bulletin

1981

40
YEARS
L A T
A N S

association of polish engineers in canada
stowarzyszenie techników polskich w kanadzie
association des ingénieurs polonais au canada
206 BEVERLEY ST., TORONTO, ONTARIO, M5T 1Z3

ERYK KOSKO → (CÓRKA) WISEMAN
65 - 37TH ST TORONTO
S. PAGOWSKI

ASSOCIATION OF POLISH
ENGINEERS IN CANADA

STP

FOUNDED IN 1941

HEAD OFFICE

206 BEVERLEY STREET
TORONTO, ONTARIO, M5T 1Z3

•

BRANCHES:

CALGARY
CALGARY, ALBERTA

•

MONTREAL
1430 DEPATIE STREET
MONTREAL, P.Q. H4L 4A6

•

OTTAWA
P.O. BOX 3325
OTTAWA, ONTARIO, K1P 5W5

•

SARNIA
340 WILLOWDALE, #505
SARNIA, ONTARIO N7T 7S8

•

TORONTO
206 BEVERLEY STREET
TORONTO, ONTARIO, M5T 1Z3

•

VANCOUVER
6191 BOUNDARY ROAD
VANCOUVER, B.C., V5S 3R1

VOL. XXXV PAŹDZIERNIK 1981 1981

biuletyn

KWARTALNIK

NUMER SPECJALNY 40-LECIA STP
1941-1981

TREŚĆ:

Str.
2 NAKAZ CHWILI
A. ZJAZD 40-LECIA
3 PROGRAM ZJAZDU
B. TABELA HISTORYCZNA STP
4. ZAŁOŻYCIELE
4 NESTORZY
5 WALNE ZJAZDY
6 PREZESI
7 CZŁONKOWIE HONOROWI
C. ZARANIE STP
8 DOKUMENTACJA POWSTANIA STP
D. KRONIKA BIEŻĄCA
12 SOLIDARNOŚĆ
12 POLSKIE ORGANIZACJE I CZASOPISMA TECHNICZNE NA OBCZYŹNIE
12 KOMUNIKAT WYDAWNICZY
13 E. 40 LAT POLSKIEJ MYŚLI INŻYNIERYJNEJ W KANADZIE
40 YEARS POLISH ENGINEERING IN CANADA
40 ANS DE GENIE POLONAIS AU CANADA
177 F. OGŁOSZENIA

ZESPÓŁ REDAKCYJNY: L. Konopko, A. A. Świderski, M. Zielińska.

The publication of this Bulletin was made possible by the financial help of the Multiculturalism Program, Government of Canada.

Published by:
THE ASSOCIATION OF POLISH ENGINEERS IN CANADA, INC.
206 Beverley Street — Toronto, Ontario, M5T 1Z3

Printed by: Polish Alliance Press Ltd.,
1638 Bloor Street West, Toronto, Ontario, M6P 4A8

1981 — 40 LAT STP

THE ASSOCIATION
OF POLISH ENGINEERS

INCORPORATED 1944

NAKAZ CHWILI

Inżynierowie polscy pojawili się w Kanadzie w większej ilości dopiero na początku drugiej wojny światowej.

Upadek Francji był ogromną stratą potencjału nie tylko militarnego, ale także i przemysłowego. Zastąpienie tej straty, a przede wszystkim przemysłowej, stało się piekącą koniecznością. Kanada, posiadająca wszystkie surowce, była bardzo korzystnym krajem do zastąpienia poniesionej straty w przemyśle wojennym. W związku z podjęciem decyzji rozbudowy przemysłu w Kanadzie, zapotrzebowanie na siły fachowe bardzo tutaj wzrosło.

Na przełomie roku 1940/41, została zawarta umowa między rządem federalnym Kanady a rządem polskim na obczyźnie, na podstawie której parę set inżynierów i techników otrzymało prawo wjazdu do Kanady na czas trwania wojny.

Warunki tych, którzy wylądowali w Kanadzie jako pierwsi, były dość ciężkie, gdyż byli zdani w zupełności na własną inicjatywę. Dlatego z początkiem roku 1941, skoro już kilkudziesięciu inżynierów znalazło się w głównych ośrodkach przemysłowych, tj. Montreal, Ottawa i Toronto, powstała myśl założenia Stowarzyszenia Techników Polskich w Kanadzie.

Stowarzyszenie założono w czerwcu 1941 r. W zadaniach Stowarzyszenia została, między innymi, podkreślona pomoc kolegom w uzyskaniu pracy stosownej do ich kwalifikacji. W tym czasie pomoc ta była bardzo ważna, gdyż większość, nie znając odpowiednio języka angielskiego, miała wielkie trudności w znalezieniu pracy na właściwym poziomie zawodowym.

Po czterdziestu latach zjawisko wydaje się powtarzać, choć w innych warunkach. Na tym miejscu nie będę rozważał tych warunków, ale stwierdzę tylko to, że coraz więcej inżynierów i techników z Polski przyjeżdża do Kanady z zamiarem osiedlenia się. Na ten fakt nie możemy zamykać oczu i musimy ponownie, tak jak w pierwszych latach Stowarzyszenia, położyć nacisk na pomoc nowoprzybywającym w ułatwianiu im osiedlić się i znaleźć pracę, w miarę możności, odpowiadającą ich przygotowaniu.

Na Oddziały Stowarzyszenia spada w tej chwili zadanie zastanowienia się, jak podołać nowym wymogom wobec których zostaliśmy postawieni.

M. Musioł

A. ZJAZD 40-LECIA

PROGRAM UROCZYSTOŚCI 40-LECIA STOWARZYSZENIA TECHNIKÓW POLSKICH W KANADZIE

Piątek, 23 października 1981

Westin Hotel (Hotel Toronto)
University Ave./Richmond St. West
18.00 Rejestracja
20.00 Towarzyskie spotkanie z Polonią — Terrace Reception Hall.

Sobota, 24 października 1981

Ontario Science Centre
770 Don Mills Road
10.00 Otwarcie uroczystości 40-lecia i otwarcie wystawy — Great Hall.

* * *

Westin Hotel (Hotel Toronto)
14.30 Walny Zjazd członków STP w Kanadzie — Toronto Ballroom.
19.00 Bankiet jubileuszowy — Toronto Ballroom.

Niedziela, 25 października 1981

11.00 Dziękczynna msza św. — Kościół św. Stanisława,
12 Denison Ave.
12.45 Spotkanie pod pomnikiem Kazimierza Gzowskiego — Lakeshore Blvd. W.
14.00 Obiad koleżeński.

* * *

— Towarzyskie spotkanie z Polonią jest pomyślane jako wieczór polski, na którym członkowie naszego Stowarzyszenia, w towarzystwie swoich rodzin, będą mogli się spotkać z przedstawicielami organizacji polonijnych, z polską prasą, radiem i telewizją.

— Otwarcie uroczystości 40-lecia i wystawy odbędzie się przede wszystkim w obecności reprezentantów świata technicznego Kanady. Przemówienie główne na otwarciu wygłosi przedstawiciel Engineering Institute of Canada prof. dr inż. Peter Wright.

— Wystawa pod tytułem "In Canada for Canada" ma dać pogląd na wkład polskiego architekta, inżyniera i technika w życie Kanady. Eksponaty obejmują różne działy budownictwa, przemysłu, wiedzy technicznej, nie wykluczając siłowni nuklearnych i takich dziedzin jak elektronika, komputory, lasery i satelity włącznie z pojazdem księżycowym. Osiągnięcia naukowe też mają swoje miejsce na wystawie. Wystawa będzie otwarta od 24 października do 2 listopada 1981 r.

— Bankiet jubileuszowy zgromadzi reprezentantów ze sfer rządowych, przemysłowych i naukowych. Głównym mówcą na bankiecie będzie federalny minister Przemysłu, Rzemiosła i Handlu, pan Herb Gray. Po bankiecie zabawa.

— W niedzielę, w czasie mszy św., kazanie wygłosi były członek STP w Kanadzie ks. inż. Włodzimierz Bakanowski.

— Po nabożeństwie nastąpi spotkanie pod pomnikiem Kazimierza Gzowskiego.

— Obiadem koleżeńskim zamkniemy uroczystości 40-lecia STP w Kanadzie.

Zarząd Główny spodziewa się licznego udziału członków Stowarzyszenia w tych uroczystościach.

B. TABELA HISTORYCZNA

WEDŁUG MATERIAŁÓW SEKCJI HISTORYCZNEJ KOMITETU 40-LECIA

1. CZŁONKOWIE ZAŁOŻYCIELE

Lp	Nazwisko i imię
1.	Aścik Antoni
2.	Brzozowski Witold
3.	Cyma Zygmunt
4.	Czerwiński Wacław
5.	De Michelis Bronisław
6.	Filip Tadeusz
7.	Herget Ryszard
8.	Jakimiuk Wsiewolod
9.	Jarmicki Zygmunt
10.	Jasiński Tadeusz
11.	Karczewski Zbigniew
12.	Korsak Kazimierz
13.	Korwin-Gosiewski Jerzy
14.	Krzyczkowski Stanisław
15.	Księski Kazimierz
16.	Kurman Mieczysław
17.	Lepszy Bolesław
18.	Maliszewski Tadeusz
19.	Meier Jerzy
20.	Nycz Stanisław
21.	Przasnyski Bolesław
22.	Rodwin Stefan
23.	Stępniewski Wiesław
24.	Suchorab Zygmunt
25.	Szwarc Aleksander
26.	Tworek Zygmunt
27.	Weinreb Marceli
28.	Żubko Jan

2. CZŁONKOWIE-NESTORZY 10 DEKADY ŻYCIA.

1. Dzwonkowski Zygmunt,
2. Kostrzyń-Till Ernest.

3. WALNE ZJAZDY

Nr	Data	Miejsce
I	15.6.41	Ottawa
II	30,31.5.42	Ottawa
III	28.2.43	Montreal
IV	15,16.4.44	Toronto
V	18.2.45	Montreal
VI	20.1.46	Montreal
VII	23.2.47	Montreal
VIII	22.2.48	Montreal
IX	27.2.49	Montreal
X	26,27.3.50	Montreal
XI	26,27.5.51	Montreal
	7.6.51	Toronto
XII	8.6.52	Montreal
XIII	17.5.53	Montreal
XIV	22,23.5.54	Montreal
XV	5.5.55	Montreal
XVI	21.4.56	Montreal
XVII	1.6.57	Montreal
XVIII	31.5.58	Montreal
XIX	30.5.59	Montreal
XX	21-23.5.60	Ottawa
XXI	20-22.5.61	Toronto
XXII	19.5.62	Montreal
XXIII	18,19.5.63	Montreal
XXIV	16,17.5.64	Sarnia
XXV	24,25.5.65	Montreal
XXVII	21,22.5.66	Ottawa
XXVI	17.6; 12.11.67	Toronto
XXVIII	25,26.5.68	Toronto
XXIX	31.5.69	Sarnia
XXX	30.5.70	Toronto
XXXI	16.10.71	Ottawa
XXXII	20.10.73	Sarnia
XXXIII	15.4.78	Toronto
XXXIV	8.10.80	Toronto

4. PREZESI ZARZĄDU GŁÓWNEGO

Elekt Zjazdu	Nazwisko i imię	Kadencja prezesa	
		od	do
I	Korwin-Gosiewski Jerzy	15.6.41	4.9.41
PO	Kurman Mieczysław	4.9.41	31.5.42
II	Korwin-Gosiewski Jerzy	31.5.42	28.2.43
III	Nowakowski Roman	28.2.43	16.4.44
IV	Rościszewski Antoni	16.4.44	18.2.45
V	Korwin-Gosiewski Jerzy	18.2.45	20.1.46
VI	Grzędzielski Aleksander	20.1.46	23.2.47
VII	Pawlikowski Józef	23.2.47	22.2.48
VIII	Pawlikowski Józef	22.2.48	27.2.49
IX	Pawlikowski Józef	27.2.49	27.3.50
X	Pawlikowski Józef	27.3.50	27.5.51
XI	Pawlikowski Józef	27.5.51	8.6.52
XII	Pawlikowski Józef	8.6.52	17.5.53
XIII	Martynowicz Antoni	17.5.53	23.5.54
XIV	Marcinkowski Władysław	23.5.54	5.5.55
XV	Martynowicz Antoni	5.5.55	21.6.56
XVI	Nyke Jerzy	21.6.56	1.6.57
XVII	Mercik Adam	1.6.57	31.5.58
XVIII	Krużyński Mieczysław	31.5.58	30.5.59
XIX	Krużyński Mieczysław	30.5.59	21.5.60
XX	Śliwiński Jerzy	21.5.60	20.5.61
XXI	Marcinkowski Władysław	20.5.61	19.5.62
XXII	Marcinkowski Władysław	19.5.62	19.5.63
XXIII	Dziembowski Ścibor	19.5.63	17.5.64
XXIV	Dziembowski Ścibor	17.5.64	25.5.65
XXV	Chełmiński Leszek	25.5.65	21.5.66
XXVI	Chełmiński Leszek	21.5.66	12.11.67
XXVII	Orłowski Stanisław	12.11.67	25.5.68
XXVIII	Orłowski Stanisław	25.5.68	31.5.69
XXIX	Orłowski Stanisław	31.5.69	30.5.70
XXX	Skonieczny Leszek	30.5.70	16.10.71
XXXI	Przygoda Zdzisław	16.10.71	20.10.73
XXXII	Strok Wojciech	20.10.73	15.4.78
PO	Morawski Szczepan	20.10.74	4.76
XXXIII	Musioł Michał	15.4.78	8.11.80
XXXIV	Musioł Michał	8.11.80	

5. CZŁONKOWIE HONOROWI — HONORARY MEMBERS

Item	NAME	Who is Who	Date of nomination
1.	Hon. Podoski Wiktor	Consul General of Polish Republic in Ottawa	15.5.1941
2.	Thompson Leslie R.	Special Liaison Officer, Department of Munition & Supply, Ottawa	28.2.1943
3.	Lea H. W.	Director, Wartime Bureau of Technical Personnel, Ottawa	28.2.1943
4.	Hon. Howe Clarence Decatur	Minister of Munition & Supply, Ottawa	15.4.1944
5.	Wright L. Austin	Secretary General of the Engineering Institute of Canada, Montreal	15.4.1944
6.	Young Clarence R.	Dean of Faculty of Applied Science and Engineering at University of Toronto	15.4.1944
7.	Hon. Mitchell Humprey	Labour Minister in The Federal Government of Canada, Ottawa	18.2.1945
8.	Herget Ryszard	Secretary General of Association and Officer at Wartime Bureau of Technical Personnel	8.6.1952
9.	Piasecki Frank N.	President of Piasecki Aircraft Corporation, Philadelphia, USA	21.5.1960
10.	Pawlikowski Józef	President of The Association of Polish Engineers in Canada	21.5.1966
11.	Hon. Drury C. M.	M.P., Minister of Industry in The Federal Government in Canada	21.5.1966
12.	Rościszewski Antoni	President of The Association of Polish Engineers in Canada	25.5.1968
13.	Jaworski Zygmunt	President of The Canadian Polish Congress in Canada	31.5.1969

C. ZARANIE STP

Dokumentacja powstania STP w Kanadzie

Karta 1.

Apel organizacyjny grupy inicjatorów, datowany 9. 5. 1941 r.

* * *

Ottawa, dnia 9 maja 1941
J. Korwin Gosiewski
329 Waverley Street

Szanowny Kolego,

Wobec tego, iż na terenie Kanady, w chwili obecnej, znajduje się 23 kolegów inżynierów, zaś nowe partie, czy to z Anglii, czy też z Portugalii są w drodze, niżej podpisani występują z inicjatywą zorganizowania Stowarzyszenia Inżynierów i Techników Polskich.

Zgodnie z protokołem, podpisanym w Londynie przez niektórych kolegów w tamtejszym Stowarzyszeniu, proponujemy utworzenie Koła, związanego ze Stowarzyszeniem Techników Polskich w Wielkiej Brytanii, jako jednostki autonomicznej.

Ze względu na to, iż Stowarzyszenie musi być zarejestrowane u władz kanadyjskich, po naradzie w tutejszym Konsulacie Generalnym R.P., proponujemy nazwę Stowarzyszenia jak następuje:

Association of Polish Engineers in Canada,
associated with Polish Engineers in Great Britain.

Stowarzyszenie nasze pozostawać będzie w ścisłym kontakcie nie tylko ze Stowarzyszeniem w Londynie, ale również ze Stowarzyszeniem w Nowym Jorku.

Utworzenie naszej Organizacji na terenie Kanady jest konieczne z wielu względów, z których najważniejsze są:

1. Reprezentacja ogółu techników polskich wobec władz kanadyjskich i placówek polskich.
2. Współpraca z Konsulatem Generalnym przy uzyskiwaniu wiz wjazdowych i wyszukiwaniu pracy dla przyjeżdżających kolegów.
3. Podejmowanie kroków, celem ratowania zagrożonych kolegów w Portugalii i Francji.
4. Współpraca w akcji pomocy kolegom z Konsulatem Generalnym R.P. oraz ze Stowarzyszeniem w Nowym Jorku.
5. Weryfikacja nowoprzybywających kolegów, jeszcze nie weryfikowanych przez pokrewne Stowarzyszenia.
6. Opiniowanie wobec władz kanadyjskich i placówek polskich.

Ponieważ Stowarzyszenie powinno, naszym zdaniem, powstać jak najszybciej ze względu na cały szereg pilnych spraw (zagrożeni w Portugalii), przeto proponujemy następujący sposób realizacji:

1. Posiłkowaniem się statutem Stowarzyszenia w Anglii, do czasu uchwalenia nowego statutu, dostosowanego do warunków miejscowych.
2. Jako siedzibę Stowarzyszenia proponujemy Ottawę, ze względu na centralne jej położenie oraz na obecność tutaj władz centralnych kanadyjskich i Konsulatu Generalnego R.P.
3. Utworzenie prowizorycznego Zarządu, składającego się z 3 kolegów, zamieszkałych na terenie Ottawy oraz 2 delegatów na Toronto i Montreal, a mianowicie:

   kol. inż. Jerzego Korwin Gosiewskiego
   " " Mieczysława Kurmana
   " " Jerzego Meiera
   " " Cymy, jako delegata na Toronto
   " " Rodwina, jako delegata na Montreal.
4. Aby Stowarzyszenie mogło funkcjonować należycie proponujemy zaangażowanie stałego płatnego sekretarza, który by załatwiał sprawy bieżące, w ścisłym porozumieniu z Zarządem oraz Konsulatem Generalnym.
5. Mamy podstawy do twierdzenia, iż Konsulat Generalny przyszedł by z pomocą materialną Stowarzyszeniu.
6. Proponujemy, aby koledzy pracujący, którzy zgadzają się na przystąpienie do Stowarzyszenia opłacali składkę. Wysokość składki została by ustalona na pierwszym Walnym Zgromadzeniu. Dla umożliwienia zorganizowania Stowarzyszenia prosimy o podpisanie załączonej deklaracji i przekazanie $5 (pięć dolarów), pod adresem kol. Mieczysława Kurmana, 141 Carling Avenue, Ottawa.
7. Prowizoryczny Zarząd funkcjonował by do pierwszego Walnego Zgromadzenia, zwołanego na jedną z najbliższych niedziel, do Ottawy, jako najbardziej centralnie położonego miasta.

Proszą Sz. Kolegę o odwrotną odpowiedź, piszemy się z koleżeńskim pozdrowieniem

(—) J. Korwin Gosiewski

(—) Mieczysław Kurman

(—) Jerzy Meier

Karta 2.

Zawiadomienie z dn. 2. 6. 1941 o terminie i miejscu I Walnego Zebrania.

* * *

STOWARZYSZENIE TECHNIKÓW POLSKICH W KANADZIE

Ottawa, dnia 2. 6. 1941 r.
adr. tym. J. Korwin Gosiewski
329 Waverley Street

JWPan inż. ______________________

____

Szanowny Kolego,

Niniejszym zawiadamiamy, że w niedzielę dnia 15 czerwca br. odbędzie się o godz. 1 po poł. w mieszkaniu kol. R. Hergeta 66 Delaware Ave. w Ottawie Walne Zebranie członków naszego Stowarzyszenia, o przybycie na które uprzejmie prosimy.

Porządek dzienny zebrania:

1. Wybór Przewodniczącego zebrania i Sekretarza,
2. Wybory Zarządu Stowarzyszenia,
3. Sprawa statutu,
4. Preliminarz budżetowy do końca br.
5. Wolne wnioski.

Przesyłamy koleżeńskie pozdrowienia.

Zarząd Stowarzyszenia

R. Herget
Sekretarz

J. Korwin Gosiewski

M. Kurman

Karta 3.

Pierwszy akt ogólny Zarządu, datowany 9. 7. 41 r.

* * *

STOWARZYSZENIE TECHNIKÓW POLSKICH W KANADZIE

Ottawa, 9. 7. 1941 r.
66 Delaware Ave.

JWPan inż. ____________________________

Szanowny Kolego,

Zwracamy się z apelem do wszystkich Kolegów, by w wypadkach likwidowania swych stosunków służbowych z firmą w której pracują dla przyjęcia pracy w innej firmie — uprzednio, przed ostatecznym zakończeniem sprawy, informowali o takim fakcie nasze Stowarzyszenie dla dalszego zawiadomienia o tym tutejszego Department of Supply.

Podkreślamy, że nikt nie jest krępowany pod tym względem w dysponowaniu swoją osobą, lecz grzeczność tego rodzaju jest wskazana w stosunku do instytucji, która się nami opiekuje i dokłada dużych starań w celu znalezienia pracy dla każdego z członków Stowarzyszenia.

Mamy nadzieję, że wszyscy, w zrozumieniu własnego jak i ogółu Kolegów interesu, dostosują się do naszej prośby.

Zarząd

J. Korwin Gosiewski
Prezes

R. Herget
Sekretarz

D. KRONIKA BIEŻĄCA

1. SOLIDARNOŚĆ

Powstały przy Zarządzie Głównym "Komitet Pomocy Polsce" zawiadamia, że do 1 września zebrano przeszło $18,000. Akcja trwa dalej. W następnym biuletynie podana będzie pełna lista ofiarodawców.

J. Słubicki

---

2. Polskie organizacje i czasopisma techniczne na obczyźnie.

Stowarzyszenie Techników Polskich w Wielkiej Brytanii wydaje kwartalnik "Technika i Nauka" jako Organ Polskich Stowarzyszeń na Obczyźnie", który obejmuje następujące organizacje:

1. Stowarzyszenie Techników Polskich w Wielkiej Brytanii.
   Institution of Polish Engineers in Great Britain.
   240 King Street, London W.6 ORF.
2. Stowarzyszenie Elektryków Polskich w W. Brytanii.
   240 King Street, London W.6 ORF.
3. Association des Ingénieurs et Techniciens Polonais,
   Winterthur. 8400, Case Postale 321, Suisse.
4. Centro de Ingenieros y Tecnicos Polacos en la Republica Argentina.
   Stowarzyszenie Inżynierów i Techników Polskich w Argentynie,
   Dom Polski, Serrano 2076.
   1425, Buenos Aires, Argentina.
5. The Polish Technical Professional Association,
   P.O. Box 169/B
   G.P.O. Melbourne, Victoria 3001, Australia.
6. Association des Ingénieurs et Techniciens Polonais,
   Place de la Source de l'Hôpital, Hôtel "Alexandria"
   Vichy, France.
7. Association of Polish Engineers
   P.O. Box 9484
   Johanesburg, South Africa.

———oOo———

Stowarzyszenie Techników Polskich w Kanadzie wydaje swój kwartalnik "Biuletyn STP".

KOMUNIKAT WYDAWNICZY

Wydanie specjalnego numeru jubileuszowego w 6-krotnie zwiększonej objętości pociągnęło za sobą wyższe koszty.

Zgodnie z komunikatem poprzednim w czerwcowym numerze 2/81 numer ten będzie rozesłany bezpłatnie do wszystkich członków z opłaconą do Zarządu Głównego składką poprzez Zarządy Oddziałów STP.

Dodatkowe egzemplarze można zamówić za uprzednim nadesłaniem wpłat czekowych po cenie kosztów własnych $7/1 egzemplarz na adres: Association of Polish Engineers in Canada, Head Office — Bulletin Fund, 206 Beverley Street, Toronto, Ontario, M5T 1Z3.

Nakład jest ograniczony. Skład do ewentualnego dodatkowego nakładu wg zamówień może być zachowany tylko do końca bieżącego roku.

Redakcja

40 LAT POLSKIEJ MYŚLI INŻYNIERYJNEJ W KANADZIE
YEARS OF POLISH ENGINEERING IN CANADA
ANS DE GÉNIE POLONAIS AU CANADA

1981 — 40 LAT STP

Page	Author	Title	Language
15	Alejski L.	An engineer in architecture.	Eng.
29	Bekker M.G.	A search for the mechanics of off-road locomotion in system analysis.	Eng.
57	Chrzanowski A.	New techniques in monitoring ground subsidence in mining areas.	Eng.
65	Czerwiński W.	Wiatraki przyszłości.	Pol.
	* * *	De Havilland glider "Sparrow".	Eng.
79	D'wonnik R.	The design of the teaching cell group.	Eng.
83	Garlicki A.M. Bowler E.H.	Railway Laboratory of The National Research Council of Canada.	Eng.
93	Kawerniński L.I.	Northwest passage S.S. "MANHATTAN". Przejście półn.-zach. kanadyjskiego arktyku.	Eng.
107	Kosko E.	Les Cours de Génie Aéronautiques Donnés par des Professeurs Polonais à l'École Polytechnique de Montréal.	Fr.
111	Łukasiewicz J.	Development of facilities for high speed aerodynamics in Canada.	Eng.
127	Orlik-Rückemann K.J.	Aircraft stability parameters at high angles attack.	Eng.
131	Orłowski S.T.	Architektura w organizacji budownictwa szkolnego.	Pol.
135	Purski S.A.	Projekt siłowni wodnych kompleksu La Grande w Quebec.	Pol.
137	Sieciechowicz W.	Care of handicaps.	Eng.
141	Stepniewski W.Z.	Over the Cradles of the DHC Canadian Mosquito, Beaver and Chipmunk.	Eng.
147	Świderski A.A.	The pittfalls and difficulties in design of high speed machinery.	Eng.
151	Wiśniowski H.U.	Evaluating wear in piston engines by quick spectrographic sampling method.	Eng.
159	Wyszkowski P.S.	The Engineering of Art: Design and construction of a Classic Guitar.	Eng.
165	Wyszkowski P.S.	Sen mojego ojca.	Pol.
167	Zaremba J.	Rozmowa o "The guide to the structural design of underground structures" z autorem T. Świderskim	Eng. Pol.
169	Zarzycki J.	Opportunities and perspectives in digital maping and automated cartography.	Eng.

L. ALEJSKI

AN ENGINEER IN ARCHITECTURE

I have spent most of my professional life working with Architects. In the process I have had to revise my engineering training in order to make meaningful contributions to their work. In architectural engineering the most advanced chapters of the theory of structure can be used only to check the stability of structure... to analyze numerically a structure already designed, not only in its general outline, but also in all its dimensional relations. The formative stage of a design, during which its main characteristics are defined, canot make full use of structural theory and must resort to intuitive and schematic simplifications.

In this paper I shall illustrate how I used this kind of engineering on four of my major project. I have choosen these projects for two reasons. First, they are representative of place where we live a great part of our lives, where we learn, work, spend our money and relax. Second, these edifices were designed by prominent architects, advocates of technical and aesthetic equilibrium in architecture.

The nature of architecture has been discussed for centuries. Whether it was art or structure aesthetics or engineering, or if a combination of both, in what proportion — was a constant challenge and a continuing subject of debate. For ages it was the architect whose role uncompromisingly encompassed all of the activities of the engineer. The many sided Renaissance man, in fact, considered all art his province, and all engineering a part of art — as witnessed by the remarkable Leonardo, whose particular genius only magnified the accepted attitudes of his time.

Not until the Age of Reason, with its philisophical and practical emphasis on "pure" science and on the importance of experimental research for the development of scientific law, did the first sign of the split between architecture and engineering appear. As empirical rationalism took over the age, natural and applied science moved into the field of technology and industry, and out of the realm of art. The 18th Century laid the groundwork for the Professional Engineer. The 19th Century, in turn, saw highly accelerated progress in structural science. Integral calculus and solid geometry were developed as technical aids in the field of mathematics; scientific tehcnology was introduced to construction to create the unprecedented field of engineering architecture. Polytechnical schools sprang up in France, Germany and Austria, training technicians in the use of the new scientific calculations, soon to be applied to revolutionary building materials: iron, steel and concrete. The field of experimental progressive constrution, of untried tehniques and unfamiliar forms, belonged exclusively to the engineer, builder of bridges, factories, railway sheds and exposition halls. The schism was complete. The architects were left behind but not for long. The realisation that the architecture and construction must be practised simoultaneously, and that construction is the means and architecture is the result, was in the offing.

The constructional necessity was translated into structural art and formed the basis of the modern architecture. One of the founding fathers of these trends, in architecture was Mies van der Rohe. Mies believed that in the epoch of science, technology, industrialization and economy — and in the social patterns which were forming through their influences, the physical realization of architecture was accomplished through the use of clear construction. Mies' knowledge of the possibilities and limitations of the materials with which we build — and particularly those which are typical and unique to our time such as rolled steel sections and large sheets of plate glass — enabled him to develop their potentialities as elements of construction and architectural expression. Mies defined the rules for the discipline of structural architecture.

Mies van der Rohe designed the Toronto Dominion Centre (Photo 1) toward the end of his career. The project, located in downtown Toronto, is comprised of three tower buildings of different height and a single storey banking pavillion. An underground shopping concourse occupying the whole site, connects the three towers with the banking pavillion and with the two level parking facility below. The structural design work began in the Spring of 1964 when Mies presented his master plan and a single crossection neatly organized on a five (5) foot module. This information was sufficient to lay out all framing plans from the roof down to the foundations. Mies never departed from those sketches. Neither was there any need for us, as structural engineers, to make changes or propose modifications. The plans were most remarkable for the clarity of their engineering. The power and grace of these ordinary shapes and patterns stemmed directly from their structural logic and were inseparable from it. Mies knew that the structural system set certain limitations and that possibilities existed only within these accepted facts.

Photo 1

The first building of the complex to be erected was the 56 storey Bank Tower. This building is rectangular in plan measuring 120 x 270 feet and rises 740 feet above the Plaza.

Tall buildings, soaring above the average height of neighbouring structures, receive the full impact of the wind, and a reasonable estimate of that force must be established before one can proceed with the design. The wind pressures proposed by the City of Toronto Building Code, at the time when the design of the Bank Tower was started, were vague and incomplete. An examination of the wind requirements of cities subject to similar meteorological conditions led to ambiguous and startling conclusions. Obviously a great amount of research was needed before a realistic wind loading curve could be drawn. Historical data on wind velocities, directions and durations was obtained and analyzed. A statistical approach was used to reduce those essentially random in nature pieces of information to a useable form.

The application of modern techniques including higher strength steel, welded connections, replacing masonry with curtain walls, lightweight floors and partition systems, all combined to greatly reduce the stiffness of the proposed building and its capacity to dissipate the swaying energy or damping. Thus newly created new aerodynamic characteristics had to be examined taking into account the integrity of structure and architectural finishes and most important the comfort of the building's occupants. Having drafted wind loading and the corresponding deflection or drift criteria, the bracing system was studied next.

The slenderness of the Bank Tower and our imposed sway limitations required the full width of the building to resist the horizontal loading. The available bracing systems for prismatic towers of similar proportions can be provided either externally or more typically, they can be built into the interior framing system. The former systems are represented by the tube concept developed during the sixties. Exterior bracing imposing critical limitations on the glazed surface of buildings, was not considered in detail. To the later systems belong the classic all rigid frame, and the more typical for the modern towers, the "rigid-braced-rigid" type of frame. The "rigid-braced-rigid" system was followed up to the stage when an estimate indicated that a further reduction of sway by one inch would cost in excess of two hundred thousand dollars. It was then that we devised another system still employing the use of two storey high outrigger trusses, placed at the two mechanical floors. The system mobilized the exterior columns and with the location of the mechanical floors at an optimum height, it proved most economical in reducing structural steel tonnage from 45 lb/sq.ft. to 37 lb/sq.ft. Since then similar wind bracing systems were adopted for the First National Bank in Seattle and The U.S. Steel Building in Pittsburgh.

The Bank Tower frame was analyzed manually. By equating the column shortening the difference of the free deflection of the braced core and the deflection of the outrigger trusses, the proping forces in the columns were found. From this point on, the bracing system became statically determinate and a long process of tunning the member sizes to fit the deflected shape began. In the process the questions of tying the exterior column to the core, the P-delta effect and elastic stability of columns arose. The pioneer work on these problems was instrumental in including the corresponding requirements in the latest S-16 and AISC Standards.

For the 46 storey Royal Trust Tower, the "rigid-braced-rigid" system was used. This tower was computer analyzed using a modified Stress program. In the third high-rise, the 33 storey Commercial Union Tower, poured in place service core was utilized to provide lateral stability. The core was ercted by slip forming. Completion of the core ahead of the other construction, offered an attractive payback by permitting erection of structural steel and installation of elevators and mechanical risers to proceed simultaneously. Although this method has been used on a number of lower buildings, only this Canadian high-rise has been built in this manner to date.

All three towers are completely clad in glass, and structural steel. Continuously welded 3/8 in. thick steel plate fascias extend horizontaly along each spandrel line and vertically at each corner column. During erection this plate served as a form for lightweight concrete which separates and isolates the plate from the spandrel beams. The 8 WF17 beams, welded vertically to the plate, support window frames and serve as rails for window washing machines. Comprehensive heat transfer calculations were required before the cladding system could be finalized. The natural temperature elongations of the horizontal plate result in substantial "hoop stresses" which must be resisted at the corner columns. To contain the temperature stresses, a self restraining band composed of interlocked fascia plate, a light weight reinforced concrete and spandrel beam, each working at different temperature level, was created.

The fourth building of the complex, the Bank Pavillion is a completely welded exposed steel structure with glass sheets mounted between solid steel bars. The columns, cruciform in shape, are spaced at the perimeter at 10 feet centres, thus providing a column free area for banking facilities. Steel plate and angle fascias, continuously welded to columns, form a rigid wind resisting tube. Roof framing, a grid of 4'-6" deep girders with flanges varying in width from 6 inches at columns to 14 inches at the centre, was butt-welded on site and jacked up into position. In this building Mies' intricate structural logic has established a creative high point in the 20th Century engineering and architectural design. The excellence of the structure was recognized by our peers with an Award from The Consulting Engineers of Canada.

A good structural organism so essential to good architecture must be worked out passionately in detail, and in general appearance. Mies' attention to details throughout the job was indeed immaculate. Huge granite slabs spanning 20 feet over the Plaza entrances to the Concourse were post-tensioned so that the interior and exterior texture would match.

During construction of the substructure the axcavated sides were protected by a tie back system of shoring — another first in Canada. The tie-backs, high tensile cables, replacing the rakers of the old system, were grouted in 20 feet long predrilled holes in shale and prestressed. This self testing system opened the site for the contractor by giving him ample space to maneuvre his trucks and cranes, store his material and saved him the labour and cost of removing the shoring and patching up.

■ The Robarts Library was designed by Warner, Burns, Toan and Lunde an associated group of New York Architects, ardent believers in united architecture and engineering. When faced with the task of designing the University Library, the nerve centre of a University Campus they began the design as a structural concept for that function and developed it as a sound solution for specific needs. Concrete construction was preferred because the nature of concrete construction makes structure and shape inseparable and gives the building robustness and substance.

Reinforced concrete presents hidden deficiencies and specific characteristics which make its structural behaviour difficult, if not algotheter impossible to foresee exactly. Its high thermal sensitivity, shrinkage, and above all plasticity, shatter our hopes of investigating or knowing either before or after construction the real conditions of equilibrium and make any concrete structure statically indeterminate. In spite of these problems, modern reinforced concrete is one of the most rewarding and expressive materials. The structural design of the library did not involve too many intricate calculations, but rather, it was an exercise in concrete technology and construction problems.

The library consists of the Main Library Building and three satelite buildings planned on a triangular module (Photo 2). The satellite buildings contain the School of Library Science, the Rare Books Library and the Service Centre. The Main Library, 200 feet high, has two basement floors and 14 floors above grade. Bridge Links, suspended on post-tensioned, 60 foot long crossing girders, join the main library with the satellite buildings. Supports for the girders are completely articulated to permit horizontal movements due to temperature and shrinkage changes and to allow for vertical movements due to creep and differential settlement.

The triagular module was chosen as being the best solution for three basic planning problems. First, due to the need to accommodate 1000 small offices or study carrels on the perimeter of the bookstack floors, a higher than normal ratio of wall perimeter was required. Second, due to the immense size of the project, requiring as it does, a whole city block, the backside of a conventionally designed building would become too overwhelming. A triangular building tends through its geometry, to give equal emphasis to each of its sides, and finally, due to the size of the building in relation to its neighbours, it was desirable to reduce the visible mass of the building as much as possible. The triangle accomplishes this admirably.

The desired quality of the job demanded a standard to which all subsequent work could be compared. Such a standard was arranged in the form of a small pavillion erected on the site before the construction started. Tested on this pavillion were different types of forms, finishes like sandblasting, bushhammering and acid etching, construction joints, reglets, inserts, etc.

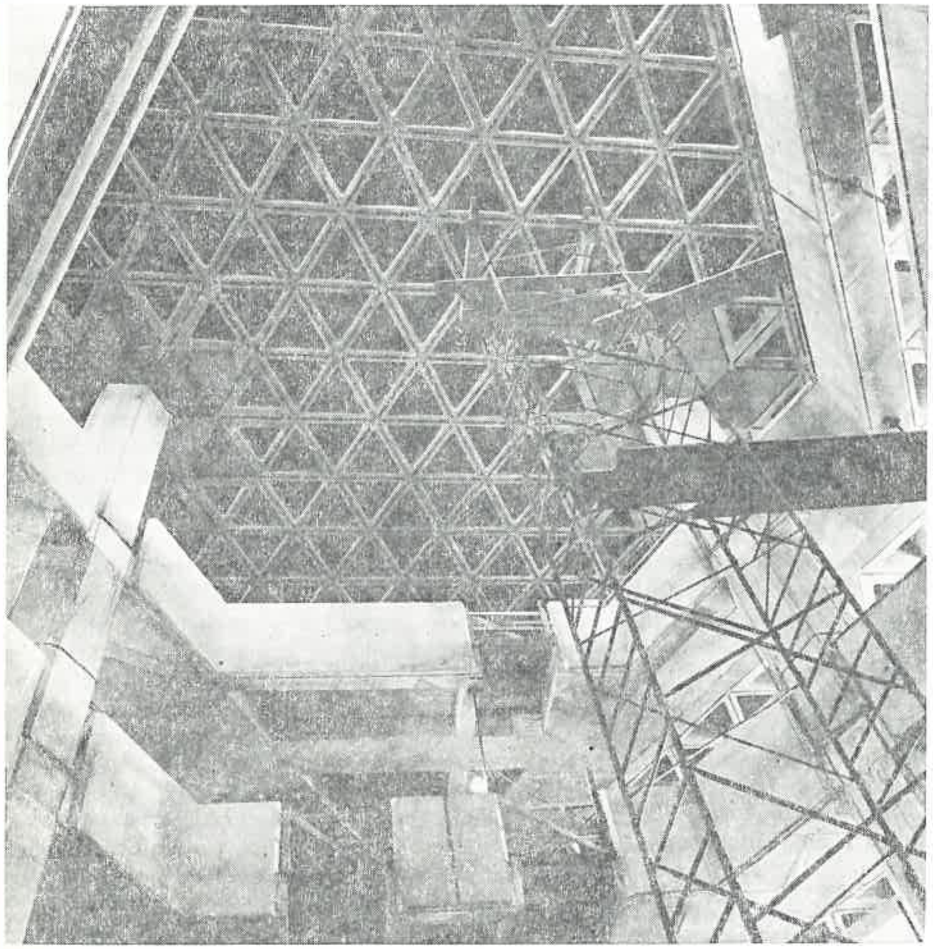


Photo 2

The bulk of the exposed concrete is architectural concrete. For most of the concrete a mix containing limestone aggregate was used. For visual contrast the concrete mix in some of the panels contained dark basalt coarse aggregate. In addition, for interior surfaces white meduza cement was added to the mix. To achieve uniformity of colour, the mixes were constantly checked in the storage yards and on site, against the previously approved standards. Basically, all exposed concrete contained approximately 5% air and plasticizer, and was poured at a 3½ inch slump. Due to constant supervision, construction problems were dealth with as soon as they were observed. For example, in the case of the rather heavily reinforced cup columns, pockets of segregated coarse aggregates were appearing at the bottom of the lift. After an investigation of the problem, it was discovered that this condition occurred when concrete was discharged from a fresh truck load. The simple solution was to set aside the first bucket, which normally contains more "stony" concrete, and make the first pour with the second half full bucket. Then the concrete from the first bucket was placed. There was no significant delay in the schedule and the new procedure corrected the problem.

Structurally the Library frame is a three-way flat slab type of construction. The triangular shape of the floor and diagonal spacing of columns required a new approach to the structural design. A matrix structural analysis by the formulation of a finite-element mathematical model, equivalent to the actual continuity of the structure, helped us in establishing the stress distribution of the system. Triangular waffle slab was selected to support the heavy library stacks loading, in order to reduce the self-weight of the floors and to provide an attractive ceiling-free soffit. To transfer the loads to the columns, star shaped solid panels, modified to suit the stress pattern flow, were employed. The sides of the main building, 330 feet in length, allowed no expansion joints. To prevent the build-up of shrinkage stresses, floors were divided by closure strips, into three corner triangles and an hexagonal centre. Closure strips were cast one month following the last pour.

The temperature stresses in the horizontal plane, by providing "relief valves" in the form of stair cases, and through the partial use of insulated precast concrete panels, were dispersed before their effct could impair the integrity of the structure.

Floors are supported on hexagonal rebated columns carrying working loads in excess of 6500 kips. At the perimeter, floors are supported on channel shaped shear-walls called cup columns. Cup columns in conjunction with core walls provide horizontal rigidity to the building. The channel-like shapes of the cup columns are functional in the sense that the columns double as duct shaft enclosures. Cup columns are insulated on the inside and completely exposed for their full height on the outside, and thus they are subject to all deformations due to ambient temperatures. By providing hinges at alternate carrel floors and by cantilevering the remaining floors, these columns are permitted free vertical thermal movement.

For the transfer of the heavy structure and storage loads to the ground, two types of foundations were considered — caissons and mat foundation. The elevation of the lower subgrade floor was established about two feet above the plane where the glacial tilt ended and water-bearing dense sand stratum began. After a review of the anticipated sizes of the caisson shafts and such caisson related problems as casing, rewatering, and the danger of collapse, we decided on the mat foundation. A well and piezometer tests conducted on the site, indicated that dewatering was necessary. A system of well points extending seven feet below the foundation was accordingly designed, resulting in the lowering of the water table to about three feet below the lowest foundation level. In preparation for the placing of the mat a 4 inch slab was poured on dry ground. This slab served as foundation for the light structural steel beam and column chair frame for upper layers of mat reinforcing. The mat foundation slab is seven feet deep, reinforced 3-way top and bottom with No. 14 and No. 18 bars. Above the mat slab there is a 2'-4" deep space filled with granular material, forming a bed for mechanical services. Slab, 8 inches in thickness above the fill, completes the foundation. To control the size of concrete placements, the mat was divided by an irregular net of keyed construction joints. Due to the size of the foundation, the units were still quite large varying from 500 to 1300 cubic yards. The largest unit took 18 hours to complete, being fed by conveyors and cranes from trucks at five points on adjoining streets. The hiatus in construction industry created by strikes pushed concreting into the hot months of the year. Placing concrete during hot weather created problems and required precautions. Initial thermal calculations indicated a 60°F adiabatic temperature rise. To limit the concrete temperature to a maximum of 100°F the concrete mix had to be placed at 40°F. To achieve this, the cement content of the mix was reduced and blended with flyash, and, plasticizer and retardant were added. In additions, aggregates before loading were cooled by shading and sprinkling, and crushed ice was mixed with the water. To further reduce the temperature gradient, the concrete mix was re-proportioned to produce a 90 day nominal concrete strength. To facilitate heat escape, a layer of fog was formed over freshly placed concrete, by adding a small volume of water through the use of perforated garden hoses. Throughout the mat placement the temperature of the concrete was measured using wire thermocouples. Recorded temperature peaks were generally below 100°. We found that the additive-laced concrete took so long to set that the heat of hydration of that mass of concrete was not a problem.

The different mixes of concrete were closely controlled and gave an excellent intest variation of 3.12%. The sophisticated details of the building elements required special attention to avoid blemishes, broken and uneven corners and reglets. To form the reglets, metal, rubber and coated wood were tested. The latter was finally selected when we found that rubber was discolouring the concrete and metal was tearing off concrete edges.

All triagular formations in waffle slabs were created with fibre glass forms. The forms, strengthened with cross bridging for rigidity, were reused on the average of 12 times before becoming fibrous on the surface. Forms were released by compressed air. To obtain the quality of the finishes requested by the architects, we specified steel forms for all vertical elements including stairs and cors. Two forms for each element were prepared and they were used in a form jumping fashion.

There was another Award for this project.

■ Toronto Eaton Centre is basically a suburban shopping centre, a modern socio-economic manifestation, dressed up with good architectural design and inserted into a decaying part of downtown Toronto. The idea of taking such an economic entity and conglomeration of shops and reinserting it into an urban situation would not occur, however, until certain shifts in consumer habits had taken place and some incentive had been offered to private developers. The attraction for developers was heightened by the liberalization of the municipality by-laws and the increasing saturation of the suburban market. Pressure from environmental groups, communities and even local governments against the unchecked growth caused by building a shopping mall out at the intersection of two highways has accelerated the moving process.

The centre was designed by Eb Zeidler, a Toronto Architect with an engineering approach to crowd movement oriented projects. In the Centre, Zeidler very successfully, addressed the problem of generating traffic on three and lately on four levels. On the upper levels, the shoppers arrive by car at the parking garages wrapped around the upper levels of the mall; on the lower levels the walking crowds of people arrive by subway. Not much of the exteriors gives a clue of offering within; not much about the architectural treatment beckons to the passerby. Like a suburban mall, one must go there knowing what is ahead.

Photo 3

The interior of the Eaton Centre, though it might suggest that its design precedent was taken from the Millan Galleria, is functional and utilitarion to a degree that it could be called futuristic. If there is a metaphor for the building it is a science fiction city (Photo 3). Actually the metaphors of technology and mechanization are consciously conveyed by the shear length and height of the building, its predominantly white colour, metal tube railings and curved glazing. The technical metaphor is also extended by the pervasive exposure in the mall of the mechanical systems of the buildings, as well as by the constructivist detailing, interconnected bridges, stairs and exposed elevators.

The centre, opened in 1977, comprises a mall, the new Eaton's Department Store and two major parking facilities. At its south and north ends the Centre is anchored by office towers, 29 storey high at Dundas Street and 34 storey high at Queen Street. There are over 350 retail shops along the mall, over 1,600 parking spaces in the parkades and connections to two Yonge Street subway stations.

Throughout this extensive project some rather intriguing problems have been posed by the complex geometry inherent in the many areas of exposed structure. Development of imaginative details to conform to the variety of architectural expressions become an unparalleled challenge to the design team. Early in 1974, work commenced, clearing the first part of the site, extending from Dundas Street on the north to Albert Street on the south. This work involved closing the three existing east-west streets, re-routing many services, and moving two buildings of historical value. The two buildings were re-erected on landscaped ground around the Trinity Church, and as a small enclave of early 19th Century architecture attest to Canadian Heritage in this modern environment.

The deep excavations were shored by the previously mentioned tie back system anchored to bedrock. Foundations consisted mainly of short caissons set into bedrock in predrilled holes. In this type of caissons, both the bearing and friction can be utilized for load transfer. We conducted two full scale tests and found that the capacity of caissons could be increased up to 75 tons per square foot, or three times the value in general use at that time.

The Yonge Street Mall building is nearly 900 feet long. The east and west segments of this structure are divided by a 60 foot wide mall open to 100 feet above street level and enclosed by a vaulted glass roof. Vault framing consists of two hinged trussed arches supporting the glazing system. At Trinity Way, Albert Street, and Queen Street, the glass vaulting cascades down to the entrances. The supporting structure is an intricate arrangement of triangular trusses, joists and hangers formed from structural steel tubes and solid rounds.

The rational estimate of snow load on the glass roof was the subject of intensive study. Again, as in the case of wind load, the building code was indefinite with regard to a "greenhouse" type of structure and we felt that the mandatory ground snow load of 40 pounds would be excessive. Data collected by the National Research Council and through the computer modelling of the anticipated conditions allowed us to reduce the basic snow load to 25 pounds, which was accepted by authorities.

The lower three floors of the mall are occupied by major retail outlets. One way slab and beam construction has been used for these areas to provide flexibility and to accommodate changes and modifications to suit all types of tenants. Above the retail levels the west half of the mall is occupied mainly by office space, and has been constructed using the conventional flat slab system on a 40 x 28 foot grid. The economy of this type of construction, coupled with the relatively minor demand for future framing revision, makes flat slab desirable for this type of occupancy.

On the east side, over the retail areas, parking spaces are provided on four levels framed on a partially post-tensioned 56 x 28 foot grid system. These floors have been designed for speedy conversion to office space when cars will no longer be permitted into the city core. To compliment it, in the area immediately south of the Eaton's store, provision has been made for the future construction of a high rise office tower.

The mall elevators, servicing both parking and office floors within the mall, have received a unique structural treatment in that the entire elevator framework including elevator pits, is suspended from steel contilevers at the glass vault level. These open elevators serve the perimeter corridors of the retail levels, which are also interconnected by a series of light, trussed bridges.

The Dundas Street Office Tower, clad in a light glass and aluminum curtain wall, is of hybrid construction. The building's light structural steel frame is supported laterally by a concrete core which was jump formed ahead of the steel erection.

The innovative eliptical shape of the tower helped to reduce wind resistance by about 15 percent. During the winter storm two years ago, while other much stiffer buildings experienced some distress and lost a number of lights, the Dundas tower weathered the storm without any mishap. Below the tower a three level reinforced concrete podium connects the tower to the Eaton's store, the Dundas subway station, and the Dundas Parkade to the West. The entrance to the podium, and indeed to the entire complex, at the corner of Dundas and Yonge Streets, has been enclosed by a glass canopy. The framing for this enclosure consists of lights joists supported on 8 foot deep triangular, spine like trusses, the longest of which spans over 110 feet. These trusses frame into triangular vierendel trussed columns formed of 12 inch diameter tubes. The glass walls, laterally supported by horizontal joists and hung from roof framings, complete the enclosure. The 34 storey Queen Street Office Tower, presently in the last stages of construction, guards the south end of the centre. A different, completely glazed curtain wall has been selected for this tower — otherwise it is similar in shape and construction to the Dundas Tower.

The Dundas Street Parkade is a 10 storey parking facility providing space for over 800 cars. The parkade employs a double spiral system with one entrance ramp from Dundas Street and another from Bay Street. The gently sloping parking floors, are themselves ramps and are constructed of one way slabs spanning between beams 28 feet apart. The system is completely post-tensiond, including the rapid exit ramp which is cantilevered 19 feet.

Throughout the project, the architectural concept dictated the integration of rather delicate structural steel elements with massive concrete structures, calling for a great deal of investigate engineering to achieve a balance in aesthetics and economy. The success of these efforts can be judged by the graceful geometry of the carefully designed structural systems which have become a major focal point of this project.

The periodic rise and fall of activity in various building types can be seen as an interesting — if incomplete — indicator of architecture and design trends over the years. A good example of that cyclical movement can be seen in theaters and auditoriums, the construction of which has had its ups and downs over the past three decades. In the late 1940's during the great postwar construction boom, there was a marked increase in school buildings at all educational levels, and rare was the new school that did not contain at least a modest auditorium. This boom went on for some twenty years, until the triple threat of recession, revision to provincial funds for education, and a declining brithdate, all combined to bring activity in school construction to a virtual halt. With theaters and auditoriums, there has been an almost opposite development. In late 1940 and early 1950 their construction fell off sharply under the direct competition of television, which was then made available for the first time to a mass audience. But by the 196$'s, the burgeoning culture boom in North America and the resurgence of an entertainment bent among the younger generation spurred activity in this building type once again. Municipalities, cultural organizations, and educational institutions vied with one another to erect the most comprehensive, innovative, or at least the most impressive token of America's newly discovered interest in the performing arts.

■ Toronto's New Massey Hall (Photo 4), a spectacular 75 foot high reflective glass-faced canopy, shaped like a triangulated cone and enclosing the structurally independent auditorium, was designed by Arthur Erickson. Supplementing the original Massey Hall built in the late 19th century, the new facility will be the permanent home for the Toronto Symphony Orchestra and the Toronto Mendelssohn Choir. With its main entrance facing Simcoe Street, the 240 x 320 foot building is flanked by a reflecting pool on the north and by a 1.5 acre Massey Hall Park on the West. The one million cubic feet main auditorium, with a seating capacity of 2,800, will be located in the centre of the building directly under the crown of the canopy. Horsehoed around the main floor are the mezzanines and balcony levels, split into sections which are progressively slopping down towards the stage. A three story high lobby, roofed over by the canopy, encircles the main auditorium and provides a gallery type access to the mezzanine and balcony sections. Directly beneath the lobby there is the musicians level containing rehearsal rooms, recording, radio and TV rooms and instrument storage facilities. Parking for 400 cars occupies the lower two floors.

Photo 4

On this job we served two masters — the Architect and the Accoustics Consultant. Erickson is an artist rather than an Architect with a strong belief that even a bare but statically correct structure will give the full effect of beauty and become true architecture. He subconsciously recognizes that forms and volumes, set by technical and functional necessity, but treated with sensibility, come to be an eloquent means of architectonic expression. Designing with Erickson is a continuous search for a perfect form or shape, even for the most trivial of details. Erickson works exclusively on models and that is why his work comes out as a stable, unified, enduring organism, balanced in all of its parts, sincere in its supporting structure and technical elements and at the same time capable of giving off that indefinable quality that we call beauty. Inside the auditorium architectural concept had to comply with the accoustical design. Solid concrete walls, ceiling and floors with eurved surfaces were chosen for the bouncing off and scattering of sound. Special adjustable banners have been provided to control reverberation time. To accoustically isolate it from the rest of the building and its outside environment, the main auditorium is designed as a separate structure, copletely divorced from the surrounding lobby and parking levels. The few contact points between the concentric buildings are separated by resilient, vibration-isolation pads to eliminate structural and ground-borne sound transmissions to the auditorium.

The two concentric buildings are a simple arrangement of columns braced by a series of inclined rings. Two such rings in the auditorium, which is mainly of structural steel construction, double as mezzanine and balcony seating areas. Supported on cantilevered trusses and completely wrapped in reinforced concrete, they project 30 feet over the auditorium floor. Cast in place, curved, reinforced concrete walls extend from the auditorium floor to the ceiling. At their tops, these walls are joined and braced by an oval concrete ring supporting the roof structure. The roof structure is a 24 foot deep space frame in which twelve interconnected truss spokes radiate from the eccentrically located circular hub. The trusses are each prestressed by a pair of cables connecting to a tension ring and supporting a service cat walk. This utilitarian structure, shaped not unlike a giant candelabra, will be completely exposed in the finished building. The trusses support steel purlins and decking over which two 3 inch thick light weight concrete slabs have been placed, separated by a roofing membrane and insulation. The purpose of the cushioned top layer of concrete is to deflect airborne noises, such as from nearby Toronto Island Airport. From the bottom chord of the roof frame are hung slotted precast-concrete slabs. Accoustic banners will be raised or lowered through the slots in the slabs. If it is the function of the auditorium structure to keep music in, the lobbys' duty is to protect the inner sanctum and keep the noise out. The lobby structure is framed in concrete. Two rows of concentric columns support three concrete rings. The top most ring acts as a soffit for the lobby, and supports the mechanical floor with its framing and a track for the window washing machine. Two lower rings composed of platforms and stairs provide access to the upper seating areas of the auditorium. The shearwall-like columns of the inner row have been designed in pairs to accommodate the double-doored sound locks.

The glass canopy enclosing the lobby is supported on a space frame looking somewhat like a giant fish net. The frame built of straight, between joints, 10 inch in diameter steel tubes, was field welded into position. The rigidity of its joints makes the frame self supporting. Articulate joints at roof level allow vertical movement. Due to the complexity of the shape of the canopy we were entrusted with the complete designing and dimensioning of the glazing. To avoid glass wastage, we choose as a basic shape a square, and to supplement it a 90° triangle, obtained by cutting the square into two halfs. Out of two squares and two triangles, flat diamond shaped units were formed, and out of these units a curved surface was generated. Another set of 90° triangles, dimensioned to fit the areas left after joining the corners of the diamonds, completed the glass surface. Design of the supporting structural mesh to fit that shape, war really an anti-climax — the computer did the rest.

Working for a quarter of a century with architects has been, for me, a most wonderful adventure and a very rewarding experience. Although there were frustrations,

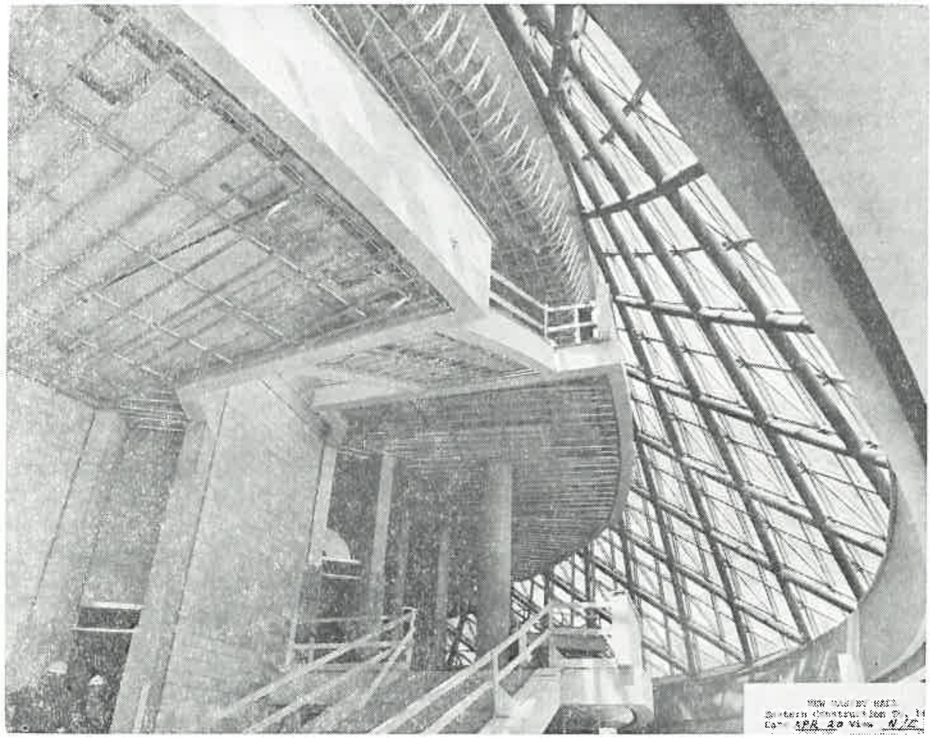


Photo 5

fights for the size of a column or beam, arguments regarding an opening in the wrong place, but, after the building was erected, all those problems were long forgotten and the pride of shared achievement and substantial contribution remained. And that probably is why I have dwelled so much on the architectural aspect of my work, and on my colleagues and clients... The Architects.

M. G. BEKKER

Dr. Mieczysław G. Bekker needs no introduction to the readers of this Bulletin. In the October 1975 issue, on the occasion of his award of the degree of Doctor of Engineering honoris causa, a note by Professor J. Lukasiewicz brought his achievements to our attention. And in July 1976 "Greg" himself gave, under the title "From Idea to Reality in 70 Years", a succinct résumé of his achievements which led to the realization of lunar ground locomotion. In the article which follows, he presents a more detailed review of the steps which marked the evolution of a new engineering discipline, the science and technology of Land Locomotion, of which he is the undisputed founder and promoter.

Editor

* * *

A SEARCH FOR THE MECHANICS OF OFF-ROAD LOCOMOTION IN SYSTEMS ANALYSES

GENERAL BACKGROUND IN THE THIRTIES

Automotive Engineering was practically a closed discipline by the 1930's. General vehicle concept, theory and empirics of dynamics, energetics and mechanical solutions of principal components achieved a considerable level of maturity both technological and operational, which have survived until this day without a substantial change.

The principal philosophy of automotive locomotion had been then as it is now, based on mass production of vehicles and the availability of roads and fossil fuel. In this situation, the road (considered as a physical medium of locomotion) simplified the problem of mechanics and economy of vehicles because it is a medium of practically fixed physical properties, mainly seen as a flat, rigid surface.

Quite to the contrary, the concept of off-road locomotion and the approach to it were in a fluid state of confusion in the Thirties in spite of a revolutionary development of agricultural, military and commercial cross-country vehicles. Although these vehicles were influenced by the developmental school of thought of automotive engineering, the medium in which they operate is obviously not a flat rigid surface, which eliminated at that time many conventional solutions and research.

Special solutions demanded a rational adaptation of the off-road vehicle to the soft uneven terrain surfaces that are also subject to changes of climate and geography. Since such an environment varies within a very wide span, the theory and empirics of highway locomotion were not quite applicable.

During the Thirties very little was known about the mechanics of phenomena which take place at the vehicle-terrain interface, although these phenomena have always defined the statistical optima of vehicle configuration, i.e., the numerical relationships between Form-Weight-Size-Power aggregate which in turn defines the Vehicle Concept.

WARSAW INSTITUTE OF TECHNOLOGY — 1936-1939

During the period 1936-1939 I had the opportunity to establish a graduate course on Terrain-Vehicle Mechanics and a supporting Laboratory at the Warsaw Institute of Technology. With the help of the Government and the Institute, I faced the task in a general way, trying to tackle the whole problem rather than its parts. The execution of the plan failed because of the outbreak of the war. However, the three years of lectures and laboratory work which took place in 1936-39 had a decisive influence

Fig. 1

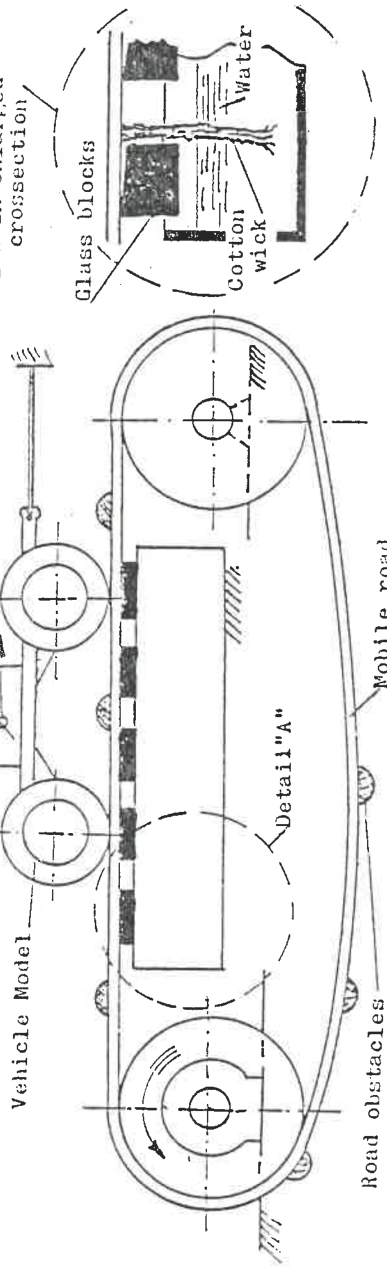


Fig. 2

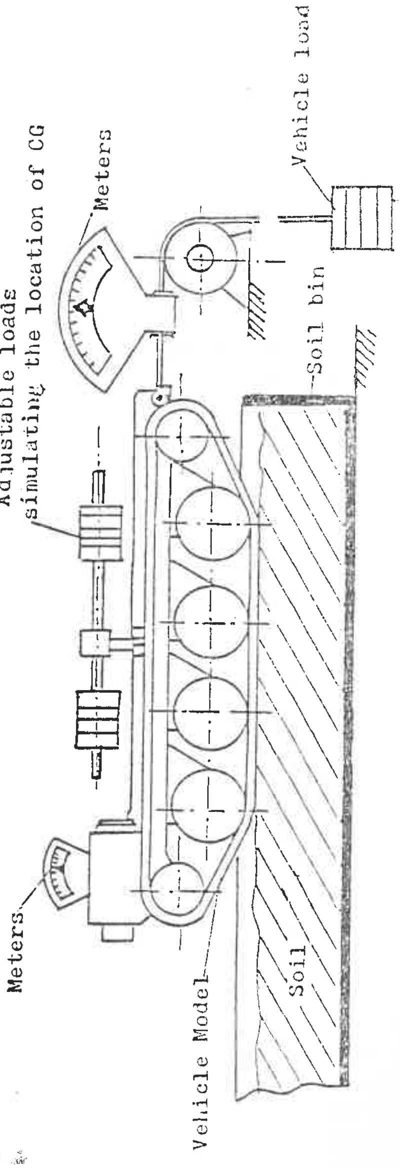


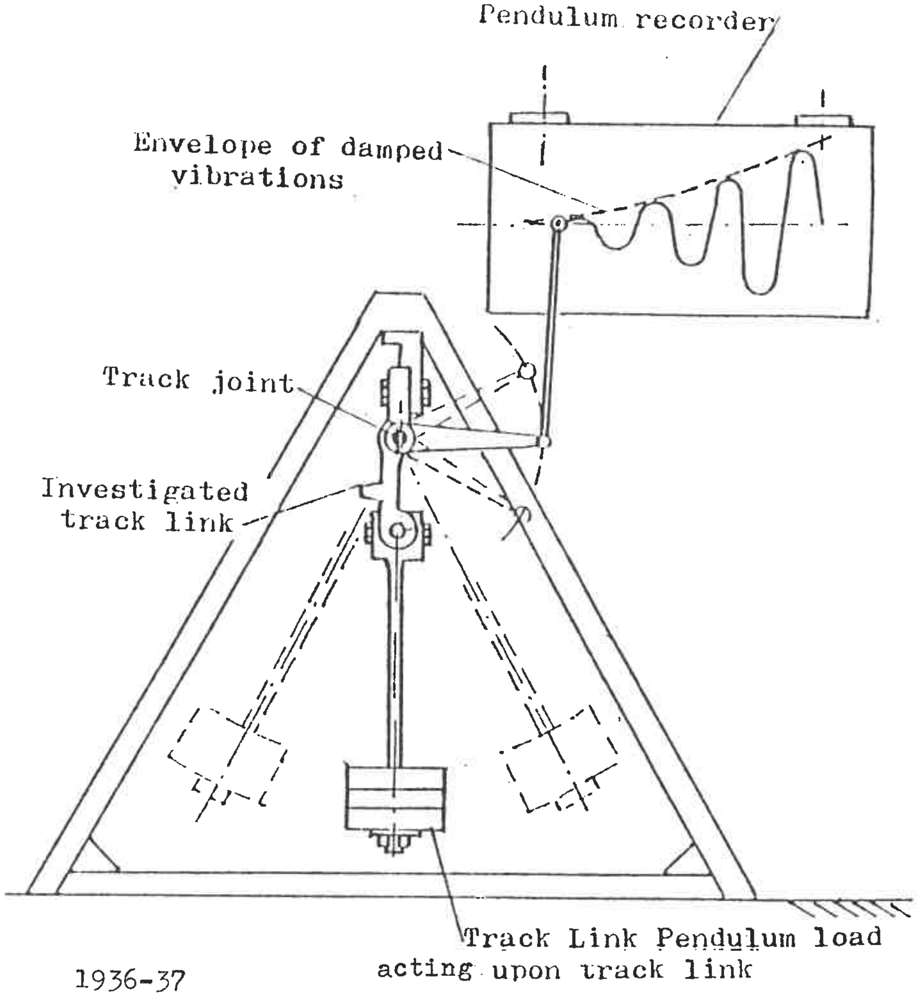
Fig. 1. Treadmill for investigation of forced vibrations and stability of vehicle models. The road is represented by a rubber band supported by glass blocks water lubricated and equipped with obstacles forcing model to vibrate. Waas vibrograph was used for monitoring vibration in XYZ axes.

Fig. 2. Soil bin for measuring motion resistance of vehicle model.

upon the methodology of my future activities. For this reason, let me briefly describe the work which, in a perspective of almost 45 years, appears to be the first attempt at a systematic, organized effort of long range scientific and technical implications in the discussed area.

The preparation of my lectures required a study of pertinent literature to a large extent previously done. The study led to the formulation of the following problems as well as to the initiation of their solution:

- explanation and delineation of trends and potentials related to cross-country vehicles;
- closed definition of methodologies for two emerging problems:
  1. locomotion on soft, plastic ground and,
  2. locomotion on a rather firm, but rough terrain surface.



1936-37

Fig. 3. Apparatus for measuring friction in track joints by determining damping of pendulum oscillations.

The first group of problems required consideration of soil mechanics and theories of plasticity; the second was related to vehicle dynamics such as ride, directional stability and obstacle crossing. In both groups of problems, the world literature was limited to a very general, simplistic treatment of the subject matter, which barely fit, if at all, our attempted solutions in the realm of off-road locomotion. Consequently, the initial plan aimed at the following tasks:

- theoretical and experimental analysis of stresses and strains in the ground under a moving vehicle, or its model;
- theoretical and experimental study of vibrations of mechanical systems with many degrees of freedom;
- establishment and introduction of some sort of numerical parameters defining the ground strength, pertinent vehicle efficiency, and its dynamics in dependence of terrain.

These points may be considered as a first primitive definition of applied mechanics for off-the-road locomotion. That definition found its expression in lectures and research which I later published in Canada and the United States (1948, 1956, 1960, 1969). Its very first application to the work performed at the Warsaw Institute of Technology was implicit in my lectures, in the research plan and in the equipment of the Laboratory established at the Institute:

1. Treadmill (Fig. 1) for studies of vehicle model vibrations and directional stability, under conditions forced by the "moving road". The idea was based on work by Kamm (1936).
2. Soil Bin (Fig. 2) for analyses of deformations of the ground, and of the vehicle motion, by means of models. General concept of the inquiry was based on work by Kanafojski (1934).
3. Pendulum-like appartus (Fig. 3) for an investigation of the friction, or other resistance in track link joints.
4. Apparatus for investigation of the dynamics and motion resistance of a freely rotating track (Fig. 4), as a function of track structure, weight, etc.
5. Special appartus patented by Waas which was purchased in Germany with the purpose of measuring various vibration parameters in three coordinates, XYZ (Fig. 1).
6. An assortment of instruments such as dynamometers tachometers, stroboscopes, soil mechanics standard laboratory equipment, cameras, etc.

The three year work at the Warsaw Institute of Technology barely allowed for the initiation of regular activities. Nevertheless, before the outbreak of war in September 1939, the treadmill, the soil bin, two vehicle models, (one tracked, one wheeled) and the pendulum type apparatus were in use. Even one of the research projects related to the resistance of track bending around the link joints, was completed and published in the "Technika Samochodowa", a journal of the Society of Mechanical Engineers (SIMP).

WARTIME INTERMISSION — 1939-1942

The interruption of activities caused by the outbreak of war was initially spent on ineffective popularization of goals, potentials gains, methods and plans related to the development of the mechanics of off-road locomotion. This was the theme of my memoranda written at the French Ministry of Armament in Paris in 1940, and later in my theory of steering tracked vehicles, written in Marseilles.

The theory's novel approach was based on equations of vehicle motion rather than on the equations of static equilibrium of forces involved known at that time.

This work was, to some extent, parallel to a study performed at the same time in England, of which I had no knowledge. Both these approaches were later used at Stevens Institute of Technology, and were briefly described in my first book published by the University of Michigan (1956).

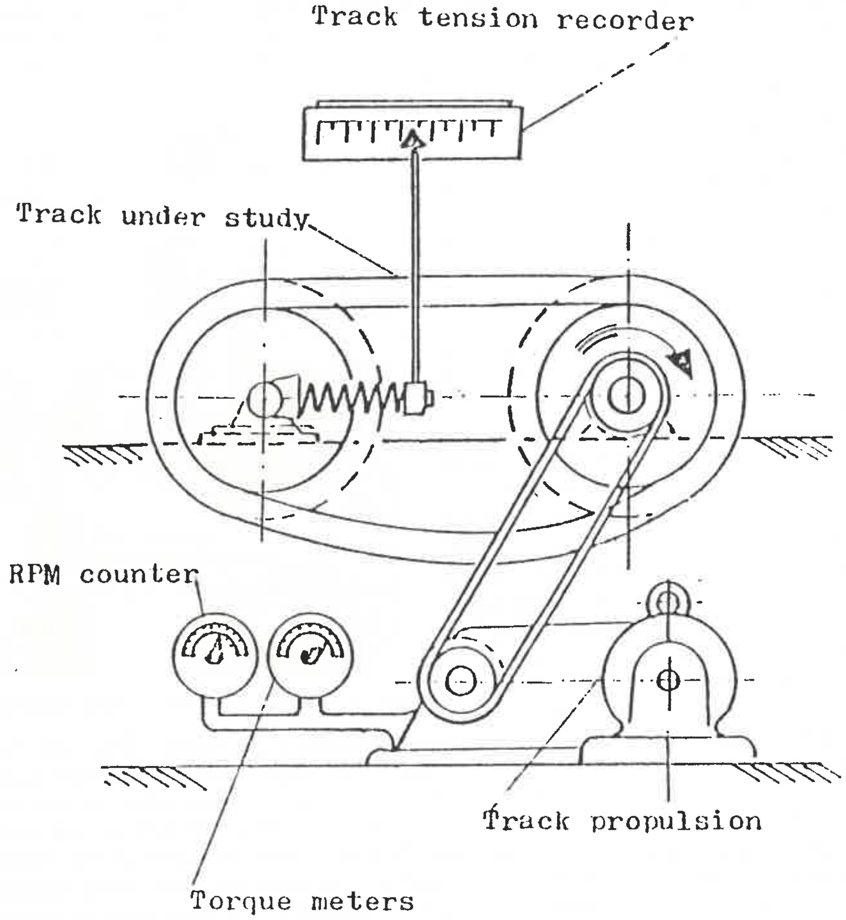


Fig. 4. Apparatus for measuring motion resistance of a freedriven track.

RESUMPTION OF ACTIVITIES IN CANADA — 1942-1950

The previously described research concepts found a favorable reaction in 1942 upon my arrival in the capital of Canada. The ensuing work was later described in a voluminous report (1948).

The soft ground performance of vehicles used in the war was rather unsatisfactory, and this problem overshadowed everything else. In England, a high ranking "Mud Committee" was established. It cooperated with the Canadian National Research Council, the Army, and with the American Society of Automotive Engineers in an active support of my ideas.

The wartime effort, however, allowed only for attempts to solve urgent current problems. It was not until about 1944, that I could undertake the long-range research programs interrupted in Warsaw. The Canadian National Research Council, the Army and the SAE provided their full sponsorship.

Experience gained in wartime clearly indicated that the continuation of Canadian tests with vehicle models in a soil bin should be supplemented with more theoretical studies of the stress-strain relationship imparted by simple models simulating the action of a wheel, track, or other loading surface.

That approach did not ignore the existing theories of plasticity developed by researchers such as Huber, Hencky, von Mises, Nadai and others, which I later mentioned in my first book (1956). However, for purely practical reasons, our approach was based on theoretical soil mechanics established by Terzaghi (1944).

The method of analysis of the effects of loading areas which represent those of a vehicle was related to the study of principal stresses and shear patterns. To this end a unique apparatus (shown in Fig. 5) was built at the Canadian Army's Proving Ground in Ottawa. The device was composed of a box filled with soil acted upon by a wheel or track model which was subjected to horizontal and vertical loads. Soil deformation was observed under the corresponding stresses by means of a rectangular grid inserted into the soil, right behind the glass wall of the box. The grid was made of a dark colored sand. It changed its shape under soil loads.

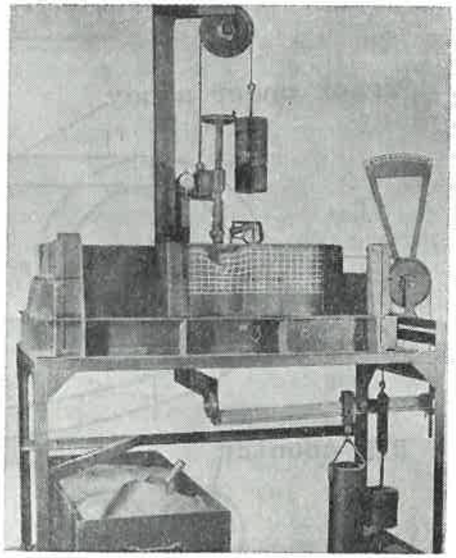


Fig. 5. Soil deformation testing apparatus.

Fig. 6 shows the scheme of the apparatus which explain its fundamental feature: during the test the model remains under a constant pre-set ratio of horizontal (H, or HR/r) to vertical load (V). The ratio could be selected by shifting the loading mass along distances a-b on the main beam. Thanks to this arrangement, the deformations of the rectangualr grid (Fig. 7) enabled one to apply the then newly developed method by Haefeli (1944) in order to graphically determine the trajectoires of principal stresses at the angle of 45-$\phi/2$).

These experiments and the underlying theory led to the formulation of the general coefficient of vehicle efficiency, expressed in the form of Drag/Lift ratio, i.e., by the ratio of motion resistance (or propulsion thrust) to vehicle weight in the given medium of locomotion. That ratio, denoted by H/V, is an universal measure of efficiency of all vehicles, including those operating in the air and on the sea. Accordingly, the ground vehicles for off-road locomotion could be evaluated for the first time, at least conceptually, in the same manner as ships and aeroplanes. Hence, we had already then a simple "terramechanics" comparable, in principle, to fluid mechanics.

In the late forties this was a fascinating idea, opening a possibility of analyzing complete systems of locomotion, in the air, on the sea, on rails and highways — and in a roadless wilderness. This was the first glimpse of a possibility of system analyses

1944-45

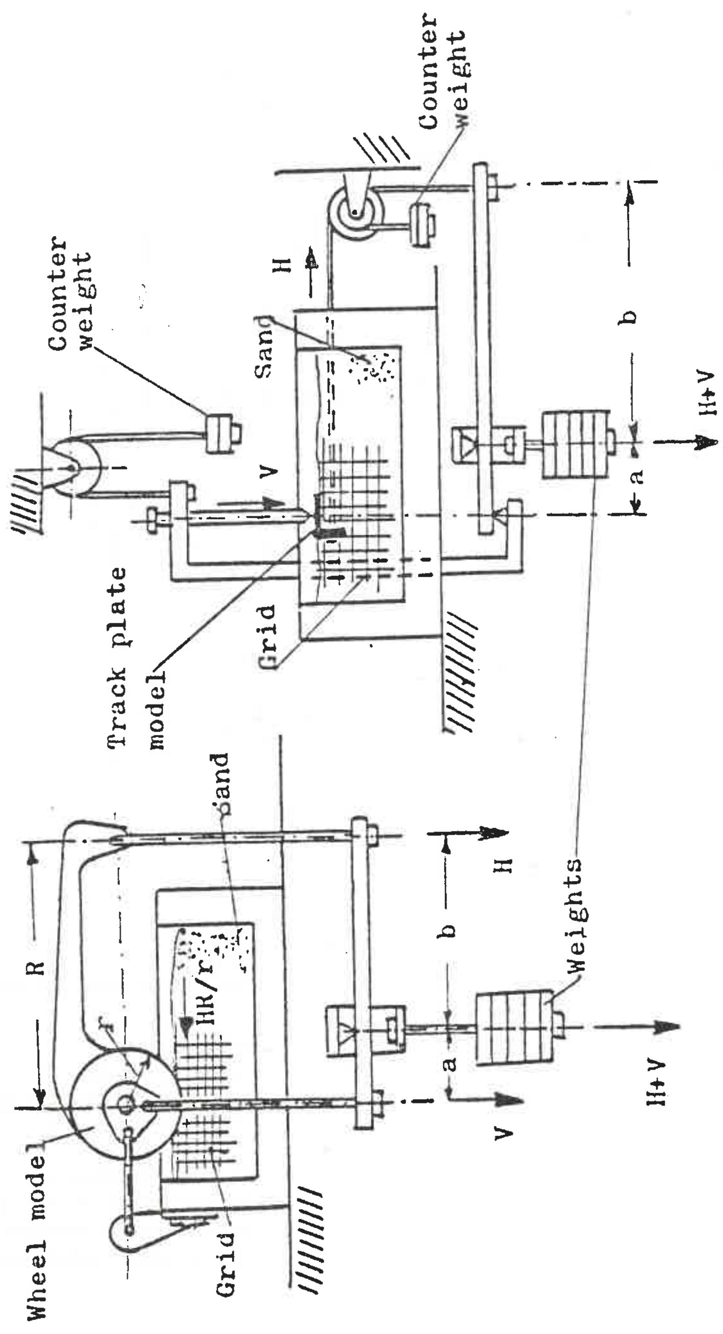


Fig. 6. Apparatus for the determination of principal stresses for a wheel model, left, and a grouser plate, right. The instrument is equipped with coordinate grids made of dark powder inserted between the sand which fills the box, and the glass wall of the box. The models are loaded by horizontal forces H, or HR/r and vertical forces V. Ratios of horizontal to vertical loads may be pre-set by moving weights H+V along the a-b distances. Weights of loading beams system are counter-balanced.

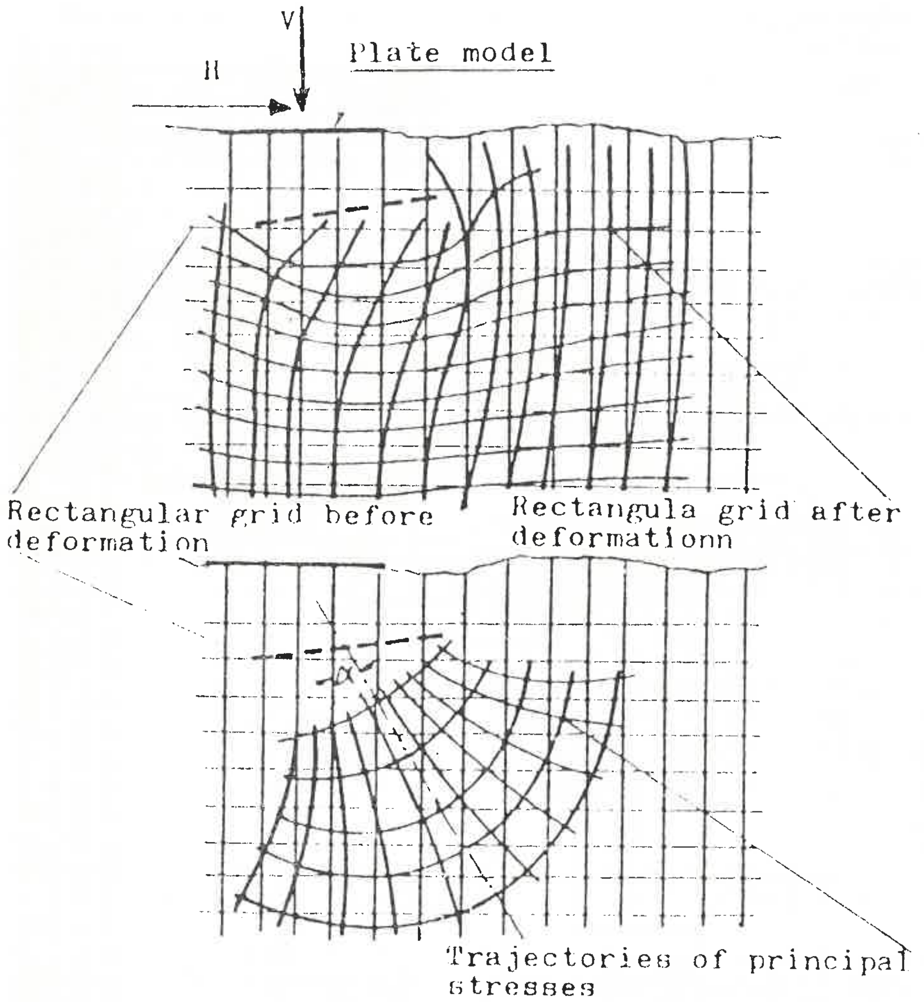


Fig. 7. Grid deformation under horizontal and vertical loads. Trajectories of principal stresses obtained using Haefeli's method.

as originally proposed in a pioneering but little known book by Neesen (1940), who showed how to bring everything under a common denominator of applied mechanics, with the exception of off-road vehicles.

The above achievement, however, was limited. Based on Terzaghi's "stability problem" solution, it encompassed only the ultimate shearing strength of the ground, postulated by the Coulomb's criterion. The criteriom defines the maximum shear stress τ max as a function of normal stress p, cohesion c and friction angle ϕ, in the following way:

$$\tau \max = c + p\tan\phi \tag{1}$$

Equation (1) does not include soil deformation; hence it cannot define vehicle

sinkage, slip and other important parameters. As a result the coefficient of efficiency H/V is approximate.

Nevertheless, the results obtained may be considered significant. For instance, analysis of the maximum capacity of the soil (max. vehicle weight allowable) and the related horizontal strength of the ground, i.e., the maximum soil thrust, showed that two distinct cases ought to be considered:

1. the "grip failure", and
2. the "ground failure" of soil as defined in my previously quoted report (1948).

An example of the first kind of failure can be seen in Fig. 8, which shows a wheel model tested in the soil bin.

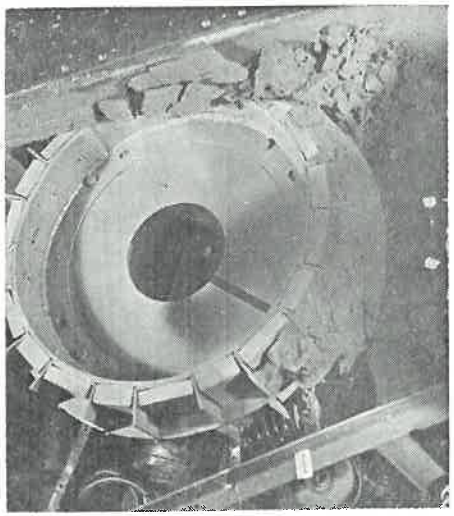


Fig. 8. Wheel model tested in soil bin.

Denoting vehicle weight by V, its ground contact area and dimensions by A=bxl, where b is the smaller dimension, and the max. soil thrust by H, the efficiency H/V for a grip failure is:

$$H/V = (Ac + V\tan\phi) \;/\; V = (c/p) + \tan\phi \tag{2}$$

where the ground pressure is: $p = V/A = V/bl$

For a ground failure, the ultimate efficiency of locomotion is:

$$\begin{aligned} H/V &= \tan\theta \\ H &= bl\,(n_c c + \gamma n_\gamma l)\sin\theta \\ V &= bl\,(n_c c + \gamma n_\gamma l)\cos\theta \end{aligned} \tag{3}$$

where, n_c and n_γ are coefficients dependent on friction angle; γ is soil density. The coefficients were calculated for various ϕ's and published in my previously mentioned report (1948), and in my second book (1960).

For the given vehicle weight V, and a ground contact area A=bxl,, soil thrust may be calculated from Equations (3), for the ground defined by parameters c, ϕ, γ. Thus Equations (3) define the vehicle efficiency (ultimate) for the given soil.

The significance of these achievements may be seen in the following points:

- for the first time it was possible to interrelate by means of mathematical models certain vehicle parameters (V, b, l, A) with generally accepted soil parameters (ϕ, c, γ), and develop these relations into algorithms for the purpose of calculating the design and performance parameters (H,V,b,1,p,H/V).

Introduction of more detail (omitted here for the sake of brevity), made it possible at that time to evaluate gear ratios, engine torques, power, fuel consumption and a more rational vehicle configuration for the postulated terrain as defined by $c\phi\gamma$ — values.

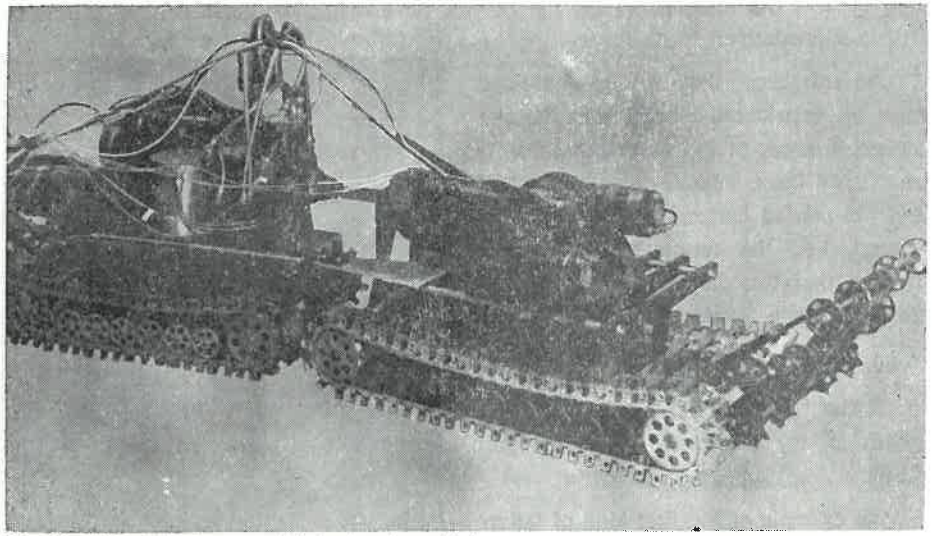


Fig. 9. Articulated spaced-link track vehicle scale model. First Canadian prototype built at Canadian Army Proving Ground, 1949.

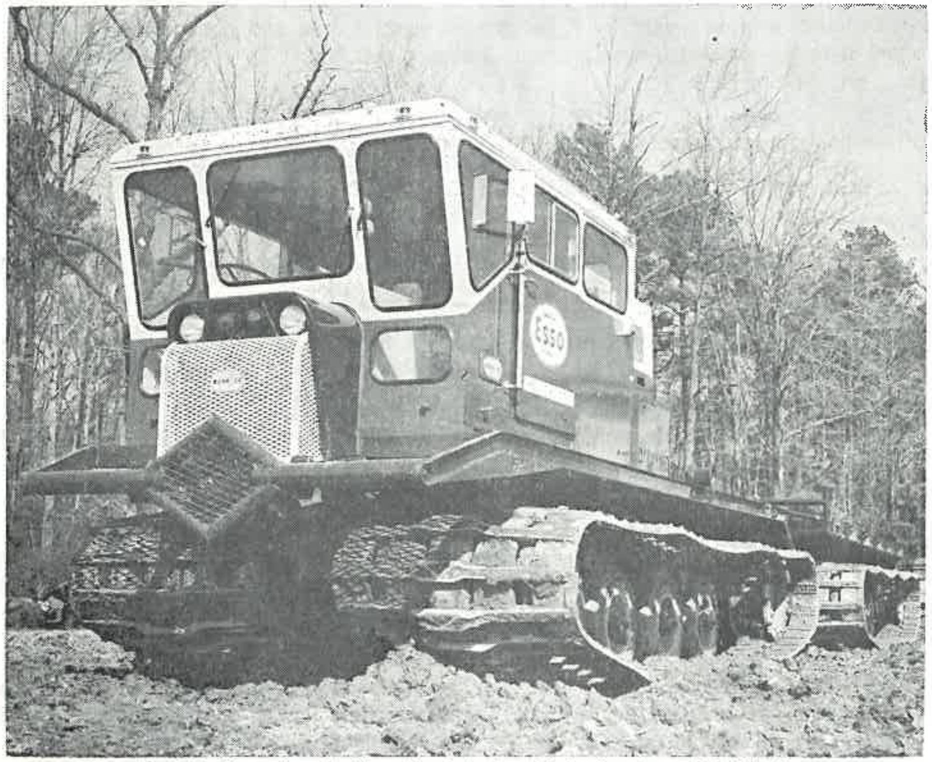


Fig. 10. Canadian built articulated vehicle for Imperial Oil C.

- In addition, the problem of grouser and spud action was elucidated from the viewpoint of their traction, in conjunction with the action of tracks and wheels. Pertinent theories, originally developed, led to the patents of the so called "spaced link track".

A model of an articulated vehicle built on the spaced link track principle is illustrated in Fig. 9. Further developments in Canada included the building of commercial vehicles such as the "Musk Ox" (Fig. 10).

These tracks have underscored and explained the fact that the bearing capacity of a loading area is not necessarily reduced when that area is made of discontinuous surfaces, according to certain rules.

Much later this had an enormous influence upon my fostering of tires made of wire mesh, which were ultimately used with our Lunar Roving Vehicle ((LRV).

Further consequences of progress made then were:

- the morphology of vehicles could be solved on a more rational basis, using ground parameters $c\phi\gamma$. Generally speaking, calculations showed that a tractor for wet clay operations should have a light weight and large ground contact area, i.e., tracks of specified dimensions, whereas a tractor for the same output for sandy soils, should be heavier, yet allowing for smaller ground contact areas, possibly tires.

It thus became clear why clayey terrain may exclude tires, while sands perfectly fit that solution. Such were the first answers to the perennial question: wheel or track?

Knowing the terrain parameters, it is now easy to solve the problem for the great variety of intermediate soil types as explained in my books (1956, 1960, 1969). The beginning was made when:

- the first soil measuring devices were built as later described in my report ((1948) and in my first book (1956).

As a historical record, it should be mentioned that the idea of using $c\phi\gamma$ parameters was conceived independently, almost at the same time, in England, by Micklethwait (1944). His short report, however, was fragmentary and not backed by any experiments. In any case,

- the work briefly described here dramatized the need for establishing and using additional parameters of terrain, besides $c\phi\gamma$ — values: parameters which would define ground deformation as function of load.

This problem was most difficult. Theories of plasticity, then in existence, were not amenable to parametric analyses of cross-country locomotion (as is the case today). Only semi-empirical solutions could have been tried.

STEVENS INSTITUTE OF TECHNOLOGY — 1950-1952

The starting point was the work by Bernstein (1913) with which I was roughly familiar, mainly through the work by Letoshnev (1936).

The original of Bernstein's pioneering paper was found in New York Central Library, and became the object of my scrutiny at the Stevens Institute of Technology, where I was establishing graduate courses and the laboratory in mechanics of off-road locomotion at the beginning of 1950, utilizing all the experience gained in Poland and in Canada.

According to Bernstein, the relation between vertical unit load p and sinkage z of a plate may be expressed by equation:

$$p = kz^{1/2} \qquad (4)$$

where k is an empirical coefficient. Its structure was subject of much speculation by

Bernstein and the others, which satisfied nobody. Numerical modifications of exponent ½ also were unacceptable, beyond a few cases.

However, the equation proposed by Taylor (1948) for the evaluation of shallow sinkage of foundations, in the following form:

$$p = \left[(k_1/b) + k_2\right] z, \qquad (5)$$

attracted my attention. k_1 and k_2 are again empirical coefficients, and b is the smaller dimension of the loading area. At the same time, I became more interested in works by Russian students of tractors and agricultural machinery (Goriatchkin, 1936) who often referred to Bernstein's equation, in the following form:

$$p = kz^n \qquad (6)$$

At the end of 1952, I was hoping that the combination of equations (5) and (6) might be useful in evaluation of sinkage and motion resistance of a vehicle due to soil compaction. However, experimental verification of this assumption had to wait almost two years because my work at Stevens was also devoted to the solution of many current problems related to the financial base of our operation.

Fortunately, the solution for horizontal loads and deformations of the ground, imparted by vehicle thrust and slip, could have been solved "on paper".

As mentioned before, Coulomb's equation (1) expresses the maximum shearing stress τ max for a certain soil deformation. Since vehicles may work at various, not necessarily optimum deformation jopt, the problem was to define any τ for any j.

Experiments had shown previously that for a surface soil shear, there are two types of function $\tau(j)$: one which reaches a definite peak and then drops down, and the other, which upon reaching the peak, practically remains constant.

Theory and experiments peprformed in the soil bin (Fig. 11) also showed that the horizontal deformation of soil j increases linearly along the ground contact area of the track, or tire (at uniform ground pressure), in accordance with a simple rule: $j = i_0 x$, where i_0 is vehicle slip, and x is the distance of the considered segment of the contact area, measured from the front end of the area.

A search for an equation that would fit the first type of shear-deformation curve disclosed that a curve of aperiodic damped vibrations has a similar form. As a result, upon changing appropriate coefficients, the $\tau(j)$ function was written:

$$\tau = \left[(c+p\tan\phi)/Y\max\right] \left[\exp\left(-K_2+\sqrt{K_2^2-1}\right)K_1 i_0 x - \exp\left(-K_2-\sqrt{K_2^2-1}\right)K_1 i_0 x\right] \qquad (7)$$

where Ymax is the maximum value of the function enclosed by rectangular brackets [ ]. K_1 and K_2 are slip parameters. Equation (7) applies to brittle ground such as hard silt, compacted wet sand, frozen ground, or snow as well as soil covered with a blanket of vegetation.

Since, in a number of cases shown later by experience, many soils display the second type of $\tau(j)$ curve, a simpler equation of a well-known form could have been used: $1-e^{-x}$. Upon the transformation of pertinent coefficients.

$$\tau = (c+p\tan\phi)\ (1 - e^{-i_0 x/K}) \qquad (8)$$

where, K is again a slip parameter. Equation (8) applies to sand, loose sandy soils, and to granular masses such as snow at low temperatures.

The method of defining K_1, K_2 or K by fitting the functions, Equations (7) and (8) into the experimental functions $\tau(j)$ was elaborated between 1950-52 and published in world literature, for instance in the book by Sołtyński (1966).

These were the results of research work at Stevens. From the practical viewpoint, besides reviving the Concept of Articulated Vehicles (Train Concept), perhaps the most

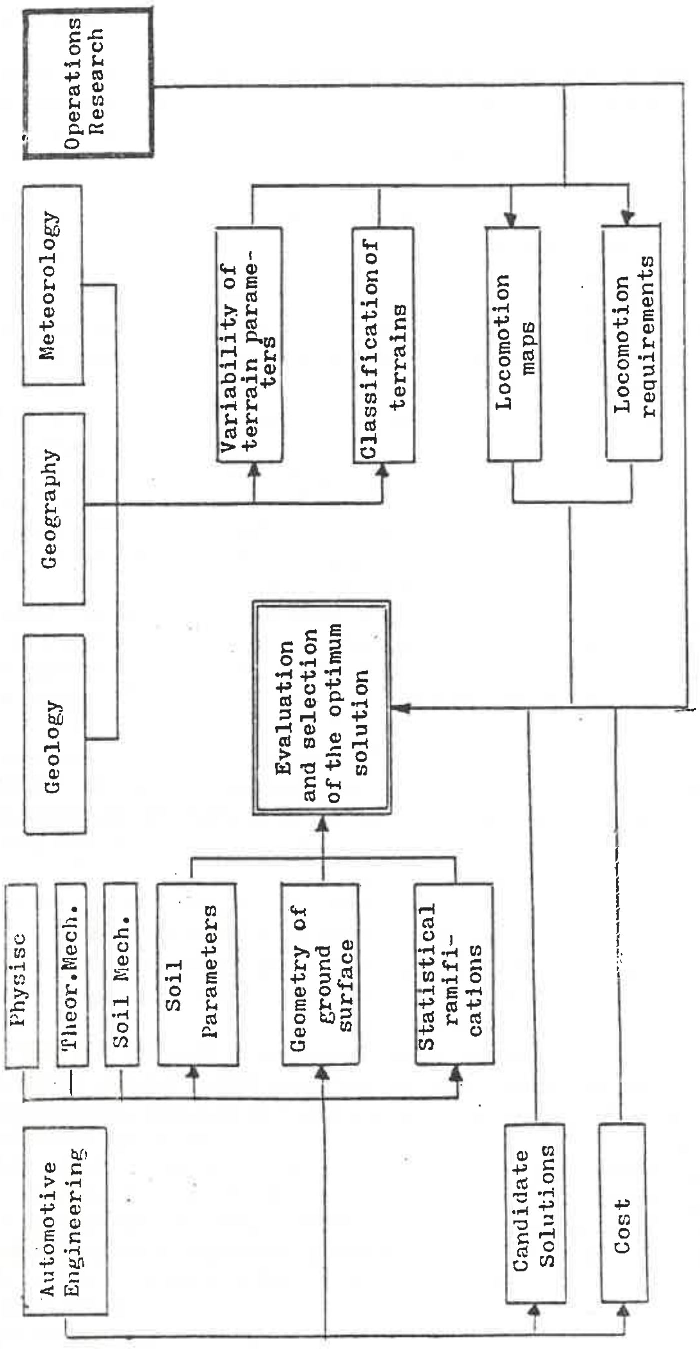


Fig. 11. General scheme of studies and respective tasks with related disciplines, which are required in optimization and selection of a vehicle.

important was the two year teaching of the Mechanics of Off-Road Locomotion at the Graduate School, which was a natural extension of work started in Warsaw and of the experience gained in Ottawa. The course was published in the form of my first book by the University of Michigan (1956, 2nd ed., 1960).

THE JOHNS HOPKINS UNIVERSITY-OPERATIONS RESEARCH OFFICE (1952-1954)

The cumulative knowledge arrived at during the years 1942-1952 was radically new and very promising; it produced wide changes in the methodology and philosophy of approach to off-road locomotion. This, in turn, created an opportunity of trying some practical solutions in the Research Office of Johns Hopkins University. On that occasion, it became evident that further progress depends on organization of systematic research on a scale larger than ever tried.

Efforts aimed in that direction were concentrated in my writing memoranda, lecturing, and discussing the problem definition, the method of approach, organization, cost, etc., with the purpose of clarifying, on a broader forum, all the pros and cons in respect to the proposed inauguration of off-road locomotion research as a self-contained, autonomous major activity.

To characterize this effort, which was without precedent, here is a partial list of institutions and organizations with which I was engaged in a lengthy dialogue: SAE, ASME, ASAE, University of Newcastle upon Tyne, Braunschweig University; Franklin Institute; Georgia, Massachusetts and California Institutes of Technology; Universities of California, Berkely and Los Angeles; Duke, Brown, Princeton, Purdue, Syracuse and New York Universities; Universities of Michigan, Minnesota and Ohio; Michigan State University and Rennsselear Polytechnic Institute.

Contacts thus established lasted for many years, with new ones continously added. The correspondence embraced a wide international circle of professionals.

A condensed partial version of problems under initial discussion may be found in my report on methods of off-road locomotion evaluation (1953). A graphic presentation of the main lines of thought is shown in Fig. 11.

Research as such was limited, in the meantime, to the continuation of work previously started. In 1953 I could return to equations (5) and (6). Following the experienced gained with the coefficients K_1, K_2, or K which fit empirical curves of surfacial ground shear, I finally combined Eqns. (5) and (6), in the new form:

$$p = [(k_c/b) + k_\phi]\, z^n \tag{9}$$

where k_c, k_ϕ and n are again empirical parameters to be used in fitting the theoretical curve into the empirical one, for plate penetration z under pressure p.

In order to check if parameters $k_c k_\phi n$ enable one to fith the experimental curve in Eqn. (9), I used a voluminous set of data found in civil engineering literature on loads and sinkage of various plates and foundations.

The calculations confirmed the basic soundness of Eqn. (9) and the adequacy of using only three parameters $k_c k_\phi n$, in the curve fitting process, which also was shown to be practically independent of plate sizes, if their aspect ratio (1/b) was larger than approximately 5, or for circular plates with radius b, which was determined later.

As it now appears, this result had a decisive, if not trailbreaking, significance for the further development of off-road locomotion mechanics. For without a solution for horizontal and vertical stress-strain relationships such as expressed by Eqns. (7), (8) and (9), further progress would be practically impossible. A proof of this is seen in a divergent mosaic of "parameters" selected either arbitrarily, or too rigorously, for various types of terrain. This has led to a conglomerate of solutions without cohesion or common denominator. As a result, parametric analyses of locomotion systems, within the statistical variety of terrains, was not achieved with these approaches.

Equations (7), (8) and (9) apply to any environmental conditions of terrain. They display exponential functions, as these seem to serve the propose best. Undoubtedly for this reason the Russian researchers, as I learned later, accepted terrain value equations which are conceptually identical though based on hyperbolic functions. As is known, however, the latter are merely combinations of exponential functions.

This underscores an obvious fact that empirical curves of horizontal shear and vertical soil compression may be fitted with any desired type of theoretical function. What matters in such cases is the question whether the effort of handling more complex equations and more cumbersome soil measuring procedure will pay off in terms of more accurate prediction in engineering systems evaluations.

During the period 1953-54, the concept of off-road mobility research became more general and inclusive as shown graphically in Fig. 11. The organizational-functional scheme also was better adapted to a more mature methodology and to more precise programming, as illustrated in Fig. 12.

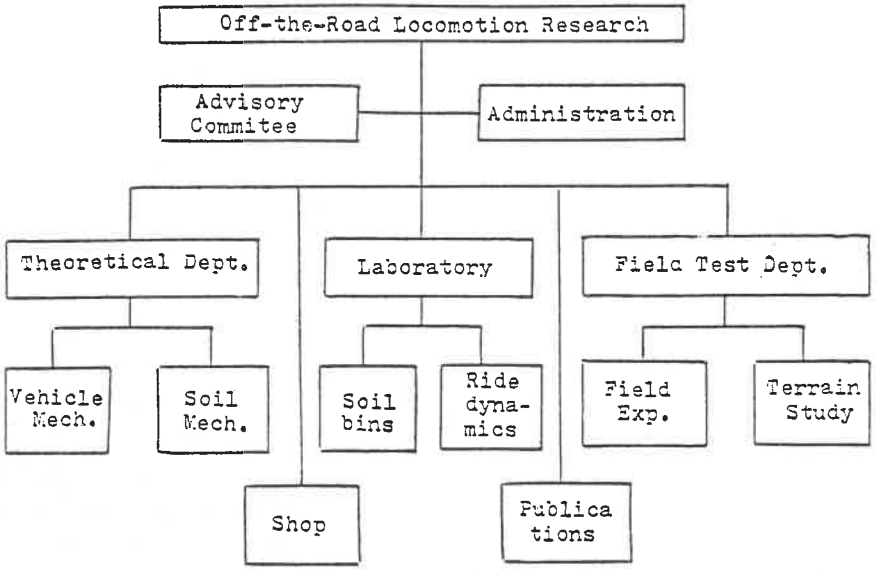


Fig. 12. Typical functional chart of an Establishment for Off-Road Locomotion Research.

LAND LOCOMOTION LABORATORY — DETROIT ARSENAL — 1954-1960

In the mid-summer of 1954 I was given the mission of establishing a new laboratory in Detroit, the center of automotive industries. Basic equipment and methodology were in principle unchanged.

During the early organizational period, much time has been spent on teaching a new approach to the old problem, on the experimental verification of Eqns. (7), (8) and (9), and on the development of algorithms for evaluation of design and performance parameters of a multitude of vehicles, missions and terrain environments.

Measuring soil parameters $k_c k_\phi n\ c \phi K_1 K_2$, or K by means of instruments called the Bevameters, enabled one to validate many practical solutions. For instance, the motion resistance of a vehicle R_c, caused by soil compaction to depth z_0 could be expressed by means of equation:

$$R_c \sim \int_0^b \int_0^{z_0} p \ db \ dz \qquad (10)$$

which could be integrated for the given p(z) as expressed by Eqn. (9).

Soil thrust for vehicle propoulsion, at width b and length l of the ground contact area, is:

$$H_{max} = \int_0^b \int_0^l \tau_x \ db \ dx \qquad (11)$$

Approximate useful power **HPi₀** of a tractor measured on its towing hook at vehicle slip i_0, may be expressed for speed v by the following formula:

$$\mathbf{HPi_0} = (H - R) \ v \ /1 - i_0) \qquad (12)$$

and the efficiency of locomotion, H/V, now including locomotion losses in the ground, is:

$$H/V = (c/p) + \tan\phi - (k_c + bk_\phi) \ z^{n+1} \ / \ (n + 1) \ V \qquad (13)$$

Equations 10 through 13 are a narrow example at an inexhaustible variety of mathematical solutions, naturally subject to refinements, which are based on bevametric parameters of soils.

One of the bevameters designed for field exploration is shown in Fig. 13. It is mounted on the second unit of an articulated vehicle, along with a terrain roughness measuring device. The front unit was instrumented with data processing equipment.

Methods of determining ground parameters from bevameter data were described in general solutions for any medium of locomotion, at least from the methodological theory on land locomotion (1956) and on "Terramechanics" (1960), illustrate the point. Other references, in Spanish, German, Russian, Italian, Japanese etc., could be cited.

The problems related to a rigid wheel, tire, track, sleigh, etc., were worked out in genral soluteions for any medium of locomotion, at least from the methodological viewpoint. In most cases uniform, semi-inifinite masses were considered with satisfactory accuracy. Stratified ground produced similar results for lighter vehicles, with shallow sinkage. Heavier vehicles considering stratification, produced problems that led to complex, not entirely explored solutions. Better bevametric solutions were worked out later and published in detail in my papers (1969, 1978).

Much effort was spent on defining more rigorous solutions based on theories of plasticity. Again, however, even with the help of the experts from Brown, New York, Syracuse Universities and the University of Michigan, and Rensselaer Polytechnic, it was concluded that the considered methods do not yield themselves to practical treatment of parametric analyses. On the other hand, these analyses, based on semi-impirical methods described here, served fairly well in the solution of such problems as articulated vehicles (Fig. 13 and 9), which, in turn, contributed to their popularization. The "spaced link" tracks also found applications, perhaps not in the ideal form but nevertheless in an "open" structure that often departed far from traditional patterns.

At the onset of this paper, I mentioned the Waas apparatus for measuring vehicle vibrations which had been purchased around 1938 for the Warsaw Institute of Technology (Fig.1). It was the most expensive, unique and advanced instrument of its type. It was to help the development of the other part of mechanics of off-road locomotion, the dynamics of vehicle vibrations.

That part could not have been tackled before World War II. My lectures at Stevens Institute of Technology in 1950-1952 also treated the subject superficially, which was then a common-place. For it was the soft ground, not the rough terrain, which attracted most of the attention. In addition, the deterministic treatment of vehicle vibrations forced by idealized sinuosoidal ground "waves" and other geometrical obstacles, had limited applications. And finally, the lack of desk calculators discouraged lenghty, tedious calculations with inacurate sliderules. The computer was not in sight yet.

It was not until the introduction of stochastic methods for treatment of statistical vibrational output of irregular exciting functions, which was worked out in the Fifties by naval architects and airplane designers, that practical solutions of terrain vehicles became possible. Work in that area, was initiated in our laboratory, in 1955, with the help of Purdue and Michigan Universities. Around 1957, the first instrument for measuring terrain roughness was built ((Fig. 13). Also an experimental set-up of a vehicle module and of a stretch of wooden "road" with a 'known' power-spectral density, was installed. This arrangement served an exploratory-tutorial purpose of introducing those concerned into the new field of inquiry. It was based on the well-known relationship:

$$S_x(\omega) = |H(\omega)|^2 S_f(\omega) \qquad (14)$$

where $S_x(\omega)$ and $S_f(\omega)$ are power-spectral densities for the excited vibration functions x,

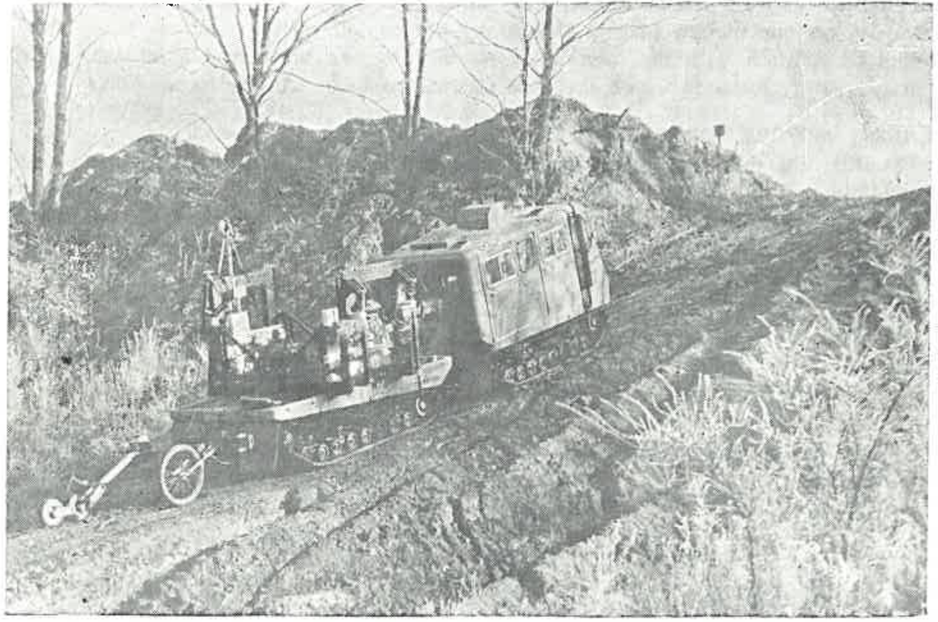


Fig. 13. Articulated track vehicle carrying a soil measuring bevameter, a terrain roughness measuring device and ancillary equipment — built for US Army.

and the exciting functions f; H(ω) is the Transfer Function whih depends on mass distribution, geometry, and elastic and damping properties of the vehicle, including its configuration.

As far as I know the Detroit Laboratory was the first organization devoted to off-road locomotion which initiated the new approach. Today, it is commonplace in the studies of vehicle dynamics.

Interest in the Laboratory's work was of international character. Travels, meetings, visits, apprenticeships and conferences attracted professionals from Europe, America and Japan. Even one of the doctoral theses of the University of Michigan was completed at our laboratory. The University of Michigan established a graduate course in the mechanics of off-road locomotion, which I taught as a special lecturer, commuting between Ann Arbor and Detroit. Other Universities have been using our written materials for regular lectures or special courses.

These activities were very stimulating. During a visit by Italian experts, for instance, I learned that Garbari (1949) had proposed during the last war solutions for tracks and wheels which were conceptually similar to our. This led to a closer cooperation with Italy. As a result, I had an opportunity of presenting at the Universities of Bologna and Milan, and at the Turin Institute of Technology, an outline of the newly emerging discipline with the recommendation for organizing a First International Conference, and for the establishment of an International Society for advancement of our studies on a broader scale.

The year 1960 was most significant because of the United States decision to land the first man on the moon within the decade. In an anticipation of a possibility of using ground vehicles for lunar exploration, I conducted and evaluated the first bevameter tests of granular masses in a vacuum, at Cornel Aeronautical Laboratory.

Although the practical result of these tests had little significance, if any at all, the exercise had a didactic effect, and called attention to the problems which did not exist on our planet. Shortly thereafter, I accepted a new position at General Motors Corporation, with the mission of establishing and organizing a laboratory for ground mobility research which included studies on lunar surface locomotion.

GENERAL MOTORS CORPORATION — 1960-1970

Starting the new venture at General Motors Corporation coincided with the end of my intensive preparation of the First International Conference on Terrain-Vehicle Systems, which took place as planned in mid-1961, in Turin-St. Vincent. Favorable reaction to the Conference, attended by some 200 engineers and students of the problems involved, broadened the circle of those interested, and incresed the international cooperation.

With the goal of advancing the discipline, the International Society for Terrain-Vehicle Systems (ISTVS), was established. The Charter of the Society was written and recorded in Durham, North Carolina, which since has became Society's legal seat.

In the meantime, the new Laboratory at General Motors required new approaches and much thought. The old philosophy which affected the establishment of similar work at Detroit Arsenal was based on attempts of integrating a variety of disciplines (Fig. 11) such as automotive engineering, theoretical mechanics, soil mechanics, physics etc. The integration aimed at a more precise definition of the mechanics of off-road locomotion based on bevametric ground measurements. The ongoing realization of such mechanics resulted in the occasional treatment of the problem within complete terrain-vehicle systems of statistical nature. Consequently, the philosophy of establishing the new activity at General Motors was more far-reaching and more precise.

It was based on pragmatic use of knowledge acquired with bevameter techniques, and on parametric analyses of optimum solutions.

The solutions, besides terrain statistics and locomotion efficiency, also considered other values of subjective-circumstantial nature such as cost, state of the art, lead time, weighing of the accepted value systems, etc. Fig. 14 shows schematically the role of off-road locomotion mechanics as a common denominator in the processing of the input-output data within that context. In principle, this scheme was not new. However, it is an illustration of first attempts of some sort of systematization and "standardization" of engineering activities which, until now, often displayed a chaotic treatment, without a common denominator, or proper sequencing. Developments and achievements in that area were later described in my third book (1969).

The problem of lunar surface locomotion absorbed most of my efforts. Almost complete initial ignorance as to the composition, structure and surface geometry of lunar terrain, led to the ideas of 1001 Nights. Exotic vehicles and soils were seriously considered not only by ourselves, but also by our competitors such as Grumman, Bendix and others. In order to avoid unforeseen difficulties, any logical possibility was explored, involving much work that could have been avoided under normal conditions.

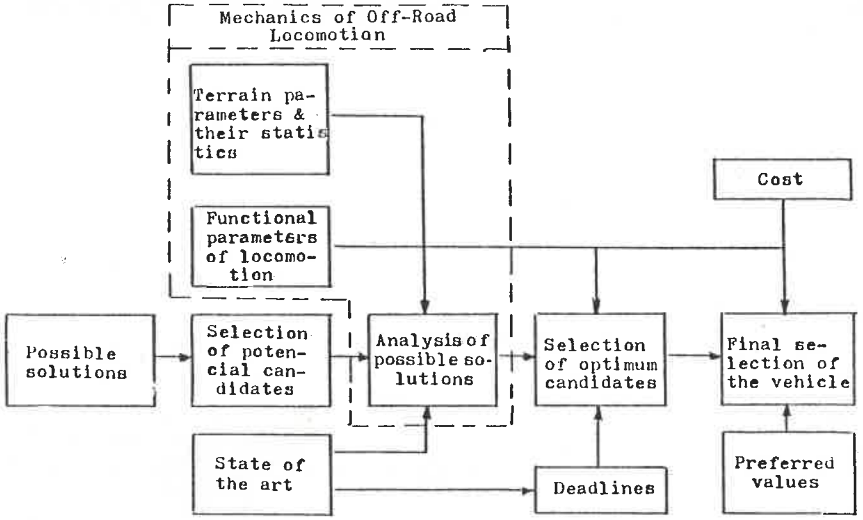


Fig. 14. Off-Road Locomotion Mechanics as a common denominator of the selection of optimum solution.

The Laboratory's equipment was now more-or-less standard. Fig. 15 shows soil bin, a dynamometer, and the soil processing equipment. Not shown is the 'treadmill' on which the dynamics of a wheed passing over obstacles were investigated using an oscillograph for the purpose of refining theoretical models with many degrees of freedom.

Hypothetical lunar soils were simulated within the wide range of physical parameters and structures. To this end a special bevameter was built, which worked in a high vacuum.

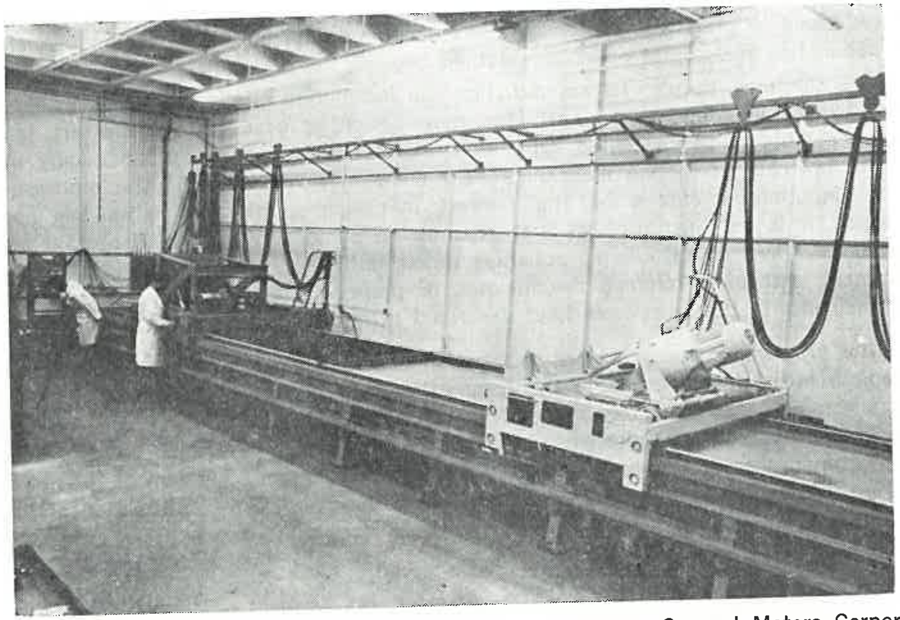


Fig. 15. Partial view of Ground Mobility Research Laboratory, General Motors Corporation, Santa Barbara, California.

Another appartus based of a free fallin gcounterweighted soil container, equipped with the bevameter, enabled one to measure soil values at g/6, i.e., at moon gravity. The following projects were completed within NASA programs:

- Automatic bevameter for work on lunar surface as a part of equipment of a small, remote-controlled vehicle built within requirements of "Surveyor" program (Fig. 16).

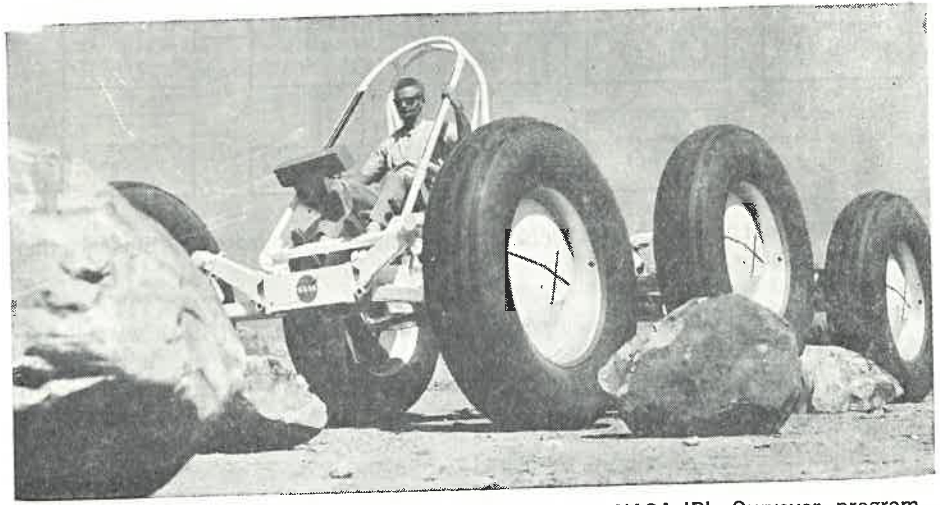


Fig. 16. Lunar soil testing bevameter, built for the NASA-JPL Surveyor program

- Experimental self-propelled model of the Surveyor Lunar Roving Vehicle (SLRV).
- Experimental chassis of MOLAB (Mobile Laboratory) vehicle built for NASA-Boeing (Fig. 17). The vehicle was to explore the moon for two weeks with two astronauts aboard upon completion of the Apollo flights.

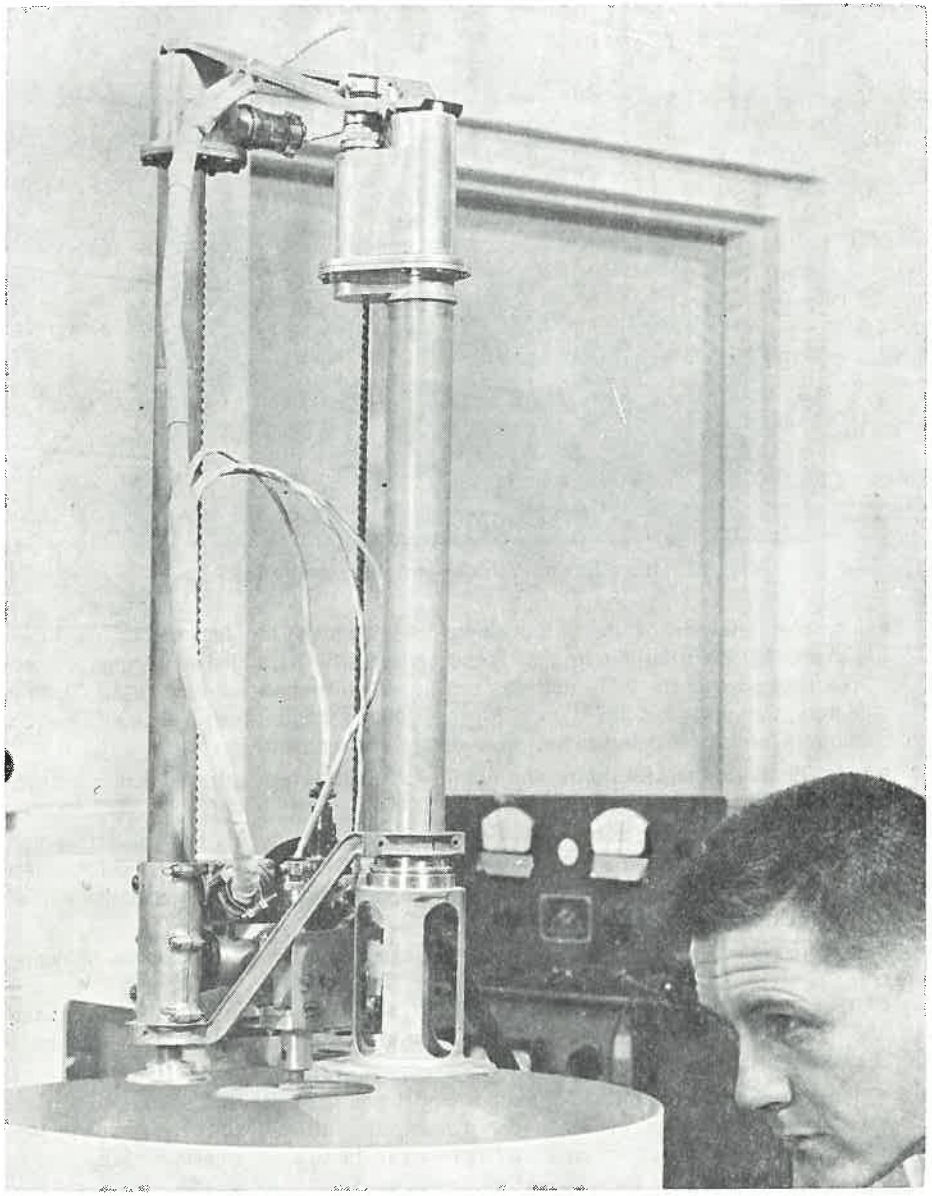


Fig. 17. Full-size prototype of the Molab vehicle.

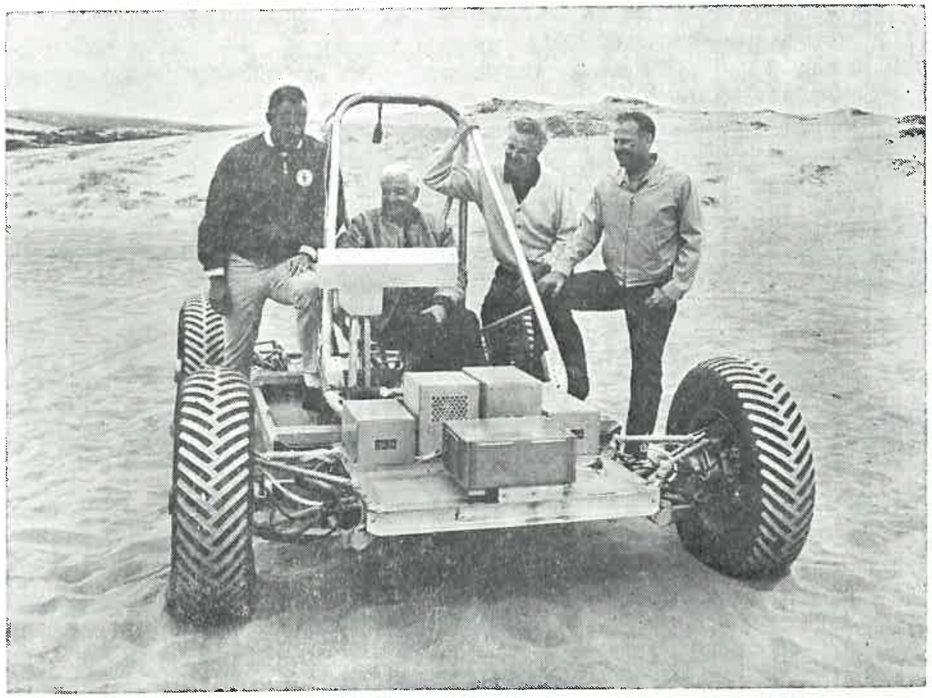


Fig. 18. Lunar Roving Vehicle prototype being testing.

- Intensive analysis of many Terrain-Vehicle Systems for locomotion on lunar surface. My contribution in that respect was initially published, among others, in a collective book (1967), and was continued, with short intervals, until General Motors was awarded the Lunar Roving Vehicle contract with Boeing. Fig 18 shows a prototype being tested in a desert environment.
- Fig. 19 shows the LRV during the Apollo 15 lunar surface extra vehicular activity at the Hadley Apennine landing site.
- Current programs in the evaluation of Vehicle Mobility on this planet, which included among others, much experimentation with articulated vehicles. An example of work in that area may be found in my report on optimization of locomotion systems. (1969a).

These programs were based on additional supporting research within the following areas:

- simulation of lunar soils with a variety of granular masses, structures and compositions, which corresponded to the gradually increasing state of knowledge of the surface of the moon;
- determination of ground deformations and loads for stratified soils;
- study of ground deformation under dynamic, repetitive loads. The problem was related to the construction of a lightweight bevameter whose working model was completed;
- Study of PSD functions for various surfaces of terrain, and various vehicle configurations;

- study of power losses in vehicle suspensions on uneven terrain;
- study and limited application of the theory of similitude, in the use of small scale vehicle models monitoring theoretical predictions.

New ideas also were put into practice. Perhaps two of them appear particularly interesting.

As mentioned before, at the beginning of studies on lunar locomotion, wild ideas often permeated professional thought. In spite of controversies, however, our work showed soon that a regular 4, or 6-wheel vehicle configuration is the only rational one. This I had advocated quite early, without unveiling the details to our competitors, in a paper read in New York at a Congress of the American Rocket Society, in 1961. The wheel concept was then crystallized as a basic running gear, as described later in my article written with my colleagues in a collective book (1967).

Since physico-chemical phenomena prevailing on the moon surface were not quite understood, the rubber tire was never considered. Studies have shown that an appropriate metal mesh produces optimum elasticity at the given load and the minimum wheel weight, thanks to 1/6 lunar gravity. Strength and durability as well as other wire tire properties were investigated on a circular treadmill and in a high vacuum on another circular test stand. Studies were performed. pertaining to the bearing capacity of tire mesh in granular masses. My theory related to the previously mentioned "spaced link track", and to the bearing capacity of "open" surfaces, proved most helpful.

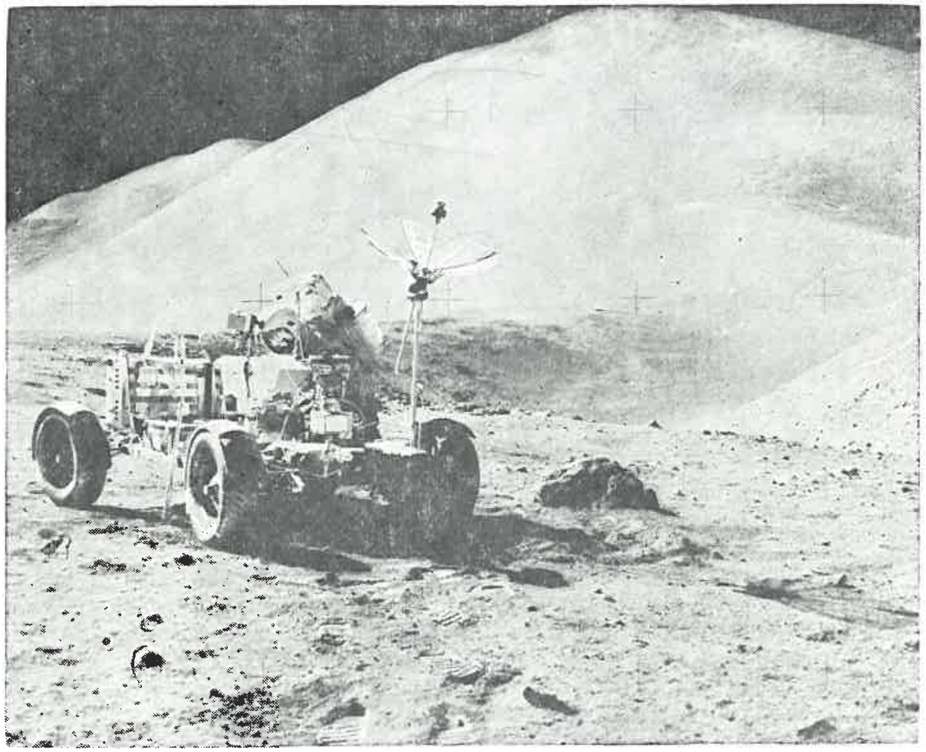
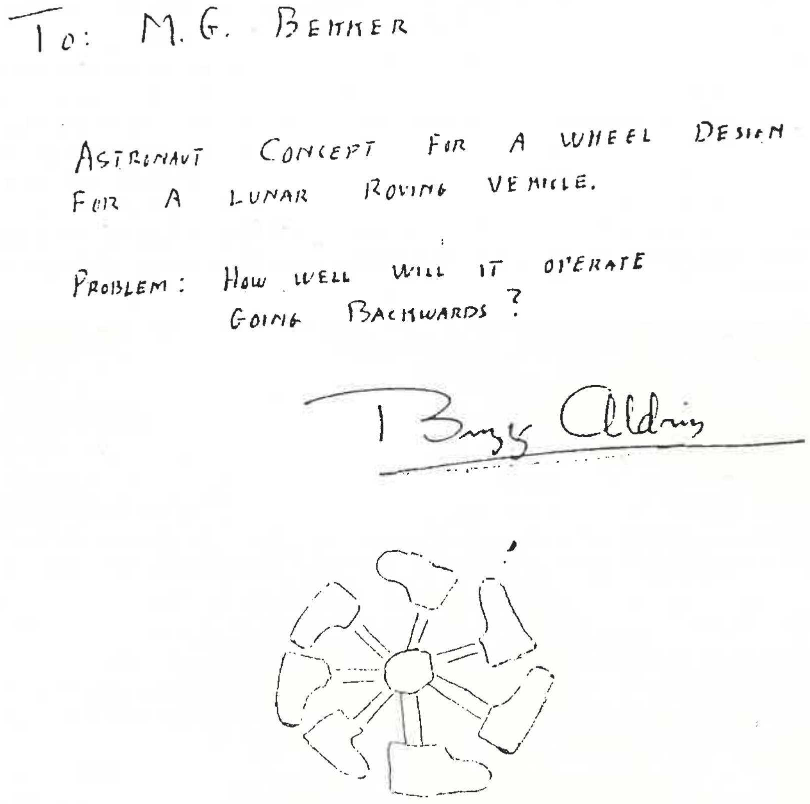


Fig. 19. Astronaut Scott with the Lunar Roving Vehicle on the Moon Surface.

When we had a meeting with the first two men who walked on the moon, the astronauts Neil Armstrong and 'Buzz' Aldrin, Armstrong expressed doubts if a wire-mesh tire makes sense. In a serious discussion, various opinions were voiced. At one moment Aldrin laughingly handed me the sketch of a wheel with booted feet which replaced the usual spokes. (Fig. 20), and asked why not make something similar. In an answer, I jokingly requested an "official order" which amid general laughter was handed to me, in the form reproduced in Fig. 20. The wire mesh tire was not rejected.

The engineering of the tire was an enormous technological undertaking which upon my retirement, was taken care of by one of my closest collaborators.



TO: M. G. BEKKER

ASTRONAUT CONCEPT FOR A WHEEL DESIGN FOR A LUNAR ROVING VEHICLE.

PROBLEM: HOW WELL WILL IT OPERATE GOING BACKWARDS?

Buzz Aldrin

Fig. 20. Some fun in a serious discussion (Houston, Texas, on Feb. 3, 1970).

The second idea which may deserve mention refers to the invention of the so called "elastic frame". Details were described in my patent assigned to the General Motors Corporation (1962). Vehicles based on this idea essentially consist of an articulated body whose elements are connected with elastic rods or flat springs (frame). Such a vehicle can overcome terrain obstacles in an unprecedented manner, hitherto unattainable by any existing solution of the same envelope, length and weight.

Numerous terrain tests confirmed the laboratory tests as shown in Fig. 21. A vehicle of this type was seen by millions at the World Exposition, in New York: it was endlessly crossing the lunar landscape, which I helped to plan and design. The vehicles built for NSA-JPL, and for NASA-Boeing, were based on the "elastic frame" concept.

At the time when the roughness of lunar surface was not known in the scale of, say, 0.5 meter, and when the vehicles were to be remotely controlled, the "elastic frame" concept was a top candidate for Surveyor and Apollo lunar landings. Although the lunar terrain's relative smoothness determined from Surveyor and confirmed by Apollo landings, did not require such an acrobatic performance, the idea of articulated vehicles based on "elastic frame" did not lose its merit. It is still, in the opinion of many professionals, a unique solution for remote controlled operations on the stony, rough surface of the planet Mars.

EPILOGUE

Work done between 1960 and 1970 appears to have demonstrated that:

- the mechanics of off-road locomotion based on bevameter techniques produced practical results in the solution of problems, not only on this planet, but also on the moon.
- Such mechanics enables the conducting of parametric analyses of terrain-vehicle systems, based on a common denominator reducible to other mechanical systems.

The block diagrams, Fig. 22 shows a general, simplified flow of information and its content required in performing system analyses. Their merit lies in the possibility

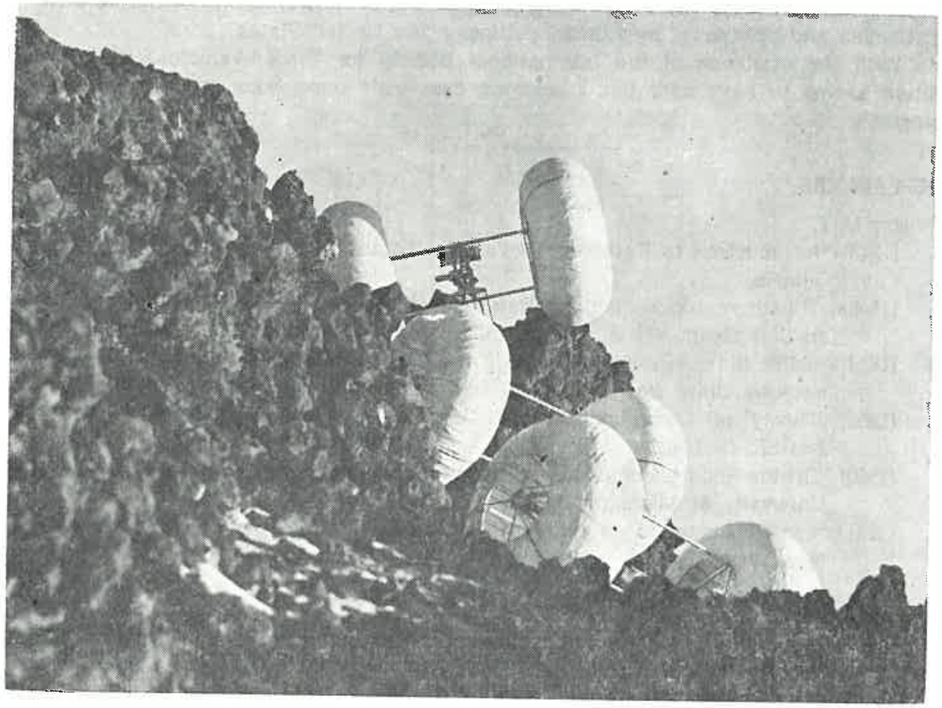


Fig. 21. Prototype of articulated elastic frame vehicle in obstacle performance.

of selecting from a number of alternate solutions an optimum solution on the basis of cost-effectiveness.

The future depends on the increasing accuracy of predictions, within the statistical range of environmental changes under consideration.

That seems to close one chapter of a search for Applied Mechanics of Off-Road Locomotion in System Analyses. Improvements and work in depth appear to dictate the contents of the next chapter.

That is the direction I tried to follow upon retiring from the General Motors Corporation in the mid 1970's. The first year, I worked as a full time consultant to the Corporation, completing the unfinished projects, which included consultation in the development of the Lunar Roving Vehicle (LRV).

Later, in addition to free-lance consulting and lecturing, I tried to trace the main lines of some developments in the following areas:

- repetitive ground loading and deformations;
- tires in a stratified ground;
- tires in a shallow snow layer;
- tracks in an "organic" soil (turf, muskeg etc.);
- automatization of bevameter data collecting, and computerization of data processing in a statistical form (already accomplished by Carleton University in Canada, in respect to data processing).

Details on the above subjects were published among others, in material prepared for the summer courses for engineers taught at Canadian and European universities, between 1974 and 1978 ((ref. 1978). These references together with my three books (1956, 1960, 1969) represent a continuing pragmatic activity, started in Poland, developed in Canada and completed in a broad outline in the United States.

With the existence of the International Society for Terrain-Vehicle Systems, the future seems to have potential. I rest my case with some hope and expectation of progress.

REFERENCES:

Bekker M. G.

(1948) "Introduction to Research on Vehicle Mobility. Can. Dept. Natl. Def. Ottawa, Ontario.

(1948a) "Photographic Method for Determining Soil Action..." Proc. 2nd Int. Conf. on Soil Mech. Vol. 3, Rotterdam.

(1953) "Methods of Evaluation of Off-the-Road Locomotion" T-247, ORO, Johns Hopkins Univ. Washington, DC.

(1956) "Theory of Land Locomotion" University of Michigan, Ann Arbor, Mich. 2nd Ed. 1960.

(1960) "Off-the-Road Locomotion — Research and Development in Terramechanics", University of Michigan. Ann Arbor, Mich.

(1961) "Land Locomotion on the Surface of Planets" ARS Journal, Vol. 32, No. 11, New York, NY. Also "Mechanics of Off-Road Locomotion" The James Clayton Lecture, Institution of Mech. Engrs., London.

(1962) US Patent No. 3, 235, 020.

(1967) "Lunar Surface Locomotion Concepts", Advances in Space Sciences, Academic Press, New York and London.

(1969) "Introduction to Terrain-Vehicle Systems", University of Michigan, Ann Arbor, Mich.

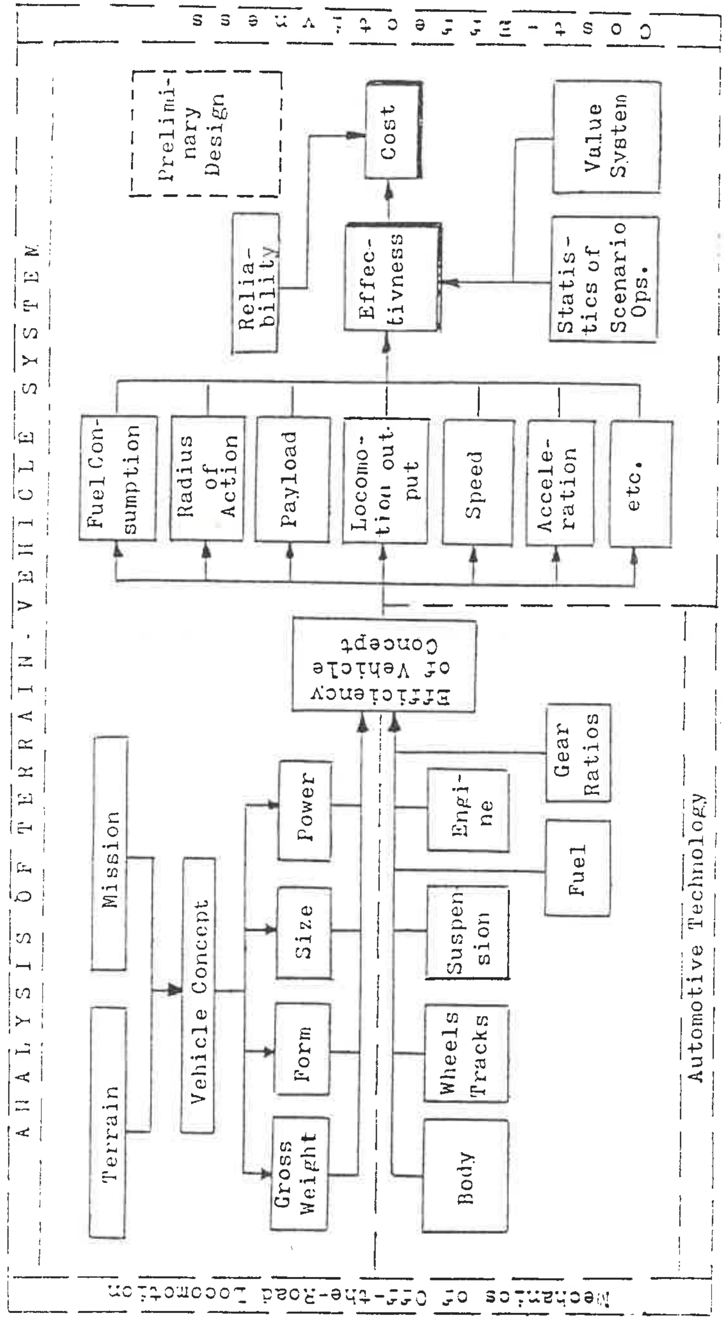


Fig. 22. Abbreviated list of items and flow diagram of operations needed for evaluation of Terrain-Vehicle Systems, based on off-road locomotion mechanics, including automotive engineering. The evaluation leads to the assessment of cost effectiveness.

(1969a) "Engineering Optimization of Terrain-Vehicle Systems" LL133, Delco Electronics, General Motors Corp., Santa Barbara, Calif. (also Bekker, 1978).
(1978) "Terrain-Vehicle Systems", Engineering Summer Courses, Carleton University, Ottawa, Canada and Royal College of Agriculture, Stockholm-Garpenberg.

Bernstein R.
(1913) "Probleme zur experimentellen Motorpflugmechanik". Der Motorwagen, Nr. 16.

Garbari F.
(1949) "Resistenza al movimento dei veicoli a ruote su tereno cedevole", ATA 2nd Annual Meeting, Rome.

Goryatchkin et al.
(1936) "Teoria i proisvodstvo selskohoziaystivennih mashin" Moscow.

Kamm W. I. E.
(1936) "Das Kraftfahrzeug" Springer, Berlin.

Kanafojski C.
(1934) "Przyczynek do laboratoryjnych badań odkształceń i oporów gleby..." Czasopismo Techniczne Nr 3-8, Lwów.

Haefeli R.
(1944) "Erdbaumechanische Probleme im Lichte der Schneeforschung" ETH, Zurich.

Letoshnev M. N.
(1936) "Kolesnye povozki" Moscow.

Micklethwait E. W.
(1944) "Soil Mechanics in Relation to Fighting vehicles" Mil. Coll. of Sci., Chobham.

Neesen F.
(1940) "Gestaltung und Wirtschaftlichkeit der Land-Wasser-und Luftfahrzeuge" Jena.

Sołtyński A.
(1966) "Mechanika układu pojazd-teren", MON Warszawa.

Taylor D. E.
(1948) "Fundamentals of Soil Mechanics" John Wiley & Sons, New York.

Terzaghi K.
(1944) "Threoretical Soil Mechanics" John Wiley & Sons, New York.

ADAM CHRZANOWSKI*

NEW TECHNIQUES IN MONITORING GROUND SUBSIDENCE IN MINING AREAS

Introduction

Ground subsidence occurs for all types of mining: underground, open pit, oil extraction. The empty spaces created by the extraction of the minerals produce caving, fracturing and collapse of the above lying and surrounding rock masses. Depending on the depth of the exploitation and on type and mechanical parameters of the rocks, the effects of the exploitation on the terrain surface may range from cavings and crevasses to the creation of gentle subsidence basins. Foundations of buildings crack, highawys collaps, and mountain slides develop. The changes in the rock structure affect the level of the underground water thus further aggrevating the subsidence problem. According to estimates of the U.S. Bureau of Mines [11] over 1.5 million acres of land, in the U.S. alone, will be affected by the mining subsidence by the year 2000, resulting in property damages of at least $2 billion. Oil extraction in California causes surface subsidences of up to 6 metres, resulting in changes of the water levels which in turn produce destructive changes to the environment.

Uncontrolled mining subsidence is not only dangerous for human lives of those who work in the mines and of those who live on the surface, and not only for underground and surface construction and for the environmental changes — but it is also dangerous from the point of view of mineral economy. Many mine companies, which look only for a large and quick profit, start the extraction of the minerals from the thickest or easiest-to-reach deposits, thereby very often undermining poorer but still very valuable overlaying deposits. The broken strata above mining workings produced by the original exploitation makes it very difficult or impossible to come back to the same area to mine other deposits later on.

Knowledge of subsidence behaviour provides for better economic planning and execution of the mining exploitation, higher safety and optimum use of the resources without ruining the environment. In addition, when considering subsidence generated by petroleum exploitation, the monitored (measured) subsidence, combined with geological information and a suitable prediction model, can provide data on the expanse of the oil field and thus aid in the estimation of available resources.

Subsidence monitoring has been an important task for many years in Europe where minerals become very scarce and are being exploited under densely populated areas. In most of the countries with a developed mining industry monitoring of the ground movement is compulsory. It is usually done by surveyors in cooperation with specialists in rock mechanics. In Canada, due to the remote location of most of the exploitation areas and vast mineral resources, subsidence monitoring has been neglected without causing too many **visible** problems, except for a few mountain slides, such as near Frank, B.C., where a village was buried. For obvious reasons mining companies in Canada, even if they do some monitoring, are not eager to publicize their findings.

The growing awareness of our environment, as well as the fact that our dwindling

---

*University of New Brunswick, Fredericton, N.B.

40 Years of Polish Engineering in Canada. Bul. APEC 3/81

resources eventually have to be exploited beneath populatd areas has generated much concern and interest in the subject.

The Department of Surveying Engineering at the University of New Brunswick specializes, at the national level, in mining surveying and rock deformation measurements as part of its research activities. An integrated survey system for monitoring mining subsidences is being developed under the author's supervision as part of the research programme including a unique telemetric monitoring system which has already been constructed.

Theory of the Mining Subsidence

Different authors give different theories and equations to describe the subsidence profile and to calculate the deformation parameters. Some of them are based on mechanical theories of dynamics of elastic bodies (12), other based on analogue modelling of the geological strata, and a number of so-called geometrical theories, for instance, Knothe's (7), Kochmanski's (8) and Kowalczyk's (9) theories, which are based on empirical data obtained from rock mechanics and geodetic measurements performed on real subsidence examples. Kratzsch (10) gives a good review of all the basic theories.

Despite the large number of different theories some basic findings are common, or differ very little from one theory to another, particularly in a case of regularly bedded deposits such as coal deposits.

Generally it is accepted (9) that if the depth of the deposit is larger than about 100 m, a continuous subsidence basin (subsidence trough) is created on the surface. A profile of the subsidence takes the form of a regular exponential bell-shaped (Gaussian) curve if the rock formations are continuous (Fig. 1).

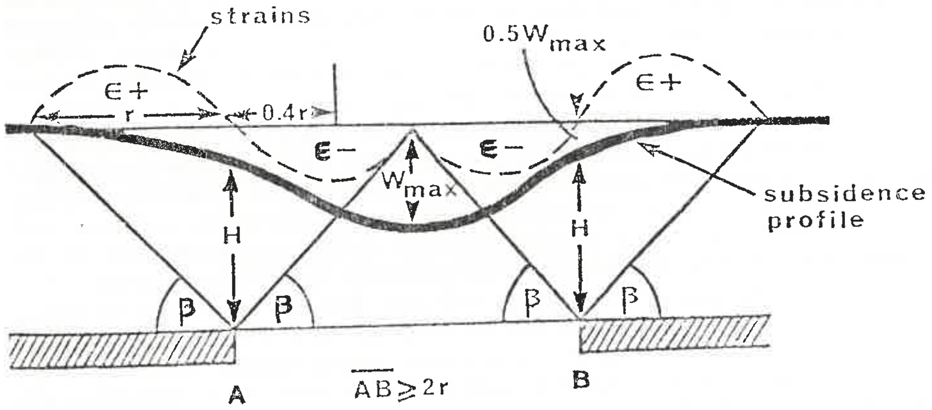


Figure 1 — Subsidence Basin.

When a large area equal to the so-called **critical area** is exploited, then the value of the subsidence achieves its maximum value Wmax, which is usually calculated from:

$$W_{max} = a \cdot g$$

where 'a' is the subsidence coefficient mainly dependent on the exploitation method and 'g' is the thickness of the exploited deposit.

The value of the coefficient 'a' averages:

a = 0.75 for caving methods of expploitation without any pillars

a = 0.5 when using dry stowing
a = 0.2 when using hydraulic back-filling
a = 0.03 for 50% strip and pillar with hydraulic back-fill.

If a larger than critical area is exploited the bell shape curve of subsidence becomes flat at the bottom with Wmax = const. over the flat area.

The subsidence above the edges of the exploitation is equal to approximately 0.5 Wmax. Usually the points which show only about 1% of Wmax are taken as being at the limits of the influence of the exploitation. The angle β (Figure 1) between the horizontal an dthe line joining the limiting point with the edge of the exploitation is called a **limiting angle.**

The value of β is larger for soft and/or elastic rocks than for a strong strata. Batkiewicz (1) gives the following values:

β = 40° ÷ 66° for plastic or very broken (due to a previous exploitation) strata
β = 34° ÷ 48° for a medium strong strata, for instance 50% of shales and 50% of sandstones
β = 23° ÷ 34° for very strong strata, for instance solid sandstone or limestone.

Some other authors give larger values of β, usually between 55° ÷ 75°.

Maximum strains ϵ (Fig. 1) occur at the points of maximum curvature of the subsidence profile. According to Knothe (7) these points are approximately at distances of 0.4r from the edges of the exploitation where r represents the radius of the critical area, and is calculated from:

$$r = H \cdot \cot \beta$$

where H is the depth of the exploitation.

The above general findings and the computational theories apply to horizontal or slightly inclined deposits (up to about 15° dip). For steeply inclined deposits, up to about 45°, all the deformation parameters are shifted towards the dip by an angle approximately equal to:

$$x = 0.7\,\alpha$$

where α is the dip angle as shown in Figure 2.

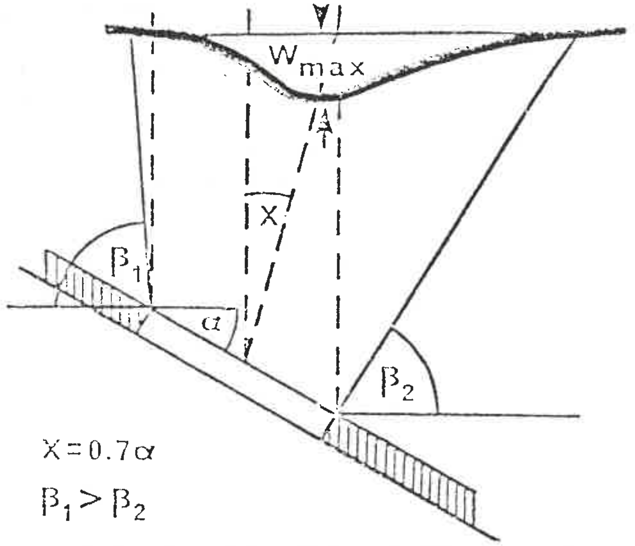


Figure 2 — Subsidence Profile for Inclined Deposits

The subsidence profile becomes then unsymmetrical with the steeper profile above the upper portion of the deposit and with the prolonged profile and extended influence in direction of the dip. Calculation of the deformation parameters becomes much more complicated. There is not yet enough experimental material available for even approximate methods.

In "virgin" exploitation areas where no previous experimental data is available one may try to predict the surface deformation on a basis of the physical properties of rocks and mechanical theories on the behaviour of elastic-plastic bodies applying, for instance, finite element calculation methods [13]. However, it would be too risky to rely only on the precalculate deformation parameters without any check during the exploitation. Therefore, a careful monitoring of the subsidence is equally important in the "virgin" areas where no subsidence theories exist as well as a check in the areas where a reasonably good agreement between a theory and actual displacements may be expected.

Methods of Subsidence Monitoring

There are basically three types of monitoring approaches, classified according to the methodology and instrumentation employed, namely:

— conventional geodetic surveying methods
— photogrammetry and remote sensing
— rock mechanics methods.

Often several of them are combined in a more comprehensive approach, as each offers advantages while also suffering shortcomings.

The **conventional geodetic surveying** methods are usually limited to geometric or trigonometric leveling surveys only though horizontal displacements of points in the subsidence areas are sometimes of equal importance. The accuracy requirements are dictated by the sensitivity of the surface constructions and utilities and the expected deformations. For instance, leveling should assure the accuracy of the determination of the absolute subsidence of selected points to be 1% of the expected maximum subsidence or better.

The horizontal surveys, usually in a form of micro-geodetic networks with measured angles and distances should allow for determinations of strain components and relative displacements of points with accuracies ranging from 10^{-4} to 10^{-5} over typical distances of 50 m to 200 m between the monitoring stations. Generally, these accuracies may be easily achieved with the present technology if proper techniques are used. Least squares adjustment and proper statistical evaluation of the deformation results, as described, for instance, in [6] should always be applied to the geodetic surveying methods.

In many cases the geodetic surveys allow for the determination of the absolute displacement of the subsidence area in respect to stable points located outside of the area of the mining influence. It is an advantage over the rock mechanics monitoring systems.

Main disadvantages of the geodetic survey methods are: slow field procedures which do not allow for an instantaneous "capture" of the dynamic process of the mining subsidence, comparatively high cost and impossibility for a continuous monitoring of the subsidence. Advantage of the geodetic surveys are: high accuracy (almost unlimited), possibilities of internal checks of the surveys (in a properly designed network of points) and conected with it, reliability of the results.

The surveying methods play an important role not only in the determination of the ground subsidence but also in the determination of the deformations of man-made structures and underground workings affected by the mining exploitation. In these cases, the accuracy requirements exceed sometimes the abilities of the present conventional survey technology and special techniques and instrumentation must be developed. In the last few years, the author and his associates developed and constructed prototypes of several instruments for the high precision deformation surveys such as the Laser Optical Plummet [2], Laser Level [3], and precision alignment systems [4]. Other metrological tools such as laser interferometers and hydrostatic levels are becoming a part of the surveying techniques. Therefore, a distinction between the surveying methods and methods used in rock mechanics measurements is rapidly diminishing.

Photogrammetry and Remote Sensing — This type of monitoring has two distinct adavantages over the others, namely a true area coverage and a complete recording at a given instant. It is therefore frequently used in addition to other methods.

The first aspect is purely interpretive. Changes are observed and recorded without direct measurements, although sometimes a motion parallax between epochs is evaluated.

Data obtained from different remote sensors provide additional information such as temperature changes caused for instance by warmer air escaping through cracks in the ground can also be utilized.

When using photogrammetry quantitatively, several approaches can be applied. The comparison of contour plans of different epochs provides an excellent overview, is however restricted in accuracy to about 0.2% of the flying height (when using a precision plotter), or a few decimetres on the ground. This may however, be useful when selecting areas of a more precise survey. The big advantage of photogrammetry is that one can go back to previous epochs if subsidence has occured at an unlikely location. With all other methods, this is impopssible. Here the complete and permanent record of an instant may be invaluable.

Similarly to conventional surveying, point measurements can be performed using a comparator or profiles measured. If the latter is done on an analytical type plotter, accuracies of 10μm and less in photo scale can be achieved, which means that ground accuracies of better than 10 cm are quite feasible.

— **Rock Mechanics Methods** — which utilize such instruments as tiltmeters and strain meters do not directly monitor absolute ground movements or subsidence profiles. This information must be derived and "extrapolated" from local on-site detections of either strains (strain meters) or tilts (tiltmeters).

When choosing the type of rock mechanics instrumentation, tiltmeters offer an obvious advantage over the strain meters in subsidence determination because tilts may be much easier translated than strains into elevtion changes between two tiltmeter stations.

If several tiltmeters are located along the profile line of the subsidence basin (Fig. 3) then the subsidence on any part of the profile can be determined by simple trogonometric relationships. For instance, if the tilts α of the terrain are measured in seconds of arc at points 1, 2 and 3 (Fig. 3) then the subsidence **h4** at point 4 in respect to point 1 can be calculated from:

$$h_4 = \frac{\alpha_1 x S_1 + \alpha_2 x S_2 + \alpha_3 x S_3}{\rho''}$$

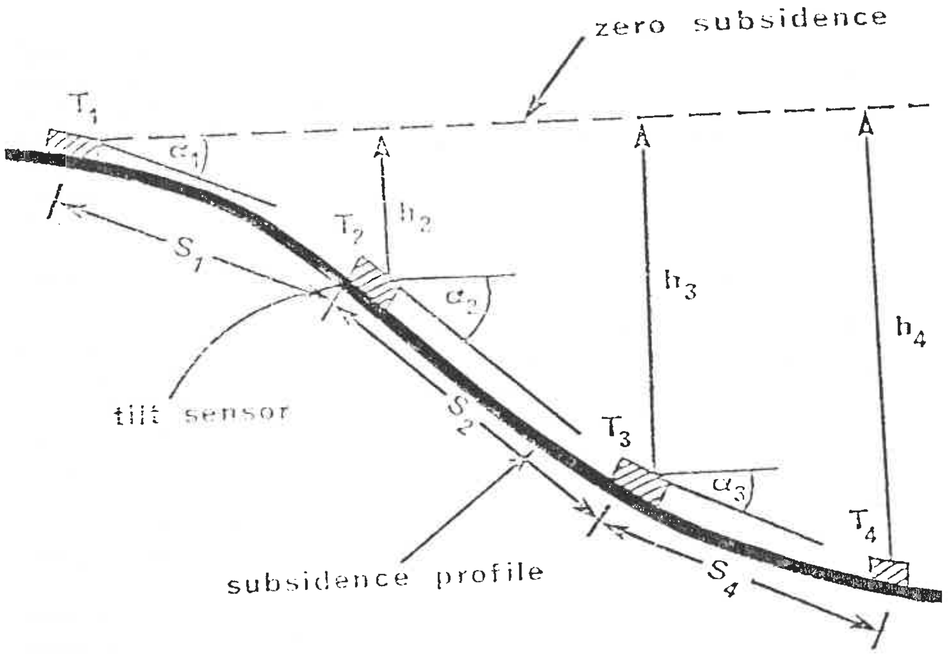


Figure 3. Use of Tiltmeters in the Subsidence Determination

or generally for a point **n**:

$$h_n = \frac{\sum_{i=1}^{n-1} \alpha_i S_i}{\rho''}$$

where Si are distances between i-th and (i+1)th tiltmeters and p" equals 206265" (1 radian in seconds).

If we assume that all tiltmeters have approximately the same accuracy (standard deviation of the tilt measurement) and the distances are errorless (measured with a high accuracy) then the standard deviation of **hn** can be calculated as:

$$m_h = \frac{m''_\alpha}{\rho''} \sqrt{\Sigma S_i^2}$$

For instance, if $m_\alpha = 5''$ and all the distances in Fig. 3 are equal to Si = 100 m then the error of **h4** in respect to the station 1 is:

$$m_h = \frac{5''}{206265} \sqrt{30\ 000} = 4 \text{ mm}$$

There are different types of tiltmeters (called also electronic levels) available in the market. Even the inexpensive ones (say $2,000) offer high accuracies, of the order of 2-3 seconds of arc in sensing the tilt angle, though they may exhibit some systematic drifts of the indications. The highly stabilized tiltmeters, with accuracies better than 0.1 second may cost as much as $20,000 or even more.

It has to be pointed out, that the use of tiltmeters for the development of a prediction theory of the terrain subsidence is, to a large extent, limited to the regular and continuous subsidence conditions as shown in Figure 3.

If the mining exploitation would produce abrupt profile changes and breaks of the ground then the information supplied by the titmeters could be misleading or even useless for the calculation of the subsidence.

The big advantage of rock mechanics instrumentation is that it can be hooked up to continuous recording devices or else be interrogated at any desired time via telemetry. Thus a continuous monitoring in time takes place.

A Telemetric Monitoring System

Upon request of the Canada Centre for Mineral and Energy Technology, a telemetry system for continuous monitoring of ground movements has recently been developed by the author together with computer science and physics experts, namely Dr. B. Kurz, A. Makosinski and Dr. W. Faig.

The system was developed to operate in a high mountain area in Western Canada to monitor ground subsidence all year round above a mining exploitation. Subsidence of a few metres and tilts of the ground up to one degree had been predicted for the area.

The monitoring system is based on the aforementioned concept of measuring ground tilts with electronic tiltmeters of a servo-accelerometer type at selected points above the exploitation area. The mechanical tilts are then transduced into electric signals which in turn are changed into radio frequency signals and transmitted to a master receiver unit located a few kilometres from the site.

A small computer, from which the titmeter stations can be interrogated at any time, is located at the master station. It has been designed so that it can be hooked up to the public telephone network, therefore, to any large computer at any location across the country.

The system is also designed and constructed so that it can turn itself off after it has been interrogated by the master station. This ensures that the unit's power base (gel-cells) lasts over the winter when access to the instruments is impossible. During that time the other monitoring methods are not applicable due to snow cover and other adverse local conditions. In the summer times however, the area is being flown for photogrammetric evaluation and small geodetic surveying program is carried out as well, as a part of the aforementioned integrated survey program.

Since September of 1980 the telemetry system with 10 tiltmeters successfully operates the test site sending useful information about the ground tilts. Details on the design and construction of the system are given in [5].

Fig. 4 shows the schematic cross-section of the field monitoring station consisting of the tiltmeter and its micro-processor based slave unit.

The interesting aspect of this system is that it can be used to monitor more than just ground movement because other sensors may be connected to the slave units. Several mining companies are showing interest in using it to monitor underground gas content, temperature, air flow, etc.

Development of the telemetric unit has been funded mainly by the Canada Centre for Mineral and Energy Technology and partially by the National Science and Engineering Research Council. The research on the development of new monitoring systems continues.

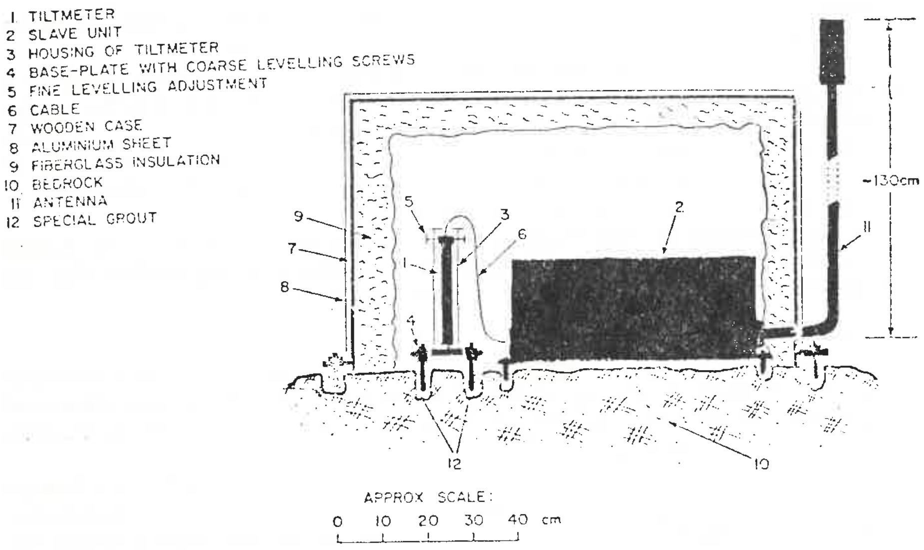


Fig. 4. Layout of the Field Station

References

[1] Batkiewicz, W.: "Calculation of the Parameters of the Terrain Deformations due to the Exploitation", (in Polish), Wyd. Śląsk, Katowice, 1968.

[2] Chrzanowski, A. and Masry, S. "Laser Optical Plummet", Canadian Patent No. 811923, 1969.

[3] Chrzanowski, A. and Janssen, D. "Use of Laser in Precision Leveling", The Canadian Surveyor, Vol. 26, No. 4, 1972.

[4] Chrzanowski, A. "Precision Alignment Surveys Using Laser", Proceedings of the XIVth International Congress of Surveyors (FIG), Washington, D.C., 1974.

[5] Chrzanowski, A., Faig, W., Kurz, B., Makosinski, A.: "Development, Installation and Operation of a Subsidence Monitoring and Telemetry System", Report submitted to CANMET (DSS File: 18SQ.23440-8-0-16). November 1980.

[6] Chrzanowski, A.: "A Comparison of Different Approaches into the Analysis of Deformation Measurements", FIG XVI International Congress, Montreaux, 1981.

[7] Knothe, S.: Równanie profilu ostatecznie Wykształconej niecki osiadania". Arch. Górn. Hutn., t.I.z.1, 1953.

[8] Kochmanski, T. "Obliczanie ruchów punktów górotworu pod wpływem eksploatacji górniczej", Warszawa, 1956, PAN.

[9] Kowalczyk, Z.: "Effects of Mining Exploitation on the Ground Surface and Structures in Heavily Industrialized and Populated Areas", CIMM Transactions, Vol. LXIX, 1966.

[10] Kratzsch, H.: "Bergschadenkunde", Springer-Verlag, Berlin, New York, 1974.

[11] Russell, O., Ameto, R. Leshendok, T.: "Remoate Sensing and Mine Subsidence in Pennsylvania", Transportation Engineering Journal, March, 1979.

[12] Salustowicz, A.: "Outline of Rock Mechanics" (in Polish), Wydaw. Śląsk, Katowice, 1955.

[13] Zienkiewicz, O.C.: "The Finite Element Method", McGraw-Hill, 1977.

W. CZERWINSKI*

WIATRAKI PRZYSZŁOŚCI

WSTĘP

Wzrastające w przyspieszonym tempie zaludnienie oraz konsumpcja paliwa przez kraje wysoce uprzemysłowione, doprowadziły sytuację energetyczną na całym świecie do kryzysu. Dobrobyt graniczący ze zbytkiem obecnej zmechanizowanej cywilizacji jest w przeważnym stopniu oparty na płynnym paliwie. Ciesząc się beztrosko tym dobrobytem, bogate społeczeństwa popadły nagle w całkowitą zależność od kilku czy też kilkunastu krajów produkujących płynne paliwo. Wielka prawda głoszona od lat przez przewidujące jednostki, pokazała nagle swoje bezwzględne oblicze; ilość płynnego paliwa jako zasobu naturalnego jest ograniczona i przy obecnym stopniu zużycia nie wystarczy nam na długo.

Ta świadomość w połączeniu z różnymi komplikacjami politycznymi, spowodowała kolosalny wzrost ceny paliwa surowego. I tak, w roku 1973/74 cena ropy naftowej wzrosła nagle z $3 na $12 za baryłkę (około 137 kg.). W siedem lat później tj w roku 1980/81, cena ta waha się obecnie pomiędzy $36-42 za baryłkę, czyli prawie 14 razy więcej aniżeli w roku 1973.

Ten niesłychany wzrost ceny spowodował wielkie zaburzenia ekonomiczne na całym świecie, nie przyniósł jednak opamiętania się, ani też zrozumienia całej doniosłości tego faktu. Samolubne bogate społeczeństwa, oraz nieudolne rządy narodów korzystających z tego chwilowego zbytku, nie są w stanie ogarnąć i zrozumieć całej powagi tej prawdy oraz jej skutków na już bardzo niedaleką przyszłość.

Przejście z jednego rodzaju źródła energii na inne na razie jeszcze nie całkowicie technicznie rozwinięte, nie da się uskutecznić w takim czasie, jaki nam jeszcze pozostał. Ogólna wiara, że technologia potrafi rozwiązać każdy problem szybko, i że to zależy tylko od ilości pieniędzy wstrzykniętych w dane zadanie nie potwierdza się w praktyce. Ludzie i rządy nie zdają sobie sprawy z granic możliwości naszej technologii, a szczególnie w wypadkach, gdzie często krótkowzroczne interesy większych grup społeczeństwa, jak również względy polityczne, gospodarcze oraz konserwacyjne będą silnie przeciwdziałać przyjęciu często nieortodoksyjnych metod otrzymywania energii z nowych źródeł. Najlepszym tego dowodem jest negatywne ustosunkowanie się poważnej części społeczeństwa do dalszego rozbudowania energii atomowej.

Temat ten jest tak obszerny i tak wielkiej doniosłości, że nie jeden ale wiele artykułów i prac powinno być napisanych, ażeby należycie go oświetlić i przedyskutować na bardziej ogólnym terenie. Celem niniejszego artykułu jest przedstawienie czytelnikowi możliwości uzyskania energii ze źródła, które zostało zupełnie zaniedbane w ostatnim stuleciu na skutek bardzo taniego i wygodnego w użyciu paliwa płynnego.

Takim źródłem energii jest energia wiatru, która jest jedną z odmian energii dostarczanej nam stale przez słońce. To potencjalne źródło energii jest ograniczone zarówno ilościowo jak i terytorialnie, każden jednak procent energii otrzymany z innego czy też nowego źródła, będzie bardzo pomocny w ogólnej sumie zapotrzebowania i zużycia energii w przyszłości.

Dynamika atmosfery

Ażeby łatwiej zrozumieć potencjalne możliwości wykorzystania energii wiatru, należy się wpierw ogólnie zapoznać ze środowiskiem w jakim wiatrak pracuje.

---

*Autor pracował jako konsultant dla firmy DAF-INDAL w Toronto przy obliczeniach i konstrukcji wiatraka NRC-220.

Ruchy naszej atmosfery czyli wiatry są rezultatem dwóch głównych przyczyn, a mianowicie obrotem ziemi, oraz nierównym nagrzaniem powierzchni ziemi przez słońce. Współdziałanie tych dwóch przyczyn jest bardzo ciekawe i skomplikowane. Niestety nie ma tu miejsca na zajęcie się tym tematem obszerniej. Wynikające z tych dwóch przyczyn wiatry, zawierają w sobie wielkie ilości enregii kinetycznej, którą ludzkość nauczyła się wykorzystywać dla swoich celów w postaci żagli do napędu statków, oraz wiatraków dla dostarczania energii mechanicznej.

Ilość energii kinetycznej we wietrze zależy przede wszystkim od szybkości wiatru oraz gęstości powietrza. Ażeby dać pojęcie o tej ilości, podaję przykład poniżej.

Wiatr wiejący z szybkością W m/s przez przekrój A m² unosi energię, która jest zdolna do wykonania pracy:

$$P = \tfrac{1}{2}\,\rho\, AW^3 \tag{1}$$

gdzie ρ — gęstość powietrza $\left(\frac{kg.s^2}{m^4}\right)$; $\tfrac{1}{2}\,\rho = \tfrac{1}{16}$

Dla wiatru wiejącego na przykład z szybkością 8 m/s przez przekrój 1 m²,

$$P = \tfrac{1}{16} \times 1 \times 8^3 = 32 \text{ kgm/s}.$$

Wyrażając tę moc w watach otrzymamy: P = 313.6 watów.

Niestety tylko część tej energii można praktycznie wykorzystać, gdyż jak to wykazał niemiecki fizyk Glauert, tylko 16/27 część tej energii można zamienić na energię użyteczną przy pomocy wiatraka.

Jak to wynika z powyższych uwag, we wzorze na moc rotoru wiatraka szybkość wiatru występuje w trzeciej potędze. Każdą więc przyczynę czy też powód zwiększający szybkość wiatru należy wziąć pod specjalną uwagę.

Na skutek tarcia pomiędzy poruszającym się powietrzem a powierzchnią ziemi, oraz tarcia pomiędzy warstwami powietrza o różnych szybkościach względnych, szybkość wiatru zmienia się z wysokością. Dla unormowania informacji o szybkości wiatru w raportach meteorologicznych podaje się ją zazwyczaj mierzoną na wysokości 10 m nad poziomem terenu.

Zmiana szybkości wiatru z wysokością wyraża się wzorem:

$$W = W_{10} \left(\frac{h}{10}\right)^{0.16} \tag{2}$$

Wzór ten jest ważny dla normalnych warunków atmosferycznych; dla naszych praktycznych celów należy założyć, że wykładnik potęgowy 0.16 zmienia się niewiele ze zmianą temperatury i wilgotności.

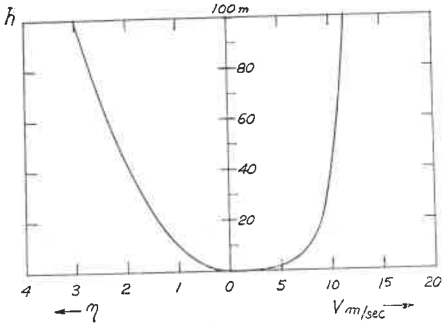


Fig. 1.

Szybkość wiatru i współczynnik mocy.

Wykres podany na Fig. 1 na prawo od punktu zerowego przedstawia rozkład szybkości wiatru z wysokością o sile 8 m/s, mierzonej na wysokości 10 m nad ziemią. Widać z tego wykresu, jak ważnym jest podawanie wysokości na jakiej szybkość wiatru jest mierzona.

Na lewo od punktu zerowego pokazana jest krzywa względnej mocy η, którą wiatr zawiera. Przyjmując np. ilość energii kinetycznej wiatru 8 m/s za jednostkę widzimy, że ilość tej energii wzrasta dwukrotnie na wysokości 42.4 m, oraz trzykrotnie na wysokości 98.6 m. Jest to bardzo ważna obserwacja, która daje nam pojęcie o wydajności rotoru wiatraka w zależności od wysokości, na której jest on zainstalowany.

Wielki wpływ na szybkość wiatru ma konfiguracja terenu, nad którą przepływa wiatr. Wielkie przeszkody dla wiatru jak wyżyny i góry powodują zwiększenie szybkości wiatru nad przeszkodami. Znane są miejscowości, w których silny wiatr wieje prawie stale. Należą do nich takie miejsca jak przełęcze oraz tak zwane siodła terenowe. Są to idealne miejsca dla instalacji wiatraków czy też farm wiatrakowych.

Jednym z takich terenów jest przełęcz San Gorgonio w Kalifornii Południowej, gdzie firma Southern California Edison instaluje obecnie wiatraki dla celów zasilania kalifornijskiej siecie elektrycznej. Okolica San Gorgonio jest uważana za najbardziej wietrzną okolicę w Kalifornii, czy też bodajże w całych Stanach Zjednoczonych. Według obliczeń Southern California Edison, cały rejon San Gorgonio może dostarczyć przy odpowiednio wielkiej instalacji wiatraków, około 6.5 bilionów kilowatgodzin rocznie*.

Następny ważny parametr, który chcę tutaj przedyskutować jest zmiana szybkości wiatru w zależności od pory roku, oraz lokalnych warunków atmosferycznych. Wiemy przecież, że wiatry nie wieją ze stałą szybkością, i że zmieniają one swoje nasilenie i kierunek. Te naogół bezładne zmiany są jednak posłuszne prawom statystyki. Dla każdej średniej szybkości wiatru obliczonej dla okresu jednego roku, według statystyki sprawdzonej wieloletnimi pomiarami, ilość godzin w roku dla każdego zakresu szybkości wiatru będzie się wahać bardzo niewiele. Ogólnie przyjęty wzór dla obliczenia trwania różnych zakresów szybkości wiatru w czasie jednego roku (8,760 godzin) dla strefy umiarkowanej, został podany przez angielskiego fizyka Ralleigh'a:

$$p\left(\frac{W}{Wm}\right) = \tfrac{1}{2}\pi .\ \frac{W}{Wm}\ .\ e^{-\tfrac{1}{4}\pi\left(\frac{W}{Wm}\right)^2} \tag{3}$$

Wzór (3) podaje prawdopodobieństwo $p\left(\frac{W}{Wm}\right)$, tj. stosunku szybkości wiatru W do średniej szybkości rocznej Wm, w funkcji tegoż stosunku.

Fig. 2 przedstawia wartości tej zależności wyliczone dla szybkości średniej Wm = 8 m/s. Widać z tego wykresu, że np. dla stosunku W/Wm = 0.8, prawdopodobieństwo wiatru W = Wm x 0.8 = 6.4 m/s wynosi 0.76. Ponieważ ta wartość jest maksymalną wartością dla funkcji Ralleigh'a, wnioskujemy z tego, że wiatry około 6.4 m/s zdarzają się najczęściej dla tej szybkości średniej.

Wyliczone przy pomocy bardzo prostej arytmetyki prawdopodobne czasy trwania dla różnych zakresów szybkości wiatrów, są podane w tabeli poniżej. Oczywiście czasy te są ważne tylko dla wiatrów o średniej szybkości rocznej 8 m/s.

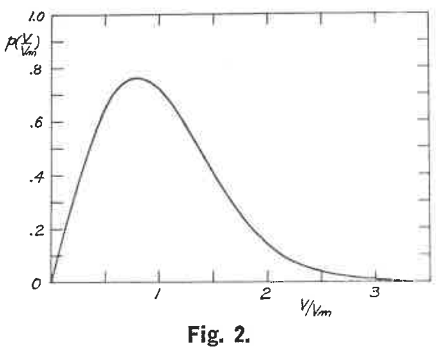


Fig. 2.

Prawdopodobieństwo szybkości wiatru.

---

*Wind Energy Report, Feb. 1980.

Przy innych średnich szybkościach czasy te będą zupełnie różne.

Zakres szybkości wiatrów m/s	Ilość godzin w roku h
0— 2	450
2— 4	1,150
4— 6	1,550
6— 8	1,620
8—10	1,523
10—12	1,066
12—14	701
14—16	409
16—18	212
18—20	110
20—22	44
22—24	22

Dane statystyczne otrzymywane z raportów metereologicznych dla naszej strefy umiarkowanej są dość zgodne ze wzorem Ralleigh'a i dlatego jest on prawie powszechnie używany dla obliczania rocznych wydajności wiatraków.

Istnieją jeszcze inne wzory dla obliczenia prawdopodobieństwa trwania wiatrów, które dają się łatwo dostosować do lokalnych warunków przez dobranie odpowiednich wykładników. Takim bardzo popularnym wzorem jest wzór Weibull'a, który łatwo daje się dostosować do innych lokalnych warunków, a w szczególności do strefy tropikalnej.

Na specjalną uwagę zasługuje strefa równikowa, a raczej strefa tropikalna, między równoleżnikami, gdzie tzw. wiatry passatowe (trade winds) wieją przeważnie ze wschodu na zachód. Wiatry te spowodowane obrotem ziemi, mają bardziej stały charakter, aniżeli wiatry w strefie umiarkowanej. Zarówno ich nasilenie jak i kierunek są bardziej ujednostajnione i nadają się idealnie do eksploatacji przy pomocy wiatraków dla zasilania lokalnych sieci elektryfikacyjnych.

Dowodem tego, że tak jest istotnie, jest wielka farma wiatrakowa instalowana obecnie na wyspie Oahu w grupie wysp Hawajskich. Instalacja ma być wykończona w r. 1983 i ma produkować 80 megawatów mocy. Koszt jej jest preliminowany na około 250 milionów dolarów.

Przedyskutowana tutaj pokrótce charakterystyka ruchów atmosfery jest bardzo pożyteczna dla głębszego zrozumienia całego problemu używania siły wiatrów dla celów produkcji energii. Zmienność nasilenia wiatrów oraz zależność ich potencjału od położenia geograficznego, są głównymi trudnościami w eksploatacji tej energii na wielką skalę.

Wiatraki

Woda i wiatr były pierwszymi źródłami energii eksploatowanymi przez człowieka. Energia wodna była produkowana tylko tam, gdzie było poddostatkiem wody, oraz istniały wystarczająco duże różnice poziomów. Energia wiatrowa była znana już od bardzo dawna, i przed erą silników parowych i spalinowych była ona w powszechnym użyciu przeważnie na morskich wybrzeżach, gdzie nasilenie wiatru i względna jego jednostajność pozwalała na prawie nieprzerwaną pracę.

Energia taniego paliwa płynnego wyeliminowała stare młyny wodne oraz wiatraki, z wyjątkiem krajów, które były tak ubogie, że nawet taniego paliwa nie miały za co nabywać. Wiatraki są ciągle w użyciu na małą skalę w Hiszpanii i Grecji w swojej dawnej prymitywnej formie.

Przed elektryfikacją środkowej i zachodniej części Stanów Zjednoczonych, rolnictwo amerykańskie używało wiatraki o małej mocy do pompowania wody dla celów gospodarczych. Tani prąd elektryczny całkowicie wyeliminował wiatraki, zastępując je elektrycznymi silnikami.

Obecne wysokie ceny paliwa zmieniają całkowicie tę sytuację. Nawrót do wykorzystania różnych źródeł energii, a w szczególności takich, które nie zanieczyszczają powietrza i nie pozostawiają trujących odpadów, spowodował odrodzenie idei wykorzystanie energii wiatrowej przy pomocy nowoczesnych bardziej ekonomicznych maszyn.

Dwa zasadnicze typy wiatraków są dzisiaj budowane i próbowane w doświadczalnych instalacjach. Pierwszy typ, który wygląda podobnie do pierwowzorów z przeszłości, posiada oś wirnika poziomą. Drugi typ, który pracuje na całkiem odmiennej zasadzie, posiada wirnik czyli rotor o osi pionowej i oba te typy są dzisiaj równolegle w użyciu.

a. Wiatraki o osi poziomej (HAWT)* — wiatraki poziomoosiowe.

Rotor tego typu wiatraków posiada zazwyczaj dwa do trzech skrzydeł, o stałej lub zmiennej szerokości. Skrzydła te posiadają zwichrzenie wzdłuż ich długości celem zachowania odpowiedniego kąta natarcia powietrza wzdłuż skrzydła, w zależności od zmiany szybkości obwodowej z rosnącym promieniem rotoru.

Fig. 3 przedstawia przekrój skrzydła wiatraka w odległości R od osi obrotu. Przekrój ten posiada kształt profilu lotniczego specjalnie dobranego do warunków pracy rotoru. Oznaczając przez ω szybkość kątową obrotu rotoru, W szybkość i kierunek wiatru, $R\omega$ szybkość obwodową elementu skrzydła, znajdziemy wypadkową szybkość wiatru V ze sumy dwóch wektorów W i $R\omega$. Kierunek szybkości V naciera profil skrzydła pod kątem α, powodując wypór L oraz opór D. Rzut wypadkowy tych dwóch sił na płaszczyznę rotoru daje wypadkową siłę styczną T powodującą moment obrotowy elementu skrzydła TxR.

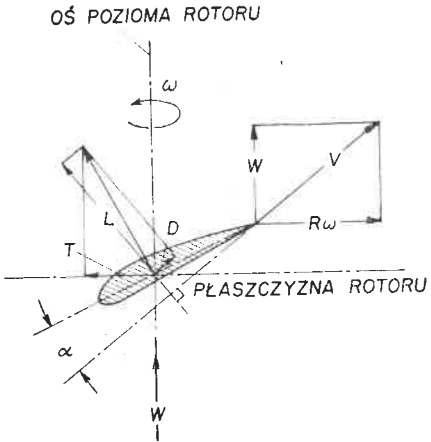


Fig. 3. Aerodynamika HAWT.

Moment obrotowy jednego skrzydła otrzymamy sumując elementarne momenty obrotowe wzdłuż całego skrzydła. Całkowity moment obrotowy wszystkich skrzydeł pomnożony przez szybkość kątową, daje nam moc rotoru.

Jak to widać z wieloboku szybkości W oraz $R\omega$, ze zwiększającym się promieniem R zmienia się kąt natarcia α. Ażeby zapewnić każdemu elementowi skrzydła pracę w optymalnych warunkach, trzeba skrzydło zwichrzyć tak, ażeby otrzymać najlepszy kąt natarcia. Ponieważ szybkość wypadkowa V wzrasta z rosnącym promieniem skrzydła, elementy oddalone najbardziej od osi obrotu dają największą siłę pociągową T, oraz największy moment, są więc najbardziej produktywne.

Ponieważ wszystkie obecne wiatraki w konstrukcji czy też budowie są przeznaczone do zasilania sieci elektrycznych, pracują one wyłącznie na stałych obrotach, napędzając trójfazową prądnicę. Kontrola ilości obrotów rotoru oraz dostarczanej mocy odbywa się przy pomocy zmiany kąta natarcia całego skrzydła, czy też jego części w partii szczytowej. Dostosowanie ilości obrotów rotoru do ilości obrotów prądnicy odbywa się przy pomocy skrzynki biegów umocowanej pomiędzy rotorem a prądnicą. Zakres szybkości wiatru, w których wiatraki pracują, rozciąga się zazwyczaj od 6 do 28 m/s.

Poniżej tej granicy energia wiatru jest niewystarczająca do napędu prądnicy, powyżej 28 m/s wyłącza się zazwyczaj wiatraki i zatrzymuje rotor z powodu bezpieczeństwa. Zatrzymanie rotoru odbywa się przy pomocy obrotu skrzydeł do pozycji zerowej, oraz włączenie hamulca.

---

*Horizontal Axis Wind Turbine.

Cały system mechaniczny wiatraków o osi poziomej składa się zasadniczo z rotoru, skrzynki biegów, hamulca oraz prądnicy i jest zainstalowany w jednym zespole na wieży odpowiedniej wysokości o konstrukcji kratowej lub słupowej. Cały ten system jest obracany naokoło osi pionowej celem nastawienia go do kierunku wiatru.

Fig. 4. Wiatrak WTG-200.

Mechanizm do tego celu składa się z czujnika kierunku wiatru oraz serwomechanizmu obracającego cały system. Jedną z głównych cech ujemnych tego typu wiatraka jest to, że cały pracujący system jest umieszczony wysoko nad ziemią na poziomie osi rotoru, co utrudnia i podraża koszty obsługi i ewentualnych napraw.

Fig. 4 przedstawia współczesny wiatrak poziomoosiowy typu WTG-200, budowany w Buffalo, N.Y. Jest to wiatrak średniej mocy produkujący 200 kW przy szybkości wiatru 13.5 m/s. Kilka egzemplarzy tego wiatraka zainstalowane są dla celów doświadczalnych w USA i w Kanadzie.

Średnica rotoru o trzech skrzydłach wynosi 24.4 m i cały zespół produkujący moc jest umieszczony obrotowo na szczycie wieży 24.4 m wysokiej. Jak widać to z fotografii, kontrola obrotów rotoru odbywa się przy pomocy obracanych wierzchołków skrzydeł. Kontrola całego cyklu pracy wiatraka odbywa się elektronicznie przy pomocy mikroprocesora. Cały ten elektroniczny system mieści się u podstawy wieży w specjalnym pomieszczeniu. Nastawia on kierunek i szybkość wiatru i decyduje kiedy uruchomić rotor. Uskutecznia się tę czynność przez obrót osi rotoru do wiatru, oraz zwolnienie hamulca. Po osiągnięciu 30 obrotów na minutę, która to szybkość jest nominalną szybkością pracy rotoru, nastawia on fazę i częstotliwość generatora z siecią i po uzgodnieniu fali napięcia i prądu włącza generator w sieć. W razie zbyt silnego wiatru lub też popsucia się któregokolwiek systemu, wierzchołki skrzydeł obracają się automatycznie i zwalniają szybkość obrotu rotoru z 30 do 5 obrotów na minutę. Przy tej szybkości zostaje włączony hamulec i rotor przestaje się obracać.

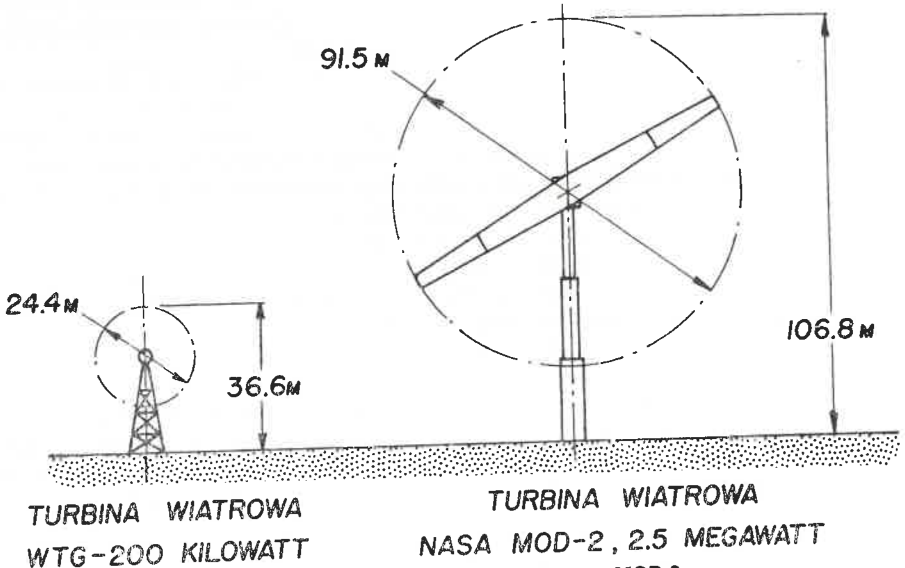


Fig. 5. Porównanie wiatraków WTG — MOD-2.

Znacznie większe wiatraki tego typu są obecnie budowane w USA przez firmy Bendix oraz Boeing. Moce dużych jednostek przechodzących obecnie próby wynoszą okoo 2½ do 3 megawatów. Fig. 5 daje porównanie wielkości pomiędzy wiatrakiem WTG-200, oraz dużą turbiną wiatrową MOD-2 zbudowaną przez firmę Boeing dla Departamentu Energii USA. Pierwszy egzemplarz turbiny już został dostarczony i zainstalowany w stanie Waszyngton na zachodnim wybrzeżu. Dwa następne egzemplarze tej turbiny mają być dostarczone w lecie 1981.

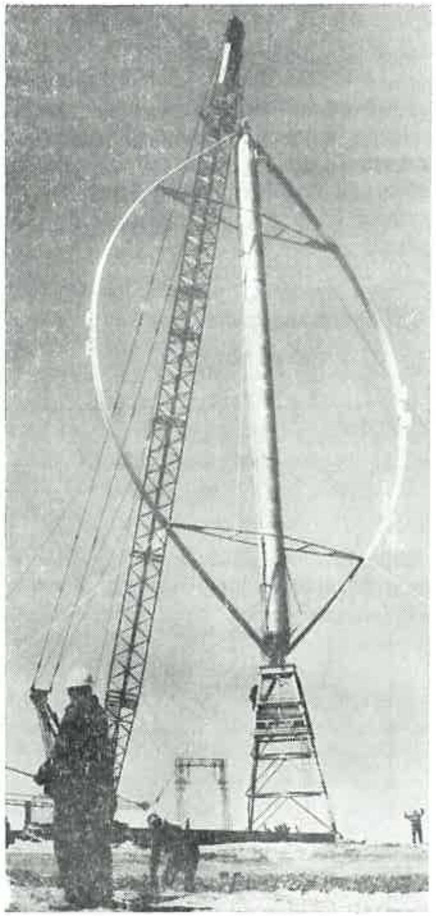


Fig. 6. Wiatrak NRC-220.

b. Wiatraki pionowoosiowe (VAWT)*

Drugi typ wiatraków, który ma duże potencjalne widoki rozwoju jest wiatrak o osi pionowej. Typ ten został wynaleziony i opatentowany we Francji i USA w latach 1925-30 przez J. M. Dorrieus'a. Aerodynamiczne zasady pracy tego typu wiatraka są bardziej skomplikowane aniżeli wiatraka o osi poziomej; zostały one obszernie teoretycznie opracowane przez National Research Council w Kanadzie oraz Sandia Laboratories, USA.

Rotor tego wiatraka składa się ze sztywnej osi pionowej ułożyskowanej na obu końcach, oraz dwóch do trzech skrzydeł o stałej szerokości i dużym wydłużeniu, ukształtowanych według tak zwanej krzywej łańcuchowej, tj. krzywej którą by przyjął łańcuch czy też giętka lina wirująca naokoło osi i zamocowana do niej na obu końcach. Górne łożysko rotoru jest podparte trzema lub czterema kablami stalowymi zakotwiczonymi do odpowiednich fundamentów. Dolny koniec rotoru wraz z dolnym łożyskiem spoczywa na odpowiedniej podporze, mieszczącej skrzynkę biegów, hamulec oraz prądnicę elektryczną.

Fig. 6 przedstawia wiatrak pionowoosiowy typu NRC-220, zainstalowany na wyspie św. Magdaleny w czasie montażu.*

---

*Vertical Axis Wind Turbine.

Wiatrak ten o nominalnej mocy 220 kilowatów został zbudowany przez firmę DAF-INDAL w Toronto na zamówienie National Research Council w Ottawie. Rotor tego wiatraka ma średnicę 24.4 m oraz wysokość 36.6 m pomiędzy łożyskami. Kolumna centralna jest wykonana z formowanej blachy aluminiowej. Dwa skrzydła o stałym przekroju mają szerokość 0.61 m i są wykonane metodą wytłaczania (extrusion). Przekrój skrzydeł posiada symetryczny profil lotniczy o 18% grubości.

Ponieważ współczynnik solidności skrzydeł jest bardzo niski bo około 0.1, skrzydła są wiotkie i dlatego są podparte dwoma poziomymi zastrzałami przymocowanymi do centralnej kolumny.

Współczynnik solidności skrzydeł wyraża się stosunkiem:

$$s = \frac{nxd}{R}$$

gdzie; n — ilość skrzydeł; d — szerokość skrzydeł; R — promień rotoru.

W części skrzydeł o największej średnicy są zainstalowane hamulce aerodynamiczne, które się otwierają automatycznie po przekroczeniu krytycznej ilości obrotów rotoru. Działają one w ten sposób, że po otwarciu niszczą one siłę napędową oraz stwarzają dodatkowy opór. Rotor jest podparty u dołu przez wieżę 10 m wysoką. Cały system kontrolny, mechaniczny oraz produkcyjny jest zainstalowany w górnej części wieży.

Aerodynamika pracy rotoru wiatraka pionowoosiowego jest pokazana na Fig. 7. Rysunek przedstawia równikowy przekrój rotoru. Promień R jest połową maksymalnej średnicy, ω jest szybkością kątową obrotu rotoru. Szybkość obwodowa spowodowana obrotem rotoru jest $R\omega$. Zakładając wiatr W miejący prostopadle do osi rotoru, oraz sumując wektorowo szybkości składowe $R\omega$ oraz W, znajdziemy łatwo szybkość V oraz kąt α owiewania profilu skrzydła.

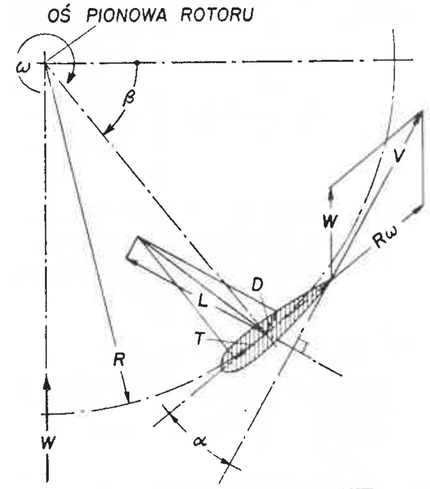


Fig. 7. Aerodynamika VAWT.

Jako rezultat szybkości powietrza V przy kącie natarcia α, otrzymamy wypór L oraz opór D elementu skrzydła. Rzut wypadkowy tych dwóch sił na oś symetrii elementu skrzydła T daje element siły napędzającej skrzydła. Sumując te elementy siły wzdłuż całej rotor. Sumując te elementy siły wzdłuż całej długości skrzydła, otrzymamy całkowitą siłę napędzającą jedno skrzydło. Ta siła napędowa zmienia się z kątem płaszczyzny rotoru β do kierunku wiatru. W wypadku rotoru dwuskrzydłowego siła napędowa jest zerem przy wietrze W wiejącym prostopadle do płaszczyzny rotoru ($\beta = 0$), osiągając maksymalną wartość w okolicy pozycji równoległej ($\beta = 90°$).

---

*Wyspa św. Magdaleny znajduje się u ujścia rzeki św. Wawrzyńca w prowincji Quebec.

Aerodynamika całego rotoru składającego się z dwóch czy też trzech skrzydeł jest skomplikowana. Skrzydło dowietrzne pracuje w innych warunkach aniżeli skrzydło zawietrzne, które porusza się w sferze powietrza zwolnionego przez oddanie części energii skrzydłu dowietrznemu, oraz oporem osi pionowej. Najbardziej efektywną częścią skrzydła w produkowaniu momentu obrotowego są elementy umieszczone w pobliżu największego promienia. Elementarny moment obrotowy spada szybko ze zmniejszającym się kątem skrzydła względem osi obrotu.

Moc wiatraka wyraża się ogólnym wzorem:

$$P = \tfrac{1}{2}\,\rho\,A\,Cp.\,W^3$$

gdzie: ρ gęstość powietrza; A — powierzchnia aktywna rotoru równa powierzchni przekroju przez rotor prostopadłego do kierunku wiatru;

Cp — współczynnik mocy; W — szybkość wiatru na wysokości środka rotoru.

Według teorii Glauerta współczynnik mocy może osiągnąć wartość 16/27 = 0.59. W praktyce, dla bardzo czystego aerodynamicznego rotoru, maksymalna wartość Cp wynosi około 0.38-0.42. Każde dodatkowe urządzenie jak np. zastrzały wspierające wiotkie skrzydła lub hamulce aerodynamiczne umieszczone na skrzydłach (widoczne na Fig. 5) powodują szkodliwy opór i obniżają współczynnik mocy.

Przy danej szybkości wiatru, współczynnik Cp jest funkcją stosunku λ, gdzie:

$$\lambda = R\omega/W;$$

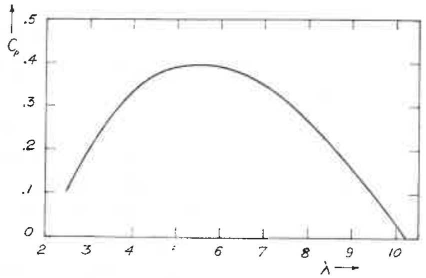


Fig. 8. Wykres Cp = f(λ).

Fig. 8 przedstawia wartość Cp w funkcji λ dla czystego aerodynamicznie rotoru. Wartości te są ważne dla rotorów, których stosunek wysokości do średnicy wynosi około 1.5, oraz których współczynnik solidności skrzydeł S wynosi około 0.125 — 0.175. Współczynnik Cp osiąga swoją maksymalną wartość dla szybkości obwodowej $R\omega$ równej około 5.5x szybkość wiatru.

Ponieważ głównym zadaniem nowoczesnego wiatraka jest zasilanie istniejących sieci elektrycznych prądem zmiennym o stałej częstotliwości, rotor musi pracować na stałych obrotach.

Wyrażając szybkość wiatru W we funkcji λ oraz $R\omega$, otrzymamy:

$$W = R\omega/\lambda \tag{5}$$

Z równań (4) i (5) otrzymamy:

$$P = \tfrac{1}{2}\,\rho\,A\,\frac{Cp}{\lambda^3}\,(R\omega)^3 \tag{6}$$

Przy stałej ilości obrotów wartość $R\omega$ dla każdego rotoru będzie wartością stałą. Wprowadzając nowy współczynnik $Kp = Cp/\lambda^3$ otrzymamy ostateczny wzór (7) na obliczenie mocy rotoru wiatraka przy stajej ilości obrotów:

$$P = \tfrac{1}{2}\,\rho\,AKp\,(R\omega)^3 \tag{7}$$

Wartości dla Kp wylicza się z krzywej $Cp = f(\lambda)$ pokazanej na Fig. 7, dla założonej stałej ilości obrotów $R\omega$.

Obliczona przez autora charakterystyka mocy dla wiatraka NRC-220 używając powyższe wzory, przedstawiona jest na Fig. 9. W wyliczeniu tej charakterystyki uwzględniono również wpływ oporu zastrzałów podpierających oba skrzydła, jak również wydajności mechaniczne skrzynki biegów oraz prądnicy. Przedstawiona tutaj charakterystyka NRC-220 zgadza się bardzo dobrze z pomiarami mocy otrzymanych w czasie użytkowania tego wiatraka na wyspie św. Magdaleny, przy ilości obrotów 36.6/min.

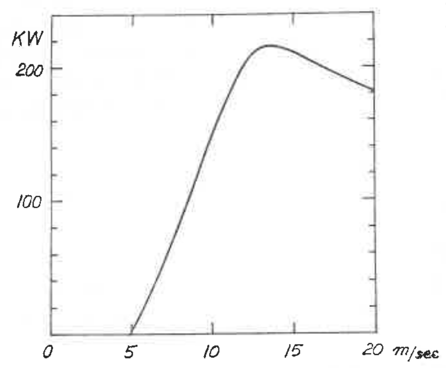


Fig. 9. Wyczyny NRC-220.

Wiatraki pionowoosiowe typu Dorrieus'a zasługują na specjalną uwagę z powodu wielu korzystnych własności. Wyliczymy tutaj najważniejsze.

- Wiatrak pionowoosiowy przyjmuje wiatr z każdego kierunku i nie musi być przestawiany przy pomocy specjalnego mechanizmu do kierunku wiatru; jest to konieczne w wypadku wiatraków o osi poziomej.
- Skrzynka biegów, hamulec oraz generator elektryczny umieszczone są na poziomie ziemie i są łatwo dostępne dla obsługi i naprawy.
- Warunek stałej ilości obrotów rotoru jest łatwy do spełnienia. Szybkość obrotowa rotoru sprzężona z szybkością obrotową generatora zasilającego sieć elektryczną o stałej częstotliwości jest samoregulująca. Ta charakterystyka dobrze kwalifikuje wiatraki pionowoosiowe do zasilania sieci elektrycznych o stałej częstotliwości, które mogą łatwo dostarczyć z zewnątrz energię potrzebną do zastartowania wiatraka, jak również stałą częstotliwość potrzebną do synchronizacji.
- Prosta konstrukcja daje w rezultacie mały ciężar całkowity, obniżający koszt fabrykacji i transportu oraz redukującą ogólny koszt wiatraków tego typu. Skrzydła rotoru mają stały przekrój oraz stały kąt natarcia wzdłuż całej długości, co bardzo upraszcza fabrykację i obniża koszt produkcji skrzydeł, bardzo wysoki w wypadku wiatraków o osi poziomej.
- Wiatraki pionowoosiowe przy maksymalnej wydajności pracują na większej ilości obrotów aniżeli wiatraki o osi poziomej o tej samej średnicy. Różnica ta wynosi około 20-25%; dzięki temu wiatraki pionowoosiowe potrzebują skrzynki biegów o mniejszej przekładni, których zarówno sprawność mechaniczna jak i cena są znacznie korzystniejsze.
- Jedyna cecha ujemna, którą wiatraki pionowoosiowe posiadają jest to, że rotor nie startuje sam ze stanu spoczynku. Musi on wpierw osiągnąć dolną krytyczną szybkość obrotów przy której napędowa siła aerodynamiczna T zaczyna osiągać wartości dodatnie. Osiąga się ją zazwyczaj przez rozpędzenie rotoru do szybkości startującej przy pomocy energii elektrycznej czerpanej z sieci, na którą wiatrak pracuje.

Wiatraki o osi poziomej mają bardzo długą i starą tradycję. Pracowały one przez wiele stuleci dostarczając energii dla bardzo skromnych ówczesnych potrzeb, i przy pomocy bardzo prymitywnych metod. Jednakże ilość nagromadzonego doświadczenia pozwoliła na szybką ewolucję tego typu.

W wypadku wiatraków pionowoosiowych trzeba było zaczynać od początku i zapoznać się stopniowo ze wszystkimi trudnościami i niespodziankami spotykanymi zawsze przy tworzeniu i rozwoju nowego typu maszynerii.

Zainteresowanie wiatrakami pionowoosiowymi datują się od bardzo niedawna. Szereg modeli o średnicy poniżej 15 m zostało zbudowane i próbowane w Północnej Ameryce i w Europie. Wystarczająca ilość doświadczenia została zebrana, ażeby zacząć budować większe modele. NRC w Kanadzie oraz Sandia Laboratories w USA pracowały i nadal pracują nad tym typem wiatraka. Pierwszy większy model produkujący 220 kilowatów został zbudowany w Kanadzie i zainstalowany na wyspie św. Magdaleny w r. 1977 (Fig. 6).

W Stanach Zjednoczonych ALCOA* na zamówienie Sandia Laboratories zbudowała nieco większy model o mocy 350 kilowatów. Model ten posiada 3 skrzydła o szerokości 0.74 m. Jest to największa szerokość skrzydła, która się daje wyprodukować metodą wytłaczania przy dzisiejszym stanie technologii. Niestety już dwa prototypy wiatraków ALCOA obecnie w próbach zostały uszkodzone z powodu złamania centralnej kolumny, oraz w drugim wypadku z powodu złamania jednego ze skrzydeł u nasady.

Te początkowe niepowodzenia przyczynią się walnie do wzbogacenia sumy doświadczeń dla tego typu wiatraków. Odpowiedni czas musi upłynąć, zanim wszystkie specyficzne problemy i własności tego nowego typu zostaną gruntownie poznane.

Przyszłość wiatraków

Po wstępnym przygotowaniu i omawianiu głównych przedmiotów oraz argumentów naszego tematu, możemy przedyskutować prawdopodobną rolę i rozwój konstrukcji wiatraków w niedalekiej przyszłości. Podobnie jak w wypadku otrzymywania energii z potencjalnych różnic poziomu wody, energia otrzymywana z powietrza jest wolna zupełnie od niepożądanych zanieczyszczeń i odpadów szkodliwych dla otoczenia i luzkiego zdrowia. Ta bardzo ważna zaleta będzie odgrywać w przyszłości coraz większą rolę w widoku na coraz większe nasze wysiłki zdążające do utrzymania naszego otoczenia w możliwie niezatrutym stanie. Jest to główny argument przeciwko zwiększeniu używania węgla czy też energii atomowej do produkcji energii elektrycznej.

Około 2% całkowitej energii dostarczanej ziemi przez słońce jest zużyte na ruch naszej atmosfery. Na przykład gdybyśmy potrafili zużytkować tylko 10% energii wiatrów wiejących blisko ziemi nad Stanami Zjednoczonymi byłby to ekwiwalent 75% całej energii konsumowanej przez ten kraj.**

Cały obecnie wysiłek konstruktorów nowoczesnych wiatraków czy też turbin wiatrowych idzie w kierunku obniżania ceny za kilowatgodzinę prądu produkowanego tą metodą. Ponieważ moc dostarczana przez wiatraki wzrasta z trzecią potęgą szybkości wiatru, główny nasz wysiłek powinien być skierowany w umieszczeniu rotoru wiatraka w strumieniu powietrza o największej szybkości. Jak to wynika z rozdziału o dynamice naszej atmosfery, kilka dróg jest otwartych dla osiągnięcia tego celu.

- Należy umieścić rotor wiatraka na jak największej wysokości nad ziemią. Jak to czytamy z wykresu na Fig. 1, przy wietrze o sile 8 m/s przeniesienie osi wiatraka z wysokości 23 m na wysokość 99 m, podwaja ilość otrzymanej energii. Warunek ten automatycznie nasuwa ideę, ażeby konstruować wiatraki bardzo duże, umieszczane na wysokich wieżach.

---

*Aluminum Company of America.

**Gustavson R. R. "Limits of Wind Power Utilization". Science, 1979.

- Wiatraki czy też farmy wiatrakowe należy instalować w okolicach, które mają najwyższy procent wiatrów o dużej szybkości. Z dotychczasowych pomiarów w USA wynika, że istnieją wyjątkowe okolice posiadające wiatry o potencjalnej energii 1,200 watów/m^2. Okolice posiadające średnie potencjały około 600 watów/m^2 są uważane za bardzo dobre, a okolice o 300 watach/^{2} są jeszcze uważane za nadające się do eksploatacji. Wszystkie inne specjalne cechy terenowe jak wysokość nad poziomem morza, konfiguracja terenowa oraz szerokość geograficzna są ważne w wyborze najlepszego miejsca na instalacje wiatraków. Cechy te były omówione w rozdziale o dynamice atmosfery.

- Wielkość wiatraka czy też wybór odpowiedniego typu zależą również w wysokiej mierze od przyszłego miejsca zainstalowania. Tereny na dalekiej północy, niedostępne z powodu braku środków komunikacyjnych, będą wymagać ze względów ekonomicznych mniejszych jednostek, specjalnie dostosowanych do lokalnych warunków klimatycznych.

Wiele pracy włożono już w znalezienie optymalnej wielkości turbiny wiatrowej. Do wszystkich względów przedyskutowanych dotychczas dochodzą dalej względy natury konstrukcyjnej, fabrykacyjnej oraz transportowej.

W pracach dotychczas opublikowanych rozmaite instytucje dochodzą do wniosku, że w wypadku wiatraków o osi poziomej, wielkie jednostki będą znacznie ekonomiczniejsze pomimo bardzo wysokiej ceny. Jak to z tych publikacji wynika, jednostki o mocy od 2 do 4 megawatów wydają się optymalne. Kilka modeli tej wielkości są obecnie instalowane w Kalifornii, na wyspach hawajskich oraz na zachodnim wybrzeżu USA.

W wypadku wiatraków czy też turbin wiatrowych o osi pionowej, sprawa ich widoków na przyszłość przedstawia się następująco. Nie ulega wątpliwości, że ten typ wiatraków posiada nadzwyczajne możliwości z powodu ich prostej konstrukcji oraz mniejszego ciężaru w porównaniu do jednostek o tej samej mocy o osi poziomej. Będąc typem nowym, posiadającym jeszcze wiele początkowych problemów wymagających rozwiązania, trzeba nam dłuższego czasu dla nagromadzenia większej sumy doświadczenia w konstrukcji oraz w eksploatacji tego typu. Czas życia dużych jednostek turbin wiatrowych jest preliminowany na 25 do 30 lat. Jest to okres bardzo długi, niestety bardzo zasadniczy w kalkulacji opłacalności tego typu maszyn do produkowania energii. Turbiny wodne oraz parowe są bardzo długowieczne i niezawodne w eksploatacji i turbiny wiatrowe należące do tej samej kategorii maszyn produkujących energię, muszą być konkurencyjne. Kwestia ceny jednostki wyrażającej się w cenie wyprodukowanej ilości kilowatgodzin, będzie rozstrzygającym argumentem w wyborze odpowiedniego typu oraz wielkości.

Większx łatwość obsługi turbin pionowych spowodowana tym, że wszystkie mechaniczne instalacje są umieszczone na poziomie terenu, a więc łatwo dostępne, oraz eliminacja mechanicznego systemu nastawiającego oś rotoru do kierunku wiatru, mogą być tutaj rozstrzygającym argumentem przemawiającym na korzyść turbin pionowych.

Ponieważ koszt produkcji maszyny tego samego typu jest wprost proporcjonalny do jego ciężaru, wiatraki pionowoosiowe mają tutaj wielką przewagę. Porównując jednostki tej samej mocy, wiatraki pionowoosiowe są około 20-25% lżejsze od wiatraków o osi poziomej. Zdaniem autora, wiatraki pionowoosiowe mają znacznie więcej potencjalnych możliwości przyszłego rozwoju oraz więcej ekonomicznych zalet.

Kanada przoduje na razie w rozwoju tego typu wiatraków. National Research Council w Ottawie, Hydro Power Quebec oraz firma DAF-INAL w Toronto, która produkowała dotychczasowe modele wiatraków dla NRC, pracują z powodzeniem w tej dziedzinie. W Stanach Zjednoczonych firma ALCOA wraz z Sandia Laboratories NASA też opracowują doświadczalne modele wiatraków pionowoosiowych. Wiele doświadczenia zostało już zebrane. Przejście z obecnej skali 220-350 kilowatów do skali znacznie większej przyniesie nowe specyficzne problemy i nowe rozwiązania. W chwili obecnej są opracowane na desce rysunkowej przyszłe modele o bardzo dużej mocy. Wyniki prac NRC wykazują, że jednostki o wielkości 2-4 megawatów powinny być optymalne ekonomicznie.

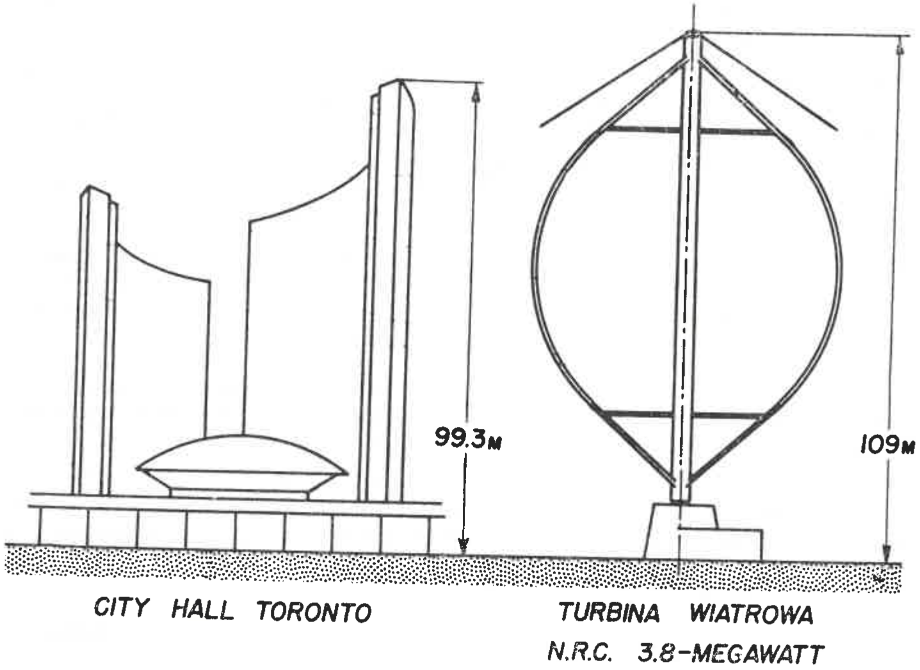


Fig. 10. Porównanie NRC-3.8 MW oraz City Hall.

Fig. 10 przedstawia najnowszy projekt NRC o mocy 3.8 megawatów. Dla porównania wielkości pokazany on jest obok City-Hall w Toronto. Niedaleka przyszłość pokaże, kiedy i gdzie ten typ wiatraka będzie szczegółowo konstrukcyjnie opracowany i zbudowany.

W niniejszym artykule autor starał się dać czytelnikowi jak najbardziej informujący obraz obecnego stanu rozwoju otrzymywania energii z naszej poruszającej się atmosfery, jak również wyjaśnić podstawy fizyczne i techniczne towarzyszące temu problemowi.

Ciągle wzrastający koszt płynnego paliwa, jak również ograniczone jego zasoby zmuszają ludzkość do rozglądania się za nowym źródłem energii. Wiatr jest jedynym naturalnym zasobem energii wolnym od zanieczyszczeń oraz trujących odpadów, który nam jeszcze pozostał do eksploatacji i od nas tylko zależy w jakim czasie i w jakiej skali ten rodzaj energii będzie dla nas dostępny.

DE HAVILLAND GLIDER "SPARROW"

Mr. W. Czerwinski joined the De Havilland Aircraft Co. in March 1941. At that time, as a result of an agreement between The Polish Government in exile in England and Canada, a small group of Polish aeronautical engineers were sent to Canada to help the Canadian war effort. Some other engineers belonging to the same group were Messrs. W. Stepniewski, T. Tarczynski, K. Korsak and Z. Jarmicki.

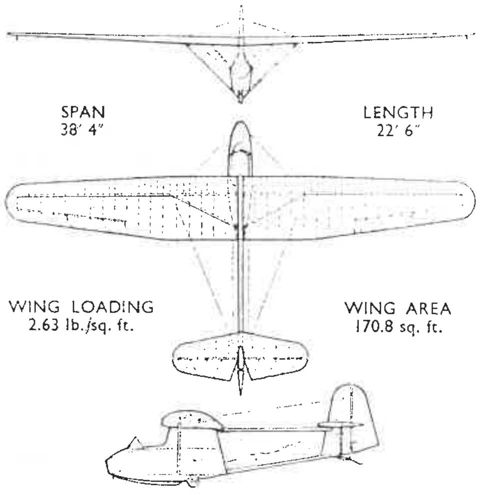
After working for few months at De Havilland, Mr. W. Czerwinski conceived an idea to form a gliding club among the members of the Engineering Department, as well as design and build a glider. His idea was enthusiastically accepted by members of the design office, and the management cordially approved the project. The managing director P. C. Garratt, a pilot himself, took a personal interest in this venture.

The design work was carried out by members of the drawing office staff in their own time, under the guidance of W. Czerwinski. Working twice a week the drawings were completed in about six months. The glider was built in the experimental shop and the maiden flight was done in the spring 1942 by the responsible designer W. Czerwinski.

The glider was named "Sparrow" and was used by the club as a preliminary trainer. The chosen type of the glider was a combination of a preliminary trainer and sailplane and did a very good work through many years of faithful service.

The designing and building a glider by DeHavilland employees was a very successful endeavour, which contributed greatly to the future development of the gliding movement in Canada. In following years W. Czerwinski designed four gliders and sailplanes, two of them together with Mr. B. S. Shenstone a very distinguished promoter of gliding in Canada.

Editor



RICHARD R. D'WONNIK,
M.R.A.I.C., A.R.I.B.A., DIPL. ING. ARCH.

THE DESIGN OF THE TEACHING CELL GROUP

The strong belief that I was capable as an architect of exploiting to the fullest degree the opportunity afforded me by a very enlightened Board of Education in the Bertie Public School System encouraged me to proceed with the design of a new concept for the school which would reflect changes in educational policy and programs; be adaptable to many teaching situations, and generally fulfill the desire of the township School board for a compact structure for the ultimate in the students' learning experience.

I was aware at the time (1964-65) of the inherent conservatism of the decision-making authorities, the ever-present considerations of the budget and regulations and building codes that were unsympathetic to the new ideas and methods in school design.

Fortunately, and to my surprise, the concept was received favourably and the project was helped with special grants for its realisation. The school was allowed to be constructed under the category of "Experimental Schools".

The school provides accommodation for grades 7 and 8 in the Bertie District Public School System. The area served is semi-rural, but three of the municipalities were rapidly approaching the over-sized village category. Therefore, transportation of almost 100% of the pupils to the school was the first requirement.

The basic factor which determined the resultant planing design of this school was the awareness of teaching aids and their operations. As educational theory has developed toward more effective teaching-learning processes, the ready availability of physical facilities and devices which technology has made possible become of utmost importance in more effective communication. In planning the areas and their relationship to each other, the best and easiest use of the audio-visual equipment and teaching materials was foremost in the arrangement of teaching spaces.

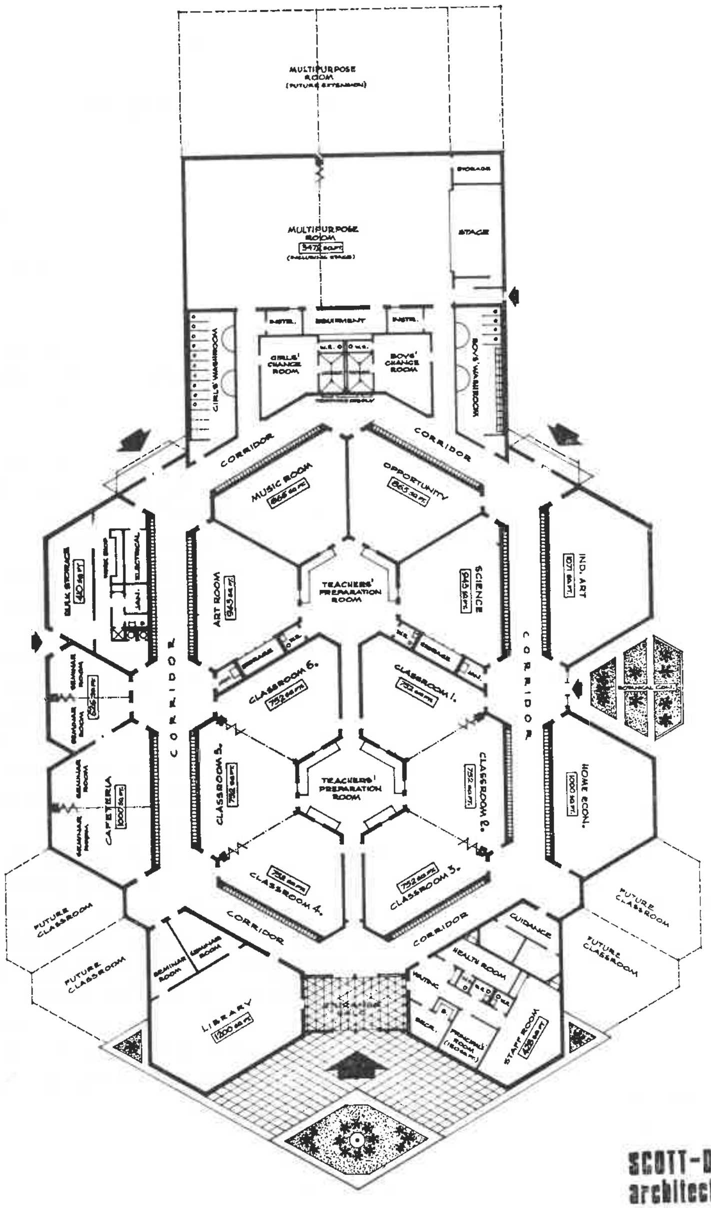
Two main teaching centres form the activity cores of cellular arrangement — all teachers in each group having ready access to the cores, their equipment, and the co-operation of the teachers themselves. Instructional aids may be pre-set and programmed in the core — resulting in the maximum of time usage during teaching periods, eliminating troublesome set-ups in the classrooms, noise of equipment etc.

Each classroom is fan shaped to allow the optimum in viewing projection or television. The "target" wall of each classroom is provided with the glass screen to allow projection from the teaching core side, a television unit and sliding chalkboards to cover both. Remote control of the equipment can be exercised by the teacher at any time during the session.

The concept of room flexibility provides push-button controlled movable sound-proof sliding-folding partitions between cellular classroom units. The design permits variations in accommodations for group work and instructions. Troughout the structure, teaching spaces are designed as hexagons, a form intended to maintain a well-proportioned and acoustically acceptable facility regardless of size.

The windowless aspect of the building which indictated by the nestling of rooms in groups has been compensated by liberal use of vibrant colours and high level of illumination. The glass areas, provided in the lantern-shaped intersections of the

D



SCOTT-D'WONNIK
architects
engineers

PLAN

TOTAL AREA
31 934 FT. 0 IN.

BERTIE AREA SENIOR GRADE SCHOOL
RIDGEWAY ONTARIO

corridor supplement the colours and artificial lighting, making the movement fro class to class a pleasent experience in daylighting.

Lack of window eliminates the problem of glare, draughts, heat loss, maintenance, lighting for audio-visual work and outside distraction to learning process, adding at the same time ample surfaces for the display of students' work. These features all contribute to and assist in the provision of an ideal container for creating ideal and constant atmosphere so desirable in a controlled learning environment.

Individual room heating, ventilating and cooling units, automatically control each rooms atmosphere according to its demands — holding the temperature at a constant level and at the same time providing a constant flow of clean filtered air. The units are operated electrically for heating and cooling. Consequently, no centralized heating and ventilating system is required. Expansion of the school is simplified to the point of "plug-in" type of unit accommodation. Increasing the school accommodation for rapidly growing areas is a matter of nestling of more cell units into the established pattern.

Economy of considerable magnitude can be maintained in any expansion programme, since the linkage of units is simple and the requirements for extension of services is practically non-existent.

Although I have not made any scientific studies as to the results and consequences of this school, contact with teachers and students lead me to believe that the Bertie Senior Elementary School has been successful in creating a more attractive learning environment.

The current reaction of the township school board to the building is expressed in the strong belief that the school design contributed to the program which is dynamic rather than a static one, and is an important environmental factor in children growth and contributes positively to their education.

A. M. GARLICKI, E. H. BOWLER*

RAILWAY LABORATORY OF THE NATIONAL RESEARCH COUNCIL OF CANADA

ABSTRACT

In recent years the railroad industry has been identified by the National Research Council of Canada as a traditional one which might benefit from cross fertilization with new technologies. To this end, the Mechanical Engineering Division has set up the Railway Laboratory to be a focus for this work, though many other specialist laboratories continue to work in this area. To assist innovators of rail vehicles in understanding the behaviour of their product and to shorten its development time, mechanical simulators of the rail vehicle's environment and mathematical models of both vehicle and environment are being provided in addition to more traditional facilities for approval testing.

STRESZCZENIE

Z uwagi na fakt, że zastosowanie nowych zdobyczy techniki może wiele pomóc istniejącemu od dawien dawna kolejnictwu, Dział Mechaniczny Kanadyjskich Państwowych Zakładów Badawczych utworzył Laboratorium Kolejowe. Ma ono stać się centrum tych prac mimo, że jeszcze inne laboratoria są zaangażowane na tym odcinku. Symulatory środowiska kolejowego, jak również modele matematyczne są udostępniane konstruktorom pojazdów kolejowych, dla uzupełnienia ich bardziej tradycyjnych urządzeń wytrzymałościowych do prób, jako pomoc w projektowaniu i przyśpieszeniu tych prac przez wyjaśnienia reakcji pojazdów kolejowych w ściśle określonych warunkach.

INTRODUCTION

"Ribbons of steel put this country together, and ribbons of steel will keep it together". This is how Mr. Frank Roberts, president of VIA Rail (Crown corporation with a mandate to operate all passenger rail service in Canada) expressed the role of the Canadian railways. In fact, since 1885, the year in which "the last spike" was driven into Canadian Pacific Rail's 2,893 mile rail link between Montreal and the Pacific, the Canadian railway system became a key factor in "welding" this part of the North American Continent into one nation. Passenger, and particularly freight train service are still the nation's major circulatory systems.

After the first fifty years of vigorous expansion, the depression and then the aviation boom, coupled with a vastly improved road network, slowed the process noticeably and cut back the passenger traffic dramatically. Recently, however, a concern of the government and of Canadians in general about the conservation of energy, and the cost of fuel oil in particular, has given fresh impetus to efficient surface transportation (4). Energy requirements of trains compare favourably with other passenger transportation modes. Providing convenience and reasonable cost can persuade people to fill the seats, we may see the resurgence of the passenger train.

With regard to freight movement, the Canadian railways play a dominant role in long distance transportation of large masses of agricultural, forestry and other resource

---

*Research Officers of the Railway Laboratory, Division of Mechanical Engineering, National Research Council of Canada.

materials, as well as considerable quantities of manufactured goods. By and large, rail transport, either in its traditional form or in the application of new modes such as piggyback or container systems, is the least costly method to move freight materials on land, because of it slow rolling friction and consequent high energy efficiency (fuel cost is about one quarter that for road truck haulage).

Despite decades of railway research by many agencies, the motion of a new rail vehicle along the track is, even now, not entirely predictable for the whole spectrum of shapes and conditions of wheels and rails. Poor curving performance and unstable running on tangent (straight) track cause unnecessary wear of rails and of car or locomotive wheels, leading to extra maintenance costs. This wear, if undetected, can contribute to derailments with enormous service disruptions and some danger to life and limb. In the case of the 10th of November, 1979 Mississauga accident, involving a breached chlorine tanker car, some quarter million people were evacuated for several days. Also, recent trends in train operation such as longer and heavier consits, have led to some costly derailments. Thus, even in this essential and well proven form of transportation, which annually moves some 236 million tonnes of goods an average of 950 km, there are challenging problems that should be solved for the benefit of the country.

To give an idea of the number and nature of railway accidents in Canada for the year 1980 (1979), the following table was prepared from the data given in a recent survey (1).

			Number of Resulting			
Accidents	**Number**		**Deaths**		**Injuries**	
Collisions	97	(66)	1	(3)	61	(72)
Derailments	303	(350)	0	(1)	103	(73)
Crossings	826	(937)	83	(98)	435	(452)
Track Motor Car	60	(48)	2	(0)	77	(78)
Fires	13	(17)	0	(0)	0	(0)
Trespassings	177	(82)	97	(51)	80	(34)
Miscellaneous	32	(48)	6	(5)	25	(46)
Total	1,508	(1,548)	189	(158)	781	(755)

The National Research Council of Canada (NRC) has built up over the years a considerable range of railway test facilities, measuring equipment, and expertise at its Railway Laboratory. Canadian users and manufacturers of rail vehicles, as well as the major operators, now make extensive use of the Laboratory's services and facilities to ascertain that their products meet basic strength and safety standards, and the objective now is to provide the means for designing and proving more efficient and cost effective equipment to compete in the world market.

The Railway Laboratory is situated near Ottawa's Uplands International Airport and has access to Canadian Pacific Rail's Prescott line. It was officially inaugurated in September 1978, albeit its strength testing facility had been in use since the 1960's.

SHORT HISTORY

The origins from which the Railway Laboratory eventually developed go back to the early 1950's when the Instruments Laboratory of the NRC's Division of Mechanical Engineering (DME) conducted research and development activities on a very wide spectrum of instrument applications, ranging from designing and building mechanical aids to surgery to making recorder systems for dynamic measurements in the fields of land, sea, and air transportation. In that decade, the Canadian railways, from time to time, requested assistance in the measurement of car behaviour and occasionally asked advice on car suspension. Since then, the Division of Mechanical Engineering has had an ever increasing number of requests for advice from railway operators on such matters as lubrication, track laying and maintenance, structural problems, the combustion of substitute fuels, and train operation in severe climatic conditions. In 1963, the McFarland siding near the Ottawa Uplands International Airport was chosen as a site for carrying out experiments on cars and components. In 1964, a car shop building and a 60 m long, 15 per cent grade ramp track were erected, thus enabling preparation for road tests and controlled velocity impacts as required for studies of the dynamic behaviour of car components during yard impacts. With these facilities, the shippers and car builders began bringing their tie down and Association of American Railroads (AAR) qualification problems to us.

In the 1970's, safety related problems posed by railway regulators (Canadian Transport Commission) showed a requirement for laboratory dynamic experiments on simulators of various kinds. It became apparent that any great innovation in running gear would have to be proven first in such a laboratory for safety and security, as well as cost considerations. Accordingly, a dynamics building was built in 1975 and serious design work commenced on a vibration stand and a curved track simulator. All this activity meant that over half of all efforts were railway oriented and the name was changed in 1976 to the Railway Laboratory. In 1978, the Laboratory's office, shop, and support staff were moved into new quarters at Uplands, attached to the Rail Vehicle Dynamics Laboratory, Building U-89.

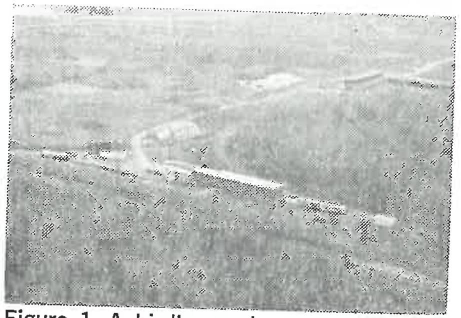


Figure 1. A bird's eyeview of the Railway Laboratory of the National Research Council of Canada, near Uplands Airport, in Ottawa. In the foreground, Building U-90 containing the squeeze frame. On its far left is the experimental reversible impact car (ERIC), on its right, dynamometer Car 1001 and the impact track. Further back are the rail vehicle dynamics laboratory (reinforced with heavy buttresses) and the office wing, both forming Building U-89. Ottawa's International Airport is in the background.

OBJECTIVES

The facilities of the Railway Laboratory have been set up with the following goals in mind:

— assistance in the design of the new equipment
— strength testing of new equipment to a standard
— performance testing of the prototypes
— analytical studies of train dynamics and of wheel/rail interaction including mathematical modelling
— improvement of the existing equipment to achieve higher speeds and efficiency, better safety and lading protection, and in the case of passenger trains, greater comfort of riding
— liaison with railway industry by participation in various committees, e.g. the Train Dynamics and Lading Damage Committee
— participation in railway projects of other NRC laboratories
— assistance in solving instrumentation problems in the neighbouring areas, such as road transport.

LABORATORY FACILITIES AND PROGRAMMES

To implement the above-mentioned objectives, the Laboratory places diversified testing and measuring equipment, programmes, and expertise at the disposal of railway regulators, users, operators and manufacturers.

Strength Testing Programmes

In response to numerous requests of railway owners, users, and regulators, and of the equipment manufacturers, for assistance in providing the strength of various structures, the Laboratory has assembled an assortment of tools, instruments and facilities. The major ones are:

A 60 m long, 15 per cent grade, impact track, where full-size cars may be impacted at predetermined velocities. The Association of American Railroads regulations, which guide the manufacture of the equipment built for interchange service on the North American Continent, require that these cars be impacted at a speed of 22 km/h, or with a force of 5.56 MN, whichever happens first. The track is also used in the development and testing of securement methods and in lading damage studies.

Figure 2. Preparing for impact test on a securement system to a flatcar for a self-propelled gun of the Canadian Armed Forces.

A squeeze frame, capable of exerting compressive forces up to 4.45 mn on rail cars and similar pieces of equipment up to 30 m long.

An experimental reversible impact car (ERIC) which contains a mechanism whereby one of its couplers can be extended and then retracted a distance of 5 m in 1.5 seconds. Each movement is limited by "hard" stops. This enables rail cars coupled to ERIC to be impact-tested in tension as well as in compression, as the limits of this extension are reached.

Road Testing Equipment

It is often necessary to observe the behaviour of lading or car suspension components, and to measure forces and accelerations, as a car moves at speed down the real track. This is particularly important when untried new equipment is under investigation to discover the bound of safe operation. To this end, the Laboratory has three mobile laboratories in use or under refit. The first is a caboose which has been extensively used in short freight train tests, or at the tail end of along ones. The second, a dynamometer car, (CP Car 62), is much stronger and is able to monitor behaviour anywhere in a freigth train. Finally, Car 1001 has been acquired to fulfill the same role as the latter in passenger trains, as it is capable of higher speeds.

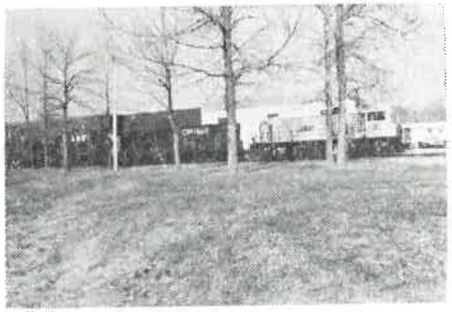


Figure 3. The Laboratory's locomotive, a fully laden 100-ton coal car and dynamometer Car 62 during brake performance tests at Uplands.

Figure 4. Inside view of the instrument section of dynamometer Car 62 during field tests.

Using one of these instrument cars, one can measure a wide variety of conditions of car or locomotive responses during an actual over-the-road run. Usual measurements in these instances are of such variables as acceleration, relative displacement, relative velocity, stresses, strains and forces. These are recorded on FM magnetic tape, with a quick look at the results provided by UV or pen oscillographs. Video monitoring with short circuit television and recording of interesting or potentially dangerous phenomena often augment the measurements. From these records, ride quality, vehicle stability, damage proneness, and derailment proneness can be calculated. Track side instrumentation in conjunction with over-the-road tests can provide such additional information as rail forces, lateral to vertical force ratio (L/V), and angle of attack.

The Laboratory also has its own 1,000 HP locomotive, which is used for general purpose duties and for tests within the Laboratory grounds and for calibrating various lateral and vertical rail force transducers developed here.

Rail Vehicle Dynamics Laboratory

A 70 m long, 9 m wide and 12 m high Rail Vehicle Dynamics Laboratory (Building U-89) contains a weigh scale, the hydraulic vibration test stand, the curved track simulator, the hydraulic power unit, the hydraulic hardline distribution system (88.5 dm^3/s at 2.4 MPa), and the control room. The building sidewalls, reinforced with buttresses, may withstand a 667 kN horizontal thrust applied at any point. The floor of reinforced concrete design is 2.4 m thick, and provides a seismic mass to damp heavy equipment vibrations. Three overhead travelling cranes (one — 75+10 t capacity, one — 75 t capacity, and one — 10 t capacity) provide all the necessary lifting power to place fully laden 100 t capacity cars on the shaker or on the simulator.

Control Room. The simulator and shaker controls are installed in an air-conditioned control room, which is independently suspended inside the main structure to prevent vibration transfer onto this equipment. Also housed in this room are some calculating, analyzing and printing equipment, such as a Hewlett-Packard Model 5420A, a fast fourier transform (spectrum) signal analyzer, and a model 9835A desktop computer with plotter and high speed line printer. Consideration is bein given to get an RS-232-C interface to permit the computer to be used either as a terminal to the NRC's IBM 370 computer or for moving data back and forth between the two computers. Eventually, a minicomputer will be purchased for controlling the curved track simulator and the shaker.

With the above equipment, signals, which are typically time histories of transducer outputs, recorded on magnetic tape in the field, are analyzed to quantify such variables as strain, force and acceleration with the view to determine their histogram and power spectral density. Correlation and cross spectrum analyses may be employed when the functional relationship between signals is to be determined. The handling of these data directly from the analyzer to the calculator, its storage, post processing, plotting, and tabulation can be done quickly and reliably. These analysis methods allow precision detection of the onset of vehicle instability, and the characterization of track roughness and ride performance. In addition, the measuring system and lading response inpputs to the recorder can be obtained for studies of damage proneness of various types of lading.

Weigh Scale. The weigh scale has been installed as a national standard and also as a precise scale for general railway use.

Figure 5. VIA Rail's RDC (Rail Diesel Car) undergoing tests on the hydraulic vibration test stand in the rail vehicle dynamics laboratory.

Hydraulic Vibration Test Stand. The trend today is require that prototype railway cars and trucks be subjected to dynamic and fatigue tests in the laboratory to determine that the dynamic design requirements have been met, and that the structure is capable of standing up to the operational environment without suffering fatigue failures.

In its present state, the Hydraulic Vibration Test Stand (HVTS) has taken the form of a rig in which two hydraulic actuators excite a ten foot section of track in the lateral sense, and by this means, shake any car clamped to this track. In the future the vertical support will be replaced by four vertical actuators to allow any movement of the track section that does not violate its remaining planar (unwarped). Further developments are planned which will allow each of the two axles to be independently excited in a plane containing on lateral and two vertical actuators. The (2) lateral and (4) vertical actuators have each 98 dynamic and 111 static plus 156 kN dynamic capacity, respectively. Their maximum amplitude is plus-minus 76 mm, and frequency of up to 50 Hz.

Curved Track Simulator. The Curved Track Simulator (CTS) takes the form of eight steel rollers supporting the eight wheels of a rail vehicle geometrically aligned to create the simulated curve and controlled in speed to exactly represent the passing of steel rails under a car. With the completion of this apparatus, it will be possible to simulate the tracking of cars at speeds up to 240km/h over perfect track with variable curvature, while monitoring rail/wheel forces, truck stability, tendencies to wear, and tendencies to derail. The use of the simulator will be of assistance to industry, as well as to the Laboratory's own researchers in the development of improved vehicles and components. The mechanization of the CTS is quite unique. It has been designed to supplement similar installations in Great Britain, France, Japan, West Germany, and in the United States. The Canadian rig was designed (by NRC personnel) with particular emphasis on studying the behaviour of heavy freight equipment (fully laden, 100 t capacity cars) over curved track with the aim of improving its durability and performance. The unusual features of this rig are:

- Each wheel of a four-axle car will be supported on a roller that will effectively provide a strip of steel moving by at the appropriate speed to simulate perfect track with left or right-hand curves up to 15 degrees in 30 m, and including tangent track.
- The supporting roller will provide the appropriate spin creep at the footprint for wheels with constant conicity (creep is a condition between pure rolling and pure slipping) by canting the rollers at the cone angle. No other known track simulator has attempted this correction.

- The rig may be adjusted prior to running to accommodate trucks that hold the axle in one of three modes: square and parallel, not square but parallel, and steering types, which align their axles radially in a curve. This feature could be automated to achieve wheel-over-roller conditions at all times.

Each roller stand (one for one axle, powered by one 150 HP and one 50 HP motor) is supported vertically on four hydrostatic bearings to facilitate geometry modifications under load. The stands are constrainted in the horizontal plane by a lever system which places the rollers on the arc of a circle. The end of car device has a triple function: to restrain the car both longitudinally and vertically in the case of wheel or roller failure, and to simulatete lateral forces from the adjacent cars.

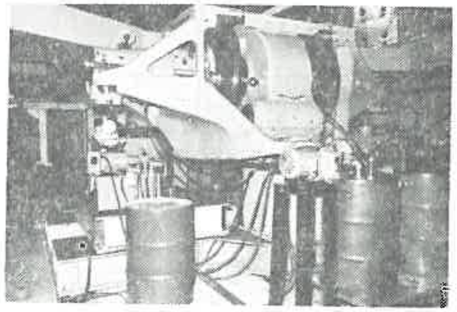


Figure 6. One wheelset roller stand of the curved track simulator being assembled in the rail vehicle dynamics laboratory. The simulator will consist of four such stands.

It will be possible in the future to simulate a spiral into a curve, side loads at the centre of gravity (centrifugal effect), side loads at the centre of pressure (wind effect), and side loads at the coupler (train action). A criterion for derailment prevention should be possible from these capabiliites. Moreover, it will be possible to simulate curves under three-axle trucks by changing the lever system to include three stands; this feature is not available elsewhere. In such case, only one truck could be accommodatedand the maximum curvature would be a little less than 15 degrees in 30 m.

Controlled Climatic Environment Building

DME's Low Temperature Laboratory is rebuilding its aging large environment chamber at the Railway Laboratory's Uplands site to permit environmental studies on railway equipment as well as the wide variety of tasks undertaken at its present location. Its main feature is a —50°C to +50°C test chamber, approximately 30 m long, 6 m wide, and 8 m high, complete with spray and snow making equipment. Space has been set aside for future ducting of air from one end of the building to the other which will enable this room to become the test section of a wind tunnel, should such a facility be deemed useful.

Proposed Expansion of the Laboratory Facilities

As part of the Laboratory's five year expansion programmem (1981-1986), the Road Vehicle and Bogie Component Life Prediction and Extension facility is proposed. It would be housed in a 15 m x 30 m building, having 1.8 m thick reinforced concrete floor for strength and mass. The key apparatus in this facility will be the Brake Bearing Wheel Test Rig (BBW), having flywheel inertia equivalent to that of a fully-laden 100 ton capacity car at 240 km/h.

Mathematical Modelling

A hybrid computer model has been developed to study control system requirements for the spindle drives and slewing motion of the CTS. A programme for mathematically defining a sequence of curves and tangents produces data for control of roller speeds and yaw motions as well as externally applied vehicle forces and moments. The model is being used to gain insight into capabilities and limitations of the track simulator.

Software programmes from the Association of American Railroads and other agencies that predict the lateral stability, curving performance, vehicle response as a function of speed, truck and vehicle geometry, and spring and damper rates, will be used for comparison with results obtainable experimentally on the full scale simulators. They are available to industry as design tools.

In House Projects

Various projects dealing with the development of novel equipment and instrumentation and techniques are presently underway. The following are worthy of remembrance.

Speed and Distance Measuring Transducer. A transducer to measure absolute and relative movements of wheels over rail has been developed. Two sensors, a known distance apart, measure the inherent magnetic surface noise of wheel and rail. These two signals are cross-correlated to produce a frequency proportional to the speed of the surface of wheel and rail. Integration of the frequency results is a measure of distance. The accuracy is high and is determined mainly by the precision by which the distance between sensors can be defined. Another type of transducer, measuring the same parameters and similar in basic arrangement to the one described above, is being developed. Instead of reading magnetic surface noise, an active write-and-read process is being employed. Both these instruments are patent pending.

Instrumented Locomotive Wheelset. This wheelset, capable of measuring lateral and vertical rail/wheel forces on a continuous and sampled basis respectively, has been built for Transport Canada. The forces are measured by means of strain gauges attached to carefully selected places on the wheel disc. Four separate radio telemetry channels are used to bring out the signal from the measuring bridges on the rotating wheelset. Extensive tests have been carried out to determine the performance characteristics of the measuring system.

Selft-Steering Trucks. Conventional trucks usually possess two axles which are parallel to each other at all times. When a curve is negotiated, the longitudinal axes of the axles cannot be oriented towards the apex of the curve. To minimize wear of both wheel and rail, the axles must be allowed to orient themselves radially to the curve. A truck, which can permit this ale geometry in curves, is called a "self-steering truck". Commercially available self-steering trucks are being tested and compared with the traditional trucks in collaboration with others. Certain in house experiments are also being contemplated.

Independently Rotating Wheelsets. The conventional wheelset consists of two wheels pressed firmly on a common axle, having two outboard plain or roller bearings. Large tangential (creep) forces, developed between the wheel and rail, are beneficial on tangent tracks and in gentle curves for steering and centering. Yet, these forces greatly intensify wear of both wheel and rail and cause energy loss in tight curves.

A wheel system in which one or both wheels are not rigidly fixed to the axle would give a good performance in curves, by virtually eliminating the longitudinal component of the tangential force at the wheel/rail interface, resulting in reduced tread and flange wear. However, independently rotating wheel sets deprive the truck of the self-centering capability on tangent track. A promising solution in this instance would be a torsional clutch between the wheels which would provide a controllable threshold torque such that free-wheeling is assured in tight curves, without losing the centering capability benefits of a "solid" wheelset on tangent track. At present, a mathematical model has been developed to establish the performance of such a wheelset.

Snow-free Track Switches. The Laboratory has installed two snow/ice-free track switches provided by Laboratories in the Mechanical Engineering Division. The standard split track railway switches used in North America and in Europe differ slightly in detail design, but all of them suffer under the winter conditions. A failure occurs when a switch is unable to complete a long compressive closure of the moving point of the rail against the stationary stock rail. Even small amounts of snow or ice that have gathered between these rails can be swept up and compressed so that completion of the switch transfer is prevented.

To eliminate manual cleaning or costly thermal or penumatic switch protection devices, two alternative switch designs have been developed. One is a horizontal stub switch, designed by the Low Temperature Laboratory, and the other, a switch with vertically positioned points designed by the Manufacturing Technology Centre, both of which shear any ice and snow build up rather than compressing it between switch point and stock rail.

CONCLUSIONS

The Railway Laboratory of the National Research Council of Canada is uniquely placed as an impartial arbiter between government and non-government agencies, customer and operator, and between academic and practitioner in the operation of Canadian freight and passenger rail services.

With the facilities at hand and those proposed, it is able to respond to the requests of Canadian industry for assistance in dynamic behaviour assessment and improvement, as well as strength testing of the existing equipment and prototype designs to meet governing specifications and standards. Also, the Laboratory is capable of carrying out in-house research and development work on novel railway methods and equipment in perceived problem areas, and to provide facilities and research for rail supporting industries.

For the foreseeable future, the rail freight transportation system is essential to Canada's well being. With determination and investment, passenger trains could become once again attractive and economic.

REFERENCES

1. Anom., SUMMARY OF ACCIDENTS — INCIDENTS REPORTED TO THE CANADIAN TRANSPORT COMMISION, YEAR 1980, Safety and Services Branch, Canadian Transport Commission, Ottawa, 1981, 115 p.
2. Brochu, Michel, NRC IS ON THE RIGHT TRACK. RAILWAY RESEARCH, Science Dimension, Vol. 12, No. 3, 1980, pp. 6-11.
3. Connock, S.H.G., C.A.M. Smith, F.B. Blader, RAILWAY LABORATORY TRANSPORTATION, Division of Mechanical Engineering, National Research Council of Canada, Vol. 7, No. 3, September 1975, 4 p.
4. Francis, John, THE NEXT GOLDEN AGE OF TRAINS, Quest, Vol. 10, No. 3, May 1981, pp. 10-23.
5. Smith, C.A.M., E.H. Bowler, FACILITIES AT NRCC FOR THE RAILWAY VEHICLE DESIGNER, Proceedings, Fifth Symposium Engineering Applications of Mechanics, University of Ottawa, 16th and 17th June 1980, pp. 255-258.

L. I. KAWERNINSKI, P. Eng.*

PRZEJŚCIE PÓŁNOCNO-ZACHODNIE KANADYJSKIEGO ARKTYKU

Raport ten został napisany w roku 1969, na pokładzie kanadyjskiego lodołamacza C.C.G.S. John A. MacDonald, po przejściu w obie strony cieśnin i kanałów Arktyku Kanadyjskiego z zachodu na wschód i ze wschodu na zachód.

S.S. Manhattan jeden z dużych tankowców amerykańskich o wyporności 143,000 ton, długości 1,605 stóp, szerokości 155 stóp, zanurzeniu 55 stóp i sile maszyn 43,000 H.P. postanowił udowodnić światu, że istnieje możliwość pokonania lodów, gór lodowych, mgieł i sztormów nowoczesną techniką marynistyczną, przez przejście przez Północną Drogę Arktyczną.

"Humble Oil" i inne firmy naftowe, które finansowały tę wyprawę, wydały 40 milionów dolarów na przerobienie "Manhattana" i przygotowanie go do tego historycznego przejścia, które było marzeniem odkrywców Arktyku w latach 1820-1850.

Franklin, McClurry czy Parry byli na tych morzach i nawigując na małych drewnianych, żaglowych statkach starali się odkryć przejście z Europy do Azji. Chcieli oni skrócić drogę i ominąć burzliwy i niebezpieczny Cape Horn.

---

*Arctic Passage specialist.

40 Years of Polish Engineering in Canada. Bul. APEC 3/81

Przesłanki tej wyprawy były wielocelowe, z punktu widzenia kanadyjskiego chodziło o rudę żelazną i inne surowce na Baffin Island, o gaz i ropę na Melville Island. Amerykanie szukali jak najbardziej ekonomicznego przewozu ropy z Alaski na wschodnie wybrzeże. A cały świat obserwował możliwości skrócenia drogi między Europą a Azją, co i w obecnych czasach jest ciągle bardzo aktualnym problemem.

W końcowej analizie jak przyjmiemy do wiadomości fakt, że siła maszyn tankowca rzędu "Manhattana" musi być zwiększona trzykrotnie i że należy ekonomię takiego przedsięwzięcia dokładnie rozważyć, to możemy stwierdzić z całą pewnością, że wyprawa "Manhattana" udowodniła światu możliwość nawigacji przez "Kanadyjską Drogę Arktyczną".

* * *

NORTHWEST PASSAGE
S.S. "MANHATTAN"

1. INTRODUCTION

The author was assigned to the C.C.G.S. "John A. MacDonald" as an observer during the "Manhattan's" maiden voyage through the Northwest Passage. The operation was divided into two parts. From July 9 to August 30, 1969, as a routine summer voyage, C.C.G.S. "John A. MacDonald" escorted various supply ships in the Arctic, acting as a supply icebreaker and giving assistance to ships in distress.

The second part of the duties from August 30 to the beginning of November 1969 was mainly concerned with escorting the S.S. "Manhattan" and giving assistance when required.

An attempt is made in this report to give a rather general picture of the ice conditions encountered during the voyage, the behaviour of S.S. "Manhattan" and C.C.G.S. "John A. MacDonald" when icebreaking, and finally, to submit the results of the experiments made.

The 16 m/m film made from 13 hours of closed circuit television tape and coloured slides of the whole journey are available for viewing.

2. THE NORTHWEST PASSAGE

The Canadian Arctic can be divided into two groups of islands, separated by a channel running east to west.

The Parry channel is divided into four sections: Lancaster Sound, Barrow Strait, Viscount Melville Sound and McClure Strait. The islands to the north are called Queen Elizabeth, to the south, District of Franklin.

The Northwest Passage is a navigation route; it starts at the entrance of Lancaster Sound and finishes at the southeast corner of the Beaufort Sea. Two navigational routes are through Prince Regent Inlet and Peel Sound. The third route (followed by Larsen in 1944) goes through Prince of Wales Strait; the west shores of Banks Island. Since the two first routes are shallow, only the third and fourth routes, suitable for deep draugt navigation, were considered for S.S. "Manhattan's" journey.

The fourth navigation route through the McClure Strait was attempted, but due to the heavy Arctic ice, was abandoned. Therefore, only one choice was left — route No. 3 — and passage was made from east to west and west to east through Prince of Wales Strait. The navigation through Parry Sound is hazardous, especially in Barrow Strait with its low lying land, the proximity of the magnetic pole and the large and heavy ice. The danger to navigation does not end there. Prince of Wales Strait, with its narrow entrance and high winds, packing, rafting and ridging the Arctic ice, is a difficult undertaking year round. The Beaufort Sea, with closing Arctic ice, currents and shallow spots in the MacKenzie estuary, adds additional requirements to the skills and experience of the ship's captain who will navigate these waters.

3. SEA ICE AND ITS PROPERTIES

The cooling of the sea surface is brought about by three processes: radiation, mixing, and evaporation. Subsequently ice formation will begin. The refining process during ice formation on the sea surface rejects most of the salt from the ice. Depending on the freezing rate, which usually is very rapid, certain amounts of the brine are trapped in the growing ice crystals.

The brine which remains in the sea ice makes it a very different material from pure ice. Consequently the physical and chemical properties of sea ice have to be examined before any conclusions on the forces connected with icebreaking of sea ice can be formulated.

Formation of sea ice begins with needles of ice which are called frasil ice. Progressive cooling makes the primary formation grow larger, fuse together and the sea surface takes on a greasy appearance. This stage is called grease ice. From grease ice we enter the phase of slush ice, then into shuga ice. The shuga ice solidifies into larger pieces of young ice called nilas. Nilas ice is extremely plastic; it bends easily on waves and when broken it gathers into larger pieces. The nilas ice is at maximum up to 5 inches in thickness and is dark in colour due to the high brine content on its surface. Due to winds and currents, nilas ice forms into round pieces 2 to 5 feet in diameter and is called pancake ice. Initial ice formation looks dark in colour, then after a period of time it turns grey and then white.

During the winter the young ice is gradually covered with snow and increases in thickness due to freezing. This new ice is broken by winds and currents, and the resulting pieces collide with and ride up over each other. This process is called rafting. At the end of the winter the new ice has reached 6-8 feet in thickness.

The ice formation which we encountered during our voyage can be divided into small floes, large floes, icefields and pack ice. Collisions which occur between these ice formations produce ridging.

During the summer months of the following year the first year ice will reject a lot of salt and become second year ice with lower salinity. Considerable melting which accurs during the summer months produces melt water which collects in pools on the irregular ice surface. It is this melting and freezing cycle which, over the years, makes the hummocky contours of the ice. This cyclic process, in a climate cold enough for the ice not to melt completely, produces second year ice, then multiyear ice which grows in thickness and hardness. It is not unusual to find floes of multiyear ice of 15 feet in thickness. When wind and currents start acting on the sea ice, pressure ridges develop. This was experienced during the voyage especially in the Prince of Wales Strait. These aged ridges are the most difficult barriers for any ship to penetrate((reaching up to 80 feet in thickness at some points).

Since the navigation route to the Northwest Passage passes through Davis Strait, some consideration has to be given to the glacier ice and icebergs. Glacier ice and icebergs differ from sea ice in form and properties. The water obtained through melting of glacier ice is very close to distilled water. The glaciers are formed from snow and the pressure of the upper layers of snow. Going through two stages of transformation (firm ice and bubble ice) it finally becomes blue glacier ice. The ends of glaciers falling into the sea form icebergs, which are carried from place to place by currents and winds. On our way we encountered icebergs from glaciers of Greenland

and Baffin Island. The Greenland icebergs move northward toward Baffin Bay and then joining the Baffin group they move southward. Sometimes as many as 500 icebergs were spotted on our radar screen within a 20 mile radius. Navigation through that mass of icebergs produces a high collision hazard especially for a large supertanker with limited manoeuvrability.

The need for an accurate estimate of sea ice strength is necessary for the design of icebreakers, or evaluating the performance of C.C.G.S. "John A. MacDonald" and S.S. "Manhattan" during the Northwest Passage.

The sea ice mechanical properties, which will be most helpful in evaluating icebreaking capabilities, can be reduced to the following measurements:

a) failure strength of the sea ice
b) Young's modulus of elasticity of the sea ice
c) Poisson's ratio
d) crushing strength for vertical or sloping surfaces (icebreaker bow).

Since the relationship between the temperature, the brine volume and mechanical properties listed above are established, the practical solution of the strength of sea ice can be evaluated by direct measurements.

The main variable controlling the strength of sea ice is vertical variation of the brine volume, which is determined by phase relationship of the ice temperature and salinity. When sea ice forms it is quite salty. The salinity decreases gradually with the brine; a vertical profile of the sea ice has a characteristic C shape. The sea ice salinity profile goes through systematic changes as the ice growth progresses, and is a function of the ice thickness. The strength of ice does not remain constant through the year. In the spring the strength distribution becomes more uniform in vertical profile. In the summer general decrease in ice strength takes place. During the autumn period the vertical profile shows a tendency to strength increase in the top layers with a general increase through the profile. During the winter the top layers of the Arctic ice are much harder than the middle and lower layers.

By measuring the temperature, the salinity and the ice thickness of the vertical profile, the strength of the sea ice can be determined.

Sea ice mechanical properties could be determined in several ways:

a) The ring tensile test: this test was developed for testing concrete and it has proven to be a very easy way for sea ice testing. A core 3" diameter is cut by a coring auger; a hole .5" in diameter is drilled in the core cylinder specimen. Then a core is cut to 3" in length and is compressed in a press. It fails under maximum tensile stress which occurs on the loading place at the inner radius. Young's modulus of elasticity and Poisson's ratio can be obtained by measuring the strains.
b) The Brazil test is very similar to the ring test except that a solid sample specimen is used. Since the critical tensile strength of the ice specimen is uniformly distributed, this test should be used in determining the failure strength of sea ice.
c) The beam test measures an upward force necessary to break the ice. A tongue of ice is cut in the floe by cutting slots through the ice on three sides. Then an upward or lifting pressure is applied until the tongue breaks.
d) Another type of test requires a load to be placed on the ice by pumping water into a tank mounted on an area of known size on the ice surface. The tank is filled with water until a fracture occurs on the ice surface.

During our journey only the temperature-salinity method to determine ice strength was used, though S.S. "Manhattan" ice parties performed other tests.

4. ICEBREAKERS AND ICEBREAKING CONSIDERATIONS

The icebreaking during the Northwest Passage could be divided into 3 parts:

a) Proceeding under normal ice conditions which represent nearly uniform ice cover.
b) Charging heavy ice characterized by ridging and hummocking which the majority of the time were under pressure
c) Proceeding through broken ice in the wake of S.S. "Manhattan".

Icebreaker performance in the ice depends on shape and strength of the hull (especially bow section), the output of the power unit and on special equipment which will increase the efficiency of the ship when breaking the ice.

Ice resistance to the icebreaker and its motion through the ice would depend on several factors:

a) The width of the ice being broken
b) Strength of the ice
c) Thickness of the ice
d) Friction between hull and ice or ice covered with snow
e) Length, breadth, draft of the ship
f) Ice waterplane coefficient
g) Ice waterplane coefficient of the bow
h) The angle of the bow entering the ice waterline
i) Ship's speed
j) Relative course to the existing wind and current
k) The wind force and current speed.

Since we cannot alter the ice conditions or weather, fitting the ship parameters for the best icebreaking capabilities should be of prime consideration during the desing stage of the icebreaker.

When the ship or icebreaker proceeds through ice, the icebreaking is achieved by the bending force with the accompanying shearing and crushing forces exerted on the ice.

The ship parameters (listed above), by their increase, will cause an increase of ice resistance. The total effect of the ship parameters on the value of ice resistance is in the order of 20-30% of the total resistance (including the ice and weather parameters).

The icebreaker proceeding through the solid ice rides with its bow into several parts which are ejected onto the ice, which at first is cut with the ice knife portion of the bow. Then, through forward motions, the icebreaker, trimmed by the stern, increases the area of the hull side coming into contact with the ice and the ice breaks by bending. Floes are formed on each side of the bow. The breaking takes place in different parts of the hull, predominantly in the forward section. The breaking is characterized by cracking, which develops slightly ahead of the ship, cracks running in all directions. In the case of C.C.G.S. "John A. MacDonald" the cracks were running first radically and then circumferentially. The ice floe adjacent to the hull submerges and the pattern is repeated as the ship goes ahead.

During the submergence the floe breaks into several parts which are ejected onto the unbroken ice or which fill the space between the hull and the edge of unbroken ice.

The friction, which is one of the main parameters in icebreaking, comes into consideration here. The friction forces are proportional to the ice pressure and to the fall of temperature and have to be included in calculations of ice resistance components. The friction coefficient between steel hull and sea ice approaches the value of steel on steel. Ice with a snow cover has the highest coefficient of friction. On the other hand, wet ice or ice mixed with water has the lowest coefficient.

It was observed by the author on October 13, 1969, during the journey on the C.C.G.S. "Louis S. St. Laurent" between Melville Island and Resolute Bay, that the pattern of icebreaking was somehow different. The ice was 2 years old, a very large uniform floe, coverage 10/10, thickness between 3 and 4 feet. The ship's speed was about 8-10 knots. Radial cracks in the ice were predominant ahead of the ship. Suddenly a straight single crack appeared, running for at least one mile, and enlarging as we were proceeding. No more radial cracks were observed. At that time C.C.G.S. "Louis S. St. Laurent" was acting as a wedge, without a crushing force being present.

Icebreakers can be divided into 3 classes:

a) Polar icebreaker with a power of over 12,000 H.P.
b) Non polar (average) from 6,000-10,000 H.P.
c) Harbour (auxiliary) below 6,000 H.P.

The length of the hull of the majority of icebreakers varies between 160-380 feet, breadth 45 feet to 80 feet. Displacement is usually between 2,000-16,000 tons. Regardless of dimensions, the hull form of the majority of icebreakers is relatively similar. The angle of the flare at midship waterline is 17° — 20°. The ratio, length to breadth, varies between 3.5 — 4.8, the ratio breadth to draft between 2.4 — 3.00. The power output per unit of displacement is also relatively similar. The deep draft of icebreakers allows for installation of large propellers and at the same time offers certain protection for propellers and rudders.

The parameters which directly improve the icebreaking capabilities include the angle of the flare at the midship section of the waterline and the angle and the shape of the bow especially at the waterline. By increasing these angles we will increase the vertical force acting on the ice. Compression (crushing) force of the bow and resulting finer ice crushing are very important. Therefore some compromise must be established. Convex frames in the bow, with a smaller angle of flare in the bow section, are predominant in Canadian icebreakers. In this way some of the penetrating force of the icebreaker in the ice is lost, while an increase of the crushing force is achieved.

Stability considerations when the ship is riding high on the ice are of prime importance, so the compromise between finer vertical shape and fuller convex shape of the bow must be carefully chosen. The transition of the vertical portion of the bow into an icebreaking angle (about 30°) should be rounded and smooth. This will also lessen instability of a ship when riding high on the ice.

The icebreaker which operates to a large extent astern, especially during ice charging operations, should have the stern form similar to the bow. The ice entrance angle should be similar to the bow form. Propeller diameters, the stern arrangement and also the position of the L.C.B. slightly ahead of amidships, govern the degree of this similarity.

Heeling and trimming tanks are other features which are incorporated in icebreaker construction. This will require a large bilge radius and a high freeboard, so that 20 degrees list can be achieved before the deck becomes awash.

The role of a helicopter cannot be omitted in modern icebreaking operations. Its primary role is ice reconnaissance and finding the easiest way through the ridges and floes. Therefore, a suitable landing platform and a hangar have to be included in the icebreaker design.

5. INSTRUMENTATION

C.C.G.S. "John A. MacDonald" was instrumented to simultaneously record the following: torque and R.P.M. on 3 shafts, motions of the ship, bow acceleration and bending stresses at midship. Closed circuit television was installed to give full coverage of "Manhattan's" performance in ice, as well as an additional camera looking downwards at the bow of C.C.G.S. "John A. MacDonald" to assess icebreaking capabilities of the ship.

Torque and R.P.M. were measured by "Maihak Rings" and recorded on a strip chart recorder. A gyro stabilized platform measured 3 angular displacements and 3 linear accelerations and was located between the midship and stern of the ship.

TABULATED RESULTS FROM EXPERIMENTS

Date Time	Shaft	Increase in Torque	Duration of Increase	Horizontal Accel. + Deaccl. -	Vertical Accelerat. Bow Up + Bow Dw -	Vertical Accelerat. Aft.	Bending Stress At Midship Compr + Tens -	Pitch Bow Up Bow Dw -	Roll	Ice Core No.	Dist. Betw. Cores	Ice Strength Max.	Ice Strength Min.	Ice Thickness
		%	Sec.	ft/sec^2	ft/sec^2	ft/sec^2	lbs/inch^2	Degrees	Degrees		ft	kg/cm^2	kg/cm^2	cm
Normal condition average				± 1.25	± 2.57	± 1.54	± 55	-	-		in	4-5 ft ice		
Oct 1 1515	Port	61.1	1.5	± 3.76	+14.16 - 5.15	± 6.43	+ 364	+ .4	±1°	Sept 30 1	500	7.17	2.19	372
Oct 1 1520	Stbd.	24.0	2.0	± 2.77 - 2.51	+16.09 - 9.65	± 2.57	+ 725	- 1.64	-	2	200	7.23	3.29	405
Oct 2 1610	Port	42.6	3.0	± 3.89	+12.87 - 5.15	± 8.37	+ 255	± .66	±1°	1	250	6.52	3.35	146
Oct 2 1611	Port	64.8	3.0	± 1.64	+ 6.43 - 9.65	± 5.53	± 182	± .2	-	2	165	6.70	3.39	309
Oct 2 1615	Centre	38.9	1.0	± 2.51	± 6.43	± 4.50	+ 182 - 73	± .6	-	3	210	7.37	3.24	197
Oct 2 1618	Stbd.	50.9	3.0	± 3.38	+14.16 - 5.15	± 5.15	+ 255	+ 1.56	-					
Oct 2 1620	Port	23.2	2.0	± 3.15	± 5.79	± 3.47	+ 182 - 173	-	-					
Oct 3 1615	Port	56.0	1.6	± 3.76	+ 8.36 - 4.50	± 5.15	+ 291 - 73	± .27	-	1 2 3	300 210 100	7.25 6.26 7.25	3.41 3.39 3.41	227 147 116
Oct 5 0800	Centre	-	-	± 3.76	+ 8.37 - 5.79	± 6.43	+ 182 - 73	± .6	-	1	480	6.41	3.52	208
Oct 5 0802	Port	86	1.8	± 5.66	+ 9.01 - 3.86	± 5.15	+ 255 - 73	± .27	±1.0	2	150	6.59	2.75	471
Oct 5 0802	Port	55	1.7	± 3.76	± 4.5	± 6.43	± 146	± .23	-	3	200	5.78	2.10	123
Oct 5 1605	Centre	6.3	1.6	± 3.15	+ 3.22 - 6.44	± 5.79	± 91	± .2	± .63		480 150 200	6.41 6.59 5.78	3.52 2.75 2.10	208 471 123
Oct 5 1607	Port	14.5	3	± 1.25	+13.51 - 6.44	± 5.15	+ 146 - 55	.4	-					
Oct 5 1608	Port	39.3	2	+ 1.38 - 5.02	+10.30 - 3.88	± 6.43	+ 255 - 73	+ 1.56	± 3.6 Heeling tanks					
Oct 6 0825	Centre	-	-	± 3.15	± 5.15	± 4.89	± 127	+ .4	-	as Oct 5	480 150 200	6.41 6.59 5.78	3.52 2.75 2.10	208 471 123
Oct 6 0830	Port	63.7	2	± 5.02	+ 6.43 - 5.15	± 3.86	+ 146 - 73	± .4	± .9					
Oct 7 0830	Centre	-	-	± 4.54	± 5.79	± 4.50	± 91	± .2	± .6	as Oct 5	480 150 200	6.41 6.59 5.78	3.52 2.75 2.10	208 471 123
Oct 7 0832	Port	45.8	2.3	± 1.99	± 4.83	± 4.38	± 91	± .2	± .4					
Oct 9 1520	Port	41	1.0	not meas.	± 3.22	± 3.99	± 55	Not meas	Not m	1 2 3	300 200 200	7.58 7.47 7.41	3.52 2.75 2.10	132 201 180
Oct 9 1522	Port	16	2.0	not meas.	± 5.79	± 3.99	+ 182	Not meas	Not m					
Oct 11 1331	Port	57.8	2.0	± 5.66	+14.8 -10.9	± 7.08	+ 291 - 78	± .4	± .4	1 2 3	300 200 190	7.24 5.75 7.23	3.07 2.66 2.89	155 46 188
Oct 11 1332	Port	25.6	1.2	± 5.02	+ 9.65 - 5.15	± 4.50	+ 146	± .2	± .4					
Oct 12 1445	Port	30.2	1.3	± 4.28	+10.94 - 7.08	± 3.86	+ 218 - 109	± .2	± .6	1 2	250 300	7.57 6.63	4.01 3.48	149 208
Oct 12 1446	Port	30.2	.9	± 3.15	± 6.43	± 5.15	+ 218 - 109	± .4	± .7					

Table 1

One vertical accelerometer was located on the bow of the ship to measure the bow acceleration.

Electric strain gauges were located at midship to measure bending stresses.

Very similar instrumentation was installed on S.S. "Manhattan" but with a larger number of sensing strain gauges and accelerometers.

Apart from shipborne instrumentation, special ice testing instruments were used to measure the ice strength, salinity and temperature.

Some measurements are presented in tabulated form in Table 1.

Description (narrative) of experiments is given below.

NOTES MADE DURING THE EXPERIMENTS

Sept. 29, Time 1,600 hrs., Melville Sound

The ice party drilled two holes and marked them with flags for ice testing. The thickness of the ice is 7.4 ft. and 14 ft., the maximum strength 7.54 kg/cm^2 and minimum strength 3.31 kg/cm^2, see Figure 3. The ship is moving astern and is approximately 500 feet from the first flag. Ahead of us is a solid large floe of ice (multiyear). The broken areas of the ice are off to portside at a distance of ½ mile. Engines are going full ahead now. The ship is gathering headway slightly to port and is aiming for the flags. We are going ahead approximately 3½ knots coming up to 4 knots. Hitting a few larger pieces of ice between us and the main section of the floe. We are now on the floe itself aiming straight for the two flags. The bow climbed the floe very hard indeed and swung off to port. We come to a stop with engines working full ahead, with the first flag approximately 12 feet on the starboard bow. All cracking occurred to port and the bow payed off very much to port. The blue multiyear ice can be seen as we start to go astern. The puddling is quite pronounced; it is fairly large and deep. On the top of the puddles we have new ice about 1 ft. in thickness. We went ahead about 150 feet into the ice in the first charge. The ship is stopped about 500 feet from the floe and we are starting to go ahead again. The ship is still off to port. Ahead of us is 300 ft. of water and broken ice. Coming up to speed again approximately 4 knots. There is a good swing to starboard, which should take us to the right of the first flag. The bow has now hit the floe. We make a sharp climb, about 2 ft., and break up a very large section of the ice, the largest I have seen us break. The first flag is down. The piece of the floe that is broken is now going down the starboard side. The bow of the ship is now in the puddle between the two flags. The ship is stopped with the engines working full ahead. We must have done another 150 ft. in this charge — total 300 ft. The ice is very thick, between 12-15 ft. on the starboard side. There are tremendous areas of broken ice tilted 30-40°. The engines are stopped and starting to go astern. The big pieces of ice are slowly moving and settling back. We have backed away now. We can see how far we dug into the ice; we were abeam of the second flag. The large piece of the floe which we have broken is easily 70 ft. across, probably 50 ft. in length; once again the multiyear colour. One of the pieces lying ahead came from the puddle area and I would say it is approximately 7-8 ft. in thickness. In the third charge with a speed of 4 knots climbing and grinding we went past the second flag.

Oct. 2, Time 1610 hrs., Melville Sound

Three holes marked with flags were drilled by the ice party. The first two flags are 160 ft. apart. Between flag two and flag three the distance is 210 ft. The thickness of ice is 4.8, 10.1 and 6.5 ft. respectively, the strength varies between 7.37 kg/cm^2 to 3.24 kg/cm^2.

Table 2

ICE AND SNOW CONDITIONS DURING EXPERIMENTS

Date	Ice Coverage	New Ice	Second Year Ice	Multiyear Ice	Ridging Hammocking	Snow Coverage Thickness	Ship Speed Est. knots	Ship Speed Meas. knots	Air Temp. F	Wind Force knots	Remarks
Oct 1	9/10	—	6/10	3/10	40%	—	6-8	—	24	10	Hitting large pieces of broken ice. Following in the wake of "Manhattan".
Oct 2	10/10	1/10	1/10	8/10	50%	3"	6½ #1 2½ #2 4½ #3	— — —	26	8	Speed estimated at each charge
Oct 3	10/19	—	1/10	9/10	20%	100% 2"-7"	6½ #1 4½ #2	11.7 #1 6.4 #2	27	7	
Oct 5 0800	10/10	1/10	1/10	8/10			4 #1 4 #2	3.77 4.23	35	16	
Oct 5	10/10	1/10	1/10	8/10	100%				31	18	
Oct 6	10/10	1/10	—	9/10	40%	100% 7"	5-6	—	29	25	
Oct 7	10/10	1/10	2/10	7/10	40%	100% 3"	6-7	—	25	15	
Oct 9	10/10	1/10	1/10	8/10	50%	100% 2"-3" drifts 8"	6 #1 4 #2	—	24	7	
Oct 11	9/10	6/10	1/10	2/10	50%	100% 2" drifts 8"	6	3.7 5.9	22	L/AIR	
Oct 12	9/10	6/10	1/10	2/10	60%	100% 3"	5 #1 6 #2	—	22	27	

We are backing into the channel made earlier this forenoon by S.S. "Manhattan", to reach our position for the experiment 600 ft. away from the first flag. Down in the engine room the alarm will be sounded as we pass abeam of the flags. The way is off the ship now. She is swinging to starboard. As the engines are working full ahead, there is quite a bit of vibration and shuddering in the ship due to the damaged starboard propeller. We are coming to a speed of 5 knots, the ice ahead of the experimental area is softer and thinner, no problem for C.C.G.S. "John A. MacDonald". Coming now to the new pressure ridge about 5 ft. high, cutting it practically head on. Speed of the ship is 4 knots. We are working hard through this ridge, the bow of the ship rising and sinking. Layers of new ice can be seen on top of the multiyear ice. The ship is grinding through, slowly coming to a stop with engines full ahead. We have gone through the ridge, but find ourselves in the experimental area in thick ice. The engines are working astern. In the last run a large crack in the ice developed on our portside. We went approximately 400 ft. astern and once more the engines are working ahead, ship aiming for the three flags. Suddenly the ship is swinging to starboard in a hummocky area of the ice. Even with the built up speed of 4 knots, the ship comes to a halt in ice estimated 14 ft. in thickness. Again we go astern, trying to back up as far as possible, to make a long run. Now we are 600 ft. away from our first flag. The speed of the ship is building gradually, we are doing 6½ knots. There is a good swing to port. We are abeam of the first flag, ship is slowing down, coming to a stop. In spite of the swing we had to port, the bow still ended up to starboard. Going astern, trying to take another run, distance to first flag 600 ft., ship building up speed coming to 5 knots. The first flag coming down on the starboard side. We are approaching the second flag very rapidly. The bow is bounding back and forth. Ice is breaking up on our starboard bow. We went approximately 20 ft. past our second flag and the ship comes to a stop, with engines working full ahead. The ship is going astern and trying once more to charge the experimental area marked with the third flag. Coming up to 4½ knots, with a slight swing to port. Passing the third flag we cut through the last section of ice very nicely. In our wake there are parts of multiyear ice, quite thick 8-10 ft., which are showing pronouncedly, forcing their way through the newer softer ice and ridging it.

6. S.S. "Manhattan"

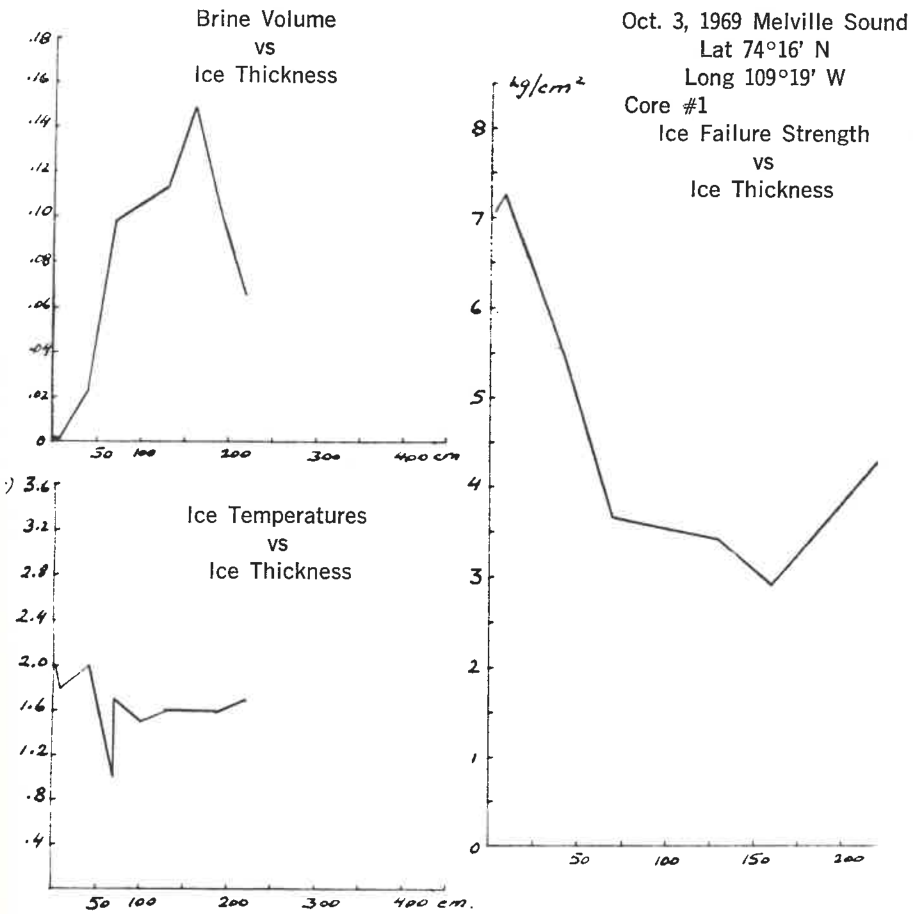
The "Manhattan" was designed to transport oil from the Persian Gulf to the United States. She was built at Bethlehem Steel's Shipyards in Quincy, Massachusetts in 1962.

"Manhattan's" Principal Dimensions

	Original	After Conversion
Length Overall	940'6"	1005'6"
Breadth	132'0"	155'0"
Depth	67'6"	67'6"
Draft	50'4¼"	52'0"
D.W.T.	43,000	43,000
S.H.P.	115,000	124,000 tons

In 1969 she underwent an extensive refitting in four different drydocks. The conversion consisted of building a new bow section for icebreaking duties, fitting a new heavy ice belt along each side, internally strengthening the stern section, and fitting 2 propellers, propeller shafts and external rudder protection.

ICE ANALYSIS DURING EXPERIMENTS


Brine Volume
vs
Ice Thickness

Ice Temperatures
vs
Ice Thickness

Oct. 3, 1969 Melville Sound
Lat 74°16' N
Long 109°19' W
Core #1
Ice Failure Strength
vs
Ice Thickness

S.S. "Manhattan's" new bow was MIT ((Wilson) M type Mk 13 with an 18° and 30° bow angle, built with 2½" steel to withstand pressures of 3,500 lbs/inch².

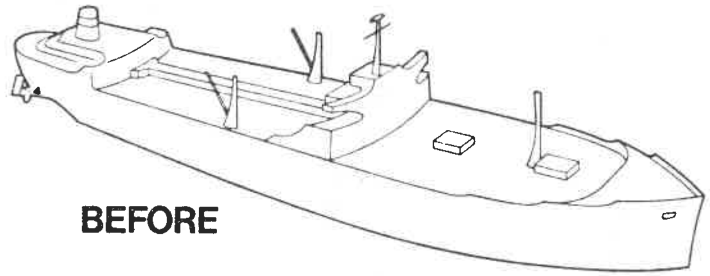
An ice belt was fitted on both sides of the ship from the new bow section to the after section; the width of the belt was 20 feet, projecting approximately 9 feet at its upper edge and 8 inches at its lower edge; the ice belt plating was 1¼" steel.

"Manhattan's" new high strength propellers were five-bladed, 23 ft. in diameter and weighed 70,200 lbs. each. The twin rudders were floating rudders. A metal pad was fitted between their upper edges and the hull to prevent ice jamming.

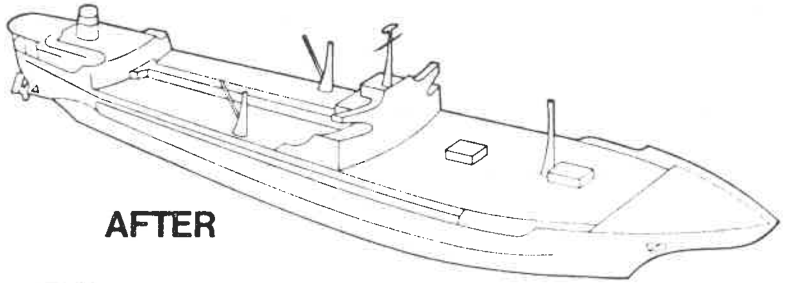
Overall performance of "Manhattan" was good; all objectives of the full scale trials were met. The operational feasibility of Arctic crossing was demonstrated and immense research data was collected to help in establishing design criteria for new icebreaking tankers.

The relationship between horsepower vs speed vs ice thicknes was evaluated. Side friction and pressure in ice and snow covered ice were experienced and analysed. The manoeuvrability of a parallel sided, long vessel was established.

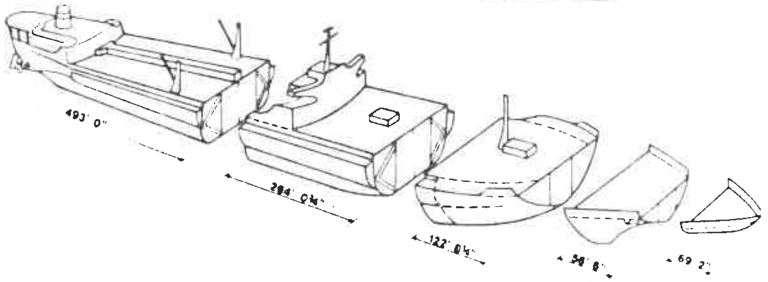
"Manhattan" itself was a well built vessel and performed her unique role exceedingly well.



BEFORE



AFTER

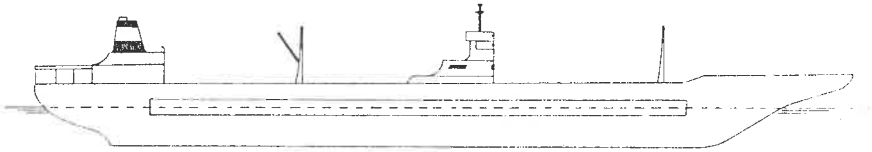


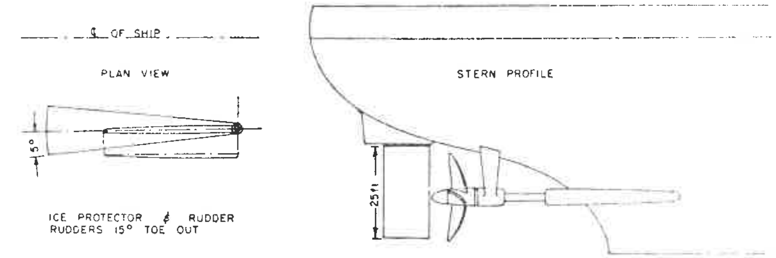
7. FINAL OBSERVATIONS

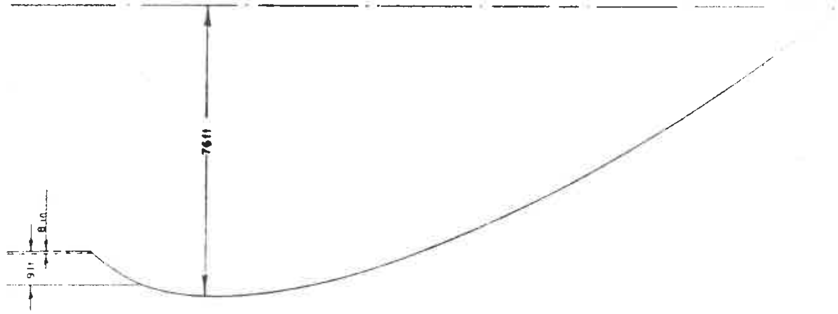
The feasibility of navigating large high-powered icebreaking tankers through the Northwest Passage exists and has been proven (at least during summer months) by the voyage of the S.S. "Manhattan".

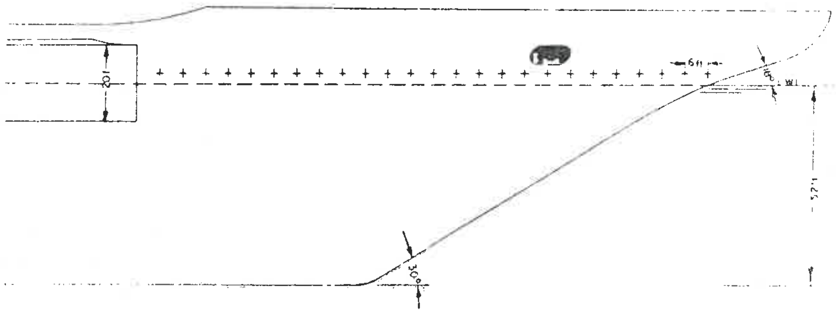
The only ice which stopped the S.S. "Manhattan" was multiyear ice, which in thickness exceeded 12 feet. There were a few exceptions, but the real problems were either inexperience of the bridge personnel in assessing the ice thickness and speed of advance of the ship or in recognizing the ice configurations and ice age. The fresh ridging, even up to 30 feet in thickness, was no problem for the S.S. "Manhattan", as was seen during the westerly passage through the Prince of Wales Strait. As a matter of fact, it seems to be the easiest way through the floes for a ship of "Manhattan's" size. On the other hand, the multiyear feathered ridging is the worst possible barrier. Unfortunately, the recognition of ridging from the ship's bridge is rather difficult. It is the opinion of the author that the S.S. "Manhattan" holed itself during the passage of the Prince of Wales Strait when, steaming confidently through new ridging, it suddenly hit an old weathered ridge.

S S MANHATTAN









The Wilson bow design was working very efficiently in the cutting mode; the stem angle was working as a knife edge but the bow shoulders were too far forward with a fine vertical angle, which resulted in poor ice crushing performance. The S.S. "Manhattan" had to repeatedly charge the same ice floe before ice crushing occurred.

As could be assessed from discussions with "Manhattan" scientific groups, the longitudinal hull stresses under severe icebreaking conditions were negligible compared with open water (storm condition) longitudinal stresses. The same conclusions could be drawn from the C.C.G.S. "John A. MacDonald's" performance.

The heeling tank system of supertankers operating in Arctic ice is of prime importance. Quick transfer of water ballast from one side to another with a rolling angle of at least 10° should be considered. From observations, this system was not working too efficiently on board the S.S. "Manhattan"; it is one of the reasons why the C.C.G.S. "John A. MacDonald" was called 26 times through the journey for assistance in freeing S.S. "Manhattan".

The bland form of the stern and the protrusions of the ice belts caused great difficulty in manoeuvring astern. Otherwise the manoeuvrability of the S.S. "Manhattan" in ice was excellent.

Double bottom and double side tanks should be included in design criteria of all future supertankers. The possibility of collision with icebergs and damage to underwater parts should be avoided at all costs to prevent catastrofic pollution of the Arctic.

The high strength propellers, shafts and rudders operated without sustaining any damage on the S.S. "Manhattan", but the C.C.G.S. "John A. MacDonald" lost two blades from the starboard propeller.

From discussions with "Manhattan" scientific personnel, it seems that maximum torques with propellers working in ice were in the order of 50% design considerations.

Navigation with the help of radar and helicopter ice reconnaissance during daylight is no problem. During darkness the help of a large radar screen, very powerful searchlights and an efficient bridge personnel make night navigation quite feasible. The training of supertanker officers and men, in Arctic navigation, seamanship and the art of icebreaking, is of prime importance.

In navigation through the Canadian Arctic, "brute force" is most important. The S.S. "Manhattan" was definitely underpowered for this kind of venture. Consideration should be given to increasing the power by at least 300%. A ship the size of "Manhattan" should have at least 150,000 H.P. for year round navigation through the Northwest Passage.

Ships which are designed for open sea use have strength and power for only a few inches of ice. To equip them for icebreaking they need not only thicker plating in the bow and ice belt and additional power. but stronger propellers and rudders and a different form of bow, plus a much better ability to go astern than is ordinarily required. It is not hard to foresee, therefore, that the capital cost of icebreaking ships will be increased enormously as the thickness of ice which they are designed to break increases, since the thrust required goes up as the square of ice thickness to be penetrated and the required power goes up at an even higher rate.

There may well be better methods of icebreaking, where ingenuity and science are substituted for "brute force", such as sawing of ice, providing good ice flow around hulls, investigation of lasers as ice cutting devices or use of hovercraft designs for icebreaker bows.

ERYK KOSKO*

LES COURS DE GENIE AERONAUTIQUE DONNES PAR DES PROFESSEURS POLONAIS A L'ECOLE POLYTECHNIQUE DE MONTREAL

L'ouverture solennelle de l'année académique à l'Université de Montréal commençait par une messe d'invocation au Saint Esprit, suivie d'une procession du corps enseignant qui prêtait un serment de fidélité à l'Église et aux lois universitaires. La cérémonie d'octobre 1943 différait des précédentes par la présence inattendue d'un groupe de Polonais qui avaient offert leurs services aux autorités scolaires du Québec.

Pour mieux comprendre la chose, il faut se mettre en Pologne au début de la guerre de 1939. Dès les premières hostilités il était clair que l'armée polonaise ne pourrait tenir tête à l'assaut combiné des forces de Hitler et de Staline. Le gouvernement polonais, ayant à peine mobilisé ses ressources militaires et industrielles, essayait, dans sa retraite, de sauver ce qui était possible de ses effectifs dans le but de les regrouper à l'étranger et servir les puissances alliées — France et Grande Bretagne — pour continuer la lutte. Ainsi, en même temps que le général Sikorski formait en France un gouvernement-en-exil et reconstruisait l'armée et l'aviation polonaises, de nombreux ingénieurs, techniciens et ouvriers spécialisés se mettaient à l'ouvrage dans les chantiers et usines de ce pays. Malheureusement, cela ne dura que jusqu'à une nouvelle débâcle et une nouvelle évacuation — cette fois vers la Grande Bretagne.

De son côté, le Canada n'était guère préparé, au début de la guerre, à jouer le rôle qui lui échouait, celui de fournir aux armées alliées une base de ravitaillement, non seulement en vivres, mais surtout en munitions et en équipement militaire. Ainsi l'industrie aéronautique d'avant-guerre n'était capable de produire que des avions du type "bush plane", et cela en petit nombre. Il fallut un grand effort pour organiser la production en masse d'avions militaires de construction britannique ou américaine. De plus, une pénurie de main d'oeuvre qualifiée se faisait sentir.

Dans ces circonstances, Victor Podoski, Consul Général de Pologne à Ottawa, suggère au ministre des munitions C. D. Howe l'idée de faire venir du personnel technique qui se trouvait en Angleterre. Un accord fut signé entre les deux gouvernements et peu à peu un total de plus de 500 personnes furent admises au Canada "pour la durée des hostilités". Ces gens — qu'il serait faux de nommer des réfugiés — se mirent rapidement au travail, animés d'un enthousiasme engendré par l'espoir d'une victoire finale sur l'ennemi commun, qui leur permettrait de regagner leur patrie libérée. Ils ne s'attendaient pas à voir cet espoir déçu par les accords de Téhéran et de Yalta.

Ce n'était pas que le Canada ait totalement manqué de personnel qualifié en aviation ou en construction aéronautique. Au contraire, ce pays a toujours pris part au progrès dans ces domaines, maintenant une tradition qui remonte aux recherches d'Alexandre Graham Bell et à son Aerial Experiment Association en Nouvelle Écosse; c'est là qu'eut lieu le premier vol à moteur dans l'Empire Britannique, accompli par un sujet de Sa Majesté dans la persone de J. D. McCurdy. On se rappelera les contributions de 'Casey' Baldwin, les expériences de W. R. Turnbull dans sa soufflerie

---

* Un des professeurs de nouvelle option "aéronautique".

de 1902, et bien d'autres. Ce fut enfin toute une génération de courageux “bush pilots”, successeurs modernes des coureurs des bois, qui ouvrit l'accès aux vastes régions du Nord. Quant à la formation des ingénieurs, l'Université de Toronto offrait des cours de génie aéronautique, de même qu'une quinzaine d'universités aux États-Unis.

Pour les francophones du Québec, la situation était bien différente. Les écoles d'ingénieurs, établies à Montréal (Polytechnique) et à Québec (Université Laval), se contentaient de pourvoir aux besoins les plus immédiats des travaux publics, des mines et de l'industrie de la Belle Province. Il n'était pas question d'aéronautique.

Au printemps de 1943, un des ingénieurs polonais, M. Gustave André Mokrzycki, entrevit la possibilité de remédier à cet état de choses. Ingénieur diplômé de la Polytechnique de Lwów et gradué de l'École Supérieure d'Aéronautique de Paris, il avait grandement contribué à l'organisation de l'enseignement aéronautique dans son pays natal; il avait été titulaire de la chaire de construction d'avions et de mécanique du vol à l'École Polytechnique de Varsovie et l'auteur d'un manuel relatif à ces sujets. Il s'entendit avec quelques-uns de ses confrères et s'assura leur coopération. Tout d'abord celle de M. Boleslaw Szczeniowski, ingénieur-mécanicien, spécialiste en machines thermiques, qui avait tenu un poste d'assistant-professeur à l'École Polytechnique de Varsovie, et depuis 1942 était attaché au personnel enseignant de Polytechnique à Montréal. Ensuite M. Joseph Pawlikowski, ingénieur-électricien de l'École Polytechnique de Saint-Pétersbourg, qui avait été chef de la section des instruments de vol à l'Institut Technique de l'Aviation Polonaise et chargé de cours à l'École Polytechnique de Varsovie. Ces deux derniers, ainsi que M. Alexandre Grzędzielski, possédaient le titre de docteur ès sciences techniques. Celui-ci, après avoir gagné de l'expérience comme constructeur d'avions, avait occupé le poste de chef du bureau de contrôle des constructions d'avions à l'Institut Technique de l'Aviation. Enfin, M. Eryk Kosko, ingénieur diplômé de l'Université Technique de Danzig (maintenant Gdańsk), s'était spécialisé dans les calculs de résistance des cellules d'avions. Grzędzielski et Kosko avaient donné des cours de résistance des structures d'avions à Polytechnique de Varsovie.

Ayant complété son équipe, Mokrzycki aborda le sujet avec M. Armand Circé, directeur de l'École Polytechnique, et lui soumit un plan d'études du génie aéronautique pour les élèves qui seraient intéressés. Les cours offerts par l'École comportaient cinq années d'études, dont les quatres premières donnaient une formation générale, plus ou moins commune à toutes les branches du génie. En cinquième année, quatre options (Travaux publics, Mécanique-Électricité, Mines-Métallurgie, et Chimie industrielle) permettaient une certaine spécialisation. Il ne serait donc pas difficile d'ajouter une nouvelle option “Aéronautique” à ce schéma. Les cinq professeurs polonais devaient former le noyau du corps enseignant cette option, avec l'assistance de quelques professeurs réguliers pour les sujets non aéronautiques.

Après discussion, ce plan fut favorablement reçu et obtint la sanction des autorités: Ministre de l'Instruction Publique de la Province et Recteur de l'Université de Montréal, dont l'École Polytechnique était, en fait, la Faculté des Sciences Appliquées. L'introduction de l'option aéronautique fut annoncée dans la presse quotidienne en automne 1943 en même temps que la nomination des nouveaux professeurs. Les journaux soulignaient l'importance de cette initiative, non seulement pour l'industrie de guerre, mais aussi en prévision du développment de l'aviation commerciale dans la période d'après-guerre.

Dans l'entretemps, les professeurs s'étaient hâtés de préparer les détails des cours dont ils étaient chargés, de décider des manuels et lectures à recommander aux élèves. L'année scolaire se composait de deux termes, chacun de 13 à 14 semaines. Au cours du deuxième terme de la cinquème année, l'élève devait non seulement suivre les conférences et exercices, mais encore préparer un travail de fin d'études (thèse et projet) qui occuperait une bonne partie de son temps. Vu ce temps si limité, l'exposition des sujets devait être concise à l'extrême. Les cours furent partagés entre les professeurs comme suit.

M. Mokrzycki se chargea de l'Aérodynamique et de la Mécanique du vol, précédés d'une introduction générale au génie aéronautique. Le docteur Szczeniowski s'occupa de Machines thermiques et de Moteurs d'aviation. Au docteur Pawlikowski échut un cours sur les Aéroports et un autre traitant de l'equipement des avions, y compris les instruments de bord; il contribua aussi au cours d'Électrotechnique, donné par d'autres professeurs, en y discutant de l'éclairage. M. Kosko donnait un cours sur la Construction et les Projets d'avion, et un autre sur les Structures d'avions et leur résistance; il conduisit aussi des séances de problèmes de structures d'avions. Des travaux pratiques simulant des exercices à l'usine furent dirigés par MM. Mokrzycki et Szczeniowski. Le docteur Grzędzielski s'occupa à préparer une liste de sujets à proposer pour travaux de fin d'études au choix des élèves; il allait servir de ses conseils et surveiller leur progrès. On organisa des visites des étudiants dans les usines aéronautiques de la région de Montréal. Avec le concours de la RCAF on put obtenir diverses pièces d'avion, des moteurs hors service, des hélices, etc. pour former une collection servant aux démonstrations; les coupes des moteurs avaient été soigneusement préparées par le personnel militaire. En dehors du groupe polonais, la direction avait engagé un ancien élève de Polytechnique, le docteur André Hone, pour enseigner un cours de Métallurgie des alliages légers.

En septembre 1943 sept étudiants se décidèrent à suivre l'option aéronautique. Bien que peu élevé, ce nombre se compare favorablement avec les inscriptions aux options Mines ou Chimie, qui ne comptaient que deux étudiants chacune. Les petites classes avaient l'avantage de permettre un rapport plus direct entre professeur et étudiants. L'année suivante l'option aéronautique fut prise par quatre étudiants seulement. Tous ces jeunes gens, qui firent partie de la 68-e et 69-e promotion de Polytechnique, n'eurent pas de difficulté à mettre à bon profit les connaissances acquises dans ces cours; la plupart trouva de l'emploi dans les industries aéronautiques de Montréal.

Le printemps de 1945 apporta des changements importants. La guerre en Europe étant terminée, l'industrie aéronautique dut réduire ses activités et son personnel. Les autorités de Polytechnique, sous un nouveau directeur, décidèrent de terminer l'option aéronautique. Le professeur Mokrzycki s'en alla en Californie chercher une meilleure fortune. Le docteur Grzędzielski allait s'établir comme instructeur au Laboratoire d'essais des matériaux à l'Université de Toronto. M. Kosko s'était engagé avec la compagnie Fairchild dans un projet d'avion en qualité de chef des calculs de résistance (chief stressman); mais il partageait son temps avec le Laboratoire d'Hydraulique, assistant le professeur Raymond Boucher dans certains travaux. Seuls les professeurs Pawlikowski et Szczeniowski, dont les intérêts ne se bornaient pas à l'aéronautique, allaient continuer leur association avec Polytechnique — ce dernier jusqu'à sa retraite.

Ce fut donc la fin d'une période d'activité généralement peu connue et qu'il nous a paru utile de rappeler à la mémoire. Il convient de mentionner que la coopération du groupe polonais avec les autorités et le personnel de Polytechnique s'effectua d'une façon particulièrement harmonieuse. La bonne grâce du directeur Circé et de son secrétaire M. Henri Gaudefroy, ainsi que le bienveillant accueil des collègues canadiens eurent vite mis les nouveau-venus à leur aise. Ceux-ci ne tardèrent pas de prendre part à la vie intellectuelle du Canada français. Plusieurs allaient présenter des abrégés de leurs travaux aux Congrès annuels de l'Association Canadienne-Française pour l'Avancement des Sciences (12-e Congrès en 1944 à Québec et 13-e en 1945 à Montréal). Les professeurs Pawlikowski et Szczeniowski devaient contribuer de nombreux articles à la Revue Trimestrielle Canadienne qui était l'organe scientifique de Polytechnique (elle devint plus tard la revue "L'Ingénieur").

JULIUS LUKASIEWICZ*

DEVELOPMENT OF FACILITIES FOR HIGH SPEED AERODYNAMICS IN CANADA

INTRODUCTORY NOTE

Efforts to develop high speed aerodynamic laboratories and test facilities started in Canada in the late 1940s and early 1950s at the Institute of Aerophysics, University of Toronto, at the National Research Council in Ottawa and at the Canadian Army Research and Development Establishment in Valcartier, Que. The decade which ended with the cancellation of the AVRO ARROW supersonic fighter project early in 1959 saw the peak of these activities; the present note gives a brief account of their history during that period, in the context of parallel developments in other countries. The author, as the first head of NRC's High Speed Aerodynamics Laboratory (until 1958), had intimate knowledge of developments at the NRC. For this reason, and because the NRC became responsible for the largest project ever undertaken in Canada in the field of high speed aerodynamic facilities, the history of the NRC contribution is treated in this note in much greater detail than the history of other initiatives.

In the historical account only the principal actors are mentioned. While it is not possible to list all other contributors, I would like to name my associates who played a major role in the design and development of the NRC's 5-ft wind tunnel. This group included D. B. Nazzer (mechanical design), P. Price (aerodynamic design), D. Long (5-ft pilot wind tunnel design), J. A. Tanner (valve controls), R. Westley (aerodynamic noise), N. B. Tucker (pilot tests), J. A. van der Bliek (instrumentation and aerodynamic design) and W. J. Rainbird, under whose direction the project was completed. Detailed design and supervision of construction were the responsibility of P. B. Dilworth, K. F. Tupper and their engineering teams. It is as a result of the efforts of this group that Canada operates today — mainly for the projects of other countries — a large, high performance transonic-supersonic wind tunnel.

HIGH SPEED AERONAUTICS IN CANADA AFTER 1945

Before World War II flight at velocities comparable or higher than the speed of sound in the atmosphere could be attained only with projectiles launched from powder-driven guns. In the final years of World Warr II new possibilities of achieving high speed flight emerged. High subsonic speeds were attained by propeller and jet aircraft, and by pulsed-ramjet missiles (V-1); supersonic speeds in excess of a Mach number of 4 (i.e., four times the speed of sound) were achieved by long range rockets (V-2, the first ballistic missile).

These impressive developments were much more advanced in Germany than in the Allied countries. After the landings in France in 1944, the German research effort in aircraft and missiles was extensively examined and found to promise attractive new vistas of development. Thus, when the war ended in 1945, the potential of high speed flight for military and civil applications was widely appreciated. The major western powers and the Soviet Union embarked on vigorous development of high

---

*Professor, Faculty of Engineering, Carleton University, Ottawa.

speed subsonic and supersonic aircraft, missiles, jet and rocket engines, and on provision of required laboratory facilities. Indeed, it became fashionable and prestigious for governments, industry and universities to be involved in high speed aerodynamics. However, the complexity of the field, the magnitude and the cost of the effort necessary to produce tangible results, and the need for large markets to pay for the developmental costs were not always appreciated.

Given the above circumstances, it is not surprising that Canada was among the countries which decided to undertake, on their own, original development of high speed aircraft and missiles. The fact that during the war Canada became a major manufacturer of aircraft (albeit of foreign design; over 16,000 military aircraft were produced in Canada during the war) may have also influenced this decision. This policy led to production of the CF-100 AVRO CANUCK twin-jet subsonic fighter (which entered squadron service in 1953), followed by the development, through the prototype stage, of the CF-105 AVRO ARROW supersonic long range fighter. Both projects were the responsibility of AVRO Aircraft Ltd. of Malton near Toronto, a subsidiary of the British Hawker-Siddeley concern. The CF-105, expected to be in production in 1956, suffered long delays. The prototype was rolled out on October 4, 1957, the day the U.S.S.R. launched Sputnik, the first artificial satellite. The CF-105 first flew on March 25, 1958 with AVRO's chief test pilot Janusz Zurakowski at controls; on April 3rd it achieved supersonic speed. In September, 1958, after an expenditure of some $300 million, the production plans were scrapped by the conservative government of John Diefenbaker. The governments of the United Kingdom and of the U.S.A. studied the ARROW project but both turned the ARROW down. The project was finally cancelled in February, 1959 (Lamontagne, 1970, p. 81-82; Shaw, 1979).

The development and production of fighter aircraft were the responsibility of the Air Staff and the Department of Defence Production. The Defence Research Board, formed in 1947 as the "fourth arm of the service" (GR, 1963, p. 206), promoted the VELVET GLOVE, a Canadian air-to-air, supersonic guided missile. This project clearly exceeded the technical resources available in Canada and, after an expenditure of some $24 million, was cancelled in 1956 (Ottawa Journal, 1956; Lamontagne, 1970, p. 79-81).

The attempts by Canada to become an independent developer of high speed aircraft and missiles spanned about a decade and were terminated with the ARROW cancellation in 1959. Ironically, this occured on February 20th, almost to the day on the golden anniversary of the first aircraft flight in Canada made by J. A. D. McCurdy in the SILVER DART on February 23, 1909, near Baddeck, Cape Breton Island, N.S., over the frozen surface of Lake Bras d'Or.

Some of the other countries, which embarked after 1945 on policies similar to Canada's, also experienced failures. Smaller or less industrialized countries of Western Europe, such as Belgium, Holland and Italy, after investing in high speed aeronautics research, had to consolidate their independent efforts with other, larger partners. Peron's plans for a modern aircraft industry in Argentina had to be abandoned. The resources that India devoted to fighter development would have been used more productively for other purposes. Only Sweden represented a notable exception among the small powers. Sweden's strong neutralist policy was successfully backed-up by reliance on home developed and produced war materiel, including advanced aircraft and missiles. The key to Sweden's success was the depth of its technological culture and the existence of a strong industry-government-university team.

HIGH SPEED AERODYNAMICS LABORATORIES

Successful development of any advanced technology requires extensive research and test facilities. When after the war Canada embarked, as noted above, on fighter and missile projects, it had no laboratories for high speed aerodynamics. Efforts to develop such facilities started in the late 1940s, under the auspices of the National Research Council and the Defence Research Board. Paradoxically, these activities were continued even after 1959, when any major engineering involvement of Canada with high speed aerodynamics ceased, and have contributed significantly to the state-of-the-art of aerodynamic testing.

DEVELOPMENTS AT UTIA

Starting in 1948, shock tubes and small supersonic, vacuum-driven intermittent wind tunnels were being developed at the University of Toronto under G. N. Patterson. In September, 1950, the U. of T. Institute of Aerophysics (now Institute for Aerospace Studies) was inaugurated in new quarters at Downsview near Toronto. The funding was largely provided by DRB and outside contracts, which included work for the U.S. Department of Defence. The work eventually centered on basic studies of shock waves and rarefied gas dynamics. The Institute did not participate extensively in Canadian missile and aircraft projects of the 1950s, but trained many highly competent scientists and engineers. Those who continued working in high speed aerodynamics often found employment in the U.S.

AEROBALLISTICS

The DRB was also promoting supersonic aerodynamics at its CARDE laboratories in Valcartier near Quebec City. Under the direction of G. V. Bull (who came to CARDE in 1951, after developing a small supersonic wind tunnel and completing doctoral studies at UTIA), aeroballistic ranges were developed and expanded at the Canadian Army Research and Development Establishment. Munitions, aircraft and VELVET GLOVE models were tested and novel, efficient test techniques were developed. In the 1960s, after Canadian missile and supersonic fighter projects were cancelled, CARDE embarked on a joint program (with the U.S. Department of Defence Advanced Research Projects Agency) of ballistic missile re-entry physics studies. Several new hypersonic ranges were developed and operated at a cost of about $2.5 million per year. The work was terminated in 1970 and since then CARDE (re-named Defence Research Establishment Valcartier or DREV) has been concerned with more conventional problems of ballistics. For this purpose, one of the ranges was converted into a drive for a 2 x 2-ft transonic-supersonic wind tunnel (Solnoky, 1971).

Bull left CARDE in 1961 for McGill University where he directed the High Altitude Research Project (HARP). In this venture, supported by the U.S. Army, McGill University and, since 1964, by the Department of Defence Production, 16-inch smooth bored ex-U.S. Navy guns were used to launch probes into the upper atmosphere. Later, additional range facilities were developed at the U.S. Army proving grounds at Yuma, Arizona, and at Highwater, Que. and North Troy, Vt., where the firing range straddled the Canadian-U.S. border between these locations. The feasibility of gun-launched satellites was studied. HARP was terminated in 1967, after Canada withdrew its support. A total of about $9.5 million was expended on HARP; Canada's share amounted to $4.3 million (Wojaechowski, 1970).

Bull continued ballistic research at Space Research Corporation, a company he established at the Highwater-North Troy range, with offices in Montreal and test facilities on Barbados and Antigua. SRC was successful in developing long range artillery shells and guns. In 1980, SRC went bankrupt, after pleading guilty of illegal exports of munitions to South Africa and being fined a total of $100,000 by Canadian and U.S. courts (Gazette, 1981).

The truly original technique of high altitude launches from large caliber guns, developed by Bull in the 1960s, offered certain advantages over the conventional rocket launchings, particularly relatively low cost, accuracy and reliability. However, it came some 10 or 15 years too late to gain general acceptance. By the time it was developed, a large variety of rocket vehicles was commercially available and many rocket range facilities were established.

Indeed, studies of the upper atmosphere with gun launches duplicated a much larger Canadian-U.S. program of upper atmosphere research in which rocket-propelled probes were used (Barrington, 1979). The program extended from 1954 to 1978 and was based on the Fort Churchill rocket range in Manitoba. Over the years, it involved several Canadian and U.S. organizations (NRC, CARDE, Defence Research Telecommunications Establishment, Canadian Army, U.S. Army, U.S.A.F., U.S. Navy, NASA among others), which provided support and participated in research. These activities led to the development in Canada of the Black Brant series of rockets. Highly successful, they were used throughout the world and achieved significant sales.

In retrospect, the wisdom of engaging simultaneously in the development of two different techniques of upper atmosphere probing appears questionable. It is apparent that these space research programs, in which many organizations were involved, lacked effective co-ordination (this has been also true of the aeronautical research, see below). While the debate over the need for centralizing space planning has been going on for nearly twenty years, in Canada — unlike in the United States — the responsibility for space R &D continues to be scattered among several agencies.

Although the objectives of CARDE and HARP activities mentioned above were in the areas of aerodynamics, aerophysics and upper atmosphere studies, it was in the field of ballistics that these efforts led to significant developments. Nevertheless, the Canadian government agencies have failed to exploit the expertise so acquired and later used by SRC. A more vigorous support by the government of innovation in the design of guns and shells could have led to the establishment in Canada of a commercially viable industry, with good export potential (SRC sales in 1979 came close to $40 million).

SUPERSONIC AND TRANSONIC WIND TUNNELS AT N.R.C.

Concurrently with the DRB-supported developments at UTIA and CARDE, and to some extent in competition with them, the NRC followed a different path which led to the construction and operation, begining in 1962, of a large 5-ft high speed wind tunnel facility.

Since 1929, aeronautical research laboratories were being developed at NRC's Division of Mechanical Engineering in Ottawa, under the direction of J. H. Parkin. Their purpose was to provide testing for industry, to support applied research in aeronautics and to train aeronautical engineers. A relatively large low speed wind tunnel (6 x 10-ft) and a spinning tunnel (15 ft-dia) were built at the NRC's Montreal Road site in Ottawa. When the war ended, NRC had no facilities for high speed aerodynamics but, in line with the British and U.S. initiatives, considered already in 1945 the design of a supersonic wind tunnel (Templin, 1945). Lack of engineers experienced in this new field thwarted progress. Suitable personnel was recruited in England and joined NRC in Ottawa in 1947-48. It consisted of F. W. Pruden, a young aerodynamicist from the National Physical Laboratory in Teddington near London, D. C. MacPhail and the writer, both from the Royal Aircraft Establishment at Farnborough. Pruden, who came to Ottawa in 1947, had experience with small supersonic tunnels at NPL (some of the earliest ones operated in England), and first-hand knowledge of much more advanced German facilities at Volkenroede, where he spent some time as a member of the British technical mission. MacPhail, a Canadian, developed a small continuous supersonic tunnel at the RAE, was involved in planning and design of new, large tunnels to be built at Bedford and, at the time of leaving for Canada, headed the Supersonics Division of RAE's Aerodynamics Department. The writer, on staff of the Supersonics Division was responsible for the design and operation of several small supersonic wind tunnels, and for a number of research projects.

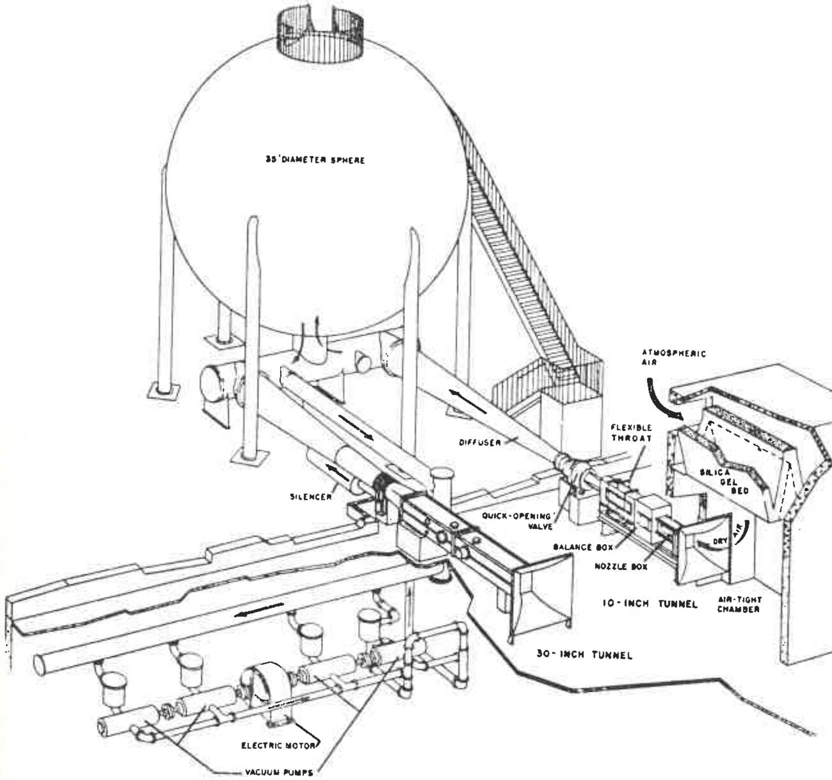
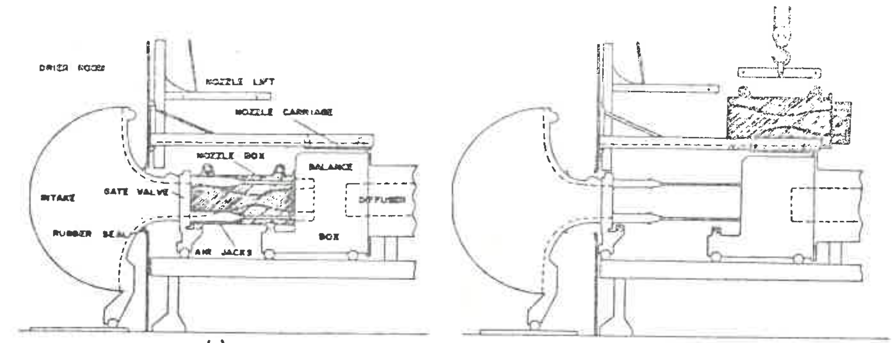


Fig. 1

Supersonic/transonic wind tunnels at the NRC-NAE High Speed Aerodynamics Laboratory, Montreal Road, Ottawa. The 10 x 10-inch tunnel started operating in 1951, the 16 x 30-inch tunnel — in 1952. In 1954, a second vacuum sphere was added.

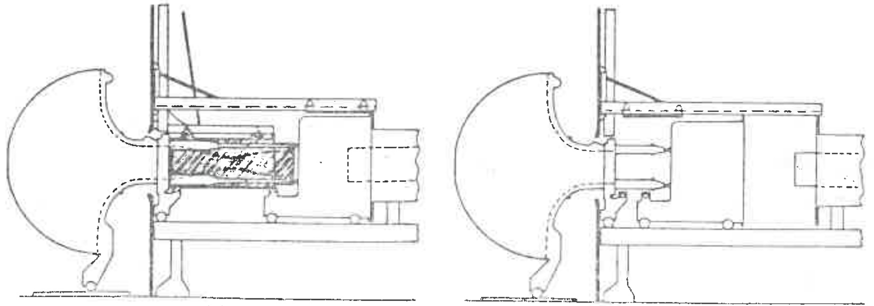
The first proposal for NRC's High Speed Aerodynamics Laboratory was made by Pruden in April, 1948 (Pruden, 1948). The design was based on two ex-German compressors, which were to drive a 10 x 10-inch continuous supersonic wind tunnel and a 20 x 20-inch intermittent, vacuum operated supersonic tunnel. In 1949 Pruden started development of an aeroballistic range. Subsequently, more modest plans were adopted

(Lukasiewicz, 1952). The range was dropped and a 10-inch intermittent, vacuum operated tunnel was built. The design incorporated worthwhile innovations. Fast Mach number change and good model accessibility were obtained through use of interchangeable, integral nozzle boxes (each for a fixed test section Mach number). This proved to be a practical scheme, much less expensive than the flexible nozzle design pioneered by the Jet Propulsion Laboratory of the California Institute of Technology in Pasadena, California. Detailed design and fabrication of the 10-inch tunnel were done by the Dominion Bridge Co. Ltd. of Lachine, Que. The new building of NRC's HSAL (at the Montreal Road site) was dedicated by the Governor General, Lord Alexander of Tunis, in 1950; the tunnel started operating in March of 1951.



(a)
NOZZLE IN POSITION READY FOR TUNNEL RUN

(c)
NOZZLE ON CARRIAGE READY TO BE PICKED UP BY OVERHEAD CRANE



(b)
TUNNEL OPEN – NOZZLE READY TO BE LIFTED OUT

(d)
BALANCE BOX OPEN

Fig. 2

Design of the 10 x 10-inch HSAL's supersonic wind tunnel, first operated in 1951, provided for quick change of Mach number through the use of integral nozzle boxes. The four steps involved in a nozzle change are illustrated above.

The capability of the 10-inch tunnel was severely restricted by its small size. It was used for tests of the VELVET GLOVE missile but was not suitable for aircraft tests; moreover, it could not cover the transonic range of speeds. For these reasons, and in view of plans for the supersonic ARROW, it was decided to construct a larger transonic-supersonic tunnel, to be driven by the existing HSAL plant. A 30 x 16-inch test section was selected for use with half-models, so that aerodynamic simulation equivalent to that attainable in a 30 x 30-inch tunnel (with full models) could be realized. The tunnel, fabricated by Canadian Vickers of Montreal and installed in the 10-inch tunnel bay, started operating in September, 1952. In 1954 a second vacuum sphere was erected, increasing the run duration from 6 to 15 seconds. The new tunnel was the first to offer transonic capability in Canada. It was used for some testing of the ARROW (although the bulk of testing was conducted in larger U.S. tunnels) and for basic aircraft configurations. Both tunnels served to develop new test techniques.

The small supersonic and transonic wind tunnels which became available in early 1950s provided only rudimentary test facilities, better suited to research than to developmental testing for the aircraft industry. They were totally inadequate in the context of the policy adopted by the government shortly after World War II, a policy (postulated already in 1945 by C. D. Howe, Minister of Munitions and Supplies and of Reconstruction) which envisaged establishment in Canada of an aircraft and aero-engine industry for the development and production of civil and military planes. (Shaw, 1979, p. 30).

EVOLUTION OF NRC'S LARGE, HIGH SPEED WIND TUNNEL PROJECT

The need for new, high performance and large wind tunnels (and other facilities) was appreciated after the war in the U.S., U.K. and France. These countries correctly concluded (partly as a result of assessment of the German war effort, as noted above) that the potential offered by aircraft and missiles could not be realized unless adequate means were provided for research and development. National programs for construction of large wind tunnels, running into tens and even hundreds of millions of dollars, were established in the late 1940s (the U.S. Unitary Wind Tunnel Program of 1949, the RAE-Bedford laboratories, France's ONERA wind tunnels in Modane and Paris). In all these instances, the technical approach did not depart from the tradition of older, low speed tunnels which ran continuously. The major design and fabrication difficulties, delays (construction was not completed until late 1950s and early 1960s) and costs stemmed from the continuous operation principle and were related to the basic incompatibility of compressor pressure ratio-volume flow characteristics versus wind tunnel requirements over a wide Mach number range, the need for large power and the complexity of drive. In fact, with the continuous tunnels the major share of the design and construction effort was devoted to the drive rather than to the test section and instrumentation (Lukasiewicz, 1953, 1955).

There was no question of the Canadian government providing the funds necessary to construct a conventional, large high speed wind tunnel for developmental testing. If such a facility were to be acquired in Canada, a more economical design solution would have to be found. The clue was the approach the Germans used in developing their supersonic tunnels, the technique already adopted by Pruden and the writer for NRC's HSAL (see above). For reasons of power economy and design simplicity, the Germans operated their supersonic wind tunnels in an intermittent rather than continuous mode. The drive consisted of a large vacuum vessel, evacuated to a low pressure, which provided the pressure drop necessary to accelerate atmospheric air through the wind tunnel duct to the required velocity (Mach number) in the test section. Run duration of some 15 seconds could be obtained. With modest pumping power, the vacuum vessel could be evacuated in a matter of minutes, so that several tunnel runs could be made every hour. Instrumentation for making force, pressure and heat transfer measurements during each run was also developed.

The principle of intermittent operation (or, more generally, of energy storage) could be pushed even further, to increase productivity and aerodynamic performance. If measurements could be taken with a model driven during each run over a full range of incidence, the data productivity of an intermittent tunnel could easily match, or even exceed, the productivity of traditional, continuously running installations. The aerodynamic performance (or scale, measured by Reynolds number) could be increased by operating the tunnel from pressurized air storage to the atmosphere, rather than from atmosphere to the vacuum vessel. This would require the use of an automatically controlled valve which would maintain constant pressure in the wind tunnel as the stored air pressure decreased during the run, and a heat exchanger (of passive storage type) to maintain constant temperature of the air entering the tunnel (the temperature would otherwise decrease due to expansion of the stored air).

The technical feasibility of such a high performance and productivity intermittent wind tunnel depended on the availability of instrumentation and controls more sophisticated than had been used so far in wind tunnels. It was the view of F. W. Pruden and the writer that the "state-of-the-art" in these two areas was sufficiently advanced to render the novel wind tunnel concept practical.

The first engineering analysis of the novel design and a proposal for a 4 x 4-ft blowdown, intermittent wind tunnel were completed in September, 1950 (Lukasiewicz and Pruden, 1950). However, the design (a 5 x 5-ft size was finally selected with air stored at 20 atmospheres) was not authorized for the next four years and another eight years elapsed before the tunnel began operating in 1962 — 12 years after the original proposal. This very long delay was not caused by technical problems. Indeed, the novel concept turned out to be sound and was translated into functional hardware without undue difficulty. The delay was due to indecision of NRC management, political manoeuvering by organizations which had a stake in the aeronautical research in Canada, and lack of a consistent government policy which, while promoting aircraft and missile development, neglected the need for research and test facilities. Each of these aspects warrants a brief review.

In addition to the already mentioned merits, engineering analysis revealed other important advantages of the novel design concept. Unlike the drive of continuous wind tunnels, the intermittent tunnel drive was found to match well the tunnel pressure ratio-mass flow characteristics over a very wide Mach number range (0 to 4), including the transonic region. Thus it became possible to cover the whole subsonic-transonic-supersonic spectrum in one facility ("trisonic" or "polysonic" were the terms later coined for such wind tunnels), an advantage that no continuous wind tunnel could offer. This extreme versatility was coupled with design simplicity. Since the wind tunnel duct proper was separate from the drive system, the design of each part of the system was not affected by other part's requirements. Finally, intermittent operation provided for excellent model and test section accessibility: with instantaneous tunnel starting and stopping, long run-up, shut-down and pumping periods were eliminated.*

This favourable engineering assessment was followed, in the 1950s, by small scale development of techniques on which the new concept relied, and operation of a pilot tunnel of the novel type (Lukasiewicz, 1953, 1955, 1958).

A major effort was devoted to the crucial problem of driven model instrumentation and data handling system. The feasibility of the concept was established by 1953, through tests in the 10-inch and 30-inch tunnels. It is unlikely that without this demonstration the novel tunnel design would have been ever approved.

Following acceptance of the 5-ft wind tunnel proposal in 1954 (see below), a complete 1:12 scale facility was built and started operating in 1955 at the HSAL. It was used for systematic investigation of critical problems and provided invaluable information for the full-scale design, particularly on heat storage, valve controls, aerodynamic noise generated by the control valve, flow stabilization, transonic test section design and Mach number regulation, diffuser design, etc.

ACCEPTANCE OF NOVEL DESIGN CONCEPT

In spite of the superior characteristics of the novel tunnel concept, its acceptance did not come easily in Canada. It soon became evident that hiring foreign experts in a new field was one thing, taking their advice — quite another matter. Conventional design concepts pursued by the most reputable (and also well funded) laboratories — those of NACA in the U.S. and RAE in England — were considered the only sound and practical ones. Not surprisingly, NACA and RAE, already committed to extensive and expensive construction of continuous wind tunnels, showed little interest in the 1950 novel Canadian proposal. Needless to say, NRC was not interested in patenting the new design, which later became standard throughout the U.S. aeronautical industry and was adopted by other countries.

Consideration of a large, continuous high speed wind tunnel was initiated at the NRC in 1952, by another group. Predictably, this study showed performance limitations and high cost of conventional design. In 1953, the writer proposed again the intermittent solution; a pressure driven, 5 x 5-ft test section design was agreed to in April, 1954. Government approval for design of the facility was given in November, 1954. In June, 1956 design contract was awarded to Dilworth Ewbank, Consulting Professional Engineers of Toronto. Construction started in 1958 and the project was completed under the direction of W. J. Rainbird; the tunnel first ran in August, 1962 and became operational in early 1963 (Rainbird, Tucker, 1959; Tupper et al, 1961; Ohman, 1976).

As far as can be ascertained, it was in Canada in 1950 that the novel wind tunnel concept was for the first time proposed and evaluated. Although it elicited no interest from government aeronautical establishments, it found wide acceptance within the aeronautical industry. Because the new tunnel type offered superior performance at a very modest cost, it was quickly adopted by aircraft firms for their own, in-house use (STA, 1969). The following U.S. companies built blowdown, intermittent wind tunnels (the year these tunnels became operational is given): United Aircraft (1956), North American Aviation (1957), Boeing (1957), Chance Vought (1958), General Dynamics/Convair (1958), Douglas Aircraft (1959), McDonnell Aircraft (1959), Lockheed — California (1960). This list included all of the major U.S. aeronautical firms. A 4 x 4-ft test section size became a widely accepted standard. Tunnels of this type were later built in England (English Electric), Netherlands (NRL), India (NAL), Romania (INCREST) and Yugoslavia (VTI). Thus the concept, which originated in Canada, was first realized — in several editions — in the U.S. The delay in Canada was due to the already noted doubts about the soundness of the novel design, as well as to organizational and political difficulties. The latter became evident as attempts were being made to consolidate aeronautical research in Canada.

---

*For these reasons, intermittent test techniques were introduced in the 1960s in continuously operating wind tunnels, an "intermittent" model being injected into a continuously running wind tunnel test section for the brief period of test (Lukasiewicz, 1973).

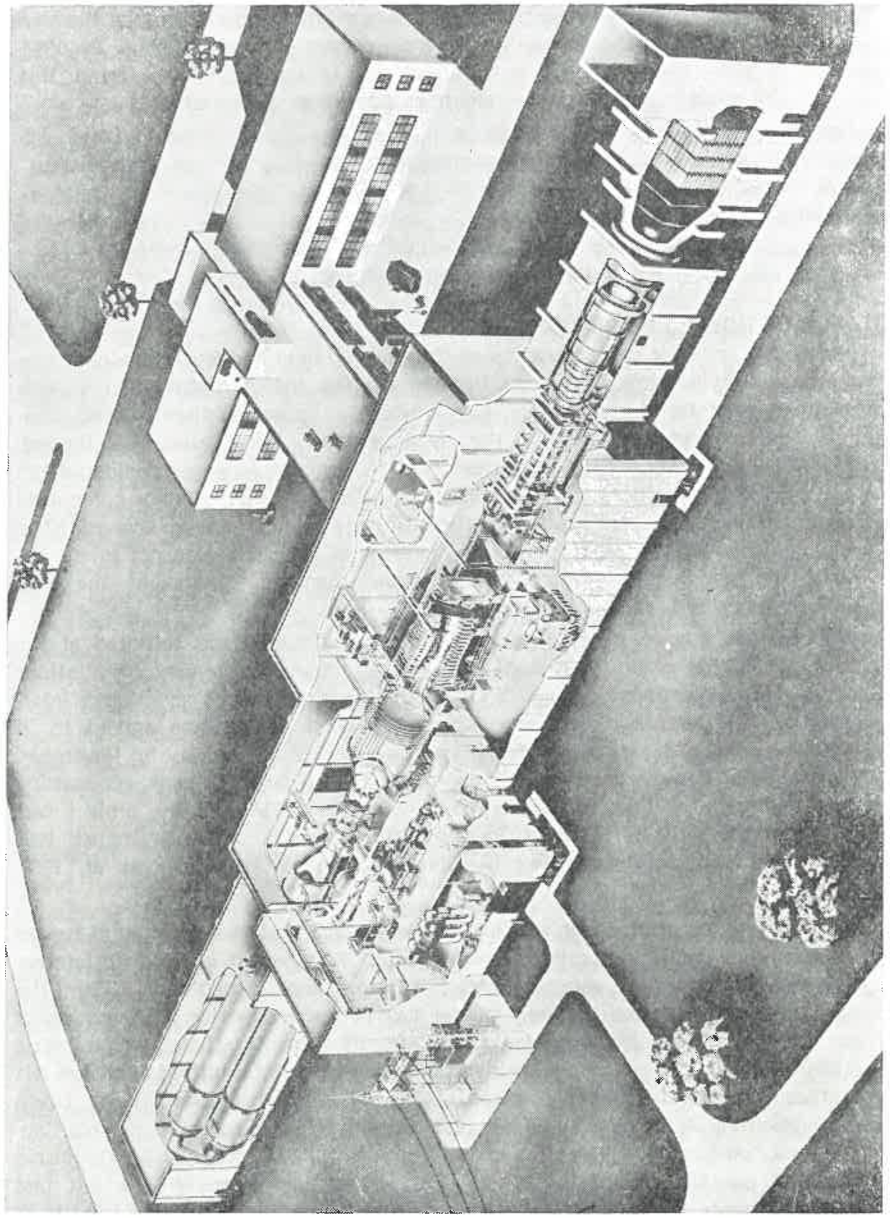


Fig. 3

Trisonic 5 x 5-ft wind tunnel at Uplands near Ottawa. This cut-away view of the 380-ft long wind tunnel installation shows, from left: 50,000 cu. ft., 20 atm. compressed air storage; pressure control valve and 11,500 H.P. compressor plant; settling chamber, contraction and flexible supersonic nozzle; transonic section, removed from the circuit; model support, variable and fixed diffusers, silencer and exhaust stack. Control and instrument rooms, shops and offices are seen in the upper-right.

FAILURE TO CONSOLIDATE AERONAUTICAL RESEARCH

Aeronautical research for both civil and military applications was the responsibility of the NRC. By 1948 it became evident that the growing military program of aircraft and engine development for the RCAF would require a large expansion of research and testing, to a degree that could not be met by the NRC alone. Moreover, the major expenditures involved could not be justified on civil grounds since most of the R & D would be for military purposes. In these circumstances, the Cabinet authorized in 1950 the creation of the National Aeronautical Establishment as a single agency responsible "for the conduct of research and experiments required for the development and operation of military and civil aircraft in Canada" (GR, 1963, pp. 275-276). The concept of the NAE as a single organization responsible for all aspects of aeronautical R & D was modeled on the British Royal Aircraft Establishment at Farnborough and was advocated by J. J. Green, in charge of aeronautical research at DRB. It envisaged consolidation of the older NRC aeronautical laboratories and the new facilities to be constructed at Uplands airport near Ottawa under the umbrella of the NAE. The operation of the NAE would be overseen by the National Aeronautical Research Committee (composed of the President of NRC as chairman, the Chairmen of the DRB and the Air Transport Board, the Chief of the Air Staff and a representative of the Department of Defence Production) and the funding for the new Uplands facilities would be provided jointly by NRC and DRB (Goodspeed, 1958).

Incredibly, the intent of the Cabinet decision creating the NAE was never implemented. Literally, the only change was the adoption of the NAE name by NRC's Division of Mechanical Engineering for its aeronautical activities; there were no organizational or personnel changes. The NAE - DME duplication worried the staff and never failed to baffle the visitors. The original intent of setting up the NAE was further subverted in 1954, when NARC agreed to a split on geographical lines, the NRC continuing to have responsibility for the Montreal Road site and the DRB assuming the responsibility for the Uplands location. Clearly, further fragmentation, rather than consolidation, would have been the result. However, the NRC was successful in opposing NARC's "decision", which was never carried out; the NRC continued to operate the new facilities at Uplands. In 1958, the NAE-DME duplication was terminated when the DME was split to form a separate NAE division. Since the split was not done on a functional basis, both units continued with aeronautical research. The goal of a comprehensive co-ordination of the aeronautical R & D was not pursued further by the NARC.

It is not surprising that 13 years after the Cabinet has decided to consolidate aeronautical R & D under the auspices of the NAE, the Glassco Report noted that "there appears to be no single body for the co-ordination of the aeronautical research and development programmes carried out by, or sponsored by, the Defence Research Board, the RCAF, the Department of Defence Production, the Department of Transport and the National Research Council" (GR, 1963, p. 279).

The failure to consolidate aeronautical research, as intended in 1950, had serious consequences for the 5-ft wind tunnel project. This facility was justified solely on the basis of testing needs of the Canadian industry, committed — through government policy — to development of advanced, indigenous military aircraft. The responsibility for military aircraft development and related R & D rested with DRB and the RCAF but the technical capability, competence and experience were within the NRC. The NRC, aware that its aeronautical laboratories would be eventually taken over by the NAE, was not too interested in obtaining funds and approval for construction. DRB and RCAF, on the other hand, were not in a position to provide a technical solution when the need became apparent. This was an unhealthy situation in which technical competence, responsibility and financial resources were fragmented between competing organizations. As noted by Lamontagne (1970, p. 85), "relations between the Defence Research Board and the National Research Council were often strained". Frequent reviews of the 5-ft wind tunnel project, funding difficulties and long delays were the result (Lukasiewicz, 1963).

DELAYS AND ESCALATION OF COST

In April, 1955 ministers Howe (Defence Production) and Campney (National Defence) stated that a $3.5 million supersonic wind tunnel would be built at Uplands Airport in Ottawa (Ottawa Journal, 1955). This was already the location of a new military field and other RCAF facilities. It would also become the new site of the NAE, to which other aeronautical activities of the NRC would be transferred on completion of the tunnel. (Already in 1953 the NRC Flight Test Section was moved to Uplands from Arnprior). In the 1956-57 estimates, DRB provided $1,750,000 for the tunnel project. The funds were frozen in 1957 by the newly elected conservative government (Montreal Star, 1958). In the 1958-59 estimates, NRC and DRB each provided $750,000 for the project. The protracted reviews were not completed until November, 1958 when the project was again approved, largely through the efforts of J. L. Orr, at that time in charge of aeronautical research at DRB. The construction was completed in 1962, at a cost of about $9 million — a very large increase over the initial estimate. This was noted (Time, 1962) by the auditor general Henderson in January, 1962, "because the extent to which the project and its cost have expanded since the original authorization was given and also because, while some seven years elapsed since the work has commenced, the project is not yet complete". In 1963, The Glassco Royal Commission on Government Organization had this to say about the 5-ft wind tunnel project:

> Although the 5-foot wind tunnel is the chief government aeronautical project in hand, it is usually considered independently of the current National Aeronautical Establishment programme. Total expenditures to date have been approximately $9 million and the project has suffered from lack of coordination; at the time of review the tunnel was still not in operation after ten year's work, although similar facilities have been established in the United States in three to four years and at less cost (GR, 1963, p. 278).

AFTER ARROW CANCELLATION

The final approval in November 1958 of the 5-ft tunnel coincided with cancellation of plans to produce the ARROW, the crucial move in Canada's abandonment of high speed aeronautics. With the missile program already scrapped in 1956, Canada had no projects which could benefit from the new, industrial scale test facility and yet, curiously, it decided to complete its construction. This was justified on the basis of future needs for development of missiles (which were to take over from fighter aircraft) and supersonic transports — clearly rather unrealistic objectives in the light of recent Canadian experience and subsequent history.

Another argument in support of the completion of the wind tunnel was based on historical experience. Even if Canada used aircraft and missiles from other countries there was always a need for modifying them for particular operational needs and this required wind tunnel facilities which, in the event of an emergency, would probably not be available for use in other lands. Furthermore to not complete the wind tunnel would prevent Canada developing any high speed aerospace project in the future; however, the government had no plans to engage again in such projects.

The paradox of the ARROW cancellation and of the approval of the Uplands tunnel reflected the confused aeronautical R & D scene in Canada in the 1950s.

Had a forceful policy and efficient organization existed, the Uplands tunnel could have been completed in the mid-1950s, at about half of the final cost and ahead of similar facilities elsewhere; it could have played a useful role in the development of various U.S., British and French aircraft, and would have served as a prototype for similar tunnels built later. Moreover, if the Canadian government had protected this technology through patents and worked in collaboration with Canadian engineering and design firms a sizeable export benefit would have been achieved. But this was not done: public funds were used to develop a technology but no effective efforts made to take it to the market place.

As noted above, in the wake of the VELVET GLOVE and ARROW fiascos, the original organizational concept of the NAE was also abandoned and the Uplands facilities continued as components of a division of the NRC; L. H. Ohman succeeded W. J. Rainbird as head of the 5-ft wind tunnel in 1970. Lacking Canadian high speed projects and cashing in on its superior aerodynamic performance, the 5-ft wind tunnel, apart from some basic research and mostly low speed testing, has been largely used for U.S., Swedish and French projects, by such clients as NASA, NAA, Boeing, Convair, Lockheed, McDonnell-Douglas, ONERA, SAAB-SCANIA, FFA, etc. (NRC, 1980).

The HSAL at the Montreal Road site, where the first NRC transonic and supersonic wind tunnels were developed, has specialized — under the direction of K. Orlik-Rückemann — in dynamic stability research. Renamed the Unsteady Aerodynamics Laboratory and equipped with a hypersonic helium tunnel (now no longer in use), it has become widely known for experimental measurements of dynamic stability and has been engaged in many U.S. and other foreign projects.

In the late 1960s it became apparent that the existing transonic tunnels, some ten or more years old, could not provide an adequate aerodynamic scale for testing of very large subsonic transport aircraft (jumbo-jets) and rocket boosters (Lukasiewicz, 1971). Since then, new high Reynolds number transonic wind tunnels are being developed in the U.S. and Europe. It is of interest to note that, until these new facilities are completed, the highest Reynolds numbers at transonic and supersonic speeds are available in the Uplands 5-ft wind tunnel, first proposed in 1950.

In the decade of Canada's involvement in high speed aeronautics significant technical innovations were made in Canada in aeroballistics and transonic-supersonic wind tunnel design. But, as high speed aeronautics was abandoned by Canada in 1959, the usefulness of these accomplishments should be questioned. The same intellectual and financial resources could have been used more effectively on projects which had a sound raison d'être in the Canadian context.

Fortunately, the design expertise and experience which have been acquired in Canada through the 5-ft wind tunnel project have not been lost but preserved and expanded, and have led to participation of Canadian consultants and industry in many wind tunnel projects, mostly abroad. Dilworth, Secord, Meagher and Associates (DSMA) of Toronto have been responsible for the blow-down tunnels of the NAE 5-ft type constructed in India, Romania and Yugoslavia, for vacuum-operated transonic-supersonic tunnels at DREV, Valcartier, Que. and at Fuji Heavy Industries in Japan, and for several wind tunnel design studies, for NATO and others. They have also designed low speed wind tunnels in Ottawa (NAE 30-ft) and automotive wind tunnels in Canada

(Imperial Oil), Sweden (Volvo), Germany (Ford). U.S. (Chrysler, Amcco, Exxon) and England (British Leyland). In a highly competitive environment, DSMA have gained international reputation as designers of modern aerodynamic test facilities.

LESSONS TO BE LEARNED

No doubt, several lessons could be learned from the history of the development of facilities for high speed aerodynamics in Canada. Investigations by Glassco (GR, 1963) and Lamontagne (1970) dealt with some of the aspects here mentioned but the remedies they prescribed have not been adopted. In the light of this review, the following points stand out most clearly.

First, decisions to embark on new technological ventures will not succeed if governed by notions of national pride, scientific prestige or novelty (the British and the French have found this more recently as developers of the Concorde supersonic airliner). Rather, such decisions should be based on a realistic appreciation of the extent of the R & D effort required and on the existence of a market large enough to pay for that effort.

Secondly, the desire to enter a new field should be matched by technical competence. The latter, if not available at home, can be imported. In any case: choose your experts carefully and, having done so — do what they tell you to do, until you have good reason to stop. Any other course of action is likely to take longer and cost more.

Thirdly, parochial institutional interests and jealousies should not take precedence over the goal that has been set. The institutions and organizations should be shaped to serve this goal, lest the goal be subverted to suit the existing institutional needs.

Fourthly, the history of the development of high speed aerodynamic R & D facilities in Canada gives further evidence — if further evidence is needed — of the failure of successive cabinets to develop effective policies (i) for science and technology and (ii) for an industrial strategy. At the time of this writing the situation has not changed.

ACKNOWLEDGEMENTS

The manuscript of this paper was reviewed by John L. Orr, Philip J. Pocock and William J. Rainbird, my former Ottawa associates who have been active in the aeronautical R & D in Canada in the 1950s and 1960s. While the responsibility for the account here given rests solely with the author, their interest and assistance are gratefully acknowledged.

REFERENCES

Barrington, R. E. (1979) Canadian Space Activities in the Past Quarter Century, **Canadian Aeronautics and Space Journal,** 25 (2), 153-169, 2nd Quarter, 1979.

Gazette (1981) Case of Dr. Bull reaches its bitter end, **The Gazette,** Montreal, 21 March 1981.

Goodspeed, D. I. (1958) **A History of the Defence Research Board of Canada,** Queen's Printer, Ottawa.

GR (1963) The Royal Commission on Government Organization (Glassco Report), **Scientific Research and Development,** Vol. 4, Section 23, pp. 183-322, Ottawa.

Lamontagne, M. (1970) **A Science Policy for Canada, A Critical Review: Past and Present,** Vol. 1, pp. 327.

Lukasiewicz, J. and Pruden, F. W. (1950) **An Economical High Speed Wind Tunnel of High Performance,** Division of Mechanical Engineering, National Research Council L.O. 5850-A, File LM2-9-1, Ottawa, September 22, 1950.

Lukasiewicz, J. (1952) Wind Tunnels in the High Speed Aerodynamics Laboratory, **NAE & NRC (ME) Quarterly Bulletin, 4,** 1952.

Lukasiewicz, J. (1953) **Development of Intermittent High-Speed Wind Tunnel Installations and Testing Techniques,** National Aeronautical Establishment Lab. Report LR-75, Ottawa, 17 July 1953.

Lukasiewicz, J. (1955) Development of Large Intermittent Wind Tunnels, **Journal of the Royal Aeronautical Society,** 59(4), 259-278, London.

Lukasiewicz, J. (1958) Some Problems of Design and Operation of Blowdown Wind Tunnels, **Journal of Applied Mathematics and Physics, ZAMP IXb** (5/6), 422-437, Basel, March 17, 1958.

Lukasiewicz, J. (1963) **Scientific R & D Activities of the Government of Canada: Diagnosis and Cure,** Unpublished Study, 89 pp., October, 1963.

Lukasiewicz, J. (1971) The Need for developing a high Reynolds number transonic wind tunnel in the U.S., **Astronautics & Aeronautics,** 9(4), 64-70.

Lukasiewicz, J. (1973) A critical review of development of experimental methods in high speed aerodynamics, **Progress in Aerospace Sciences** Kuchemann, D. (ed.), Pergamon Press, **14,** 1-26.

Montreal Star (1958) PC Economy Drive Delays Wind Tunnel, **Montreal Star,** 25 January 1958.

NRC (1980) **National Aeronautical Establishment,** National Research Council, Ottawa, 48 pp.

Ohman, L. H. (1976) The Role of the NAE 5 x 5-foot Wind Tunnel in the Development of Modern Airfoil Sections, **Canadian Aeronautics and Space Journal, 22** (1), 1-22, January-February 1976.

Ottawa Journal (1955) Supersonic Wind Tunnel for Uplands, **The Ottawa Journal,** 6 April, 1955.

Ottawa Journal (1956) The Velvet Glove Fiasco, **The Ottawa Journal,** 25 July, 1956.

Pruden, F. W. (1948) **A Proposal for a High Speed Aerodynamic Laboratory,** National Research Council, Division of Mechanical Engineering, Report MA-205, Ottawa, 30 April, 1948.

Rainbird, W. J., Tucker, N.B. (1959) The Five Foot Blowdown Wind Tunnel at the National Aeronautical Establishment, **Proceedings, Decennial Symposium,** Institute of Aerophysics, University of Toronto, pp. 194-213, 1959.

Shaw, E. K. (1979) **There Never Was an Arrow,** Steel Rail Educational Publishing, Toronto, 261 pp.

Solnoky, P. (1971) An economic analysis of the operation of the aerodynamic and laser test facilities of the Defence Research Board of Canada, **Problèmes généraux relatifs aux moyens d'essais aérodynamiques,** Proceedings, 8ème Séminaire du Groupe sur la Recherche pour la Défense de l'OTAN, Institut Franco-Allemand de St. Louis, 4-7 May, 1971, pp. 119-165.

STA (1963) **Wind Tunnel List,** Supersonic Tunnel Association, 19th Semi-Annual Meeting, May 1963.

Templin, R. J. (1945) **Design Considerations of Supersonic Tunnels,** Division of Mechanical Engineering, National Research Council, Ottawa, Report MA-158.

Time (1962) How to spend money, **Time,** p. 9, 16 February 1962.

Tupper, K. F., Dilworth, P. B., Jenkins, L. A. (1961) **The N.A.E. Five Foot Supersonic Wind Tunnel,** Engineering Institute of Canada 1961 Annual General Meeting Paper No. 40, 8 pp.

Wojaechowski, M. (1970) Harp Fiasco, **Science Forum, 3** (1/13), pp. 12-16.

KAZIMIERZ J. ORLIK-RÜCKEMANN*
Tekn. D. (KTH), FCASI, FAIAA,

AIRCRAFT STABILITY PARAMETERS AT HIGH ANGLES OF ATTACK

The flight behaviour of an aircraft (or missile) can be modelled mathematically by a set of equations of motion that take into account the inertia, propulsion and aerodynamic characteristics of the aircraft as well as the effects due to gravity. The response of the aircraft to an intentional or unintentional disturbance (such as a control deflection, a change in power setting or an atmospheric gust) can be predicted by solving the equations of motion in terms of the variables of motion and their time rates of change. The variables of motion consist, in the simplest case, of three linear coordinates defining the displacement of the aircraft center of gravity from an equilibrium position and of three angular coordinates defining the angular displacements of the aircraft from its reference attitude around the center of gravity. The time rates of change of these variables consist of linear and angular velocities (and in some cases also accelerations) in the above mentioned degrees of freedom. Thus, the three linear degrees of freedom encompass translation in the longitudinal, lateral and vertical directions, whereas the three angular degrees of freedom consist of rotation in pitch (nose up or down), yaw (nose to the left or right) or roll (one wing up and the other down, or vice versa).

The aerodynamis reactions acting on the aircraft can be expressed in the form of three forces (drag, sideforce and lift) and three moments (pitching moment, yawing moment, rolling moment) in the same previously-mentioned six degrees of freedom. These aerodynamic forces and moments are represented in the equations of motion by the superposition of contributions caused by the various displacements and velocities (or accelerations). In the case of a linear variation of a given aerodynamic reaction with a particular displacement or velocity, the proportionality constant is called a **stability derivative,** the stability of the aircraft being the primary objective of a study of its flight behaviour. In a more general case, when the stability derivatives can no longer be considered to be constants, the term "stability derivative" may be replaced by "stability parameter".

It follows from the above that a complete set of stability derivatives could encompass as many as 108 derivatives of the various aerodynamic forces and moments due to the translational and rotational displacements, velocities and accelerations. The amount of analytical and experimental work that would be required to determine all these derivatives and the complexity of solving a set of equations containing all the necessary terms would be formidable. Fortunately, however, it can be shown that for an aircraft flying at a relatively low angle of attack and at zero angle of sideslip (i.e. approximately heading into the relative wind). the majority of all the theoretically possible derivatives either are zero, have a negligible effect on the resulting solutions of the equations of motion, or can be expressed by a combination of other derivatives, leaving only 12 to 15 independent derivatives that are considered significant enough to be retained in the mathematical model. Of these, the derivatives of the three aerodynamic moments are more important than the derivatives of the aerodynamic

---

* Head, Unsteady Aerodynamics Laboratory, National Research Council of Canada.

lift and sideforce (with all the derivatives due to drag usually ommitted from the stability analysis). The derivatives due to various (usually angular) displacements are called **static** derivatives, while those due to various (angular) velocities and (translational) accelerations are called **dynamic** derivatives. For flight at low angles of attack (and zero sideslip) the stability analysis is normally based on the use of 3 static moment derivatives and 5 to 8 dynamic moment derivatives (in addition to 2 or 3 force derivatives).

This relatively comfortable situation undergoes a drastic change when the flight envelope of the aircraft is extended to include maneuvers at high angles of attack. Such maneuvers have become typical of modern high-performance fighter aircraft as well as of the space shuttle orbiter. The resulting aerodynamic flow about the aircraft features many phenomena that are normally absent from the flight at low angles of attack; such phenomena include various forms of flow separation, cross flows, and the formation, shedding and bursting of vortices from both the forebody and the wing leading edges. These phenomena. in turn, give rise to all kinds of non-linear, unsteady and hysteresis-type flow effects, that are sometimes responsible for the occurrence of some of the stability and control problems known as "wing rock", "nose slice", etc., or that, in some cases, can precipitate an early spin departure.

The geometry of the typical modern fighter aircraft, with its long forebody, is particularly conducive to the formation and shedding of the so-called forebody vortices. These vortices, at high enough angles of attack, are known to shed in an asymetric fashion, giving rise to the occurence of lateral forces and moments even if the aircraft itself continues to head symmetrically into the wind (i.e. has zero sideslip). A further complication arises when the aircraft performs a rotary motion such as an angular oscillation, as often results after a disturbance. This introduces the time element into the already rather complex flow pattern. The vortices change their lateral and vertical positions as functions of the angle of attack which itself is a function of time. The various components of the aircraft. such as the fin and the horizontal stabilizer, move in and out of the local flow regions in which they are embedded. To make matters even more complex, all these motions take place not in a manner simultaneous with the motion of the aircraft, but with a certain delay, mainly due to the convective time lag. The delay is a function of the distance of the station under consideration from the station at which a particular flow phenomenon, such as the shedding of a vortex, occurs. Thus, lateral aerodynamic reactions that have components both in phase and out of phase with the motion of the aircraft can be expected to materialize, resulting in effects that have to be represented by means of both static and dynamic stability derivatives.

The asymmetric shedding of forebody vortices provides an example of a fighter aircraft experiencing lateral aerodynamic reactions when performing longitudinal maneuvers (changes in angle of attack). Another such example can be provided by aircraft equipped with the so called "direct sideforce controls". Such an aircraft can perform an equilibrium flight at a non-zero sideslip angle. Whatever the reason for the the asymmetric flow over the aircraft, its presence is conducive to the occurrence of static and dynamic lateral aerodynamic reactions (such as the yawing moment or the rolling moment) in response to the longitudinal maneuver (such as a pitching motion). Such effects are known as cross-coupling effects and the corresponding derivatives are called static and dynamic **cross-coupling** derivatives. These derivatives were virtually unknown a few years ago, and a considerable effort is now underway to develop methods to determine these new aerodynamic parameters and to incorporate them in the mathematical models of the aircraft flight behaviour.

The need to include the cross-coupling derivatives together with the need to recognize certain unsteady effects, that are normally small at low angles of attack, increases the number of parameters that should be considered for an analysis of flight at high angles of attack to 6 static moment derivatives and 12 to 15 dynamic moment derivatives, more than doubling the number required for the study of flight at low angles of attack. In addition, all the derivatives can now be expected to be strongly non-linear functions of the angle of attack, which makes the task of establishing a complete set of the required stability parameters even more demanding.

The Unsteady Aerodynamics Laboratory of the National Research Council has played a prominent role in identifying, at an early stage, the possibility of occurence of these special effects in a high-angle-of-attack flight, in developing the experimental equipment and techniques necessary to determine the new, never-before-measured stability parameters, in obtaining the first set of the pertinent experimental static and dynamic data, and in confirming, by means of a sensitivity analysis on a computer, the importance of including this kind of information in the mathematical model of the flight behaviour of a modern fighter aircraft (Refs. 1-2). This work had had appreciable impact on the international aerospace community, as witnessed by the well-attended 1978 Symposium on Dynamic Stability Parameters in Athens, Greece (organized and chaired by the undersigned) (Ref. 3), and the very popular 1981 Lecture Series with the same title (organized and directed by the undersigned) which was given at the NASA Ames Research Center in California and at the von Karman Institute in Belgium (Ref. 4). Both these events were arranged under the auspices of the NATO Advisory Group for Aerospace Research and Development (more specifically by its Fluid Dynamics Panel, of which the present author is the current chairman) and the attendance included participants from 12 countries.

References

1. Orlik-Rückemann, K. J. "Aerodynamic Coupling Between Lateral and Longitudinal Degrees of Freedom". AIAA 15th Aerospace Sciences Meeting, Los Angeles, California, January 1977; AIAA Journal, vol. 15, no. 12, pp. 1792-1799, December 1977.
2. Orlik-Rückemann, K. J. "Dynamic Stability Parameters at High Angles of Attack". 12th Congrerss of the International Council of the Aeronautical Sciences, Münich, W. Germany, October 1980; Proceedings, pp. 265-277.
3. Dynamic Stability Parameters, NATO AGARD FDP Symposium, Athens, Greece, May 1978; AGARD CP-235.
4. Dynamic Stability Parameters. NATO AGARD FDP Lecture Series, California and Belgium, March 1981; AGARD LS 114.

S. T. ORŁOWSKI
Dipl. Arch. M.Sc (ARCH), FRAIC, RIBA

ARCHITEKTURA W ORGANIZACJI BUDOWNICTWA SZKOLNEGO

O wydziale badawczym planowania szkół w Ontario

Każda praca zawodowa ma swoje różne okresy — jedne pełne zadowolenia z osiągnięć, inne pełne mozołu i monotonne, a także okresy wyjątkowo ciekawe, które najlepiej zapisują się w pamięci.

W pracy architekta najważniejszą rzeczą jest wzgląd na człowieka, dla którego tworzymy środowisko. Pominę tu ciekawe rozwiązania nowych domów mieszkalnych, które mają za zadanie zadowolenie tylko jednego klienta, mającego przeważnie swoje określone wymagania — wie co chce, a zajmę się tematem ogólniejszym — wpływanie na zmianę i poprawę otoczenia ludzi, którzy wracają do domu po ciężkim dniu pracy nie mają siły ani koncepcji, by sami wpłynąć na jakiekolwiek zmiany czy ulepszenia.

Wykształcenie architektoniczne przygotowuje nas nie tylko do rozwiązań technicznych projektów, ale także skłania nas do szukania nowych dróg do prac badawczych.

Szczęśliwym zbiegiem okoliczności oraz dzięki mądrości ówczesnego ministra szkolnictwa p. William Davis w latach 60-tych, kiedy przeżywaliśmy rozwój szkolnictwa i budownictwa szkolnego, powstał wydział badawczy planowania szkół w ministerstwie. W tym samym czasie powstała też koncepcja założenia wyższych szkół zawodowych.

Wydział ten postawił sobie za zadanie:

a) Kierownictwo i pomoc w przewidywaniu przyszłych potrzeb budynków szkolnych, dociekanie bieżących potrzeb celem właściwego wykorzystania istniejących budynków w obliczu nowych wymagań programowych oraz szukanie nowych rozwiązań technicznych i zastosowanie materiałów, które pozwoliłyby na uzyskanie optymalnej wygody z zachowaniem ekonomii, stylu i konstrukcji.

b) Ustalenie potrzeb istniejącego programu edukacyjnego i przewidywanie zmian, które mogą zajść na skutek rozwoju systemu nauczania i wprowadzenia nowych programów w szkołach podstawowych, gimnazjach i szkołach zawodowych pogimnazjalnych oraz w szkołach specjalnych dla głuchoniemych, niewidomych oraz dla dzieci i młodzieży z zaburzeniami psychicznymi.

c) Publikowanie broszur informacyjnych traktujących o powyższych zagadnieniach w oparciu o badania tegoż wydziału, dla użytku administratorów i rad szkolnych, pedagogów, architektów, urbanistów i inżynierów.

Grupa architektów zajmująca się badaniem i przygotowywaniem do druku ilustrowanych publikacji wzrosła z początkowej liczby kilku zaledwie osób, do 22 architektów.

W okresie rozkwitu prac badawczych przygotowano i wydano około 40 prac, które udostępnione były wszystkim instytucjom szkolnym w Ontario oraz w innych prowincjach a także instytutom badawczym budownictwa szkolnego w innych krajach, kontynentalnym oddziałom UNESCO i szkolnym władzom w ponad 25 krajach. Wiele z tych publikacji zostało przetłumaczonych, względnie przedrukowanych przez inne państwa.

Główną zasadą we wszystkich publikacjach była zwięzłość i jasność języka. Dodatkowym czynnikiem pomocniczym były graficzne ilustracje oraz estetyka. Treść publikacji była przygotowana w ten sposób, by zarówno osoby pobierające decyzje o rozwoju szkolnictwa a także architekci mogli korzystać z materiału tam zawartego. Ilustracje i wykresy pozwalały na zrozumienie idei nawet w wypadku małej znajomości języka angielskiego.

40 lat polskiej myśli inżynieryjnej w Kanadzie. Biul. STP 3/81

W czasie wystaw prac badawczych i architektonicznych zarówno w Kanadzie jak i za granicą publikacje nasze przyciągały oko zainteresowanego swoją elegancką prostotą. W roku 1974 na Międzynarodowej konferencji w Berlinie publikacje te cieszyły się największą popularnością na wystawie, do tego stopnia, że trzeba było okładki przybić gwoździami do stołów, bo znikały.

W ocenie największego Centrum badawczego budownictwa szkolnego w Stanach Zjednoczonych (Educational Facilities Laboratories, New York) finansowanego przez Fundację Forda, publikacje Ontaryjskiego Ministerstwa Edukacji zasługiwały na najwyższe wyróżnienie. Dzięki temu wielu Kanadyjczyków i instytucji kanadyjskich otrzymywało fundusze na prace badawcze.

Usługi konsultacyjne naszej sekcji dostępne były wszystkim osobom czy instytucjom zaangażowanym w budownictwie szkolnym — np. współpracowano z Federacją nauczycieli w Ontario i innymi instytucjami. Ponadto utrzymywany był kontakt z innymi prowincjami Kanady, z agenturami UNESCO i innymi grupami badawczymi. Wynikały z tego ciekawe kontakty czy to z daleką Nową Fundlandią w Kanadzie, czy też słoneczną Bermudą na południu i wiele, wiele innych.

Raz w roku z początku, a potem częściej organizowane były konferencje celem:

a) Porównania i wymiany zdobyczy badawczych pedagogów i innych osób odpowiedzialnych za kierownictwo i planowanie w dziale pomocy naukowych w Ontario.

b) Dalszego rozwoju filozofii nauczania i skrystalizowania zamierzeń i celów czynników oficjalnych oraz osób indywidualnych zainteresowanych przedmiotem.

c) Przekazania wyników prac badawczych sekcji, wymianie idei i przedstawienia problemów pedagogom, administratorom, architektom, inżynierom oraz fabrykantom biorącym udział w konferencjach.

Konferencji takich odbyło się około 20 a w tym 4 wielkie konferencje poświęcone programowaniu i planowaniu wyższych szkół technicznych w Ontario.

Konferencje te nie tylko gromadziły siły wykładowe z Kanady, ale także brali w nich udział specjaliści w dziedzinie planowania środowisk szkolnych od szkół podstawowych do uniwersytetów włącznie z innych krajów. Uczestnicy konferencji oceniali te spotkania bardzo wysoko.

W dyskusjach nad planowaniem szkół brali udział poza architektami i inżynierami oraz ekonomistami — pedagodzy, wybrani członkowie rad szkolnych, politycy, przedsiębiorcy budowlani, przedstawiciele związków zawodowych a także ludzie, którzy codziennie opiekują się utrzymaniem budynków. Chodziło bowiem o to, by całe społeczeństwo wiedziało co się robi i mogło partycypować w planowaniu.

Do zespołu, który pracował nad badaniami do roku 1972, a był właściwie jedyną taką grupą w Kanadzie, wchodzili Kanadyjczycy (rdzenni) oraz Anglosasi, Polacy, Duńczyk, Egipcjanin, Niemiec, Chińczyk i Japończyk. Było to małe biuro międzynarodowe reprezentujące ogromny wachlarz doświadczeń zdobytych często poza Kanadą. Dzięki szerokiej wiedzy i entuzjazmowi grupa ta przyczyniła się do powstania w Ontario najbardziej interesujących budynków edukacyjnych.

Już 1 września 1967 roku 22 College w Ontario przyjęły studentów rozpoczynających nowy typ studiów. Pomieszczenia w tym czasie były różne — opuszczone budynki fabryczne, prefabrykowane budynki i klasy oraz dawne centra zawodowo-techniczne.

Utworzenie tych College'y w bardzo krótkim czasie było nielada wyczynem. Program budowy nowych ośrodków nauczania w całym Ontario wymagał ustalenia obejmujące:

a) Program edukacyjny z opisem pomieszczeń przygotowany przez ciało pedagogiczne.

b) Program architektoniczny wraz z planem dalszego rozwoju.

c) Szkice i wstępny kosztorys.

d) Rysunki i specyfikacje z ostatecznym kosztorysem.

e) Przetarg i budowa.

W rezultacie stałej kooperacji pomiędzy biurem planowania i czynnikami nowopowstałych College'ów mamy dziś w Ontario 22 uczelnie z 106 centrami nauczania. Istnieją one celem udostępnienia ludności całego Ontario możliwości kontynuowania nauki i przygotowywania do różnych zawodów.

Architektura i inżynieria tych budynków oraz ich wyposażenie należy do najciekawszych nie tylko w Kanadzie ale też w świecie.

Wiele zadowolenia miałem kierując tą komórką w Ministerstwie. Pragnę jeszcze wspomnieć oddzielnie dwoje architektów — Polaków z tej grupy a mianowicie Marynę Pain oraz Wojtka Kubickiego.

Maryna Pain, która ukończyła architekturę na PUC'u w Londynie, była nie tylko wybitnym architektem ale też uzdolnioną malarką. Odpowiedzialna była w naszej grupie za przeprowadzenie badań nad potrzebami szkół dla upośledzonych. Była to praca pionierska wymagająca dogłębnych konsultacji z nauczycielami, psychologami etc. Rezultatem tych żmudnych dociekań były wydawnictwa: "Special Education Facilities for Emotionally Disturbed Children" oraz "Schools and Playgrounds for Trainable Mentally Handicapped Children", cieszące się wielkim uznaniem nie tylko w Kanadzie ale i za granicą. Zbudowane zaś budynki szkolne i rezydencje dla dzieci i młodzieży wymagających specjalnych warunków ze względu na ich upośledzenia, będą trwałym pomnikiem dla upamiętnienia wkładu pracy Maryny Pain, która zmarła przedwcześnie w wieku lat 52.

Wojtek Kubicki, absolwent Politechniki Warszawskiej, cichy, spokojny, zdolny architekt i genialny ilustrator odpowiedzialny był za szatę graficzną naszych publikacji. Jego proste a pełne wyrazu ilustracje oddawały treść zawartą w broszurach, pomagały lepiej zrozumieć nasze założenia. Wykresy i ilustracje pozwalały nawet osobie nie mającej nic wspólnego z architekturą lub mało znającej język angielski odczytać treść pracy.

Tu pragnę dodać, że pomysłowe rysunki czy karykatury Wojtka Kubieckiego często ozdabiały mój gabinet.

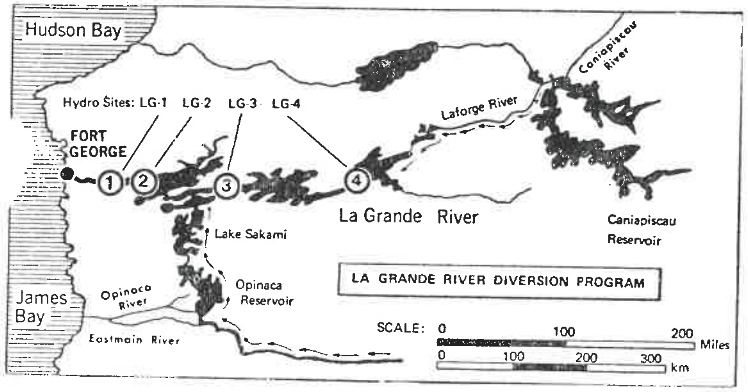
Cieszę się, że mogłem brać udział w całym tym przedsięwzięciu, co chociaż wydział badawczy planowania szkół w ministerstwie już nie istnieje, to owoce tej pracy pozostały i służyć będą następnym pokoleniom.

INŻ. S. A. PURSKI*

PROJEKT SIŁOWNI WODNYCH KOMPLEKSU LA GRANDE W QUEBEC

Kompleks La Grande największą budową naszego stulecia? Chyba tak. Położony na północy prowincji Quebec w Kanadzie, swoim obszarem pokrywa 176,,000 kilometrów kwadratowych, czyli mniej więcej powierzchnię równą 56% obecnego obszaru Polski.

Oprócz innych, wody głównych rzek tego obszaru, a więc rzek Opinaca, Caniapiscau (poprzez Laforge), po całkowitym zakończeniu budowli piętrzących, kanałów itp., spływać będą do głównej rzeki La Grande wpadającej do zatoki James. Na tej właśnie rzece, w szybkim tempie, postępuje budowa czterech siłowni: LG 1, LG 2, LG 3 i LG 4 (patrz rys. 1). Decyzja budowy zapadła w 1971 r. Właściwa praca rozpoczęła się na dobre w 1975 r. Planowane jest zakończenie pierwszej fazy Kompleksu La Grande, obejmującej siłownie LG 2, LG 3 i LG 4, o łącznej mocy 10,269 Megawatów, w 1985 r. Druga faza Kompleksu z elektrowniami LG 1, LA 1, LA 2, Brisay, EM 1 i EM 2 dorzuci dalsze 3,293 Megawaty. Razem więc łączna moc Kompleksu La Grande będzie 13,562 Megawaty, a za tym swą mocą przewyższy siłownię brazylijsko-paragwajską Itaipu budowaną obecnie na rzece Parana w Południowej Ameryce. Elektrownia Itaipu, uważana dotychczas za największą na świecie, będzie miała 18 turbin po 700 Megawatów, czyli razem 12,600 Megawatów.



W związku ze światowym kryzysem energetycznym, przystąpiono również w Quebec do wstępnych studiów siłowni na rzekach Nottaway, Broadback i Rupert (Kompleks NBR) wpływający także do zatoki James, ale bardziej na południe od rzek Kompleksu La Grande (patrz rys. 2).

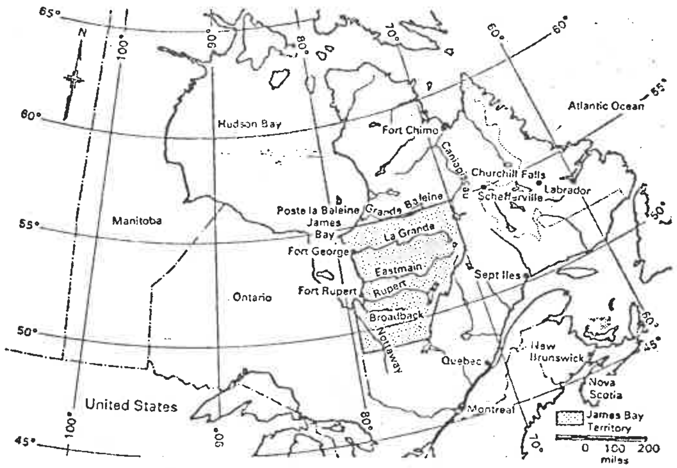
Nie jest celem tego krótkiego artykułu podawanie zbyt wielu szczegółów i opisywanie problemów technicznych, które trzeba było pokonać i które jeszcze stale piętrzą się przed projektantami i budowniczymi. Ukazało się już sporo publikacji w związku z tym kolosalnym przedsięwzięciem, między innymi, w numerach z lipca i sierpnia 1976 r. miesięcznika brytyjskiego "Water Power & Dam Construction", w kanadyjskim czasopiśmie "Heavy Construction News" z 20 czerwca i 1 sierpnia 1977 r. itd. Bardziej

---

* Konsultant, Biura Projektów Rousseau, Sauvé, Warren et Associés, Inc., Montréal.

zainteresowani mogą tam znaleźć te szczegóły. Raczej intencją jest tutaj zwrócenie uwagi ogółu czytelników.

Na ten szalony wysiłek technologiczny i fizyczny, którego podjęła się ludność tej prowincji licząca około sześć milionów, ludność, która zachowała od pierwszych dni osiedlenia się poza oceanem swego zahartowanego trzema wiekami ducha pionierskiego, niestety tak rzadko teraz spotykanego na świecie. Bez tego ducha, zapału i sprawnej organizacji, realizacja projektu w warunkach podarktycznych byłaby wprost niemożliwa. Należałoby sobie życzyć aby, być może za parę lat, ktoś tak mógł pisać o projekcie Wisła!



Trzeba również podkreślić, że całe projektowanie jak i budowa są dziełem Quebec, a olbrzymia część wyposażenia i materiałów jest produkowana właśnie w tej prowincji. Jest to możliwe ponieważ jest tutaj cały szereg biur projektów czołówki światowej wyspecjalizowanych na tym polu i z długoletnim doświadczeniem opartym także na eksploatacji źródeł energii wodnej w najrozmaitszych warunkach klimatycznych. Właśnie w Quebec znajdują się chyba największe na świecie zakłady mechaniczne, projektujące i budujące turbiny wodne, a także przeprowadzające badania modelowe.

Wiele różnych artykułów z wykresami, tabelami i zdjęciami dodatkowo ilustrują ogrom Kompleksu La Grande. Na zakończenie należy nadmienić, że już 1 października 1979 r. o godz. 19:45 popłynął liniami wysokiego napięcia pierwszy prąd z pierwszej turbiny do Montrealu, a więc na parę miesięcy przed przewidzianym terminem, a uroczysta oficjalna inauguracja, przy udziale gości z różnych stron świata odbyła się 27 października 1979 r.

W. SIECIECHOWICZ, Eng. Arch., MRAIC

CARE OF HANDICAPS

By coincidence 1981 is the Year of the Handicapped as well as the anniversary of the Association of Polish Engineers in Canada. Such a state, for us, was social and temporary. Here we shall be concerned with the severely handicaped whose physical state is permanent.

Hanicapped people are described in Ontario Legislation as people with any degree of physical disability, infirmity, malfunction, or disfigurement.

Our society actually discriminates against this group of people. Imagine a person who can hardly hold a pencil with his fingers trying to turn a door knob which is designed for a person with a strong grip; or, a person who can hardly push his wheelchair with his frail and disfigured arms, coming against an insurmountable obstruction — a street curb. This form of discrimination was officially recognized by provincial authorities in the mid 1970's. As a result, we now provide, in all our new public buildings, sanitary facilities which are suitable for wheelchairs; we cut curbs to form short ramps; and in all public places we provide ramps alongside stairs. A good example of this new approach is the new Eaton Center, which has many ramps.

It is estimated that 10% of the population of Ontario is handicapped, and a third of this group is severely handicapped. In spite of the fact that such a large proportion of our population is severely handicapped, virtually no attention was paid to their needs up until the late 1960's.

An Ontario Parent Group whose children were severely handicapped, decided to do something about the plight of their children. They decided to build a home which would provide for the future needs of their children even if it had to be built without the aide of the government. The Parent Group approached business people, service clubs, organized telethons and walkathons, and collected enough money to start thinking about building a home designed especially for the requirement of the severely handicapped. It should be noted that severely handicapped people require 100% attention.

Prior to the action of the Parent Group, young handicapped persons stayed in a Home for Crippled Children, but when they reached the age of sixteen they would graduate into oblivion. There was nothing provided for them. If their parents were still alive and able to take care of them, they might go home, but if not, they would have to go a mental institution, or they were very lucky if they able to get into an Old Peoples Home or a Nursing Home. This was a tragic situation because many of these people, though physically disabled, were mentally alert, and in many cases they had more than average intelligence.

I joined this committee and dedicated Parent Group in the late 1960's. After several meetings the basic programme for the Home was established. It was decided that the building should not accommodate more than 36 permanent residents, preferably in single bedrooms. In addition, there should be several units for temporary residents, called Parent Relief Service. This Service would provide a handicapped person with a place to stay should the parents wish to go on a holiday, or, in an emergency should the parents require hospitalization. In such situations the handicapped person could come to the Home on a temperary basis for two to three weeks.

This Home was to be called Participation House. It would serve a wide range of handicapped people; people with multiple sclerosis, paraplegics, but most of the residents were to be from the cerebral palsy group.

Cerebral Palsy is not a disease. It is not an illness. It is brain damage to the motor areas of the brain. I understand that damage occurs, in most cases, at birth.

The form of the disability varies greatly. A very mild case of Cerebral Palsy might not be noticeable from the outside. The person may be able to speak with only a very slight impediment, but when you shake his hand, the grip will be light and not evenly controlled. The other extreme is a person whose muscle control is very erratic; speech is impaired, and often is only an undecipherable noise; movement is jerky and the body may be severely distorted. Such a person may only be able to move about in a wheelchair with assistance, and some individuals must have especially designed aids in order to support them in reasonable comfort.

To design a living environment for such a group proved to be an interesting challenge. There was not a single structure in North America that satisfied the requirements of the severely handicapped. I had to depend entirely on my own research and judgement. I selected twenty-two future residents, young and old, men and women to visit and to get to know. I visited them several times at their places of residence.

To establish their needs and requirements was not so simple. It was difficult to communicate with them, they were very withdrawn, and did not feel comfortable with strangers. But even this was a lesson for me. At first, I observed them from a distance, so that they would be unaware of their being watched, and not disclosing my interest in their actions and behaviour. After several visits, many of them started to open up. If they could not answer my questions verbally, they would answer by trying to smile or 'talked with their eyes'. As one of the mothers told me: "Poor Karen, you would think that she is a vegetable, but look into her eyes, and you will see my beloved Karen".

Visiting these people in institutions was a sad experience, as many of them were in an hospital environment and they were not sick, or, they were in mental institutions and their eyes told me that they did not belong there, or, they would be in an Old Peoples' Home, though they were only eighteen years of age.

I met Betty in her parent's home. As I talked to her parents, she wheeled her chair into the room, went right into the corner, complained about something in an inaudible voice, and started to scream. The screaming lasted for several minutes... her mother went to talk to her. There was no response. Her parents had to wheel her out of the room and we could continue our conversation. The observation here was one of noise, but I never realized that in Betty's case there was a psychological reason — she was frustrated. Several weeks later I met her again. She was happy to see me and showed her hapiness in her smiling eyes and she gave out a noise, which again only a mother could understand, but I thought that she recognized me and wanted me to be there. She accepted me as a friendly person who would not laugh at her but who would accept her naturally.

I met Paul in an Old Peoples' Home. He was a handsome twenty year old. He had distorted limbs, and so could barely operate his wheelchair, but his head movements were well-controlled as he had healthy and strong neck muscles. Paul had graduated from high school and liked writing. His father had bought him a typewriter and he communicated to us by punching letters on the typewriter with a pencil-like gadget strapped to his head.

Having accumulated masses of observations I started to design a building which would satisfy their specific needs. As I said before, most of the people displayed a reservation towards strangers — we provided them with a landscaped interior courtyard so they could be happy among themselves, or, with the people they knew well.

They like to wander around 'to go for a walk' in their wheelchairs — we located the building close to a residential area, so they can explore the residential neighbourhood, and during the harsh Canadian winter time we provided them with rather long corridors, with changing directions and vistas.

They like to get out of their wheelchairs, to stretch on the floor, to find comfortable positions for their distorted bodies — we gave them a room with thick padded carpet.

They seemed to enjoy relaxing in the buoyancy of water — we provided them with a hydro-therapy room, and so on.

I may add that we provided them with several therapeutic areas, but they are not in a pure sense therapeutic activities which improve physical conditions. These activities are designed to give the residents a daily occupation, relaxation, or to restore any physical capacities which were neglected or temporarily lost when they lived elsewhere.

The residential area consists of pairs of single bedrooms, connected by washrooms for economy. One Home unit consists of six single bedrooms with a specially equipped bathroom and a common room. Six Home units are connected by a corridor which continues further to the daily activities area, and which encloses the central courtyard.

The daily activity area includes the very popular workshops, dining room, involvement center and hydro-therapy pool.

It is a pleasure to see residents and others sitting in the workshop struggling very hard to complete some small assignments. In the case of Paul, he would have a tool strapped to his head so that he can push nuts and bolts into a plastic container, which will then be closed by someone else who is able to do that task. Production here could not be classed as efficient, but whatever it is worth to the client, the residents are paid for their work and they share equally in the income.

After we completed construction of the building, I visited my handicapped friends many times. We found that the residents after having lived in their new home only a short time had changed favourably beyond recognition. They were clean, happy and independent. Karen would smile to me with her big expressive brown eyes; Betty screamed to me as loudly as before, but no longer from frustration, but from happiness. I wandered among them and thought what is the real reason for such drastic changes, and I think apart from the physical environment which suits them, a feeling of independence, security and friendly togetherness creates an environment of happiness.

Since that time we have built three more Participation Houses, providing a happy environment for only a fraction of the need in Ontario.

W. Z. Stepniewski

OVER THE CRADLES OF THE DHC* CANADIAN MOSQUITO, BEAVER, AND CHIPMUNK

Personal reminiscences

Immediately after the surrender of Japan, the vigorous, but surprisingly even-keeled and panic-free activities with which the de Havilland of Canada plants had been humming through the war years ceased with unreal suddenness. I tmust have been with mixed emotions that the hordes of office and plant workers — many of whom were very attractive females in shapely overalls and tight-fitting pants — left plants through now familiar gates — many for the last time. No doubt, for some, it would entail personnal hardships and uncertainty regarding future employment, now that their war efforts had attained a successful conclusion. However, the departing employees could take pride in their accomplishments, as witnessed by over one thousand de Havilland Tiger Moths, built in the DHC plants, as well as by the hundreds of British-produced Avro Ansons which had been converted from bomber to trainer configurations. Both aircraft had been distributed to various flying centers located throughout Canada, and had represented a significant contribution to both primary and advanced training of thousands of allied pilots and navigators (many of them of the Polish Air Force). While these, indeed, were important accomplishments; undoubtedly the Canadian Mosquito, as one of the most famous fighter-bombers of World War II, symbolized their ultimate pride and accomplishment. One thousand thirty-four Mosquitos were built at DHC plants and they, with their English "brothers", played an important role in the conquest of Nazi-dominated Europe.

As I passed through the plant gates with the departing throng, I shared many of their thoughts — with one significant exception. For me, this was not for the last time. Because of my previous involvement with the development of the Beaver and the more recent Chipmunk, the following Monday I would return to the smaller, but still vigorous, de Havilland of Canada.

As the process of the company's contraction from one of the major allied aircraft producers had been sudden, its rebirth and growth to its former position of prominence; especially at the beginning, was rather slow, and often, painful.

Prior to the War, DHC had been a relatively small outfit established by the parent company — de Havilland of England — as a production plant and a service depot for the DH aircraft. This Canadian branch was under the general management of a good-natured, even-tempered, generally charming, and able pilot, P. C. Garratt.

With the outbreak of the War, but especially after the fall of France and the intensified bombing of England, it became necessary to expand, and expand again and again, the aircraft-producing facilities outside of the British Isles. In this respect, Canada, because of its proximity to the then officialy-neutral, but friendly, industrial giant of the USA, appeared as one of the most desirable spots for developing large-scale aircraft production facilities.

The task of acquiring new production and office buildings plus manufacturing equipment, although not an easy one could, and was brilliantly accomplished using chiefly Canadian managerial, labor, and material resources, plus US machinery.

However, it was more difficult to find experienced aeronautical engineers in

---

* de HavillandAircraft of Canada.

sufficient numbers to form even a nuclei of technical organizations capable of guiding design modification and production of already developed aircraft, let alone even dreaming of designing and developing new prototypes. Because of this situation, the eyes of the de Havilland management in both England and Canada, and the Canadian government, turned toward the Polish aeronautical engineers already in England, as well as those who, after escaping from the Nazi-occupied or Nazi-controlled parts of France, were slowly, but steadily, making their way toward neutral Portugal — often with forced stops in the concentration camps and jails of the then Facist Spain and French North Africa.

An agreement between the Canadian government and the Polish Government in Exile opened the way for the transfer to Canada of dozens of Polish aeronautical engineers who, at the time, were either in active service or at the disposition of the Polish Air Force. But, since there is probably no government in the world, even under urgent war-time conditions, that can function without red tape — entanglements developed regarding payments for transportation and similar seemingly trivial matters. At this point, the de Havilland Company greatly contributed to cutting through the red tape by guaranteeing the cost of transportation of the Polish engineers to Canada to the tune of a very high (at that time) sum of $200,000. All costs of transportation were later repaid by the engineers.

I believe that de Havilland's financial guarantee was obtained largely due to the actions of W. J. Jakimiuk, the well-known designer of the Polish PZL fighters, including the very advanced Jastrzab, the Hawk, and a commercial transport. Jakimiuk had had pre-war connections with the parent de Havilland Company in England. They knew him, not only through his professional reputation, but also personaly which, undoubtedly contributed to his selection as Chief Designer of the DHC. Thus, he was the first of the Polish aeronautical engineers to arrive in Toronto — either at the end of 1940 or the beginning of 1941. He immediately began to assemble his engineering team, including as many aeronautically experienced Poles as practically possible.

Through mysterious doings of various governmental agencies, a group of Polish aeronautical engineers in London (some of who, myself included, were fortunate to have their wives with them) was ordered to Greenock in Scotland where, on the first of March 1941, they boarded the Polish translantic ship, "Batory". Our ship was shortly joined by two fast merchantment, and our little convoy sailed for an unknown (to us) port in Canada.

Our convoy probably contained a more valuable cargo than a few Polish aeronautical engineers, since we were escorted by four destroyers to the extent of their radius of action. An antiaircraft cruiser was with us until we passed out of the range of the German land-based aircraft and the battleship Revenge chaperoned us throughout the entire voyage.

Except for a few U-boat alerts accompanied by cannonades of depth-charges and sightings of miles and miles of debric from ill-fated ships, the crossing, although rough, was otherwise uneventful, and on the 10th of March, we reached Halifax in Nova Scotia.

After a coupe of war-years in Europe, Canada appeared to us unreal: lack of blackouts, and plenty of fresh fruits — especially oranges — somehow impressed us most.

A brief stop at the hospitable home of Consul and Mrs. Brzezinski (parents of a young boy, Zbig, who was to become the National Security Advisor to President Carter) and then to Toronto, and the beginning of my most pleasant 5-year association with de Havilland of Canada.

W. Czerwinski and I were the first to join the Jakimiuk team, and, in rapid succession, other Polish aeronautical engineers began to arrive at DHC. Efforts, later crowned with success in July, were being made to get T. Tarczynski out of Portugal.

A few months after our arrival, it became clear that shortly, production of the Tiger Moths and modifications of Avro Ansons would cease, and all the efforts of de Havilland of Canada would be concentrated first on engineering modifications of the Mosquito, as required by the installation of US-produced Packard-Martin engines, and then continuous production of those aircraft. This decision was accompanied by a mostly politically motivated change in the top management, wherein Garratt was replaced as a General Manager by a young energetic lawyer — politically close to the Central Government in Ottawa.

However, engineering remained firmly in the hands of the de Havilland Company. Here, the field was dominated by the towering (both physically and mentally) personality of Jakimiuk. In addition to all his technical qualifications, he spoke English well, and could, in an almost opera-quality bass-baritone, sing a vast repertoire of songs from operatic arias to folk melodies. He had a charming good-natured French-English wife, Mary, whose memory can never be erased from the hearts and minds of all the Polish engineers and their wives who were fortunate enough to have met her socially.

When we arrived, Jakimiuk was already well established both technically and socially. He had become a member of the prestigeous Granite Club — an exceptional feat for a newcomer in the ultra-consrvative, very English, Toronto of those days.

In addition to Jakimiuk, there were quite a few Polish engineers within the organization who were nursing in one way or another the fledging Canadian Mosquito. One of them, Czerwinski who, as one of the leading designers of the very successful gliders and high-performance sailplanes in Poland as well as an advanced twin-engined trainer Wyzel (the Setter), had a wealth of experience, especially in wooden constructions — an attribute of great value in the case of the Mosquito — an aircraft almost entire made of wood. It is of no wonder, hence, that he was considered as a final authority in problems related to the technology and design of all wooden components. While at DHC, he also designed plywood wings as a replacement for the war-shortage-affected aluminum ones for the North American Harvard trainer. In addition, he guided a team of Canadian-Polish enthusiasts from DHC who designed and built a glider called the Sparrow, which Tarczynski flight-tested, and in which our Canadian friends, under the guidance of their Polish colleagues, were learning to fly.

Along with Czerwinski, the Mosquito airframe design problems were also getting a helping hand from K. Korsak and T. Tarczynski. K. Korsak, a mercurial chap always ready for a practical joke, or a technical invention, first served in PZL as an assistant to Jakimiuk until he became head of his own design team, developing a light-weight fighter, Sokol (the Hawk). Tarczynski, who was also a PZL graduate, had served as a co-designer of the all-mental twin-engine fighter-bombers, the Wolf and Lampart (the Leopard). He also had wood-design experience, due to the sail planes that he and I designed together.

Powerplant aspects were under the watchful eye of K. Ksieski, an experienced engine designer from the Engine PZL, while Z. Jarmicki was taking care (as in the pre-war days in PZL) of the fuel systems, and W. Kulej was knowledgeable of the mysterious electric currents running through the body of the Mosquito.

Aerodynamics, stress, and some technological aspects were my responsibility as the head of the Aerodynamic and Structures Divisions of Engineering.

Our Canadian colleagues exhibited a greatly appreciated friendliness toward us which, in spite of the language barrier, guided us into closer and closer mutual relationships, often resulting in lifelong friendships. The unquestionable champion among our guides was my associate; a young Canadian engineer, Lawrence Janis. Perhaps because of his Greek origin, he poccessed a unique talent for languages, and almost from the beginning, as we were acquiring subtleties of the English language from him, he was learning Polish. At times, we wondered if it would not be easier to teach the whole engineering staff Polish than to elevate our own English to a workable level. Unfortunately, not all of our Canadian colleagues were as talented as Janis ("twój dobry przyjaciel"): **"your good friend"**, he used to say, so we had no alternative but to mutilate and torture the King's English in our process of learning.

Personally, I was doubly fortunate in regard to my linguistic problem: in addition to Janis, Ben Etkin, a young graduate of the University of Toronto, entered my orbit. He was later to become an internationally known professor and Dean of Engineering at that university. With his help, my reports and memos had risen to a professional level.

From the perspective of the present, it appears that not much time had passed before the doors of the assembly bay daily began to open more and more frequently, rolling out Mosquitos.

Personally, I have never had the thrill of riding in that famous aircraft, and I believe that from our Polish DHC group, only Jakimiuk and Tarczynski were fortunate enough to achieve that goal.

Although Mosquito production was running at full speed, and thus required the continuous support of Engineering, Garratt and the rest of the original Canadian de Havilland management, as well as the parent company in England, came to the conclusion that at least some low-level effort should be directed to the development of a new aircraft to be produced at the Canadian plant to ensure against sinking to pre-war levels during the transition to peacetime conditions.

It was hence decided in 1943, or perhaps even earlier, that a new aircraft should be developed that would be aimed toward the Canadian market; especially, to bush-type operations. It was appropriately to be named the Beaver.

Jakimiuk was the guiding spirit of the effort directed toward putting those ideas into practice. He tried to get as much information as possible about the practical operational aspects, often personally interviewing bush pilots and operators. I believe that Garratt while still on the sidelines, but especially after his return to the helm DHC after V-J Day, showed a keen interest in the technical specifications and basic concepts of this future, specifically Canadian, aircraft.

The Beaver was supposed to the "at home" on any of the three basic elements of the Canadian landscape: water, snow, or dry land. However, special emphasis was placed on water-borne operations, since experience had shown that the countless lakes of Canada provided the most versatile, readily-available base for bush-type activities. At one point, it was discussed whether the Beaver should be an amphibian of the haul type, or have floats. The float configuration was selected because of many practical operational advantages; for instance, ease of docking, and some other aspects that could be easily overlooked by those who are not intimately familiar with bush flying. For instance, the fact that canvas could be stretched between the floats was of importance to future operators. This piece of fabric would provide a very handy "catcher" for tools and small parts which might be accidentally dropped when servicing the engine at the dock.

The decision to go for the float-type configuration was very fortunate for the Beaver's future. By replacing the floats with a wheel-type landing gear, the aircraft would acquire the configuration that made it so popular in many countries of the world and in which it appeared as the "work-horse" of the U.S. Army.

I don't believe that other Polish engineers other than Jakimiuk and myself were involved in the concept-formulation of the Beaver. My personal contribution was limited to the selection of the wing airfoil section and planform, plus type and shape of the flaps. Aerodynamic and structural aspects of the actual design of the aircraft were guided by my successor, Dick Hiskock, who later took Jakimiuk's place as Chief Designer and became a guiding spirit of the development of such highly sucessful DHC aircraft as the Otter and the Caribou.

As supposedly the first-born post-war product of DHC, the Beaver was the result of a well-planned parenthood and the high hopes of the company rested with that aircraft. In many respects, the original plans and hopes were fully realized, and often exceeded all expectations — with one exception: the Beaver missed its distinction of being the first post-war, as well as the first original design of DHC. The agile little Chipmunk suddenly appeared from nowhere; or more strictly, was conceived as a result of a suggestion from the parent company in England, and captured the honor of being the first born.

Around V-E Day, the parent company indicated that after the war, there would be a need for a primary two-seater trainer, and that DHC should design and build such an aircraft. Small-scole preliminary efforts in that direction started shortly after the cessation of hostilities in Europe, and the name Chipmunk was selected for the machine. However, full-scale activities began shortly after V.J Day and sudden transition of DHC from a Government-controlled company to its original organizational form took place under the stewardship of Garratt. Even in the changes of the top management, Jakimiuk remained as a rock in his position of Chief Designer. As to myself, about fifteen minutes after termination of my employment with the war-time company, I was formally rehired by the civilian DHC. As to the other Polish engineers; by that time, practically all of them had found employment in other aeronautical companies either in Canada or in the USA, or were heading for other fields of activities, including small private enterprises of their own.

With respect to the technical aspects of the Chipmunk, it was decided that in spite of definite production advantages of a rectangular wing with a constant section, the wing should be tapered because of better aerodynamic characteristics as well as esthetic appeal. As to flying qualities, it was decided that the Chipmunk should be basically a pilot's machine with quick positive response to control inputs, while still retaining a good degree of static and dynamic stability and absence of any viscous stall characteristics. My efforts were directed toward achievement of those flying qualities and generally good aerodynamic characteristics.

In order to obtain gentle stall, a highly-cambered airfoil (USA B35) was selected for the tip section, while the root section consisted of the NACA 2415 airfoil, resulting in an aerodynamic washout of a few degrees. Intermediate airfoils were developed as cross-sections of a truncated cone extending between the NACA 2415 and USA B35 airfoils. The walls of the cone were formulated by straight line joint points having tangents of the same inclination on the contour of the root as well as on the tip sections. In this way, single-curvature of the wing was obtained; thus it was not necessary to stretch the metal sheets on the D-spar and a smooth surface of the fabric-covered aft portion of the wing was assured.

Attention to stability characteristics, relations betweent g's and control displacements, tailoring of flap characteristic, etc., produced a machine that indeed, won the approbation of the pilots.

A Canadian-Polish triumvirate, under the general chairmanship of Jakimiuk, guided the design of the Chipmunk and implemented the above-outlined objectives. This rather informal body consisted of Fred Buller, Ken Smith, and myself. Ken and Fred took care of the airframe design and powerplant installation; while aerodynamics, stress, and some technology aspects constituted my share of the technical pie.

During our frequent contacts throughout the work day, as well as during lunch periods and good traditional tea breaks, we forged a harmonious cooperation, probably made even easier by the fact that the three of us possessed a highly developed sense of humor. This helped to eliminate the tension and stress inherent in our work. Working with Jakimiuk, those two gentlemen, and other members of the design team, and watching the smooth progress of the design of the Chipmunk, I was experiencing a feeling of "job satisfaction" to a degree not often encountered even in our highly-motivated profession.

Nevertheless, the lore of the new field of rotary-wing aircraft, and VTOL in general, became so strong that I left DHC in January of 1946, and followed Tarczynski to Jet Helicopter Company in Montreal. This was an organization created by W. Brzozowski to design and build a helicopter equipped with a jet-driven rotor. This concept was based on Brzozowski's invention of jet combustors.

While in Montreal, one day in May I received a letter from Jakimiuk, describing the roll-out of the Chipmunk. Reading the letter, and looking at the pictures enclosed, it was hard to realize that the aircraft had been designed, built, and flight-tested in less than one year. Furthermore, this "little miracle" was accomplished with an actual weight empty lower than estimated; and to my best knowledge, with practically no overtime, or any crises or panics.

The Chipmunk was produced in large numbers by the parent company in England, and distinguished itselft in RAF University squadrons and in the hands of private pilots. I watched its progress with much pride and interest and some degree of sentimentality, and was thrilled on reading of such events as winning world championships in aerobatics.

It is obvious that I always wanted to have at least a ride in that machine, and feel its response to my hand on the controls. Unfortunately, somehow, I never had that opportunity. However, I had better luck in that respect with the Beaver.

In the early sixties, when at Boeing Vertol, I was in charge of the design and development of a tilt-wing VTOL flight research aircraft — the VZ-2. My chief design engineer and I had to attend an important conference connected with our project at NASA, Langley. The day before the meeting, a very severe snowstorm blanketed Virginia and neighboring states with about two feet of snow. The runways in Newport News, Va. were already plowed; so we could fly there from Philadelphia, Pa. in a commercial plane. But the connecting roads between Newport News and Langley were far from being in shape for travel by automobile.

Fortunately, after a few telephone calls, Major "Robby" Robertson volunteered to fly us in a US Army plane from Newport News to Langley where, of course, being not only a NASA Center but also a base of the Tactical Air Command, the runways were kept free and clear of ice and snow. One can imagine my joy when at the Newport New airport, I realized that Robby was taxiing toward us in a Beaver.

The short flight to Langley gave me little opportunity to become truly acquainted with the aircraft. Fortunately, that same afternoon, Major Robertson gave us a ride to Washington, D.C. This time, I had enough time to get a better feel of the aircraft and its total "personality". The whole encounter was somewhat like meeting a person full grown, over whose cradle one used to lean quite often in the distant past.

A. A. ŚWIDERSKI

THE PITFALLS AND DIFFICULTIES IN DESIGN OF HIGH SPEED MACHINERY

Streszczenie: Artykuł dyskutuje dwie publikacje National Research Council w Ottawie, które ukazały się w roku 1977, na temat współczynników sprężynowych i tłumiących filmu olejowego w łożyskach ściernych. (NRC-Eng.-92 i NRC-Eng.-93). Publikacje te zebrały i porównały liczbowo i graficznie wyniki studiów nad kilkoma typami łożysk ściernych, przeprowadzone przez kilkudziesięciu autorów z różnych krajów i różnych organizacji.

* * *

Turbomachinery operating speeds are increasing every year, therefore the knowledge and appreciation of the factors influencing the dynamic characteristics of the high speed machinery is very important.

The purpose of this article is to draw the attention of designers of high speed machinery to the difficulties when studying the existing literature dealing with bearing's behaviour.

Any type of rotating machinery is composed of a rotating shaft supported by stationary bearings, bearings' housing and a foundation. Each of these elements has its own resilience and elasticity. Consequently, for calculation purposes every one of them could be replaced by a spring of different springing and damping characteristics. The bearing's supports and foundation have a much higher rigidity than the bearings themselves. For this reason, designers usually assume that only the bearings are elastic elements when their supports and foundation have rigid bodies.

External disturbances that effect the rotor vibration are easier to deal with and to correct, providing that the bearings themselves are of sound design. Factors such as misalignment, assymetrical couplings, electrical and fluid forces and imbalance are the most typical. Unbalance is the most common source of rotor vibration and imposes a force at the running frequency of the rotor. The above mentioned forces are amplified at the critical speed of the rotor-bearing system, which depends on the bearing properties.

Because the dynamic bearing properties are so intimately concerned with the aspectes of the rotor behaviour, an accurate knowledge of the stiffness and damping characteristics is essential for the ppredicition of rotor dynamics.

The National Research Council in Ottawa published in 1977 two reports compiling the results of theoretical and analytical results cbtained by workers in many different organizations and countries.

The two papers (NRC-ENG-92, by A. A. Świderski and E. N. Dudgeon and NRC-ENG-93, by A. A. Świderski) tabulated, and compared results from over forty different publications, a significant part of the available publications.

For those wishing to delve more deeply into the subject of bearing stiffness, comparison of theoretical and experimental methods, tabulations of characteristics of different types of bearings, standardized nomenclature and large number of graphs compiled in the NRC Reports might help in their studies. However, special care must be taken if the original sources quoted are used. Unfortunatly, there is a wide variation in the published literature. Standardization of symbols is lacking, forces are confused with reactions, Sommerfeld number with its reciprocal, spring coefficients

40 Years of Polish Engineering in Canada. Bul. APEC 3/81

symbols are sometimes reversed, etc. The NRC Reports "normalized" the nomenclature and explained it. The selected results have been presented as dimensionless coefficients in both tabular and graphic form, plotted against Sommerfeld numbers.

The NRC Reports summarize a significant part of the available publications, leading to the solution of the dynamic coefficients. These coefficients differ widely in theoretical as well as experimental results. Owing to the large number of researchers, as well as the lack of solid comparison standards, no attempt has been made in the Reports to evaluate the coefficients numerically.

A minority of analysts and designers are completely rejecting the use of finite spring and damping coefficients until the time when the theoretical predictions will be fully verified by experimental studies. However, the vast majority of the authors are strongly advocating the need to know and use oil film coefficients, as very valuable tools in designing high speed rotating machinery.

Theoretical analysis and calculations have been reported in the literature by a considerable number of authors. Unfortunately, the experimental evidence seems to be rather limited, as compared with the theoretical treatments, suggesting that the theoretical due to the availability of high speed computers with large memory banks, has outplaced the empirical support.

The NRC Reports on coefficients have, for convenience of use, been grouped into four categories, according to nominal bearing type:

1. Full circular bearings
2. Partrial circular bearings
3. Tilting-pad bearings
4. Special bearings

Although the first category has been studies the most extensively, both theoretically and experimentally, it is less widely used now in situations where the accurate knowledge of the rotor dynamic behaviour is important, because of the susceptibility of this bearing's configuration to high speed whirl. Many new high performance rotors use tilting-pad journal bearings because of their high stability in spite of their high cost. Partial and circular bearings and non-circular bearings are still frequently used in place of full circular bearings, to provide a measure of insurance for stability.

After such a lengthy description of the content of the NRC Reports, a few words describing the nature of the coefficients are warranted.

When a hydraulic fluid film bearing is running under steady, loaded conditions, the rotor assumes an eccentric position in the bearing, so that a convergent fluid film is formed in the clearance space. Pressure is build up in the convergent film to support the applied load. If a rotor vibration of small amplitude is applied on top of the steady force, the film regime remains essentially unchanged, and small movements of the oil film accompany the rotor motion. It has to be mentioned that in case of the oil film whirl, rotor vibration amplitudes may be comparatively large, so that the oil film characteristics are significantly altered. This seriously complicates the detailed study of the self-excited vibration in oil films. However, the onset of whirl may be estimated by limiting the study of the case of small vibrations. This provides considerable analytical simplification.

The starting point of most analyses is the lubrication equation for an isoviscous lubricant (Reynold's equation). The dynamic coefficients are obtained as the gradients of the hydraulic forces. The rotor is given an arbitrary small motion with an assigned frequency around the steady-state centre. It is assumed that the system perturbations are sufficiently small that the bearing film forces will be linear in form.

Under these conditions the dynamic force components Fx and Fy, acting in the bearing along fixed co-ordinate axes x and y respectively, may be expressed by:

$$Fx = -KxxX - CxxX - KxyY - CxxY$$

$$Fy = -KyyY - CyyY - KyxX - CyyX$$

where X, Y are mutually perpendicular radial displacements, and K and C are dynamic stiffeness and damping coefficients respectively. Suffixes "xx" and "yy" denote main coefficients, while "xy" and "yx" denote the cross-coupled coefficients.

The optimum value of bearing is a compromise between the forces transmitted at critical speeds, and forces developed at the operating and/or maximum speeds. If the bearing's spring and damping qualities are known, then with this information the natural frequency and the oscillating conditions can be calculated as a simple spring-mass system. However, if the damping characteristics of the bearings cannot be calculated and the system can still operate over the first critical speed, this indicates that the system has been overdesigned.

Conclusion

The dynamic characteristics of journal bearings influence both the phenomena of the response to disturbance and unstable rotor vibrations. The effect of oil-film has a profound influence on the behaviour of rotating shafts. A number of large manufacturing concerns have developed finite-element or other numerical methods of determining bearing coefficients or predicting bearing behaviour. These programs require fairly significant computation resources.

It is hoped that this article will serve as a guide to smaller manufacturer or independent researcher who is starting to search through the available literature.

H. U. WISNIOWSKI*

EVALUATING WEAR IN PISTON ENGINES BY QUICK SPECTROGRAPHIC SAMPLING METHOD

Została wypracowana nowa metoda oceny zużycia cylindrów i pierścieni w silnikach tłokowych. Polega ona na spektrograficznej analizie próbek oleju smarującego, pobieranych przez małe, specjalne otwory w cylindrach. Metoda ta, szybka, prostsza i wielokrotnie tańsza od dotychczas używanej metody radioaktywnej, którą przewyższa i pod innymi względami, okazała się bardzo użyteczną w ocenie czynników wpływających na zużycie silników. Wpływ różnych paliw, różnych olejów smarujących, materiału cylindrów i innych czynników ruchu został zbadany i niektóre wyniki podane.

* * *

INTRODUCTION

This method of assessing wear of cylinders and piston rings was primarily developed as part of work to determine the possibilities of running locomotive diesel engines on unrefined Canadian crude oils. Afterwards, it was also used extensively with standard diesel fuel. The purpose of developing this method was to obtain quick evaluating of engine wear.

The engine used for these investigations was a General Motors locomotive diesel engine, model 567C (in set with electrical generator) installed in the National Research Council Diesel Laboratory. This is a V-type, two-stroke cycle, 12-cylinder engine (Fig. 1). Some additional particulars of the engine are as follows:

Bore, 8-½ in.
Stroke, 10 in.
Cast-iron cylinder liners
Cast-iron piston rings
Maximum governed speed, 800 rpm
Idling speed, 275 rpm
Rated horsepower, 1200 Bhp

The engine has nine fuel rack positions including idling. These rack positions are also referred to as "notches".

The crankcase capacity of the engine is large, being about 135 imp. gal.

Direct measurements of the wear of cylinder liners and piston rings are too time-consuming and laborious. To obtain sufficiently reliable wear figures a minimum of about 1000 hr of running in a laboratory engine under one set of investigated conditions would be necessary, after which time the engines has to be dismantled and the wear measured.

The radioactive tracer method requires expensive test equipment. Moreover, the irradiation of necessary engine components would be difficult with a large engine of the size used. As it was not possible to install special gutters to collect oil from individual engine cylinders because of the oil cooling system used for the pistons, it seemed that the radioactive tracer method could only be employed by measuring the radioactivity of the whole of the lubricating oil in the crakcase. The disposal of large amounts of radioactive oil would be difficult.

---

* H. U. Wisniowski P. Eng., Principal Research Officer N.R.C. (retired) was in charge of N.R.C. Diesel Laboratory since its very beginning.

After much consideration it was decided to try to sample the oil through holes drilled in the walls of particular cylinders. It was also decided to analyze the oil samples taken in this way by a spectrographic method instead of the radio-tracer technique.

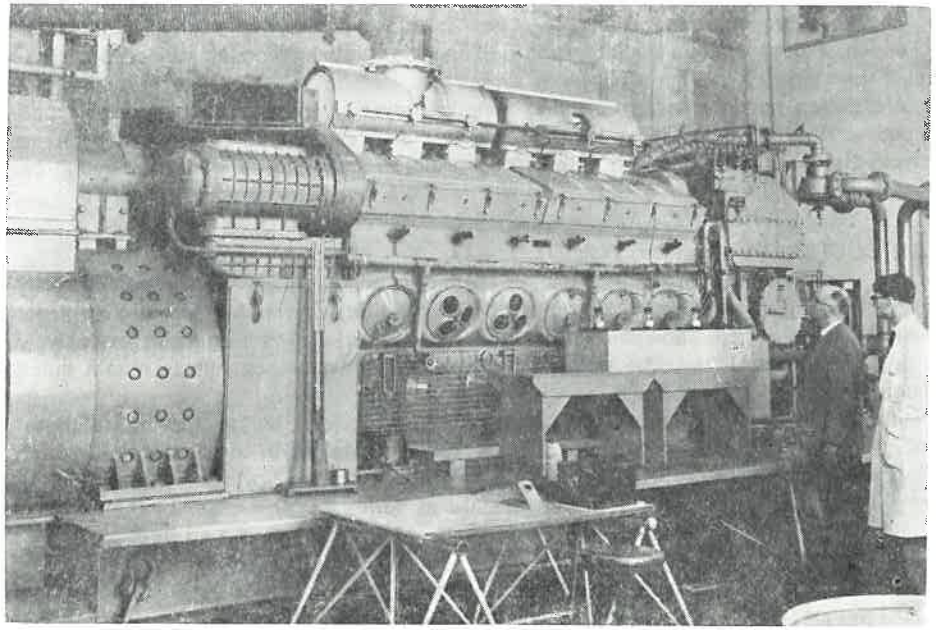


Fig. 1 General view of the locomotive diesel engine in N.R.C. Diesel Laboratory.

The method can be used in any engine without regard to size amount of oil in crankcase, number of cylinders, or lubrication system. The oil from one or any desired number of cylinders can be sampled. If different materials are used for cylinders or cylinder liners and rings, for instance, chrome and cast iron, then the method shows the wear of these in each cylinder separately. If only iron is used, then the method shows the wear for the cylinder and rings together. The wear, if any, of cast iron pistons would be also included in both cases.

THE METHOD

It was felt that the sampling hole should be drilled in the lower part of the cylinder to supply oil representative of average wear of the liner and rings. Also, a lower hole would be opened by the piston toward the end of its downward travel when the pressure in the cylinder is low; then the discharging of the oil would pose no major problem. A lower hole should affect the processes in the cylinder less, and this is important when the hole is relatively large. Such a hole was needed to obtain sufficient quantity of oil for spectrographic analysis.

For the present investigation, a 5/64-in. (0.078-in.) hole was drilled 1-¾ in. above the top of the air-inlet ports in each liner designated for this work. The diameter of the sampling hole was determined experimentally so as to supply a sufficient quantity of oil during a running time of one to two hours under all engine conditions. The quantity of oil required for the analysis was about 10 cc. The hole was drilled in a tapered plug made from brass to prevent rusting. The plug was installed through the water jacket into the liner using a taper reamer No. 7. The inside end of the plug was recessed approximately 1/64-in. from the liner wall. A copper pipe of 1/8-in. id (3/16-in. tubing) and about 2 4in. long was connected to the outside end of the plug. The copper pipe was led outside the engine where the oil sample was collected (Fig. 2).

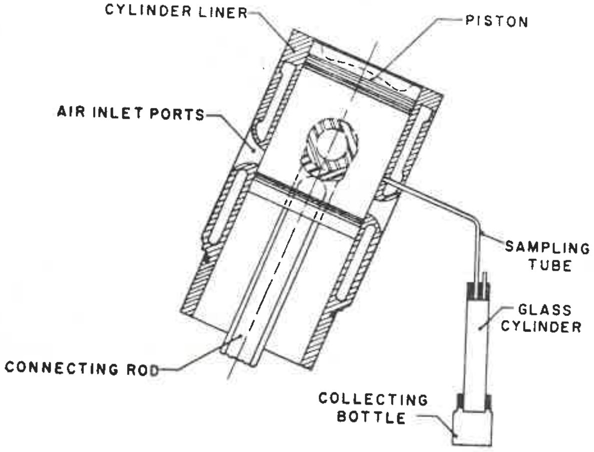


Fig. 2 Cross section of engine cylinder showing sampling arrangement (diagrammatically).

Even though a low hole was used, the oil and exhaust gases were driven out of the cylinder with considerable force. The oil sample was separated from the gases by expansion into a cylinder made up of a removable glass tube (1-3/8-in. id x 11 in. long) sitting in a 4-oz glass jar. The copper tubing was inserted through a hole in the rubber stopper in the top of the glass tube. The exhaust gases escaped through a vent in the rubber stopper. The oil collected on the sides of the glass cylinder and in the jar. Sufficient time was allowed for the oil to drain down in the jar. The sample collection arrangement is shown in Figs. 2 and 3.

The vents in the stoppers of sampling glass cylinders were connected to the common pipe leading the fumes to the engine-intake air filter (Fig. 3). This was done to avoid an excessive air contamination in the engine room when more than three cylinders were used for sampling.

As is well known, the rates of wear in engines change with time. Changes as high as 1:4 on different days have been reported. Therefore, a comparison of effects of different operating conditions should be made within as short a period as possible.

For the same reason, the method of sampling used here, like other quick methods (e.g. radioactive tracer technique) to supply wear data on a short-term basis, should be used with caution for predictions of long-term engine wear. The sampling method has a comparative value and, while it does not furnish direct absolute wear figures, it is very useful in giving an assessment of short-term wear.

It was found to be a good procedure to change the crankcase oil frequently in order to keep the concentration of wear metals in it as low as possible. Otherwise, it was difficult to discount the metal content of the crankcase oil from the results of cylinder oil sampling. After each change of engine notches, a period of 15 min.

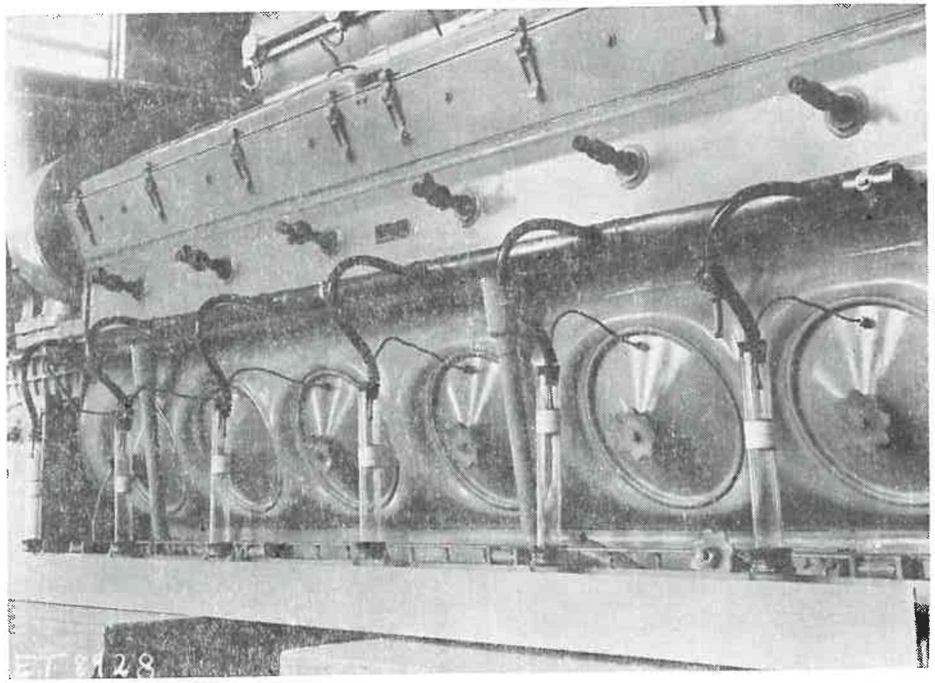


Fig. 3 Collecting oil samples.

was allowed to flush the pipe of oil representing the preceding engine conditions.

The amounts of iron, chromium, and other wear metals in the oil samples were measured by emission spectroscopy. This work was carried out at the C.N. Technical Research Centre.

The tests revealed another advantage of this method over the radio tracer method. Spectrographic analysis is not restricted only to the metals expected. In the case in point, using a marine diesel-lubricating oil with zinc dithiophosphate additive, the presence of silver was noted. This indicated that the oil was attacking the silver coating on the piston pins. This fact would not have been detected by the radio tracer method using only one or two kinds of isotopes.

During the first period of measurements, three engine cylinders were equipped for sampling, two with chrome-plated liners and one with a cast-iron liner. Afterwards, for investigation of different types of chrome-plated liners, five cylinders of the engine were equipped with these liners and two cylinders were equipped with new cast-iron liners for comparative war measurements.

ENGINE TEST SCHEDULES

As the method was new, nothing was known in the beginning concerning either its possibilities or limitations. The engine test schedules and programs were gradually developed as the investigation progressed.

The first engine test schedule was broken into three parts:

Part A. Conditioning of the Engine. Run Part B but without sampling.

Part B. Sampling at Different Speeds and Loads. Idle 1-½ hr, taking first set of samples; idle 1-½ hr more, taking second set of samples; run second notch 2 hr, taking third set of samples; run fourth notch 1-½ hr, taking fourth set of samples; run sixth notch 1-½ hr, taking fifth set of samples; run eigth notch (full load) 1-¼ hr, takin sixth set of samples. Total running time for Part B was 9-¼ hr.

Part C. Sampling at Steady Speed and Load. Run sixth notch, taking five sets of samples at 2-hr intervals over 9-¼ hr.

Concerning Part A, it was found that stops of more than about 12 hr affected the initial wear. Consequently, the engine was run for a conditioning period before sampling began. When it was desired to determine the effect of long shutdowns on engine wear, sampling according to Part B began immediately after the engine was started.

Part B was run to assess the wear at different speeds and loads. It comprised two sets of samples at idling for a better check of idling conditions and one set of samples at other notches. Only every other notch was sampled to reduce the number of analyses. The time spent on running Part B was established by the time required to collect sufficient quantities of oil at each notch.

Part C of the schedule was run at sixth notch (650 rpm and approximately 70 percent rated hp), as this was thought to represent average engine speeds and loads. The length of Part C was set at 9-¼ hr to be the same as in Part B. The number of sets of samples was restricted to five, because these gave an adequate picture of the wear with a minimum number of analyses.

When the semi-ashless oils were tested with standard diesel fuel, the engine wear was markedly reduced, and the comparison of test and reference results seemed to be less reliable because of small ppm figures. To increase the engine wear, Part D of the schedule was introduced during which the engine was run continuously at full load (eighth notch). Thus, the new schedule, called a heavy or fully-load schedule (in contrast to the former, average-load schedule), comprised:

Part A. As before, but taking a set of samples after the last 1-¼ hr (at full load).

Part D. Sampling at Full Speed (800 rpm) and Full Load (1200 bhp). Run eighth notch 9-¼hr, taking the second set of samples again after 1-¼ hr, and then four sets of samples at 2-hr intervals.

The test program consisted at least of two runs on the same engine schedules. One schedule would be run with the test variable, while the other would be run with standard or reference conditions. For example, if one run were to test a fuel, then the next run would be made using standard No. 2 diesel fuel for comparison.

TEST RESULTS

Many test runs have been carried out to investigate a wide variety of engine-operating conditions. They comprised screening many crude oils as diesel fuel and investigating effects of liner materials, defective injectors, effect of cooling water temperatures, performance of lubricating oils, and so on. Some results are presented to illustrate the scope and possibilities of the test method.

Standard No. 2 diesel fuel and a conventional railway diesel locomotive oil were used, except as noted for particular runs.

The results of the runs were presented in the form of diagrams and average wear figures. When diagrams did not contribute to the better understanding, only average wear figures were given for the sake of simplicity. To enable comparison of test and reference runs, samples were taken at the sam times in Parts B, C, or D of the engine schedule. The arithmetic average of the amounts of wear metal in a set of samples from each cylinder was taken as a figure of merit for each run.

All runs made with gradually increasing speed and load (Part B of the test schedule) showed generally increasing wear rate with speed and load. Fig. A (a, b, c) shows typical wear diagrams under these conditions. However, the character and degree of this increase depended on the initial conditions, i.e., whether the engine was started after a longs stop (shutdown) period, specially on crude oil, or the test was made after the engine had run continuously for several hours.

The latter case was considered more normal, i.e., not influenced by additional effects of long-stop periods.

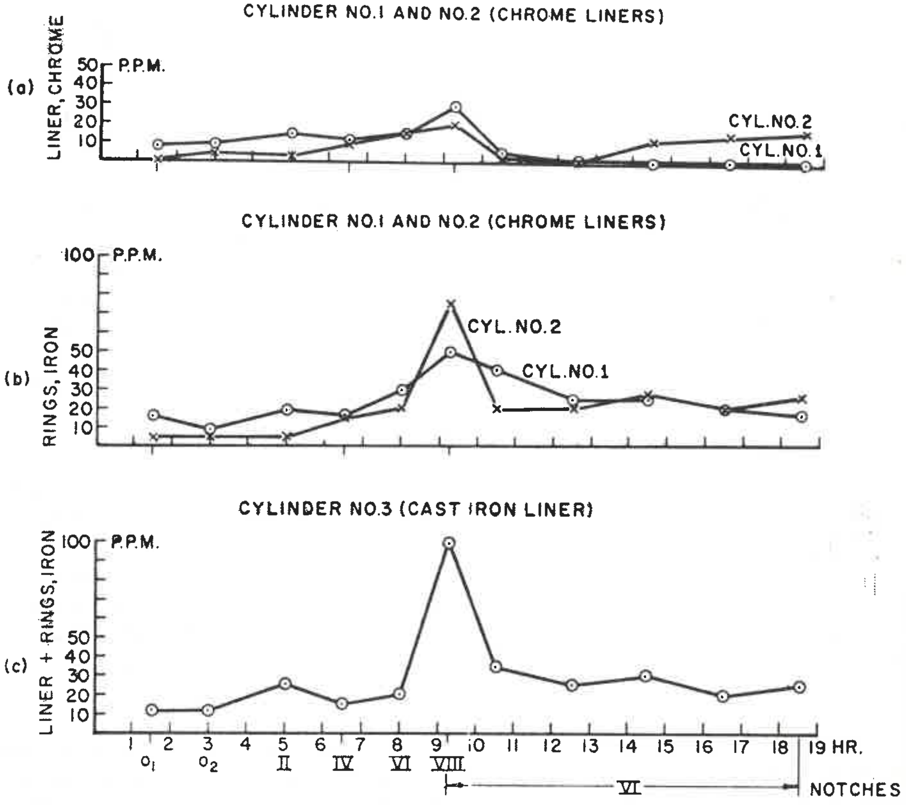


Fig. 4 Wear with crude, increasing speed and load, engine conditioned.

When the engine was stopped for more than about 12 hr, specially immediately after runing on crude oil, it was found that the initial wear, particularly that of chrome liners, was higher. This condition persisited for several hours, but usually less than the time required for Part B of the schedule, i.e., 9-¼ hr, and was more pronounced at higher notches.

The amount of wear particles blown out of the cylinder, which increases with speed and load, was not measured. These blown-out particles probably originate mostly from the top piston ring.

TESTS OF CRUDE OILS

Many crudes were investigated with respect to engine wear in order to determine their suitability as diesel fuel. An example of such tests is given in the following Table.

The wear on crude was generally higher than the wear on standard fuel.

Table: Effect of crude oil on wear of chrome and cast-iron liners and rings.

Test schedule	Test run Parts B and C	Ref. run Parts B and C	
Test run conditions (Engine (Fuel oil (Lub. oil	Conditioned Crude Ref. oil	Conditioned Std. No. 2 Ref. oil	Ratio Test/ref. Approx.
Wear in No. 1 and No. 2 cylinders (combined)			
Average amount of chromium (liner wear)	8.8 ppm	4.8 ppm	1.8
Average amount of iron (ring wear)	23.2 ppm	18.7 ppm	1.25
Total of above amounts (liner and ring wear)	32.0 ppm	23.5 ppm	1.35
Wear in No. 3 cylinder			
Average amount of iron (liner and ring wear)	28.8 ppm	18.1 ppm	1.6

The advantage of the spectrographic method over the radio tracer method was shown once more during the investigation of the Athabasca tar sands synthetic crude. First runs with this fuel showed adnormally high wear figures. This was ascribed to the silicon content in the oil, indicated by the samples from the cylinders. As no silicon was found in analyses of the synthetic crude suspicion had been directed to the recent excavation near the diesel laboratory, which was filled with very fine, loose sand. During the runs the windows and doors in the engine room had to be kept open to prevent excessive increase in ambient temperature in the room. However, this greatly increased the possibility of sand dust ingestion.

Three large, oscillating water sprinklers were installed at this excavation site, which kept te sand well wetted during the following wear runs. This measure was effective because the results of the next run showed improvement in wear, and the results of further runs were quite satisfactory.

The experience with the presence of a harmful, abnormal amount of silica in the engine suggested an investigation of intake air filters used in the locomotive diesel engines.

INVESTIGATION OF SEMI-ASHLESS LUBRICATING OILS

Developments in engine lubricants have led to the offering of new types of oils for railway diesel engines. These are the so-called "ashless" and "semi-ashless" oils. An ashless oil contains organic dispersants in contrast to the metallo-organic dispersants previously used. Consequently, the ash formed by the metals is eliminated. As the other additives and inhibitors are also organic, the oil forms no ash and is "ashless". A semi-ashless oil contains the new ashless dispersants and conventional metallo-organic dispersants. Other additives are conventional.

It was claimed that use of semi-ashless oils reduces engine wear. To prove this in field service a period of one to two years would be necessary. The spectrographic sampling method offered the possibility of a great time saving in screening these new oils with respect to wear.

Three semi-ashless oils designated A, B and C were initially tested in the laboratory engine. The results were rated by comparison with conventional railway diesel oil.

As mentioned in the foregoing, because of the reduced wear with semi-ashless oils, a full-load test schedule (Parts A and D) was introduced to increase engine wear and to make the comparison of test and reference results more reliable.

On average-load schedule, all three oils showed a reduction in wear which amounted to 55 percent for oil A. On full-load schedule, the wear reduction was less (20 percent) for oil A and none for oil B. Oil C showed about the same average reduction on both test schedules, but the wear figures were rather inconsistent. The production of this experimental oil was discontinued.

Assuming that runing schedule of locomotive diesel engines in service would be at the most somewhere in between the two laboratory schedules, it can be expected that the use of semi-ashless oil A will result in appreciable wear reduction.

INVESTIGATION OF CHROME-PLATED LINERS

Several different types of chrome-plated cylinder liners were used in locomotive diesel engines of Canadian railways, but som uncertainty existed about wear properties of particular types.

To investigate this problem, three types of chrome-plated liners were installed in the laboratory engine. Two cylinders were equipped with new cast-iron liners for comparative wear measurements. Again, the wear figures for identical liners were combined. Prior to wear runs, the engine was run for a brak-in period of over 50 hr.

The wear figures showed higher wear in the chrome-plated liners than in the cast-iron liners. This was so during the first runs just after the break-in period of 50 hr. The chrome-plated liners were kept in the engine, and later runs showed wear figures of chrome liners approaching more closely those of cast-iron liners. These runs, after about 250 hrs counting from the installation of the liners, were made for investigation of other problems.

CONCLUSIONS

The combination of special oil sampling and spectroscopy which was used for quick evaluation of cylinder and piston ring wear is much cheapepr, simpler, safer, and more readily and universally applicable than the conventional radioactive tracer method.

The method is very useful in assessing wear rates, specially in cases where there are drastic changes or differences. Without complicated, expensive, and long preparations, it allows a quick check under critical conditions and consequent elimination of many factors causing abnormal wear.

S. PAUL WYSZKOWSKI, Luthier

THE ENGINEERING OF ART:

DESIGN AND CONSTRUCTION OF A CLASSIC GUITAR

Lutherie is the craft, the science and the art of making stringed musical instruments. Currently some progress is being made in application of structural acoustics to what has been for centuries and to a large degree still remains an empirical-intuitive art.

Musical instruments are imbued with magic and mystique. From their earliest beginnings they had religious significance for music is both food for the spirit and a manifestation of the spirit. To this day, they are treated with a reverence and a bit of awe. (Electronic synthesizers, in their stark, accoustically nonfunctional breadboard form, are a notable exception — but then one hesitates to call them musical instruments).

Making a fine musical instrument is a work which must be in touch with the spirit of music and at the same time calls for a very practical and exact understanding of mechanics of wood, strings and human hands and ears. It is a total, integrated event that includes the music, the luthier, the performer, the audience, and something the flower generation has called the good vibrations.

Vibrations, good, bad or indifferent, are subject matter of acoustics, a relatively young branch of mechanics dealing with periodic motion and wave propagation in the range of audible frequencies (30 — 20,000 Hz). All traditional string instruments, including the guitar, have arrived at their present form without benefit of consciously applied acoustics. It is a tribute to the practical genius of the craftsmen-artists who have developed the present forms that they have left little room for substantial improvement. What the luthier of 1980s strives for is not so much development of a better instrument as achievement of quality assurance.

Some marginal improvements are possible by refining the proportions which the traditional lutherie established over the centuries of cut-and-try. However, any major design changes invariably have led to deviation from the very qualities which give the instrument its unique character. The result is a different, not necessarily a better instrument.

A much more profitable use of the accoustical science lies in precise characterization of the structural differences between mediocre, good and superb instruments so that a reasonably skilled luthier can predictably turn out instruments of a quality that formerly required a combination of genius and several lifetimes of practical experience to achieve.

The violin is a case in point: after the pinnacle of success achieved by Antonio Stradivarius and some of his colleagues and students, for several hundred years violin makers could do no better than to imitate faithfully his masterpieces. With the advent of applied acoustics, some of the structural reasons for the fine quality of the Stradivarius, Amati and Guarnerius violins have become apparent. Violins are being made today which are fully comparable to the best of Stradivarius, without resorting to imitation. At the same time, it is acknowledged that it is all but impossible to improve on this standard of quality.

The guitar is not quite so perfectly balanced an instrument. Although it is older than the violin, it has been throughout much of its history primarily a folk instrument and has kept its folk identity to this day. The classic guitar is a late development but its spiritual beginnings go back to the VIIIth century conquest of Spain by the Arabs. The Arabs brought with them the lute, a virtuoso solo instrument which eventually became universal in Europe outside of Spain. The Spaniards, however, refused to use their conqueror's instrument and developed instead a native form of the guitar into an instrument musically fully competitive with the lute, the vihuela. Although it was not the instrument of the modern classic guitar. Virtuoso music for the plucked strings flowered in the XVIth century but as the harpsichord and the violin asserted their dominance in the XVIIth century the vihuela and later the lute went into decline and ultimately oblivion. The more primitive and gutsier guitar survived as a folk instrument especially among the Spanish Gypsies of Andalucia. It also acquired a gentille sort of existence as a portable instrument suitable for ladies and lovers.

Not until late XVIIIth century did guitar begin to gain stature as a virtuoso instrument. Several guitar virtuosi emerged from Spain and Italy, the strongholds of the guitar tradition, amazing audiences throughout Europe. By then the former glory of the lute and the vihuela had long been forgotten.

In the second half of the XIXth century the classic guitar underwent major development increasing in size, volume and projection. It has remained to this day pretty much in the form given it by Antonio Torres in the 1870s. The changes introduced by contemporary luthiers have been few and subtle having primarily to do with the shaping of the accoustical response of the soundboard for improved loudness, clarity, projection, sustain and evenness. None of these improvements have been dramatic.

The contemporary classic guitar is a six stringed instrument strung with nylon strings and pitched in the same range as the cello, with a compass of 3½ octaves. Its form is too familiar to require description. The soundboard, to which the strings are directly attached by means of a slightly raised stringholder or bridge, is the heart of the instrument. The box serves to modify and enrich the vibrations of the soundboard while providing the required rigidity to the instrument as a whole. Functionally, the guitar as an acoustic mechanical transducer which converts the mechanical energy of the vibrating strings into sound energy has been compared to a loudspeaker. However, there are important differences between a guitar and a loudspeaker, not only in form but in principle.

The desirable characteristics of a loudspeaker: extremely fast response, uniformity over the audible spectrum, and zero sustain, are hardly desirable in a guitar. A "flat" response at all frequencies would rob a guitar of its individuality. An extremely fast response with no sustain would make a singing legato impossible. The major difference between a loudspeaker and a guitar is that a loudspeaker is continuously driven by an external signal while a guitar is driven by discrete impulses relatively widely spaced in time. In between the impulses, the guitar as a whole behaves as a freely vibrating system like a bell or a gong. The loudspeaker merely reproduces the signal. The guitar shapes it, gives it life, and makes it into a musical sound.

Essentially, the soundboard, in cooperation with the box, must be capable of resonating with all the frequencies in the instruments range. Further, there should be no sharp resonance peaks or deep antiresonant valleys in the reponse spectrum. These would make certain notes stand out objectionably from their neighbours. Guitarists do compensate automatically for unevenness of response while playing, and some unevennes is inevitable. It is the price of individuality of tone, of its particular and unique beauty. However, there are limits beyond which unevenness of reponse cannot be tolerated.

To achieve a wide range resonant response with broad rather than sharp peaks it is necessary to accept some damping. There is some damping in the system in any case, partly due to internal friction of the vibrating components, partly to the radiative loading on the soundboard. The more damping is introduced into the system the less sustain or volume can be achieved, depending on how the structural parameters are balanced within the available degrees of freedom. The effect of damping increases with frequency. Clear, ringing trebles of good volume, sustain and quality are notoriously hard to set.

The structural parameters with which a luthier works in designing a soundboard are mass, compliance and the resistance of internal friction. The fundamental equation of motion which guides the design is

$$M \frac{d^2x}{dt^2} + R \frac{dx}{dt} + \frac{1}{K} x = f$$

where M is mass, R — resistance, K — compliance, x — displacement normal to the surface of the soundboard, and f is the natural frequency.

This equation relates mass, stiffness (1/K), frictional resistance and the resonant frequency of a simplest possible vibrating system in which the three parameters are lumped into separate regions of space (e.g. a rigid mass suspended from a weightless spring and attached to an inelastic dashpot). Even though reality is not that simple, this first approximation provides some sense of perspective and direction. Electrical engineers reading this may have noted that this equation is analogous to the equation for a tuned circuit, substituting inductance for mass, capacitance for compliance, and voltage for displacement. In fact, the soundboard, and for that matter, the entire instrument, can be treated as a network of simple tuned circuits and equations describing an actual structure can be developed from the network theory. This works for lower frequencies where lumping of the parameters is a permissible approximation, but at higher frequencies the structure behaves as a continuous system. In this region the wave equation must be applied, and things get mathematically complex. However, there are computer programs used for finite element structural analysis which are readily adaptable to analysis of soundboard vibration. All that is required is that the stifness/mass matrix of the soundboard be determined. This can be accomplished in part with a suitable jig allowing measurement of deflections under known loads at predetermined points. Mass matrix is more problematic, wood being a material of variable density. Since luthiers go to great lengths to procure highly uniform pieces of wood for construction of the soundboard, reasonable approximations can be calculated.

A non-mathematical technique for visualizing the behaviour of the soundboard over the full frequency range uses the Chladni patterns, patterns formed by dancing glitter particles sprinkled over the soundboard which is excited either by a speaker or directly by a small magnet attached to it and driven by a coil. The glitter particles collect at the nodes clearly indicating the forms of the modes of vibration at different frequencies. Some semi-quantitative notion of the degree of resonance at each mode can be obtained from observing the energy of the dancing particles. A more sophisticated technique for achieving the same end is laser interferometry.

The form of the modes and their frequencies can be manipulated within certain limits. This is accomplished by adjusting distribution of mass and stiffness over the vibrating area of the soundboard. What looks like a piece of flat board from the outside is actually a complex braced structure. The most common form of bracing is that developed (though not originated) by Torres: a fan-like arrangement of seven light braces radiating from a sturdy transverse bar mounted just under the soundhole and defining the vibrating portion of the soundboard. The thickness of the soundboard itself may be graduated, as well as the weight and stiffness of the braces. The bridge is also a structural member of the soundboard and its form and mass must be appropriately adjusted. Generally the intent is to enhance resonance in both the low and high frequency ranges simultaneously using the principle of a coaxial speaker. Larger regions which vibrate at low frequencies are provided with low compliance by reducing stiffness at their perimeters, while smaller stiffer areas in the vicinity of the bridge respond to the higher frequencies.

Besides its acoustic function, the bracing also serves to reinforce the soundboard mechanically against the pull of the strings. The interaction between the mechanical and accoustical function introduces further constraints. The properties of the materials become critical.

The woods used for soundboards are alpine white spruce, western American red cedar and recently redwood. Sitka spruce is also used extensively in instruments of lesser quality. There is a very good reason for using these woods: they happen to have the highest stiffness/density ratios of any available woods and for that matter most other natural or synthetic materials. At the same time they have low internal damping.

The highly anisotropic character of these woods (stifness is typically 20 times greater in the direction of the grain than across the grain) influences the shapes of the modes of vibration (at higher frequencies the vibrating areas are elongated along the grain) and enriches the harmonic content of the sound. The shape and size of the vibrating area of the soundboard and the anisotropy of the wood need to be in a harmonious relationship to each other. Since the anisotropy varies widely, this harmony must be brought about by adjustment of the bracing pattern. A luthier is very conscious of the relative stifnesses and selects the wood accordingly.

The woods used for the back and sides of the body are very different in character. The acoustic function of the body is twofold: in the low frequency region it is to add reasonances to the response curve of the instrument which are lower than can be obtained with the soundboard working independently; and in the high frequency region, to act as a reflector and projector of the sound waves generated by the rear surface of the soundboard. Phase relationship between the directly radiated and the reflected sound is important. It varies, necessarily, with the wavelength, the distance between the soundboard and the back of the instrument baing fixed. Ideally the in-phase frequencies would correspond to resonance valleys in the response of the soundboard, thus reinforcing weaker notes, but at present it is beyond the skill of a luthier to arrange his resonance peaks so neatly. It is also, perhaps, not necessary, since some unevenness in response exists in any case. It would be unfortunate however if there were a strong resonant peak at an in-phase frequency.

At low frequencies the back responds to the vibrations of the soundboard. The phase relationships in this case are not related to the wavelengths, which are considerably larger than the dimensions of the instrument, but to the nature of acoustical coupling between the soundboard and the back. However, the main effect at the low frequencies is that of the interaction of the soundboard with the cavity of the body. The result is a splitting of the lowest resonant frequency of the soundboard into two frequencies, a still lower one and a higher one. While this provides a resonant peak for the guitar's lowest notes, it also creates an embarassing valley between it and the next peak. One partial solution is to rely on inter-string sympathetic resonance to fill in the valley somewhat. Still, this valley, which is present in all guitars, does not seem to have been a serious problem to performers. This may be because the valley affects only the fundamental tone of the note. The first and second and higher harmonics are already in a resonant region. The ear has the fortunate ability to hear the fundamental note even when it is missing, as long as its principal harmonics are present. Nevertheless, the quality of the note is not as full as with the fundamental present.

The traditional wood for the body of the classic guitar has been Brazilian rosewood (Dalbergia nigra) a hard, dense, resinous wood. Its density provides sufficient inertia so that the vibrations of the sounboard are not dissipated in excitation of those parts of the instrument which do not contribute to sound radiation. Its hardness provides a reflective surface for the medium to high frequencies. The resinous content probably damps the highest frequencies mellowing the sound. There are other woods with similar characteristics but the mystique of the classic guitar has it that only Brazilian rosewood gives the true classical sound. Unfortunately, this wood has become virtually impossible to obtain in quality required, that is straight grained, quarter cut (grain running perpendicular to the surface). The search for a worthy substitute is on, but die-hards are still refusing to use anything else. Indian rosewood, actually a different species, is most commonly used as a substitute. I suspect first the difference in the tone between a fine Indian rosewood instrument and a fine Brazilian rosewood instrument can only be picked up by a properly prejudiced ear.

Synthetic substitutes for wood, both for the soundboard and the body, exist. For the soundboards, a graphite-epoxy composite has been used successfully. For the body, glass-epoxy laminates semm to do the job quite well. These materials offer the advantage of controlled uniformity of properties but traditional luthiers shudder in horror at the very idea of using synthetics. Sacrilege!

There is, indeed a case to be made for wood which because of its unpredictability results in variants and "sports". No two instruments are the same. Some turn out to be exceptionally fine, others at least interesting or unusual. This is part of the natural process of the evolution of the instrument. The best instruments are analysed and something more is learned about what makes a good guitar. Once we are dealing with predictable synthetics that evolutionary path is closed. Greater control is not synonymous with better quality — merely more uniform quality. Uniformity has never been the long suit of the creative luthier. Here, then, the engineering of art meets its limits.

Ultimately, a musical instrument is an organic creation, a product of and for life. Like life, and like music and art in general, it should be a blend of the expected and the unexpected, familiar and different. It **needs** to have its peculiar quirks of character along with a basic reliability and competence. It needs to be more than functional — it must be beautiful.

S. PAUL WYSZKOWSKI, P. Eng.

SEN MEGO OJCA

Mój ojciec, Władysław Wyszkowski, był człowiekiem całkowicie praktycznym a przeto człowiekiem rzeczywistym. Duch jego działał konkretnie; miał do czynienia z betonem i stalą. Ale mosty same się nie budują. Ludzie budują mosty a mój ojciec budował ludzi: budował ich w duchu tak, żeby praca szła jak było potrzeba.

Nie było w tym żadnej ideologii, żadnych teorii kierowania ludźmi. Działał odruchowo ze "zdrowego rozsądku"; patrzył się na świat wzrokiem niewykrzywionym ideałami, przypuszczeniami czy obawami; widział co jest i czego potrzeba, i kierował się prosto do celu. "Bez cudów" jak sam mówił. Świat jego był światem rzeczywistych możliwości. Jego powodzenie polegało na uznaniu rzeczywistości takiej jaka jest i na prostolinijnym podejściu do rozwiązania wszelkich trudności. Potrzeba było do tego dużej uwagi i świadomości: wszystko musiało być jasne i zrozumiane. I tak było.

Chociaż zaczął po przyjeździe do Kanady w 1942 roku jako prosty kreślarz u DeHavillanda, już w 1945 pracował w TTC jako kierownik grupy budowlanej, która projektowała pierwszą kolejkę podziemną w Kanadzie a później dozorowała jej budowy. To była praca pionierska, na wielką skalę, wymagająca właśnie takiego prostego, jasnego podejścia i utrzymania duchowej perspektywy pośród trudności i komplikacji. W 1954, po otworzeniu kolejki, jego następny projekt już czekał na niego: w Lakeshore Expressway Consultants jako główny inżynier budowlany przy zaprojektowaniu szosy przelotowej imienia Fredryka Gardinera. Ta olbrzymia praca zawarła wszystkie elementy strukturalne całej szosy i objęła nie tylko ich zaprojektowanie ale i wykonanie. Osobiście dozorował wszystkiego i był tym duchem poruszającym w rozwiązywaniu wszelkich praktycznych problemów przez szereg lat aż do samego dnia otwarcia. Jego ostatnim projektem było kolegium w Scarborough. Futurystyczne w pojęciu i radykalne w architekturze wymagało rozwiązania nowych i niezwykle trudnych problemów w budowie. Otrzymał za tą pracę w 1967 Canadian Design of Merit Citation. A za jego stała uczynność i pełnoduszny udział w życiu inżynierii kanadyjskiej przysądzono mu w 1969 roku Sons of Martha Medal "for simple service simply given in common need". Umarł w 1970 r., skończywszy swoją pracę.

W roku 1960, kiedy dozorował budowy szosy Gardinera, doświadczył jednego z najdziwniejszych zdarzeń w swoim życiu. Budowa doszła w tym czasie do tej fazy kiedy wznosiło się kolumny i na nich spoczywające żelbetowe belki po których szosa biegnie nad ulicami Yonge i Bay. Wszystko szło dobrze przy jego pilnym dozorze.

Jednej nocy podczas tej roboty, mój ojciec obudził się nagle w zimnym pocie z przerażającego snu. Śniło mu się że w jednej z żelbetowych belek nie założono stalowych prętów wzmacniających i już widział katastrofalne tego skutki: załamanie się szosy nad ulicami pełnymi ruchu i ludzi.

Sen taki pewno nie jest zdarzeniem nadzwyczajnym w życiu inżyniera. Troska nad odpowiednim wykonaniem projektów budowlanych sprawiła pewno niejednemu inżynierowi bezsenną albo koszmarną noc. Tak też to sobie mój ojciec pewno i wytłumaczył następnego ranka. Ale tak był dotknięty tym snem, że pierwsza rzecz, ruszył na budowę sprawdzić jak rzeczy stoją. Nigdy nie był przesądny, ale tym razem nie mógłby sobie darować, gdyby nie sprawdził, chociaż taka rzecz była zupełnie nieprawdopodobna.

40 lat polskiej myśli inżynieryjnej w Kanadzie. Biul. STP 3/81

Pamiętał dokładnie, gdzie wyśnił sobie brak prętów i poszedł prosto do tego miejsca. Tam już formy do lania betonu były założone i czekano tylko na dostarczenie betonu. Ojciec zajrzał do formy i natychmiast stwierdził, że część prętów w istocie nie była założona.

Oczywiście wszystkie belki i kolumny były potem sprawdzone ale tylko tej jednej i tylko w tym miejscu zabrakło prętów. Jak to się mogło stać zaginęło w mgle przeszłości, ale stało się, wbrew wszelkiemu nieprawdopodobieństwu. I tak, gdyby nie sen mego ojca, możliwe że ten odcinek szosy Gardinera zapadłby się pod większym ciężarem. Ale stoi, a kiedykolwiek przejeżdżam tamtędy, przypomina mi się to niezwykłe wydarzenie.

JAN ZAREMBA

Rozmowa o "THE GUIDE TO THE STRUCTURAL DESIGN OF UNDERGROUND STRUCTURES" z autorem Tadeuszem Świderskim

Z. Przypadkowo dowiedziałem się, że kolega pracuje nad wydaniem przepisów regulujących wykonywanie konstrukcji podziemnych. Czy to byłoby coś w rodzaju kodyfikacji i jakie obejmowałoby działy?

Ś. Przygotowałem zbiór doświadczeń innych kolegów i moich własnych, bo niestety w naszej specjalności nie było zesumowania przepisów do budowy tego rodzaju konstrukcji. Uważam, że to co opracowałem jest raczej materiałem przygotowawczym do dyskusji, której wynik w następstwie może doprowadzić do wyczerpującej kodyfikacji. Przedmowa do mojej pracy i spis rzeczy dadzą koledze dostateczną odpowieź na jego pytania. Oto one:

Preface

This guide to the Structural Design of Underground Structures has been prepared from information collected and experience gained during the design and construction of the Toronto Subway System. Design began in 1944 and has evolved over the years to the point where the guidelines given in this brochure represent current practice in Toronto.

It is the product of the work of many people, both within and outside the Commission. A list of these people would be endless.

The author was the head of the Structural Section for 20 years and incorporated in this work the experience of those who designed the Yonge Subway (Front Street to Eglinton) as well that of his co-workers from all levels of the Engineering Organization and many colleaghes from several Consulting Engineer's Offices.

Tadeusz Świderski

Index

I Structural Design
II Demolition
III Underpinning, Cut-off Walls and Relocation of Buildings
IV Excavation
V Fill
VI Drainage
VII Waterproofing and Dampproofing.

Z. Czy istnieje w Kanadzie względnie w jakimkolwiek kraju na świecie ustawodawstwo dotyczące w szczególności konstrukcji podziemnych?

Ś. Oczywiście nie można z całą stanowczością twierdzić, że nie istnieje, gdyż w międzyczasie może coś się ukazało i nie doszło do mojej wiadomości; z tego co mi wiadomo nie ma dotychczas na całym świecie kodyfikacji tego rodzaju. Dlatego właśnie opracowałem w formie kodeksu przepisy, jakimi kierujemy się w chwili obecnej przy budowie kolejki podziemnej w Toronto. Zbierając je miałem na celu przede wszystkim pomoc moim kolegom tak w Toronto, jak i poza Toronto przy ich pracy nad projektowaniem budowli podziemnych.

Z. Czy zdaniem kolegi wybudowanie kolejki podziemnej ma duże znaczenie dla rozwoju i jednocześnie zmianie charakteru miasta?

Ś. Tak nawet bardzo, bo zapewnienie dobrego i szybkiego transportu zachęca do budowy całego szeregu dużych obiektów wzdłuż trasy kolejki.

Z. Czy kolega ma coś wspólnego z tym budownictwem?

Ś. Doskonałe pytanie! Właśnie chciałem powiedzieć, że muszę sprawdzać wszystkie tego rodzaju budowle, aby nie zagrażały bezpieczeństwu naszych podziemnych linii. Władze miejskie nie wydadzą pozwolenia na budowę bez mojej wyraźnej aprobaty.

Z. Czy zebranie przepisów, o których rozmawiamy tuż przed pójściem na emeryturę — co, jak wiem ma nastąpić w najbliższym czasie uważałby kolega za coś w rodzaju ukoronowania swej życiowej kariery inżynieryjnej?

Ś. Tak, chcę przekazać swoje doświadczenie inżynieryjne innym i mogę to zrobić z czystym sumieniem, bo nigdy nie miałem ujemnych wyników w swojej pracy.

Z. Mam wrażenie, że przepisy regulujące wykonywanie podziemnych konstrukcji, które kolega zebrał i sam fakt, że prawdopodobnie nie istnieje na świecie podobna kodyfikacja, bardzo zainteresuje czytelników Biuletynu. Czy pozwoli kolega, że naszą rozmowę przekażę do redakcji.

Ś. Z największą chęcią. To może czasami wywołać dalekie echo zza Toronto lub nawet Kanady od dyskutanta całkiem luźno lub zupełnie niezwiązanego z nami. Każdy przyczynek jest korzyścią.

DR. J. M. ZARZYCKI*

OPPORTUNITIES AND PERSPECTIVES IN DIGITAL MAPPING AND AUTOMATED CARTOGRAPHY**

INTRODUCTION

It is generally accepted that accurate and up-to-date terrain information is the foundation of orderly exploration and management of natural resources and the planning of urban centres, transportation routes, preservation of environment, and a host of other activities related to man's exploits on earth. Since the beginning of civilization the map or plan has been, and still remains today, the most common method of portraying terrain information. Cartographic conventions have evolved over the centuries from an artistic portrayal of the terrain to a more technical or scientific representation of the earth's surface. Today an increasing number of users demand terrain data in digital form in addition to, or in place of the traditional graphics.

The developments in the last decade in computer technology, particularly in the field of computer graphics have opened new vistas to those engaged in providing and managing terrain information. These developments have far-reaching implications, with effects on the storage, display and use of topographical information that are not yet fully appreciated.

In the traditional approach, the graphic manuscript or the reproduction negatives are the principal archival storage of the terrain information. In digital mapping the graphic manuscript is replaced by a digital data file, and the graphic data base is replaced by a topographic digital data base.

Digital mapping technology has the potential to greatly facilitate the use of terrain data by many other professions that are employing geo-referencing principles for the presentation and analysis of their own data, and are overplaying information peculiar to their disciplines upon a topographic map (or a skeleton of it) to display an almost infinite variety of themes. The use of "digital maps" in engineering applications is increasing steadily.

We now have the technology to create digital topographic data banks and data bases. But the degree of usefulness of digital terrain information and consequently the economic benefits of digital mapping will depend, to a large extent, on the degree of sophistication of the classification system of topographic features, an efficient reference system of all data and a file structure that provides for extensive data base management operations. Simple digitizing and encoding of terrain data for subsequent drawing by a computer assisted drafting table will not satisfy the needs of most users of digital data. The system must not only provide capabilities to satisfy general cartographic data processing, but must be capable of providing the base for geographically referenced information systems. However, we must be cognizant of the fact that despite great advances in digital mapping technology and data base management systems during the last decade, we have not yet reached the stage,

---

*Director Topographical Survey Department of Energy, Mines and Resources, Ottawa, Canada

** Presented at USGS Centennial Symposium where the computer can efficiently provide answers to all questions related to the information contained in a digital data base.

A human looking at a map immediately perceives the spatial relations between features but the computer performs dismally in this area and the associated computer costs are often extremely high.

COMPONENTS OF A DIGITAL MAPPING SYSTEM

Any digital mapping system consists of three basic components.

1. The Data Base Management System
2. The Data Input or Data Collection System
3. The Data Output System.

The Data Base Management System

The data base management system is the most critical element of the total system. Its structure and sophistication will determine the degree of usefulness of the collected data. The structure and composition of data base management systems are being vigorously discussed and thoroughly investigated by senior officers of many national mapping programs, and I think it fair to say no concensus has as yet been reached. It is an adventurous person that attempts to describe the ultimate management system, so I will limit myself to describing briefly the data base structure employed at Topographical Survey of Canada. But before I begin, I would like to make the distinction between data bank and data base.

A digital data bank is a collection of data stored in files, which can be accessed and retrieved in an orderly manner. Just as books might be withdrawn from or replaced in a library by using the catalogue shelf number or book number, so can an item (eg. a given contour) or file (eg. file of all contours) be accessed or retrieved in a digital data bank. The action in both cases is independent of the intended use of the information contained in the book or in the digital file. It is a process of simple retrieval of information and there is no facility to relate information contained in files to each other or to answer questions about this relationship (i.e. number of houses above certain elevation).

On the other hand, **a digital data base** contains, in addition to the files, functions for the user to define in terms of a logical model the data elements and the particular association between these elements. The data base system, by means of appropriate software, accesses the data and brings them into association to fulfill the user's requirements, or to provide the answer to the question the user has asked.

The operation is similar to putting a question to a researcher in a library. The researcher would get the data from the books and bring them together for study to enable the question to be answered.

The access paths in a digital data bank and a data base are not the same. In the digital data bank the access paths are the file and the physical organization of the files. It is basically a file management operation. In the digital data base, however, the access paths within the computer system and storage are defined by the user's model for bringing the relevant or selected data into association. Since it is not feasible to foresee all possible applications of digital data, the data is collected without prior knowledge of all its subsequent possible uses. Therefore, data must be collected and stored in such a manner that its eventual use is not tied specifically to a single application, but is available for a variety of applications.

The Canadian Topographic Digital Data Base Management System

The digital topographic data base system of the Canadian Topographical Survey is feature oriented. To simplify the storage and management of the very large amounts of data required for mapping, an efficient means of referencing the data is necessary. The cartographic features are organized on the basis of map sheets, each of which will correspond to a file in a digital system. The sum total of the individual map sheet files constitute a file system. At the file system level of data handling, there is a capability of data storage, data access and data retrieval, based on the knowledge of data content and data orgnization of the files. Each feature is classified according to its cartographic definition, i.e. as roads, bridges, houses, contours, etc., and may be divided into as many segments as the user wishes. A feature (Figure 1) may have associated with it a number of attributes or characteristics; for example, a contour may be described in terms of its height, location (on land, ice or glacier) and type (normal, depression, approximate, auxiliary); a road in terms of its name, road type or construction and so on. Each feature entity is described by a different set of attribute values that make the feature unique. Retrieval of any feature may be based on attribute values. The basis for all cartographic features is their position on the earth's surface. Therefore, each feature is defined in terms of its UTM coordinates. Textual information, such as names are also included in the data base, but cannot be used for retrieval as this is unstructured information. Features of like-type are grouped into classes and the classes are grouped to form a map (Figure 2).

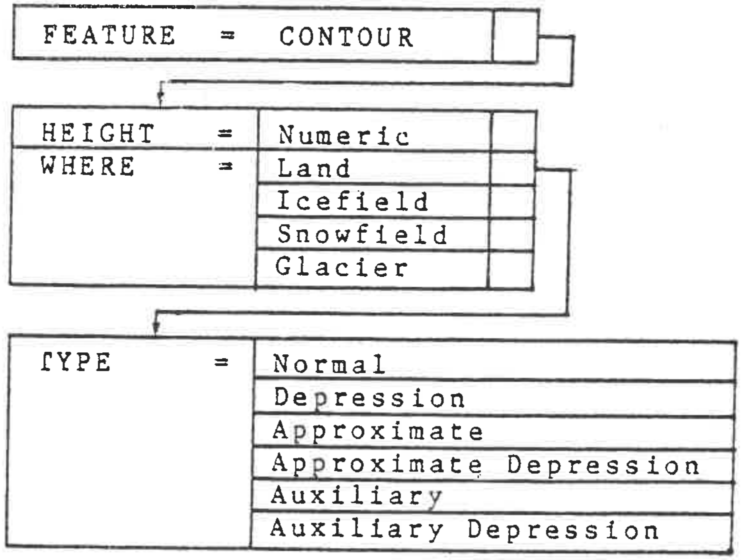
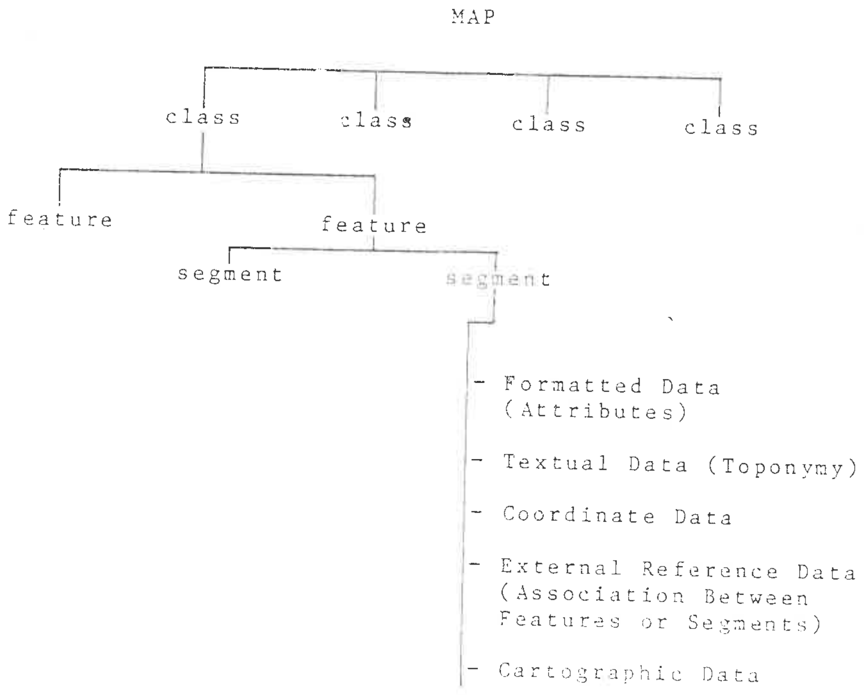


Fig. 1

Data Input System

The input to a topographical cartographic data base comes basically from two sources.

1. Digitization of existing graphics.
2. Direct digitization from air photography on a photogrammetric instrument.



MAP FILE

Fig. 2

The choice between one or the other method depends very much on local conditions and requirements. A county which has accurate up-to-date maps at different scales would most likely opt for digitizing of existing graphics by employing manual digitizers, semi-automatic line following such as the one developed by Laser-Scan of the United Kingdom, or Raster-Scan techniques.

The last two have made considerable progress during the last few years. The development of interactive (man-machine) graphic data collection and editing systems make the digitization on photogrammetric instruments a practical proposition. It gives the stereo plotter operator unrestricted access to the digital data of the stereo model he is compiling and of the surrounding stereo models compiled by him or others. The operator may view these models at any scale on a CRT and perform any necessary corrections or editing. He can tie in adjacent stereo models and perform any required function on the digital data that he normally would on a penciled manuscript in the graphical compilation mode.

Instruments such as the Gestalt Photomapper 2 generate a dense grid of terrain elevations which can form a part of a digital topographic data base.

Data Output System

Digital data offers the possibility of producing on demand an unlimited variety of outputs. However, in order to harness the full power offered to us by digital technology, we must re-examine our practices, concepts and traditions surrounding the cartographic conventions which were designed to a large degree to accommodate the abilities and limitations of the human draftsman. We must revise cartographic specifications to take full advantage of computer assisted drafting systems and not to attempt to make the computer slavishly duplicate human operations. However, we must not lose sight of the basic objective of making a map, that is to portray the terrain with clarity and fidelity in accordance with the needs of today's map users.

Since the geometric accuracy of terrain data is contained in the digital data, the positional accurary of the graphics could be of secondary importance. One can foresee that in the future maps will be printed and distributed in a different manner than today. The production of printing plates directly from digital representation files would eliminate most if not all of the photo-mechanical processes. Organizations or even individuals could interogate regional digital topographic data bases and view a map display on a CRT in their office or at home. They may even have the ability to produce the map of their interest in monochrome or in colour. The technology to accomplish this is now available.

SOME IMPLICATIONS OF DIGITAL TOPOGRAPHIC DATA BASES

The accuracy of the topographic data acquired by graphical map making methods and then subsequently digitized is always constrained by the compilation scale. However, this is not the case when terrain data is digitized directly in the stereo plotter. Whereas in the traditional mapping process the original graphic manuscript compiled photogrammetrically at a given scale is the limiting factor governing the accuracy of topographic data, in digital map compilation the accuracy of the data is limited only by the scale of the photography, the visual accuity and manual dexterity of the photogrammetric operator. The accuracy of the digital data is independent of map scale. There is on displacement of features to avoid crowding and no slippage of the scribing tool in following a different line. The digital data is always of higher accuracy than the resulting graphics. Thus maps at several scales can be automatically drawn from the same photogrammetrically obtained digital data to graphic accuracies that are standard for each scale.

When we speak of a map at a given scale we intuitively form a mental concept as to the accuracy and content of terrain information portrayed on that map. However, in terms of digital data, "scale" becomes meaningless. We have to develop and get used to a new concept applicable to the digital environment, which would be equivalent to the concept of "scale" in the graphical environment. This new concept would include standards of geometric accuracy, precision and level of topographical content of digital data. For example, at the lowest level of content a road may be defined by its centre line. At a higher level the road could become a "host feature" defined by the lines demarcating the sidewalk, shoulders, ditches and right of way.

Traditionally terrain elevation is represented by contours. This type of relief depiction is well understood by most map readers, but for computer applications, the relief is best represented by a digital elevation model. It could be then argued that the digital topographic data base should contain DEM information and not contours. Contours at different intervals could be automatically generated on demand from the DEM's.

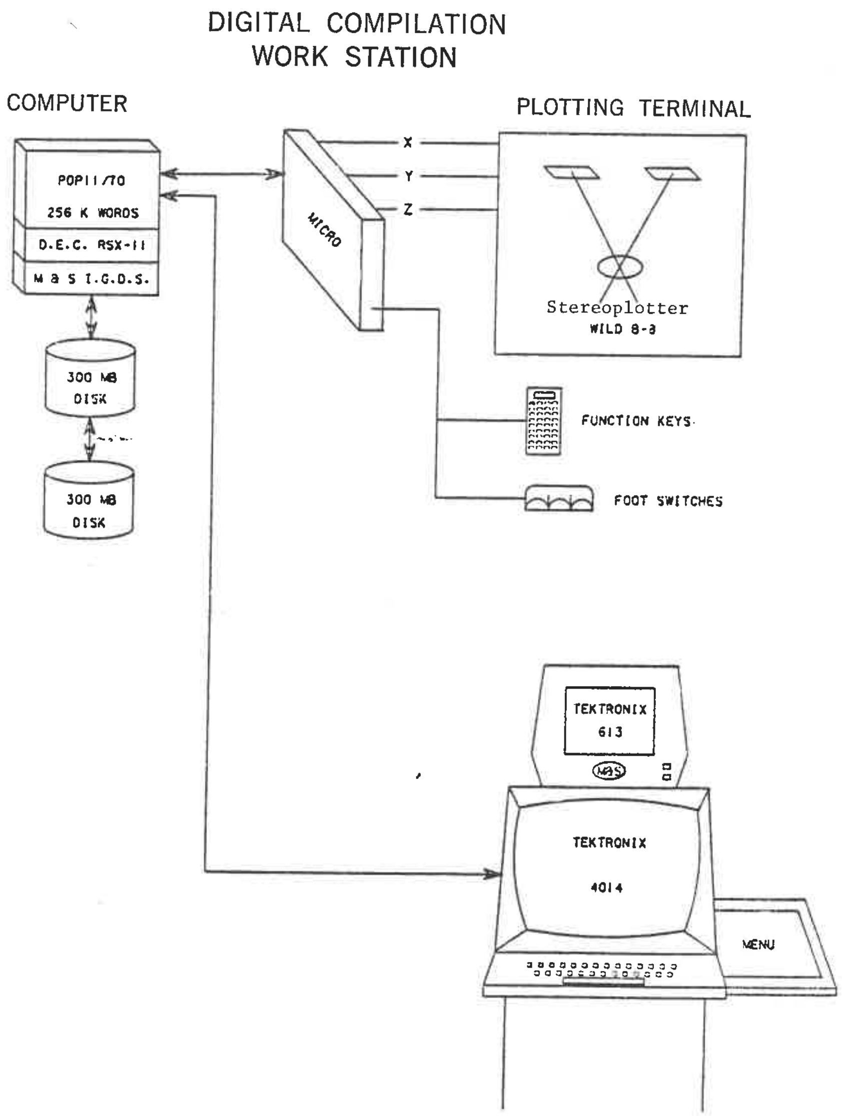


Fig. 3

In digital mapping two basic types of digital files should be considered.

1. Position File
2. Representation File

The **position file** contains edited and checked data collected directly in digital form on a photogrammetric instrument or from large scale plans where the position and shape of features is not distorted by cartographic representation. In this file all topographical features are recorded in their true geographical position without regard to cartographic symbolization.

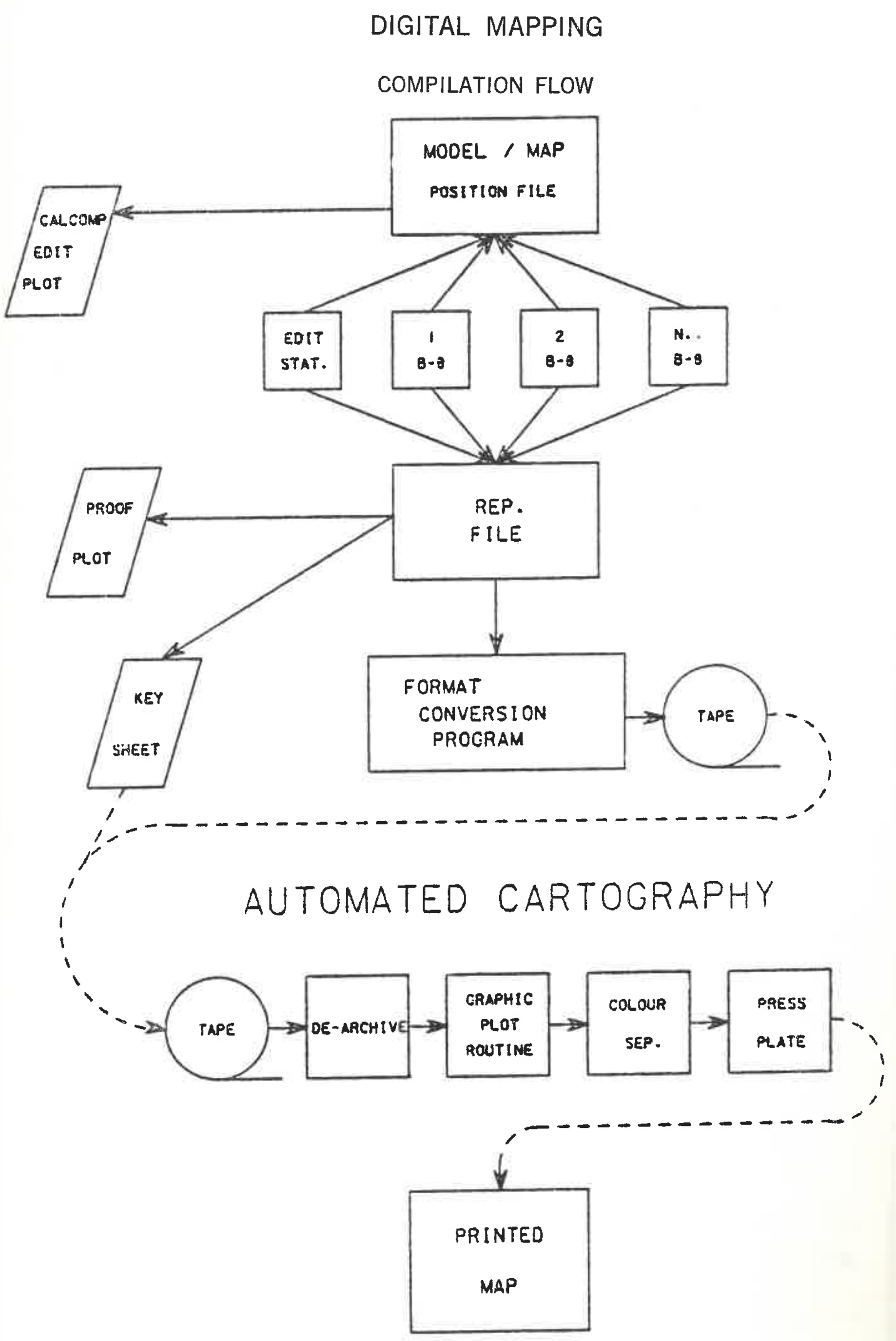


Fig. 4

The **representation file** is created by the cartographer for each scale of map from the position file. A computer assisted interactive cartographic system permits the cartographer to displace or delete features, select appropriate symbols, and then to issue appropriate commands for the automatic drafting of colour separation negatives.

On the surface it would appear that the creation of the position and representation files could be accomplished independently by the photogrammetrist and the cartographer without reference to one another. This however, is not the case. The classification and referencing of topographic features, and the coding and organization of the digital files at the data collection stage has an enormous influence on the software required for the cartographic treatment of the data. In fact, the classification and referencing governs the efficiency of the cartographic phases of map production and the whole data base structure. Therefore, development and operation of a digital mapping system which includes computer driven negative scribing must be a joint effort of the photogrammetrist-topographer and the cartographer. The computer scientist is naturally an important member of the team, but he must remain subservient to the map maker.

The successful application of a digital mapping system in production does not only depend on a thorough engineering development of the system, but to a large extent on clearly defined operational procedures and standards. Any deviation however small may render data useless, cause software systems to crash or may require costly manual intervention.

ACTRON CONSULTANTS LIMITED
11 HELENE STREET SOUTH
MISSISSAUGA, ONTARIO L5G 3A8
PHONE: 274-7744

CONSULTING ENGINEERS
PROJECT MANAGEMENT
PRESIDENT: GEORGE K. KOWALCZYK, P.Eng.

ZDZISŁAW PRZYGODA, F.E.I.C., P. Eng.
CONSULTING STRUCTURAL ENGINEERING
SERVICES: Feasibility studies, design, supervision, investigation of structural failures, reports, arbitration, expert advice in legal construction disputes.

Z. PRZYGODA & ASSOCIATES LTD.
12A Finch Ave., West
Willowdale, Ontario, M2N 2G5
Telephone: (416) 221-1531 — Canada

J. P. KLOC & ASSOCIATES, INC.
CONSULTING ENGINEERS

162 BAYVIEW FAIRWAYS DRIVE
TORNHILL, ONTARIO, L3T 2Y8
TELEPHONE: (416) 881-3153

Christopher Z. Tworkowski, B.Arch., M.R.A.I.C.

181 BELSIZE DRIVE
TORONTO, ONTARIO, M4S 1L9
TELEPHONE: (416) 484-6959

PACZKI DO POLSKI
EKSPRESOWA DOSTAWA W CIĄGU 14 DNI

Paczka nr 1. Cena kan. $32.00. Waga około 10.75 funtów
Szynka — smalec — szynka mielona — boczek.
Paczka nr 2. Cena kan. $52.00. Waga 18.75 funtów
Szynka — boczek — szynka mielona — smalec — kawa.
Paczka nr 3. Cena kan. $54.00. Waga 19.25 funtów
Szynka — smalec — szynka mielona — przecier pomidorowy — salami — tłuszcz roślinny — rodzynki — ryż — kawa — herbata.
Paczka nr 4. Cena kan. $60.50. Waga około 22 funtów
Szynka — smalec — szynka mielona — salami — tłuszcz roślinny — ryż — śliwki — kawa — herbata — kasza manna płatki owsiane.
Paczka nr 5. Cena kan. $64.00. Waga około 17.75 funtów
Szynka — salami — boczek — szynka mielona — smalec — kawa.
Paczka nr 6. Cena kan. $64.00. Waga około 18.75 funtów
Szynka — smalec — szynka mielona — salami — kawa — herbata.
Paczka nr 7. Cena kan. $37.00. Waga 19.75 funtów
Mąka — cukier — szynka.
Paczka nr 8. Cena kan. $28.00. Waga około 12.75 funtów
Proszki do prania: Purex — Ivory snow — mydło toaletowe.
Paczka dla niemowląt. Cena kan. $52.00. Waga ok. 17 funtów.

Zapraszamy do korzystania z naszego fachowego i kilkuletniego doświadczenia.

- Podróże indywidualne, grupowe i czarterowe do Polski i innych krajów świata;
- Sprowadzanie krewnych z Polski;
- Załatwiamy wszystkie formalności z uzyskaniem paszportów, wiz tp.;
- Kupony Orbisu;
- Przesyłki pieniężne do Polski;
- Dysponujemy dużym wyborem tur po dostępnych cenach do ciepłych krajów: Bahamas, Bermuda, Jamajka, Floryda, Kuba, Hawaje, Hiszpania itp.;

Dogodna komunikacja i bezpłatne parkowanie — Dojazd koleją do stacji Keele.

Po bliższe informacje i nowe cenniki podróży prosimy zgłaszać się do naszego biura.

BIURO PODRÓŻY
ZWIĄZKU POLAKÓW w KANADZIE
TRAVEL & TOURS LTD.
1640 Bloor Street West
Toronto, Ontario, M6P 4A8
Tel. 531-4444, 532-3326