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CASI LOG
CARNET DE L'IASC

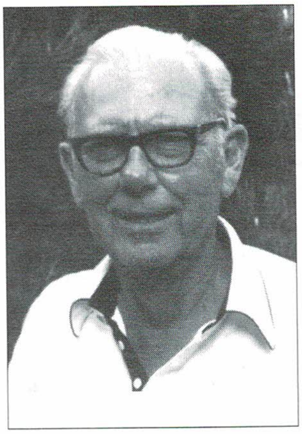
October ■ octobre 2000, Volume 8, No. 5

1913-2000

Harold Raymond Foottit

Chairman of the CASI Interim Council 1953/54

by R.D. Richmond, FCASI



Ray was born at Vancouver B.C. in 1913 and passed away in June of this year. As a young man in the early 1930s, he was amongst a very small and diverse number of Canadians seriously interested in the technical aspects of aeronautics.

He graduated in 1934 from the Curtiss Wright Technical Institute of Aeronautics in California, a well recognized organization at that time, where he won the prize for original design and a letter of commendation from its President. The following year, he travelled to the UK, as were other like-minded enthusiasts, to gain training or experience in what was a very prolific industry. In 1935, he entered the design department of Heston Aircraft, moving the next year to Fairey Aviation. With World War II looming, married and possessing a newborn, he returned to California to join the Stress Department of Vultee Aircraft Company, and later, the Ryan Aeronautical Company, where for a period he was an instructor in that company's Aeronautical School.

In 1942, he joined the RCAF, at Headquarters in the Directorate of Aeronautical Engineering as Staff Officer in charge of Airworthiness, before his promotion to Squadron Leader in the Aircraft Development Section. He resigned his commission in mid-1945 to return to Ryan as Chief of Stress Analysis but rejoined RCAF Headquarters as Officer in Charge of Airframe Development the following year, with the rank of Wing Commander. Apart from two field postings and time at Staff and Defence College, Ray spent most of his career during the 1950s and 1960s at Headquarters, progressing to the rank of Air Commodore as the Director General of Aerospace Systems. It was a very active time during much of this period within the RCAF and consequently the Aerospace Industry where he had an active responsibility for the development of such well-known projects as the Sabre 5 and 6, the CF-100, the Argus Maritime Patrol Aircraft and the Tutor. During that time, he was also appointed, in 1957, Director of Aircraft Engineering - Assistant for Weapons Systems on the much publicized Arrow Project.

He retired from the service in 1967 and joined the Department of Industry, Trade and Commerce as Director of Aerospace for a period of five years, where he continued to influence aircraft development. The next ten years, he maintained his interest in Aerospace through consulting work with J.T. Taylor and Associates and later with Foottit, Mitchell and Associates.

As an active member of the Ottawa Aeronautical Society, one of the founding groups of CASI, Ray was one of those nominated to represent that organization in the discussions that took place with the other charter groups. How the CAI (CASI) was formed was well documented by him in the first issue of the CAI Log, including that he was "pushed" into the Chair of the Interim Council; it needs to be added that it was by acclamation. Although the four original organizations all had the same objectives, there were many diverse opinions on how they should be achieved. The formalization of the Institute within nine months from the initial informal meeting can be credited to Ray's affable but determined diplomatic skills in reconciling a multitude of issues.

It was recognized early in the formative process that one of the essential elements of the Institute would be its own publications to convey information and as a vehicle for the membership to record technical papers. Ray was a writer, particularly on aeronautical subjects, who was later recognized by the Air Industry and Transport Association in 1956 with his receipt of their Writer of the Year award for "outstanding Aviation reporting". This talent led him to become the initial Chairman of the Institute's Publication Committee, which produced the first Log in September 1954, just four months after the inaugural meeting. The Journal followed in 1955. Both these publications continue as a tribute to his determination to making the Institute a success. In 1973, he received the C.D. Howe award in recognition of his leadership abilities.

Ray Foottit left an indelible imprint on Canadian Aerospace; as a military officer, a skilled engineer, an administrator and his unselfish dedication to the formation of this Institute.

Contents

Sommaire

CASI LOG
CARNET DE L'IASC

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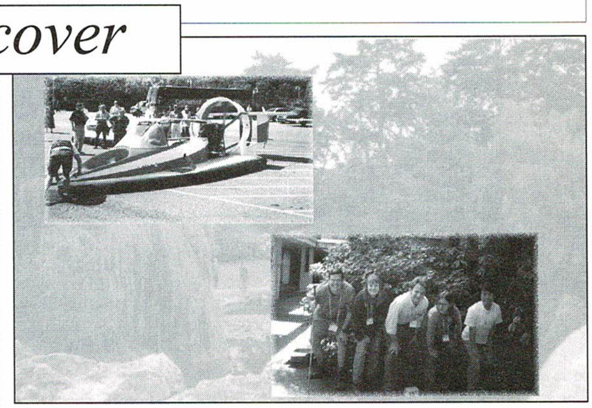
CASI Log is published six times per year: February, April, June, August, October, December. Individual members receive a subscription as a non-deductible component of their annual membership. Non-members may subscribe at an annual cost of $16.00 Cdn (NAFTA) or $20.00 Cdn (elsewhere).

Le Carnet de l'IASC est publié six fois l'an: février, avril, juin, août, octobre et décembre. L'abonnement au Carnet est inclus dans la cotisation annuelle de nos membres individuels. Pour les non-membres, l'abonnement annuel est offert au prix de 16,00 $ can (NAFTA) et 20,00 $ can (ailleurs).

cover



Upper Left corner: A hovercraft demonstration on Toronto's waterfront during our Canadian Air Cushion Technology Society Conference, August 28-29th. **Lower Right corner:** Our volunteers for success: University of Victoria students help make a success of our 22nd Remote Sensing Conference.

Message from the Executive Director

When I was young September meant one thing and it filled me with dread: back to school. Nowadays autumn is my favourite season, not least because even as Nature slows down in preparation for winter's slumber, the pace of business perceptibly quickens. It's an invigorating time.

Your HQ has been working hard over the summer, with two conferences in August - the Annual General Meeting and Conference of CRSS in Victoria, and of the Canadian Air Cushion Technology Society in Toronto. We also moved our offices down two floors and we now occupy a somewhat larger space on the 6th floor. Please drop in if you're in the area!

Executive and Strategic Planning Committee meetings took place on September 11, and September 12 saw the meeting of the full Council. Many of you will be happy to hear that CASI's web site will be substantially upgraded and expanded, with the process beginning this year. We invite each of you to let us know what improvements you would most like to see - and to volunteer some of your time and expertise if you would like to help.

I am hoping to meet many of you at your Branch meetings this fall. A Branch Kit is in preparation that is intended to help local Executives to administer Branches, plan meetings, organize programs, manage finances and so on. Again your input is most welcome, particularly as to the topics you would like to see covered in the Kit.

The high point of our autumn season will be Astro 2000, the 11th CASI Conference on Astronautics, November 7-9 in Ottawa. The theme is Canada in Space - Opportunities and Challenges and the lineup of papers and keynote speakers is certain to appeal to anyone interested in space. The topic will be covered from a wide variety of angles - scientific, military, commercial, technological, financial. Delegates to Astro 2000 will be enlightened with a wealth of practical information, and enriched by the opportunities to develop personal relationships and to network with like-minded professionals.

I hope to see you there!

Geoff Languedoc

Welcome to our New Corporate Partner!

AeroVations Associates

History of the Canadian Remote Sensing Society

We are preparing an article for the CASI Log that describes the history of the Canadian Remote Sensing Society. To assist us with this project, we would appreciate receiving your anecdotes, recollections and photographs, particularly from the earlier days of the Society.

Please send me your text input via e-mail, **bryerson@kim-geomatics.com**. If you are sending photos (scanned or hard copy) please ensure they are well packaged and send them via regular mail, to me at: **Dr. Bob Ryerson, c/o Box 1125, Manotick, ON K1A 1A9.**

Thank you.

Call for Papers

FLIGHT MECHANICS AND OPERATIONS SYMPOSIUM

Regal Constellation Hotel, Toronto, Canada
29 April - 02 May 2001

Organized through the Flight Mechanics and Operations Section of the Canadian Aeronautics and Space Institute in conjunction with its 48th Annual Conference

The Flight Mechanics and Operations Section of CASI is a forum for exchange of technical information on all aspects of the integrated flight vehicle engineering and operations. The objective of the symposium is to become the primary venue for communication among the various elements of the Test and Evaluation (T&E) and Operations communities in Canada.

This Symposium offers a unique opportunity to learn, network, and do business with others having similar interests. Recipients of this Call for Papers are strongly encouraged to give it the widest possible circulation.

Topics

Applicable topics/areas of interest include, but are not limited to, the following:

- *Flight Dynamics*
- *Flight Test Engineering*
- *Stability, Control and Flying Qualities*
- *Aircraft Operations*
- *Cockpit Technologies*
- *Aviation Human Factors*
- *Aircraft Systems and Avionics*
- *Pilot-Aircraft Interface*
- *Simulation and Training*
- *Flight Safety*

Presentations, Exhibits & Publication

Papers are invited on any of the above topics or related topics that would be of interest to the Section participants. Papers selected for the Symposium will be allotted thirty minutes for presentation, questions, and discussion. Submissions are also welcome for display at a "poster session" to be presented at the Symposium. Poster displays are intended to be graphical exhibits based upon the written paper, outlining individual research or showcasing broader organizational accomplishments. Details of exhibit guidelines are available upon request. Attendees will receive a bound copy of the collected papers presented. Authors are encouraged to submit their work for publication in the Canadian Aeronautics and Space Journal. Authors are responsible for expenses incurred in preparing papers and illustrations and for all costs to attend the Symposium, including the registration fee.

Submission

Authors submitting abstracts must complete the registration form (see CASI web site or call the CASI office) and return it with their abstracts by mail, fax, or e-mail to the Section Chair by 15 December, 2000. Submissions may be made in either English or French. Abstracts may be a maximum three pages in length, including figures. Authors will be notified of acceptance before 30 January, 2001. Instructions for preparing final papers will be sent at that time. Final papers must be sent to the Section Chair before 30 March, 2001. Authors considering submission of papers are encouraged to call the Section Chairman for further information.

Address

Address all abstract submissions or inquiries to:

CASI Flight Mechanics
and Operations Symposium
Mr. Robert Erdos, MCASI
NRC/IAR Flight Research Laboratory
Building U-61
Ottawa, ON K1A 0R6
Phone (613) 998-3180
Fax (613) 952-1704
E-mail: robert.erdos@nrc.ca

Call for Papers

Structures and Materials Symposium and Canadian Air Force Aircraft Structural Integrity Conference

Regal Constellation Hotel, Toronto, ON
April 29-May 2, 2001

"Aircraft Structures, Integrity and Technology Management"

In conjunction with the 48th Annual Canadian Aeronautics and Space Institute Conference, CASI Structures and materials Section and National Defence Director of Technical Airworthiness are sponsoring a three-day symposium.
The Symposium will be an opportunity to demonstrate how technology will help Canadian Aerospace industry continue tremendous successes of the previous decade. Papers are sought that illustrate how technology can be leveraged to strengthen the development of products through partnerships between large, medium and small companies. In keeping with budgetary realities, global markets and increased competition we are also interested how technology can lead to reduced cost of operations, maintenance and continued safe operation beyond original design goals. Topics may include, but should not necessarily be limited to:

- Integrated design tools
- Multi-disciplinary optimization
- Structural design, analysis and test, including certification issues
- Technical data management for geographically dispersed locations
- Structural modelling and simulation technology
- Advanced materials and process development
- New repair methods
- Smart structures and processes
- Integration of non-destructive inspection methods into aircraft structural management
- Durability, damage tolerance, failure analysis and loads monitoring
- Internet aware structures and materials applications
- Environmental degradation, corrosion
- Planning structural integrity programs

Please note that in addition to regular CASI awards, there will be an extra award for the best student paper.

Submission

Abstracts of 200 - 500 words, in either official language, should be submitted to the Conference Chair, preferably by e-mail (MS-WORD), on or before January 15th 2001. Submissions by Mail or Fax will also be accepted.
Please ensure that you include the information contained on the form printed on the reverse of this sheet with your submission. No translation facilities or services will be provided. Authors of papers accepted for presentation will be advised on or before February 12th 2001 and will be required to submit an extended abstract of their presentation or full paper
on or before Monday March 12th 2001.

Presentation and Publication

Each paper is allotted approximately 30 minutes for presentation including discussion and questions from the floor. Authors are encouraged to provide copies of their presentation for distribution at the Symposium/inclusion in the proceedings and to submit full-length papers of their work for
inclusion in the CASI Journal.

Address

Address one copy of your abstract to one of the following organizers :

Mr. B. James Miller
Manager, Engineering & Customer Support
Comtek Advanced Structures Ltd.
1360 Artisans Court
Burlington, ON L7L 5Y2 Canada
Tel: (905) 331-8121
Fax: (905) 331-8125
E-Mail: jmiller@comtekadvanced.com

Maj. Jean-Francois Leclerc
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Cumberland House
400 Cumberland Street
Ottawa, ON K1A 0K2 Canada
Tel: (613) 993-0663
Fax: (613) 998-6922
E-Mail: maj.jf.leclerc@debbs.ndhq.dnd.ca

Message from the General Manager

Message du Directeur général

This year, the CASI HQ Staff has been extremely busy. Usually, the summer months allow us a brief interval of relief to review our operating plans, evaluate our progress and adjust our strategies, if necessary. However, with this past summer's loaded schedule, we had almost no respite.

After closing our books on the Annual General Conference in Ottawa, in May, we immediately turned our full attention to the logistics, already underway, for two more conferences:

The Remote Sensing Conference was held in Victoria, on August 20-25. The venue was the beautiful campus of the University of Victoria, under ideal weather conditions. Two hundred and nine delegates participated and 135 oral and paper presentations were delivered. Initial feedback indicates that the program was current, informative and very well received.

A few days later, we were off to Toronto for the Canadian Air Cushion Technology Society Conference on August 28 and 29. On the first day, there were demonstrations, at Toronto's waterfront, of a variety of hovercraft. On the second day, a series of technical sessions was held. There were 40 delegates from Europe, the United States and Canada, and there was a lot of enthusiasm, networking and benchmarking.

Then, back to the office where the landlord decided to exercise the lease option to relocate us to Suite 618 from 818 (same street address; same postal code, same phone, fax and e-mail). September in Ottawa is a big month for commercial and residential moving. So, our movers arrived four days late and the telephone company followed suit, during which time the office equipment was in limbo --- no phones, no fax, no e-mail, no computers. We're slowly but surely getting back to normal. Drop in and see your new CASI Headquarters!

Please note our new address:

Suite 618 - 130 Slater Street
Ottawa, Ontario K1P 6E2

Marie Juneau

Notre horaire cette année a été très chargé. Ordinairement, la saison estivale nous permet de ralentir un peu, afin d'évaluer notre performance et notre progrès, et d'ajuster nos stratégies afin de rencontrer nos objectifs pour l'année. Cependant, aucun repos n'était possible pour nous en 2000…

Dès la fermeture de notre Conférence annuelle du mois de mai à Ottawa, nous avons dû immédiatement tourner notre attention vers les deux conférences de l'été :

Premièrement, la conférence sur la télédétection, tenue à Victoria, du 20 au 25 août. Quelle belle ville! Le campus de l'université de Victoria resplendissait de beauté naturelle, et nous avons tous profité de la température idéale. Notre assistance comptait 209 délégués et nous avons reçu 135 présentations techniques orales et écrites. À date, toutes les indications sont que notre programme était courant, à propos et reçu avec enthousiasme.

Quelques jours plus tard, nous étions sur la route encore une fois, pour la conférence de la Société canadienne sur la technologie du coussin d'air, tenue à Toronto les 28-29 août. La première journée était réservée aux démonstrations d'aéroglisseurs de tous genres, au bord de l'eau, suivie le lendemain par une série de sessions techniques, où nous avons reçu une quarantaine de délégués provenant de l'Europe, des États-Unis et du Canada. Ils ont pris plein avantage de l'occasion pour partager leurs connaissances, profiter du réseautage et pour encourager les nouveaux venus.

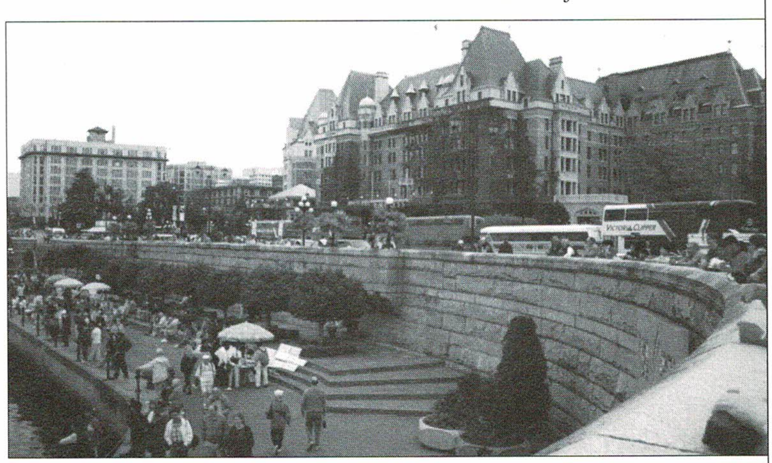
De retour au bureau national à Ottawa, il n'y avait aucun temps à perdre! Le propriétaire avait décidé d'exercer l'option contractuelle de location pour nous faire déménager de notre local 818, au local 618. Le mois de septembre à Ottawa semble être le mois de la crise du déménagement, soit commercial ou résidentiel. Nos déménageurs sont arrivés quatre jours en retard, ainsi que les techniciens pour les lignes téléphoniques, alors donc, nous nous sommes retrouvés sans téléphones, télécopieur, courriel, ordinateurs, etc.

Nous revenons de nouveau à la normale, et sommes fiers de notre nouveau bureau plus spacieux. Il nous ferait plaisir de vous recevoir, ainsi que vos commentaires.

Surtout, prenez note de notre nouvelle adresse :

Suite 618, 130, rue Slater
Ottawa (Ontario) K1P 6E2

Marie Juneau



Minutes of the AGM of the Manitoba Branch of the CASI

Held at the 17 Wing Officers' Mess, 28 June 2000

The Branch Chairman Alan Tring opened the meeting at 6:45 p.m. by welcoming the members and guests present.

The Chairman noted that traditionally the first item on the agenda should be the reading and approval of the minutes of the previous AGM. The Chairman apologized that no minutes were prepared for last year's meeting and promised that this oversight would be corrected this year.

The Branch Treasurer, Jim Jarrett was unable to attend the meeting and the Chairman presented a report on his behalf.

The balance in the Branch chequing account stands at $1377.25, which is approximately $255 higher than at the same time last year. It was noted that the Branch receives $100 from CASI HQ for each meeting held during the year, the condition being that we submit a report for inclusion in the CASI Log. We received $300 this last year as the report for one meeting is still outstanding. We remitted $100 to the Student Branch, as they organized and hosted the first meeting of the season.

A report on Student Branch activities followed and was presented by the Student President Dale Oleschuck.

Dale reported that in addition to organizing the October meeting and visiting several of the local aerospace companies, the students participated in the CASI-sponsored Glider competition held in Ottawa earlier this year and placed fourth out of seven; an improvement on the eighth out of eight achieved last year (their first year of participation). Of the nine members involved, five went to Ottawa for the competition. The students now have a larger room allocated at the university for use of the CASI members, which is expected to raise the profile of the group in the next school year.

The Chairman reported that the Manitoba Branch had had another successful year with meetings being generally well attended, the numbers being boosted as last year by the presence of U of M student members of CASI, which was gratifying. The students participated in running Branch affairs by attending the two Committee meetings held during the year. There are presently 57 regular members of the Branch and 21 student members in Manitoba. In addition, we have 14 members in Saskatchewan and one in NW Ontario who are affiliated with the Manitoba Branch for a total of 93. Of those, we count on about one third for regular attendance at our meetings. We have e-mail addresses for about half the membership which has cut down the time required to prepare and the cost of mailing meeting notices.

Four regular meetings were held during the year, including the President's visit. Two Committee meetings were also held; one in October and one in April, to discuss Branch affairs.

In October, the student members organized a meeting at the U of M with a presentation by Kelly Woiden of Bristol Aerospace on the Hokum-X helicopter refit project.

The President of the CASI, Mr. Patrick Whyte visited the Branch in December. After a gala dinner in the Officers' Mess at 17 Wing, Mr. Whyte spoke to us on "A Supplier Partnership Model for the 21ST Century".

In March, a group of members and friends toured the Combined Services Building at Winnipeg International Airport. This building houses the operations of the airport Emergency Response Service and the equipment used to provide regular maintenance of the runways.

The April meeting was held at the St. James Branch of the Royal Canadian Legion at which time Mr. Vince Lopata of Acsion Industries spoke on "Electron Beam Curing of Composite Materials".

After thanking the out-going Branch Organizing Committee, the Chairman announced that the following members had agreed to continue to serve on the Committee for the coming year.

Alan Tring	*Standard Aero Ltd*	*Chairman*
Ron Fielding	*Boeing Canada*	*Past chairman*
Jim Jarrett	*Bristol Aerospace*	*Treasurer*
Don Pearsons	*Canadian Forces*	*Councillor*
Don Jennings	*Boeing Canada*	*Member*
Bill Kolafa	*Standard Aero Ltd*	*Member*

In addition, the following members have kindly offered to help in running the Branch and organizing activities.

Kathryn Ferguson	*Standard Aero Ltd*	*Member*
James Watson	*MRM Steel*	*Member*

There being no other nominations from the floor, the Committee members were considered elected by acclamation.

Those present were invited to suggest ways in which the Committee could better serve the members or to suggest meeting subjects (names of potential speakers or places to visit). In this respect, the following suggestions were put forward; Malcomb Hinds suggested a tour of the Nav Canada ATC Centre at the airport.

Jim Poplow suggested a visit to the Altitude Training Facility. Murray Auld promised to put us in contact with someone at the Southport flight training centre in Portage LaPrairie.

There being no other business, the meeting was adjourned at 7:20 p.m. The meeting was followed by a most enjoyable Bar-B-Q sponsored by the Branch. The food, prepared by the Mess kitchen staff, was excellent and our members and their guests spent a pleasant couple of hours socializing after the meal.

EMS Technologies System to Provide NASA Shuttle Missions Better Tracking Capabilities in Space

EMS next-generation CALTRAC(TM) Star Tracker allows shuttles or satellites to pinpoint their direction quickly over a wide area

OTTAWA, July 25 /CNW/ - EMS Technologies, Inc. (Nasdaq - ELMG) is announcing today the successful completion of the first flight of its new CALTRAC(TM) Star Tracker system aboard the NASA Space Shuttle Atlantis on mission STS-101. The tracker provided critical navigation functions to the mission crew during an experiment of orbital attitude readiness involving the International Space Station.

The EMS system also will fly on one of NASA's Discovery missions, Genesis, scheduled for launch in January 2001. The two-year mission will involve sending a spacecraft to collect pieces of the Sun, called solar wind samples, to help scientists better understand the make-up of the solar system.

"EMS Technologies is pleased to provide NASA with a high speed, fully autonomous star tracker that can assist NASA's experimental requirements and assure that satellites maintain proper attitude continually while in flight," said Al Hansen, president and COO, EMS Technologies.

The CALTRAC Star Tracker system has a wide field of view so it can quickly provide attitude pointing for satellite or shuttle missions. It also features its own power supply and processor so it doesn't draw on the shuttle's central processing system.

Developed by EMS Space & Technology Optical Products Group in Ottawa, Ontario, the Star Tracker provides the shuttle's position as a reference for other navigational devices, such as the GPS (Global Positioning System) and the INS (Intertial Navigation System).

"The EMS Star Tracker system performed well throughout our STS-101 mission, providing a high data rate, and extremely accurate tracking for long periods of time," said Stewart Bain, director - Optical Products, EMS Space & Technology Group. "The system has demonstrated that it can meet NASA's critical navigational requirements in the rugged environment of space."

EMS Technologies, Inc.

EMS Technologies, Inc. is a leading innovator in the design and manufacture of wireless and satellite solutions, and focuses its unique range of advanced technologies on the needs of broadband users. The company is headquartered in Atlanta, employs 1,600 people worldwide, and has major manufacturing facilities in Atlanta, Ottawa and Montreal. For more information, visit the company on the World Wide Web at www.ems-t.com.

For further information: Halina Sejdak-Rydel, EMS Technologies - Canada, (613) 727-6277, ext. 1290, rydel.h(at)ems-t.com; Anne Wainscott, EMS Technologies - Atlanta, (770) 263-9200, ext. 4326, pr(at)ems-t.com/(ELMG)

CAISU Conference:

"Space: Not Just Rocket Science"

In conjunction with the CASI ASTRO 2000 Conference, the Canadian Alumni of the International Space University (CAISU) are hosting a one-day event, Nov. 6, 2000, dedicated to exploring the interdisciplinary, international and intercultural nature of space. The program is geared for undergraduate/graduate university level students and young professionals. Morning lectures spanning topics from Space Sciences & Engineering to Business & Law, are followed by a challenging Team Project in the afternoon, incorporating all these aspects as they relate to "Crew Selection Criteria for a Mars Mission". This is a unique opportunity to gain a hands-on introduction to space career and educational opportunities, and to network with young leaders in the space industry.

Program

7:30 - 8:30 a.m.	Registration and Registration Kit Distribution
8:30 - 8:45 a.m.	Welcome
8:45 - 9:15 a.m.	Lecture 1: Space Engineering/ Mission Planning
9:15 - 9:45 a.m.	Lecture 2: Space Physical Sciences
9:45 - 10:15 a.m.	Lecture 3: Space Life Sciences
10:15 - 10:45 a.m.	Break
10:45 - 11:15 a.m.	Lecture 4: Psychology of Long Duration Missions
11:15 - 11:45 a.m.	Lecture 5: Space Business & Marketing
11:45 - 12:15 p.m.	Lecture 6: Space Policy & Law
12:15 - 12:30 p.m.	Question Period
12:30 - 1:30 p.m.	Lunch with Keynote Speaker (TBD)
1:30 - 2:30 p.m.	Team Project Introduction / Panel Discussion
2:30 - 7:15 p.m.	Team Project: Crew Selection Criteria for a Mars Mission - Brainstorming - Consolidation - Presentation Preparation - Group Project Presentation
7:30 - 9:30 p.m.	CASI Mixer and International Space University Poster Session
9:30 - 10:30 p.m.	Wrap Up

Project Working Groups :

1) Physical Science
2) Legal & Ethics
3) Space Architecture
4) Remote Sensing & Robotics
5) Space Life Sciences
6) Space Sociology
7) Space Engineering
8) Political & Financial Matters / Publicity

The International Space University (ISU) is an internationally renowned institution dedicated to promoting international, intercultural, and interdisciplinary space education not only at the post-graduate level, but within industry as well. For more information, join us at the conference, or visit ISU's website at www.isunet.edu.

Canada's Encounter with High-Speed Aeronautics*

- *JULIUS LUKASIEWICZ*, FCASI

The war years from 1939 to 1945 were years of dramatic growth for the Canadian aeronautical industry. Yet, while the volume of output by 1945 was prodigious, in terms of design and development capability, Canada was still an infant country: most design work was British or American. The war years were also the time when high-speed aeronautics was an infant enterprise; until the mid-1940s, flight at speeds approaching or exceeding the speed of sound had remained the exclusive domain of gun-launched projectiles. But, with supersonic speeds having become feasible, in 1945 Canada embraced high-speed aeronautics in the hopes of gaining a place in the forefront of technological progress.

The vision was short-lived, though the efforts devoted to achieving it were not insignificant. In the years following the war, the Canadian government spent hundreds of millions of dollars to establish a presence in the field.[1] Hundreds of engineers and technicians were lured from abroad, large aircraft and engine plants were operated and laboratory facilities were developed. These efforts took place against the backdrop of similar activities in the United States, Britain, France, and other countries.

Before the end of the war, high subsonic speeds had been attained by propeller and jet aircraft, and by pulsed-ramjet missiles (FZG76 or V-1). Supersonic speeds in excess of Mach 4 had been achieved by long-range rockets. (the first ballistic missiles, A4 or V-2).[2] These developments were much more advanced in Germany than in the Allied countries. Indeed, a U.S. Army Air Forces intelligence report issued shortly before the war's end warned that "German development in jet-propelled aircraft...may well be regarded as the greatest potential threat...to Allied air superiority."[3]

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When Allied forces overran German aeronautical research facilities following the landings in France in 1944, the evidence collected by technical intelligence promised attractive new vistas of development, for both military and civil applications.[4] Almost immediately, the major Western powers and the Soviet Union stepped up the development of jet and rocket engines, high-speed subsonic and supersonic aircraft, and missiles. They also began developing major new laboratory facilities.

Canada's desire to be a part of this activity was hardly surprising. After all, it had become fashionable and prestigious for governments, industries, and universities to involve themselves in high-speed aeronautics. Furthermore, conventional wisdom dictated that nations ought not be dependent on other nations for armaments. And economists reckoned that "the design, development and production of modern weapons has a spin-off that raises the whole technological and economic level of a nation." [5]

Added to these arguments were powerful political priorities. As the war drew to a close, the reigning Liberal government did not relish the prospect of shutting down the country's huge military aircraft industry. The attendant unemployment would do nothing to improve the government's fortunes in the impending elections. Moreover, Canada had attained a certain status as a major wartime aircraft manufacturer, and there appeared to be legitimate reasons to believe it might be able to sustain a viable industry in peacetime as well. It was thus that Canada came to be one of the many countries deciding to undertake - each on its own - the original development and manufacture of high-speed military aircraft, jet engines, and missiles.

As recounted below, the Canadian effort was brief and for the most part unsuccessful. By 1959, all major projects had been halted. The only legacies of the country's ambitious venture into high-speed aeronautics were a relatively minor program of aerodynamic and aeroballistic research that continued into the 1960s and the establishment of a large British-owned conglomerate of mostly heavy industries. The Canadian experience will be reviewed here under two headings: large industrial-scale projects and the more modest research efforts. This examination points clearly to the basic causes of failure[6] and suggests strategies that might have been more likely to succeed.

The political, institutional, and bureaucratic aspects of this episode cannot and should not be divorced from the essentially technical factors involved. Indeed, technical questions are particularly significant where innovation is involved, as in the case of development of intermittent wind tunnels.

Dr. LUKASIEWICZ, professor of mechanical and aerospace engineering at Carleton University, Ottawa (1971-97), was engaged in supersonic aerodynamics research at the Royal Aircraft Establishment, Farnborough, United Kingdom, from 1945 to 1948. He then joined the National Research Council of Canada and from 1950 to 1957 was head of the High Speed Aerodynamics Laboratory in Ottawa; from 1958 to 1968 he was Chief, von Kármán Gas Dynamics Facility, ARO, Inc., Arnold Engineering Development Center, U.S.A.F., Tullahoma, Tennessee. His publications include Experimental Methods of Hypersonics (New York, 1973), The Railway Game: A Study in Socio-Technological Obsolescence (Toronto, 1976) and The Ignorance Explosion: Understanding Industrial Civilization (Ottawa, 1994).

Industrial-Scale Programs:

Jet Aircraft, Turbojets, and Missiles

During World War II Canada produced more than 16,000 military aircraft of British and American design; at its peak in 1944, the Canadian aircraft industry employed 116,000. As early as 1943, planning for the industry's postwar future was initiated. An interdepartmental committee recommended the continuation of government support "for at least the next ten years" and asserted that "politically, commercially and as a measure of defence, it is essential to encourage the design and development of aircraft in Canada."[7] Conditions favourable to the "expansion of [private] business and employment" were to be created through the release of war surplus assets to industry and the creation of financial incentives to encourage research, development, and capital investment.[8]

In the aircraft and engine sector, the government relied on A.V. Roe Canada Ltd. (commonly known as Avro) to achieve these objectives.[9] Avro was incorporated in September 1945 (as a subsidiary of the British Hawker Siddeley Group), following an agreement with the government stipulating "the establishment in Canada of a design, research and development organization to promote... design and manufacture in Canada" of military and commercial aircraft and gas turbine engines.[10] After taking over government-owned Victory Aircraft Ltd. in Malton near Toronto (the largest aircraft plant in Canada), Avro began work in 1946 on jet fighter, turbojet, and commercial jet projects. In 1954, Avro Aircraft Ltd. and Orenda Engines Ltd. became the A.V. Roe Canada subsidiaries responsible for aircraft and engine programs.

The government's support of the Avro enterprise reflected the aspirations of the Royal Canadian Air Force, which saw for itself an independent role in air defence requiring an independent aircraft industry. When the RCAF found there was no plane in production or on the drawing board that RCAF would consider to be suitable as an all-weather fighter for northern defence, they commissioned the Avro CF-100 and Orenda programs.[11] These were to be the only Avro projects which saw production beyond the prototype stage. The CF-100 Canuck was the first fighter constructed by Avro. A twin-jet subsonic aircraft, it first flew in 1950 and entered service with the RCAF in 1953. The total cost of the program was about $750 million for 692 aircraft, engines, and spare parts for the RCAF;[12] 53 aircraft were made for export to Belgium.

Even before the first Canuck flew, the RCAF had started (in 1948) looking for a successor to the CF-100. Again it found nothing suitable for "Canadian requirements."[13] In December 1953 however, Avro was given a $27-million, five-year contract to build two prototypes of a new design; it was to be a large (50,000 pounds plus), twin-jet, supersonic (Mach 2), two-seat, long-range interceptor. In 1954, it was given the designation of CF-105 Arrow. The Arrow prototype (**Figure 1**) was rolled out on October 4, 1957, the day the Soviet Union launched *Sputnik*. The Arrow's first flight was on March 25, 1958, with Avro's Chief Development Pilot Janusz Żurakowski[14] at the controls; on April 3, it achieved supersonic speed, and on November 11 it flew at Mach 1.98, the highest Mach number it ever attained. Three months later, the Arrow project was cancelled by the Conservative government of John Diefenbaker.[15] In 1962 the Malton plant was sold to de Havilland Aircraft of Canada Ltd. (also of the Hawker Siddeley Group) and Avro became Hawker Siddeley Canada Ltd.

In engine development, Avro had somewhat more success.[16] The first project was the Chinook, a small 3,000-pound thrust experimental engine (only three were made) which first ran in 1948. The 7,000-pound Orenda was the next design; it first ran in 1949 and was produced in large numbers in the 1950s (3,824 were built) to power the Avro CF-100 and the North American F-86

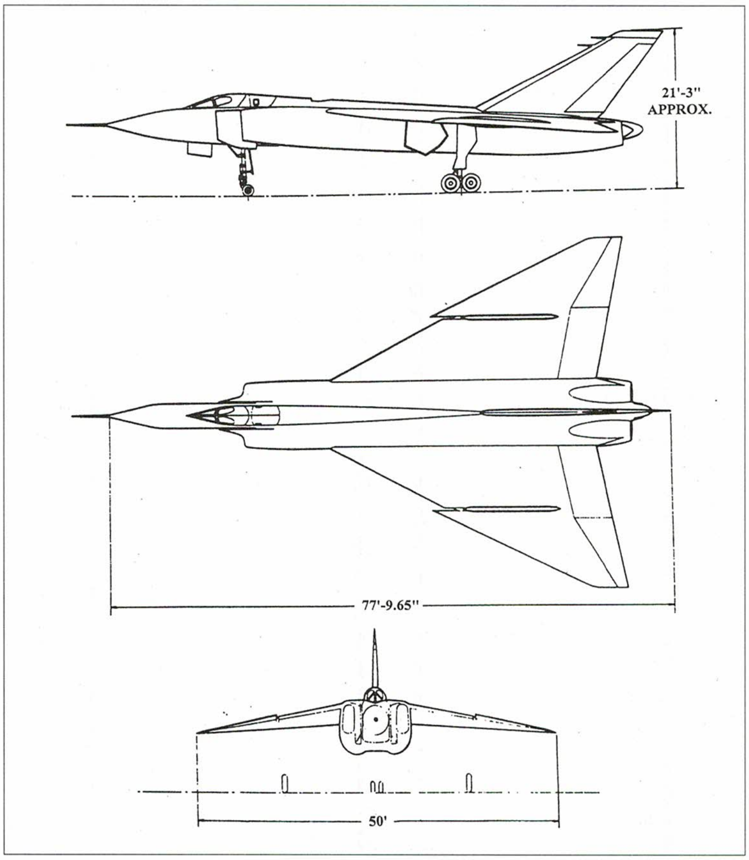


Figure 1. - Mark I Avro Arrow CF-105 fighter which first flew in 1958; the aircraft and engine projects were cancelled by the Canadian government in 1959. Mark II Arrow (with Iroquois engines) was to have a combat radius of 290 miles with five minutes of combat at Mach 1.5. (J. Woodman, "Flying the Avro Arrow," *Canadian Aeronautics and Space Journal* 25, No. 1 [1979]: 2.)

Sabre (built by Canadair Ltd. of Montreal). In 1953 work began on the 20,000-pound thrust PS13 Iroquois, intended for the CF-105 Arrow. The project was highly successful, and Iroquois were installed in the sixth and seventh Arrows, the first Mark IIs.[17] The assembly of these aircraft was almost completed when the Iroquois program was cancelled on the same day the Arrow was scrapped. Since then, Orenda Engines Ltd. has manufactured U.S. turbojets, Orenda industrial gas turbines, and spare parts, and has provided engineering and test services to the industry.

Originally, Avro's design and development responsibility for the Arrow was to have been limited to the airframe; British or American engines and an American weapon system were to have been used.[18] But within two years the development of British and American engines intended for the Arrow was cut off, and the Arrow had to be switched to a third engine (the Pratt & Whitney J75) of much smaller thrust; further redesign was needed to install the Orenda Iroquois engine in the Mark II prototypes.[19] Even greater difficulties plagued the Arrow's weapon system. In 1955, the RCAF chose the Douglas Sparrow air-to-air missile and the Hughes Aircraft Co. fire control system. When Hughes, the manufacturer of the Falcon missile, declined to participate, the RCAF contracted with the Radio Corporation of America for Astra, a fire control system to be developed to the RCAF's specifications. After the Sparrow development was abandoned in 1956, the RCAF "patriated" it for completion in Canada. In September 1958, both the Sparrow and the Astra were cancelled to reduce costs, and Avro was given a contract to procure yet another missile and fire control system from Hughes.

And so the CF-105 program, which as originally conceived involved only one major development - the airframe - in Canada, had grown to unmanageable proportions through the addition of engine, missile, and fire control projects.[20] The weight of the aircraft grew and the performance deteriorated. Moreover, the procurement originally forecast at 500-600 CF-105s was reduced to about 100 by 1957. These changes in development and production plans brought delays and cost escalations. The Avro's cost estimate for forty aircraft (including development) rose from $118 million in 1954 to $298 million a year later.[21] As the cancellation of the program was being considered, efforts were made to rescue the Arrow through sales abroad. The British and Americans were approached in 1958 and 1959, but repeatedly turned the Arrow down.[22] Why would anybody want to buy a product that is incomplete? Can you imagine, "We are having a bit of a problem with our program, delays and such, not sure when it will be done or how much it will cost, but, you'd be interested to buy some, wouldn't you?" - commented Janusz Żurakowski.[23]

In January 1958, James H. Douglas, the US Air Force Secretary envisaged to purchase CF-105s in squadron strength, to be integrated into the continental defence system, to operate from Canadian bases by RCAF personnel. The Canadian Ambassador stated that this would pose political problems, Canada being traditionally associated with the common defence as a contributor rather than a beneficiary. The subject was then dropped.[24]

The final decision to cancel the Arrow came in 1959. To soften the impact, the cancellation was carried out in two stages. In September 1958 the government halted production of the CF-105; on February 20, 1959, it terminated all Arrow and related contracts.[25]

The decision was justified in military as well as financial terms. Prime Minister John Diefenbaker stated that outstanding achievements in the development of Arrow had been "overtaken by events." With the introduction of missiles, the bomber threat had diminished and manned fighter aircraft had become obsolete; the Arrow would be "out of date by the time it got into production." In any event, "substantially cheaper U.S. interceptors would be available... to meet the... demands of North American or European defence."[26] The new plan called for Canada to acquire U.S. ground-to-air Bomarc nuclear warhead missiles and the SAGE (Semi-Automatic Ground Environment) defence network. Canadian industry was to share in the production of military equipment "for North American defence generally."[27]

Ironically, it was the Bomarc that "was very soon proven to be virtually obsolete before it was set-up" (as Diefenbaker admitted in his memoirs).[28] And so as early as 1960, Canada was buying U.S. aircraft to replace the aging CF-100s and F-86s. The F-101s were followed with purchases of F-104s, F-5s and F-18s.

As if to ensure that no trace of the Arrow venture would remain to haunt it, the Canadian government had all evidence physically destroyed - the aircraft as well as Avro's technical reports, records, drawings, films, and photographs[29]- in what can only be regarded as a mindless and paranoid gesture.

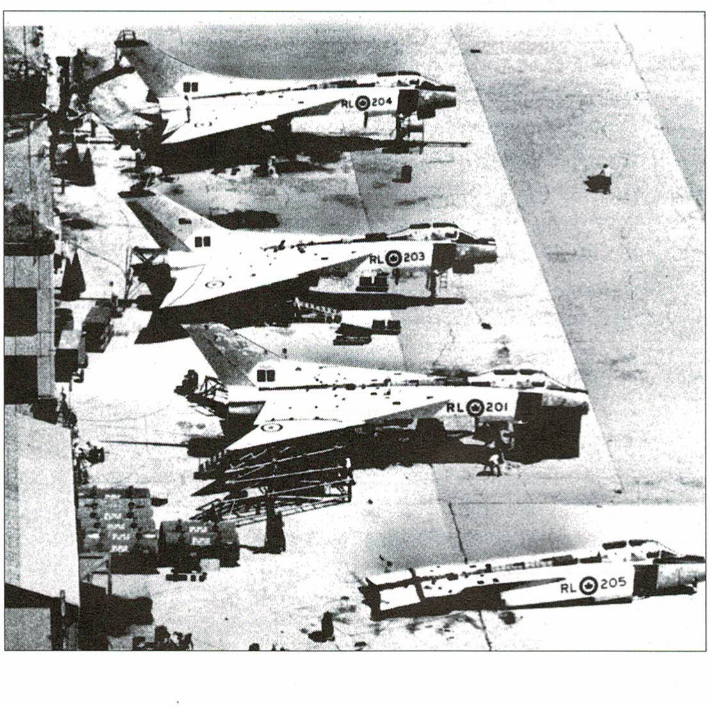


Figure 2.- Four Mark I Avro Arrows (nos. 201, 203, 204, and 205) being reduced to scrap at the Avro Aircraft Ltd. plant in Malton on the orders of the Canadian government. Photographer Herb Nott was not allowed to take photographs inside the Avro premises; this unique picture was shot by Nott in April 1959 as he overflew the area in a rented aircraft (Herb Nott & Co., Toronto; see Zuuring, n.9 above, pp.118-133 for more photographs).

The five flying Mark I Arrows and the two almost completed Mark IIs, as well as thirty others in assembly, were cut up (**Figure 2**) and sold for scrap: 2,785 tons for

$304,370.[30] Not a single plane was preserved for flight research or for Canada's Aeronautical Collection. Only a nose section of the first Mark II Arrow was saved; it is now exhibited in the National Aviation Museum in Ottawa. As noted by test pilot Żurakowski, "we were using the experience and the knowledge of other countries... but we destroyed the results of our work. Does that make sense?" [31]

The cancellation of the Arrow meant a massive elimination of jobs at Avro and its 650 contractors (13,800 jobs at Avro alone) and the write-off of $400 million in public funds. But probably the most serious and costly consequence of the Arrow's demise in 1959 was the dispersal and mass exodus from Canada of so much technical and managerial talent, assembled and trained at great expense in the highly skilled business of aircraft and engine design and manufacture. Former employees of Avro were in great demand in the United States, where the post-*Sputnik* aerospace boom had already started. Many found work in American industry and research, some joined Pratt & Whitney Canada Inc., others returned to England.

Avro had two other unsuccessful ventures. The first, a medium-range commercial jet project, was initiated by Avro in 1946 in consultation with Trans-Canada Airlines (TCA), the country's flag carrier. A C-102 Jetliner prototype first flew in August 1949, within two weeks of the maiden flight of Britain's de Havilland Comet, which in 1952 became the first jet to enter commercial service. But the aerodynamics of the C-102 did not reflect the state of the art: the wing was straight and thick, rather than swept and thin. And the engines expected to power the Jetliner were not ready; four Rolls-Royce Derwent Vs had to be used instead of two RR Avons. Avro would not guarantee performance, price, and delivery, so TCA refused to order the C-102. A sale to National Airlines in the United States fell through. In 1947, the Canadian government ordered two C-102 prototypes. After the first one was built, Avro was told in 1950 to concentrate all its efforts on military aircraft for the Korean War. By 1957, the expense of a thorough inspection was considered prohibitive, and the prototype C-102 was destroyed on Avro premises. The government spent $6.6 million on the Jetliner; the cost to Avro was $2.3 million.

Avro's Project Y or "flying saucer" was yet another aborted effort. It involved the development of a saucer-shaped vehicle capable of vertical and horizontal motion. Jets issuing from the vehicle's circular perimeter were to provide propulsion and control. The 1,500-mph "flying saucer" was said to be "so revolutionary that when it flies all other types of supersonic aircraft will become obsolete."[32] The RCAF gave Avro $229,000 for Project Y in the 1950s. Before termination several years later, the project was continued under a U.S. Department of Defense contract as a much more mundane subsonic Avrocar.[33]

The cancellation of the Arrow project in 1959 put a formal end to the development of Canada's military high-speed aircraft, large jet engines, and missiles. But the development of jet aircraft continued at Canadair Ltd. with the CL-41 Tutor, a two-seat trainer produced from 1961 to 1967, and the CL-89 military surveillance drone, produced after 1969.[34] In 1976 work started on the Challenger executive jet, a program which led to the development of Regional Jet and Global Express.

As for Avro, while the government's hopes for that firm were not fulfilled, the company itself - and its British parent - had reason to be satisfied. Avro had been the brainchild of Sir Roy Dobson, an aggressive entrepreneur who had recognized - and seized - a moment of opportunity. In short order, his infant company acquired the country's largest aircraft plant and secured contracts for jet fighter and turbojet development. It also interested the nation's flag carrier in a jet transport. All this Dobson accomplished on the basis of a $2.5 million loan guaranteed by a Canadian industrialist. The venture was a risky one, but Avro took no risks. The company preferred - and the government provided - the safety of grants and cost-plus contracts. Indeed, Avro "seemed horror-struck at the prospect of having even to compete in a normal market-place situation."[35] After the Arrow was cancelled, Avro's proposals for alternative work did not envisage any financial backing by the company. When - inevitably - its aerospace projects began to decline, Avro was ready: in 1955, it launched a major diversification into heavy manufacturing, steel, and coal. In 1956, it offered one-sixth of its shares for sale in Canada. As noted by Dow, "it was to a great extent buying us out with our own money."[36] Twelve years after opening its doors at Malton in 1946, Avro became the third largest corporation in Canada; it did 45 percent of the business of the entire Hawker Siddeley Group. In 1958, Avro comprised thirty-nine companies, with 41,000 employees, and logged $371 million in net sales - but aviation production accounted for only one-third of its labour force and 40 percent of its profits.

Concurrently with Avro's jet fighter and turbojet projects, the Defence Research Board (formed in 1947 as the "fourth arm of the service") promoted the Velvet Glove, an air-to-air supersonic guided missile, to be deployed from CF-100 fighters. Having Canadians actually develop and manufacture a missile was thought to be the most effective way to keep the country abreast of this new weapon type. In contrast to the jet fighter projects, the Velvet Glove was conceived with very conservative performance specifications. It was designed to meet the threat of propeller-driven bombers of World War II vintage. The project was managed by the DRB's Canadian Armament Research and Development Establishment (CARDE) at Valcartier, Quebec. It began in 1951 and by 1955 involved several companies including Canadair, Canadian Westinghouse, and Computing Devices of Canada. Some 300 missiles were built and test fired. By the mid-1950s, however, it had become apparent that the Velvet Glove and CF-100 were inadequate to cope with jet bombers. In July 1956 the Minister of National Defence announced the cancellation of the Velvet Glove and stated that the U.S. Sparrow missile would be produced in Canada instead. The project had cost $24 million; the Sparrow was cancelled in September 1958.[37]

Research Activities:

Aerodynamics Laboratories, Wind Tunnels, and Aeroballistics

The Canadian government's involvement with aeronautical research dates back to 1929, when the National Research Council's Division of Mechanical Engineering started developing aeronautical laboratories in Ottawa under the direction of J.H. Parkin (1890-1981). These laboratories were intended to provide testing for industry, to support applied research in aeronautics, and to train aeronautical engineers. Initially located in a remodelled lumber mill on John Street, during the war years the aeronautical laboratories were transferred to a new NRC site east of Ottawa. They were considerably expanded: a relatively large low-speed wind tunnel (6x10 foot) and a spinning tunnel (15-foot diameter) were built.

By 1948, the growing military aircraft and engine programs were straining the capabilities of the NRC and its largely non-military budget. Moreover, with the creation of the Defence Research Board in 1947, the responsibilities for aeronautical research became confused. In 1950, the cabinet authorized the creation of the National Aeronautical Establishment as the single agency responsible "for the conduct of research and experiments required for the development and operation of military and civil aircraft in Canada."[38] The concept was modelled on the British Royal Aircraft Establishment at Farnborough and envisaged the consolidation of older NRC aeronautical laboratories with the new facilities, which were to be constructed at Uplands Airport near Ottawa. The operation of the NAE was to be overseen by the National Aeronautical Research Committee, and funding for the new Uplands facilities was to be provided jointly by the NRC and the DRB.[39]

The proposed arrangement amounted to "shared responsibility" management; it was of questionable effectiveness. And, curiously, the five members of the National Aeronautical Research Committee, with one possible exception, had no personal experience in aeronautical research. In any case, the cabinet decision creating the NAE was never fully implemented. The NAE label was adopted in 1958 by a division of the NRC, which continued to operate the Montreal Road and Uplands Laboratories. Commenting on aeronautical research in Canada, the Glassco Report noted in 1963 that "there appears to be no single body for the coordination of 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."[40] Moreover, the RCAF "was frankly and unequivocally opposed to a separate defence research organization" (*i.e.*, the DRB), and "relations between the Defence Research Board and the National Research Council were often strained."[41] In short, the situation was not conducive to the coordination of aeronautical research. And, in the end, the development of laboratories for high-speed aerodynamics, initiated in the late 1940s, was continued independently by the Defence Research Board and the National Research Council.

Canadian research in high-speed aerodynamics and aerophysics had been started at the University of Toronto by G.N. Patterson, who obtained a doctorate in physics there in 1935 and subsequently gained experience in aerodynamics in England, Australia, and the United States. After returning to Toronto in 1947 as a professor of fluid physics, Patterson submitted in February 1949 "A Detailed Proposal for a Supersonic Aerodynamic Laboratory." In July 1949, with a $350,000 grant from the Defence Research Board, he established the University of Toronto Institute of Aerophysics (UTIA). The Institute quarters at Downsview near Toronto were inaugurated in September 1950. Its financial support came from the DRB, as well as from contracts with the U.S. Department of Defense and other agencies.

Over the years, a variety of experimental equipment was developed at the Institute, starting with 5x7-inch and 16x16-inch supersonic intermittent vacuum-driven wind tunnels (the latter modelled on the Peenemünde-NOL tunnel of the same size) and shock tubes; other facilities included a 5x5-inch hypersonic blowdown tunnel, hypersonic shock tunnels and ranges, low-density and plasma tunnels, apparatus for studies of sonic boom and blast waves, low-speed tunnels, and associated instrumentation.[42] Research at the Institute centered on basic studies of shock waves, rarefied gas dynamics, and aerodynamic noise.[43] 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 south of the border.

Concurrently with the DRB-supported developments at UTIA and to some extent in competition with them, the NRC followed a path which led to the construction and operation, beginning in 1962, of a large 5-foot high-speed wind tunnel facility. In the immediate postwar years, a lack of engineers experienced in this new field thwarted progress. But suitable personnel were recruited in 1947 and 1948 from the Royal Aircraft Establishment and the National Physical Laboratory in England. The first proposal for NRC's High Speed Aerodynamics Laboratory was made by F.W. Pruden (1922-58) in April 1948.[44] The design was based on two compressors obtained as war reparations from Germany. They were to drive a 10x10-inch continuously running supersonic wind tunnel and a 20x20-inch intermittent, vacuum-operated supersonic tunnel. In 1949, Pruden started developing an aeroballistic range. Subsequently, more modest plans were adopted,[45] the range was dropped, and a 10x10-inch intermittent tunnel was built (**Figure 3**). The NRC's new High Speed

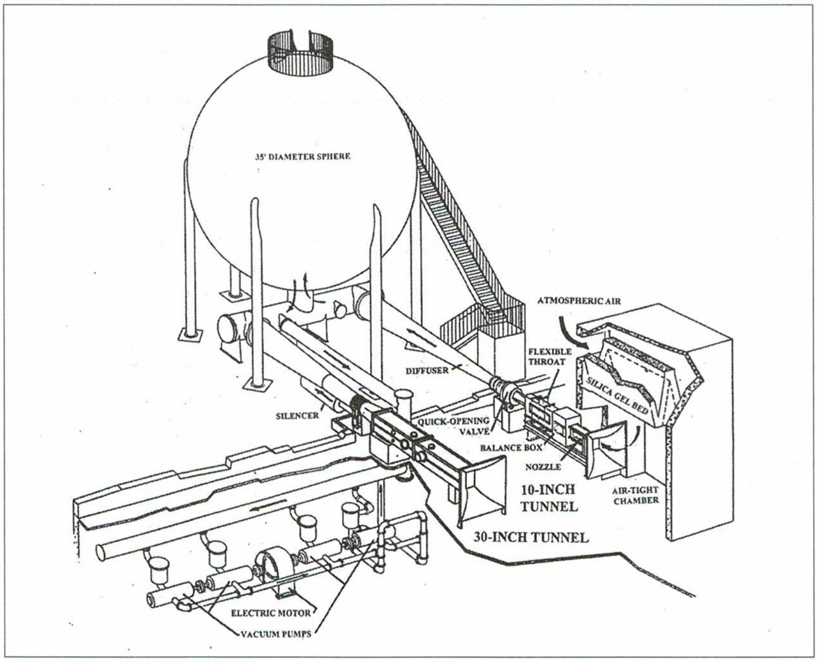


Figure 3. - Supersonic/transonic wind tunnels at the NRC High Speed Aerodynamics Laboratory, Montreal Road, Ottawa. (See n. 45, fig. 1.)

Aerodynamics Laboratory building (on Montreal Road) was dedicated in 1950, and the tunnel started operating in March 1951.

The drive of the 10-inch tunnel was of a type used in some of the first supersonic tunnels. The concept, which offered power economy, design simplicity, and low cost, had been introduced in the late 1920s by Ludwieg Prandtl in Göttingen, applied in Aachen, and further developed in Peenemünde, the centre responsible for the V-2 (A-4) rocket missile and other weapons.[46] Essentially, the drive consisted of a large vessel evacuated to a low pressure, which provided the pressure drop necessary to acceler ateatmospheric air through the wind tunnel duct to the required Mach number in the test section. The design allowed run durations of some fifteen seconds at Mach numbers up to 4.5. With modest pumping power, the vessel could be evacuated in a matter of minutes, so that several tunnel runs could be made every hour, and instrumentation was devised to make force, pressure, and heat-transfer measurements during each run.[47]

The design of the NRC's 10-inch wind tunnel followed German aerodynamic practice but incorporated mechanical improvements. They included good access to the model, adequate space for model support and instrumentation, and quick Mach number change made possible through the use of interchangeable integral nozzle boxes (each for a fixed test Mach number; see **Figure 4**). This proved to be a worthwhile scheme for a small tunnel - much less expensive than a flexible nozzle capable of covering the same wide range of Mach numbers.[48]

Nonetheless, 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 the impending supersonic Arrow project, a larger transonic-supersonic tunnel was planned, to be driven by the existing HSAL plant. A 30x16-inch test section was selected for use with half-models, so that aerodynamic simulation equivalent to that attainable in a 30x30-inch tunnel (with full models) could be realized. Installed in the 10-inch tunnel bay (**Figure 3**), the tunnel started operating in September 1952. Two years later a second vacuum sphere was erected, increasing the run duration from six to fifteen seconds.

The new tunnel was the first to offer transonic capability in Canada. It was used for some testing of the Arrow and basic aircraft configurations.[49] New test techniques were developed in both tunnels. Since 1959 the HSAL has specialized in dynamic stability research. Renamed the Unsteady

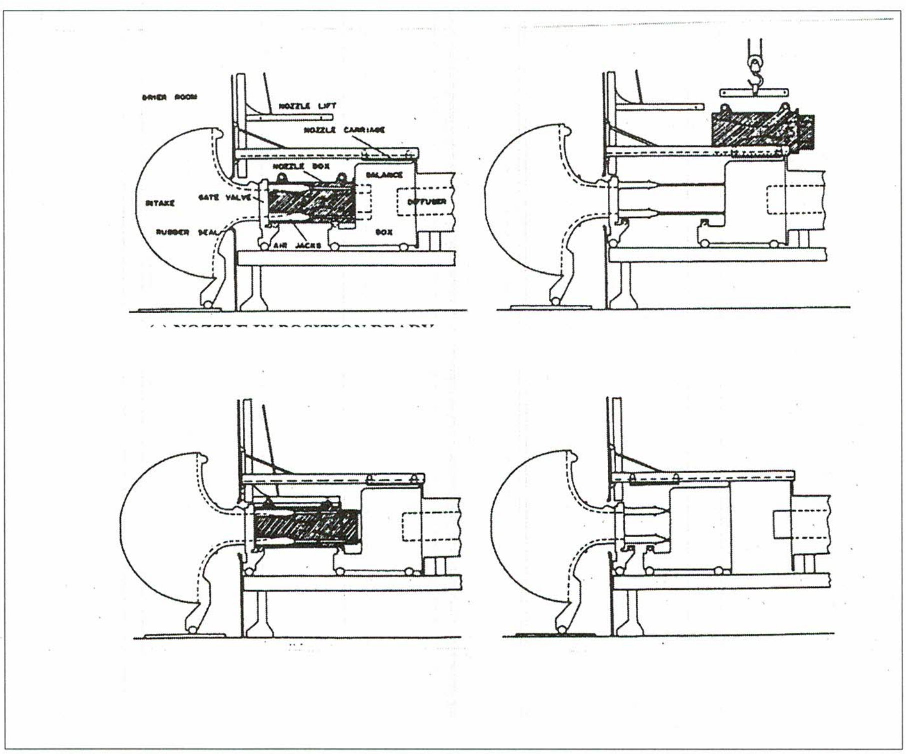


Figure 4.- Design of the 10x10-inch HSAL's supersonic wind tunnel, first operated in 1951, provided for quick change of Mach number through the use of integral nozzle boxes. The four steps involved in a nozzle change are illustrated above. (See n. 45, fig. 5.)

Aerodynamics Laboratory, it has become widely known for experimental measurements of dynamic stability and has been engaged in many foreign projects. The 10-inch tunnel was converted to hypersonic operation with helium. At the end of 1980s, the HSAL tunnels were no longer in use.

The small supersonic and transonic wind tunnels that became available in Canada in the early 1950s were better suited to research than to developmental testing. Certainly, they were totally inadequate in the context of the policy of aeronautical industry self-sufficiency adopted by the government shortly after World War II. In contrast to Canada, the need for new, high-performance large wind tunnels was appreciated in the United States, Great Britain, and France. After the war, these countries correctly concluded that the potential offered by aircraft and missiles could not be realized unless adequate means were provided for research and development, and in the late 1940s they established national programs for construction of large wind tunnels, running into tens and even hundreds of millions of dollars: the U.S. Unitary Plan Wind Tunnels of 1949, the RAE-Bedford laboratories, France's ONERA wind tunnels in Modane and Paris.

The technical approach adopted in the United States and Britain in the prewar years had been followed in the construction of all large high-speed wind tunnels and in the subsequent upgrading of their performance.[50] It reflected the tradition of large, closed-circuit, low-speed facilities which ran continuously, a design dating to Prandtl's Göttingen wind tunnel of 1909.[51] Prandtl's closed-circuit design was well suited to low speeds: it was energy efficient (through the recovery of kinetic energy in a diffuser downstream of the test section) and it allowed control of the Reynolds number (*i.e.*, the aerodynamic scale) independently of the airspeed by varying the pressure, and hence the air density, in the tunnel circuit. However, the application of Prandtl's design to high subsonic and supersonic speeds turned out to be expensive and presented serious technical problems.[52]

The construction of a conventional, large high-speed wind tunnel for developmental testing was clearly beyond the financial reach of the Canadian government. And, in any case, the large engineering staff needed for such an undertaking was not available in Canada. But such a facility was required, and so a more economical solution had to be found. The necessary clue was provided by the approach the Germans had used in developing their supersonic tunnels, already adopted for NRC's High Speed Aerodynamics Laboratory: this was the principle of intermittent operation (or, more generally, of energy storage), which could be pushed even further to increase productivity and aerodynamic performance. If measurements could now be taken with a driven model - a model driven over a full range of incidence during each run - the data productivity of an intermittent tunnel could easily match, or even exceed, the productivity of traditional, continuously running installations. Moreover, intermittent operation would provide excellent model and test-section accessibility: with instantaneous tunnel starting and stopping, long run-up, shutdown, and pumping periods would be eliminated.[53] 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 the atmosphere to a 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 because of expansion of the stored air). A layout of the proposed scheme is shown in **Figure 5**.

The technical feasibility of this type of high-performance and high-productivity intermittent wind tunnel depended on the development of instrumentation and controls more sophisticated than any that had been previously used in wind tunnels. But it was the view of F.W. Pruden and this 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 analyses of the new design and a proposal for a 4x4-foot blowdown intermittent wind tunnel were completed in September 1950.[54] These demonstrated the advantages of the new concept, including the ability to cover the whole trisonic (*i.e.*, subsonic, transonic, and supersonic) Mach number range in a single tunnel.[55]

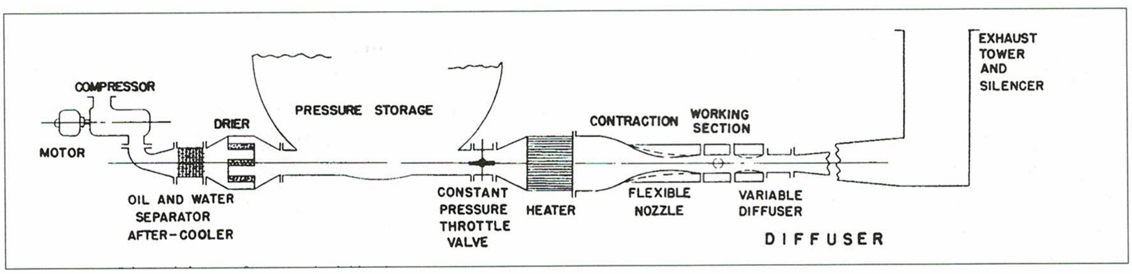


Figure 5. - Schematic layout of a pressurized, blowdown wind tunnel installation first proposed in1950. In the actual 5-foot wind tunnel completed in 1962, the storage type heater was located inside the pressure storage, upstream of the constant pressure throttle valve. (See n.54: Lukasiewicz, 1953, fig.3, and 1955, fig.2.)

Notwithstanding its favourable characteristics, acceptance of the novel tunnel system did not come easily. Conventional designs pursued by the most reputable (and also well-funded) laboratories were considered the only sound and practical ones. In the United States and Britain, in spite of difficulties that surfaced from the initial planning stages for large high-speed wind tunnels,[56] the intermittent option was apparently never considered by the organizations in charge of national wind tunnel programs.[57]

The National Advisory Committee for Aeronautics and the

Air Force in the United States and the RAE in Britain had virtually no experience in short-duration wind tunnel testing. Not surprisingly, NACA and RAE showed no interest in the intermittent technique; they were already committed to extensive and expensive construction of continuous wind tunnels.[58]

The intermittent concept, proposed in 1950 in Canada, was first used in 1956-57 by American aircraft builders, to whom the idea appealed because, as flight speeds had increased into the supersonic range, the quantity of aerodynamic data required for aircraft design and the cost of obtaining them had escalated. The F-100 (the first operational U.S. supersonic fighter) required over 50 percent more wind tunnel test time than the subsonic F-86, with 60 percent of it in high-speed wind tunnels, compared with only 17 percent for the F-86. Clearly, new initiatives were required; North American Aviation, Inc., and Boeing Airplane Co. were among the first to take them.

The projects were completed in 1957. The NAA design featured a 7x7-foot, Mach 0.2-3.5 facility with a 10,000-horsepower drive; Boeing's was a 4x4-foot, Mach 1.2-4.2 supersonic tunnel. The favourable characteristics of the intermittent design were fully realized at a fraction of the cost of the conventional tunnels. To obtain sixty seconds of test time per hour, the intermittent tunnels required as little as five percent of the power needed by the continuous facilities, and the cost of the intermittent tunnels was down to about 15 percent of that of the conventional ones. As shown in **Figure 6**, the Reynolds number matched or exceeded that available with the continuous installations over the whole Mach number range.

Following the lead of North American and Boeing, other U.S. companies built large blowdown, intermittent wind tunnels: Chance Vought and General Dynamics/Convair in 1958, Douglas Aircraft and McDonnell Aircraft in 1959, and Lockheed-California in 1960.[59] By 1960, all of the major U.S. aeronautical firms were operating such facilities. A 4x4-foot test section became a widely accepted standard, and tunnels of this type were later built in England (English Electric), The Netherlands (NRL), Sweden (FFA), India (NAL), Romania (INCREST), and Yugoslavia (VTI).

The NAA facility, proposed in 1952, was completed within five years. But in Canada, the 1950 proposal awaited approval for four years. In that period, major efforts were devoted to solving the crucial problems of driven model instrumentation and data-handling systems.[60] By 1953, the feasibility of the driven model technique had been firmly established through tests in the 10-inch and 30-inch tunnels. And it is unlikely that the novel tunnel design would ever have been approved without these tests.

In 1952, even as these activities progressed, another group at the NRC began considering a large, continuous high-speed tunnel. Predictably, their work showed the performance limitations and high costs of the conventional design. In 1953, I again proposed the intermittent solution; and in April 1954 a pressure-driven, 5x5-foot test section design (with air stored at 300 pounds per square inch) was approved by the NRC. Authorization to proceed with the preparation of design specifications came in November 1954.

A complete 1:12 scale pilot of the planned facility was built and started operating at the HSAL in November 1955. It provided invaluable information for the full-scale design, particularly on heat storage, valve controls, aerodynamic noise generated by the control valve, flow stabilization, diffuser configuration, transonic test-section design, and Mach number regulation.[61]

In April 1955, the government announced approval for construction of the 5-foot tunnel at an estimated cost of $3.5 million, and the design contract was awarded in June 1956 to Dilworth Ewbank, Consulting Engineers of Toronto. But the fragmentation of responsibility for aeronautical research and mounting difficulties with the Arrow program delayed the project.[62]

Funding was frozen in 1957.[63] Following protracted reviews, the project was reinstated in November 1958, largely through the

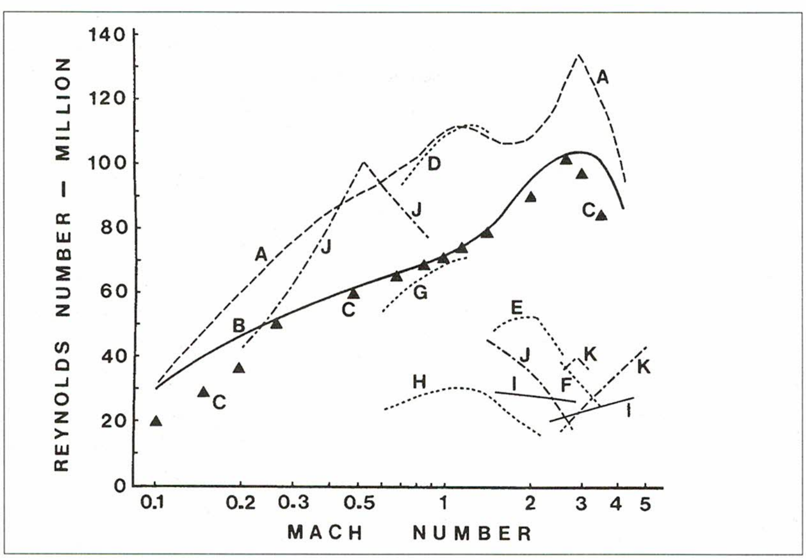


Figure 6.- Maximum Reynolds number (based on the square root of test section cross-sectional area) of large intermittent and continuous wind tunnels. Wind tunnel owner, test section size (feet), drive power (horsepower), and year operational in parentheses; usable run time given for intermittent tunnels. Intermittent trisonic: NRC (5x5, 11,500, 1962) A - 5 seconds, B - 10 seconds; NAA (7x7, 10,000, 1957) C - 10 seconds. Continuous: NASA-Ames: D(11x11), E(9x7), F(8x7), unitary (216,000, 1957); G(13.5 x13.8, 110,000, 1956); H(6x6, 60,000, 1956); NASA-Langley: I, unitary (4x4, 100,000, 1956); RAE-Bedford: J(8x8, 80,000, 1957); K(3x4, 88,500, 1960). (See n.48 and Rockwell International Trisonic Wind Tunnel, User's Manual, NA-78-258, Rockwell International, Los Angeles, rev. March 1983; AGARD, The Need for Large Wind Tunnels in Europe, AGARD-AR-60, Paris, 1972, p. 78; D. Brown, Information for Users of the National Research Council's 5x5 Foot Blowdown Wind Tunnel at the National Aeronautical Establishment, NAE-LTR-HA-6, Ottawa, September 1977; Research Facilities Summary, V. II, Wind Tunnels, NASA Ames Research Center, Moffett Field, California, December 1965; Technical Facilities Catalog, 1. NHB 8800.5 A [I], NASA, Washington, D.C., October 1974 edition.)

efforts of J. L. Orr, at that time in charge of aeronautical research at DRB. Construction began 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.[64] (see **Figure 7.**)

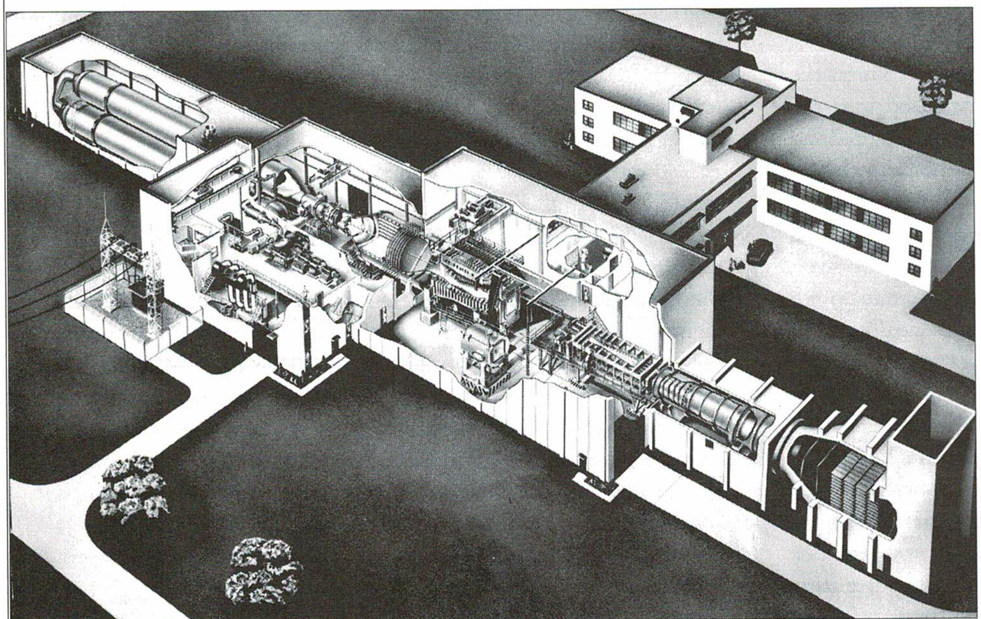


Figure 7.- Trisonic 5x5-foot wind tunnel at Uplands near Ottawa. This cutaway view shows, from left: 50,000-cubic-foot, 300-pounds-per-square-inch compressed air storage; pressure control valve and 11,500-horsepower compressor plant; settling chamber, contraction, and flexible supersonic nozzle; transonic 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. (See n. 64: Rainbird and Tucker, fig. 1.)

The tunnel had taken twelve years to complete, much longer than similar facilities in the United States. At $9 million, the final cost of the project was more than double the original estimate. This drew the attention of the auditor general "because of 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."[65] In 1963, the Glassco Royal Commission on Government Organization had this to say about the 5-foot wind tunnel project: "Although the 5-ft wind tunnel is the chief government aeronautical project in hand, it is usually considered independently of the current National Aeronautical Establishment programme...the project has suffered from lack of coordination; at the time of review the tunnel was still not in operation after ten years' work, although similar facilities have been established in the United States in three to four years and at less cost."[66]

The Canadian tunnel cost about twice as much as similar facilities built several years earlier by the U.S. aircraft industry. This reflected not only a much longer design and construction period, but also Canada's very limited in-house engineering resources and lack of experience in the design and fabrication of large, yet highly precise wind tunnel components. Government procurement procedures, which involved some twenty contractors, also contributed to cost escalation and delays.[67]

The final approval of the 5-foot wind tunnel in November 1958 coincided with the Arrow's cancellation. With the Velvet Glove missile program already scrapped in 1956, Canada had no projects able to benefit from its new, industrial-scale test facility. And yet, curiously, the government decided to complete the project, saying the facility would be needed for the development of missiles (which, recall, were naively expected to replace manned aircraft) and supersonic transports. These were clearly unrealistic objectives in the light of recent Canadian experience, but history was put forward as an argument in support of the wind tunnel. Even if Canada used aircraft and missiles from other countries, there would always be the need to modify them, and this required wind tunnel facilities - or so the argument went. Not completing the wind tunnel was also seen as preventing Canada from developing high-speed aerospace projects in the future - not that the government had any such plans. After its completion, the 5-foot tunnel, cashing in on its performance, was used largely by U.S., Swedish, and French clients, including NASA, NAA, Boeing, Convair, Lockheed, McDonnell Douglas, ONERA, SAAB-SCANIA, and FFA.[68]

While supporting research at the Institute of Aerophysics in Toronto, the DRB was also promoting supersonic aerodynamics at its CARDE laboratories. An experimental technique known as aeroballistics, in which freely flying models are launched from special guns, was used. G.V. Bull, who had come to CARDE in 1951 after developing supersonic tunnels at UTIA, directed the work, and indeed directed the bulk of aeroballistics activities in Canada for over twenty-five years. Under his leadership, aeroballistic ranges were developed and expanded at CARDE; munitions, aircraft, and Velvet Glove models were tested; and novel, efficient test techniques were devised.[69] After the Canadian missile and supersonic fighter projects were cancelled, CARDE embarked on a joint program (with the U.S. Department of Defense Advanced Research Projects Agency) of reentry physics studies in support of ballistic missile development. Several new hypersonic ranges were developed and operated at a cost of about $2.5 million per year. Their work was terminated in 1970, and since then CARDE (renamed the Defence Research Establishment Valcartier or DREV) has been occupied with more conventional ballistics problems. For this purpose, one of the ranges was used as a vacuum reservoir to drive a 2x2-foot transonic-supersonic wind tunnel.[70]

In the 1960s, Canada became active in original large-scale developments in aeroballistics. They were likewise the brainchild of G.V. Bull, who left CARDE in 1961 for McGill University in Montreal. There, as head of the Space Research Institute, he directed the High Altitude Research Project (HARP), a joint venture with the U.S. Army Ballistic Research Laboratories (BRL) in Aberdeen, Maryland. The project dealt with the application of guns to launching high-altitude probes for study of the upper atmosphere; it was funded by the U.S. Army, McGill University, and, after 1964, the Canadian Department of Defence Production. Bull was responsible for development of 16-inch calibre launchers. In 1962, a range facility was established on Barbados using 16-inch, smooth-bored, U.S. Navy surplus guns (**Figure 8**). Later, additional range facilities were developed at the U.S. Army's Yuma Proving Ground in Arizona, and at a range straddling the Canadian - U.S. border between Highwater, Quebec, and North Troy, Vermont. Smaller launchers (5- and 7-inch calibre) were operated by BRL on the East Coast. Altitudes of up to 181 km were reached with the 16-inch gun system and up to 75 km with the 5-inch gun. Profiles of electron density and wind were measured in the upper atmosphere. In Highwater, a 16-inch horizontal launcher was used for aerodynamic studies of ballistic missile nose cones. With a shot weight of 270 pounds, 100-pound cone models could be launched at velocities as high as 8,700 feet per second, that is, at a Mach number of about 8 - a remarkable result when compared to the standard 2,800 feet per second performance of 16-inch guns.[71]

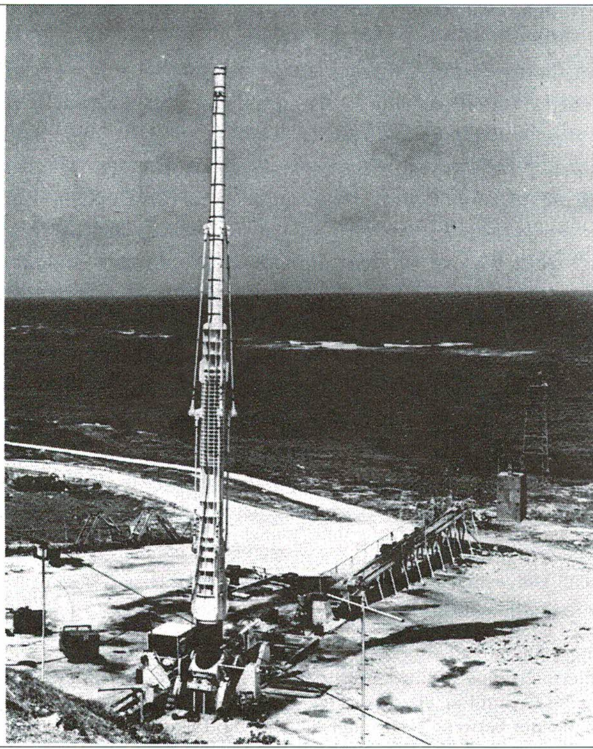


Figure 8.- HARP launcher in elevated firing position on Barbados, B.W.I. The system consisted of two 16-inch U.S. Navy surplus guns smooth-bored to 16.4-inch diameter and joined to form a 119-foot 5-inch long, 200-ton barrel, the largest gun in the world. A powder charge up to 980 pounds has been used. A muzzle velocity of 7,100 feet per second (maximum acceleration at launch of 15,000 g) was attained with a 400-pound shot weight, a 185-pound payload reaching an altitude of 595,000 feet (181 km). (Courtesy of Space Research Institute, Montreal.)

Later, rocket-assisted payloads were developed to augment the performance of the guns, and the feasibility of gun-launched satellites was studied. It was estimated that a 60-pound payload could be placed in orbit using a three-stage, rocket-assisted, 2,000-pound vehicle in a 16-inch gun.[72] A 32-inch calibre launcher was also considered (**Figure 9**). But the HARP project was terminated in 1967 after Canada withdrew its support. A total of about $9.5 million was spent on HARP; Canada's share amounted to $4.3 million.[73]

The truly original technique of high-altitude launches from large-calibre guns offered certain advantages over conventional rocket launchings, notably the relatively low cost and high accuracy and reliability. But the idea came too late to gain general acceptance; by the time it was developed, a large variety of rocket vehicles was commercially available and governments had invested heavily in rocket range facilities. Moreover, rocket launchings did not subject payloads to the very high acceleration loads present in gun launchings (50,000 Gs in 5-inch guns and 15,000 Gs in 16-inch guns).

HARP's studies of the upper atmosphere duplicated a much larger Canadian - U.S. program which used rocket-propelled probes.[74] This program was run between 1954 and 1978 from the Fort Churchill rocket range in Manitoba. Over the years, it involved several Canadian and U.S. organizations (NRC, CARDE, the Defence Research Telecommunications Establishment, NASA, the Canadian and U.S. Armies, the U.S. Air Force and Navy, among others). In Canada, these activities led to the development of the Black Brant series of rockets produced by

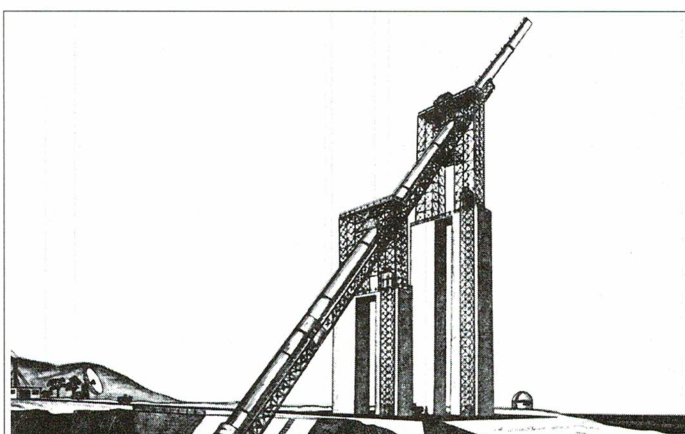


Figure. 9. - According to the estimates made by the HARP project team, a 1,000-pound payload could be placed in the earth's orbit using a three-stage rocket vehicle launched from a 32-inch gun, sketched above. This proposal represented modern embodiment of the technique described by Jules Verne in his 1865 novel *De la Terre à la lune.* (See n. 72, fig. 17.) This was also the design of Babylon, Bull's supergun for Iraq.

Bristol Aerospace Ltd. of Winnipeg. Highly successful, they were sold and used throughout the world.

Bull continued ballistic research at Space Research Corporation, a company he established at the Highwater-North Troy range, with offices in Montreal and additional test facilities on Barbados and Antigua; in the 1980s, it operated world wide. He revolutionized the art of artillery, steeped in long military tradition, through application of aerodynamics and modern design methods. With GC-45 (Gun Canadian, 45-calibre long barrel, 155-mm bore) and Extended Range Full Bore Base Bleed shells, the range of conventional guns was doubled. Canada failed to exploit the commercial potential of GC-45 but several countries outside NATO acquired or produced this superior weapon. It was perhaps the frustration with lack of interest and support in Canada that contributed to Bull's tragic involvement with the development and sales of arms.

In 1980, he pleaded guilty of illegal exporting of munitions (under a UN embargo) to South Africa.[75] Detained for four months in a Pennsylvania prison, he moved in 1981 to Europe and re-established SRC operations in Brussels. Starting in 1987 he began designing and building superguns for Iraq. In 1991 UN inspectors discovered on a hill north of Baghdad Baby Babylon, a 35-cm calibre, 52.5-m barrel gun. It was the prototype of Babylon, a 1-m calibre, 145-m long weapon with an estimated range of several hundred kilometres. In fact Babylon was the gun shown in **Figure 9**, proposed already in 1966 as a satellite launcher.

On March 22, 1990, 62-year old G.V. Bull was assassinated in Brussels. It was believed that Israel, within the range of Iraq's superguns and fearing an attack with chemical or nuclear projectiles, was responsible for the murder. In April, components of Babylon, surreptitiously manufactured and bound for Iraq, were seized in England, Germany, Italy and Turkey.

In the months and years after his assassination, G.V. Bull has been the subject of many articles, books and TV docudramas, some sensational, others superficial and inaccurate. A comprehensive and sensitive biography of this most talented, imaginative and daring Canadian engineer and enterpreneur has yet to be written.

In 1988, Bull published (with Charles H. Murphy as co-author of the chapter on HARP) his last work: *Paris Kanonen - The Paris Guns (Wilhelmgeschutze) and Project HARP* (Verlag E.S. Mittler & Sons GmbH, Herford und Bonn, 246pp.). This extensive monograph contained a remarkable analysis of performance of the Paris Gun, which bombarded Paris from April to August 1918. After the war, all technical data related to the Paris Gun was destroyed by Germans. Using modern computational techniques and data from an unpublished manuscript by Krupp's director of artillery development, Bull was able to resolve the secrets of the Paris Gun design, 70 years after the shelling of Paris.

The Anatomy of Failure

The decision to undertake the Arrow program has not been questioned in Canada, but its abandonment has been widely condemned. According to conventional wisdom, Arrow was a weapon system well ahead of its time, and its cancellation robbed the country of the opportunity to establish an international presence in high-speed aeronautics.[76] The present analysis, the similar experiences in other countries, and the structuring of more recent aircraft projects do not support this assessment and indicate that the Arrow was a classic example of how a country such as Canada should not approach development of sophisticated, advanced, and expensive technology.

Canada's venture into high-speed aeronautics was characterized by technical and managerial difficulties, inept organization, and bureaucratic inefficiency. But the failure of the enterprise resulted from a more fundamental cause: the unrealistic goal of achieving industrial and military sovereignty and self-sufficiency in military aviation. Throughout the 1950s, Canadian decision-makers in the military, political, and bureaucratic domains allowed themselves to be swayed by visions of prestige and national pride. They failed adequately to assess and appreciate the resources, experience, and large markets necessary to pay for research and development costs. Erroneously, the country's record as a wartime manufacturer of aircraft was regarded as a significant foundation for original design work. Even private ventures such as Avro - a new company with imported talent and generous government funding - badly misjudged the extent of the task before them.

The costly experiment was rooted in a poorly conceived military strategy, which rejected a joint role for the RCAF and the U.S. Air Force in favour of a separate RCAF role in northern defense. The operational requirements that flowed from this imperative yielded specifications for an extremely complex weapon system (the Arrow), of a performance exceeding that of any aircraft then in production or under development.[77] (Similarly, off-the-shelf missiles and electronics were not acceptable.) The scale and complexity of the program forced adoption of major components from abroad. Indeed, even during the initial planning for the Arrow, the use of a U.S. weapon system and American or British engines was envisaged, thus defeating one of the purposes of the program - to establish an independent Canadian presence. Ironically, efforts to rescue the Arrow through foreign sales "were blocked by the very logic that led Canada to build its own aircraft in the first place."[78] In the United Kingdom and the United States, as in Canada, depending on foreign sales for weapons was seen as a potential threat to national security, and exporting know-how and jobs in a vital defense industry was not acceptable.

As in the case of the Arrow, unrealistic premises were at the root of the Velvet Glove missile fiasco. The development of an original missile was considered necessary to ensure operational familiarity with a new weapon type.[79] But in light of the Canadian Forces' experience with foreign weapons in both world wars, this was an obviously untenable proposition, and an expensive and uncertain method of acquiring missile know-how. Moreover, the desire to keep the project simple (given limited capabilities and resources) resulted in technical specifications that addressed the threat of the previous rather than the future war and thus sealed the fate of the Velvet Glove as an obsolete weapon even before it was developed.

Although managerial and technical inexperience was not the chief cause of these various failures, it was nevertheless much in evidence. Neither the RCAF nor Avro had any experience in the procurement and engineering management of complex weapon systems such as the Arrow; both underestimated the impact of specification and equipment changes.

It was only in October 1957 - fourteen months before the cancellation - that an RCAF office was set up to coordinate the Arrow program. As noted later (in a CBC interview) by G/C H.R. Foottit, the head of the new office, "... costing was done by somebody, equipment was purchased someplace else, contracts were let all separately ... within the Air Force in the early days [project management] was all parcelled out in different directorates and with different people doing different things".[80] As for the Avro, "there has been mismanagement of the engineering aspects of the program" (the RCAF was not advised of "a sudden, unexpected reduction of the aircraft's performance") and confusion regarding changes in scheduling.[81]

As a rule, designing an aircraft on the basis of an engine still under development is avoided; and yet this course was followed by Avro. On two occasions (C-102 and CF-105), designs had to be changed drastically when the selected turbojets were unavailable. Frequent changes in the engine and the weapons system intended for the CF-105 forced expansion of the project well beyond its planned scope and contributed to an intolerable escalation of costs. The available resources and expertise were not adequate to carry on missile development. The aerodynamic design of the C-102 was obsolete, and the plane suffered from many potentially hazardous deficiencies (the Air Transport Board concluded that years of work would be needed before a production aircraft could be certified).[82] Project Y (the "flying saucer") demonstrated an unhealthy tendency toward unorthodoxy for its own sake accompanied by publicity that verged on science fiction.

Only in the field of jet engines did Avro achieve outstanding success. Avro's Orenda, a state-of-the-art engine in the Rolls-Royce Avon class, was produced in large numbers and exported successfully. The Iroquois, a large supersonic turbojet, featured the application of advanced materials (more titanium was used in its construction than in any other engine at the time) and developed a higher thrust and had a larger thrust-to-weight ratio than competing designs.[83]

The government's abandonment of all Avro programs and its decision to destroy all evidence demonstrated clearly that (rhetoric notwithstanding) neither the politicians nor the military understood the process of innovation and industrial strategy. "... government inexperience in understanding the problems and costs of research and development in modern industry" were to blame - noted Janusz Żurakowski.[84] Missile technology, then in its early years, had been heralded naively as a substitute for manned aircraft.

It has been often stated that John Diefenbaker was responsible for ordering the destruction of the Arrow planes and all related materiel. No evidence has surfaced which would give credence to this belief. Indeed, Mr. Diefenbaker may not have been aware of the fate that awaited the Arrows.

It was Air Marshal Hugh Campbell, chief of the Air Staff, who in a memorandum[85] to George Pearkes, the Minister of National Defence, recommended on April 26, 1959 that all Arrow materiel be reduced "to scrap". Selling it in "its original state... could lead to subsequent embarassment... airframe and engine could conceivably be used... as a roadside stand".

No other uses were envisaged by the Air Marshal. The RCAF, the very organization which initiated and funded the Arrow project, demonstrated a complete lack of appreciation of the value of research and technology.

So did the constructors of the Arrow. When government contracts were no longer available, the British-owned A.V.Roe Canada Ltd. - by then a conglomerate of heavy industries - was not prepared to continue development with its own funds (even though the Iroquois engine offered good prospects) and abandoned aeronautics.

The largest R&D investment ever made by the government was wiped out overnight with no attempt to salvage any part of it.[86] And the Avro enterprise was viewed, not in the context of a broad industrial strategy, but in the narrowest of political, military, and budgetary terms.

The Russians did better. Their unsuccessful Tupolev Tu-144 supersonic jetliner, developed to compete with the Anglo-French Concorde, was abandoned in 1978 but not scrapped. Modified as Tu-144LL it serves as a development test bed for a second generation supersonic transport. This is a joint NASA-Tupolev project, initiated in 1996, in which six American and British industrial partners are participating.[87]

The reasons for the failure of the Arrow and other projects, as outlined above, have been seldom recognized. On the contrary, no single event in Canadian history has been so mythologized as the Avro saga.[88] In 1980s and 1990s books, TV docudramas, a play and countless newspaper and magazine articles portrayed cancellation of the "wholly Canadian"[89] Arrow as "the greatest failure of our nationhood"[90], a national disaster which crippled aircraft industry and destroyed the greatest engineering team. The Arrow program "could have given Canada the influence and status equal in the world to France, Britain or Japan".[91] The Arrow became a national icon, "the fastest jet in the world",[92] "better than any other fighter",[93] "a plane without equal",[94]"on the cutting edge",[95] "easily 25 years ahead of its time, if not more",[96] "the most powerful aircraft in the world",[97]"an engineering equivalent of walking on the water without getting your feet wet",[98] "an aesthetic epiphany so far in advance of anything ever built anywhere else in the world that it staggers imagination"[99]... The "revolutionary"[100] C-102 Jetliner was an equally magnificent achievement, "a milestone in aviation development" which introduced commercial jet transport.[101]

The Arrow myth-makers have ignored the success of Canada's aeronautical design as if there were a need to invoke the Arrow episode to prove it. Pratt&Whitney Canada engines, de Havilland Beavers and Dashes, Canadair jets and water bombers can be seen in the skies of many countries.

For the myth to be created, the fundamental cause of the Arrow demise had to be overlooked and its technical excellence extolled, so that its cancellation could be viewed as an unjustifiable and disastrous decision which destroyed the pinnacle of Canadian engineering achievement. It was not acknowledged that there could be no independent role for Canada in air defence of North America, that defence of Montreal and Toronto required the same weapon systems as the defence of Detroit and Chicago, that therefore Canada's presence in military aircraft industry must be based on cooperation and coordination with the United States to access the huge U.S. market.

The Arrow was neither militarily nor economically viable. Its cancellation was inevitable, irrespective of technical merits. But, as the myth required, the cancellation was blamed on the conservative government of the day and the military, the pressure from the US government, the CIA[102] and the American aircraft industry which protected its interests.

Actually it was Gen. Charles Foulkes, Chairman of the Chiefs of Staff who on August 25, 1958 recommended (contrary to the advice given on 21 August, 1958 by Air Marshal Hugh Campbell, Chief of the Air Staff) to the Minister of National Defence cancellation of the Arrow project.[103] In fact the mistake was to start the project, not to cancel it; the post-war liberal government was responsible. As for the Arrow being a "wholly" Canadian effort, the myth fails to note that Avro was mounted with a significant influx of British engineers and was owned in UK by its parent, the Hawker-Siddeley Group.

Regarding the extraordinary performance - the foundation of the Arrow myth - one should first note that years before Arrow's first flight the U.S. and other countries already acquired extensive supersonic fighter experience (see **Figure 10** below) and that absolutely all technical information needed to design the Arrow was of US or British[104] origin; none of it was Canadian. This was true, for example, of the "area rule", a crucial new technique of drag reduction at transonic and supersonic speeds developed by Richard T.Whitcomb of NACA (predecessor of NASA) in the early 1950s[105] and applied to Arrow in 1954. How was it possible then for the Arrow design to be "25 years ahead of its time"? How could one suggest that 25 Avro engineers, who had no experience in space flight and rocket propulsion, joining NASA after Arrow was cancelled was as significant as the acquisition of the German rocket team after the war, responsible for development of liquid fuel rockets and long range missiles, a technology totally unknown outside of Germany?[106] No aircraft design can proceed without data from wind tunnel tests. At the time of Arrow development no suitable tunnels existed in Canada; Avro had to rely on tests performed in the U.S.

The aerodynamic design of Arrow suffered from a number of difficulties. A report dated November 19, 1954[107] of a visit by a delegation of RCAF, DRB and NAE to NACA Langley laboratories listed several of them: zero-lift drag underestimated by "50 percent or more", "intake lip design likely to result in prohibitive drag penalties at supersonic speeds", a "wing planform... of the type which gives serious pitch-up tendencies", "directional [lateral] stability characteristics... poorer than had been experienced in the United States". Perhaps the most significant observation concerned the use of low aspect ratio delta wings : "the high drag due to lift ... makes them poor planforms for high endurance and long range".

Summary of a meeting held a month later (on 20-21 December 1954) at NACA HQ in Washington, in which Avro also participated,[108] indicates that some of the deficiencies have been corrected, such as the drag estimate (following the application of area rule) and intake design. However, both meetings were concerned with poor lateral stability of CF-105. The region of instability covered almost the entire operational range above Mach 1.5 in the stratosphere. The problem also occurred at high angles of attack at low speeds.[109] Avro relied on the use of artificial lateral stabilization system, which was called euphemistically "yaw damper". The NACA stated that "all steps should be taken to ensure aerodynamic stability before resorting to electronic means",[107] that "artificial lateral stabilization is undesirable itself" and recommended "a concentrated test program... to explore aerodynamic means of providing lateral stability"[108]. Avro did not follow NACA's advice.

Ventral fins installed under the rear fuselage were known to be an effective remedy; they were used on some American and Soviet fighters probably for the same reason. On NAE's initiative subsonic wind tunnel tests were carried out on an Arrow model equipped with double ventral fins: the lateral instability disappeared but Avro refused to investigate this further.[109] Avro displayed great confidence in their artificial stability system based on the 1950s vacuum tube technology. It may not have been a judicious choice.

The speed of the Arrow has been often singled out as the proof of its "cutting edge" design. In fact, Arrow was part of the fifties "supersonic wave", as is evident from **Figure10**. From 1956 on several fighters, listed in the figure, attained Mach numbers close to and in excess of two; several, fully armed, entered squadrons before 1960, clearly years before Arrows could have been ready for service.

As for the "revolutionary" Jetliner there was nothing revolutionary about its design; in fact, as already noted, the opposite was the case. Cruising at 650 km/h it was much slower than its contemporary de Havilland Comet at 800 km/h and no faster than much more fuel efficient, piston engine Douglas DC-7, in service since 1953.

Historian Granatstein aptly assessed the legacy of the Arrow when he wrote in 1997 that "Time has made the Avro Arrow an empty vessel, filled with romance, nostalgia, loss and longing, and cast it adrift on a nation's restless soul".[110] These are precisely the ingredients necessary to make the Arrow myth fly. The books *Shutting Down the National Dream* (1988 and 1997, see ref. 84) and *Storms of Controversy: The Secret Avro Arrow Files Revealed* (1992 and 1997, see ref. 85), the play "The Legend of the Arrow" (by Clinton Bomphray, staged at the NAC in Ottawa in January-February 1990), the CBC-TV docudramas "There Never Was an Arrow" (1980) and "The Arrow" (1997), a seriers of "The Avro Arrow" videos (Aviation Videos Ltd.), among others are full of romance and nostalgia, titillate imagination with suggestions of evil interference by the U.S. politicians and agencies, and with the intriguing possibility that one of the five CF-105s escaped the wreckers, got away and is hiding somewhere in a barn, as journalist June Callwood speculated in the January 13, 1997 issue (pp. 56-57) of *Maclean's*.

The nation's soul has been restless indeed. An Aerospace Historical group announced in 1989 the building of a full scale replica of the Arrow.[111] Search for bits and pieces of CF-105s goes on, the Arrow Alliance was organized in 1999 by Peter Zuuring to "keep the dream alive" and build by 2009 (the centenary of the first powered flight in Canada) a flyable full scale replica of CF105, and recovery of free flight CF105 models from lake Ontario is underway.[112]

Canada's experience in high-speed aeronautics was not unique; other countries which embarked on similar policies after 1945 were equally unsuccessful. Argentina, for example, tried to develop a modern independent aircraft industry with the help of a German team headed by Dr. Kurt Tank, former technical director of the Focke-Wulf concern. As if anticipating events in Canada, Tank's jet plane designs were named *Palqui* - meaning Arrow. But the project was abandoned in 1956, and the plant was converted to automobile manufacture. Tank moved to India that same year to develop the HF 24 Marut, a subsonic fighter powered by British engines produced under licence. After some 140 HF 24s were built, the development of indigenous jet aircraft in India was also discontinued. In 1962, Egypt attempted to enter the field through the licencing of jet designs developed in Spain by Willy Messerschmitt. These projects were cancelled in 1969, even before the first flight of a delta-wing fighter with an Egyptian engine. Clearly, notions of sovereignty and national pride can provide a powerful motivation toward the achievement of extraordinarily difficult technical tasks, as in the case of the U.S. "Man on the Moon" Apollo project. But such motivation alone cannot ensure success; it must be matched by adequate experience, resources and markets.[113]

Among the lesser powers which embarked on independent high-speed aircraft development after the war, Sweden represented a notable exception. Its neutralist policy was successfully backed up by a reliance on war materiel developed and produced domestically, including advanced aircraft and missiles. Furthermore, extensive research and test facilities were provided to assist the industry. The key to Sweden's success was the depth of its technological culture and the existence of a strong industry-government-university partnership supported by a decisive and consistent policy.[114] Nevertheless, Sweden's reliance on foreign equipment has been increasing. Its latest combat plane, the SAAB Grippen is produced since 1995 jointly with British Aerospace, with parts manufactured in Hungary.

In 1958, Canada's independent air defence policy was superseded by NORAD, the joint United States-Canada continental air defense organization. Only then was the fallacy of the rationale behind the Arrow and other military projects clearly exposed. Under NORAD, the inclusion of special "Canadian requirements" in military aircraft specifications was no longer relevant or necessary. Neither was a Canadian insistence on an independent domestic supply of aircraft; the RCAF's equipment needs became part of the integrated requirements of NORAD and NATO. If there is a lesson to be learned, it is that the goals of military and industrial sovereignty are no longer attainable in the increasingly interdependent and integrated world of industrialized countries. Although "nations continue to act as though they were sole masters of their fate," sophisticated technologies require a larger base than most states can provide.[115] Increasingly, international military alliances such as NATO and various transnational industrial operations provide the answer. They offer both the diversified industrial infra-

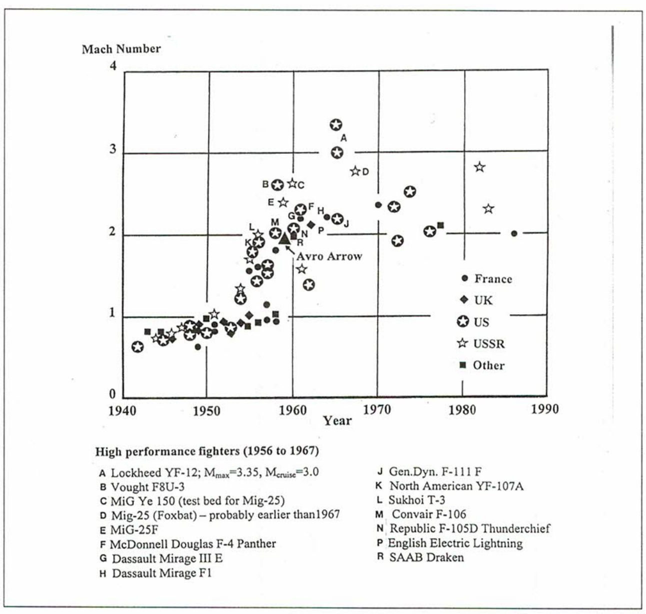


Figure 10. - Jet fighter speeds.
The speed of fighters increased dramatically in about 1954 and within two years attained Mach 2. This diagram was compiled by R.J.Templin, based on data from *The Complete Book of Fighters: An Illustrated Encyclopedia of Every Fighter Built and Flown,* W. Green and G. Swanborough, Salamander Books Ltd, London 1994. It was first published in Zuuring (n.9), p. 173.

structure needed for advanced and complex projects and the large market needed to pay very high research and development costs.

Particularly in aeronautics, international cooperation and coproduction have become the norm. The early examples include the British-German-Italian Tornado combat aircraft, the Anglo-French Jaguar supersonic fighter trainer, the Franco-American CFM power plant, and Franco-German antiship and antitank missiles. British, German, Italian and Spanish firms are currently engaged in the Eurofighter project. In civil aviation, there are the highly successful Airbus wide-body jets, produced by a consortium of French, British, German, and Spanish companies and relying heavily on American-made components.

Industrial collaboration on an international level has been an effective mechanism of participation in the aerospace enterprise.[116] Ideally, such collaboration should involve firms over the whole cycle of research, development, manufacturing, and worldwide marketing for a component or range of products.

Such full-cycle world mandate responsibility has seldom been achieved. For many years since the Arrow, Canada has been limited largely to sporadic licenced production of U.S. equipment for the RCAF or to the fabrication of components for American aircraft companies. An exception has been the operation of Pratt & Whitney Canada Inc., which develops and manufactures small gas turbine engines for air, land, and marine applications. This Canadian subsidiary has the support of its giant parent (United Technologies) and has sole responsibility for this particular class of power plants, for which it has captured a large share of the world market.[117]

Notwithstanding the lessons of the Avro venture and the subsequent development of international cooperation in the air industry, the Canadian government again embarked on an independent jet aircraft project in 1976. This time, the company was Canadair Ltd. (purchased from General Dynamics in 1976 for $46.6-million) and the project was the Challenger, a wide-body executive jet.[118] Originally the development of the Challenger was expected to cost $106 million, with a break-even point of 136 planes sold (to be reached early in 1982). But once again unrealistic specifications could not be met: the plane was much heavier, had a shorter range, and needed a longer runway than anticipated. Once again, an unproved engine was selected and another one substituted. And 1,200 major modifications had to be made. In 1983, the company posted a loss of $1.4 billion, the largest corporate loss (in current dollars) ever recorded in Canada,[119] and the estimated break-even point rose to 389 planes sold by 1992.

Similar difficulties were experienced by de Havilland Aircraft of Canada Ltd., the other aircraft company owned by the Canadian government (since 1974). Because of high development costs and few sales of its commuter-type aircraft, between 1982 and 1984 de Havilland required an infusion of $500 million in government funds; a further $1 billion was estimated necessary to keep the company operating through 1988.[120] Rather than continue massive subsidization, the Canadian government sold de Havilland in 1986 for $90-million to Boeing Co. of Seattle, Washington (Boeing later received $161-million in compensation). However, heavy subsidization by federal and Ontario governments continued.

Thanks to Bombardier, Inc. of Montreal it was not in vain that $2-billion of public funds was spent in support of Canadair and de Havilland. Bombardier acquired them at bargain prices: Canadair in 1986 for $123-million and de Havilland in 1992 for $70-million. The troubled Challenger project was turned around and led to the development of regional jets.[121] Bombardier Aerospace has since become the leading manufacturer of regional turboprops and jet aircraft, business jets and amphibians.

Applied research activities suffered from the same lack of realism and competence that marked the Avro and Velvet Glove projects. Given the fragmentation of responsibilities among organizations (each jealously protecting its overlapping interests), it is not surprising that the magnitude of research and test support required by the aircraft industry was not appreciated and programs were not coordinated, either with industry or among the laboratories.[122] The cancellation of the Arrow was coincident with the final approval of the 5-foot trisonic wind tunnel, reflecting the confused R&D scene in the 1950s. The development of experimental facilities was conducted independently by the NRC's High Speed Aerodynamics Laboratory, the DRB's CARDE organization, and the DRB-supported University of Toronto Institute of Aerophysics. Jurisdictional disputes delayed the completion of major test facilities, as in the case of the 5-foot wind tunnel. Upper-atmosphere study projects were duplicated through the simultaneous development of two different techniques.

The deficient management of applied research did not altogether prevent worthwhile developments from occurring; rather, their potential was not recognized and they were not exploited commercially. In the case of the novel wind tunnel design, the comparison of Canada's handling of the need for adequate aerodynamic test facilities to the U.S. experience makes this very clear. In the United States an industrial organization such as North American Aviation, Inc., was able to come up with a novel solution (technically and economically appropriate) and have corporate management "buy" the untried concept, build and operate a pilot model, and design, fabricate, and erect the facility - all within five years. Confidence in technical judgement at all levels, the constraints of a limited budget, and pressing need for aerodynamic data were responsible for the remarkable performance. In Canada, the opposite situation prevailed: hesitation and bureaucratic inefficiency led to delays and excessive costs. Furthermore, no attempt was made to exploit innovation: public funds were used to develop technology but nothing was done to protect it through patents and to take it to the marketplace. Innovations in aeroballistics were similarly neglected. Canadian government agencies failed to exploit the expertise acquired through CARDE and SRI/HARP activities and later used by Space Research Corporation. More vigorous government support for innovation in the design of guns and shells could have led to the establishment of a commercially viable industry, with good export potential (SRC sales in 1979 came close to $40 million).

Although Canada's novel wind tunnel design was not commercially exploited by the government, private engineering consultants have ensured that the design experience acquired in Canada through the 5-foot tunnel project will not be completely lost. Indeed, it has led to the participation of Canadian consultants and industry in many foreign wind tunnel projects. Dilworth, Secord, Meagher and Associates (DSMA) of Toronto has been responsible for blowdown tunnels of the NRC 5-foot type constructed in India, Romania, and Yugoslavia; for vacuum-operated transonic-supersonic tunnels at DREV, Valcartier, Quebec, and at Fuji Heavy Industries in Japan; and for several wind tunnel design studies for NATO and others. DSMA held a license for the application of cryogenic techniques to blowdown intermittent tunnels. The firm had also designed low-speed wind tunnels in Ottawa (NRC 30-foot) and automotive wind tunnels in Canada (Imperial Oil), Sweden (Volvo), Germany (Ford), the United States (Chrysler, Amoco, Exxon), and England (British Leyland). In a highly competitive environment, DSMA gained an international reputation as a designer of modern aerodynamic test facilities.[123]

In addition to its relevance to Canadian aeronautics, the history of the development of large intermittent wind tunnels recorded here is more generally significant as an example of the obstacles which often get in the way of innovation. It illustrates how institutionalized engineering conservatism can make it difficult for experienced practitioners to adopt, or even merely consider, nontraditional approaches. In this case, decades of experience limited to continuous wind tunnel testing prevented the largest and most reputable aeronautical research organizations - the NACA in the United States and the RAE in Great Britain - from considering a short-duration technique. It was left to uninhibited newcomers, lacking the resources available to their peers, to come up with novel solutions offering superior economy and performance.[124]

The history of continuous versus intermittent wind tunnels was reenacted to an extent in the 1970s, when efforts were made to develop techniques for attaining the high Reynolds numbers required to simulate large aircraft and rocket aerodynamics at transonic speeds.[125] Again, the bias toward continuous flow operation may have been a factor in the rejection of the Ludwieg-tube and other short-run systems and the selection of continuous, cryogenic wind tunnel design for the new National Transonic Facility (NTF) completed in 1983 at the NASA Langley Research Center.[126] Again, those faced with limited resources and those experienced in short-duration testing opted for intermittent-type facilities.[127]

The paradox of major organizations, active at the leading edge of technology progress and yet technologically conservative, has been noted before. It seems clear that resistance to change is as much a trait of human nature as are inventiveness and creativity.[128]

Notes and References

1 Unless otherwise noted, current Canadian dollars are quoted.

2 German and Allied designations, respectively.

3 *German Air Force Jet-Propelled Aircraft*, USAAF Intelligence Report, February 10, 1945.

4 "The highlights of the German research work were known fairly completely to us by about August, 1945," said R. Smelt in a comprehensive review of information on German research obtained by the British ("A Critical Review of German Research on High-Speed Airflow," *Journal of the Royal Aeronautical Society* 50, no. 432 [December 1946]: 899 - 934). For other reports on Allied technical intelligence in 1944-45, see: P. R. Owen, *Note on the Apparatus and Work of the W.V.A. Supersonic Institute at Kochel, S. Germany*, Royal Aircraft Establishment, Farnborough, United Kingdom, RAE Tech Note Aero 1711, 1712, October 1945; 1722, November 1945; 1742, January 1946; L. G. Pooler, "German Aerodynamical Institutes and Interviews with German Scientists," *Symposium on Aerodynamics*, Johns Hopkins University, Applied Physics Laboratory, Bumblebee Report no. 29, December 6-7, 1945; R. V. Jones, *Most Secret War; British Scientific Intelligence 1934 - 1945* (London, 1978); and *J. V. Becker, The High-Speed Frontier: Case Histories of Four NACA Programs, 1920-1950* (Washington, D.C., 1980). For assessment of military potential see, for example, *Toward New Horizons*, a twelve-volume report prepared on behalf of the U.S. Army Air Forces Scientific Advisory Board by Theodore von Kármán and submitted to Gen. H. H. Arnold, Commanding General, AAF, on December 15, 1945.

5 M. Lamontagne, *A Science Policy for Canada, Report of the Senate Special Committee on Science Policy, 1, A Critical Review: Past and Present* (Ottawa, 1970).

6 They were not identified in the following major investigations of Canada's science policy conducted in the 1960s: Ibid.; *The Royal Commission on Government Organization (Glassco Report)*, 4, *Scientific Research and Development* (Ottawa, 1963), Section 23, pp. 183-322.

7 J. de N. Kennedy, *History of the Department of Munitions and Supply* (Ottawa, 1950), p. 30; RG 28A, vol. 155, Public Archives of Canada, Ottawa.

8 *White Paper on Employment and Income*, Department of Reconstruction and Supply, Ottawa, April 12, 1945, page l.

9 Avro's projects, particularly the aborted Arrow supersonic fighter (see below), have been the subject of a highly emotional but poorly documented controversy in Canada, as evident from contributions by M. Peden, *Fall of an Arrow* (Stittsville, Ont.: Canada's Wings, 1978); E. K. Shaw, *There Never Was an Arrow* (Toronto: Steel Rail Educational Publishing, 1979); R. Organ, R. Page, D. Watson, and L. Wilkinson, *Avro Arrow* (Cheltenham, Ont.: Boston Mills Press, 1980, 1992) among others. Studies by J. Dow, *The Arrow* (Toronto: J. Lorimer, 1979) and P. Zuuring, *Arrow Scrapbook: Rebuilding a Dream and a Nation* (Dalkeith, Ont.: The Alliance Press, 1999) offer a more balanced assessment and refer to some primary sources. Canada's air defence policy and the Arrow cancellation are also discussed in Prime Minister John Diefenbaker's *One Canada, Memoirs of the Right Honourable John G. Diefenbaker*, Vol. 3, *The Tumultuous Years 1962 -1967* (Toronto, 1977), especially pp. 17 - 76. For an overview of Canadian aeronautics, see R. D. Hiscocks, "Aircraft Design in Canada from Silver Dart to Challenger and Dash 8," *Canadian Aeronautics and Space Journal* 30, No. 2 (June 1984): 99-113.

10 "Hawker buys Malton Aircraft Plant," *Canadian Aviation* 18, No. 8 (August 1945): 137. The agreement was a personal priority for both C.D. Howe, Minister of Munitions and Supplies and of Reconstruction, and Sir Roy H. Dobson, a Director of Hawker Siddeley and Managing Director of A.V. Roe & Co. Ltd. of Manchester, England.

11 According to Air Marshal W. A. Curtis, Chief of the Air Staff (1947-53) and subsequently Vice-Chairman of the Avro board of directors ("Developing Canada's Air Defences," *Saturday Night* 68, no. 30 [May 2, 1953]: 7-8).

12 Lamontagne (n. 5 above), p. 81; Dow (n. 9 above), p. 77.

13 The U.S. F-101 was among the aircraft considered and rejected; in 1961, Canada acquired sixty-six used F-101s in a complex exchange arrangement which involved purchase of 35 Canadair CL-44 cargo aircraft by the United States. *Engineering Dimensions*, January-February 1989, p.36.

14 A former pilot in the Polish Air Force and, after 1947, a test pilot with the Gloster Aircraft Co. in England, Janusz Zurakowski joined Avro in 1952. He enjoyed a reputation of "the most brilliant test pilot," a man with "a built-in ability to diagnose airplane responses." Flying the Gloster Meteor F-8 in 1951, he invented the cartwheel figure, the first new aerobatic stunt in twenty years ("Twin-Jet Pinwheel," *Time* [Canada ed.] 58, no. 23 [December 3, 1951]: 45 - 46; Dow [n. 9 above], pp. 79, 153).

15 After twenty-two years of uninterrupted Liberal rule, the Conservatives came to power in June 1957 and governed until the Liberals were returned to office in April 1963.

16 See B.A. Avery, "The Orenda History," *Canadian Aeronautics and Space Journal* 5, No. 2 (1979): 134-141.

17 Before the Iroquois was ready, the Pratt & Whitney J75 engine was used in Mark I prototypes.

18 See J.C. Floyd, "The Canadian Approach to All-Weather Interceptor Development," *Journal of the Royal Aeronautical Society* 62, No. 576 (December 1958): 845 - 866.

19 The J75 engine had a sea-level thrust of 12,500 pounds compared to the 19,250-pound thrust of the Iroquois.

20 When in 1956 Avro took on the management of the weapon system, F. Smye, President of Avro Aircraft predicted that this could jeopardize the whole CF-105 program (Zuuring, n.9 above, p.94).

21 Avro Brochure AD15, September 1954; Campney to Howe, November 24, 1955, C.D. Howe Papers, Public Archives of Canada, Ottawa.
22 Dow (n. 9 above), pp. 117, 124; Zuuring (n.9 above), pp. 90-91.
23 Zuuring (n. 9 above), p. 90.
24 Ibid, p.94. The perceptions of national sovereignty and military independence have since evolved. In July, 2000 a plan for sharing, in case of need, long range military transport aircraft and crews with the U.S. was being considered ("Canada, U.S. may share military aircraft", *The Globe and Mail* (Toronto), 21 July, 2000 pp.A1, A6).
25 Ironically, this occurred almost to the day on the golden anniversary of the first powered flight in Canada (and in the British Empire by a British subject) made by J.A.D. McCurdy in the Silver Dart on February 23, 1909, near Baddeck, Cape Breton Island, Nova Scotia, over the frozen surface of Lake Bras d' Or.
26 *House of Commons Debates, Official Report*, 2, Ottawa, February 20, 1959, p. 1221; Diefenbaker (n. 9 above), pp. 36, 33. Regarding missiles, this was also the view of a retired chief of the Canadian Army staff who announced that "the day of the airplane as a defence mechanism is finished.... It has been replaced by missiles as the primary weapon. The Arrow is... the last of its line and kind" (*The Telegram*, Toronto, September 24, 1958). Canadians were not alone in making such naive forecasts. Following the launching of *Sputnik*, Nikita Khrushchev allowed that "Now the bomber and fighter can go into the museum" (*New Scientist* 95, no. 1325 [September 30, 1982]: 928).
27 *House of Commons Debates* (n. 26 above), p. 1223. Actually, production sharing had continued throughout the Avro period and beyond, through the wartime practice of licensed manufacturing of military aircraft (by Canadair Ltd.); aircraft produced in this manner included the T-33 jet trainer and F-86 jet fighter in the 1950s, followed by the F-104 and F-5 jet fighters in the 1960s and 1970s.
28 Diefenbaker (n. 9 above), p. 44. The Canadian government's conviction that manned aircraft for air defence would become obsolete was not shared by other members of the North Atlantic Treaty Organization or by the Soviet Union. It also contradicted statements made in 1957 and 1958 by the Minister of National Defence and by the Canadian Deputy Commander-in-Chief of the North American Defense Command (NORAD); Dow (n. 9 above), pp. 113, 134, 156. Both superpowers continued to maintain large fleets of intercontinental bombers and manned interceptors.
29 On March 6, 1959 the RCAF requested the Department of Defence Production to instruct Avro to retain for a limited period of 9 months all Arrow and Iroquois engineering data, but it is uncertain whether any escaped destruction (Zuuring, n.9 above, p.130).
30 Zuuring (n.9 above), p.127
31 Dow (n. 9 above), p. 141; Shaw (n. 9 above), pp. 87-92; J. Zurakowski, "Test Flying of the Arrow and Other High Speed Jet Aircraft," *Journal: Canadian Aviation Historical Society* 17, No. 4 (Winter 1979): 100-111, quote on p. 108.
32 According to a report in *The Times* of London, quoted in Lamontagne (no. 5 above), p. 79; see also S. Young, "Forty Years of Work at the McDonnell Douglas Canada Ltd. Plant, Malton," *Canadian Aeronautics and Space Journal* 25, No. 2 (1979): 128-132.
33 The two Avrocar prototypes are in the United States (one in the Smithsonian Air and Space Museum in Washington, DC). It is planned to bring one of them to Canada.
34 On Canadair, see F.C. Phillips, "A History of Aerospace Research and Development in Canadair Ltd.," *Canadian Aeronautics and Space Journal* 25, No. 2 (1979): 112 -121.
35 Diefenbaker (n. 9 above), p. 38.
36 Dow (n. 9 above), p. 101.
37 D. I. Goodspeed, A History of the Defence Research Board of Canada (Ottawa, 1958); also Lamontagne (n. 5 above), pp. 74 - 81.
38 See n. 6 above.
39 See n. 37 above. The NAR Committee was composed of the President of NRC as Chairman, the Chairman of the DRB, the Chief of the Air Staff, and the Deputy Ministers of Transport and Defence Production.
40 See n. 6 above.
41 Goodspeed (n. 37 above), p. 59; Lamontagne (n. 5 above), p. 85.
42 UTIA, *Progress Report on Research Supported by Grants from the Defence Research Board*, 1952-53; 1953-54.
43 *Official Opening, September 26, 1950,* Institute of Aerophysics, University of Toronto; *Addresses at the Opening of the New Building*, pt. 1, *Decennial Symposium*, Institute of Aerophysics, University of Toronto, October 14-16, 1959; G. N. Patterson, *The Role of the Research Institute in University-Industry Cooperation*, Institute for Aerospace Studies, University of Toronto, 1967.
44 F. W. Pruden, *A Proposal for a High Speed Aerodynamic Laboratory*, National Research Council, Division of Mechanical Engineering, Report MA-205, Ottawa, April 30, 1948. See also R.J. Templin, *Design Considerations of Supersonic Tunnels*, National Research Council, Division of Mechanical Engineering, Report MA-158, Ottawa, 1945.
45 J. Lukasiewicz, "Wind Tunnels in the High Speed Aerodynamics Laboratory," *NAE & NRC (ME) Quarterly Bulletin*, Vol. 4 (1952).
46 On the concept, see A. Busemann, "Profilmessungen bei Geschwindigkeiten nahe der Schallgeschwindigkeit," *Jahrbuch der Wissenschaftlichen Gesselschaft fur Luftfahrt* (1928), p. 95; C. Wieselsberger, "Die Uberschallanlage des Aerodynamischen Instituts der Technischen Hochschule Aachen," *Luftwissen*, No. 4 (1937): 301-303; L. Prandtl, *Essentials of Fluid Dynamics* (New York, 1952), p. 306 et seq.; H. H. Kurzweg, "The Aerodynamic Development of the V-2," pp. 50-69 in *History of German Guided Missiles Development*, ed. Th. Benecke and A. W. Quick, AGARDograph 20 (Brunswick, Germany, 1957). After the war, the two 40x40-cm Peenemünde tunnels were shipped from Kochel in Bavaria (moved there after the bombing of Peenemünde in 1943) to the U.S. Naval Ordnance Laboratory in Silver Spring, Md., and reactivated in 1948. See Smelt and Owen (n. 4 above); also W. Bollay, "Aerodynamics of Supersonic Aircraft and Missiles," *Symposium on Ordnance Aeroballistics*, NOLR-1131, U.S. Naval Ordnance Laboratory, White Oak, Silver Spring, Md., June 28, 1949, pp. 27-49; and H. H. Kurzweg, "The Aeroballistic Research Facilities at NOL," *NOL Aeroballistic Research Facilities Dedication & Decennial*, NOLR-1238, U.S. Naval Ordnance Laboratory, 1959, pp. 18-37. In 1948, a 16x16-inch supersonic tunnel-essentially a copy of the 40-cm Peenemünde design - was built by North American Aviation, Inc., in Los Angeles (see Bollay, above). Provision for storage of dry air was introduced in this installation.
47 See Owen (n. 4 above) and Kurzweg (n. 40 above). When Sweden embarked on indigenous design of military aircraft and missiles after World War II, it opted for the affordable, vacuum-driven intermittent tunnels and extended the German experience to larger sizes (0.5x0,5-m and 1x1-m test sections, operational in 1955), driven models (see below), and unconventional vacuum storage in chambers blasted out of rock (Bo K.O. Lundberg, "Aeronautical Research in Sweden," *Journal of the Royal Aeronautical Society* 59, no. 538 [October 1955]: 647-681; *The FFA Aerodynamic Research and Test Facilities*, FFA Memorandum 33, Flygtekniska Forsoksanstalten [Stockholm, 1964]).
48 Because of machining and handling difficulties (see, e.g., Becker, n. 4 above, p. 104), interchangeable solid nozzle blocks or integral nozzle boxes were not used in medium-size and large wind tunnels; the RAE-Bedford 3x3-foot (J.Y. G. Evans and A. Spence, *Development of Wind Tunnels* at the RAE, RAE Technical Report 71040, 1971) and the NACA-Langley 4x4-foot supersonic tunnels (dismantled in 1977; W. T. Schaefer, Jr., *Characteristics of Major Active Wind Tunnels at the Langley Research Center*, NASA Technical Memorandum TM X-1130,July 1965) were among the largest equipped with solid block nozzles. Variable geometry designs were more practical in large wind tunnels (see n. 55 below).
49 Most testing of the Arrow was conducted in larger U.S. tunnels; also 1: 8-scale models were tested in free flight at the CARDE-Picton (Point Petre) and NACA-Langley ranges, see Floyd, (n. 18 above)., Zuuring (n. 9 above), pp.158-161.
50 The following major tunnels were upgraded in the years indicated: NACA-Langley: 8-foot diameter, 1945; 4x4 foot, 1950; 16-foot diameter, 1951; NACA-Ames: 16-foot diameter, 1955; 6x6 foot, 1956; RAE-Farnborough: 10x7 foot, 1956.
51 D. G. Tietjens, *Applied Hydro- and Aeromechanics* (New York, 1957), pp. 253- 254.
52 This was recognized by Prandtl some twenty years earlier and led him to the concept of intermittent tunnels (see n. 46 above).
53 The use of driven models in intermittent tunnels was envisaged at North American Aviation, Inc., in 1949 (Bollay, n. 46 above), but the "driven model technique" was developed at NAA only after 1952, when the large intermittent project was started. The benefits of intermittent test technique were realized 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 (see J. Lukasiewicz, "A Critical Review of Development of Experimental Methods in High Speed Aerodynamics," in *Progress in Aerospace Sciences*, ed. D. Kuchemann [Oxford, 1973], pp. 1 - 26). However, it should be noted that ingeneral intermittent operation is not suitable for air-breathing propulsion testing, for which relatively long duration flows are usually required.
54 J. Lukasiewicz and F. W. Pruden, *An Economic High Speed Wind Tunnel of High Performance, with Notes on Contraction Ratio and Reynolds Number Control*, National Research Council, Division of Mechanical Engineering, L.O. 5850-A, File LM2-9-1, Ottawa, September 22, 1950. Results of subsequent studies were reported in J. Lukasiewicz, *Development of Intermittent High-Speed Wind Tunnel Installations and Testing Techniques*, National Aeronautical Establishment Laboratory Report, LR-75, Ottawa, July 17, 1953, and "Development of Large Intermittent Wind Tunnels," *Journal of the Royal Aeronautical Society* 59, No. 4 (1955): 259 - 278.
55 Trisonic was a term introduced by North American Aviation, Inc. (now Los Angeles Division, Rockwell International Co.); see W. Daniels,Jr., Design and Development of North American Aviation Trisonic Wind Tunnel, AGARD (Brussels, 1956). Trisonic operation called for a practical method of varying the test-section Mach number over a wide range. By the time the design of large intermittent tunnels started, the fully flexible nozzle provided the required solution. The basic idea of a continuous curvature aerodynamic contour compatible with the elastic shape of a flexed nozzle wall and the flexible nozzle design were pioneered by the Jet Propulsion Laboratory, California Institute of Technology, and the Sandberg-Serrell Co., both of Pasadena, Calif. (A. E. Puckett, "Supersonic Nozzle Design," *Journal of Applied Mechanics* 15 [December 1946]: A-265-A-270; *Design and Operation of a 12-Inch Supersonic Wind Tunnel*, Institute of the Aeronautical Sciences preprint no. 160 [New York, 1948]; H. N. Riise, *Flexible-Plate Nozzle Design for Two-Dimensional Supersonic Wind Tunnels*, JPL, CIT, Report no. 20-74, Pasadena, Calif., June 9, 1954; J. T. Kenney and L. M. Webb, *A Summary of the Technique of Variable Mach Number Supersonic Wind Tunnel Design*, AGARD, AGARDograph no. 3 [Paris, 1954]). The JPL 12x12-inch supersonic tunnel was the first to be equipped, in 1948, with a successful flexible nozzle. The design was subsequently used in larger JPL tunnels, in the large intermittent tunnels, in several tunnels at the Arnold Engineering Development Center (up to 16x16-foot size), in the NACA-Lewis propulsion test tunnels, in the RAE-Bedford 8-foot and 3x4-foot tunnels, among others.
56 The most fundamental problem involved matching the pressure ratio - volume flow

characteristics of the tunnel to those of the compressor (a problem encountered already in the 1930s in the design of the first continuous supersonic wind tunnel - see J. Ackeret, "High Speed Wind Tunnels," *Proceedings, Fifth Volta Congress* [Rome, 1935]; NACA TM 808, 1936), and providing the extremely high power (in the 50,000- to 200,000-horse-power range) needed to attain the desired Mach and Reynolds numbers. The aerodynamic and structural design of compressors had to be pushed to the limit, and variable-speed electric motor drives had to be developed for power levels not encountered before. The structural and mechanical design of the closed wind tunnel circuit presented serious difficulties. For a comprehensive discussion, see R.F. Huntsberger and J.P. Parsons, "The Design of Large High-Speed Tunnels," pp. 127-142; W. Wadkin and T. Barnes, "Notes on the Design and Construction of the Welded Steel Structure for the 8 Foot x 8 Foot High Speed Wind Tunnel at the National Aeronautical Establishment, Bedford," pp. 153-166; J. Clark, "Design and Construction Aspects of High Power Wind Tunnel Drive Systems and Large Diameter Compressors," pp. 167-191 in *Papers Presented at the Fifth Meeting of the Wind Tunnel and Model Testing Panel*, AGARD, AG15/PC (Paris, 1954); J. Lukasiewicz, "Development of Large Intermittent Wind Tunnels," *Journal of the Royal Aeronautical Society* 59, no. 4 [1955]: 259-278, and n. 53 above; L. J. Cheshire, J.Y.G. Evans, W.A. Goodsell, and P.H. W. Wolff, "The Design and Construction of the Compressor for the 8 Foot by 8 Foot High-Speed Wind Tunnel at R.A.E. Bedford," *Proceedings of the Institution of Mechanical Engineers* 176, no. 15 (1958): 549-584; E. P. Hartman, *Adventures in Research: A History of Ames Research Center* 1940 - 1965 (Washington, D.C., 1970); and D.D. Baals and W.R. Corliss, *Wind Tunnels of NASA* (Washington, D.C., 1951).

57 When Ames Unitary Plan project was found to require three, instead of one, different continuous tunnels to cover the stipulated Mach number range from 0.7 to 3.5, an intermittent operation was not envisaged. Indeed, it was asserted that "no single tunnel can properly cover the entire range of aircraft and missile flight." See Baals and Corliss (n. 56 above), p. 66. The Canadian proposal was discussed in New York with W. G. A. Perring, director, and other members of the RAE delegation during their visit to the United States in October 1950; they showed no interest in the intermittent design.

58 The literature of the period reflects a lack of familiarity with the intermittent technique, a situation that persisted even after large intermittent tunnels became operational in 1957. H.W. Liepmann and A.E. Puckett, authors of one of the first American texts on compressible flow (*Introduction to Aerodynamics of a Compressible Fluid* [New York, 1947]), wrote in 1947 that, "aside from the short operating time," the chief disadvantage of a blowdown wind tunnel operating from pressurized air storage to the atmosphere "is the impossibility of controlling the density... [which] varies continuously." Evidently, the use of a pressure control valve was not considered. Neither the 1954 review of *Design and Operation of Intermittent Supersonic Wind Tunnels* by A. Ferri and S.M. Bogdonoff, AGARD, AGARDograph no. 1, Paris, nor the definitive 1961 Princeton (N.J.) monograph series on *High Speed Aerodynamics and Jet Propulsion*, 8, pt.2, Wind Tunnel Techniques, ed. F.E. Goddard, pp. 427- 770, mentions the application of intermittent operation to large wind tunnels or the use of driven models.

59 *Wind Tunnel List*, Supersonic Tunnel Association, Nineteenth Semi-Annual Meeting, May 1963.

60 J. Lukasiewicz, "Some Problems of Design and Operation of Blowdown Wind Tunnels," *Journal of Applied Mathematics and Physics*, ZAMP IXb, No. 5/6, (Basel, March 17, 1958): 422-437; also n. 54 (1953 and 1955).

61 Lukasiewicz (n. 60 above). The pilot tunnel has been since moved from HSAL to Uplands and is now operated from the 5-foot tunnel pressure storage.

62 J. Lukasiewicz, "Scientific R&D Activities of the Government of Canada: Diagnosis and Cure" (unpublished study, October 1963).

63 "PC Economy Drive Delays Wind Tunnel," *Montreal Star*, January 25, 1958.

64 W.J.Rainbird and N.B. Tucker, "The Five Foot Blowdown Wind Tunnel at the National Aeronautical Establishment," *Proceedings, Decennial Symposium*, Institute of Aerophysics, University of Toronto, 1959, pp. 194-213; K.F. Tupper, P.B. Dilworth, and L.A. Jenkins, *The N.A.E. Five Foot Supersonic Wind Tunnel*, Engineering Institute of Canada 1961 Annual General Meeting Paper no. 40, 1961; L.H. Ohman, "The Role of the NAE 5x5-Foot Wind Tunnel in the Development of Modern Airfoil Sections," *Canadian Aeronautics and Space Journal* 22, No. 1 (January-February 1976): 1-22.

65 "How to Spend Money," *Time* (Canada ed.) 79, No. 7 (February 16, 1962): 9.

66 *Glassco Report* (n. 6 above), p. 278.

67 See Rainbird and Tucker (n. 61 above). According to the NAA data, the cost of trisonic, pressure-storage type tunnels ranged from $2 to $4.5 million (U.S.) for test sections from 4x4 foot to 7x7 foot, respectively; see Daniels (n. 52 above).

68 National Aeronautical Establishment, National Research Council, Ottawa, 1980.

69 G.V. Bull, "Some Aerodynamic Studies in the C.A.R.D.E. Aeroballistics Range," *Canadian Aeronautical Journal* 2, No. 5 (May 1956): 154-163; G. V. Bull, *Aeronautical Studies in the Aeroballistics Range*, CARDE Report no. 302/57, July 1957; 1957 Jahrbuch der Wissenschaftlichen Gesellschaft für Luftfahrt, p. 247; G.V. Bull and H.F. Waldron, "Summary of Aerodynamic Studies in the CARDE Aeroballistics Range," *Decennial Symposium, Proceedings*, pt. 3, Institute of Aerophysics, University of Toronto, October 14-16, 1959, pp. 288-319.

70 P. Solnoky, "An Economic Analysis of the Operation of the Aerodynamic and Laser Test Facilities of the Defence Research Board of Canada," and "Problèmes généraux relatifs aux moyens d'essais aérodynamiques," *Proceedings, 8e séminaire du groupe sur la défense de l'OTAN*, Institut Franco-Allemande de St. Louis, May 4-7, 1971 (St. Louis, France, 1971), pp. 119-165.

71 G.V. Bull, "Development of Gun-Launched Vertical Probes for Upper Atmosphere Studies," *Canadian Aeronautics and Space Journal* 10, No. 8 (October 1964): 236-47; C.H. Murphy and G.V. Bull, "Review of the High Altitude Research Program (HARP)," *The Fluid Dynamic Aspects of Ballistics*, AGARD Conference Proceedings No. 10, North Atlantic Treaty Organization, Advisory Group for Aerospace Research and Development, September 1966, pp. 403-437.

72 G.V. Bull, D. Lyster, and G.V. Parkinson, *Orbital and High Altitude Probing Potential of Gun Launched Rockets*, SRI-H-R-13, Space Research Institute, McGill University, Montreal, October 1966.

73 M. Wojaechowski, "Harp Fiasco," *Science Forum* 3, No. 1/13 (1970): 12 - 16.

74 R.E. Barrington, "Canadian Space Activities in the Past Quarter Century," *Canadian Aeronautics and Space Journal* 25, no. 2 (1979): 153 - 169.

75 See "Case of Dr. Bull Reaches Its Bitter End," *The Gazette*, Montreal, March 21, 1981.

76 See n. 9 above.

77 As noted by J.C. Floyd, Avro's Vice-President, Engineering, responsible for the Arrow: "the CF-105 was, of necessity, a considerable advancement over contemporary aircraft, and there were few reports or tests... on which to base... design" (n. 18 above, p. 847).

78 Dow (n. 9 above), p. 46.

79 Goodspeed (n. 37 above).

80 Quoted by Dow (n. 9 above), pp. 110-111.

81 G/C H.R. Foottit to F.T. Smye, President, Avro Aircraft, 4 December 1957; see Zuuring (n.9 above), p.80.

82 Dow (n. 9 above), p. 49.

83 Avery (n. 16 above). In 1957 the French became interested in the Iroquois for their Dassault-Mirage IV fighter but in view of the uncertain future of the Arrow program did not order the engine.

84 G. Stewart, *Shutting Down the National Dream* (McGraw-Ryerson Ltd., 1997): ix-x.

85 P. Campagna, *Storms of Controversy: The Secret Avro Arrow Files Revealed* (Toronto: Stoddart, 1997): Appendix

86 Some forty years later the NRC Aero Library (Parkin Library, see Zuuring, n.9 above, p.212) - the only extensive collection of aerospace technical literature in Canada - met a similar fate. It was abolished and dispersed among the holdings of CISTI (NRC's Canadian Institute of Scientific and Technical Information), with no access to stacks and a computerized catalog that offers only listings of research report numbers.

87 See *Aviation Week & Space Technology*, March 1996, p.32-33; *Flight International*, 18-31 December 1996, p.26-27.

88 J.L.Granatstein, "The myth of broken Arrow", *The Globe and Mail*, January 11, 1997; M.Bliss, "Shutting down the Avro myth", *Report on Business Magazine*, p.29, February 1989.

89 P. Campagna, "An Aviation Chapter in Canadian History", *Engineering Dimensions* 9, No.5 (September/October 1988):51.

90 "The Legacy of the Avro Arrow", *The Globe and Mail*, January 18, 1997.

91 K.R. Leckie (n.84 above), p.xii.

92 Zuuring (n.9 above), p.4.

93 B. Etkin, "The Arrow: What might have been", *The Globe and Mail*, January 22, 1997.

94 Organ *et al.* (n.9 above), p.ix.

95 See n.85 above, p.98.

96 Ibid., p.180.

97 See n.89 above, p.51.

98 J. Izsak, Letters, *Report on Business* (April 1989):13.

99 G. Sprung, "Director's Notes", *Prelude* 12, no.2 (NAC: January-April 1990):3.

100 See n.85 above, p.9.

101 Ibid., p.190; n.96 above, p.47.

102 There has been speculation that the CIA was "nervous about the prospect of a foreign aircraft outperforming its top secret U2 spy plane". (See B.D.Johnson, "Raising the Arrow", *Maclean's*, 110, No.2 [January 13, 1997]:50). This high altitude, long range subsonic reconnaissance aircraft bore no relation whatsoever to a supersonic fighter.

103 Zuuring (n.9 above), pp.98-99.

104 A wing design similar to Arrow's was developed earlier by Supermarine Vickers-Armstrong (Aircraft) Ltd. for Swift and Scimitar interceptors. See R. Rose in *Engineering Dimensions*, January-February 1989, p.35.

105 Whitcomb, R.T., Kelly, T.C., *A Study of the Flow Over a 45° Sweptback Wing-Fuselage Combination at Transonic Mach Numbers*, NACA RM L52DO1, 1952; also Whitcomb, R.T., *A Study of the Zero-Lift Drag Rise Characteristics of Wing-Body Combinations Near the Speed of Sound*, NACA Report 1273, 1956.

106 See n.102 above; P.Campagna, "The Arrow, the RCAF, and Canada" *CASI Log* 2, No.3 (September 1994): 10.

107 Zuuring (n.9 above), p.66.

108 Ibid., p.67.

109 R.J. Templin, private communication.

110 See n.88 above.
111 *Engineering Dimensions* (May/June 1989), p.7.
112 Zuuring (n.9 above), pp. 138-139, 158-161,177-211,225-234.
113 Notwithstanding its past failures, Argentina was reported to be planning again (in the wake of its 1982 defeat in the Falklands) the development of combat jet aircraft ("Aircraft Builder Moves Towards Combat Sales," *Aviation Week & Space Technology* 119, No. 4 [July 25, 1983]: 35 - 36). Egypt, on the other hand, was going into limited production of U.S. and West European designs ("Egypt Seeks Technology Transfer," *Aviation Week & Space Technology* 119, No. 7 [August 15, 1983]: 129-159). Even some of the world's most highly industrialized and economically powerful countries have reached the limits of resources and markets. Witness Soviet, British, and French efforts to develop supersonic transports. The Soviet Tu-144 never entered regular service, while the Anglo-French Concorde proved a technical success but an economic disaster; only 16 production models were built, and by 1983 three Air France aircraft were being cannibalized for spare parts.
114 See Lundberg (n. 47 above).
115 The quote is from E.B. Skolnikoff, "Technology and the Future Growth of International Organizations," *Technology Review* 73, No. 8 (1971): 38-47.
116 Indeed, it is through international collaboration that Canadians first became involved in aeronautics as members of the Aerial Experiment Association established in 1907 by Alexander Graham Bell, who came from Scotland to Canada and moved to the United States in 1872. The association included two Canadians, F.W. Baldwin and J.A.D. McCurdy, and two Americans, T. E. Selfridge and G.H. Curtiss; they constructed several kites, gliders, and man-carrying power-driven biplanes and conducted test flights near Hammondsport, N.Y., and Baddeck, Nova Scotia. The activities of the AEA concluded with the development in 1908-9 of the Silver Dart biplane, in which McCurdy made the first powered flight in Canada (J.H. Parkin, "The Evolution of the Silver Dart," *Canadian Aeronautical Journal* 5, No. 2 [February 1959]: 39-46; see n. 25 above).
117 See C.B. Wrong, "The Story of Pratt&Whitney Aircraft of Canada," *Canadian Aeronautics and Space Journal* 25, No. 2 (1979): 142-152; K.H. Sullivan, L. Mulberry, *The Pratt&Whitney Canada Story* (Toronto: CANAV Books, 1989); E.L. Smith, "Powerplant Development at Pratt&Whitney Canada, Inc.", *Canadian Aeronautics and Space Journal* 36, no.4 (December 1990): 224-229.
118 See *Aviation Week & Space Technology* 118, no. 20 (May 16, 1983): 63-69; 118, no. 25 (June 20, 1983): 24-25; 119, no. 13 (September 26, 1983): 121-122; also, *A Report by Senator Jack Austin on Canadair Ltd. to the Standing Committee on Public Accounts and to the Standing Committee on Finance, Trade and Economic Affairs*, Minister of State, Ottawa, June 7, 1983; and J. Lukasiewicz, "The Arrow: A Canadian Object Lesson in Failure," *The Globe and Mail* (Toronto), February 20, 1984, p. 7.
119 $370 million in 1958 dollars, *i.e.*, an amount about equal to the cost of the Arrow project.
120 James Rusk, "De Havilland Woes May Cost $1 Billion," *The Globe and Mail* (Toronto), April 10, 1984, pp. 1-2.
121 E. McConachie, "The Story of the Canadair Regional Jet", *CASI Log* 7, No. 5 (December 1999): 7-10.
122 These problems were tackled more effectively in the United States as a result of such studies as the above-mentioned 1945 von Kármán report for the AAF (n. 4 above) and NACA's National Aeronautical Research Policy proposal of 1946, endorsed by all the agencies concerned (*Government and Aircraft Industry Concur on National Aeronautical Research Policy*, NACA Press Release, April 1, 1946; see also, *NACA 33rd Annual Report 1947*; Hartman [n.56 above], p.120). Years later, when the Soviet *Sputnik* spurred an expansion of aerospace R&D, a new institutional framework was established through the creation, on October 1, 1958, of the National Aeronautics and Space Administration, which took over from the forty-three-year-old NACA and carried a much broader mandate.
123 After DSMA was bought out by an American company in the 1990s, this activity was continued in Toronto by Aiolos.
124 Examples of engineering conservatism in the development of hypersonic wind tunnels are noted by Lukasiewicz (n. 53 above).
125 See, *e.g.*, J. Lukasiewicz, "The Need for Developing a High Reynolds Number Transonic Wind Tunnel in the U.S.," *Astronautics & Aeronautics* 9, No. 4 (1971): 64-70.
126 In cryogenic wind tunnels, stagnation temperatures down to about 100 degrees K (- 280 deg F) are obtained through evaporation of liquid nitrogen. Operation at such temperatures allows attainment of much higher Reynolds numbers with smaller drive power than at normal temperatures. For example, at a pressure corresponding to a ten-second run in the NRC 5-foot trisonic wind tunnel, a four-times-larger Reynolds number (per unit length) is obtained in the NTF, at a stagnation temperature of 110 deg K. For a history of the cryogenic wind tunnel development, see E.C. Polhamus, "The Large Second Generation of Cryogenic Tunnels," *Astronautics & Aeronautics* 19, No. 10 (1981): 38-51.
127 The Douglas Aircraft Co. in the United States and ONERA/CERT in France; see Polhamus (n.126 above).
128 See, *e.g.*, E.E. Morison, *Men, Machines, and Modern Times* (Cambridge, Mass., 1966); and J. Lukasiewicz, "The Institutionalization of Obsolescence," in *The Railway Game* (Toronto, 1976), pp. 240-245.

New Members

July 27th to September 13th, 2000 (incl.)

Lewis Adkins
Chuck Andersen
Michael Armstrong
Alexander Azimov
Leonard Belfroy
Mark Blenner-Hassett
André Benoit
Jeffrey Castellas
Ron Caves
Todd Clapperton
Brian Clarke
Caren Dymond
Yosef Elhady
Patricia Eves
Kathryn Ferguson
Philip Ferguson
Dickson Fong
Pat Giangaspero
Colin Gillespie
Kevin Jones
Jeffrey Jordan
Michael Kamel
Wootae Kim
Mikhail Koulev
Richard Laszlo
David Leverington
Augustine Lo
Mark Loewen
Laird McKinnon
Andy Melnyk
Carl Olivier-Gooch
Matt Peters
Robert Rochon
Grandt Sathaniell
John Skierka
Charladaen Smith
Aneeqa Syed
Pierre Traore
Laurence Vigeant-Langlois
Cari Wells
Jason Westra
Russell Wildeman
Andy Woo
D. Bruce Yake

New Associate Fellows of CASI

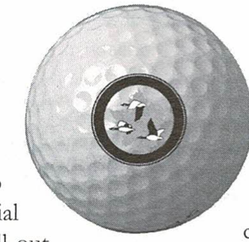
Summer 2000

Doris Jelly
John Maris
B. James Miller
Andrew Reif
Yuexi Xiong
David Zingg

WE HAVE MOVED

Canadian Aeronautics
and Space Institute
130, rue Slater Street
<u>*Suite 618*</u>
Ottawa, Ontario K1P 6E2
Tel: (613) 234-0191
Fax: (613) 234-9039
E-mail: casi@casi.ca
Website: www.casi.ca

CASI Golf Tournament 11 August 2000



The 47th Annual Golf Tournament between the Quebec (Montreal) and Ottawa Branches of CASI took place at the Hawkesbury Golf and Country Club on August 11th, 2000. This year the Ionian Financial Group Inc. also participated in the tournament to fill out the numbers for a "Shotgun Start" at 1:00pm, and in addition, Ionian funded the barbecue lunch for all the participants. The weather was cloudy and threatened rain all afternoon, but it held off until the last foursome finished, and then it poured!

Everyone enjoyed the afternoon and once the scores were entered into the computer and a fine roast beef dinner was served, we were able to announce the winners. The Longest Drive on #9 was won by Fred Agnew, and the Closest to the Hole on #12 was won by Florence Marshall. The EB Schaefer Memorial Trophy for CASI Members Low Gross was awarded to Fred Agnew; the Wright Memorial Trophy for CASI Members Second Low Gross was claimed by Raymond Banister; and the Chadborne-Escoffery Trophy for CASI Quebec Members 2nd Low Gross was won by Bill Marshall. The Conrathskellar trophy which has been provided for years by Ray Conrath, was held up for competition this year between the CASI Members Low Gross (Fred Agnew) and Guests Low Gross (Wayne Baird), and was won by Fred Agnew. The "Skins" pot was shared equally between six players. Fred Agnew was then presented with the Bob Germain Memorial Plaque for his outstanding support of the Annual CASI Golf Tournament for many years.

Prizes were then awarded on alternating gross and net scores based on the Atlantic Handicapping System. When the top eight CASI members from Quebec were compared with the top eight members from Ottawa, once again Quebec came out on top and will have their Branch name inscribed on the Railway and Power Engineering Trophy for the year 2000.

Geoffrey Languedoc, the new Executive Director of CASI in Ottawa, was a participant in all of the activities and indicated in his words after dinner that he was pleased with the CASI Member turnout this year. He hoped that CASI Headquarters would be able to play a bigger role in the tournament next year. Doug Gilligan, the Chairman of the Quebec CASI Branch highlighted the coming September meeting of the Branch which will feature the noted lady pilot, aviation historian and author, Shirley Render.

Tony Colitto, the Vice President Business Development of Ionian Financial Group spoke as well and indicated that they were very pleased to join with CASI in this year's event.

Special thanks go this year to Andy Kossak who ran the Registration table, the Skins Game, and afterward entered the scores with help from Jennifer Ashworth. The portable computer and printer was again provided by Keith Meredith of the Quebec CASI Branch.

Profits from this golf game are used by the Quebec Branch to help fund CASI Student Branch activities in the Montreal Universities, and to help enable high profile guest speakers to be engaged for CASI Branch meetings during the year.

Reported by: Jack Henry, CASI Quebec Treasurer and CASI 2000 Golf Organizer.

Tournoi de golf IASC le 11 août 2000

Le 47e Tournoi anneul de golf entre les divisions IASC du Québec (Montréal) et Ottawa a eu lieu au Club de golf de Hawkesbury le 11 août 2000. Cette année, le Groupe financier Ionien inc. a aussi participé au tournoi en complétant le nombre de joueurs aux départs simultanés au coup de fusil de 13 h 00. De plus, Ionien a parrainé le barbecue de midi pour tous les participants. Le temps était nuageux et il y a eu menace de pluie tout l'après-midi. Cependant, le temps a tenu bon jusqu'à ce que le dernier quatuor ait terminé et à ce moment la pluie torrentielle a déclenché!

Tout le monde s'est avéré satisfait de l'après-midi, et dès que les pointages ont été entrés dans l'ordinateur et qu'un superbe repas de rosbif eût été servi, nous étions en mesure d'annoncer les gagnants.

Le coup le plus long sur le numéro 9 a été décerné à Fred Agnew, et le plus proche sur le numéro 12 a été décerné à Florence Marshall. Le E.B. Schafer Memorial Trophy pour le plus bas résultat brut de membre de l'IASC a été remporté par Fred Agnew; le Wright Memorial Trophy pour le deuxième plus bas résultat brut de membre de l'IASC a été décerné à Raymond Banister; le Chadborne-Escoffery Trophy pour le deuxième plus bas résultat brut de membre de l'IASC du Québec a été décerné à Bill Marshall.

Le gagnant du Trophée Conrathskeller, lequel Ray Conrath fournit depuis des années, a été déterminé selon une compétition entre les gagnants des résultats les plus bas bruts de membre de l'IASC (Fred Agnew) et d'invité (Wayne Baird). Fred Agnew l'a remporté. Six joueurs ont également partagé la cagnotte " skins ". Par la suite, on a décerné la Plaque mémorielle Bob Germain à Fred Agnew en reconnaissance de son appui continu du tournoi annuel de golf IASC.

On a, par la suite, décerné des prix sur une base alternante de résultats bruts et nets selon le système Atlantic Handicapping. Lorsque les huit meilleurs membres de la division du Québec ont été comparés aux huit meilleurs membres de la division d'Ottawa, encore une fois la division du Québec a été en tête, c'est donc le nom de cette dernière qui sera gravé sur le Railway and Power Engineering Trophy pour l'an 2000.

Geoffrey Languedoc, le nouveau directeur exécutif de l'IASC à Ottawa, a participé à toutes les activités, et a indiqué lors de son allocution après le dîner qu'il était content de la participation des membres de l'IASC cette année. Il a exprimé le souhait que le siège social de l'IASC sera en mesure de jouer un rôle plus important lors du tournoi de l'année prochaine. Doug Gilligan, le président de la division IASC du Québec, a souligné que la réunion de septembre mettra en vedette une femme pilote reconnue, Shirley Render, historienne et écrivain de l'aviation.

Tony Colitto, vice-président de Développement des affaires du Groupe financier Ionien inc., a indiqué qu'Ionien était ravi de s'être joint à l'IASC pour l'événement de cette année.

Nous tenons à remercier tout spécialement Andy Kossak qui s'est occupé du poste d'inscription, de l'inscription au concours " skins ", et par la suite, avec l'aide de Jennifer Ashworth, de l'entrée des pointages. Keith Meredith, de la division du Québec, nous a encore une fois fourni l'ordinateur bloc-note et l'imprimante.

La division du Québec utilise les profits de ce match de golf pour aider au financement des activités des divisions IASC d'étudiants aux universités de la région de Montréal et pour faciliter l'engagement de conférenciers de renommée pour les réunions de la division IASC pendant la saison courante.

Ce rapport rédigé par : Jack Henry, trésorier de l'IASC Québec et organisateur du Golf IASC 2000.

Dr. Jim Gower receives the CRSS Gold Medal Award

On 24 August 2000, Dr. Jim Gower was presented with the Canadian Remote Sensing Society Gold Medal Award at a ceremony held in Victoria during the banquet of the 22nd Canadian Remote Sensing Symposium.

The Gold Medal Award was introduced by the Canadian Remote Sensing Society in 1986 to recognize either a significant new advance in remote sensing research, development, technology or applications, or a significant long-term contribution to the field of remote sensing in Canada.

The theme of the award was Dr. Gower's contributions to the development of remote sensing ocean applications in Canada.

Dr. Marc D'Iorio (right) Vice-Chair of the Canadian Remote Sensing Society, presents the CRSS Gold Medal Award to Dr. Jim Gower dur ing the Banquet of the 22nd Canadian Remote Sensing Symposium. (Photo by Tom Alfoldi)

Dr. Gower received the Ph.D. degree from Cambridge (Radio-Astronomy) in 1966. He joined Fisheries and Oceans Canada's Institute of Ocean Sciences (IOS) in Sidney, B.C. in 1971 where he is a Research Scientist. For nearly 30 years he has been a spokesman for the value of remote sensing for ocean observation.

Dr. Gower currently plans and supervises the program of the remote sensing facility at IOS where daily NOAA AVHRR and SeaWiFS data are acquired and archived. From May to October these data are used in an operational search for bright plankton blooms that are indicators of red tide events.

Dr. Gower was instrumental in early adoption of a linear array spectrometer for airborne remote sensing (while everyone else was using photo-multiplier tubes) and this led to the discovery that one could measure solar stimulated chlorophyll fluorescence. He later led development of the Fluorescence Line Imager (FLI), one of the first imaging spectrometers built on two-dimensional CCDs.

Although Dr. Gower's most important contributions have been in the area of ocean colour, he has made significant contributions to the development of applications and utilization of data from many remote sensing systems, usually with application to British Columbia's coastal regions. For example, he has worked on and demonstrated the role of satellite remote sensing data from CZCS, TM, the TOPEX/POSEIDON altimeters, and the ERS and RADARSAT SAR sensors, to name a few. He has taken special efforts to validate remote sensing observations with in situ measurements taken by operational buoy networks and by experimental sensors. Furthermore, ocean models have figured into the validation of many of his remote sensing observations.

Dr. Gower's contributions span ocean phenomena of many scales. For example, in the case of SAR, he developed an expression for the tilt modulation associated with ocean wave imaging and has demonstrated the use of SAR data for fishing vessel detection. On the other hand, he has used AVHRR and altimeter data to study basin-scale events in the North Pacific.

Dr. Gower is very active in the international remote sensing community, being a member of the MERIS Science Advisory Group and the SeaWiFS Science Team. As well, he has been involved with numerous national and international working groups such as NASA's Ocean Color Working Group and SEASAT SAR Team.

Dr. Gower is an Associate Editor for the Canadian Journal of Remote Sensing. He has been instrumental in the organization of many large, international-scope conferences including IGARSS'89 / 12th Canadian Symposium on Remote Sensing in Vancouver, the series of Pacific Ocean Remote Sensing (PORSEC) conferences, especially PORSEC'96 in Victoria, and the series of Oceanography from Space conferences that have been held at 10 year intervals in Venice. He has a long and well-respected list of scientific publications and has edited the proceedings of many meetings, such as those from the conferences noted above.

Jim has a remarkable curiosity that has taken him in many different directions over his career. He always has time for others and his insight, breadth of experience, and humour are appreciated by those who work with him.

Success! Canadian Remote Sensing Society Ottawa Chapter Summer Picnic

The CRSS Ottawa Chapter held its 4th annual summer get-together on Thursday July 20, 2000. An informal, friendly gathering took place at Mooney's Bay Beach from 5:30 - 7:30, although many stayed later and enjoyed the beautiful evening. Approximately 25 were in attendance, including 10 children. Many of the same people who have attended previous picnics were there, and it was great to see a number of new faces as well. The Chapter supplied refreshments and munchies and some of the guests contributed from their own picnic baskets. Games were organized for the children, including a three-legged race, modified egg on a spoon race, and balloon games. The children enjoyed the games and all participants received a prize for their efforts. Draws for two adult gift packages also took place; congratulations to the winners. The evening was a great success!

Thanks to all those who attended and assisted in making it an enjoyable summer evening. We hope to see you all at future events.

Jennifer Sokol / Kimberly Haddow

CALENDAR ❖ CALENDRIER

October / octobre

Unmanned Vehicles for Aerial, Ground, and Naval Military Operations, October 2000. Contact: Joe Templin, Tel: 613-993-2423, E-mail: joe.templin@nrc.ca, or Mike Nituch, at Telephone: 613-990-8074, E-mail: mike.nituch@nrc.ca.

Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components Symposium, October 2000, Hungary. Contact: Stewart Baillie, Tel: 613-998-3071, E-mail: stewart.baillie@nrc.ca,or Mike Nituch, Tel: 613-990-8074, E-mail: mike.nituch@nrc.ca.

Preliminary Announcement and Call for Papers for Applied Vehicle Technology (AVT) Symposium, "Unmanned Vehicles (UV) for Aerial, Ground and Naval Military Operations", 9-13 October, 2000, Ankara, Turkey. Contact: Prof. Dr. Roland Decuypere, Royal Military Academy, Department of Mechanics (MAPP), 20 Renaissance Avenue, B1000 Brussels, Belgium. Tel: ++322-7376550, Fax: ++322-7376550, E-mail: roland.decuypere@mapp.rma.ac.be.

Forest 2000 - The Sixth International Congress and Exhibition on Forests, 23-26 October, 2000, Porto Seguro Convention Center, Porto Seguro, Bahia, Brazil, held by BIOSFERA - The Brazilian Institute for the Environment. Program includes technical, scientific, political, economic, social and cultural aspects of forests and the environment, with special attention to matters of protection and conservation of the Amazon rainforest. For more information, visit their home page http://www.biosfera.com.br/forest_2000.htm or send a blank e-mail to biosfera@biosfera.com.br .

AIAA & Aviation Week Space Business Conference and Expo, Doubletree Hotel, San Jose, CA, 30 October - 1 November 2000, Contact: Beth Eddy, Exhibit Sales Director, Tel: (800) 240-7645, Fax: (561) 750-7270, E-mail: beth_eddy@mcgraw-hill.com

November / novembre

Fourteenth International Conference and Workshops on Applied Geologic Remote Sensing, 6 - 8 November 2000, held at the Alexis Park Resort in Las Vegas, Nevada. Geologic Remote Sensing and Digital Integration of Information. Contact: Marilyn Dehring, tel: 1-734-994-1200, ext. 3350, fax: 1-734-994-5123, or E-mail: dehring@erim-int.com. http://www.erim-int.com/CONF/conf.html.

11th CASI Conference on Astronautics, "Canada in Space – Opportunities and Challenges", 7-9 November 2000, to be held at the Crowne Plaza Hotel, Ottawa, Ontario, Canada.

IX Latin American Symposium on Remote Sensing, Puerto Iguazú, Misiones Argentina, 6-10 November 2000. Contact: SELPER-ARGENTINA, Universidad Nacional de Laján, Ruta 5 y 7 : (6700) Laján, Buenos Aires, Argentina. Tel: +54 2323 423979, int. 248 y 225. Fax: +54-2323 425795. E-mail: proditel@mail.unlu.edu.ar,Website: webs.demasiado.com/proditel.

Airshow China 2000, 3rd China International Aviation and Aerospace Exhibition, 6-12 November, 2000, Zhuhai, China. Contact: Kelly Knight, Project Manager, Kallman Worldwide Canada, Tel: 604-857-1392, Fax: 604-857-1394, E-mail: Kellyk@kallman.com.

2001

March / mars

26th Annual FAA Commercial Aviation Forecast Conference, March 13-14, 2001, Washington, D.C. Convention Center. Contact: helen.kish@faa.gov , Tel: 202-267-9943, or Website: http://api.hq.faa.gov/apo_home.htm .

May / mai

The Military Technical College, Cairo, Egypt, is organizing the Ninth International Conference on Aerospace Sciences & Aviation Technology, ASAT-9, May 8-10, 2001. This Conference is sponsored by the Egyptian Ministry of Defense. There will be scientific sessions, separate exhibition and seminars devoted to the presentation of latest achievements in aerospace applications. Call for papers - typing instructions: Invitation/registration. Contact: Dr. Galal Rabie, by e-mail at: asat@afmic.gov.eg .

June / juin

Digital Earth 2001 Call for Papers - The Digital Earth Program Cttee invites the submission abstracts for presentations at the International Conference to be held in New Brunswick, Canada, June 24-28, 2001. Submission deadline is December 1, 2000. see details, or Contact: David Finley, Program Chair, e-mail : programchair@digitalearth.ca Tel: 1-506-444-4644, Fax: 1-506-453-3898, or visit their Web site at www.digitalearth.ca .

EMS Technologies Wins $6 Million Contract to Redesign Search & Rescue Satellite Payload

Contract with Canada's Department of National Defence To Extend Until Early 2003

MONTREAL, Sept. 5 /CNW/ - EMS Technologies (NASDAQ - ELMG) has won a firm fixed-price contract from Canada's Department of National Defence valued at more than $6 million (C$9 million) to redesign the Search & Rescue Satellite Aided Tracking (SARSAT) radio-frequency payload. The SARSAT payload is a radio repeater that flies aboard meteorological satellites and receives distress signals from Emergency Locator Transmitters (ELT) on downed aircraft, from Emergency Position-Indicating Radio Beacons on board ships, and from Personal Locator Beacons carried by hikers and campers.

The SAR repeaters currently in service have played a major role in saving more than ten thousand lives in over 3,000 separate SAR incidents over the last fifteen years. The distress signals, once received by the repeater, are returned to earth via one or more of the 35 Local User Terminals operated by search and rescue authorities in 20 countries.

Don Osborne, vice-president and general manager of EMS Technologies' Space & Technology Group in Montreal, commented, "EMS's satellite repeater experience dates back to the Alouette satellite forty years ago. As the technologies have changed, we have consistently been able to remain at the forefront of satellite innovation and development. I am pleased that our technologies have played such an important part in so many lives that could otherwise have been lost."

EMS Technologies designed and manufactured the six repeaters currently in service on board orbiting satellites. The re-design of this equipment is required to match various operational parameters of the new platform. For example, the current frequencies of 121.5 MHz and 243 MHz will be phased out in the future. The 406 MHz frequency, also currently in use, will remain as the principal distress frequency.

The current contract includes the system concept study, the repeater concept, and detailed designs and qualification model manufacturing and testing. Flight repeaters, due for launch in 2008, are not covered by this contract. This contract runs until early 2003.

About EMS Technologies, Inc.

EMS Technologies, Inc. is a leading innovator in the design and manufacture of space and terrestrial wireless solutions, focusing its unique range of advanced technologies on the needs of broadband and mobile information users. The company is headquartered in Atlanta, employs 1,600 people worldwide, and has major manufacturing facilities in Atlanta, Ottawa and Montreal. For more information, visit the company on the World Wide Web at:
http://www.ems-t.com/www.ems-t
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