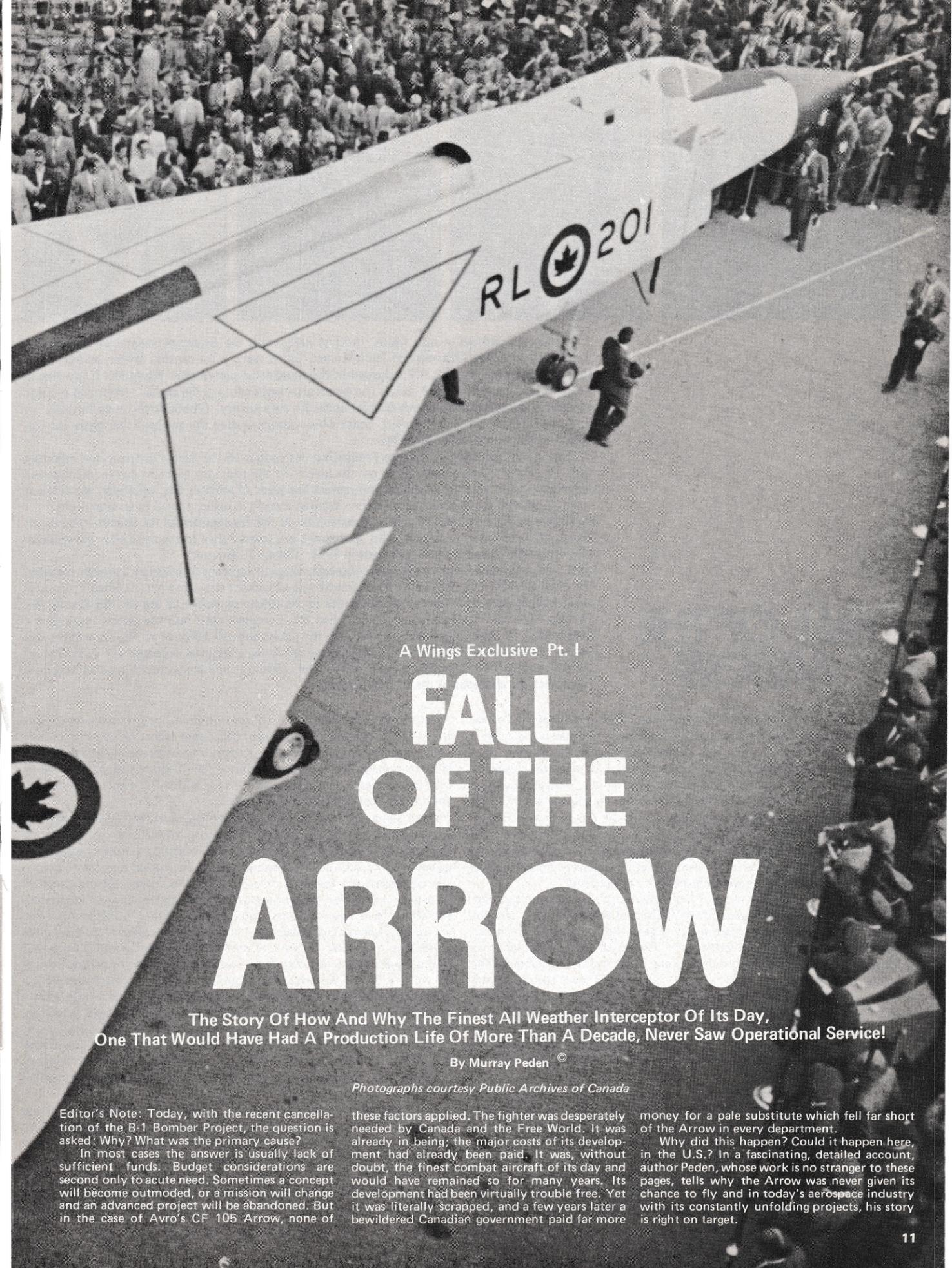


Twelve hundred sq. ft. area of Avro's Arrow dwarfs crowd on her roll out 21 years ago on October 4, 1957. Thirty-four ton machine was a wonderful piece of engineering and mated with the powerful Orenda Iroquois engine, it is probable that later models would still be in service today, had it been put into production. Like the Arrow, Iroquois engine was also a revolutionary design and would have given the Arrow a top speed in excess of 2,000 mph, a magnificent accomplishment for the day, surpassed only by the Lockheed SR 71.



A Wings Exclusive Pt. I

FALL OF THE ARROW

The Story Of How And Why The Finest All Weather Interceptor Of Its Day, One That Would Have Had A Production Life Of More Than A Decade, Never Saw Operational Service!

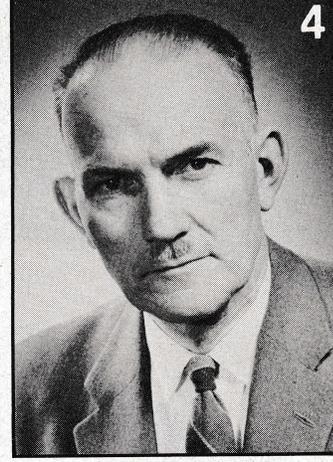
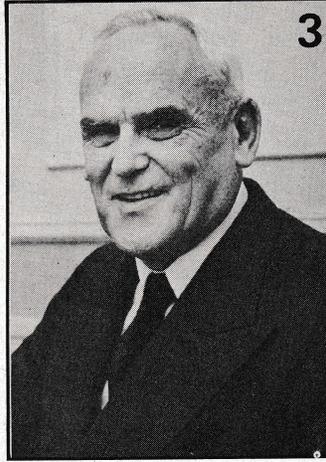
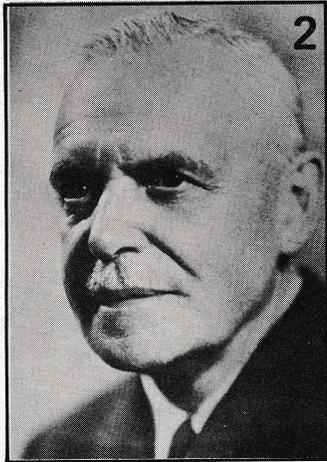
By Murray Peden ©

Photographs courtesy Public Archives of Canada

Editor's Note: Today, with the recent cancellation of the B-1 Bomber Project, the question is asked: Why? What was the primary cause? In most cases the answer is usually lack of sufficient funds. Budget considerations are second only to acute need. Sometimes a concept will become outmoded, or a mission will change and an advanced project will be abandoned. But in the case of Avro's CF 105 Arrow, none of

these factors applied. The fighter was desperately needed by Canada and the Free World. It was already in being; the major costs of its development had already been paid. It was, without doubt, the finest combat aircraft of its day and would have remained so for many years. Its development had been virtually trouble free. Yet it was literally scrapped, and a few years later a bewildered Canadian government paid far more

money for a pale substitute which fell far short of the Arrow in every department. Why did this happen? Could it happen here, in the U.S.? In a fascinating, detailed account, author Peden, whose work is no stranger to these pages, tells why the Arrow was never given its chance to fly and in today's aerospace industry with its constantly unfolding projects, his story is right on target.



FALL OF THE ARROW

Just three days before the 50th anniversary of powered flight in Canada the Prime Minister rose in the House of Commons in Ottawa and made a statement the effect of which was to dash the struggling Canadian military aircraft and engine industry from its proud position as temporary leader of the western world — perhaps the whole world — and relegate it, almost instantly, to the industrial minor leagues. When Prime Minister John George Diefenbaker announced the cancellation of the CF-105 Arrow on Friday, February 20th, 1959, he demolished in one brutally final stroke what another Member of Parliament publicly categorized as “the greatest single achievement in Canadian aviation history, and the greatest combined effort of design and development ever undertaken in this country”.

That member went on to say: “Not only that, I regret that this government did not have the courage to finish (Arrow) No. 6 and let it take the world’s speed record away from the Lockheed 104. I think this is a matter which will cause regret to Canadians for decades to come — that when we had reached a stage where, in a few weeks of additional development and testing, this plane could have captured the world’s speed record for this country, the decision should have been made not only to stop work on the plane but to cut up the corpse and put it underground as soon as possible.”

These strong comments came from a political opponent; but many Conservatives in the House, and scores of thousands more across the country, shared Liberal Paul Hellyer’s indignation. The Arrow affair cut sharply across party lines.

John Diefenbaker had become Prime Minister through the interplay of the usual mix of political forces, coupled with an exhibition of tenacity, showmanship and ability on his own part. But able as he undoubtedly was in many ways, John Diefenbaker showed marked weakness and vacillation in the formulation and implementation of National Defense policy, and in the related aspects of foreign policy. His government’s strangely skewed assessment of the Arrow situation, which seemed at times to reflect personality clashes and a studied hostility to the project more than the objectivity

1. Air Marshal Wilfred Austin Curtis, (left) standing with the Governor-General of Canada, His Excellency Viscount Alexander of Tunis, center. Curtis was a most capable officer, an apt choice for the moderniser the R.C.A.F. required in the transitional period after World War II. He died in Toronto on August 7th, 1977, only a few weeks after responding to the author’s letter and offering to assist in the preparation of this account of the Arrow’s history. (Public Archives of Canada).

2. Prime Minister Louis St. Laurent, under whose administration the go-ahead was given for production of the Arrow and its new engine.

3. C.D. Howe, Minister of Defense Production. He supported the Arrow program, but admitted that the cost of development, “gave me shudders!” In the end, cost overruns due to inflation and indecision would cost the Canadian government hundreds of millions but, ironically, the cost not to go ahead with production of a marvelous weapon already in being, proved to be even more.

4. Charles A. Grinyer, who figured so prominently in the development of the Orenda Iroquois, an engine 20 years ahead of its time. This photograph was taken only a few months after the cancellation of the Arrow and Iroquois programs in 1958. (Charles A. Grinyer).

5&6. Canada’s first homegrown fighter; conceived, designed, built and powered by Canadian industry, the Avro CF-100, was the world’s first straight-winged combat aircraft to exceed Mach 1, and provided builder Avro with invaluable experience in the follow on design of the CF-105 Arrow. All-weather “Canuck” interceptor served with first line European units into the sixties, more than a decade after its initial flight and, in doing so, the power and reliability of its Orenda engines also became noteworthy. This winning combination of Avro, a business acronym for A.V. Roe of Canada, and its Orenda engines subsidiary was soon attested to and the partnership could now look forward to the challenge of the CF-105 project.

it purported to be founded upon, set in train a flood of criticism. In due course it also precipitated a series of dependent events which were to cause serious and worsening political problems, ultimately resulting in the fall of the government. The self-destruction of the Diefenbaker administration over the non-issue of nuclear warheads for BOMARC missiles was directly linked to the cancellation of the Arrow.

Like some nightmarish reversal of the standard Horatio Alger story, a reversal in which the climax saw multiplying misfortunes cascading upon the hero, the demise of the CF-105 Arrow produced a series of scenes that taxed credulity, even among the government’s staunchest supporters. Having just completed the spending of over 340 million dollars of the Canadian taxpayers’ money for the purpose of designing and building an interceptor aircraft to have a performance unsurpassed anywhere in the world — and having been spectacularly successful in producing an aircraft carrying those prestigious credentials — here was the Prime Minister cancelling the 6-year long program at the very moment it was about to reach fruition, seemingly not fully realizing what would shortly ensue. The February 20th cancellation announcement caused the discharge that very afternoon of approximately 14,000 skilled employees at the A.V. Roe Canada Limited’s plants in Malton, and the abrupt cessation of work for an estimated 15,000 other skilled tradesmen employed by the 2500 subcontractors and suppliers linked with A.V. Roe on this great project. Many of those subcontractors and suppliers, firms that had expanded to handle Avro Aircraft Ltd.’s growing requirements, were soon petitioned into bankruptcy.

As if that were not enough to have to answer for, the Minister of Defense Production, Raymond O’Hurley, had to rise in his place on April 22nd, to correct a misstatement he had inadvertently made the previous day and acknowledge that five almost fully completed Arrow aircraft were in fact being dismembered by workmen with acetylene torches at that very moment. And although he announced that “the five *finished* craft have not been touched” the fact was that the government’s incredible ineptitude in

this phase of the affair was going to see those other five machines as well, superb aircraft in flying condition, torched into small pieces of industrial excreta in readiness for their consignment to a place of honor in a Hamilton junkyard.

This appalling act of vandalism, perpetrated on five finished and flyable aircraft that the Prime Minister had indicated were costing the taxpayers approximately \$12,500,000.00 each, was regarded by many as exceeding in callousness the government's brutality in causing the immediate dismissal of all the workmen.

It would have taken Shakespearean tragedy itself to outdo the protracted demise of the CF-105 Arrow for over-all emotional impact, for, superimposed on the consciousness of everyone watching this painful affair was the gnawing uncertainty injected by the repetitively insistent tone of Sputnik 1's beeper. That harbinger of revolutionary change had first startled the world on October 4th, 1957 – ironically, the very day on which the first completed Arrow had been towed in triumph from its hangar at Malton for a "roll-out" ceremony as a prelude to its impending ground trials.

The rapid advance of Russian space technology generally, and particularly the unexpectedly rapid strides in missile capability demonstrated by Sputnik's launching, was destined to be one of the several factors that sealed the fate of Canada's most advanced military aircraft, leaving Canada, after Prime Minister Diefenbaker threw in the towel, to join the many nations wholly dependent upon the United States for research, design and development in the aircraft industry.

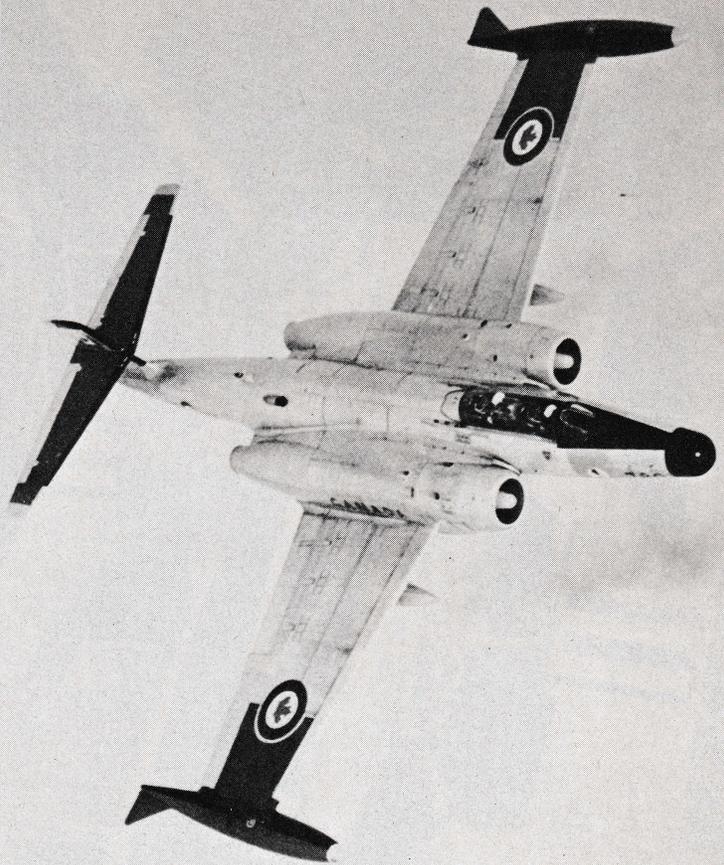
II

After World War II, the R.C.A.F. was engaged in a search for a new fighter capable of performing the somewhat specialized role required of an interceptor operating over the vast and sparsely populated areas of Canada. Tactical factors militated in favor of an aircraft of considerable range, preferably a twin-engined all-weather aircraft carrying both a pilot and a navigator-radar operator. Air Marshal W.A. Curtis was authorized to lead a team of R.C.A.F. specialists given the assignment of checking with aircraft manufacturers all over North America and the United Kingdom to see whether any fighter with the specifications they had in mind was nearing production, or even on the drawing board. Neither in the United States nor Britain was such an aircraft to be found. Therefore, Air Marshal Curtis recommended that an aircraft designed to meet the specifications compiled by the R.C.A.F. be built in Canada.

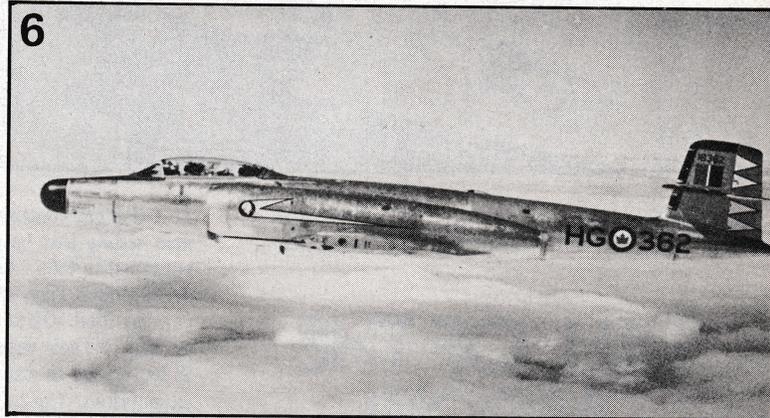
From bitter experience in World War II he had learned what happened when a country was dependent upon other countries for its weapons. R.C.A.F. squadrons had frequently been in the unenviable position of having to accept second-grade aeroplanes that had become surplus to American or British requirements. Thus Canadian fighter squadrons had been flying anemic Curtiss P-36 Mohawks and P-40s when better aircraft were urgently required for first line service, and were in fact being used by the countries building them. No. 6 Group, the R.C.A.F. Group in R.A.F. Bomber Command, still had a number of squadrons flying Halifaxes at the end of the war despite the fact that the Lancaster was a better aircraft, and the more pertinent fact that Canadian factories had built some 400 Lancasters under license by that time. But those aircraft had not been under the allocational control of the Canadian government. The lesson was abundantly clear: if a government expected to be able to funnel first line planes to its own squadrons, from the first years' production runs available, it had to build them itself.

Of even more importance to a country, from a long-term point of view, was the fact that by designing and building its own aircraft it automatically acquired two concomitant benefits of great value: Firstly, it got aircraft tailored specifically to its own needs in the combat role it chose to assume. Secondly, it acquired and retained the skilled work force, the technological expertise, and the sophisticated testing facilities that enabled it to keep pace with, or outdistance, its competitors or potential enemies. Building, under license, aircraft that had been designed, tested, modified and brought into production elsewhere, is not a remotely comparable substitute. There is a critically important time factor involved in copying another country's designs. In the aircraft industry an elapsed time of six years between first drawings and first production run is probably close to the norm. So a country content to copy another's production aircraft is soon many years behind in design and testing technology. Thus the short-term "bargain" seemingly obtained by the avoidance of research and development costs, is frequently the path to more and more economic and technological depen-

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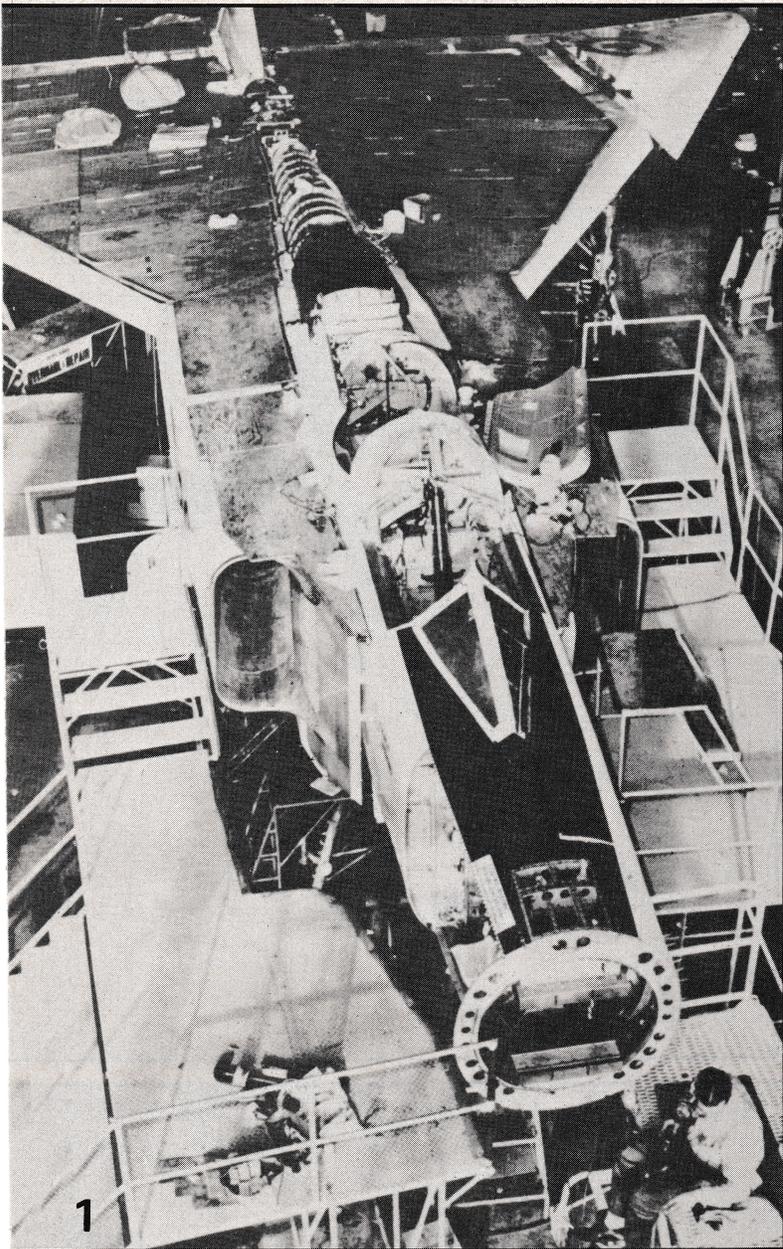


6



dence. This was certainly not the path most thinking Canadians wanted to tread, Canada being a country which from its birth had rejected the status of "hewers of wood and drawers of water". Air Marshal Curtis' group were well aware of all the factors involved, and any recommendation W.A. Curtis made merited careful consideration. Air Marshal Wilfred Austin Curtis was a Canadian who had served his country well. In World War I, as a young man of 23, he had transferred from the Canadian Army to the Royal Naval Air Service in 1916. As a fighter pilot he had then won the status of "Ace", with 13 victories to his credit; and during 1917 and 1918 he won the Distinguished Service Cross twice, together with several Mentions in Despatches, before being wounded and sent home.

In 1947 Air Marshal Curtis was named Chief of Air Staff, in which capacity his first act, typically, was to launch a thoroughgoing modernization program in the R.C.A.F., one aspect of which was this search for a new fighter. The recommendation of Air Marshal Curtis and his team was acted



upon in due course, with the result that the highly successful CF-100 was designed and built in the A.V. Roe Canada Limited plants at Malton, near Toronto. This Company was a holding company (which later went public) organized by Sir Roy Dobson at the behest of, and controlled by, the British Hawker-Siddeley Group. The operating subsidiaries directly concerned were Avro Aircraft Ltd. and Orenda Engine Ltd.. The companies' CF-100 was widely recognized as a first class airplane, and in fact proved so successful in its all-weather interceptor role that some \$50,000,000.00 worth were purchased by Belgium for the discharge of its newly assumed N.A.T.O. responsibilities.

In 1951, bearing in mind the lengthy period between design and production, the R.C.A.F. began looking ahead again to the new airplane that would succeed the CF-100, and serious studies were initiated. Again highly ambitious and distinctive requirements were suggested, and ultimately embodied in the R.C.A.F.'s "Final Report of the All-Weather Interceptor Requirements Team" which was delivered in March, 1952, to Avro Aircraft. (Another canvass of aircraft factories in all the N.A.T.O. countries, particularly the American plants, had indicated that no aircraft with similar performance requirements was even being planned elsewhere.)

The new Canadian interceptor sought was to be a twin-engined, long-range, all-weather machine, capable of high speeds to enable it to catch the bombers which it was anticipated would be in the Soviet inventory by the late 50s and early 60s. It would be a two-place airplane like the CF-100, but it would be supersonic; and it was to carry a highly sophisticated fire control and weapons system, of which the most promising type then appeared to be the American Hughes MX-1179, complemented by six Falcon missiles.

Discussions with A.V. Roe were carried on in 1952, and in 1953 the Liberal government of Prime Minister Louis St. Laurent made the momentous decision to proceed with the development of the radically new design and the production of two prototypes. The initial appropriation approved was for \$30,000,000. Unit cost on a production run was roughly estimated, on the assumption that five hundred or six hundred aircraft would be needed by the R.C.A.F. The unit cost derived on the basis of those ball park figures appeared to be one and a half million or two million dollars per aircraft. (The CF-100, Mark V, was then being turned out at \$750,000.00 per unit.)

C.D. Howe, Minister of Defense Production, made the uncharacteristic statement: "... we have started on a program of development that gives me the shudders, a supersonic plane and a supersonic engine ... Before we get through it will be around \$100 million. That is a program no other country has carried through successfully as yet." He was talking about development cost alone, of course, when he spoke of a total of \$100 million. Obviously if he visualized the production of 600 aircraft at a cost of \$2 million each, he was prepared to spend an additional \$1.2 billion of the taxpayers' money, over and above any unamortized portion of the \$100 million development cost. The total outlay would be spread over many years; nevertheless C.D. Howe had the jitters, and C.D. Howe was not

FALL OF THE ARROW

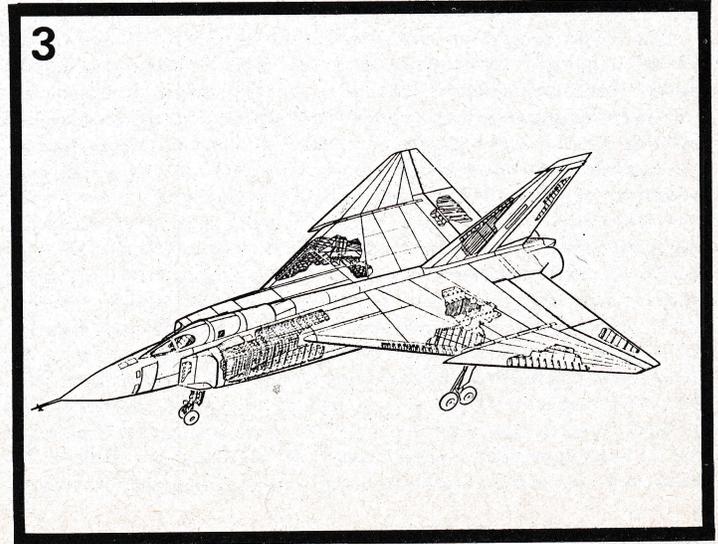
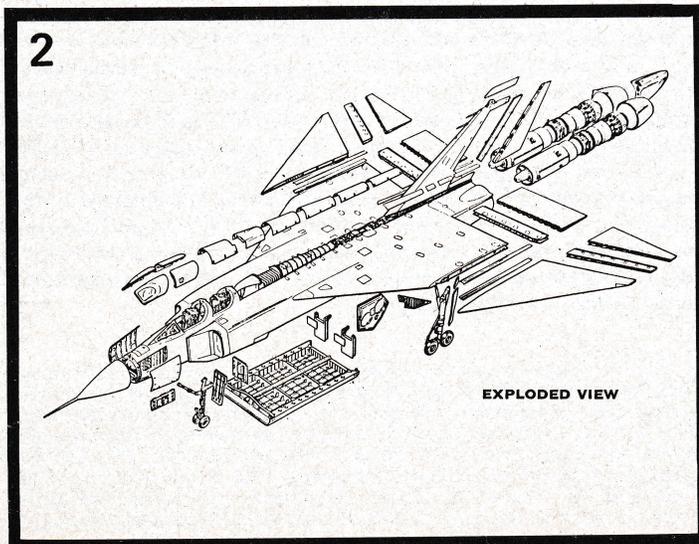
1. The great venture into supersonic aircraft design gets underway on the production line. Workman sitting just below the nose affords comparison for judging size of the Arrow. Cockpit was equipped to take a Martin-Baker C.5 ejection seat. Preliminary design was completed in 1954.
2. Exploded view of CF-105. Operational Arrows would have weighed nearly 40 tons with full combat load. Delta shape allowed for thin wing section without large weight penalty. Engines, ducting and rear fuselage were suspended from inner wing.
3. Irony was to dominate Arrow's history. The aircraft and its powerplants all performed beyond expectation. The bulk of the development costs had already been spent and the aircraft was ready for large scale production when it was cancelled. Ironically, after the cancellation, Canada spent millions of dollars on decidedly inferior McDonnell F-101 Voodoos.
4. Arrow's first public appearance at Malton hangars, October 4, 1957. Originally, 105 was to have been powered by a pair of Rolls Royce RB-106 engines, but early in 1954 Rolls abandoned the project. Avro's subsidiary, Orenda, was then designing a large supersonic engine as a private venture which could be tailored to the Arrow, but would not be ready for installation in the first few aircraft. As a consequence, Curtiss Wright's J67 was substituted, but when work on that engine was also cancelled, Pratt & Whitney's J75 was utilized as a replacement. Even with this rather makeshift arrangement, the Arrow reached 1000 mph in a climb at 50,000 ft. With a pair of Orenda Iroquois engines developing a combined thrust over 50,000 lbs s.t. a potential of Mach 2.5 would have not only been possible, but routinely achieved.
5. Size of CF-105 is obvious in roll out photo. In addition to phenomenal performance, Arrow was to have incorporated the new R.C.A. Astra missile guidance system and Sparrow II missiles, the latest and most advanced in the world. Unfortunately, both projects were abandoned by the U.S. developers and the advanced Sparrow missile was not produced until the advent of the Grumman F-14 Tomcat, some 15 years later.

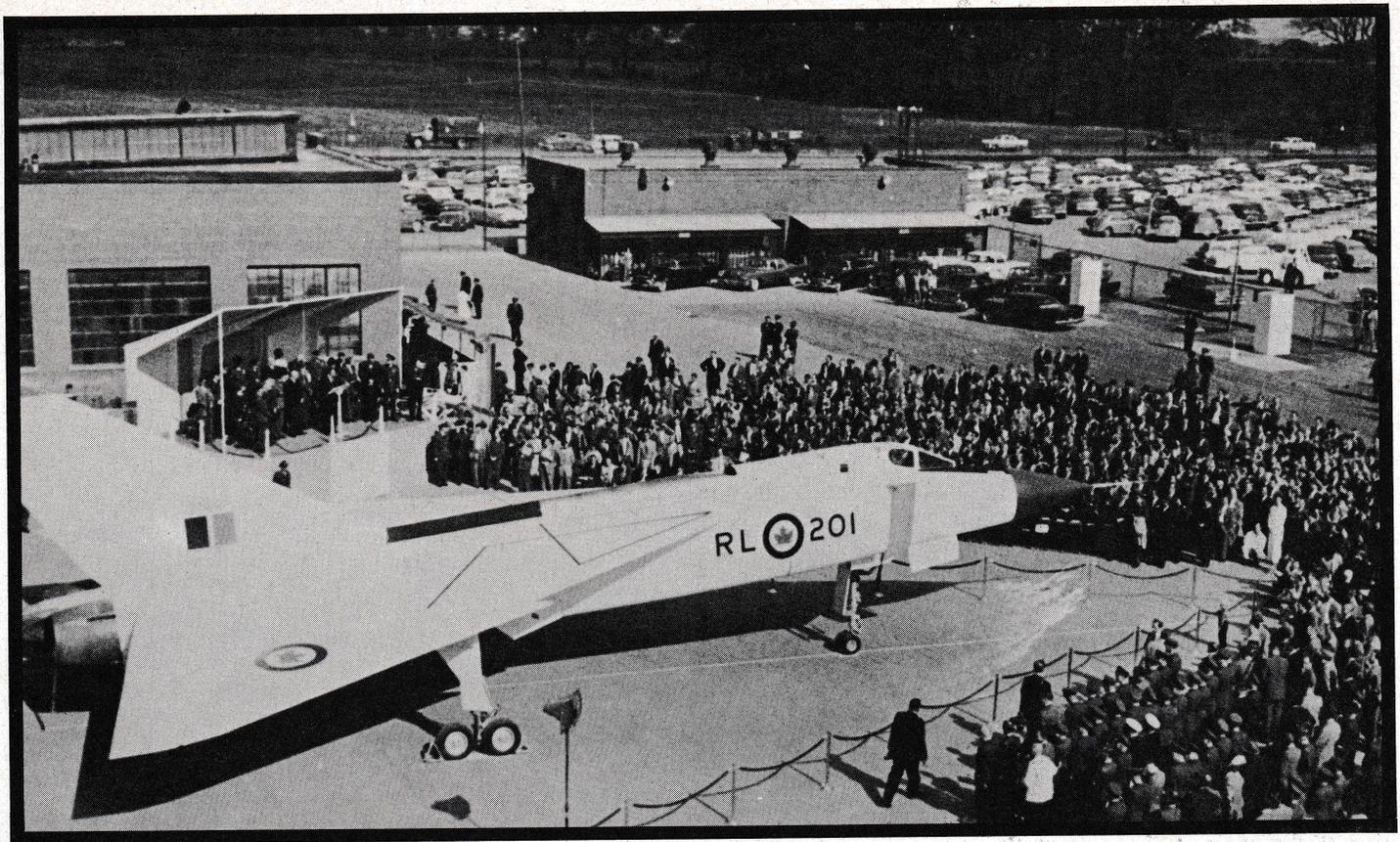


known as a man of frugal habits where spending in the grand manner could be justified. Avro Aircraft Ltd. ignored the reports of his belated timidity and self-doubts and set about the task in hand.

The new interceptor, styled the CF-105 Arrow, was to be a tailless, (i.e. lacking horizontal stabilizers) high Delta wing aircraft, this decision on the configuration flowing from an analysis of weight and efficiency factors. To James C. Floyd, the aero-dynamics engineer carrying over-all responsibility for the design, the Delta wing promised the lightest wing for a low thickness/chord ratio while still providing, due to its large root chord, satisfactory thickness for fuel and undercarriage stowage. A wing area of 1200 square feet was settled on, representing in the design team's view the optimum compromise between minimum weight and maximum performance. High wing placement promised the lowest weight coupled with the easiest access to engines, armament and electronic gear.

From July, 1953 until July, 1954, a great deal of preliminary design work was carried out establishing loads, basic aerodynamic parameters and dimensions. Of these multitudinous tests and experiments the public heard next to nothing, of course, either while they were being carried out or later.





Above: Arrow No. 1 poses for her admirers. Among the dignitaries on the platform at the left were the Minister of National Defence, George Peakes, V.C., and the Chief of Air Staff, Air Marshal Hugh Campbell. Note the R.C.A.F. band seated in the foreground.

Right: Arrow featured a small anhedral (droop) of four degrees, designed to reduce the length of the landing gear. Leading edge notch on Delta wing shows up well. Interior of thin wing was converted into a series of six fuel cells, a so-called "wet wing" in which all electrical and hydraulic components were immersed in fuel.

The magnitude of the enterprise was never broadly understood. The contracts with the company were modified — actually, replaced with a series of separate contracts. Now several Mark I "prototypes" were planned, then a Mark II series, the latter to include a further number of test aircraft before authorization was given for the final production run.

For the Mark I Arrow three power plants had been considered: The Rolls Royce RB-106, the Bristol B.O.L.4, and the Curtiss-Wright J-67. All three units were equipped with afterburners, but all three were also in the early development stage and had not yet run. The engine finally selected was the Rolls Royce RB-106; but in 1954 Rolls Royce decided to abandon its development. The decision was then made to switch to the Curtiss-Wright J-67 for the first prototypes of the CF-105 Arrow and to turn to the design of a new and more powerful engine — to be developed in the Orenda plant — for later models of the aircraft.

The Arrow project, so much more ambitious than the work on the CF-100, required a substantial enlargement of Avro's design and support teams. Exotic techniques not required in the construction of subsonic aircraft were demanded by the new problems of supersonic flight, so specialists with the requisite skills had to be recruited. E.J. Silling, an English mechanical engineer, might be taken as representative. He had had several years experience in aircraft design, prefaced by a stint during World War II as an R.A.F. technical instructor, before starting his design career on the Canberra, the world's second jet bomber.¹ After emigrating to Canada he worked on the CF-100, then transferred to the Arrow team. Asked about the formation of that group, Silling responded: "The design team was composed of Englishmen, Canadians, Poles and Americans. The Englishmen were in the majority, as Avro had just completed their third annual recruiting drive through the British Isles. Canadians were local men, mostly in administrative positions. The Poles were recruited in Britain, and the Americans (were) contract workers, hired by Avro from a broker. The most outstanding Englishman was an absolute wizard on aerodynamics. A Cambridge don, I believe. The Poles were very good — mostly key men from the Polish aircraft industry.

1. The German Arado 234 B Blitz has a legitimate claim to being the first.

The most outstanding Pole was a mathematician whose capabilities in those days of slide rules and simple adding machines just bordered on sorcery. Among the Americans, one produced mind-boggling designs of sophisticated hydraulic components. Another worked on the drag chute, producing in the process several innovations patented by Avro . . . The head of the Arrow design team was an Englishman named Frost.² From the outset sights were set very high. At every staff meeting held to discuss some problem or decision, the opening phrase was: "This has never been attempted before. But sometime in the future it will be done. Let us do it now".

Preliminary wind tunnel work had been carried out prior to mid-1954 when the first production drawings were completed and passed to manufacturing. At this point the complex aerodynamics of supersonic flight required intensive wind tunnel work. The American N.A.S.A. made available some of its extensive facilities, free of charge. An assortment of additional problems and deadlines accompanied the R.C.A.F.'s decision to switch from the proven Hughes fire control system and to design and install instead a completely new weapons and fire control system of even more advanced specifications. The new system, called "ASTRA" was to be developed in Canada by R.C.A., Honeywell Controls, and Computing Devices of Canada.

A.V. Roe Ltd. argued against this switch, which was going to produce a limited improvement in weapons system efficiency at a potentially heavy financial cost. The R.C.A.F. and its directorate of Armament Engineering were adamant; not only were they switching to ASTRA as the weapons and fire control system, they were switching to a new and undeveloped missile as well — the Sparrow II.

2. John Frost was one of Avro's many innovative designers. In 1951 he had embarked upon the design and development of a flying saucer, after having studied their aerodynamic efficiency for a lengthy period. He eventually built a flying model at Avro, but encountered seemingly insurmountable control problems every time he got the craft airborne. The Canadian government gave up and withdrew its backing after spending approximately \$2,000,000.00. The United States government persevered, and backed Frost's project to the tune of \$10,000,000.00; but eventually shelved it, the control problem not having been satisfactorily mastered.



III

If the Canadian public were seldom adequately informed by newsmen of the remarkable accomplishments of their aircraft industry in designing and building the supersonic Arrow, they were told even less about the complementary achievement of Orenda Engine Ltd. in designing and building the Iroquois engine. True, trade publications carried accurate articles on the progress of this magnificent power plant; but by and large the daily newspapers and the commentators missed the significance of Orenda's great success. Certainly they missed most of the hundred and one minor technological triumphs that would have given their readers, listeners and viewers some benchmarks upon which to formulate a proper appraisal. This untypical myopia could not be blamed on the tight security maintained on certain critical performance data. The trade papers, including the Company's own "Avro Canada News" and "Orenda" published a wealth of material through which the magnitude of the developments were reasonably obvious to anyone who wished to look.

By contrast, Canadian newsmen had been at pains as recently as 1953 to make the public aware that Orenda-built engines had been highly successful when installed in the American designed — but Canadair-built — Sabre jets being flown by the R.C.A.F. Similarly, when the R.C.A.F. moved on to the Orenda-powered CF-100s, the excellent performance of both engine and aircraft were widely reported. In the development of the P.S. 13 Iroquois engine, Canada's newsmen had at hand a gold-plated Canadian success story; yet few of them gave it more than passing mention. The story certainly seemed to warrant ample coverage. Here was a newly-formed

Canadian company not only competing with the American "Big Three" in gas turbines — Pratt & Whitney, General Electric, and Curtiss-Wright — but competing so successfully as to have one of the Big Three come to Orenda in due course to negotiate a contract for the rights to build this remarkable engine under license in the United States.

Every literate adult in Canada knew the vital part played in World War II by the famous Rolls Royce aero-engines, particularly the great Merlins that powered the Spitfire, the Hurricane, the P-51 Mustang, and thousands of Lancasters. But it is doubtful that more than a handful of Canadians ever came to realize that Canada's Orenda Iroquois marked a greater advance over its predecessors and competitors than the Merlin engine had over its immediate progenitors. The full story of the Iroquois' development, detailing the skill and determination displayed in the conquest of its early technical problems, would require a book in itself. Here, a thumbnail sketch must suffice.

In 1951 and 1952, Orenda had tried unsuccessfully to interest the R.C.A.F. in the development of a new jet engine, this time one with approximately 12,000 pounds thrust.³ The failure of these efforts, and the prospective development by American engine manufacturers of power plants that would be reasonably comparable, persuaded Orenda's management that they would have to embark upon a much more ambitious project

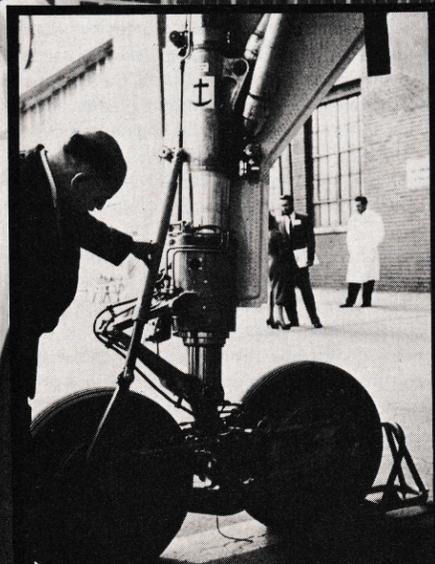
3. The Canadair-built F-86 Sabres, styled the CL-13B Mk 6, were powered with the Orenda 14, which had no afterburner and delivered a maximum thrust of 7600 pounds.

FALL OF THE ARROW

Below: Looking very much like the giant Arrow it was, CF-105 stands ready prior to flight testing. Pilot's cockpit was 14 1/2 ft over the runway, with radar officer behind him. Undercarriage track was approximately 25 1/2 feet wide. Engine intakes are closed off by removeable plugs and inboard landing gear doors hang down from inner well in this photo.

Bottom Left: The size and complexity of the main undercarriage of the Arrow are suggested in this photo. The undercarriage members were designed and built by Dowty of Canada Ltd., the tires and brakes by Goodyear. (Air and Space Division, National Museum, Ottawa).

Right: The fixed geometry inlet ramp of the Arrow is clearly shown here. The chisel-edged style of the 12 degree intake ramp is apparent, as are the perforations on its face, the latter comprising a form of boundary layer bleed.



in order to be competitive after the lengthy development period, particularly against the "Big Three".

Orenda's answer was Project Study 13 (P.S. 13) which it was thought would ensure the necessary lead over the competition if it could be brought off. The concept involved a radical increase in power and a marked improvement in the critical thrust-to-weight ratio. A key figure in this substantial undertaking was Charles A. Grinyer.

Charles Grinyer joined the A.V. Roe complex in Canada in April, 1952. His earlier career had included a stint in England with the Bristol Aeroplane Company Ltd. where he had figured in the development of the Olympus and Phoebus jet engines as well as various prop-turbines. Prior to that phase he had spent ten years with the British Air Ministry, where his work had involved him in the early development of jet engine test procedures. He had not been long in Canada before his ability prompted his promotion, first to Chief Engineer, G/T (Gas Turbines), and subsequently to Vice-President Engineering and Chief Engineer at Orenda Engine Ltd. Upon his arrival in Canada, he was quickly involved in the many problems spawned by P.S. 13.

The development of a new jet engine is an extremely costly enterprise,

a high risk venture made doubly uncertain by the tightly limited market available and by the vagaries of defense policy. Nowadays it would be virtually unheard of for a company to tackle such a project without government underwriting. In 1952 no such underwriting was available from the Canadian government, at least not until a company had demonstrated the practicability of its proposal by building a prototype that could display the performance predicted. When P.S. 13 began, it was strictly a private venture, financed by private capital. Obviously the Hawker-Siddeley Group could not rush into such a venture until the proposed design had been given close and sceptical scrutiny. Winning the authorization of the Hawker-Siddeley Group's Design Council took Orenda's designers two full days of debate, starting October 14th, 1953. Orenda's engineers were proposing to break much new ground. In their bold design they had dispensed with the normal centre structure in a two-spool lightweight concept, the two rotors and shafts having no centre bearings. Furthermore, except for their shafts the two compressors were to be constructed entirely of titanium, effecting a great weight saving.

The members of the Design Council focused most of their criticism on the two bearing shaft arrangement and the absence of the centre structure. However they allowed their criticism to be overborne by the manifest advantages of weight reduction, low cost and reliability. Early in December, 1953, authority was given to commit \$300,000 for the purchase of three ingots of titanium (such ingots having lengthy delivery times). On January 13th, 1954, Orenda was given the authorization it needed: Proceed with the detailed design and manufacture of three engines. Thus P.S. 13 was finally launched, as a private venture, with an initial limit of \$3,500,000.

Orenda's earlier design, rejected by the R.C.A.F., had aimed at producing an engine capable of 12,000 pounds thrust. P.S. 13 had the rather breathtaking objective of developing an engine with an air mass flow of 300 pounds per second, producing 20,000 pounds of dry thrust — 25,000 pounds with afterburner augmentation.

By utilizing various shortcuts it was hoped to have an engine on test in twelve months. This called for some highly efficient organization, and for such expedients as farming out the production of a supply of afterburners. Also, since the engine control system requirements were new and would require further time for adequate contract negotiations, the company decided to manufacture only "slave" controls for the first tests. Once it could demonstrate the basic engine, the company hoped to procure a government contract; but there were a great many hurdles to overcome before that aspiration could be realized.

Predictably, having set themselves such lofty targets, Orenda's engineers were not long in encountering problems, many of them stemming from the exploratory nature of much of the work. The problem of hydrogen embrittlement — another manifestation of which we shall shortly be examining — presented itself at an early stage. The three titanium ingots originally purchased were found to have a hydrogen content of over one hundred parts in a million. A method of reducing this to a maximum of twenty parts in a million had to be devised. Lab experimentation showed that it could be done using a vacuum furnace at moderate temperature. Although the only one readily available to Orenda Engine Ltd. was of a very limited capacity (35 pounds), it provided the means by which the job was eventually done.

A memorable milestone was achieved in December, 1954. On December 5th the first P.S. 13 was delivered to test; and at 4:24 p.m. on the 19th of December, after the requisite preliminary checks had been made, flared into life and ran on its own power.

Charles Grinyer describes the discouraging developments that first took place:

"At about 6,000 rpm a bad vibration band set in which it was impossible to run through. Both rotors were affected and so the remainder of the test was given to starting and running below the troubled band. This was a bad blow to our morale, as the results were quite contrary to our rig test results. In the end we chose to believe the rig tests and to look for some other explanation. Therefore, a very careful examination during the strip of the engine disclosed that oil had gained access to the high pressure compressor drum. This had occurred during the oil checks to the bearings. It left us with the puzzle as to why both rotors vibrated, and we were not to find the answer to this until some time later. Testing then followed a more or less routine pattern. This disclosed further troubles associated with titanium. First, the compressor blades began to seize in the slots of the titanium discs, and this was eventually overcome by silver plating the blade roots. The second fault was much more serious in that the titanium would catch fire from frictional rubs.

FALL OF THE ARROW

"It had been hoped and expected that the Canadian Government would place a contract after the demonstration run; and although this had been marred by the vibration trouble, it had been explained very quickly, and subsequent engine runs showed the oil had been the cause. Still, it was not before about mid-June, 1955, that such a contract was placed — by which time the cost of the project to the Company had risen to \$8,500,000."

Under the terms of the contract the company was awarded approximately one-third of the costs incurred to that date. A further third was to be paid when the engine passed certain special milestone tests. This left Orenda with about one-third of its money in the project, for which it retained the right to sell the manufacturing rights on the engine outside Canada. It was shortly after the signing of the agreement that the name Iroquois was selected for the engine.

Starting in June, 1956, preliminary flight rating tests (P.F.R.T.'s) were run on the Iroquois, firstly with a Lucas fuel system and later with a Bendix. In each case the engine successfully passed a 50 hour P.F.R.T. at a rating of 16,000 pounds dry thrust, in other words, 80% of full designed power. Shortly after the Bendix test in September, 1956, Orenda lost one of the engines in a fire caused by the ignition of the titanium in the high pressure compressor. The first fire — there were several fires, and more than one engine lost before the engine was perfected — was the result of a blade failure, the piece becoming trapped and then "wiped" by the remaining blades. As Mr. Grinyer explains: "Because titanium is such a poor bearing material and a poor conductor of heat, this caused the material to heat up to the point of incandescence, and the air pressure blew a hole in the compressor casing. Then a torch effect occurred setting the whole engine on fire. Water failed to control the blaze, and we had to develop a powder method of fire control".

Having discovered by costly experience that titanium had its limitations for use in aero-engines, Grinyer's team decided to remove titanium from the stator rings and to substitute steel for titanium in the high compressor casing. This switch to steel carried a weight penalty of about 300 pounds, but over-all weight savings had been so substantial that this minor backsliding did not cause inordinate agonizing. A further modification was required to deal with the vibration problem. Tests had disclosed that if one shaft vibrated, the vibration was transferred to the other. By rig test the engineers discovered that this phenomenon could be avoided if the bearings were mounted in the same plane. With the bearing of the inner shaft directly below the bearing of the outer shaft any coupling effect between the shafts was avoided. Once the necessary modifications had been conceived and installed, testing proceeded with great success. In April, 1957, a test was run at 18,000 pounds dry thrust, and before the end of the year a 20,000 pound dry thrust test had been run. Orenda Engine Ltd. had proved its point, the Iroquois having achieved the tremendous full dry thrust performance called for by its ambitious designers. Of course much additional work remained to be done, much air testing, refinement and polishing.

The company had made arrangements, through the R.C.A.F., for the loan of a B-47 from the United States Air Force for the flight testing of the Iroquois. In preparation for the flight testing, which was to be carried out by an R.C.A.F. crew, R.C.A.F. personnel took conversion training on a B-47 at a Strategic Air Command base in the United States. The American Air Force was keenly interested in the potential of the Iroquois engine, hence in the early stages of P.S. 13 a close liaison had developed between the U.S.A.F. and the Orenda team. The Assistant Secretary of the Air Force and various members of his staff frequently met with the Orenda group; and it was as a direct result of the excellent rapport developed that extensive wind tunnel test facilities and the B-47 aircraft had been made available to Orenda, free of charge. In Canada the B-47 was modified by Canadair to carry the Iroquois engine. The great new power plant was to be carried in a special pod under the right tailplane of the aircraft — a distinct departure from the normal nose or under-the-fuselage installations frequently employed for flying test-beds. When the aircraft was rolled out of Canadair's workshops at Cartierville, Quebec, its newly trained crew were quickly given

some graphic demonstrations of the tremendous potential of the Iroquois.

In the following weeks over 125 hours of air flight testing was carried out, supplementing the thousands of hours of ground running, and the Iroquois tested to the full altitude limits of the six-jet-engine B-47. Perhaps the simplest way to drive home the achievement of the Orenda designers is to point out that the single Iroquois engine mounted on the B-47 could deliver more than the total thrust of four of the B-47's jets. The B-47 was not a supersonic aircraft, and was limited both in its forward speed and its altitude. An Iroquois with a limited rating of only 16,000 pounds dry thrust was more than sufficient for the B-47; and in fact, once airborne with the Iroquois started, it was necessary for the crew to throttle the normal J-47 engines right back to idling when the Iroquois was developing 16,000 pounds dry thrust. Meanwhile, afterburner tests had been carried out, with rigs, both at Marquart in California, and at Malton. Once complete engine and afterburner controls had been secured from subcontractors, the full rating tests were carried out with engine and afterburner, about mid-1958. The Official Type Test, the passing of which would in effect constitute the R.C.A.F.'s final acceptance of the power plant, was scheduled for February, 1959. Although there were no problems of any great magnitude manifesting themselves by the fall of 1958, Charles Grinyer suggested in September that the Type Test be deferred until August, 1959, to ensure that there would be no slip-up. He specified that certain work had to be completed to ensure the success of the Type Test. When he said that he would be ready to run the Type Test by August, 1959, he was fully satisfied that there would be no problem. In previous years he had sent ten different engines to Type Test, and without fail, all had received approval.

To understand what designers have to face, however, it should be pointed out that the Type Test was a lengthy and expensive process. Since it was the official way of approving an engine, it was controlled by the R.C.A.F. for all military applications. The term itself had come from the early British aero-engine days, and was carried over into the jet-engine era. The Type Test contemplated the following:

A particular engine would have to be built for the test. All parts would be checked against production drawings, checked both as to dimensions and part numbers. As Charles Grinyer explains it:

The test itself commences with a performance curve, and a given number of accelerations. The endurance part consists of 15 Ten-Hour periods, some of which cannot be run without a ten-hour interval, while others must have less than two hours between them. Total accelerations must exceed 100. No stop is permitted in the period, without the penalty of re-running that period. The thrust levels vary in the periods, and very complete records are taken.

"The test is completed by another performance curve. It is not usual to expect approval if the performance has decreased by more than 3%. Only limited service is permitted, and this has to be specified before the test starts. The engine is stripped down and parts examined for wear or failure. Dimensional checks are again made, and the parts again checked to the drawings. The Test is thought to represent about 400 hours of military flying."

With Mr. Grinyer's 100% batting average, his vast experience, and his habit of cautious understatement, it is not surprising that no one ever suggested that the Iroquois would not have passed its Type Test with flying colors.

For the sake of continuity and coherence we have followed the account of the development of the Iroquois engine to its final stages — at which point that development had entailed the expenditure of \$87,000,000 and untold hours of effort and testing. The development of the Arrow airframe itself was equally arduous, equally replete with problems, and equally studded with technological triumphs of varying degree. But we must return to the point where only the general parameters of design had been determined.

The general configuration of the Arrow having been determined by the design specialists and confirmed through intensive wind tunnel tests, it became the task of the production engineers and draftsmen to translate the designers' bold conception into an actual airframe that would perform within the extremely demanding parameters designated as objectives. Item: A wing so thin that it seemed structurally impossible with existing materials. Item: An airframe that would function efficiently in an outside ground level temperature range running from -65°F to +165°F. Item: An aircraft upon which all routine maintenance operations could be performed quickly and easily, the objective being the ability to change an engine in less than thirty minutes — without hand tools or lifting tackle.

FALL OF THE ARROW

So demanding were the general dimensional and structural limits that the CF-105 Arrow seemed at the outset an incongruent assemblage of acute problems — problems moreover that would yield only to incompatible solutions. Again, a description of all the challenges to be surmounted would require a separate book. A few representative examples will serve to suggest the host of others that accompanied them:

Due to the magnitude of the forces involved in supersonic flying, it was essential that all flying controls be power driven. But hydraulic jacks of the conventional design were too thick to fit into the thin wing. Existing jacks of small enough diameter did not provide sufficient force with the accepted standard hydraulic pressures. Going to higher pressures would entail a long series of prohibitively expensive changes. The solution ultimately hit upon seemed to be to design exceptionally long, thin jacks with two or more compartments having pistons in tandem. But on the test bench the jacks bulged between the compartments, the outside boundaries being rigidly held by the diaphragms separating the compartments. To borrow one of E.J. Silling's apt descriptions: "It was like trying string around a sausage." The cure was to fashion stronger materials and change cylinder wall thickness. But even this required a difficult balancing of objectives, since thicker walls meant either increased external diameter — which would infringe upon precious space — or decreased internal diameter which would reduce piston area and lead to insufficient power. Only after lengthy experimentation was the right balance struck.

Linkages for the controls also proved difficult to design. The exceptionally thin wing imported a lack of space which prevented the structural engineers from making cross-sectional areas big enough to provide the necessary strength. Once again custom-built improved materials provided the answer. The engineers took the tensile strength of steel alloys and heat treatments to the ultimate limits available at that time, complementing the research and experimentation being done in the use of titanium. The latter metal was utilized not only for jet-engine blades — where A.V. Roe's process was so advanced that it eventually sold some \$2,000,000.00 worth to U.S. engine manufacturers — but for certain critical areas of the airframe as well. The extremely thin wing virtually precluded the sacrifice of further space for tanks, at least of the conventional type; so the interior of each wing was itself converted into a series of six integral fuel enclosures. Two rubber cell-type tanks in the fuselage completed the fuel stowage on the Mark 1, although on the projected Mark 2 provision was made for one external drop tank of 500 Imperial gallons, and the projected Mark 2A and Mark 3 were to be fitted with an additional internal tank to increase the range. The integral tank arrangement meant that within the "wet wing" all the electrical and hydraulic components were immersed in fuel, and this imported a host of sealing problems that had to be overcome. The flexing of the wing in flight posed further difficulties, causing leaks; but here the answer — when they discovered it — was to purchase from an American firm the rights to a process of injecting sealant along channels in the wing joints.

The drag parachute attachment which the Arrow, a "hot" aircraft, required during landings, was found to put inordinately heavy loads on the structure. These had to be provided for by modification. The related problem of designing a release mechanism of limited size for the chute took a considerable time to resolve. To prevent galling, it was essential to have an extraordinarily hard metal surface on this device. The trigger mechanism and release control designs both posed novel problems as well. All the many challenges were met, often with highly ingenious responses, with the result that Avro ultimately took out a substantial number of patents on the new processes and designs involved.

The stipulation regarding easy engine maintenance spawned its own difficulties. These new engineering obstacles were addressed, and mastered, by having each engine clamped to rails. After removing the engine cowling, a trolley could be run up against the engine nacelle. The trolley had matching rails; thus, after releasing the self-sealing fuel lines and engine controls, by hand, the engine could be released and run out onto the trolley.

The supersonic configuration imported its own complex problem: flying stability had to be sacrificed. This meant that continual attitude corrections had to be made during flight. The essential automatic flight corrections were initiated through a long nose boom carrying the pitot and static tubes well out of the way of shock waves. This long boom was also fitted with small sensor vanes to control pitch, roll and yaw. The sensors operated magnetic switches that sent signals to a "black box" stability augmentation system built by Minneapolis Honeywell, which in turn operated the hydraulic valves on the control jacks whenever the aircraft attitude changed slightly in flight. Thus the necessary corrections were made even during maneuvers. Nevertheless, even when the theoretical answers had been produced, the engineers encountered new problems stemming from the almost continuous flexing and vibrating of the boom. Again much experimentation with titanium provided the answer. The Minneapolis Honeywell "black box" was to function flawlessly in time; but early in the flight test program it was to provide one stunning surprise. Meanwhile there were other engineering barriers to circumvent.

At the supersonic speeds contemplated for the Arrow, it was essential that a minutely gauged response be obtained from the flight controls. To provide the most accurate response, signals to the hydraulic control valves were provided by strain gauges which measured the minute movements of the control column under the pressure applied by the pilot. The power-operated from the pilot's controls; therefore the pilot had no "feel" available for judging the very substantial loads imposed on the airframe. Artificial "feel" was fed into the pilot's controls by a device containing springs, dampers, and weights, which read G loads during maneuvers. A complete emergency control system operating the control valves also had to be fashioned.

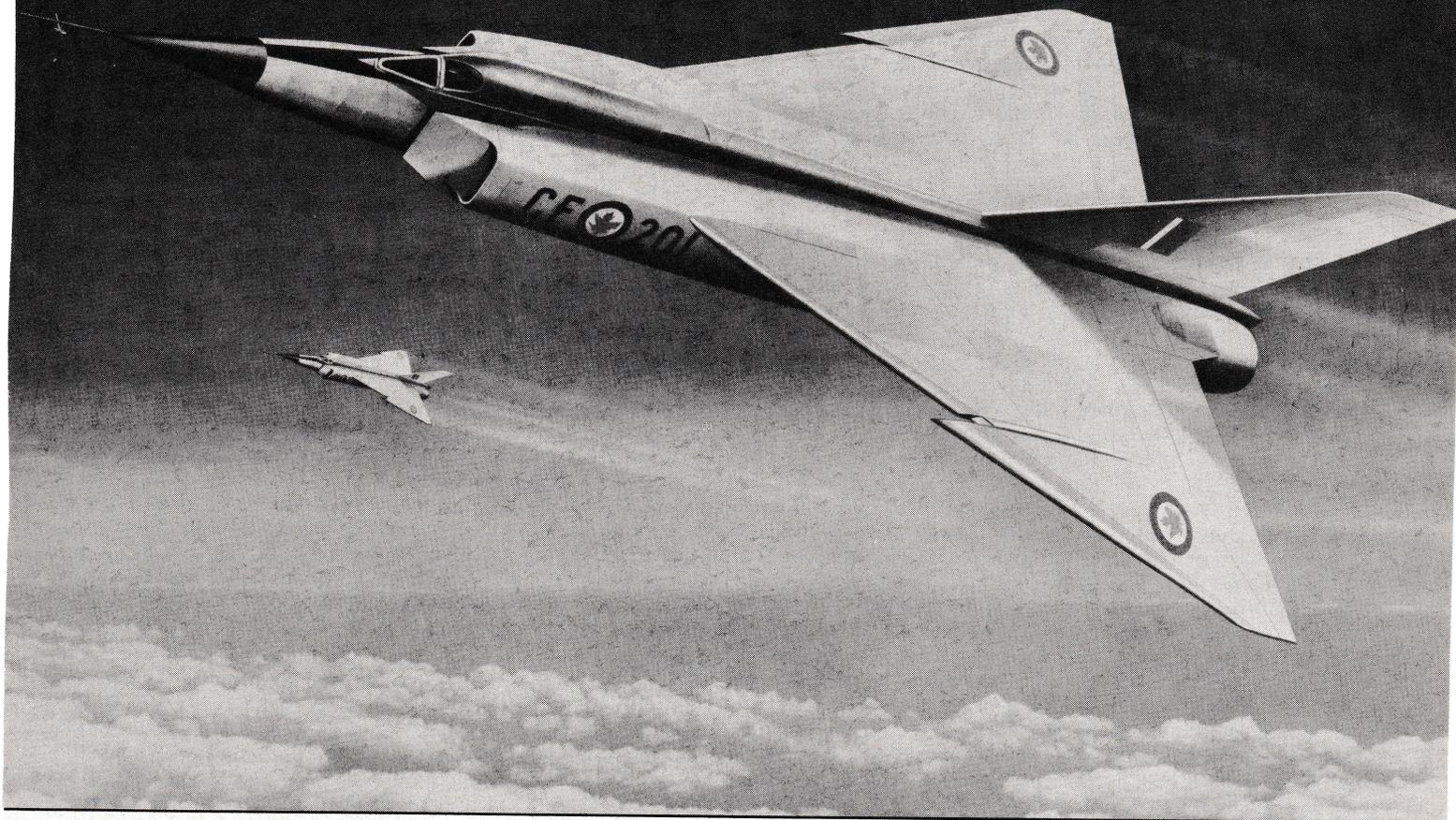
Another challenging feature was a device whose objective was to keep control surface movement proportional to flying speed. For example, full operation of the rudder pedal might move the rudder through an arc of 15° at taxiing speeds or while landing. At supersonic speeds, the same pedal movement would move the control surface only 1°, giving the same in-flight response. This was done by measuring airspeed with an electronic device which in turn operated a motor that varied the control linkage.

Fashioning the undercarriage for the new aircraft raised yet other questions of technique, and carried the crews to new levels of expense in that field. To the layman an aircraft's landing gear is a mundane item. This is definitely not so to the pilot, dependent upon its proper functioning for a safe return to earth. And to the engineer required to design and manufacture the necessary undercarriage, it can present — as it did with the Arrow — a whole range of specialized problems. In the Arrow's case these flowed from weight limitation, from extra stress associated with higher landing speeds, and from the fact that the thin wing afforded no stowage and the body only a limited amount.

Harry Ralph, presently a consulting engineer in Kirkland, Washington, joined A.V. Roe in September, 1953, then moved to Dowty Equipment of Canada at Ajax, Ontario, a year later when that company was awarded the contract for the Arrow landing gear. In response to a query about the problems encountered in producing the gear, he pointed out that development of the ultra high tensile alloy steel which was found necessary for the relatively slender gear was an extremely expensive proposition. The ultimate strength of the material ranged from 260,000 to 280,000 pounds per square inch.

As was the case with so many other features of the aircraft, many new manufacturing techniques were found necessary to make this material a practical proposition when utilized for an aircraft landing gear. After the application of the sophisticated heat treatment applied to the alloy, it was found that a thin, hard and brittle layer (the "hydrogen embrittlement") was found to form all over the work piece. This layer had to be removed, since it created poor fatigue qualities in the part concerned. As a result, every item designed and produced from this material had to be machined approximately 95% all over prior to heat treatment, and then machined 100% all over again in order to get rid of the hydrogen embrittlement layer. One needs no technical background to appreciate the extra difficulty — and the radically increased cost — of producing each part twice, in effect, with only the final machining bringing the component down to the specified

4. The 650 mph Boeing B-47 carried 6 General Electric J-47-GE-25 engines, each capable of 5970 lbs (max.) thrust, and turning out 4478 lbs each at the 75% cruise setting. The afterburner thrust of a fully rated Iroquois (25,000 lbs) actually exceeded the cumulative maximum thrust of four J-47s by more than 1100 lbs.

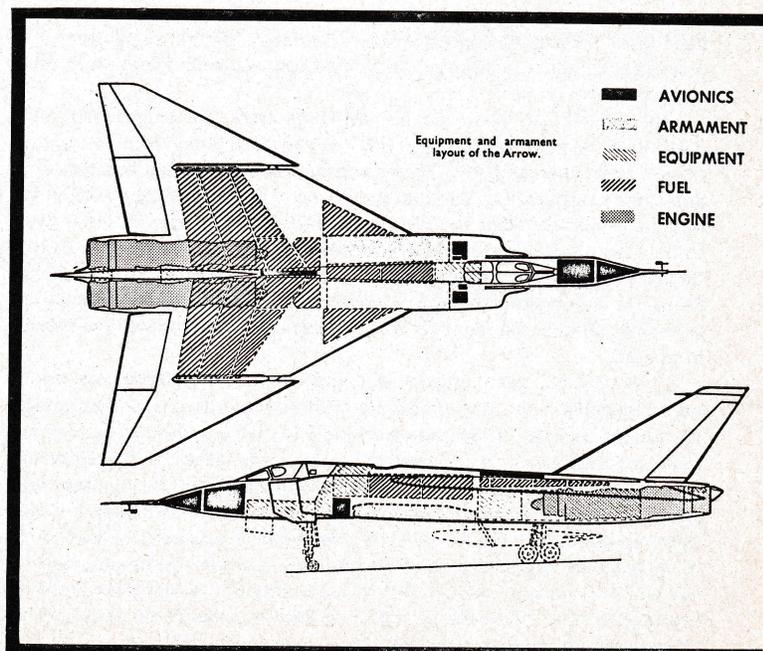


Above: Artist's conception of the CF-105 in flight shows how apt the name "Arrow" was. Aircraft responded beautifully to controls. The nose lifted off at 120 knots and the aircraft began to fly at 170. Stick forces were light and touchdown was usually accomplished at 165 knots, with the drag parachute being allowed to deploy and stream when the nosewheel had settled. Below: Breakdown of Arrow's systems. Note that fuel is carried completely in the wing, with mid section of fuselage acting as a weapons bay, the avionics ahead of it.

tolerance, after application of a preliminary machining and a sophisticated heat treatment.

Work on other parts of the aircraft ran into comparable obstacles. The tremendous ground level outside heat range (-65°F to +165°F) within which the aircraft had to function efficiently produced bizarre effects on ball bearings, for example. E.J. Silling has provided a full description: Ball bearings pressed into cranks at ambient temperatures simply fell out at +165°F. If the bearings were pressed in at the high temperature limit, they jammed solidly at -65°F. The engineers found, after considerable experimentation, that if the bearings were made to extremely close limits they could be made to work. But then no bearing manufacturer would even attempt to produce bearings to the tolerances demanded. Eventually the company persuaded one manufacturer to provide suitable bearings by way of "selective assembly". This too was extremely costly, but it worked. By selecting balls which were dead on the minus tolerance size, then installing them only in ball races which had come out exactly on the plus tolerance limit, the assemblies could be made to function efficiently over the whole temperature range. One more problem was laid to rest.

Similar difficulties were faced with control cables. When the airframe was cold, the slack control wire hung in festoons. When a test airframe approached the upper temperature limit, the heat pulled the wires so tight that pulley brackets collapsed and fittings were torn loose. The solution for this problem was found to be self-adjusting cable quadrants. Although these were already in existence, many of them had to be substantially modified to fit in tight places.



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Perhaps even this microscopic sampling of the multitudinous problems encountered will serve to suggest the heavy technological demands made upon the design and fabricating teams. It may serve as well to hint at the ingenuity, industry, and general talent of the highly skilled work force that had been mustered to implement the R.C.A.F.'s vision of its new aerial weapon.

V

In 1953 Air Marshal Curtis, now sixty years of age, retired from the R.C.A.F., and promptly began a new career as Vice-President of A.V. Roe Canada Ltd. As Vice-President of A.V. Roe his principal concern in 1953 and 1954 was to oversee, while wearing a different hat, the whole Arrow project, the program to which much of his energy had ultimately been directed as the R.C.A.F.'s Chief of Air Staff.

While work was progressing during 1954 it was learned that the Russians had developed a jet bomber, and that they had exploded a nuclear bomb. This latter accomplishment the Russians thus demonstrated several years earlier than had been anticipated in the west, thanks to some diligent spying and the assistance of traitors. The threat against which the Arrow had been pointed seemed to be developing exactly as anticipated, except for the speed of the Russians' progress, which lent a further spur to the strenuous efforts being made at Avro.

While the Arrow had been progressing to the point where production drawings were being channeled along to the manufacturing section, the government had been moving to shore up the aircraft's financial prospects, already so worrisome to C.D. Howe. Ralph Campney, Minister of Defence in the administration of Prime Minister Louis St. Laurent, journeyed to Washington to speak to his counterpart there and ascertain whether the Americans would be interested in purchasing the Arrow, assuming the finished machine met its highly impressive projected specifications. The American government officials gave warm encouragement to the production of this seemingly remarkable machine — but no firm commitment to buy. Nevertheless, the Canadian government took considerable comfort from this moral support.

Mention has already been made of the setbacks that occurred in 1955 with the U.S.A.F. abandoning development of the Curtiss-Wright J-67 engine, after the abandonment by Rolls Royce of the powerplant that had been first choice for the Mark 1 Arrow. Ultimately the Pratt & Whitney J-75 was selected, and A.V. Roe's management could turn its attention to other problem areas.

The R.C.A.F.'s insistence on switching from the Hughes MX-1179 weapons system to the new ASTRA had carried the day with the government despite the company's strong recommendation to the contrary. The Sparrow II missiles that were to complement the new system were in the early development stage in Douglas Aircraft plants in the U.S. They were to be adapted in Canada to their role with the ASTRA-equipped Arrow by Canadair Limited and Douglas Aircraft, working from the basic U.S. design. Primarily the Canadian companies were to concentrate their efforts on the guidance and fire and flight control systems — at least that was the original intention.

The R.C.A.F.'s seeming desire to go first class in every respect was readily understandable — in fact, on purely military grounds it was undoubtedly the proper decision. They were working on what promised to be the most advanced interceptor in the western world — why take the Hughes system with Falcon Missiles when the ASTRA with Sparrow IIs promised more efficiency and hence maximum utilization of the superlative weapons platform represented by the Arrow? The government's acquiescence was harder to understand, on purely practical grounds, because the development of the ASTRA and the Sparrow II held high potential for complex problems and soaring cost. And here, according to Carl V. Lindow, the government's officers did an uncharacteristically inefficient job in their negotiating and

writing of specifications. Lindow, who was one of Avro's senior engineers (now retained as a consultant by Boeing) is critical in describing this phase:

"It was Armament Engineering, also specifying the ASTRA electronic system, that was to cause the cost of the weapons system to escalate and put it in jeopardy even if the government had not changed. These features, the Sparrow II missile with its guidance and the ASTRA advanced electronics had a very significant contribution to the cost of the system. There were other missiles and other electronic systems that could be procured more or less off the shelf which would have been highly satisfactory and about 95% as effective.

"In particular, the ASTRA system contract won by R.C.A. was ill-conceived in that the initial contract statement of work definition asked for only about 10% of the work that was ultimately required to develop the system. The system specified would have been by far the highest performing system in the world with a 1 megawatt peak power magnetron — capable of automatically flying the airplane onto its target, (with) ground mapping capability, data link and every other facility imaginable. R.C.A. performed technically in an excellent manner, but perhaps could have furnished more information on what the ultimate cost was going to be. When it was realized that the ultimate cost of developing the ASTRA Fire Control System was going to be between 100 and 200 million dollars the program was cancelled and the Hughes . . . radar fire control system adopted along with the Hughes (Falcon) missiles which was what we at Avro had advocated at the outset. These decisions resulted in a very small degradation of the weapons system capability — with a very large saving of cost."

One of the first points that had to be considered by those responsible for the new aircraft's weapons system was the sharply reduced reaction time that advances in aviation had imported. Thus, the armament staff had carried out careful studies of the needs of an aircraft weapons system that would work in the early warning and ground control defense system. As Air Vice Marshal Easton points out: "With aircraft closing speeds approaching Mach 4 plus, and both aircraft supersonic, . . . the time left to detect, get to the attack position, and deliver the attack without losing any opportunity, becomes very small. If you limit yourself to pursuit only, then penetration of the defense area becomes excessive and allows the attacker to optimize his defense against you — such as countermeasures ECM, retro-firing weapons, etc. Consequently, if nuclear weapons are being delivered by the attacker, you would be considered less than prudent if you did not optimize your defense weapons system. In addition to what has been said, the best chance of destruction of the enemy's nuclear weapon is the use of nuclear warheads in your airborne defensive weapons . . ."

Reviewing the state of the art at that time, A.V.M. Easton went on to mention that "Sperry, Collins had automatic flight and landing systems in use, as did some others, such as PYE of the U.K. and R.C.A. in the United States. Also, inertial navigation systems were reaching a high state of development, with some systems in use. Map reading capability in radars had been in use for some time, e.g., bombing radars. In fact, the CF-105 had all these features. The Sparrow missiles were in U.S. Navy use and the Sparrow II was in an advanced stage of development; it had the range and control and warhead capabilities that were necessary, and fire control was no problem — having been in use for some years. The MX-1179 and Falcon missiles were good, but short in three areas. The power of the radar was insufficient in our estimation to meet the range and countermeasure requirements, and the missile (fell short) in range, countermeasure and payload for the period 1958 onward, against the type of threat to be expected."

"We put all our requirements together and approached the Hughes Aircraft Co., who had done such a good job for us on the MG2 system in the CF-100, to see if they would be interested in taking on development of system. The outcome of the meetings spread over three days in Culver City, California, was that it was MX-1179 and Falcon or they were really not interested. However, other companies were approached, such as R.C.A., Westinghouse, Minneapolis Honeywell, Sperry, G.E. Ltd., and Emerson. These companies had been building radars and fire control systems for both U.S.A.F. and U.S.N. These companies were interested, and put forward proposals to integrate the fire control and flight control systems. The higher powered magnetron was generally accepted as necessary to get the added range and greater security in the face of ECM (electronic countermeasures). As a result of the various proposals, the ASTRA program was called up."

Reviewing the comments of Carl Lindow and A.V.M. Easton, each an

(Text continued on page 59)

5. The main design team of Avro's earlier and highly successful CF-100 had been the team of J.C. Floyd, Bob Lindley, Jim Chamberlin and Carl V. Lindow.

and headrest created uncomfortable eddies at the back of their heads, especially in the wintertime. This was cured in the PA-7 by creating a large sloping pane windshield — sometimes described as the sexiest windshield ever seen on any airplane — and raising the entire fuselage structure aft of the cockpit. In addition, a high volume cockpit heater was installed.

Almost three dozen PA-7s were built at Bryn Athyn before a disastrous fire consumed most of the frame structure and reduced seven Super Mailwings on the production line to twisted, charred skeletons. Pitcairn Aircraft, Inc. then moved into a new 80,000 square foot factory building at Pitcairn Field No. 2, to which all of the Pitcairn Aviation (fixed base) operations had been located about ten miles north of Bryn Athyn and went back to producing PA-7s. As a historical note, "Pitcairn Field No. 2" is now the Naval Air Station, Willow Grove, Pa. and several of the Pitcairn buildings, including the factory, still are in daily use.

In 1929 Harold Pitcairn's career took a new turn. For many years he had been interested in rotary wing flight — he held helicopter patents dating back to 1924 — and he became associated with the Spanish genius Juan de la Cierva, inventor of the Autogiro, to further the development of rotary wing flight. Pitcairn sold his air mail line, including the bases he had built at Richmond, Spartanburg, Greensboro, Atlanta and Miami to Clement M. Keys and the Curtiss-Keys group, retaining only the factory and Pitcairn Field No. 2, together with a few of his top engineers and flight associates. Within months, the name of Pitcairn Aviation, Inc., was changed to Eastern Air Transport, Inc. (as emblazoned on the sides of the Mailwing on display at the National Air and Space Museum): in 1934 the airline's name was changed to Eastern Air Lines, Inc. by which it is known today.

The sale of the air mail line did not stop the production of the Mailwings by Pitcairn Aircraft. In 1930 its factory personnel proudly wheeled out the PA-8, the biggest Mailwing of them all. A full-chested performer behind its 300 hp Wright R-375 radial,

the "Big Eight" incorporated improvements developed from the cumulative experience of air mail operators with millions of miles of flying and was expected to sell well to all mail carriers. Unfortunately, the passage of the Air Mail Act of 1930 — which provided that thereafter air mail subsidy payments would be computed, not on the actual loads carried, but on the assumption that every cubic foot of payload capacity was filled with seven pounds of mail — meant that air line operations of large, multi-engine cabin model aircraft would be profitable. Although some air carriers continued to use Mailwings as late as 1935, the Act of 1930 was the death warrant for any market for new, single engine, open cockpit, biplane air mail planes. Eastern ordered only six PA-8s and no one else was interested. In 1931 Pitcairn ordered the line closed down so that Pitcairn Aviation, Inc. could concentrate on rotary wing flight. It was the end of the Mailwing line.

A handful of Pitcairn Mailwings still exist and a mere three or four are actually in flying condition. Leading the flight across the ceiling of the National Air and Space Museum is the original PA-5 Mailwing — the first one ever built — beautifully and lovingly restored by Joseph F. Toth, a retired Eastern Air Line Captain, but it will never fly again, except in the hearts of its beholders. A similar PA-5, also restored to original condition and wearing the black and yellow livery of Pitcairn Aviation and Eastern Air Transport regularly graces the skies above Shannon Airport, Fredericksburg, Va., under the sure hand of Chief Pilot Merton Meade, Jr. Thousands of spectators at meetings of the Experimental Aircraft Association have seen the last surviving PA-8, restored by Jack Rose of Spokane, Washington. Another PA-5, a Sport Mailwing, clad in burgundy and yellow, is frequently seen by weekend pilots in the vicinity of Philadelphia. Based at Trenton-Robbinsville Airport, it is flown by another former Eastern Air Lines pilot. His name is Stephen Pitcairn and he owns and flies the very airplane specially built more than 50 years ago for his late father, Harold F. Pitcairn.

FALL OF THE ARROW

(Text continued from page 24)

expert in his field, it is easy to understand and reconcile the small degree of divergence in their views. Carl Lindow was presumably interested primarily in getting the best possible flying machine airborne, and was critical of factors jeopardizing that objective. Air Vice-Marshal John Easton regarded it as a waste not to utilize the potential of the aircraft (weapons platform) to the full, particularly in view of the performance and weapons capabilities to be anticipated from the bomber threat. In retrospect, he parts company with Carl Lindow over the latter's belief that the difference in performance between the two weapons systems and their missiles can accurately be quantified and expressed in simple terms. He underlined the point that the Falcon missile was more vulnerable to countermeasures, and concluded:

"If the ASTRA system had been carried to completion it would have been superior to the MX-1179 in range of radar, ability to withstand electronic countermeasures, adaptability to other weapons such as Sparrow II, the British missiles, and some others with ranges which could exploit the all-round choice for opportunity of attack on the hostile aircraft. Consequently, trying to put any percentage figure on comparative effectiveness could be misleading. For example, I think that the chance of frontal attack with MX-1179 and Falcon in the environment I mentioned above would be zero."

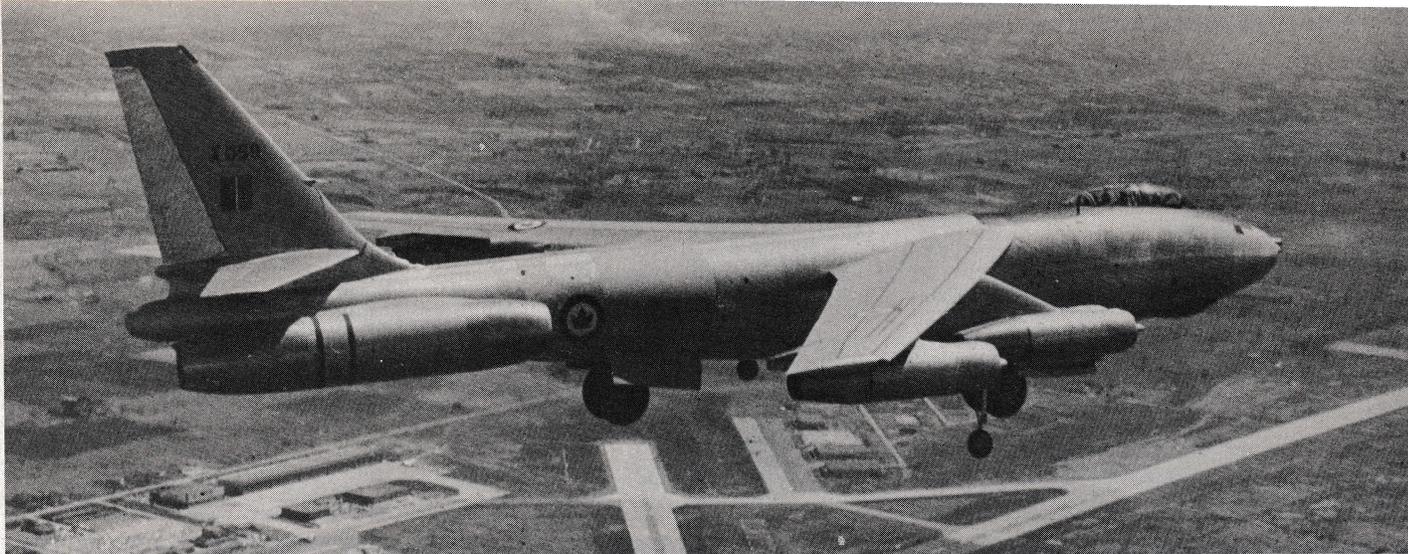
If A.V.M. Easton, and other R.C.A.F. officers consulted regarding the various phases of the development of the Arrow and its weapons system, differ with Mr. Lindow on the importance of ASTRA in the ultimate denouement, they are definitely at one with him in their refusal to pretend that they were infallible, or that even with the benefit of hindsight they cannot see where their decisions could profitably have been modified. Both sides are in agreement on the point that there were cogent reasons for the decisions they elected to make, and that, at the time, they believed those

decisions to be the best ones, all things considered. That the new missile program, i.e., involvement in the development of the Sparrow II, commended itself to the government, was rather surprising, since the government was in the process of persuading itself to cancel the "Velvet Glove" Canadian missile program that it had backed for years, and must have been fully aware of the potential costs if the parameters of the program were not rigidly controlled.

Douglas Aircraft Co., which had designed the airframe for Sparrow I, was to perform the same function for Sparrow II. Sperry Gyroscope Co. had been the prime contractor on the Sparrow I development, working in concert with Douglas and Aerojet. Over a period of approximately ten years, bringing that project to the operational level had consumed the sobering total of 4,000,000 engineering man hours. Now Douglas was embarking upon the development of Sparrow II so that it could be used for the projected naval interceptor Douglas was under contract to build, the F-5D Sky Lancer. Apart from Canadair and Douglas, the companies in Canada who were to work on adapting the Sparrow II for use with the Avro CF-105 Arrow included Avro Aircraft Ltd., Canadian Westinghouse Company Ltd., Computing Devices of Canada Ltd. and DeHavilland Aircraft of Canada.

This decision by the government to proceed with Sparrow II missile development — unless it was very sharply circumscribed — represented yet another incipient reversal in policy. In 1956 the Liberal government proceeded to terminate a most extensive program, begun in 1951. Project "Velvet Glove" had been designed to develop and bring into production in Canada a missile system upon which considerable initial research had been done by its own agency, the Canadian Armament Research and Development Establishment. A great deal of expertise had been accumulated by the Canadian firms involved, and a substantial measure of success achieved; but just before the weapon was to go into production the government of Prime Minister St. Laurent cancelled the project, flushing five years of effort and \$24,000,000.00 of the taxpayers' money down the drain. Aimed in a different direction, the Canadian missile industry was sent off again, this time engaged in the adaptation and development of Sparrow II. Unfortunately, some months later the United States government abandoned the Sparrow II, leaving the full burden of its extremely expensive development on the companies adapting it for use with ASTRA and the CF-105

(Text continued on page 62)



Boeing B-47 Stratojet on loan to Orenda to test new Iroquois engine, yet in Canadian markings. Single Iroquois was so powerful that it generated nearly 1,000 lbs additional thrust over and above power output of B-47's four G.E. J 47s, so much so that they had to be throttled back to idle while Iroquois was operating. (Peter M. Bowers)

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Arrow — in effect the Canadian government. Despite the diligence of A.V. Roe's management, headed by its President and General Manager, Crawford Gordon, and notwithstanding the innovative industry of its highly skilled work force, the Arrow program, through suffering unavoidable setbacks and government directed modifications, had encountered the sharply rising costs invariably associated with those business hazards. From the outset the program had been subject to frequent government review. Under the St. Laurent Cabinet it was renewed at each stage on the clear understanding that it could be terminated on very short notice at any time. Nevertheless, the highly encouraging technological progress induced the government to continue its approvals in spite of the fact that in 1955 the funds then available, \$211,000,000.00, had promised to be insufficient to complete the development originally estimated by C.D. Howe and Avro's management at \$100,000,000.00.

In a speech in the House of Commons George Pearkes later emphasized that at this time the company had been informed by the Liberal government that "... while there were to be some forty CF-105 airframes produced at a cost of \$191,000,000, and fourteen Iroquois engines at a cost of \$70,000,000, it was to be understood that the program for both the airframes and the engines could be halted and abandoned at any appropriate stages if this was found to be expedient or necessary". Pearkes went on to point out that by 1955 the St. Laurent government had calculated that approximately \$300,000,000 would be required for development, with an additional \$1,544,000,000 to be earmarked for the equipping of fifteen squadrons — instead of the original nineteen contemplated. The number of squadrons to be equipped had been reduced because the unit cost of the Arrow had gone up from the original estimated maximum of \$2,000,000 to \$2,600,000 per aircraft. As the already heavy cost burden increased, the government's reservations about the project became even more pronounced. Its uneasiness was compounded by further information it began to receive late in 1955, to the effect that American aircraft plants, with United States government backing, had proceeded with the development of aircraft alleged to have somewhat similar performances to that of the Arrow. The F-100 and the F-102 (after re-design known as the F-106) had passed the drawing board and prototype stages and were approaching production.

The F-100, the world's first supersonic fighter, had been underway well before the Arrow, and the first prototype had actually flown at Edwards Air Force Base on May 25th, 1953. Although supersonic, its speed was far below that intended for the Arrow. Convair's Delta Dagger, the F-102, had flown in prototype form five months after the F-100, in October, 1953; but it had succumbed initially to the supersonic flight instability with which the Arrow's engineers had grappled, and it ultimately had to be re-designed — and was further refined as the F-106 Delta Dart. Again, the U.S.A.F.'s specification simply required from these two aircraft a speed in excess of Mach 1, not the Mach 2 figure laid down for the first Arrow.⁶ Although

these aircraft differed significantly in several respects from the proposed Arrow, and were not designed to achieve several of the performance characteristics demanded by the R.C.A.F. in its specification, they made it clear that the Arrow would not have the field to itself and would be up against strong sales competition when it was ready for squadron service. This decreasing likelihood of easy sales to the United States, sales which would have enabled Avro to reduce significantly the heavy unit cost associated with the now contemplated run of 500 aircraft, deepened the St. Laurent cabinet's concern over the financial burden this aircraft would represent.

As 1956 wound to a close and 1957 arrived, with its prospects of a federal election, Avro's progress against the complex problems imported by Mach 2 supersonic flight continued satisfactorily, even if not at the pace originally hoped for. Before the beginning of 1957 it was clear the 1955's target of a first flight in May, 1957, would not be met; and shortly it became equally apparent that the alternative date of August, 1957, would also prove too optimistic. But at least the end was in sight, and ground trials on a finished aircraft could finally be scheduled for October, 1957. In the interval, however, certain changes in the political and military situation took place. They were critically important changes.

VI

The Canadian federal election of June 10th, 1957, produced election returns that surprised the majority of the electorate. To the somewhat complacent Liberal government of Louis St. Laurent the result was a shattering upset. John Diefenbaker's Conservative Party achieved a plurality, and on June 21st were sworn in as a minority government. The Conservatives had been out of office federally for over twenty years, and although John Diefenbaker himself, and several of his new Cabinet Ministers, had seen considerable service as opposition Members of Parliament, the feel of the reins of power was strange to their grasp. The federal civil service had been a Liberal fiefdom seemingly from time immemorial, and the new relationships established between the political masters and their permanent Deputy Ministers were not universally those of full confidence and trust.⁷ George R. Pearkes, was a man of many parts. The Victoria Cross he was entitled to wear attested sufficiently to his personal courage. He coupled with that attribute an easy and modest charm, an abundant quota of fairness, and great diligence. He was quickly apprised of the essential inside information regarding the Arrow program, and of developments in Canada's N.A.T.O. relationships and responsibilities. With little breathing space he found himself being briefed for his role in John Foster Dulles' impending visit to Canada. With that meeting behind him he had scarcely had time to digest all the financially significant minutiae of the Arrow program when the Russians launched the first intercontinental ballistic missile on August 27th, 1957.

Before the implications of that event had been long pondered the Russians followed it with a startling surprise by launching Sputnik I on October

6. The revised F-106 first flew on December 26th, 1956. With the new Pratt & Whitney J-75-P-17 engine the F-106 eventually achieved a maximum speed of Mach 2.3.

7. A similar situation obtained with respect to a few leaders of the Armed Forces. One of Prime Minister Diefenbaker's Cabinet Ministers described to me a scene he personally witnessed that fall when the reigning monarch, Elizabeth II, opened the Canadian Parliament for the first time. As the Prime Minister approached to pass a group of V.I.P.s seated with their wives, a very senior R.C.A.F. officer turned to his wife and said "That's one son of a bitch I don't stand up for".

4th, 1957. The radio waves that emanated from that triumphant satellite were as nothing compared with the shock waves it sent through every foreign office and military establishment in the western democracies.

In the United States humiliation at being thrust into second place by technologically superior Russian space scientists was overshadowed by military concern at their startling accomplishment, for the polished aluminum of the world's first satellite, twenty-three inches indiameter, encompassed inner equipment that brought its total weight up to 184 pounds. America's first satellite, when it belatedly took to the air, was little more than one-ninth the weight of Sputnik. By applying their own calculations of launcher-to-satellite weight, American scientists estimated the weight of the Russian launching rocket at something over 100 tons, far superior in motive force to anything then within American capabilities.

The fact that Sputnik was much larger than anything the western democracies had considered practicable bespoke a much more advanced military threat should rocket engines of that size be applied to I.C.B.M.s. Shaken western military advisers began a thoroughgoing reappraisal and updating of the relative strengths of the great powers. It seemed that Russia could fairly claim the title of First World Power, a title that had seemed firmly in America's grasp in the first years after Hiroshima and after the hydrogen bomb. Many journalists were over-hasty in according the palm unreservedly and immediately to the Russians, and over-all there was a general tendency amongst their number to over-react and move towards the ranks of the determinedly pessimistic. This climate of opinion could scarcely fail to have some effect in due course on American and Canadian politicians.

But at Malton on October 4th, 1957, the remarkable achievement of the Russians took a distant second place to an event of much more immediate importance. The roll-out ceremony of the first Arrow was to take place before a hangar whose doors had spawned many a Lancaster only a dozen years before. In those dozen years, partly under the impetus of Air Marshal Curtis' vision, the Canadian military aircraft industry had moved from the two hundred mph Lancaster to the Arrow, an aircraft, so rumour had it, calculated to make the Lancaster look like something from the shop of the Wright Brothers.

At ten minutes past three that afternoon, a crowd of one thousand V.I.P.s and almost ten thousand other highly interested spectators saw the Honourable George Pearkes, V.C., pull the symbolic golden cord, and a few seconds later the first CF-105 moved forward from the deep shadows in the hangar, broke through the bunting into the bright sunlight and took up a position in the center of the roped off enclosure. Here she was to bask briefly in the gaze of her admirers before embarking upon extensive ground trials. This aircraft, representing the first fruit of almost six years' challenging labor, invited close scrutiny.

She was clearly a winner. Pilots know that nine times out of ten when a new airplane truly looks like a winner it performs accordingly — provided it has not been short-changed in its power plant. Measured against that criterion Arrow 25201, the first of the initial series of thirty-seven on Avro's production line, was assuredly a winner, for she was an impeccable white vision of aerodynamic loveliness. To a pilot's eye she exuded an almost mesmerizing air of grace, power, efficiency and pride.

The pilot's cockpit of the Arrow stood 14 feet 6 inches over the runway: (the CF-100's comparable measurement was 10 feet 7 inches); the fin stretched up another 7 feet to 21 feet 3 inches. Excluding the long nose boom, she was 77 feet 9.65 inches long from the nose to the trailing edge of the fin, some 25 feet longer than the CF-100 and 15 feet longer than today's Grumman F-14 Tomcat. She was tailless, i.e., without a horizontal stabilizer, which enhanced the clean appearance of the empennage. From wingtip to wingtip she measured 50 feet at the widest point, and her main undercarriage had a track with a width of 25 feet 5.66 inches. The run between the nose wheel and the main landing gear was 30 feet 1 inch.

Viewed from the front, the modest anhedral of four degrees on the high delta wing (embodied in the design to reduce landing gear length) contributed to the over-all impression of some speedy bird of prey, poised hawk-like for a thrust from steel tendoned legs into takeoff and pursuit. A group of favored insiders who were perched just over the Avro banner across the top of the hangar, got an equally impressive plan view, the clean angularity of the 1200 square foot white Delta wing providing a striking suggestion of arrowhead speed. There was no doubt about it, the CF-105's sophisticated dash marked it as a champion. The roll-out ceremony, belated though it was, was quickly transformed into the harbinger of success.

George Pearkes sensed the feeling, and expressed the general sentiment

in his brief remarks. He gave recognition to the gleaming thirty ton Arrow as a milestone in the annals of Canadian aviation, and styled it enthusiastically "the symbol of a new era for Canada in the air". The new Chief of Air Staff, Air Marshal Hugh Campbell, followed with a significant endorsement, saying, in part:

"The planned performance of this aircraft is such that it can effectively meet and deal with any likely bomber threat to this continent over the next decade. . . . Because this aircraft . . . is a twin engine, two-place machine, and because it will embody what will be the most modern equipment in the airborne interception and fire control fields, it should have an inherent flexibility in operations and promising future development potential. For these reasons we look to it to fill a great need in the air defense system in the years to come."

The following day's newspaper photographs of the spectacular new fighter gave Canadians cause for pride. A few short weeks before, on July 27th, 1957, John Foster Dulles had made his first call upon the new Conservative administration of John Diefenbaker. After a five-day interval, Defence Minister George Pearkes had made the somewhat surprising announcement that Canada's government had agreed to the proposal earlier put forward by the United States that the two countries link their continental air defense establishments in a single combined North American Air Defense Command.

The surprise, it should be noted, stemmed only from the speed with which the decision had been made and announced. The preceding Liberal government had declined to take precipitate action on a proposal with such far-reaching implications, particularly with an election impending. But under the Diefenbaker administration, NORAD had been launched immediately, and became operational at its Colorado Springs headquarters only a few days after the Arrow's roll-out ceremony at Malton. Canada's then Chief of Air Staff, Air Marshal Roy Slemon, a talented airman who was highly regarded by colleagues on both sides of the border, had been appointed Deputy Commander of NORAD, and it was apparent that the appointment carried genuine responsibility. Seeing the photographs of their new supersonic interceptor gave Canadians a heightened sense of pride: the Arrow was an assurance that Canada, traditionally one of the most air-minded nations in the world, would do more than simply hold its end up in the NORAD compact. It would provide NORAD not only with a highly qualified Deputy Commander and the support of a strong R.C.A.F., but also with an aircraft that gave promise of being the finest, most sophisticated interceptor in the world.

Meanwhile, at Malton the ground trials of the Arrow went on apace during November. By December the taxiing tests were begun, the final, if somewhat lengthy prelude to the great moment everyone at Avro had strained for — the moment of truth when the Arrow rose from the runway and tested its wings on the first flight. As that moment drew nearer the instability of the political situation surrounding it became more pronounced, in marked contrast to the majority government stability that had obtained during the Arrow's first four and a half years.

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(To be Continued)