Introduction

The CF-105 Arrow was a delta-winged interceptor aircraft, designed and built by A.V. Roe (Avro) Canada as the culmination of a series of design studies that originally began in 1953. The Arrow is considered by many to have been one of the most advanced technological achievements by the Canadian aviation industry. The CF-105 design was capable of near-Mach 2 speeds at altitudes in excess of 15,250 meters (50,000 feet) and it was intended to serve as the Royal Canadian Air Force’s (RCAF) primary interceptor in the 1960s and beyond.

However, in February 1959, in the midst of its flight test program, the development of the CF-105 Arrow (including all of its associated programs, such as the Orenda Iroquois jet engines, Astra fire control system and missile armament systems) was abruptly cancelled before a scheduled final project review had taken place, sparking an intense and often bitter political debate. The controversy engendered by this cancellation, and the subsequent destruction of all of aircraft then in production, still remains a topic for debate amongst historians, politicians, authors and aircraft enthusiasts. This decision not only resulted in the termination of the aircraft program but also led to the demise of Avro Canada.

Background

Prior to 1939, as “war clouds” loomed on the horizon, the Canadian government encouraged a number of “shadow factories” to be set up in order to produce British aircraft designs in relative safety. The National Steel Car Corporation of Malton, Ontario was one of those factories formed in 1938 and it began producing various aircraft types such as the Avro Anson. In 1942, it was renamed Victory Aircraft Limited (Ltd.), when the Canadian government took over ownership and management of the main plant. During the war, Victory Aircraft built a variety of Avro (United Kingdom) aircraft designs including 3,197 Anson trainers, 430 Lancaster bombers, one Lincoln bomber, six Lancastrian transports and one York transport.
In 1945, the Hawker Siddeley Group based in the United Kingdom (UK) purchased Victory Aircraft Ltd. from the Canadian government, creating A.V. Roe (Avro) Canada Ltd. as the wholly owned Canadian branch of one of its aircraft manufacturing subsidiaries, the UK-based A.V. Roe and Company. Avro Canada then began operations in the former Victory Aircraft Ltd plant. In the immediate post-war period, Avro Aircraft (Canada), turned to the repair and servicing of a number of Second World War-era aircraft types, including Hawker Sea Fury fighters for the Royal Canadian Navy (RCN) and North American B-25 Mitchell and Avro Lancaster bombers for the RCAF. But from the outset, the company also invested in research and development and embarked upon an ambitious set of design programs with a jet engine, a jet-powered fighter and a jet-powered airliner all on the drawing boards.
A.V. Roe Canada Ltd. was later restructured in 1954 as a holding company with two separate aviation subsidiaries: Avro Aircraft Ltd. and Orenda Engines Ltd., which began operating under these names as of the 1st of January 1955. Each of these company’s facilities were located across from one another in a complex at the perimeter of Malton Airport. The total labour force of both these aviation companies had reached some 15,000 employees by 1958.

In the aftermath of the Second World War, the Soviet Union had begun developing indigenously-designed long-range bombers with an ability to deliver nuclear weapons both to Western Europe and to North America. For the United States (US) and Canada, the main threat was initially perceived to be from these high-speed, high-altitude bombers being launched directly from the Soviet Union over the Arctic against military bases and cities / industrial centers at the heart of the continent. Consequently to counter this threat, both countries began the development of long-range, high-speed interceptors that could engage and destroy these bombers before they could ever reach their targets.

Here in Canada, in 1946, Avro Canada undertook the design of a suitable jet-fighter in this regard for the RCAF, resulting in the CF-100 Canuck all-weather interceptor. Unfortunately, for a variety of reasons, the Canuck was to undergo a lengthy and troubled prototype and gestation period before finally entering mainstream service seven years later in 1953. Nevertheless, it went
on to become one of the most enduring aircraft of its class, soldiering on in a variety of roles until 1981.

Design Evolution

By 1949, even before the subsonic CF-100 prototype interceptor had made its first flight, consideration was already being given to the form and necessary performance of a possible successor. But it was the outbreak of the Korean War in 1950 that would really kickstart further design studies. The RCAF had closely watched the developments in Communist tactics and technologies demonstrated during that war.

Both the jet-powered Mikoyan-Gurevich MiG-15 and MiG-17 fighters showed how far Soviet capabilities had evolved. The RCAF also felt that development of a jet bomber capable of attacking North America with a nuclear payload would be well within Soviet capabilities by 1958 and consequently the CF-100 Canuck would require a supersonic, missile-armed replacement by this same time.

![A sketch illustrating an early two-seat C-104 supersonic delta design as conceived by Avro Canada. This sketch includes the proposed engine change procedure - (Avro Canada Image via Author’s Collection)](image-url)

In September 1951, Avro Canada submitted a brochure to the RCAF outlining three proposals for an advanced supersonic fighter. One of these proposals outlined a delta-wing planform design with two jet engines providing an all-weather capability with a two-man crew. This delta-wing design had many of the advantages of swept wings in terms of transonic and supersonic performance, but offered much more internal room and overall surface area. This, in turn, provided more room for fuel; an important consideration given the inefficient, fuel-hungry, jet engines of the era, and the large wing area provided ample lift at high altitudes. The delta-wing also enabled slower landings than swept wings in certain conditions. The disadvantages of the delta planform were increased drag at lower speeds and altitudes, and especially higher drag while maneuvering. For the interceptor role, however, these were minor concerns, as the aircraft would be spending most of its time flying straight and level at high altitudes and high speed, therefore mitigating these disadvantages.
In March 1952, the RCAF provided Avro with its initial requirements document entitled "Final Report of the All-Weather Interceptor Requirements Team", detailing the requirements for a supersonic interceptor to replace the CF-100. For the RCAF team, two engines were considered essential because of the need for increased reliability over the vast stretches of uninhabited wilderness in northern Canada. A two-man crew was deemed equally necessary to deal with the interception complexities. The supersonic requirement was demanding but considered absolutely necessary because of the expected development of jet bombers. At that time, the "Mid-Canada Line" was the main radar chain for North America, and the main RCAF stations were predominately located either at the same latitude(s) or even further south. In order to adequately intercept bombers in a timely manner following their detection, the interceptors would therefore need supersonic intercept speed as soon as possible after take-off.

In June 1952, Avro submitted a response to the RCAF with brochures entitled "Designs to Interceptor Requirements". The submission was essentially two versions of the same basic design known as C104: the single-engine C104/1 and twin-engined C104/2; both using a high-mounted delta-wing, two-man crew design with provision for rockets and missiles. The primary advantages of the C104/2 design was its larger overall size which offered a much larger internal weapons bay along with its twin-engine reliability. Avro was considering three different turbojet engines for the C-104 at this time: the British-made Bristol Olympus OL-3, the US-made Curtiss-Wright J67 (itself a development of the Bristol Olympus), and the Avro Canada (Orenda) TR.9.

Several months later, in October, the National Aeronautical Establishment (NAE) completed its analysis of the prospective C-104 designs and the C-104/2 was considered preferable. The design as proposed by Avro, was, however, considered too heavy by the NAE and it was recommended that the Avro should
undertake further evolutionary design studies of the C-104/2. The RCAF also made further adjustments to its own requirements, calling mainly for an increase in operating altitude.

Among other studies, Avro Canada assessed various armament options for the C104/2 supersonic delta design including (clockwise) options for four Velvet Glove missiles, four conventional bombs, a twin 30 mm Aden gun pack along with folding fin rockets or a reconnaissance pack to be fitted in the ventral armament bay - (Avro Canada Images via CA&SM)

RCAF AIR 7-3 Specification and the C-105

Over the following months, extensive discussions continued between Avro Canada and the RCAF as they examined a range of alternative sizes and configurations for the supersonic interceptor, culminating in RCAF "Specification AIR 7-3" in April 1953. This AIR 7-3 specification called specifically for a crew of two and a twin-engine design requiring a range of 556 kilometers (300 nautical miles (nmi)) for a normal low-speed mission and 370 km (200 nmi) for a high-speed intercept mission. It also specified operation from a 1,830 meter (6,000 ft) runway, a Mach 1.5 cruising speed, an altitude capability of 21,336 m (70,000 ft), and a maneuvering capability for 2 "g" turns with no loss of speed or altitude at Mach 1.5 and 15,240 m (50,000 ft). The specification also stipulated just five minutes from starting the aircraft's engines to reaching an altitude of 15,250 m (50,000 ft) at Mach 1.5. It was also to have turn-around time on the ground of less than 10 minutes. An RCAF team then visited US aircraft companies and also surveyed British and French manufacturers before concluding that no existing or planned aircraft could fulfill these demanding requirements.

In May 1953, Avro delivered a report, "Design Study of Supersonic All-Weather Interceptor Aircraft", outlining the major features of a updated C-104/2 design, which was now known as the C-105. A change to a thin "shoulder-mounted" delta wing allowed rapid access to the aircraft's internal systems, weapons bay, and engines. This thin wing was required for supersonic flight and the delta design provided the lightest structure
available for a low thickness chord ratio while still providing a large root chord allowing adequate thickness for fuel and for stowage of the undercarriage. The new design also allowed the wing to be built as a single structure sitting on the upper fuselage, simplifying construction and improving strength. This wing design, however, required a very tall main landing gear that still had to fit within the thin delta wing, thus presenting an engineering challenge. Five different wing sizes were outlined in the report, ranging between 93 m² to 130 m² (1,000 ft² and 1,400 ft²); a 111 m² (1,200 ft²) sized version was eventually selected as the best compromise between the high-altitude performance of larger wing areas and the weight-saving advantages of smaller areas. The design would be tail-less, since the placing of a tailplane on the thin fin envisaged for the aircraft would be difficult and the stalling characteristics resulting from the use of such a tail were not considered acceptable. The powerplant selected for the design was not determined in the report, but the Rolls-Royce RB. 106 turbojet was now included as one of the possibilities, in addition to those types previously mentioned (all with afterburners). The armament was to be stored in a large internal bay located in a "belly" position, taking up over one third of the aircraft fuselage, and it was envisaged that a variety of weapons could be deployed from this bay. For armament, Avro recommended the Hughes MX-1179 fire control system, with six AIM-4 Falcon guided missiles along with up to fifty 5.1 cm (2 in) folding-fin aerial rockets (FFARs).

This is one of Avro Canada’s further refined concepts for the C-105 series evaluations. This particular concept is for a single-seat version featuring four Falcon missiles and a 130 m² (1300 ft²) wing area - (Avro Canada Image via CA&SM)

Early CF-105 Developments

In July 1953, a ministerial directive from the Department of Defence Production authorized Avro Canada to proceed with a full design study in order to meet specification AIR 7-3 under the project designation of "CF-105".
In December, an order for two development prototypes then was approved at a cost of CA$27 million. By this time, plans were already being formulated for full-scale procurement of the type by the RCAF with 1958 being the anticipated date for the operational introduction of the aircraft. The projected numbers of aircraft required ranged between 500 and 600 at a cost of CA$1.5 to $2 million per aircraft. The RCAF's plan for employment of the CF-105 at this point envisaged nine regular squadrons and eleven auxiliary squadrons.3

The CF-105 program was formally approved without any recorded discussion at a 17 December 1953 Cabinet meeting.4 The cost of the development program was estimated to be CA$26.9 million. Lieutenant General Charles Foulkes would later write that “the probable costs of the engine and armament system were only very roughly indicated. There was some hesitation in recommending a programme of such complexity and magnitude and with so many unpredictable factors and hidden costs.”5

Ultimately, the entire CF-105 "system" was to consist of four main components: the airframe, the turbojet powerplant, the fire-control system, and the associated armament system. Originally, the only component slated for development in Canada was the airframe itself by Avro Canada, but later Canada was to eventually assume responsibility for all the other components as well. How each of these various components of the design would eventually be dealt with would weigh very heavily into the ultimate fate of the aircraft.
The first of these, the Arrow (as the CF-105 was eventually to be named) airframe presented the Avro Canada designers and engineers with enormous challenges, as it was to be among the first truly operational supersonic aircraft, and many problems of supersonic flight had yet to be solved. For example, the aerodynamic loads had to be fully established and the effect of manoeuvrability on the structure required detailed investigation. A wide number of stressing cases were, therefore, fully investigated. The problem of frictional heating also required close examination. For example: "at 1,931 km/h (1,200 mph), air friction raises the temperature of an aircraft’s skin by 150°C (300°F). Even at high altitudes, with the outside air temperature at around 10°C (50°F) below zero, the skin temperature is still 4.4°C (40°F) above the boiling point of water". Another problem was that of sound. Both aerodynamic and engine noise could possibly damage skin panels and / or loosen structural fasteners. To assist the designers and engineers in solving many of these and related problems, the wind-tunnel became one of the critical tools. The first tests in the wind-tunnel development program were run in September 1953.

At first, the CF-105 project was limited in scope, but the introduction of the Soviet Myasishchev M-4 Bison jet bomber and the Soviet Union's testing of a hydrogen bomb dramatically changed Cold War priorities. In March 1955, the contract was upgraded to CA$260 million for five CF-105 Mk.1 flight-test aircraft, to be followed by 32 CF-105 Mk. 2s with production engines and fire control systems. The overall pace and intensity of activities on project accelerated accordingly.

In order to meet the aggressive timetable now being set by the RCAF, Avro decided that CF-105 program would adopt the Cook-Craigie plan; effectively eliminating the traditional prototype phase. This same approach had been adopted by the USAF on Convair's F-102 Delta Dagger program. The first test airframes were therefore to be constructed on production jigs. Any changes would be then incorporated into these jigs while testing continued, with full production starting when the test program
was complete. As Avro Canada’s vice-president of engineering, Jim Floyd, noted at the time, this was a risky approach, however:

...it was decided to take the technical risks involved to save time on the program... I will not pretend that this philosophy of production type build from the outset did not cause us a lot of problems in Engineering. However, it did achieve its objective.

In order to mitigate risks, a massive testing program had already started. By mid-1954, the first production drawings were issued and wind tunnel work began, along with extensive computer simulation studies carried out both in Canada and the United States using sophisticated computer programs. By the time the first aircraft was rolled out for public display in 1957, Avro had completed an exhaustive series of wind-tunnel studies. The NAE wind tunnel in Ottawa was used for both low-speed and high-speed testing, while transonic and supersonic tests were carried out at the Cornell Aeronautical Laboratories in Buffalo, New York and at the National Advisory Committee for Aeronautics (NACA) wind tunnel at Langley Field, Virginia respectively. The NACA also provided the Lewis Laboratory in Cleveland for air-intake tests. Seventeen models, ranging from 1/80th to 1/6th scale, were used in these tests.

The wind-tunnel tests were only one part of the extensive program designed to investigate, test and confirm the supersonic theories and designs. Between December 1954 and January 1957, Avro Canada conducted another innovative program in which large, heavily-instrumented, free-flight models were mounted on solid-fuel Nike rocket boosters for aerodynamics tests. Nine such models were launched at the Canadian Armament Research and Development Establishment (CARDE) range at Point Petre, Ontario, and two more at the NACA Wallops Island range in Virginia. These models were used for aerodynamic drag and stability testing and were flown to a maximum speed of Mach 1.7 before being intentionally crashed into the water. In every case, the launch and the subsequent separation of the model and booster proved successful and a significant amount of valuable aerodynamic information was gathered.
Top - A wind tunnel study of the delta wing shape characteristics led Avro to include a “dog tooth” leading edge notch to better control the flow of vortices over the wing - (CA&SM Image)

Bottom - One of the models used to assess the flutter characteristics of the delta wing and control surfaces - (CA&SM Image)
At the Avro factory, a full-scale mock-up was prepared to provide a three-dimensional check on installation clearances and general accessibility. One of the first tasks of the mock-up was to check the clearance of the Curtiss-Wright J67 turbojets, that had by this time been nominated to power the CF-105.

An extensive structural test program with five separate phases was developed as follows:

**Preliminary Design Testing** - This testing was required by the company to establish critical structural assumptions and material selection in the ongoing design. This involved simplified test specimens and coupon testing. The forward fuselage and intake duct area was an example where test specimens were used to determine resistance to buckling and deformation at high pressures;

![Example of extensive testing](image)

*This is an example of the type of extensive testing conducted by Avro Canada to assess individual component design and their strengths. This is a static test of main wing box structure with extensive strain gauging in place - (CA&SM Image)*

**Proof of Compliance Testing** - These series of test were conducted on static test airframes and were engineered to confirm the design’s compliance with the applicable structural specification (in this case Military Standard Mil-S-5710);

**Component Fatigue Testing** - These tests were to be scheduled as required if the full-scale specimen fatigue testing did not adequately assess specific areas / components. The undercarriage design was prime example. The complexity of the design and use of super-high heat treated steel in its manufacture necessitated specialized component tests;

**Fail-Safe Testing** - A full-scale test was scheduled to be conducted on a static test article; and

**Elevated Temperature Testing** - The supersonic demands and the thermal stresses induced by high speed flight caused significant concerns. Elevated temperature testing assessed the creep and
deformation on many of the structures within the airframe. For example, a model was constructed to assess the effects of transient heating on the inner wing fuel tanks.

Another important ingredient in the development program was that of the experimental test pilot staff. When the CF-100 was nearing the time of its first flight in January 1950, Avro's associate within the Hawker Siddeley Group in the UK, Gloster Aircraft, had "loaned" its chief test pilot, A.W. "Bill" Waterton for the initial tests. In the intervening years, however, Avro Canada had built up a competent test-pilot staff of its own. Those most closely associated with the CF-105 project included Avro's chief development pilot, Janusz "Jan" Zurakowski, who was also an ex-Gloster test pilot, together with Wladyslaw "Spud" Potocki and Peter Cope along with the RCAF's leading test pilot, Flight Lieutenant (F/L) Jack Woodman.

**Test Pilot Influence** - The test pilots were involved in the project long before the prototype was ready for flight. In the case of the CF-105 *Arrow*, the pilots worked in close co-operation with the engineers on key design aspects of the electrical, fuel and hydraulic systems along with the control systems and emergency features. Flight simulators controlled by an analogue computer were constructed both for the investigation of control responses and for training. A mock-up of the cockpit was mounted above a truck to check pilot visibility while taxiing — first without and then with the needle nose. The pilots also worked closely with designers and "human-factors engineers" in designing the cockpit layout. Their influence in this area was considerable. It was later reported that General Joseph Caldara, the United States Air Force's (USAF)
Director of Flight Safety, considered the Arrow's cockpit layout to be "the best he had seen". The test pilots also personally prepared for the actual flight-test program by training at Convair's test facility at Palmdale, California, where they flew the single-engined, delta-winged F-102 Delta Dagger.

The CF-105 Arrow Airframe and Sub-System Design

All of the previous wind tunnel testing and free-flight experiments showed the need for only a small number of aerodynamic design changes, mainly involving the wing profile and positioning. To improve
high-alpha performance, the leading edge of the wing was drooped, especially on outer sections. A “dog-tooth” was introduced to control span-wise airflow, and the entire wing given a slight negative camber which helped control trim drag and pitch-up tendencies. At the insistence of the RCAF, the “area-rule” principle,\textsuperscript{11} which had been made public in 1952, was also applied to the design. This resulted in several further changes including the addition of a tailcone, sharpening the radar nose profile, thinning the intake lips, and reducing the cross-sectional area of the fuselage below the canopy.

The airframe design that evolved to meet the AIR 7-3 specification can therefore be described as an all-metal, high-wing, delta-planform monoplane. The aircraft was primarily constructed of aluminum and steel but also used a measure of magnesium and titanium in the fuselage, the latter limited largely to the area around the engines and to fasteners. Titanium was still expensive and not widely used because it was very difficult to machine. The basic construction of the airframe itself was also fairly conventional for the period, however, with a semi-monocoque frame and a multi-spar wing. The specific details are as follows:

**Wing:** This consisted of a three-part (i.e. one inner and two outer wing sections) all-metal delta wing structure with a sweep-back of 61 degrees at the leading edge. The wing had a thickness to root chord ratio of 3.5%. The wing was also given 4 degrees of anhedral strictly to reduce the length required for the main landing gear. This particular characteristic had no appreciable aerodynamic effect. The outer wing consisted of a multi-spar box beam, with heavily tapered skins and ribs running to the main spars. The outer wing was bolted to the inner wing by a peripheral joint covered by a fairing. The inner wing consisted of a main torsion box containing spars, ribs and machined skins. The engines were suspended from the inner wing.

*The basic make-up of the CF-105 Arrow structure can be seen in this Avro Canada drawing - (CA&SM Image)*
**Fuselage:** The semi-monocoque fuselage was designed primarily around the two engines with the cockpits situated between the intakes. It was an all-metal, bonded structure with a detachable weapons bay on the lower surface. The fuselage was primarily constructed of aluminum and magnesium alloys, and titanium was only used around the area of the jet pipe where heat resistance, low weight and high strength was needed. The air inlets were of fixed geometry with intake gills immediately adjacent to the compressor inlet. These gills opened automatically at Mach 0.5 and allowed air to bypass the engine for cooling and aerodynamic reasons. A 12-degree intake ramp was used to create an oblique shock wave at supersonic speeds in order to achieve optimum pressure recovery characteristics. Perforations were installed on the face of the ramp to prevent “intake buzz” caused by the interaction of the inlet shock wave and the boundary layer flow on the ramp. The vertical stabilizer and all to the control surfaces were also of all-metal construction.

A detailed view of the fixed geometry intake on the CF-105; the splitter plate, intake ramp and perforations used to control “intake buzz” problems are all clearly visible - (CA&SM Image)
**Landing Gear:** As previously mentioned, the landing gear design was further complicated by the high-wing, delta-planform design. A fully retractable, tricycle-type gear was designed. The forward gear consisted of dual wheels and retracted forward. The main gear had two-wheeled tandem bogies that retracted both inboard and then forward into the wing and were attached to the inner wing’s main torque box. An emergency system allowed extension of the landing gear by means of pneumatic pressure from a 35 MPa (5,000 lb/in²) nitrogen storage bottle. Toe pressure on the pilot’s rudder brake pedals actuated control valves via cables and allowed differential and proportional braking of the two pairs of main wheels. No anti-skid protection was provided on the early aircraft. The nose wheels were steered with the rudder pedals, which were mechanically linked to a steering control valve. The steering angle was approximately ±55 degrees which permitted a 180 degree turn to be made on about a 6.4 m (21 ft) radius. The CF-105’s wheel track was 9.21 m (30 ft 2 1/2 in).

**Accommodation:** The crew members were seated in tandem with separate cockpits. Each cockpit was pressurized and air-conditioned. Cabin pressure remained the same as the outside air up to 3,050 m (10,000 ft). Above this altitude, the differential between cabin pressure and aircraft pressure increased linearly until a differential pressure of 0.32 to 0.35 kg/cm² (4.5 to 5 lb/in²) would be reached at 18,290 m (60,000 ft). Each cockpit had an independently operated, two-piece clam-shell canopy. Each canopy was opened or closed by electrical actuators controlled by switches and was locked or unlocked manually. In an emergency, gas generating cartridges could be fired from inside or outside the aircraft. The Arrow had two independent oxygen systems. The normal system converted liquid oxygen into gaseous oxygen for crew-member breathing and pressure-suit inflation. In case of emergency, an oxygen cylinder was attached to the forward part of each seat pan and provided a minimum of 20 minutes supply.

**Ejection Seats:** Each crewman was provided with a Martin-Baker Mk C5 ejection seat. If ejection was necessary, the canopy was opened and the seat ejected by pulling a large overhead firing handle down over the face. An alternate firing handle was located on the seat pan.

**Flying Control System:** A rudimentary fly-by-wire system was employed, in which the pilot’s input was detected by a series of pressure-sensitive transducers in the stick, and their signal was sent to an electronic control servo that operated the valves in the hydraulic system to move the various flight controls. This resulted in a lack of control feel; because the
control stick input was not mechanically connected to the hydraulic system, the variations in back-pressure from the flight control surfaces that would normally be felt by the pilot could no longer be transmitted back into the stick. To re-create a sense of feel, the same electronic control box rapidly responded to the hydraulic back-pressure fluctuations and triggered actuators in the stick, making it move slightly; this system, called "artificial feel", was also a first in the Canadian aircraft design field. The ailerons, elevators, and rudder were all fully powered, using hydraulic pressure supplied by two pumps on each engine. The hydraulic components were controlled electrically, or mechanically through cables and linkages, there being no direct mechanical control or feedback. There were three modes of control planned for the final Arrow configuration. The normal mode was characterized by a damping system, automatically stabilizing the aircraft in all three axes and co-ordinating rudder movement with movement of the ailerons and elevators. The planned automatic mode was never ultimately fitted to the design. The emergency mode's role is self-explanatory: the hydraulic components for operating the ailerons and elevators were controlled mechanically. Yaw stability and turn coordination was maintained by an emergency yaw damper. In the normal mode, pilot-feel at the control column was provided by the damping system. In the emergency mode, only spring feel was provided.

The CF-105 Arrow program used a sophisticated (for the day) simulator to test and prove the flight control system - (CA&SM Image)

Hydraulic System: The CF-105's thin wing required aviation's first 28 MPa (4,000 psi) hydraulic system to supply enough force to the control surfaces, while using small actuators and piping. The CF-105 Mk 1 had two independent hydraulic systems of 28 MPa (4,000 psi). One pump on each engine supplied the "A" system while another pump on each engine supplied the "B" system. The "A" system was responsible for supplying the control-surface actuators and damping servo for emergency yaw damping. The "B" system supplied the control surface actuators and damping servos for pitch, roll and yaw-damping. Another utility hydraulic system, distinct from the flying-control hydraulic system described above, consisted of two pumps, one on each engine-driven gearbox, again rated at 28 MPa (4,000 psi). The landing gear, wheel-brakes, nosewheel steering, and speed brakes were all operated by this latter system.
**Fuel System:** Fuel was carried in two bladder-type tanks in the fuselage and six integral tanks in each wing. Total capacity was 11,401 litres (2,508 Imp gal) of jet fuel. A jettisonable long-range tank for another 2,273 litres (500 Imp gal) was planned for later aircraft and would have been carried on a centreline fuselage station for ferry missions (see previous page-8 drawing).

**Weapons Bay:** The weapon’s bay was larger than that of a B-29 *Superfortress* and it was designed to be quickly reloaded or interchanged after use. The weapon’s bay was not designed to be lowered in flight but instead had sets of retractable doors that opened in flight to allow for missile or rocket launches. Extra fuel or gravity bombs could also be carried in the weapons bay.

*The CF-105 Arrow weapons bay was intended to be a quick change item and featured custom designed support equipment to facilitate its rapid installation and removal as seen here. The drawing on the following page depicts how a weapons bay with Sparrow II missiles would be uploaded to the aircraft - (CA&SM & Avro Image / drawing)*
Speed Brakes & Drag Chute: Two speed brakes were fitted at the bottom of the fuselage immediately aft of the armament bay. They were hydraulically operated and designed to open and hold at speeds of up to Mach 1. A drag chute was also installed in the aft end of the fuselage.

The CF-105 Arrow landing speeds and typical Canadian conditions necessitated a large drag chute as seen here deployed from RL-201. The inset view illustrates the two speed brakes in the deployed position - (CA&SM & Author’s Collection Images)
Navigation and Communication: The navigation equipment in the CF-105 Arrow Mk 1 consisted of a Radio Magnetic Indicator, a UHF Homer, a ARN-6 Radio Compass, and a J4 Gyro Compass. The communications equipment consisted of a ARC-34 UHF radio and AIC-10 Intercom set.

Associated Programs

The Orenda Iroquois - The next of the associated programs to be undertaken was that involving the powerplant. The Rolls-Royce RB. 106 had been the original choice for the engine, but when this was abandoned in the UK early in 1954, the Curtiss-Wright J67 was selected as a replacement. Meanwhile, in September 1953, Avro Canada had started, through its subsidiary Orenda Company, to design a new turbojet engine, known as the Orenda TR-13, financing the development from its own funds.

The progress of this latter project was encouraging and, with rumours of the J67’s imminent abandonment by the USAF, the Canadian government funded the production of the Orenda TR-13 engine. It was then decided that the Curtiss-Wright J-67 would be used as an interim powerplant in five Mk 1 aircraft, while Mk 2 pre-production and all production aircraft would be fitted with the Orenda engine, now designated as the PS-13 (and later named the Iroquois). When the J67 was officially cancelled by the US government in 1955, the Pratt & Whitney J75 turbojet was substituted as the next "interim" engine in the CF-105 Mk 1 Arrows. This interim approach was considered necessary because of the risks involved in testing both a new airframe design and a new engine simultaneously. Unfortunately, this change resulted in considerable further redesign as the J67 had already been engineered to fit into the ground mock-up and the J75 did not have the same mounts or dimensions.

The Iroquois engine was intended to provide high performance at supersonic speeds. On 13 January 1954, an "instruction to proceed" was received from the Department of Defence Production and, on
17 December 1954, the prototype *Iroquois* made its initial run. By July 1958, the engine had completed over 5,000 hours of bench running in test cells at Malton and in flight tests; some 2,000 hours of additional testing had been completed by the time the *Iroquois* was cancelled and the turbojet had already been installed in a CF-105 Mk 2 in preparation for flight testing. The planned program cost for the development, tooling, prototype and pre-production engines was set at just under CA$117 million.

The *Iroquois* was a two-spool, axial-flow turbojet with an afterburner. In contrast to the *Arrow*, with its complex systems and high number of parts, the *Iroquois* was based from the beginning on both simplicity and light weight. Orenda pioneered new territory in the use of titanium. Twenty per cent by weight of the completed *Iroquois* consisted of titanium. The earlier Orenda turbojets, which then powered Canadair *Sabres* and Avro CF-100s, also had more parts while producing less power. The *Iroquois* weighed 2,675 kg (5,900 lb) dry by comparison with the previous Orenda 9 at 1,160 kg (2,560 lb). (These comparisons take into account the American *Marquardt* afterburner of the *Iroquois* as the earlier Orenda did not have an afterburner.) The *Iroquois* rating was reported to be 13,608 kg (30,000 lb st) with afterburner for take-off, while the maximum rating of the Orenda 9 was just 2,883 kg (6,355 lb st).

In addition to the testing of the *Iroquois* in cells at Malton, further altitude testing was carried out at the NACA Lewis Flight Propulsion Laboratory wind-tunnel at Cleveland, and the NACA wind-tunnel at Tullahoma. The Cleveland tests revealed the engine’s successful operation under sustained high inlet temperatures, an ability to make normal relights up to 18,290 m (60,000 ft), which was the limit of the tunnel, and recorded the highest dry thrusts measured to that time in North America for a turbojet.

The *Iroquois* engine was truly an innovative design. A brief summary of its advanced features / design “firsts” include the following:\(^\text{12}\)

- Its thrust-to weight ratio was considerably higher than its contemporaries;\(^\text{13}\)
- Its oxygen-injection relight system was a design first;
- First variable stator blades on a twin-shaft engine;
- First use of a transonic first-stage compressor;
• First “hot streak” afterburner ignition system;
• First fully variable afterburner rather than the standard “on/off” system;
• First bleed-bypass system for both intake and exhaust;
• First by-pass engine design, albeit with a very low bypass ratio; and
• Combination of the above two points with an ejector nozzle that used the bypass air to create thrust at the exhaust nozzle while also improving intake flow. Most contemporary engines merely used a straight pipe.

The Iroquois flight test program was also unique. In 1956, the USAF loaned a six-engined Boeing TB-47B Stratojet, USAF serial 51-2059, to the RCAF for use as a flying test bed for the Orenda Iroquois. Canadair Limited (Ltd), at Cartierville, near Montreal, Quebec spent more than a year modifying this B-47 for its task, fitting a large nacelle to the starboard rear fuselage underneath the horizontal tail to house the Iroquois. This pod was 9.14 m (30 ft) long and about 1.83 m (six ft) in diameter. They modified the B-47’s co-pilot station to incorporate controls for the Iroquois and converted the existing navigator’s station to a flight test engineer’s station. Approximately 900 kg (2,000 lb) of photo recorders, oscillographs, telemetry equipment and other test instrumentation was mounted on a platform in the bomb bay. In addition, 3,630 kg (8,000 lb) of ballast had to added the nose of the B-47 in order to counter the weight of the new engine pod. All of this added weight and structure required considerable strengthening of the fuselage and consequently the rear fuselage was double-skinned and new reinforcing bulkheads and longerons were also added. Probably the biggest challenge for the Canadair team was designing a retractable door for the engine pod’s intake in order to prevent the Iroquois engine from windmilling in flight when not powered.
Top - Canadair first completed a trial mock-up of the Iroquois pod installation as seen in this view.
Bottom - The now complete X059 test bed upon arrival at Malton - (Bill Upton Collection Images)
The company consequently assigned its own model number of “CL-52” to the project. This CL-52 / TB-47B flew in RCAF markings, but retained the last three digits of its USAF serial number, which followed the prefix “X” in order to become the RCAF serial number “X059”. The B-47 left Cartierville for Malton on 15 April 1957.

On 13 November 1957, the B-47, flown by Michael Cooper-Slipper, Orenda’s chief test pilot, with Leonard Hobbs as co-pilot, and John McLachlan as flight engineer, took the *Iroquois* into the air for the first time. The B-47 was being flown under limitations because of an oil leak discovered in one of its J47 engines two days earlier. A engine change to allow for testing at full power would have meant a month's delay, but all went well within these limitations.

Including this initial flight, the CL-52 spent a total of 31 hours in the air testing the *Iroquois* engine. In subsequent test flights, the XB-47 crew was able to essentially reduce all six regular engines to idle and power the XB-47 on the thrust alone from the *Iroquois*. The program did not go flawlessly, however, as a turbine blade failure on a later test flight caused considerable damage to the engine nacelle and part of the rear fuselage.

After the termination of the *Iroquois* program, the *Iroquois* engine was removed from the CL-52 and the XB-47 test-bed was returned to the USAF. This unique B-47 was scrapped at Davis-Monthan Air Force Base shortly thereafter.

**The Fire Control System** - All did not go so well with the Arrow's less spectacular, but equally important, systems. As already mentioned, Avro had initially recommended the use of a Hughes MX-1179 fire-control system. Had this recommendation been followed, the outcome of the ensuing Arrow controversy might have been somewhat different. The RCAF wanted to have a 1.02 meter (40 in) radar dish for the Arrow, believing that a dish of this size was necessary to meet their specifications. Hughes was the obvious choice as a contractor for the new radar as its systems were already standard in the CF-100. But the American company rejected the proposed contract on the grounds that such a large radar dish could not be used in USAF interceptors, thus restricting its marketability to a relatively small batch of Canadian aircraft. It was later said that Avro was willing to manage with a smaller Hughes dish, but RCAF's insistence on their specification eventually caused the contract to be awarded to the Radio Corporation of America (RCA), with its associates Minneapolis-Honeywell.
The name for RCA's integrated electronic system responsible for automatic flight control, fire control, telecommunications and navigation sub-systems in the Arrow was the Astra I. The overall Astra system integration requirements were demanding and complex. Consequently, the way forward was broken down into an incremental approach. RCA was required to deliver a partial Astra system with the minimum communication, navigation, Identification Friend or Foe (IFF) systems, flight instruments, and air data sensors to permit the test aircraft to fly the initial research and development phases. This was to be followed by a “developmental” Astra system and then by a “pre-production” variant before proceeding to “full-production sets”.

Specific details on the overall sub-system developments and problems are now virtually non-existent. However, a brief description of the various Astra sub-systems is as follows: 15

**Automatic Flight Control Sub-System (AFCS)** - The automatic flight control system consisted of a vertical and heading reference unit, an air data computer and the AFCS couplers. The system's function was to automatically control the aircraft's flight path vector and orientation. The AFCS commanded the control surface motions through a damping system by means of the couplers. The AFCS provided vertical and heading reference information for all of the other sub-systems, was the central source for all air-data information, and provided overall control of the aircraft. The AFCS had an automatic attack mode, an
automatic navigation mode, an automatic approach for landing mode, a pilot-assist mode to hold either pitch, heading, bank, altitude and/or Mach No. and finally a manual manoeuvring mode.

**Fire Control Sub-System** - The fire control system included the airborne interception radar, ballistics and kinematics computers, missile auxiliaries, an optical sight, and associated equipment. The primary functions of the system were to acquire and track the target, to provide the correct steering signal for either manually or automatically steering the aircraft during the intercept, to automatically fire the aircraft’s armament at the correct time, and to provide a visual indication for breakaway. The radar, in addition to target detection and tracking, also was to provide navigation aids in the form of radar beacon interrogation and ground mapping. Passive homing on X-band jamming was also to be provided as an added countermeasure capability. The system was also intended to be operated in conjunction with an infrared system for passive detection and tracking.

**Telecommunication Sub-System** - This system was intended to provide two-way UHF communication, voice-coded data link reception, UHF homing, LF/MF radio compass, homing on L-band jamming signals (ECM homer), air-to-air and ground-to-air IFF coverage with interrogator and transponder units and a crew intercom.

![A side view drawing of the proposed locations for the electronic equipment in the Arrow Mk 2 - (Avro Canada Drawing via CA&SM)](image)

**Navigation Sub-System** - The navigation system consisted of a dead reckoning navigation computer, a doppler radar and an integrated destination indicator. This system was intended to be self-contained and to be capable of indicating the actual geographic location of the aircraft (with bearing and distance to target or base) at all times. The navigation computer received inputs from telecommunications, radar and air data equipment and supplied outputs for the fire control radar, AFCS and navigation display indicator. Display data was to include the present position and track of the aircraft, range to target data along with radio compass and UHF homer azimuth data.
Unfortunately problems in development of each of these sub-systems mounted. Changes led to more changes, and the costs escalated. The constant alterations initiated by RCA also directly affected Avro, since the CF-105 airframe had to be modified each time to accommodate the revised designs. Ultimately, progress on the integrated system proved to be very disappointing. The overall cost of delivering a basic Astra I was an estimated CA$100 million and its lack of promise eventually led to its cancellation.

Ironically, Hughes later developed a system for versions of the Convair F-106 Delta Dart, similar to the one initially requested by the RCAF.

The Armament System - The armament system was another source of trouble for the CF-105 Arrow. Avro Canada recommended the Hughes AIM-4 Falcon air-to-air missile. The RCAF was initially suggesting it required up to six Falcon missiles along with varying numbers of FFARs. The RCAF then scrapped the requirement for the rockets and increased the number of Falcons required to eight (four infrared-guided and four radar-guided AIM-4 missiles).

From the government’s perspective, however, the original planned armament was the Canadian-designed / produced Velvet Glove air-to-air missile. Work on this design had dated back to 1947, when the Defence Research Board was assigned the duty of studying the field of air-to-air missiles. In 1950, approval had been given to design and manufacture such a missile, in order to familiarize the Board, the RCAF and Canadian aerospace industry with guided missiles development and to provide a modern weapon for future fighters. Canadair Limited was the Canadian company selected to produce the Velvet Glove, under the company designation of CL-20. The program was undertaken, however, on the understanding that, should development of the missile fall behind that of similar projects of the Western nations, then it would be abandoned in favour of those developments. The Velvet Glove was a first-generation missile design using semi-active radar homing for a pursuit trajectory. When other developments did indeed start to overtake the Canadian design, the decision then made to terminate the project and to acquire an American system, rather than to attempt to improve the Canadian design. The Velvet Glove, as a result, was cancelled in 1954 after CA$24 million had been spent on the program.

After evaluating Avro’s engineering mock-ups and a full-scale wooden mock-up in February 1956, the RCAF demanded further changes, selecting the advanced RCA Astra fire-control system employing the equally advanced United States Navy Sparrow II missile in place of the MX-1179 and Falcon combination. The initial RCAF request was for three Sparrow IIs to be carried. This was later increased to four Sparrow IIs. At a 7 December 1955 Cabinet meeting, CA$65 million was then approved for the production of 900 Sparrow II missiles through to 1965. Canadair was selected as the prime contractor to license produce the design in Canada and it, in turn, invested in new facilities and personnel to accomplish the task. Several CF-100 Mk 5Ms were allocated to Cartierville to facilitate the development work.

Avro vocally objected to these changes on the grounds that neither of the RCAF’s choices were even in testing at that point in time, whereas both the MX-1179 and Falcon were almost ready for production and would have been nearly as effective at significant cost savings. The customer, however, prevailed.
Above - a drawing of the proposed AIM-4 Falcon installation with 8 missiles in the Arrow Mk 2 - (Avro Canada drawing)

Below - a drawing of the proposed Sparrow II installation with 4 missiles. Note how the fins would have protruded from the weapons bay as depicted in the inset drawing. - (Avro Canada drawing via CA&SM)
Unfortunately, similar to the Astra system, the RCAF’s primary choice for a missile, the **Sparrow II**, ran into serious development problems. The United States Navy (USN) had been developing this radar-guided missile in cooperation with the Douglas Aircraft Corporation. The missile’s radar-seeker head was guided by a “K-band” system but the development testing had proved this design to be disappointing as the radar could often not properly see through clouds or rain disturbances. Consequently the USN did not give the project a high priority as compared to other programs and threatened cancellation of the program. When, after further review, the **Sparrow II** was officially cancelled by the USN in 1957, influenced perhaps by the facilities left vacant by previous cancellation of the Velvet Glove program, the Canadian government undertook to complete the development of the **Sparrow II** in Canada. Canadair was quickly awarded a contract to finish development and manufacture the **Sparrow II** (known in Canadair as the CL-54) even though they expressed some concerns about the viability of the project. This change added yet more expense to the overall CF-105 project and by 1958, the new government was having “second thoughts”. Progress on the **Sparrow II** was slow and, by September 1958, the government reversed itself and cancelled the **Sparrow II** program as a cost saving measure. To that point, Canadair had only manufactured two **Sparrow** missiles in house and modified five others that had been supplied by Douglas. Ironically, Canadair would find alternative work in manufacturing 550 sets of wings and other components as a sub-contractor on the Boeing Michigan Aeronautical Research Center or BOMARC missile program.
Following the eventual cancellation of the Canadian version of the *Sparrow II* due to mounting expenses, the RCAF reverted to specifying the Hughes *Falcon* missile but supplemented it by adding the nuclear-tipped *Genie* MB-1 rocket together with the Hughes MA-1C fire control system.

*Had the final missile installation in the CF-105 Arrow proceeded, the missile installation (and fire control system) would have been remarkably similar to that installed on the Convair F-106 Delta Dart aircraft as seen above. The installation would have included a mixture of radar-guided AIM-4s (front) and infrared-guided AIM-4s (rear) - (Photo courtesy of Joseph May)*

*Before the program was cancelled, the RCAF was considering the nuclear-tipped AIR-2A Genie rocket as potential armament for the CF-105. This massive rocket, equipped with a 1.5 kiloton warhead, would have required a considerable redesign of the weapons bay and only 2 rockets could be carried. This photo shows the Genie in comparison to a folding fin aerial rocket (FFAR). The extended tail fins on the Genie would have been retracted for stowage - (Author’s Collection)*
Summary - According to Jim Floyd, “The [Avro] company was [always] very concerned that the development costs of all these items would eventually be accounted against the aircraft program”. Unfortunately, this would prove to be the case. “At the time of cancellation, the airframe costs were overshadowed by the anticipated costs of the avionics and armament.”

Production of the Prototype / Pre-Production Aircraft

With initial designs under way and development proceeding, by December 1956, Avro now had contracts for 37 pre-production CF-105 Arrows: five Mark (Mk) 1s and 32 Mk 2s. The Mk 1 referred to pre-production aircraft equipped with Pratt & Whitney J75 turbojets and test equipment in lieu of armament. The Mk 2 was the fully developed version, to be powered by the PS-13 Iroquois turbojet. Avro decided that the prototype and pre-production aircraft should be built with production tooling, allowing full production to get under way immediately. So as to make this possible, Avro Canada invested in new machinery and developed new techniques, among which included a new fibreglass-cloth process; an electronically-controlled skin-mill for machining large integrally-stiffened wing panels, as well as smaller cutters, a huge Siempel Kamp rubber-forming press for forming metal parts with accuracy and without the need for hand-finishing, and a large autoclave pressure-chamber for metal bonding.

A station drawing of the proposed Arrow Mk 2 - (Avro Canada Drawing via CA&SM)
The scale of production can also be gathered from the size of some of the contracts that ensued: 17

<table>
<thead>
<tr>
<th>Date</th>
<th>Item</th>
<th>Value (Cdn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>29 Mar 1955</td>
<td>Production of CF-105 aircraft, spares, ground handling equipment</td>
<td>$56,056,278</td>
</tr>
<tr>
<td></td>
<td>and publications</td>
<td></td>
</tr>
<tr>
<td>20 Mar 1955</td>
<td>Design and development of CF-105</td>
<td>$29,136,350</td>
</tr>
<tr>
<td>07 Aug 1956</td>
<td>Publications for CF-105</td>
<td>$42,637</td>
</tr>
<tr>
<td>19 Sep 1957</td>
<td>CF-100 engineering ref. Sparrow II for CF-105</td>
<td>$20,000,000</td>
</tr>
<tr>
<td>25 Mar 1958</td>
<td>Production of CF-105 Mk.2</td>
<td>$33,933,894</td>
</tr>
<tr>
<td>21 Jul 1958</td>
<td>Repair &amp; overhaul CF-105 airframe components</td>
<td>$400,000</td>
</tr>
<tr>
<td>07 Aug 1958</td>
<td>Repair &amp; overhaul CF-105 airframe components</td>
<td>$500,000</td>
</tr>
</tbody>
</table>

The complexity of the new design can be further judged by comparing the CF-105 to its predecessor, the CF-100. The CF-100 Mk 5 weighed 10,433 kg (23,000 lb) empty, while the CF-105 Mk 1 weighed almost double that at 22,244 kg (49,040 lb). The CF-100 had approximately 13,000 parts as compared to 38,000 for the CF-105. In addition to the aircraft itself, ground-handling and maintenance equipment involved yet
an important production effort; a joint Avro / RCAF maintenance engineering team designed up to 200 separate pieces of support equipment for the CF-105 Arrow fleet.

As work on the pre-production aircraft progressed, a massive industrial network for full production was organized. Approximately 650 outside suppliers were fully engaged, employing an estimated 5,000 people. At the Malton plant, which in its war-time guise as Victory Aircraft had employed 10,000 personnel at the peak, Avro Aircraft Ltd. now had 9,500 workers, while Orenda Engines had a further 5,000.

**Roll Out** - The CF-105 program came to the forefront of Canadian and even international news in 1957. Early that year, the name “Arrow” had been officially adopted and public interest and anticipation grew as the rollout date approached. Even in the USA, where coverage of Canadian news was rarely a priority, close attention was given to the approaching ceremony. On 4 October 1957, a crowd of some 12,000 people, many of them “Avroites” (as the company termed its employees) released from work for the ceremony, gathered at the Malton airport.

![The first CF-105 Arrow RL-201 emerging from the hangar on roll-out day - RCAF Photo via Author’s Collection](image)

After the preliminaries, the Minister of National Defence, the Hon. George R. Pearkes, VC, addressed the gathering, extolling the virtues of the aircraft and emphasizing the historical significance of the roll-out. "I now", he said, "have pleasure in unveiling the Avro Arrow — Canada's first supersonic aircraft — a symbol of a new era for Canada in the air." 18 A large curtain across the entrance to the hangar at the end of Bay #1 was drawn back as the RCAF band played the RCAF March Past, revealing the impressive lines of the Arrow, huge for a fighter, with its high-wing layout accentuating its size. The airframe was completely white (with the exception of the radome) for anti-radiation flash protection. The roll-out was dramatic and it grabbed headline attention around the world.

On the very same day, however, the Soviet Union launched the world’s first satellite known as Sputnik. This was perhaps an unfortunate coincidence, as it served to highlight a growing controversy concerning the fate of the Arrow. The steadily rising costs were making the Canadian government uneasy and this was providing ammunition for critics. Along with these fiscal concerns, however, came a more involved argument concerning the future effectiveness of the Arrow as an aircraft. As an interceptor, the critics claimed, the Arrow was perhaps unsurpassed, "but", they asked "are interceptors, and aircraft in general not obsolete in the light of recent developments in missiles?"

Pearkes attempted to calm these fears in his speech at the rollout, saying, in part: 19

*Much has been said of late about the coming missile age and there have been suggestions from well-intentioned people that the era of the manned aeroplane is over and that we should not be wasting our time and energy producing an aircraft of the performance, complexity and cost of the Avro Arrow. They suggest that we should put our faith in missiles and launch straight into the era of push-button war. I do not feel that missiles and manned aircraft have, as yet, reached the point*
where they should be considered as competitive. They will, in fact, become complementary. Each can do things which the other cannot do, and for some years to come, both will be required in the inventory of any nation seeking to maintain an adequate ‘deterrent’ to war.

However, the aircraft has this one great advantage over the missile. It can bring the judgement of a man into the battle and closer to the target where human judgement, combined with the technology of the aircraft, will provide the most sophisticated and effective defence that human ingenuity can devise.

These views were not necessarily shared by others in key positions. General Guy Simonds, who had been Canada’s Chief of the General Staff in 1953, when the decision to proceed with the CF-105 project had been taken, became one of the most vocal opponents of the aircraft. His view was simple, that except for a very short intervening period, which did not justify the development of a new aircraft, missiles would soon replace bombers and all combat aircraft would be obsolete. That an enemy might retain both missiles and aircraft, or that the overlapping period might be quite long, or that the complementary nature of aircraft and missile systems might eventually be proved requiring the maintenance of both, were possibilities that “missile” proponents, such as Simonds, never adequately considered.
Conversely, there were, of course, many proponents for the CF-105 Arrow project. Air Marshal Hugh Campbell, Chief of Air Staff, stressed "an inherent flexibility in operations and promising future development potential" that the design provided. Former Air Vice Marshal John L. Plant, who was the Air Member for Technical Services when the Arrow go-ahead was given, and who was now president and general manager of Avro Aircraft Ltd., condemned the convenient use of the term "obsolete" as indiscriminate, since there is always "a better airplane on the drawing board behind". Wing Commander John Gellner, later a prominent Canadian aerospace analyst, attempted to reason calmly about the issue, pointing out that, for the peacetime duties of Air Defence Command, manned fighters were necessary. The RCAF at the time was making an average of two interceptions a day. In fact, of course, these "interceptions" were more of the nature of "investigations" as opposed to hostile interceptions as they usually involved straying airliners or private aircraft.20

The argument that the Arrow program was beyond the financial means of a "middle power" like Canada would have been perhaps more realistic, since the project was running up huge costs for the Canadian taxpayers. The additions of concurrent development programs for the powerplant, fire-control system and armament systems to the original airframe program had inevitably caused the price per unit to escalate. Had the development of the airframe and powerplant alone been pursued, supported by existing American fire-control and armament systems, the cost of the project might have been more acceptable. But the financial aspects of this controversy, which now had a firm basis in reality, were always accompanied by the arguments concerning the obsolescence of the Arrow as a weapons platform.21

On roll-out day in 1957, however, these arguments were no more than the first rumblings of the approaching storm. Work continued on the Arrow, but under a new government, John Diefenbaker's minority Progressive Conservative government, came to power that year. Among the planks in Diefenbaker's platform was a promise to reduce government expenditures, and the Arrow program was
obviously a prime target. The estimated cost per aircraft was variable according to the parameters being used, but it was inevitably increased by any reduction in the actual numbers likely to be ordered. From the early projections of 500 to 600 aircraft, the number required by the RCAF had first slipped to 400, still enough to equip nine regular and eleven auxiliary squadrons. It was later decided however, that the auxiliary pilots would not be able to handle such a sophisticated jet fighter and planned procurement was then cut to just 100 aircraft. A 1955 cost estimate for the Arrow had been CA$2.6 million per copy but this had now been completely overtaken by events.

First Flight - After several postponements, the CF-105 Arrow's first flight was made on 25 March 1958. Jan Zurakowski, Avro Canada's Chief Development Pilot, had the honour of making the inaugural flight. The armament bay of the Arrow (serial 25201, code “RL”) was packed with instrumentation for the transmission of signals to a telemetry van. The CF-105 was accompanied by two chase aircraft: a CF-100 piloted by ”Spud“ Potocki, with Avro photographer Hugh MacKechnie and his still and cine cameras, in the navigator’s seat, and a Sabre flown by F/L Jack Woodman, whose helmet had been fitted with a special adapter to allow for the mounting of yet another cine camera.

At 0949 hours, the two chase aircraft were circling over the end of runway 32. The CF-100 then flew parallel to the runway on the east side, while the Sabre did the same on the west side. As the two aircraft flew low alongside the runway, the Arrow gathered speed and took off, climbing towards the north, using only 915 m (3,000 ft) of the 3,353 m (11,000 ft) available to become airborne.

Jan cautiously increased the speed of the Arrow to 480 km/h (300 mph) and to a height of 3,050 m (10,000 ft). After briefly flying over Malton at varying altitudes while checking the response of controls, engines and testing the undercarriage and air brakes, he returned for an uneventful landing on runway 32. The drag-
chute billowed and filled, slowing 25201 almost to a stop before being jettisoned. Upon leaving the cockpit, he reported "good flying qualities, no surprises, no trouble" and also made the general comment, "it handled very nicely."  

The Flight Test Program - The flight test program was originally scheduled as an eight-phase program. The first series of tests were designed to evaluate the basic handling qualities of the aircraft, to evaluate the flight control system, to check instrumentation and telemetry, and to confirm the safety of flight under potentially adverse conditions. The initial series of flights involved pre-production testing and systems development employing the first five Mk 1 aircraft which were equipped with the Pratt & Whitney J75 engines. The 6th aircraft was to be the first Mk 2 version equipped with Iroquois engines. Unfortunately, only a portion of the initial Phase I pre-production testing was actually completed. The first five aircraft flew a total of 66 flights for a grand total of 70 hours and 35 minutes flight time (NB - 7 hr 51 min of this total was at supersonic speeds.)

The following is a summary of the initial tests and flights completed in this year long period:  

<table>
<thead>
<tr>
<th>Test Description</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>First engine runs</td>
<td>04 Dec 1957</td>
</tr>
<tr>
<td>First taxi trials</td>
<td>24 Dec 1957</td>
</tr>
<tr>
<td>First flight (a/c 25201)</td>
<td>25 Mar 1958</td>
</tr>
<tr>
<td>First flight (a/c 25202)</td>
<td>01 Aug 1958</td>
</tr>
</tbody>
</table>
First flight (a/c 25203) 22 Sep 1958
First flight (a/c 25204) 27 Oct 1958
First flight (a/c 25205) 11 Jan 1959
Final flight(s) (a/c 25201 & 25204) 19 Feb 1959

A summary of flights by aircraft tail number is as follows:

<table>
<thead>
<tr>
<th>No. of Flights</th>
<th>Flight Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>25201</td>
<td>25 hr 40 min</td>
</tr>
<tr>
<td>25202</td>
<td>23 hr 40 min</td>
</tr>
<tr>
<td>25203</td>
<td>13 hr 30 min</td>
</tr>
<tr>
<td>25204</td>
<td>07 hr 0 min</td>
</tr>
<tr>
<td>25205</td>
<td>07 hr 40 min</td>
</tr>
<tr>
<td>Total</td>
<td>70 hr 30 min</td>
</tr>
</tbody>
</table>

(A complete record of the individual flights by aircraft tail number can be found in Appendix 1)

Because of the maiden flight, Jan Zurakowski’s name is indelibly attached to the Arrow. Although technically too old for “high performance” flying, (the normal limit then was 40 years of age) Jan continued flying on the Arrow until he was 44. “Spud” Potocki then took over most test flights and, in fact, had the most flight hours on the Arrow of any of the four test pilots. The Arrow achieved supersonic speed on its third and seventh flights, reaching Mach = 1.5 at 15,250 m (50,000 ft). The highest speed recorded Mach = 1.97 / 1.98, was just short of the design max of Mach 2.0. About 95% of the flight envelope was explored and handling was found to be generally satisfactory, although not flawless. The aircraft flying characteristics were similar to that of other delta wing aircraft like the Gloster Javelin or the Convair F-102 Delta Dagger, but the CF-105 Arrow was said to have a more positive response to control movement.

Jan Zurakowski had already successfully completed the first portion the test-flying program when RCAF test pilot F/L Jack Woodman made his first familiarization and initial assessment flight. While Jan had stated the aircraft handled “very nicely”, Jack Woodman was more critical indicating while that at certain speeds and altitudes the Arrow flew as well as any aircraft he had ever flown, at other points, it was very sensitive on the controls and difficult to fly. For instance, on his first flight he reported that at low and high indicated airspeeds, the aircraft behaved reasonably well, with the controls being effective, responsive and
with the aircraft demonstrating positive stability. However, due to the sensitivity of the controls, the aircraft was difficult to fly accurately. The following recollections come directly from an article later written by Jack Woodman:

On my first flight, I reported that at low and high indicated airspeeds the airplane behaved reasonably well, the controls being effective, with good response, and the aircraft demonstrated positive stability. However, due to the sensitivity of the controls the aircraft was difficult to fly accurately. At high Mach numbers, I reported the transition from subsonic to supersonic speed to be very smooth, compressibility effects negligible, and the sensitive control problem experienced at lower speeds and altitudes eliminated. The aircraft, at supersonic speeds, was pleasant and easy to fly. During approach and landing, the handling characteristics were considered good; approach speed was 190 kts [352 km/h]; touchdown was at 165 kts [305 km/h], drag chute was deployed at 155 kts [287 km/h] and the aircraft rolled the full length of the runway. Attitude during approach was approximately 10 deg, with good forward visibility.

On my second flight, I reported that the general handling characteristics of the Arrow Mk 1 were much improved. The yaw damper was now performing quite reliably, although turn co-ordination was questionable in some areas. The roll damper was not optimized as yet, and longitudinal control was sensitive at high IAS.

On my sixth and last flight, I reported longitudinal control to be positive with good response, and breakout force and stick gradients to be very good. Lateral control was good, forces and gradients very good, and the erratic control in the rolling plane, encountered on the previous flight, no longer there. Directionally, slip and skid were held to a minimum. At no time during the flight was there more than 1 deg of sideslip and the problem of turn co-ordination appeared to be eliminated at this point. Final approach to landing was at 175 kts [324 km/h] and a 3-deg glide-slope; attitude was approximately 12 deg, touchdown was at 160 kts [296 km/h] and the landing roll was estimated at 6,000-6,500 ft [1,830-1,980 m] with little or no braking.

However, he also further stated of the test program “that excellent progress was being made in the development of the Arrow.”

"Spud" Potocki who flew the Arrow described a typical flight as follows:

[On takeoff] the initial acceleration is not too impressive, unless AB [afterburner] is used. Keep the heading at all cost by small and rapid brake application, until about 80 — 100 knots [148-185 km /h] is reached. A brake connection has been made at about 110 knots [204 km/h], so don’t worry too
much about this. Just keep that heading, and watch the ASI [airspeed indicator]. At 130 knots [241 km/h] apply very gentle pull on the stick and see that nose comes up. Sometimes a bounce is experienced just after initial elevator movement. The nose of the aircraft has only to rise about 5 degrees to get takeoff attitude. Therefore, only small elevator movement is necessary to obtain this. Once the nose boom comes up to horizon, hold that attitude. Now at this stage without AB the aircraft will ride on the wheels. If there is any tendency to depart from precise heading, rudder bar should be used for corrections, but only with care, as the feel of rudder is such that will give higher responses for the same force as speed increases, which is in opposition to Sabre and CF-100 feel. If the aircraft develops a small deviation from heading, accept this, provided the judgment is made correctly that the wheels will leave the deck before coming off the runway. But this can be done just prior to unstick.

The aircraft unsticks at about 160 — 170 knots [296 - 315 km/h] and must not be pulled off the runway, or it will come down again on wheels and lift is lost by elevator deflection. After unstick, climb away, watching the sideslip or ball indication, and correcting accordingly on rudder, to eliminate sideslip. The gear must be raised before 200 knots [370 km/h] is attained. This means steepening the attitude up after unstick, or slightly throttling back, prior to gear up selection. As the aircraft unsticks, the airframe will vibrate noticeably. As the gear comes up, marked directional disturbances are felt. If allowed to develop without correction by rudder, some rolling effects may follow, the lateral control being rather heavy at this speed to suppress the roll. The best thing to do after unstick is to select normal gear-down damper on the trigger. This will tend to eliminate yawing tendencies.

After gear is up, vibration ceases and smooth flight begins. The elevator control is somewhat heavy, so is aileron, both break-out forces being about 4 lbs [2.3 kg]. The elevator, in addition, has a steep feel slope for small control movements. The first thing to do is to trim the aircraft to fly without using force. Then select gear-up mode on the right hand switch. The sideslip elimination is very good and, once gear-up mode is selected, rudder bar can be left alone. The next thing to do is to trim the aircraft with the damper to give zero sideslip either on the ball or the sideslip indicator. Then the aileron and pitch trim should be obtained. If throttling back was necessary before wheels-up selection, the throttles should have been opened right up.

The air conditioning makes lots of noise in the cockpit and, as the oxygen is breathed, this noise level seems to fluctuate. This is normal. Prior to wheels locking up, the automatic brake is applied to stop wheels rotating. This results in brake pedals being depressed away from the pilot's foot. As the pedals come down, there may be some rudder bar motion connected with it. On the climb, attain
speed of approx. 300 — 350 knots [556 - 648 km/h] and establish climb at that speed.

The view from the aircraft on the climb is quite good and the attitude in military thrust is not at all excessive. There is noticeable lag in response on both elevators and ailerons, but this is, at present, quite normal. When reaching height of 25,000 feet [7,620 m], aim to hold 0.85M, or thereabouts, or otherwise very slow climb performance will result from this, particularly if speed is allowed to fall below 0.7M.

Subsonic Flight Without Damper

The aircraft has less directional stability than long tail arm aircraft such as the Sabre or CF-100. Hence, it is easier to induce sideslip. The rudder, of course, is the primary source of sideslip inducement, but also aileron. The aileron drag of down-going aileron creates an out-of-balance directional condition resulting in yaw (called adverse aileron yaw, as it is, in direction, acting against the intended turn). This is very prominent in this aircraft without the dampers and, if aileron is worked fairly vigorously to maintain level flight, continuous reversed sideslip will appear without actually touching the rudder. In the highly-swept aeroplanes the effect of sideslip always results in strong dihedral effect. That is to say, if the aircraft nose is yawed to starboard, the port wing will have a tendency to come up in a roll. This is magnified at high angles of incidence, or at certain Mach numbers and attitudes. So that sideslip due to any cause will always result in a tendency to roll which, if suppressed by the aileron, will generate more sideslip. The main object in flying the aircraft without the damper is, therefore, to use co-ordination of rudder and aileron at all times, if sideslip is to be kept under control. If the aircraft rolls to port, due to starboard sideslip, starboard rudder and starboard stick movement should be used to regain level flight. The essential thing, however, is to remember that accurate directional trim is essential in this type of flight. So, prior to disengaging the dampers, one should ensure that, directionally, trim is as near as perfect.

Subsonic Flight with the Damper in Yaw Only

This is quite straight forward, particularly if the gear-up mode is engaged. Any turn, in this case, is automatically co-ordinated. This results in flight without sideslip. For the damper gear-down mode, the transient directional disturbances are well-damped, but, in a steady turn, some sideslip will be evident to the pilot (normally port sideslip in a turn to port, and vice versa). This must be eliminated by small rudder input, which should be removed once straight flight is achieved.

Supersonic Flight

Whilst it is possible at certain altitudes to achieve supersonic flight without afterburning, it is recommended that the AB is used for supersonic flight. The transition from subsonic to supersonic flight is characterized by small disturbances in roll, which might, or might not be detected at about
0.92. Also, pitch may appear a bit touchy. Supersonic penetration occurs at 0.95 and can be detected on instruments by a large jump in height indication (approximately 1500 feet [450 m]).

Once the aircraft settles in supersonic flight, the control in pitch and roll improves markedly due to general reduction in sensitivity in control. The flight is much steadier and easier, provided the damper in yaw is used. Without the damper the sideslip will be generated with ease, and must be eliminated by co-ordination of controls as previously mentioned. Past certain areas, the pilot will experience utmost difficulty to fly the aircraft clean (without dampers). Therefore, no clean mode (without the damper) is allowed, unless specially briefed. As no rolling manoeuvres have been done yet on the aircraft, and no excessive manoeuvring in pitch, this is, at the present, prohibited.

The acceleration in supersonic flight is rapid. Although no marked trim changes accompany this, it is difficult to fly aircraft accurately on instruments to any accuracy — at first. This particularly refers to the Mach number or ASI stabilization. The deceleration from high supersonic flight is rapid if the afterburner is closed. The engine should, however, never be throttled back past 90% RPM until the speed falls off to subsonic value. (The tests on the intake behaviour after rapid closing of throttle have not been completed as yet.) The air brake supersonically does not have much effect. It must be appreciated that any turn gives increased drag, and Mach number may tend to fall. (Special briefing must be obtained before any appreciable g is pulled on aircraft in excess on 1.5 indicated g at high Mach numbers.)

**Descent**

Throttle back to approx. 80% RPM. Extend air brakes and descend at 0.8 — 0.9 MN [Mach number]. Occasionally, some intake rumble may be experienced, which manifests itself in the form of high frequency vibrational noise coming from sides of cockpit. As the speed is reduced with undercarriage up (at max. landing weight — 56,000 pounds [25,401 kg]), towards 185 knots [343 km/h] first indication of buffet is felt in the form of some airframe vibration. This will tend to increase in intensity from 170 knots [315 km/h]. ...Lateral behaviour becomes progressively heavier as the speed is reduced (characteristic of spring feel), because the aileron movements needed for balanced flight are more pronounced. The control in pitch also becomes more sluggish and much
attention is needed to keep accurate height by judicious throttle manipulation (approx. 90% RPM are needed at 160 knots ASI [296 km/h]) to maintain altitude. If the power is reduced, very high rates of descent would result. With the gear down, the vibration is felt through the airframe. This is directly dependent on the airspeed. It is severe in some aircraft at 250 knots [463 km/h], moderate at 200 knots [370 km/h] and light-to-moderate at speeds around 180 knots [333 km/h]. More drag resulting from the gear requires more throttle to hold altitude (160 knots [296 km/h] approx. 90% RPM). Provided the damper is used, there is no problem to fly at speeds around 170 knots. Without the damper, conditions are much more difficult, and very careful handling is necessary, particularly directed towards elimination of sideslip.

**Approach and Landing**

Downwind should be entered at 250 knots [463 km/h], air brake extended and speed reduced to 200 knots [370 km/h] ASI when the gear can be selected down. There is very little trim change connected with gear lowering, but height will be lost unless power is immediately increased for level flight. Check for correct gear indication, as well as external check by the chase plane. A wide circuit is recommended for approach. Before turn on the base leg is made, the damper mode gear switch should be selected to gear down mode. On receiving green light indication, turn commenced on base leg. During the turn it will be necessary to co-ordinate the controls to eliminate sideslip. (In the gear-down mode this is purposefully allowed to enable the pilot to correct for drift prior to touchdown.) Quite large rudder force may be necessary to achieve this sideslip elimination. Once a straight run is achieved, it will be found that the view on approach is quite limited. Therefore, very careful approach must be made. The speed should be gradually reduced to 180 knots [333 km/h] and held at that figure. (If higher approach speeds are used, long run results which, in case of parabrake failure, may lead to overrun of the runway.) A cross-check should be made on the
incidence indicator which, at that speed and max. landing weight (56,000 lbs [25,401 kg]), should register approx. 12° – 13°.

The beginning of the runway should be just visible over the nose of the aircraft which, for convenience, may be very slightly moved to one side of the windscreen just outside the divider panel. This is recommended, since it is felt that some familiarization is necessary before one is fully accustomed to the use of divider panel. Up to about 1 mile from the runway beginning, elevator and power adjustments should be made to achieve steady descent of approx. 1,000 ft/min [305 m/min], aiming to touch down about 500 feet [152 m] from beginning of runway. As runway is approached, the thrust setting for the rate of sink should be kept steady and the aircraft allowed to keep sinking until a gradual check is made on sinking rate, as the ground is approached, with the elevator. At this time the attitude will increase and, as the aircraft touches the ground, the throttle should be gradually closed. Beware of closing throttles too early, as the aircraft will sink very rapidly and heavy landing will result.

If the speed is excessive after crossing the runway, any elevator manipulation after touchdown may send the aircraft into the air again and heavy porpoise may result. In this case the stick should be immobilized centrally and the aircraft allowed to damp the porpoise by itself. Any tendency to chase the aircraft motion in this case will result only in aggravating the condition.

After touchdown the nose wheel should be put gently down on the runway and, once firmly down, the parabrake streamed. It is extremely important that the location of the parabrake handle be checked several times before takeoff, so that there is no need of visual check after landing. The parabrake is very effective, but often erratic in behaviour and has, in the past, given severe swing tendency, which must be instantaneously corrected with brake. Maintain straight run until aircraft slows down, using mainly brakes, as rudder effect is negligible with falling speed and there is no nose wheel steering. The parabrake should be jettisoned when clear of runway.

There was only one flight where a test observer flew in the rear seat; all other test flights were made solo or with test pilots in both cockpits. The test observer, Mr. D.E. Darrah, flew in Arrow 25203 on 19 February 1959, in the second-to-last ever flight of any CF-105.
Two minor landing accidents marred the otherwise highly successful, ongoing test flight program. The first involved aircraft 25201 flown by Jan Zurakowski on 11 June 1958. The accident was due to the left-hand landing gear not being fully extended when it was selected down. As a result, it was not parallel to the aircraft’s line of flight and remained cocked at an angle, even though no indication had been provided to the pilot. During the landing run, Jan realized that the aircraft was pulling to the left and he could not maintain direction. Suspecting that the braking parachute had not opened evenly, he jettisoned the chute but with no improvement. The aircraft exited the runway at a speed of approximately 48 km/h (30 mph) and the undercarriage collapsed on contact with the soft ground.

On investigation, it was confirmed that the left undercarriage leg had not completed the proper lowering cycle due to a broken retracting chain which jammed the system and during the landing run the wheels were at about a 45° angle to the direction of travel, producing a higher drag than the brakes on the right side could compensate for. With the decrease of speed, rudder effectiveness decreased and the aircraft could not be prevented from changing direction. The undercarriage main extension spring and chain mechanism were subsequently re-designed.

A second accident took place with aircraft 25202, flown by “Spud” Potocki. During the landing roll out, all four wheels skidded and the tires burst. The pilot consequently lost directional control and the aircraft again ran off the runway, damaging the right undercarriage leg. The pre-production aircraft were not fitted with any anti-skid systems and the follow on investigation initially suggested pilot error, as he was thought to have simply applied too much braking pressure and locked the wheels. The RCAF consequently demanded that Avro remove test pilot “Spud” Potocki from the program.

As it later turned out, during this landing the aircraft had experienced a small vibration on touch down which resulted in an inadvertent electrical signal to the stability augmentation system which, in turn, caused a full down deflection of the elevators. The Arrow’s elevators were large and when deflected fully down, acted as powerful flaps, increasing wing lift so much that only 20% of the aircraft weight was on the main wheels. Potocki was not aware of this and normal application of the brakes locked the wheels.
Once the problem had been properly diagnosed, a solution was quickly engineered and the program resumed.

The test flights were virtually all conducted from Avro's facility in Malton, Ontario. The exception was one flight which had to be diverted to RCAF Station Trenton because of a problem on the runways in Malton. The aircraft overnighted in Trenton and was flown out the next day.

None of the first five aircraft were equipped with an armament system. Instead each of these aircraft was equipped with a sophisticated data acquisition system. The Arrow data acquisition and handling system was composed of an airborne multi-channel recorder (magnetic tape), phono panel, oscillograph, an airborne radio telemetry link, a mobile telemetry receiving station, and a mobile data reduction unit. The aircraft armament bay, which was a removable self-contained unit, was used to house all of the airborne instrumentation.

This instrumentation system proved to be a constant source of trouble during the Arrow test program. “During the first series of flights, the system was plagued with a number problems that were probably due to the thousands of wires and connections running to the instrument pack”...“these problems were never really resolved, and many a flight was delayed because of this system.” 26
On the day the Arrow program was cancelled, Arrow No. 6 (25206), the first of the Iroquois equipped Mk 2s, was 98% complete and was an estimated two weeks away from its first flight. Performance results collected on flights of five Arrow Mk. 1 aircraft fitted with Pratt & Whitney J75 engines were used to estimate the performance of the Mk. 2 Arrow fitted with Iroquois engines. The Arrow with J75 engines was heavier than with Iroquois and had to be ballasted for the correct centre of gravity position; a Mk. 2 with Iroquois engines did not need ballast and was about 2,268 kg (5,000 lbs) lighter, and had 40 to 50% more thrust. It was estimated that it had a high chance of beating the world speed and altitude records held at that time by the United States.

Unfortunately, however, at the time of its cancellation, the Arrow was still a unproven design and years away from becoming an effective military weapons system. The RCAF had calculated that it would require 1,700 flight hours (an optimistic assessment giving the complexity of its systems) to fully clear the aircraft for operational service. At the time of cancellation, the five prototypes had accumulated a total of just over 70 hours (and two, albeit minor, accidents) in the 11 months since the first airframe took to the air. This lack of progress was also a major source of friction between Avro and the RCAF, when the latter discovered that the F-106 Delta Dart test program was achieving figures as high as 100 hours per month.
Another significant problem was that Avro engineers had designed many of the mechanical components as though they were for a "one-of-a-kind" research aircraft rather than to meet military operational availability and maintainability requirements. For example: 27

- Access to the control surface actuators could only be obtained by removal of control boxes that were held on by 400 close-tolerance, torqued fasteners for the ailerons, 372 for the rudder and 500 for the elevators.

- These parts were not interchangeable, but rather custom fitted to an individual airframe. A replacement would have to be clamped in place. For fastener holes that did line up, the fasteners could be re-installed. For those that did not line up, the holes had to be drilled oversize, tapped, and have oversize fasteners installed. It was estimated that removal and replacement of any one of these control boxes would require about 70 man-hours, but the specified inspection interval was only 50 hours.

These are only few examples of maintain-ability / interchangeability problems, and as early as July 1956, the RCAF had informed Avro that these problems were entirely unacceptable. Avro's solution was to increase the inspection intervals rather than to make the components interchangeable. It had been these and other maintenance-related problems that were in part responsible for the glacially slow pace of the test flying.
It is not enough merely to place the interceptor in the vicinity of its target; once there, it has to find and destroy it. The RCAF had been banking on RCA’s Astra / Sparrow missile system, and when it was cancelled in late 1958, Avro was left scrambling to fit the Hughes MA-1 / Falcon system already used in the F-106 into RL-206 which was itself several months away from flying. An initial trial installation of the Iroquois engine also revealed that it did not quite fit as planned. Although not a major problem, these issues continued to slow the program and added to the rising costs.

Follow-on Testing and RCAF Basing Plans

As previously mentioned, the Arrow program was then unusual in that the program skipped over the normal prototype stage and moved directly instead to five pre-production aircraft. A further 29 Arrow Mk 2 aircraft were also in various stages on the production line at the time of the programs cancellation. (Further details of the plans for each of these aircraft can be found in Appendix 2.)

Consequently, RCAF plans for follow-on testing and for the eventual service introduction were well developed. The flight test program for the Arrow was to have been divided into eight phases, of which the first three were for contractors test and development evaluations including a preliminary RCAF evaluation and the other five were for the RCAF’s detailed operational test and evaluation purposes. The fourth phase was to consist of RCAF performance and handling trials. Next came an all-weather evaluation in the fifth phase. The sixth phase was an intensive flying trials program followed by the aircraft weapons system evaluation in phase seven. Finally, phase eight operational suitability trials were to have confirmed the complete weapon system and would have developed maximum-effectiveness techniques for operational deployment.

Within the RCAF, the responsibility for the overall program testing, including phases 2,4,5 and 7, lay with the Central Experimental Proving Establishment (CEPE) located in Ottawa. However the majority of the testing including phases 4, 5 and 7 was intended to be conducted using the CEPE facility at RCAF Station Cold Lake, Alberta. This station’s main lodger unit was the Aircraft Armament Evaluation Detachment (AAED) of CEPE and it was in fact the first unit to be based at Cold Lake. It made use of a large weapons range area and a fully instrumented test range around Primrose Lake near the southern boundary of the range area. The other RCAF unit involved in the testing process was the Operational Proving Unit (OPU). This little known unit was formed at RCAF Station Uplands. The OPU was to have been equipped with nine Arrow Mk 2 aircraft in addition to T-33, F-86 and CF-100 aircraft by the summer of 1962. Using these various aircraft, the OPU would have verified the operational suitability of the Arrow in simulated combat conditions. However, the unit formed and “then quietly stood down when the aircraft they were formed to operate, the Avro Arrow, was cancelled.” CEPE and its AAED sub-unit went on to become the Aerospace Engineering Test Establishment (AETE) still located today in Canadian Forces Base Cold Lake.

As part of the weapons testing phase, the Arrow aircraft would have fired missiles on the Primrose Test Range. Included in this phase were firings against live targets in the form of Ryan KDA-4 Firebee drones which would have been launched from Lancaster Mk 10DC drone-carrier aircraft. The Firebee drones were acquired specifically for planned testing of the Sparrow II missiles for use on both the CF-100 and CF-105 aircraft. In the addition to the Lancaster aircraft, used as a launching platform and control mothership for the drones, H-34 helicopters were also stationed in Cold Lake to act as drone recovery aircraft.

The RCAF was also absorbed with planning new infrastructure for the program including new alert hangars, missile storage, and training facilities amongst others. The RCAF was also grappling with the possibility of forward deploying the CF-105 to more northern operating locations. The shorter runways
there prompted studies of runway and hangar requirements, arresting gear, and short take-off assistance as well as studies for longer range and increased fuel tankage for the airframe itself.

The massive size of the CF-105 necessitated various studies of the hangar requirements and support equipment necessary to sustain the aircraft fleet in harsh conditions. These studies of alert hangar arrangements are just two examples - (Avro Drawings via CA&SM)
The top drawing details the clearances required for servicing the CF-105 Arrow Mk 2 and the bottom drawing illustrates a potential arrester hook installation for the aircraft - (Avro Drawings via CA&SM)
Political issues

From as early as 1953, some senior Canadian military officials within the various Chiefs of Staff had begun to question the program. It was not until June 1957, however, when the governing Liberals lost the federal election and a Progressive Conservative government under John G. Diefenbaker took power, that the aircraft’s fate began to noticeably change.

Of prime concern in Ottawa were the mounting costs. The CF-105 Arrow appeared to be far from being operational and there were questions of costly re-engineering work that continued to occur. Orenda’s Iroquois engine proposed for the Mk 2 production aircraft was also lagging behind schedule. Worse off was the Astra fire control system — it seemed to be getting nowhere. Naturally, almost any technical problem could be overcome by pouring in money. But Ottawa was weary of Avro Canada overruns. What had begun as a CA$1.5 million fighter had grown in steps to CA$4 million, with ranges between CA$8 million to CA$13 million being forecast for a smaller RCAF production run. In comparison, a later model CF-100 Mk.5 had cost just CA$700,000 and the cost of the F-106 Delta Dart was CA$5.59 million.

John Diefenbaker had campaigned on a political platform of reining in what the Conservatives claimed was "rampant Liberal spending". The Arrow was not the only major industrial project targeted during the campaign; others such as the "million dollar monster" postal-sorting computer produced by Ferranti Canada were also singled out for political "scorn".

In August 1957, the Diefenbaker government signed the North American Air Defense (NORAD) Agreement with the United States, making Canada a partner with the American air defence command and control system. The USAF was in the process of completely automating their air defence system with the Semi-Automatic Ground Environment (SAGE) project, and offered Canada the opportunity to share this sensitive information for the overall air defence of North America. One aspect of the SAGE system was control of nuclear-tipped BOMARC anti-aircraft missiles. This led to studies on basing BOMARCs in Canada in order to push the intercept line further north. The planned deployment was found to be extremely costly. In 1958, the new Minister of National Defence (MND), George Pearkes, reported that:28

The introduction of SAGE in Canada will cost in the neighbourhood of $107 million. Further improvements are required in the radar... NORAD has also recommended the introduction of the Bomarc missile... will be a further commitment of $164 million... All these commitments coming at this particular time... will tend to increase our defence budget by as much as 25 to 30%.

The Bomber Re-assessment 29 In the early 1950s, the US had developed a top-secret spy plane, the Lockheed U-2, which was first flown in August 1955. The Central Intelligence Agency wasted no time flying the U-2 brazenly into Soviet air space to collect first hand intelligence. The first operational flight departed Wiesbaden, West Germany on 4 July 1956 and penetrated as far as Moscow on its mission. Over the next four years, some 30 U-2 overflights, plus others skirting the Soviet borders, were then made. Flying as high as 21,946 m (72,000 ft), the U-2 at first seemed invulnerable but the Soviets
eventually countered the threat by firing salvos of surface-to-air missiles along the flight path of these spy flights. On 1 May 1960, a U-2 piloted by CIA pilot Francis Gary Powers was shot down by a barrage of these missiles and the US overflights abruptly came to an end. With the help of these flights, however, detailed assessments of the Soviet's true capabilities emerged.

The ungainly looking Lockheed U-2 spy plane was able to provide US intelligence services with a much more accurate picture of the Soviet bomber threat - (Photo credit: open source Wikipedia)

In September 1957, then-top secret US National Intelligence Estimates (NIE) reported that the Soviets had fired at least 275 short / intermediate range ballistic missiles and had already test-fired Inter-Continental Ballistic Missiles (ICBMs). More bad news came with the December 1957 NIE report which suggested that the Soviets likely would have 100 operational ICBMs as early as mid-1959 and perhaps 500 by mid-1960.

The U-2 missions also provided enough data about the true Soviet bomber threat to likely sound the "death knell" for projects like the CF-105. In his history of the Lockheed U-2, author Jay Miller concluded:

The results of the Agency's overflight efforts were indeed impressive. During the first few missions ...U-2 flights quickly revealed that the long-argued Soviet jet bomber threat, represented by the Myasishchev Mya-4 Bison and Tupolev Tu-95 Bear, was relatively small. They also revealed, however, that Soviet activity in the ICBM field was accelerating, and that forthcoming missile developments would have to be countered, and rapidly.

The need for a defence against ballistic missiles consequently became much more of a Western priority. The existence of Sputnik had also raised the spectre of attack from space, and, as the year progressed, word of a "missile gap" began spreading. An American brief of a meeting with MND George Pearkes records that he "stated that the problem of developing a defence against missiles while at the same time completing and rounding out defence measures against manned bombers posed a serious problem for Canada from the point of view of "expense". It is also inferred Canada could afford the Arrow or the SAGE with the BOMARC, but not both. The costs for the Arrow program were continuing to climb. In May 1958, Avro was reporting the following expenditures for the project:  

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic development costs</td>
<td>$52,402,975</td>
</tr>
<tr>
<td>Product improvement and flight test</td>
<td>$54,013,803</td>
</tr>
<tr>
<td>Tooling/tooling improvement</td>
<td>$30,929,886</td>
</tr>
<tr>
<td>Manufacturing: 8 aircraft, spares, publications, ground support equipment</td>
<td>$64,787,839</td>
</tr>
<tr>
<td>Manufacturing: 29 follow-on aircraft</td>
<td>$148,272,790</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>CA $350,407,293</strong>*</td>
</tr>
</tbody>
</table>

*Note - these costs were exclusive of the Iroquois, Astra and Sparrow II systems
The images above, and the first one on the next page, depict the first five Mark 1 Arrows - (RCAF & Avro Images via the Author's Collection)
The RCAF HQ was now seriously concerned about rising costs and other problems, such as the slow pace of test flying, Avro's lack of concern over maintainability issues and shifting delivery dates (e.g. only five of the eight aircraft promised for December 1958 were actually delivered). In addition, senior officers

*The first of the Mark 2 Arrows, RL-206, was in the final finishing stages on the production line at time of the program’s cancellation - (Avro Image via the Bill Upton Collection)*
were deeply split over the threat from the manned bomber and the issue of missiles versus manned interceptors. A study was undertaken on the option of canceling the contract after the delivery of the first 37 aircraft and using the latter to form just two squadrons of 10-12 aircraft each in the Ottawa area. This study concluded that the magnitude of the logistic support that would be required far exceeded the operational value of these two squadrons. The minimum operational nexus was calculated as five squadrons (i.e. 50-75 aircraft).

At the Cabinet Defence Committee (CDC) meeting on 15 August 1958, the MND, George Pearkes outlined the government’s position: 32

The present programme, which called for the re-equipping of the nine RCAF all-weather squadrons in Canada with CF-105 aircraft, presented a requirement, with training and backup, for a production order of 169 CF-105 aircraft at a forecast total expenditure of over two billion dollars during the period 1959-1960 to 1963-1964. In consideration of the heavy costs of this program, and of the need for making provision for such future requirements as defence against inter-continental ballistic missiles, the Chiefs of Staff had given consideration to several alternative plans. They had advised that production of 60 CF-105 aircraft for the equipping of five squadrons was unacceptable because the costs per aircraft for this smaller number would be increased to $9 or $10 millions, not including amortization of development and preproduction costs. Consideration had also been given to the hope that a return could be obtained from the funds already spent on the project, but this plan was considered unacceptable because even at a cost of about $475 million not enough aircraft would be provided to form and maintain one effective operational squadron.

Pearkes then stated that he and the CDC agreed that the only feasible course of action left was to cancel the CF-105 Arrow program in favour of an alternative American interceptor and to begin negotiations with the U.S. to site two of its projected chain of BOMARC bases in Canada along with its complementary SAGE system, and additional heavy and gap-filler radars, all to be cost-shared with the US. It was explained that such negotiations would necessarily also include an arrangement whereby the US would supply nuclear weapons for the BOMARCs and the interceptors. Pearkes added that the decision to recommend cancellation had been influenced by a number of factors: the heavy financial burden of the project; the rapid Soviet shift of resources from bombers to ICBMs; the availability of comparable American interceptors at approximately half the cost of the Arrow; the cheaper and more efficient nature of missiles versus aircraft; and the lack of any foreign interest, especially from the US, in purchasing the Arrow. 33

But the CDC refused to accept Pearkes’ recommendation to cancel the program and deferred any decisions. Pearkes tabled the cancellation request again in September, and also formally recommended installation of the BOMARC missile system. The latter recommendation was accepted but, again, the CDC again refused to cancel the entire Arrow program. The CDC wanted to wait until a major review of the project scheduled for 31 March 1959. Efforts to continue the CF-105 Arrow program through cost-sharing with other countries were then explored with renewed impetus.

Foreign interest

Canada had already tried to market the Arrow project, primarily to the US and Britain. But the aircraft industry in both these countries were considered in the national interest and the purchase of foreign designs was rare; moreover both the US and the UK had also cancelled a number of their own projects.

Promisingly, from 1955 onwards, the UK had already shown some clear interest in the Arrow. In April 1956, the UK's Air Council had recommended a purchase of up to 144 CF-105 Arrows for the Royal Air
Force (RAF) to serve alongside the Saunders-Roe SR.177 mixed-power interceptor. The proposed powerplant for an RAF version of the Arrow was either the the Bristol Olympus 7R with a rating of 75.6 kN (17,000 lbf) dry, or 105.4 kN (23,700 lbf with afterburner), the Rolls-Royce Conway at 81.6 kN (18,340 lbs dry), or 132.1 kN (29,700 lbf with afterburner), or the de Havilland Gyron at 86.7 kN (19,500 lbs dry), or 124 kN (28,000 lbs with afterburner). Options for procurement of the Arrow either directly from Canada or by setting up a production line in the UK, were studied; the unit price per aircraft built in the UK being estimated at £220,000 each for a production run of 100 aircraft. This CF-105 purchase was originally intended to serve as a “stopgap” solution until the UK's own F.155 interceptor project came to fruition; however with the F.155 due in 1963 and the Arrow not likely to reach the RAF before 1962, there appeared to be little point in proceeding. Then, in 1957, the infamous UK Defence White Paper, described as "the biggest change in [UK] military policy ever made in normal times", led to the cancellation of almost all British manned fighter aircraft (including the F.155) then in development. The release of this White Paper completely curtailed the likelihood of any CF-105 purchase. By January 1959, the UK's final answer to any CF-105 purchase or co-manufacturing option was a firm “no” and instead a counter offer was made to sell Canada the single-seat English Electric Lightning interceptor.

In America, the USAF had already developed three aircraft with performance intended to be broadly similar to the Arrow, originally as part of their previous “1954 Interceptor” project—the McDonnell F-101 Voodoo, the Convair F-102 Delta Dagger and the F-106 Delta Dart. Two more advanced interceptors, the Republic XF-103 and the North American XF-108, were still under development, although both were later cancelled in the early design and mock-up phase as a result of the latest intelligence assessments. In the end, the US decision to cancel their own interceptors, along with a firm rejection of an offer to procure Arrows for their own use, added weight for the justification of canceling the Arrow in Canada.

Additionally, acting on media speculation that the Iroquois engine program was also in jeopardy of being cancelled, the French government, whose original intention was to place a major order for 300 Iroquois engines for the Dassault Mirage IV bomber, chose to end negotiations with Orenda in October 1958 and opted instead for an upgraded version of the indigenous SNECMA Atar turbojet engine.

Cancellation

With these possible solutions gone, Diefenbaker and his government had to face the hard decisions. The Canadian edition of Time magazine stated that up to a week before Diefenbaker's final public address dealing with the fate of the Arrow, some cabinet ministers still supported full production. In the end, the
Prime Minister called his ministers to Ottawa to discuss the problem — recalling one home from the United Nations and others from the Commonwealth Trade Conference in Montreal.

*The Avro Canada assembly line was in full swing right up until the day of cancellation - (Avro Image via the Author’s Collection)*
On 23 September 1958, the Canadian prime minister issued a statement to the press outlining his policy on the CF-105. Production would be postponed, although development would continue until March 1959, when the situation "would be reviewed"; the Astra and the Sparrow II systems were, however, cancelled immediately, to be replaced by the Hughes MA-1 fire control system and Falcon missiles. This substitution was supposed to reduce the cost of 100 production Arrows from CA$1,261.5 million to CA$896 million. The SAGE complete with BOMARC missiles along with additional "gap-filler" radar stations would be used to bolster the Canadian air-defence system.

This statement was not interpreted the same way by everyone. To opponents of the Arrow, it seemed to mean that the formal cancellation of the program was merely postponed until March. The views of the media were similarly divided: some were still anticipating eventual production, while others accepted the September statement as tantamount to a cancellation. Conversely, Avro and Orenda interpreted this decision in the most favourable light and assumed the excellence of their products alone guaranteed some form of continued production.

On 21 October 1958, hoping to stave off further cancellation talk, Avro Canada wrote a letter to the MND, offering a firm fixed price contract to "deliver 100 operational Arrow aircraft complete in all respects including the Iroquois engine and the MA-1 fire control system, for approximately $3,500,000 each." This cost excluded the development and tooling costs and also any Government Furnished Equipment (or GFE). The last 17 of the original 37 aircraft ordered were to be included in this figure of 100.

Through December 1958 and into January 1959, the Cabinet vacillated on a cancellation decision. Its members were well aware of the potential economic fallout (up to 25,000 jobs at 400 Canadian and 250 US sub-contractors), along with the social and political impacts of canceling the project. A number of options were discussed and rejected since the service chiefs were by now adamant that they didn’t really need the aircraft.

On 14 February 1959, Avro Canada asked the government for an additional CA$40 million to continue with its activities. This is the final straw and Cabinet unanimously votes to cancel the project.

All doubts were finally settled on 20 February 1959, when “the axe fell”. Prime Minister John Diefenbaker rose in the House of Commons to make a statement on the Government policy for air defence. Of the CF-105, he said:

The Government has carefully examined and re-examined the probable need for the Arrow aircraft and Iroquois engine known as the CF-105, the development of which has been continued pending a final decision. It has made a thorough examination in the light of all the information available concerning the probable nature of the threats to North America in future years, the alternative means of defence against such threats, and the estimated costs thereof. The conclusion arrived at is that the development of the Arrow aircraft and Iroquois engine should be terminated now. Formal notice of termination is being given now to the contractors. All outstanding commitments will, of course, be settled equitably.

This day would become known as “Black Friday” within the Canadian aviation industry. The Minister of National Defence, George Pearkes, was later quoted as saying:

We did not cancel the CF-105 because there was no bomber threat, but because there was a lesser threat and we got the BOMARC in lieu of more airplanes to look after this.
The decision to terminate the program immediately put 14,528 Avro employees out of work as the company, in turn, terminated their employment citing the government’s “surprise” announcement. In addition, nearly 15,000 other employees in the Avro supply chain of outside suppliers were also adversely affected. Declassified company records show Avro management was caught completely unprepared by the suddenness of the announcement by the government; while executives were aware that the program was in jeopardy, they expected it to continue at least until the March review. It was widely believed that, during this lead-up to the review, the first Arrow Mk 2, RL-206, could also be prepared for an attempt at both world speed and altitude records.

It has since been suggested that Avro’s mass dismissal of its employees was a pressure tactic designed to force the Government either to reconsider its decision or to find other contracts for the company, but if this was the case, the tactic failed miserably. The government was infuriated:

The lay-offs had been particularly abrupt, the excuse given by Avro being that the company had received no advance notice of the Prime Minister’s announcement. This was unfair and misleading. The company officers were well aware, or they should have been, that the contract might be cancelled and should have been making preparations accordingly.

*CF-105 RL 203 made the last test flight of any Avro Arrow on the day of the program’s cancellation, 20 February 1959 - (Avro image via the Author’s Collection)*
A last ditch attempt was then made by Avro Canada to provide the six already completed Arrows to the National Research Council (NRC) of Canada as high-speed test aircraft. The NRC refused, noting that without sufficient spare parts and maintenance, as well as qualified pilots, the NRC could make no use of them. A similar proposal for the Royal Aircraft Establishment at Boscombe Down then resulted in some preparations for a transatlantic ferry operation. But this proposal, like others from the US, was never realized.

The Arrow’s cancellation and the ensuing turmoil led to the end of Avro Aircraft Limited (Canada). The company’s President and General Manager, Crawford Gordon Jr, was fired shortly after the cancellation. In 1962, the Hawker Siddeley Group formally dissolved A. V. Roe Canada and transferred all its assets to Hawker Siddeley’s newly formed subsidiary, Hawker Siddeley Canada.

Conversely, Orenda Engines Ltd. survived, primarily as a maintenance and overhaul plant for existing jet engines, but the days when it designed powerplants like the PS-13 Iroquois were over.

---

The cancellation of the CF-105 was devastating to Avro Canada as a company but the officially ordered destruction of all the aircraft under production along with all of the associated programs / material puzzles many observers to the current day. In the view above, the Mark 1 aircraft are awaiting the scrap man’s torch - (CA&SM Image)

Aftermath

Within two months of the project cancellation, all aircraft, engines, production tooling and technical data were ordered to be scrapped and destroyed. Officially, the reason given for the destruction order from Cabinet and the Chiefs of Staff was to destroy classified and "secret" materials used in the Arrow / Iroquois programs. The action has been attributed by some to Royal Canadian Mounted Police fears that a Soviet "mole" had infiltrated Avro Canada; a fact later confirmed to some degree in the Mitrokhin archives.41

The continuing controversy over this particular “destruction” order was commented upon as late as 4 April 1979, when Mr. C.R. Nixon, the Deputy Minister of National Defence, responded to a question from the Canadian Broadcasting Corporation as follows: 42

As a result of an extensive search of our files, we have found some correspondence dealing with the subject. This ... largely substantiates the statements made by Mr. O’Hurley to the effect that, in
the opinion of the Department of National Defence, the aircraft should be scrapped. The department was faced with the problem of how to dispose of prototype aircraft whose sophistication and technology were very advanced and quite sensitive from a military point of view... the aircraft had not been sufficiently tested to be put into service ... it would have been too expensive to continue the test program... the prototypes ... were offered firstly to the National Aeronautical Establishment and, later, to the Royal Aeronautical Establishment in the United Kingdom. Both organizations declined ... the only real alternative left was to scrap the aircraft, as there was no question of letting them fall into the wrong hands, whether ... of foreign interests or ... entrepreneurs wishing to acquire a tourist attraction. Furthermore, there is no indication in the documentation that the aircraft were considered to have some heritage value, or that it would be appropriate to display them in an aeronautical collection.

The *Iroquois* engine, which had completed thousands of hours of test running, was clearly superior to its contemporaries, and interest in licensed production had been expressed by several foreign companies. Had the engines been exempted from this destruction order, and sales abroad more actively pursued, it is possible that something valuable might have been salvaged from the program. At the time of cancellation, fourteen development *Iroquois* engines had been built and had these had completed 6,700 hours of test running. A further 96 engines were on order and in various stages of completion.

---

**Compare this view of scrapping process to the one on the previous page. The destruction of several Mark 1’s is now already complete - (CA&SM Image)**

Following the cancellation of the Avro *Arrow* project, CF-105 Chief Aerodynamicist Jim Chamberlin led a team of 25 engineers to join the National Aeronautics & Space Administration (NASA) and went on to become lead engineers, program managers, and heads of engineering in NASA's manned space
programs—Projects *Mercury, Gemini* and *Apollo*. This expatriate team eventually grew to 32 ex-Avro engineers and technicians, and become emblematic of what many Canadians later viewed as a “brain drain” to the US. Many other engineers, including Jim Floyd, found work abroad in either the UK or the US. Work undertaken by both Avro Canada and Floyd benefited supersonic research at Hawker Siddeley, Avro Aircraft’s UK parent, and contributed to programs such as the HSA.1000 supersonic transport design studies, which were ultimately influential in the design of the *Concorde*. Test pilot Jan Zurakowski retired completely from aviation. Fellow test pilot “Spud” Potocki joined North American Aviation and Jack Woodman went to Lockheed.

In 1961, the RCAF obtained the first batch of 66 McDonnell CF-101B *Voodoo* aircraft (equipped with *Falcon* missiles and *Genie* nuclear rockets), one of the American designs the RCAF had originally rejected, to serve in the role originally intended for the Avro *Arrow*. The controversy surrounding this particular acquisition, and Canada’s acquisition of nuclear weapons for the *Voodoos* and BOMARCs (under US control) eventually contributed to the collapse of the Diefenbaker government in 1963.

**Conclusion**

In hindsight, the technological excellence of the CF-105 *Arrow* and especially of the associated *Iroquois* engine have been confirmed by many knowledgeable observers. The expected performance of the CF-105, when compared then current and even later offerings from American and Soviet design bureaus,
would have been outstanding. The CF-105 Arrow was considered by some aviation industry observers to be one of the most advanced aircraft in the world. The respected British aviation analyst, Bill Gunston stated: "In its planning, design and flight-test program, this fighter, in almost every way the most advanced of all the fighters of the 1950s, was as impressive, and successful as any aircraft in history." 44

But the decisive factor leading to the cancellation of the CF-105 Arrow program was the overall continually escalating cost of the project which was directly attributable to the acceleration and expansion of the program from just one project to four separate and concurrent developmental system projects - the Arrow airframe, the Iroquois engine, the Sparrow II missile, and the Astra fire control system. The cost for some of these systems had only been vaguely estimated during the initial phase of the program and the complexity of simultaneously integrating all four of these systems was ignored by many. What seemed feasible in the budgetary environment of 1952-1953 was later proven to be uneconomical in the fiscal climate of 1958-1959. Given the financial implications of the project, noted historian, J.L. Granatstein, concluded that the decision to cancel the project was "the correct one" and "the only one possible in the circumstances. Despite arguments then and later about the CF-105's technological sophistication, Canada could simply not afford to pay the costs involved in creating a modern weapons system....The only error in the government's decision was that it had not been made earlier." 45

But another factor which made the program unviable was also the dramatic strategic shift driven by the rapid pace of development with other kinds of modern weapons. By the late 1950s, the rise in importance of the guided missile was bringing into question the viability of a manned interceptor. The steady growth in the strategic and tactical significance of missiles, both as a threat in the form of ICBMs supplanting bombers, and as a means of defence in the form of the BOMARC replacing manned interceptors had a collective negative impact on the Arrow program. The inclusion of BOMARCs coupled with the SAGE in the RCAF’s arsenal definitely undermined the Arrow program. At the same time, the RCAF’s operational requirement for interceptors in 1958-59 was one-sixth of what had been anticipated in 1952.

Apart from the cancellation of the program, the subsequent destruction of all of the completed airframes and virtually all of the systems, probably for security reasons, has resulted in the parts of the CF-105’s history achieving mythical proportions. The fact that complete examples of the aircraft were not properly preserved remains a case for further speculation.
Although nearly everything connected to the CF-105 Arrow and Orenda Iroquois programs was destroyed, remnants of the projects were “squirreled away” by some close to program and by last ditch efforts to save the completed airframes for testing. The severed cockpit and nose gear of the sixth CF-105 Arrow Mk 2 RL-206 were preserved. Nose cones, two outer panels of RL-203’s wings (including their ailerons) were saved and as were several Iroquois engines. A myriad of smaller parts and souvenirs have emerged in subsequent years. Two of the original Martin Baker ejection seats and additional Iroquois engines are examples of the latter.

The Museum’s Cockpit Section - RCAF 25206 / RL-206

CF-105 Arrow RCAF serial 25206 / RL-206 was the first Mk 2 Arrow. It had been test-fitted with the prototype Iroquois engines and like the previous five Mk 1 aircraft it was primarily intended as a test aircraft being fitted with an instrumentation pack in lieu of an armament bay. It was, however, already significantly different than its predecessors with many different parts and assemblies due to the engine change and it incorporated a new radar nose profile along with refined aerodynamic profiles in other areas.

The nosecone section of Avro Arrow RL-206, currently on display at the Canada Aviation and Space Museum in Ottawa, was removed from the Avro Aircraft plant in Malton by members of the Institute of Aviation Medicine at the RCAF Flying Personnel Medical Establishment, a detachment of RCAF Station Downsview on Avenue Road in Toronto, where it resided for many years and was employed in high-altitude testing work. The Commanding Officer of the Flying Personnel Medical Establishment, Wing Commander Roy Stubbs, provided this prologue to the former aircraft:

One day after a change of government, the new RCAF Chief of the Air Staff came to inspect our facilities and programs and after lunch, I asked if he would like to see something special. I showed him a piece of the Arrow; cockpit section and engine nacelles and a few other bits. I asked him what
we should do with it and he said to keep it hidden until the climate in Ottawa was right, and then he would arrange to have it placed in the National Aeronautical Museum in Ottawa. Eventually this was done and at least a bit of history was saved.

The cockpit / nose section of RL-206 - the first Arrow Mk 2 was preserved by RCAF personnel and it now resides in the Canada Aviation and Space Museum. The lower image provides an interesting comparison of technologies with the nose of RL-206 alongside the RCAF’s current fighter, the CF-188 Hornet - (CA&SM image and Bill Upton Photo)
The outer wing sections of RL-203 (above) and an Iroquois engine (below) are two additional components from the CF-105 Arrow program that are preserved at the Canada Aviation and Space Museum - (CA&SM images)
A Brief Chronology of Events for the CF-105 Arrow Program

- **Apr 1953** - Avro Canada receives a design contract for $200K;
- **Aug 1953** - the contract is increased to $500K;
- **Oct 1953** - the Minister of National Defence (MND) orders all work on the project halted; Avro is ordered to concentrate all its efforts on fixing the problems with the CF-100. (This directive also had some negative effects on Avro's C-102 Jetliner project)
- **March 1954** - the project is re-instated at $1,325K to cover two prototypes plus one airframe for static testing. The Curtiss-Wright J67 and Pratt & Whitney J57 are added to the list of engine options.
- **June 1955** - the RCAF agrees with Avro on Cook-Craigie production plan, and calculates that 37 aircraft and 1,700 flying hours will be required to prove the aircraft and its systems for operational service;
- **July 1955** - the contract is reduced from 40 to 37 aircraft in accordance with RCAF calculations;
- **July 1956** - all three foreign engine projects have either been cancelled or have severe problems. Orenda proposes its PS-13 Iroquois, then in advanced development. The RCAF agrees that this is the best engine available and the best option for Canadian industry;
- **Oct 1956** - RCAF program office proposes the name Arrow for the CF-105.
- **Dec 1956** - Avro agrees to deliver the first eight aircraft (five P&W J75 powered Mk 1, three Iroquois powered Mk 2) by Dec 1958, and the remaining 29 Mk 2 by early 1961; the cost has now risen to $242M + engines;
- **Aug 1957** - the newly elected Conservative government puts an austerity program in place, cancels CF-100 Mk VI;
- **Oct 4th 1957** - roll-out of Arrow No. 1, RL-201;
- **Dec 1957** - RCAF complains of mismanagement at Avro relating to changes in performance, scheduling, etc, that are not being reported to the program office;
- **Jan 1958** - Avro Engineering Section is re-organized, possibly in response to RCAF complaints;
- **March 25th 1958** - first flight of RL-201 with Jan Zurakowski at the controls;
- **May 1958** - Avro submits revised cost estimates of $350M + engines;
- **June 11th 1958** - First accident - RL-201 undercarriage collapses on landing, aircraft sustains minor damage;
- **June 1958** - The US Navy drops out of the Sparrow II missile program and the RCAF opts to "go it alone" and forces Avro Canada to go along with the Astra integrated fire and flight control system and its associated Sparrow II missile. This pushes total program cost for aircraft, engines, electronics, test and ancillary equipment and spares to $789M;
- **June - July 1958** - The RCAF HQ is now seriously concerned about rising costs and other problems, such as the slow pace of test flying, Avro Canada's lack of concern over maintainability issues and shifting delivery dates (e.g. only five of the eight aircraft promised for Dec 1958 will actually be delivered). In addition, senior officers are deeply split over the threat from the manned bomber and the issue of missiles versus manned interceptors. A study is undertaken on the option of canceling the contract after the delivery of the first 37 aircraft and using the latter to form just two squadrons of 10-12 aircraft each in the Ottawa area. The study concludes that the magnitude of the logistic support that would be required far exceeds the operational value of the asset. The minimum operational nexus is calculated as five squadrons (50-75 aircraft);
Aug 21st 1958 - Minister of National Defence (MND) George Pearkes and Chief of the Air Staff (CAS) Air Marshal Hugh Campbell agree that the RCAF still requires the CF-105;

Aug 25th 1958 - the Joint Chiefs recommend to the MND that the Arrow program be cancelled and be replaced with missiles, specifically the BOMARC;

Aug 28th 1958 - Cabinet makes no decision on the Joint Chiefs' recommendation, but the program will be kept under review with a decision by Mar 1959;

Nov 5th 1958 - Air Marshal C. Roy Slemon, deputy commander of NORAD, states that there will be a need for manned interceptors for the foreseeable future. The Cabinet and many MPs are very upset with his statement;

Nov 11th 1958 - second accident - RL-202's undercarriage collapses on landing. Avro Canada claims malfunction of the flight control system as the cause; the RCAF maintains it is pilot error and demands Avro remove test pilot “Spud” Potocki from the program;

Oct 1958 - Avro desperately tries to avoid cancellation and offers to freeze airframe costs for future deliveries of up to 100 aircraft;

Dec 1958 - Jan 1959 - The Cabinet vacillates on a decision. Its members are well aware of the economic (up to 25,000 jobs at 400 Canadian and 250 US sub-contractors), social and political impacts of canceling the project, and a number of options are discussed and rejected since the service chiefs are adamant that they no longer need the aircraft;

Feb 14th 1959 - Avro Canada asks for an additional $40M to cover ongoing expenses. This is the “final straw” and Cabinet unanimously votes to cancel the project;

Feb 20th 1959 - "Black Friday" - Prime Minister John Diefenbaker makes the formal announcement in the House of Commons canceling the entire project. Avro Canada, in turn, lays off 14,000 employees;

Mar 1959 - The possibility of NAE using the aircraft as research vehicles is studied; the conclusion is that this is not a viable option. There is some discussion about retaining RL206, fitting the Iroquois engines, and going for an absolute world speed record. This idea is dropped as being too expensive;

Apr 7th 1959 - The Chief of Air Staff (CAS) (Campbell) formally recommends to MND that they proceed with destruction of everything associated with the Arrow; the MND agrees;

Apr 14th 1959 - CAS advises Department of Defence Production that the destruction contract must specify that everything is to be cut up before being sold for scrap unless a better price can be obtained by not doing so;

May 1959 - The National Aviation Museum (NAM) pleads for an Arrow, or at least major components, and an Iroquois engine. There are also requests from civilians to preserve at least RL-201 as part of Canada's aviation heritage;

July 1959 - The scrapping of the airframes and tooling proceeds quickly and by July all six finished aircraft are cut up and junked. The exception is the nose section of RL-206 which is removed to the Institute of Aviation Medicine (IAM) in Toronto for use as a research tool. In total, there were 1,244 tonnes of scrap that brings a total of $304,370 for a cost recovery of 24.5 cents per kilogram; and

Post-July 1959 - Lots of minor components are salvaged during the scrapping or subsequently recovered from junk yards, such as the outer wing panels of RL-203, that passed through various hands before arriving at the NAM. The production engine Iroquois Mk 2 No. X-104 migrates from Orenda to NRC, then eventually to the NAM (now the Canada Aviation and Space Museum).
Planned CF-105 Variants

Mark 1

The Arrow Mk 1 was the initial version powered by two Pratt & Whitney J75 turbojet engines that produced 105 kN (23,500 lbf) of thrust each. The Mk 1 variant was to be used exclusively for development and flight testing. Five aircraft were completed.

Mark 2

The Mk 2 version was to be fitted with the Iroquois engine and would be evaluated by RCAF acceptance pilots as well as Avro test pilots. The Astra / Sparrow fire control / missile systems had been terminated by the government in September 1958 with all aircraft to instead employ the Hughes MA-1 / Falcon combination. At the time of cancellation of the entire program, the first Arrow Mk 2, RL-206, was ready for taxi trials; Avro expected it to break world speed records, but it never flew.

Mark 2A

The Mk 2A version was to be a relatively minor upgrade of the Mk 2 with provision for extra (internal) fuel tankage for increased range, with an increase in gross weight resulting in some modifications to the landing gear, and with the fitting of variable geometry jet pipe nozzles.

Mark 3

This development would have increased the speed of the aircraft from Mach 2 to Mach 3 and the combat altitude from 18,288 m (60,000 ft) to 21,336 m (70,000 ft). The modifications needed for this version were more extensive and included uprated Iroquois Mk 3 engines, providing additional thrust, along with variable geometry intakes. The basic geometry of the original design, however, remained basically unchanged.

These are drawings of possible follow-on versions of the CF-105 Arrow that Avro Canada provided in a brochure to the RCAF in order to explain the possible options for further development - (Avro drawings via CA&SM)
These drawings provide further details for the development of the Arrow Mk 2A (top) and the Long Range Arrow proposal (bottom) - (Avro drawings via CA&SM)
Avro CF-105 Arrow Specifications

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Arrow Mk 1</th>
<th>Arrow Mk 2 (projected)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>25.30 m (83 ft 0 in)</td>
<td>24.40 m (80 ft 0 in)</td>
</tr>
<tr>
<td>Wing Span</td>
<td>15.24 m (50 ft 0 in)</td>
<td>15.24 m (50 ft 0 in)</td>
</tr>
<tr>
<td>Height</td>
<td>6.25 m (20 ft 6 in)</td>
<td>6.40 m (21 ft 0 in)</td>
</tr>
<tr>
<td>Wing Area</td>
<td>113.8 m² (1,225 ft²)</td>
<td>113.8 m² (1,225 ft²)</td>
</tr>
<tr>
<td>Empty Weight</td>
<td>22,244 kg (49,040 lb)</td>
<td>20,412 kg (45,000 lb)</td>
</tr>
<tr>
<td>Normal Weight</td>
<td>25,855 kg (57,000 lb)</td>
<td>28,318 kg (62,431 lb)</td>
</tr>
<tr>
<td>Max Gross Weight</td>
<td>31,117 kg (68,602 lb)</td>
<td>31,228 kg (68,847 lb)</td>
</tr>
<tr>
<td>Internal Fuel</td>
<td>13,170 litres (2,897 Imp gal)</td>
<td>14,988 litres (3,297 Imp gal)</td>
</tr>
<tr>
<td>External Fuel</td>
<td>n/a</td>
<td>2,273 litres (500 Imp gal) drop tank</td>
</tr>
<tr>
<td>Engines (ea 2)</td>
<td>P&amp;W J57 JTA-23</td>
<td>PS-13 Iroquois</td>
</tr>
<tr>
<td>Thrust</td>
<td>55.6 kN (12,500 lbf)</td>
<td>85.6 kN (19,250 lbf)</td>
</tr>
<tr>
<td>A/B Thrust</td>
<td>82.2 kN (18,500 lbf)</td>
<td>115.6 kN (26,000 lbf)</td>
</tr>
<tr>
<td>Max Speed (@15,000 m)</td>
<td>M 1.98</td>
<td>M 2.0+</td>
</tr>
<tr>
<td>Service Ceiling</td>
<td>16,150m (53,000 ft)</td>
<td>18,288 m (60,000 ft)</td>
</tr>
<tr>
<td>Climb Rate</td>
<td>195 m/s (38,450 ft/min)</td>
<td>222 m/s (44,500 ft/min)</td>
</tr>
<tr>
<td>Combat Radius</td>
<td>483 km (300 mi)</td>
<td>660 km (410 mi)</td>
</tr>
</tbody>
</table>

Accommodation: Two crew (pilot and radar operator) in tandem, pressurized, air-conditioned cockpits with automatic Martin-Baker Mk C5 ejection seats.

Armament: For Mk 2 (only) - To consist of 6 Falcon (3 IR & 3 Radar-guided) air-to-air missiles or 2 Genie rockets in a removable pack housed in an interior armament bay with Hughes MA-1 fire control system.
### Appendix 1

**Avro Canada CF-105 Mk 1 - Individual Aircraft Flight Records**

<table>
<thead>
<tr>
<th>Date</th>
<th>Flight No.</th>
<th>Duration (hr:min)</th>
<th>Total (hr:min)</th>
<th>Pilot</th>
<th>Purpose (and Remarks)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RCAF 25201</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25 Mar. 1958</td>
<td>1</td>
<td>0:35</td>
<td>0:35</td>
<td>Zurakowski</td>
<td>Initial flight. (Speeds up to 250 kt and altitude to 11,000 ft)</td>
</tr>
<tr>
<td>01 Apr. 1958</td>
<td>2</td>
<td>0:50</td>
<td>1:25</td>
<td>Zurakowski</td>
<td>(Nosewheel failed to retract.) Flight restricted to handling below 250 kts. Altitude to 30,000 ft for cockpit pressurization check</td>
</tr>
<tr>
<td>03 Apr. 1958</td>
<td>3</td>
<td>1:05</td>
<td>2:30</td>
<td>Zurakowski</td>
<td>M:1.1 Unserviceable rendering telemetry inoperative. No high speed work</td>
</tr>
<tr>
<td>15 Apr. 1958</td>
<td>4</td>
<td>1:15</td>
<td>3:45</td>
<td>Zurakowski</td>
<td>Undercarriage snap after 'g' pull at 450 kt. Aborted high speed briefing</td>
</tr>
<tr>
<td>17 Apr. 1958</td>
<td>5</td>
<td>1:10</td>
<td>4:55</td>
<td>Zurakowski</td>
<td>M:1.25 at 49,000 ft. Height of 50,000 ft reached</td>
</tr>
<tr>
<td>18 Apr. 1958</td>
<td>6</td>
<td>0:55</td>
<td>5:50</td>
<td>Zurakowski</td>
<td>Familiarization. M:1.4</td>
</tr>
<tr>
<td>19 Apr. 1958</td>
<td>7</td>
<td>0:40</td>
<td>6:30</td>
<td>Zurakowski</td>
<td>Familiarization. M:1.2</td>
</tr>
<tr>
<td>22 Apr. 1958</td>
<td>8</td>
<td>1:10</td>
<td>7:40</td>
<td>Woodman</td>
<td>Ottawa telemetry check. M:1.5</td>
</tr>
<tr>
<td>23 Apr. 1958</td>
<td>9</td>
<td>0:45</td>
<td>8:25</td>
<td>Potocki</td>
<td>Ottawa telemetry check. M:1.2</td>
</tr>
<tr>
<td>11 Dec. 1958</td>
<td>13</td>
<td>1:10</td>
<td>14:00</td>
<td>Potocki</td>
<td>Ottawa telemetry check. M:1.7</td>
</tr>
<tr>
<td>05 Jan. 1959</td>
<td>17</td>
<td>1:00</td>
<td>18:35</td>
<td>Potocki</td>
<td>Ottawa telemetry check. M:1.7</td>
</tr>
<tr>
<td>05 Jan. 1959</td>
<td>18</td>
<td>0:45</td>
<td>19:20</td>
<td>Potocki</td>
<td>Ottawa telemetry check. M:1.7</td>
</tr>
<tr>
<td>07 Feb. 1959</td>
<td>24</td>
<td>1:00</td>
<td>24:50</td>
<td>Potocki</td>
<td>Ottawa telemetry check. M:1.7</td>
</tr>
<tr>
<td><strong>RCAF 25202</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01 Aug. 1958</td>
<td>1</td>
<td>1:35</td>
<td>1:35</td>
<td>Zurakowski</td>
<td>Initial flight. 30,000 ft</td>
</tr>
<tr>
<td>23 Aug. 1958</td>
<td>2</td>
<td>1:00</td>
<td>2:35</td>
<td>Zurakowski</td>
<td>M:1.5. Damper checks</td>
</tr>
<tr>
<td>26 Aug. 1958</td>
<td>3</td>
<td>1:05</td>
<td>3:40</td>
<td>Zurakowski</td>
<td>M:1.62</td>
</tr>
<tr>
<td>26 Aug. 1958</td>
<td>4</td>
<td>1:00</td>
<td>4:40</td>
<td>Zurakowski</td>
<td>M:1.7</td>
</tr>
<tr>
<td>26 Sep. 1958</td>
<td>12</td>
<td>1:00</td>
<td>13:40</td>
<td>Zurakowski</td>
<td>Ottawa telemetry check. M:1.5</td>
</tr>
<tr>
<td>Date</td>
<td>Time</td>
<td>Duration</td>
<td>Pilot</td>
<td>Flight Details</td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>------</td>
<td>----------</td>
<td>---------</td>
<td>--------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>03 Oct. 1958</td>
<td>15</td>
<td>1:25</td>
<td>Potocki</td>
<td>Pitch oscillation investigation</td>
<td></td>
</tr>
<tr>
<td>03 Oct. 1958</td>
<td>16</td>
<td>1:05</td>
<td>Cope</td>
<td>Familiarization. M:1.5</td>
<td></td>
</tr>
<tr>
<td>05 Oct. 1958</td>
<td>17</td>
<td>0:50</td>
<td>Potocki</td>
<td>All dampers up to M:1.45. 500 kt at 9,000 ft. Undercarriage doors open. Stick tape with yaw damper.</td>
<td></td>
</tr>
<tr>
<td>29 Oct. 1958</td>
<td>19</td>
<td>0:45</td>
<td>Potocki</td>
<td>Flutter check. M: 1.7</td>
<td></td>
</tr>
<tr>
<td>29 Oct. 1958</td>
<td>20</td>
<td>0:45</td>
<td>Potocki</td>
<td>Flutter check. M: 1.8</td>
<td></td>
</tr>
<tr>
<td>08 Nov. 1958</td>
<td>21</td>
<td>1:10</td>
<td>Potocki</td>
<td>Assessment of modified elevator. Parallel servo and feel trim to rear not satisfactory</td>
<td></td>
</tr>
<tr>
<td>11 Nov. 1958</td>
<td>22</td>
<td>1:15</td>
<td>Potocki</td>
<td>510 kt ASI 7,500 ft. Max speed of M: 1.95 – 1.96 obtained from 50,000 ft</td>
<td></td>
</tr>
</tbody>
</table>

RCAF 25203

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Duration</th>
<th>Pilot</th>
<th>Flight Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>22 Sep. 1958</td>
<td>1</td>
<td>1:35</td>
<td>Zurakowski</td>
<td>Initial flight. M:1.2</td>
</tr>
<tr>
<td>01 Oct. 1958</td>
<td>2</td>
<td>0:45</td>
<td>Potocki</td>
<td>Snag clearance. M:1.7</td>
</tr>
<tr>
<td>06 Oct. 1958</td>
<td>3</td>
<td>1:00</td>
<td>Cope</td>
<td>Performance 1A tailcones up to M: 1.7 at 50,000 ft.</td>
</tr>
<tr>
<td>16 Oct. 1958</td>
<td>4</td>
<td>1:10</td>
<td>Potocki</td>
<td>Fuel consumption and level speed checks at 35,000 ft. Subsonic</td>
</tr>
<tr>
<td>17 Oct. 1958</td>
<td>5</td>
<td>1:05</td>
<td>Woodman</td>
<td>Undercarriage door trouble starboard side. Low speed P.E.s with F-86</td>
</tr>
<tr>
<td>18 Oct. 1958</td>
<td>6</td>
<td>1:10</td>
<td>Potocki</td>
<td>Level speeds and fuel consumption. Supersonic on climb</td>
</tr>
<tr>
<td>19 Oct. 1958</td>
<td>7</td>
<td>1:15</td>
<td>Woodman</td>
<td>Partial P.E.s. aborted high speed checks due to red light at M:0.95</td>
</tr>
<tr>
<td>31 Oct. 1958</td>
<td>8</td>
<td>1:00</td>
<td>Cope</td>
<td>Utility hydraulic failure. Gear down flight</td>
</tr>
<tr>
<td>07 Nov. 1958</td>
<td>9</td>
<td>1:10</td>
<td>Cope</td>
<td>Fuel consumption at 35,000 ft and single engine checks. Air conditioning failure refrigerated. Subsonic</td>
</tr>
<tr>
<td>20 Jan. 1959</td>
<td>10</td>
<td>0:55</td>
<td>Potocki</td>
<td>Check flight to M: 1.7 with modified elevator system. Aircraft turbine seized</td>
</tr>
<tr>
<td>01 Feb. 1959</td>
<td>11</td>
<td>1:15</td>
<td>Woodman</td>
<td>RCAF damper check</td>
</tr>
</tbody>
</table>

RCAF 25204

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Duration</th>
<th>Pilot</th>
<th>Flight Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>27 Oct. 1958</td>
<td>1</td>
<td>1:10</td>
<td>Potocki</td>
<td>Initial flight gear down 250 kt maximum</td>
</tr>
<tr>
<td>22 Nov. 1958</td>
<td>2</td>
<td>1:05</td>
<td>Potocki</td>
<td>Check flight</td>
</tr>
<tr>
<td>30 Nov. 1958</td>
<td>3</td>
<td>1:10</td>
<td>Potocki</td>
<td>Continuation of snag clearance to M: 1.2</td>
</tr>
<tr>
<td>02 Feb. 1959</td>
<td>4</td>
<td>1:10</td>
<td>Cope</td>
<td>Check flight directed to Trenton</td>
</tr>
<tr>
<td>03 Feb. 1959</td>
<td>5</td>
<td>1:15</td>
<td>Potocki</td>
<td>Gear down ferry to base</td>
</tr>
<tr>
<td>07 Feb. 1959</td>
<td>6</td>
<td>1:10</td>
<td>Potocki</td>
<td>Clearance flight limited to M:1.5 by pedal judder</td>
</tr>
</tbody>
</table>

RCAF 25205

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Duration</th>
<th>Pilot</th>
<th>Flight Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 Jan. 1958</td>
<td>1</td>
<td>0:40</td>
<td>Potocki</td>
<td>Initial flight gear down</td>
</tr>
</tbody>
</table>

Program Terminated 20 February 1959

Totals: 66 flights, 70:30 hrs (or 2 % of anticipated test & evaluation flying hours)
Appendix 2

Planned Disposition for the first 37 Avro Canada CF-105 Mk 1 & Mk 2 Aircraft

<table>
<thead>
<tr>
<th>#</th>
<th>Type</th>
<th>Status</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Flight Test Aircraft for Phase 1 Contractor Airworthiness Trials, Phase 2 RCAF Compliance Trials and Phase 3 Contractor Development work</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25201</td>
<td>Mark 1 Test &amp; Development Aircraft</td>
<td>Fitted with J75 engines &amp; instrumentation pack only</td>
<td></td>
</tr>
<tr>
<td>25202</td>
<td>Mark 1 Test &amp; Development Aircraft</td>
<td>Fitted with J75 engines &amp; instrumentation pack only</td>
<td></td>
</tr>
<tr>
<td>25203</td>
<td>Mark 1 Test &amp; Development Aircraft</td>
<td>Fitted with J75 engines &amp; instrumentation pack only</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Flight Test Aircraft for Fire Control System Development</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25204</td>
<td>Mark 1 Test &amp; Development Aircraft</td>
<td>Fitted with J75 engines &amp; instrumentation pack only</td>
<td></td>
</tr>
<tr>
<td>25205</td>
<td>Mark 1 Test &amp; Development Aircraft</td>
<td>Fitted with J75 engines &amp; instrumentation pack only</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Flight Test Aircraft for Iroquois Development</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25206</td>
<td>Mark 2 Test &amp; Development Aircraft</td>
<td>Fitted with Iroquois, Instrumentation pack for Iroquois tests</td>
<td></td>
</tr>
<tr>
<td>25207</td>
<td>Mark 2 Test &amp; Development Aircraft</td>
<td>Fitted with Iroquois, Instrumentation pack for Iroquois tests</td>
<td></td>
</tr>
<tr>
<td>25208</td>
<td>Mark 2 Test &amp; Development Aircraft</td>
<td>Fitted with Iroquois, Instrumentation pack for Iroquois tests</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Flight Test Aircraft for Phase 3 Development Tests including Armament Trials</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25209</td>
<td>Mark 2 Test &amp; Development Aircraft</td>
<td>Fitted with Iroquois, Instrumentation pack</td>
<td></td>
</tr>
<tr>
<td>25210</td>
<td>Mark 2 Pre-Production Aircraft</td>
<td>Fitted with Iroquois, no MA-1 system and with instrumentation pack only</td>
<td></td>
</tr>
<tr>
<td>25211</td>
<td>Mark 2 Pre-Production Aircraft</td>
<td>Fitted with Iroquois, no MA-1 system and with instrumentation pack only</td>
<td></td>
</tr>
<tr>
<td>25212</td>
<td>Mark 2 Pre-Production Aircraft</td>
<td>Fitted with Iroquois, no MA-1 system and with instrumentation pack only</td>
<td></td>
</tr>
<tr>
<td>25213</td>
<td>Mark 2 Pre-Production Aircraft</td>
<td>Fitted with Iroquois, no MA-1 system and with instrumentation pack only</td>
<td></td>
</tr>
<tr>
<td>25214</td>
<td>Mark 2 Pre-Production Aircraft</td>
<td>Fitted with Iroquois, no MA-1 system and with instrumentation pack only</td>
<td></td>
</tr>
<tr>
<td>25215</td>
<td>Mark 2 Pre-Production Aircraft</td>
<td>Fitted with Iroquois, no MA-1 system and with instrumentation pack only</td>
<td></td>
</tr>
<tr>
<td>25216</td>
<td>Mark 2 Pre-Production Aircraft</td>
<td>Fitted with Iroquois &amp; MA-1 fire control system with instrumentation pack</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Phase 4 - Performance &amp; Handling Trials Aircraft</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25217</td>
<td>Mark 2 Pre-Production Aircraft</td>
<td>Fitted with Iroquois &amp; MA-1 fire control system with instrumentation pack</td>
<td></td>
</tr>
<tr>
<td>25218</td>
<td>Mark 2 Pre-Production Aircraft</td>
<td>Fitted with Iroquois &amp; MA-1 fire control system with instrumentation pack</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Phase 5 - All-Weather Trials Aircraft</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25219</td>
<td>Mark 2 Pre-Production Aircraft</td>
<td>Fitted with Iroquois &amp; MA-1 fire control system with instrumentation pack</td>
<td></td>
</tr>
<tr>
<td>25220</td>
<td>Mark 2 Pre-Production Aircraft</td>
<td>Fitted with Iroquois &amp; MA-1 fire control system with instrumentation pack</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Avro [System] Development Aircraft</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25221</td>
<td>Mark 2 Production Aircraft</td>
<td>Fitted with Iroquois, MA-1 fire control system and Falcon / Genie weapons bay</td>
<td></td>
</tr>
<tr>
<td>25222</td>
<td>Mark 2 Production Aircraft</td>
<td>Fitted with Iroquois, MA-1 fire control system and Falcon / Genie weapons bay</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>RCAF Operational Proving &amp; CEPE Unit - Aircraft for Operational Suitability &amp; Weapons Tactics Development</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Phase 6 - Intensive Flying Assessment Trials Aircraft</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25223</td>
<td>Mark 2 Production Aircraft</td>
<td>Fitted with Iroquois, MA-1 fire control system and Falcon / Genie weapons bay</td>
<td></td>
</tr>
<tr>
<td>25224</td>
<td>Mark 2 Production Aircraft</td>
<td>Fitted with Iroquois, MA-1 fire control system and Falcon / Genie weapons bay</td>
<td></td>
</tr>
<tr>
<td>25225</td>
<td>Mark 2 Production Aircraft</td>
<td>Fitted with Iroquois, MA-1 fire control system and Falcon / Genie weapons bay</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Phase 7 - Weapons Evaluation Trials Aircraft</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25226</td>
<td>Mark 2 Production Aircraft</td>
<td>Fitted with Iroquois, MA-1 fire control system and Falcon / Genie weapons bay</td>
<td></td>
</tr>
<tr>
<td>25227</td>
<td>Mark 2 Production Aircraft</td>
<td>Fitted with Iroquois, MA-1 fire control system and Falcon / Genie weapons bay</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Phase 8 - Operational Suitability Trials Aircraft</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25228</td>
<td>Mark 2 Production Aircraft</td>
<td>Fitted with Iroquois, MA-1 fire control system and Falcon / Genie weapons bay</td>
<td></td>
</tr>
<tr>
<td>25229</td>
<td>Mark 2 Production Aircraft</td>
<td>Fitted with Iroquois, MA-1 fire control system and Falcon / Genie weapons bay</td>
<td></td>
</tr>
<tr>
<td>25230</td>
<td>Mark 2 Production Aircraft</td>
<td>Fitted with Iroquois, MA-1 fire control system and Falcon / Genie weapons bay</td>
<td></td>
</tr>
<tr>
<td>25231</td>
<td>Mark 2 Production Aircraft</td>
<td>Fitted with Iroquois, MA-1 fire control system and Falcon / Genie weapons bay</td>
<td></td>
</tr>
</tbody>
</table>
25232 Mark 2 Production Aircraft Fitted with Iroquois, MA-1 fire control system and Falcon / Genie weapons bay
25233 Mark 2 Production Aircraft Fitted with Iroquois, MA-1 fire control system and Falcon / Genie weapons bay

Attrition Aircraft
25234 Mark 2 Production Aircraft Fitted with Iroquois, MA-1 fire control system and Falcon / Genie weapons bay
25235 Mark 2 Production Aircraft Fitted with Iroquois, MA-1 fire control system and Falcon / Genie weapons bay
25236 Mark 2 Production Aircraft Fitted with Iroquois, MA-1 fire control system and Falcon / Genie weapons bay
25237 Mark 2 Production Aircraft Fitted with Iroquois, MA-1 fire control system and Falcon / Genie weapons bay

In total, approximately 3,000 flying hours were expected to required in order to complete all the tests and evaluations of the CF-105 Arrow.

List of Abbreviations
AIM – Air Intercept Missile
CAS - Chief of Air Staff
CA&SM - Canada Aviation and Space Museum
IFF - Identification Friend or Foe
LAC - Library & Archives Canada
MND - Minister of National Defence
NORAD – North American Air Defence (Command)
NRC - National Research Council
OPU - Operational Proving Unit
RAF - Royal Air Force
RCAF – Royal Canadian Air Force
SAM – Surface-to-Air Missile
UHF – Ultra-High Frequency
USAF - United States Air Force
USN - United States Navy
VHF - Very High Frequency

REFERENCES

Books:
Smye, Fred Canadian Aviation and the Avro Arrow, Publisher: Randy Smye, Oakville, ON, Canada, 1989.
Articles:
Bradford, Robert
“Avro’s Fallen Arrow”, Air Enthusiast / Eight.
Buttler, Tony
Larsen, Layne
Larsen, Layne
Mellberg, Bill
“Too Good to be True - A Personal View of the Avro Canada CF-105 Arrow”, Air Enthusiast, No. 54 Summer 1994.
Woodman, Jack
“Flying the Arrow”, Canadian Aviation Magazine, August 1978 and/or Presentation to CASI Symposium, CASI Paper, 16 May 1978
Zurakowski, Jan
“Flying the Avro Arrow - Test Flying the Arrow (And Other High Speed Aircraft)”, CAHS Journal, Winter 1979

Unpublished papers:
Dubelby, Thomas
“The Avro Arrow” - self-produced manuscript
Isinger, Russell Steven
Shortt, A.J.
Avro CF-105 Arrow, Canada Aviation & Space Museum Notes
Avro Newsmagazine, April 2, 1958
Avro Newsmagazine, Special Edition, Summer, 1958
Avro Newsmagazine, August 29, 1958
Avro Newsmagazine, Special Supplement, Vol 5 No. 4, March, 1959

Websites:
http://en.wikipedia.org/wiki/Avro_Canada_CF-105_Arrow
http://en.wikipedia.org/wiki/Orenda_Iroquois

Acknowledgements & Thanks:
Special thanks to Bill Upton for his support and encouragement including supplying many of the images used in this history. Thanks also to the Royal Canadian Air Force and the Canada Aviation and Space Museum for the many other images used herein. (2015)

ENDNOTES

1 Today, this same airport is known as Toronto Pearson International Airport.
2 The more northern Distant Early Warning (DEW) radar chain was not completed until 1958.
3 Use of the new aircraft in NATO was never formally proposed, but was under consideration within RCAF staffs at the time.
4 Drawn from LAC, Records of the Privy Council Office, RG2, Cabinet Conclusions, 17 December 1953. See also House of Commons, Sessional Papers 837, 838, nos.198, 198a-d (1959); House of Commons, Standing Committee on Estimates, Minutes of Proceedings And Evidence, No. 1 (5 June 1958), and No. 12 (7 July 1958); and DHH/DND, CSC Report, for further contractual and financial information on the project.
5 Drawn from DND Directorate of History Heritage, Foulkes Papers
6 Drawn from “Avro’s Fallen Arrow”, Air Enthusiast / Eight - Page 65
The Cook–Craigie plan was an approach to the development process of civil and military aircraft that could dramatically reduce the time needed to bring a new design into service. In the late 1940s, USAF Major Generals Laurence C. Craigie, who was the deputy chief of staff for development, and Orval R. Cook, who was the deputy chief of staff for materiel, proposed that new designs should move directly into the production phase without the construction of prototypes. Previous to this traditional aircraft design had followed a time-honored formula: after the blueprints were drawn up, a small series of prototype aircraft were constructed in order to test the concept. Data from the ensuing flight tests influenced the revisions that were made to the design. If these changes were wide-ranging and/or significant, additional prototypes would be built. Once the prototype cycle was complete, the design would then enter a "pre-production" stage with further evaluation. Only once this stage was completed satisfactorily, would series production begin. The Cook–Craigie plan promoted the elimination of the entire prototype cycle and instead entering straight into the pre-production stage. If the initial examples flew as expected, production could then start immediately. The plan required considerable confidence in the design from the outset; if the design had any inherent flaws, the manufacturing jigs used during pre-production would have to be modified or replaced.

Convair used the Cook-Craigie plan for both the F-102 Delta Dagger and the F-106 Delta Dart programs, both of which were supersonic interceptors. Like the CF-105 program, the F-102 and F-106 suffered development problems surrounding aerodynamics, engine selection, fire control system and weapons fitment and consequently suffered serious delays on the production line and in deliveries.


The "area rule" principle was developed by Richard T. Whitcomb, a young aerodynamicist at NACA's Langley Research Center in Hampton, Virginia in early 1950's. His development of the "area rule" revolutionized how engineers looked at high-speed drag and has impacted the subsequent design of virtually every transonic and supersonic aircraft. Simply stated his principle indicated that two airplanes with the same longitudinal cross-sectional area distribution have the same wave drag, independent of how that area is distributed laterally (i.e. in the fuselage or in the wing). Furthermore, to avoid the formation of strong shock waves, this total area distribution must be smooth. As a result, aircraft have to be carefully arranged so that where the wing is located, the fuselage must be correspondingly narrowed or "waisted", so that the total area doesn't change much. Similar but less pronounced fuselage waisting must also be used at the location of a bubble canopy and perhaps the tail surfaces.

Drawn from The Avro Arrow Myth - Part II by Col (Ret'd) Layne Larsen - Page 37

According to official DND estimates of the period, the PS-13 was over 1,000 lbs lighter than other engines in the same power class and at its 20,000 lbf rating exceeded the Gyron by 22% and the J67, J75 and RB-106 by over 50%. See Campagna, Palmiro Storms of Controversy: The Secret Avro Arrow Files Revealed - Chapter 3 page 71

Some references indicate that all six regular engines were shut down and the XB-47B was powered by the TR-13 Iroquois alone. This is simply not possible as the regular engines were still needed to maintain electrical power and also to counter the asymmetrical thrust from the Iroquois. A considerable reduction in their power settings was however practical.

Drawn from "Too Good to be True - A Personal View of the Avro Canada CF-105 Arrow", Air Enthusiast, No. 54 Summer 1994 - Page 54


Drawn from "Avro's Fallen Arrow", Air Enthusiast / Eight - Page 68

Ibid. - Page 70

Ibid.

Ibid. - Page 71

Drawn from The Arrow - Avro CF-105 Preliminary Operating Instructions & RCAF Testing / Basing Plans - Pages 123-124


29 This section is based upon Larry Milberry’s editorial at [http://www.canavbooks.com/editorial/TheGreatArrowDebate.php](http://www.canavbooks.com/editorial/TheGreatArrowDebate.php)

30 Ibid.


32 Drawn from LAC, CDC Minutes, 15 August 1958

33 The ongoing American disinterest in purchasing the Arrow had once again been confirmed at an August meeting between Pearkes and Neil McElroy, US Secretary of Defence. At that meeting McElroy also urged Canada to adopt BOMARC and SAGE. There is no evidence that Pearkes challenged this advice, which is not surprising as it was identical to that being proffered by the RCAF. NAC, CDC, 15 August 1958, 4, 6; and Smith 310. Pearkes had also met with US Secretary of State John Foster Dulles in July, and received much the same response.


35 At the time of cancellation, two MA-1 system were on order from Hughes and RL-202 was being modified to accept this fire control system.


37 This Avro request likely consisted of CA$28 million for a fixed development fee to compete the program, CA$7 million to cover tooling costs plus additional money to complete further airframes. See Appendices of Campagna, Palmiro, *Storms of Controversy*.

38 See Bradford, Robert, “Avro’s Fallen Arrow”, *Air Enthusiast / Eight*, Page 72

39 See “File 79/469 Folder 19,” *Directorate of History, Department of National Defence*

40 Drawn from LAC, Cabinet Committee Minutes, 23 February 1959

41 Drawn from: Andrew, Christopher and Vasili Mitrokhin. *The Mitrokhin Archive: The KGB in Europe and the West*. Eastbourne, East Sussex, UK: Gardners Books, 2000 - Page 219. Air Vice Marshall Easton of the RCAF also later confirmed that security was the primary reason for the complete destruction of all the aircraft. See Campagna, Palmiro, *Storms of Controversy* - Page 170


43 Apart from the attempt to sell the *Iroquois* to France, a last ditch attempt was made by Orenda to sell the *Iroquois* to Republic Aviation in the United States in order to re-engine Republic’s F-105 *Thunderchief*. The intent was to market the *Thunderchief* as Canada’s next strike fighter in NATO as the USAF had just selected the type for this same role. When the Canadian government showed no interest, the project was shelved. The CF-104 *Starfighter* went on to fulfill this Canadian requirement, with the contract going to Canadair Ltd. See Smye, Fred, Canadian Aviation and the Avro Arrow - Page 103.


46 Some references suggest that the cockpit of RL-206 was “smuggled out” of the Avro plant by RCAF personnel. This is not, however, accurate as there was / is official paperwork remaining which clearly authorizes the preservation of “one complete cockpit in the configuration established by the RCAF...to be made available to the Institute of Aviation Medicine.” See the Appendices of Campagna, Palmiro, *Storms of Controversy* - Aircraft Branch Memo, 7 April 1959

This information is an amalgamation of information from three sources: *Avro Arrow*, Boston Mills Press, Erin, ON, Canada - Page 60 plus various details from Dubelby, Thomas “The Avro Arrow” which is self-produced (draft) manuscript and the author’s book: *The Arrow - Avro CF-105 Preliminary Operating Instructions & RCAF Testing / Basing Plans*