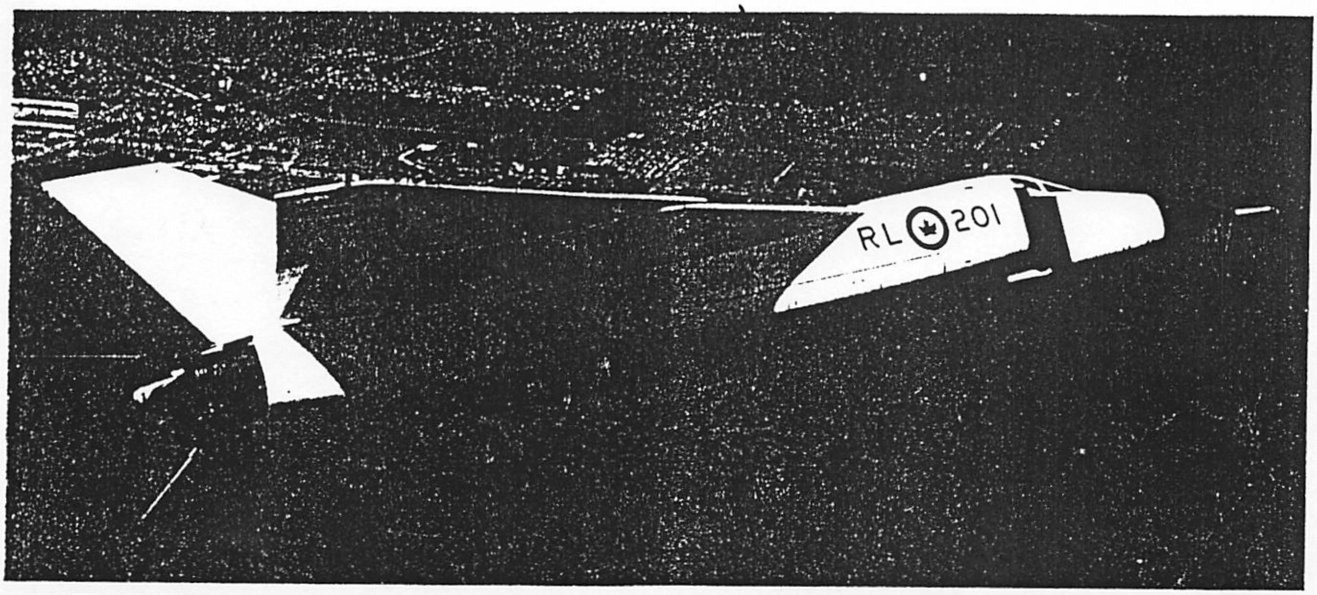


AVRO'S FALLEN ARROW

Robert Bradford tells the story of the Avro CF-105 Arrow, the ambitious and so nearly successful all-weather supersonic interceptor, on which work ceased in 1959 because of escalating costs and premature doubts about the future rôle of manned aircraft in the face of expected missile developments.

THE ORIGINS of the CF-105 Arrow can be said to go back to 1949, when, even before the CF-100 subsonic interceptor prototype had made its first flight, consideration was already being given to the form and necessary performance of a possible successor. But it was the Korean War of 1950-51 that set in motion the train of thinking that led eventually to the authorisation of a design study and, in 1953, an order for two prototypes of what would become one of the most controversial and eventually ill-starred warplanes of the 'fifties.

The Royal Canadian Air Force, as it then was, had been watching closely the developments in Communist tactics and technology as these were demonstrated in practice during that war. The introduction, for instance, of the MiG-17 showed how far Soviet capabilities had evolved. The RCAF felt that development of a turbojet bomber capable of attacking North America with a nuclear load would be within Soviet capabilities by 1958. Thus, the CF-100 Canuck (See "Canadian Innovation", AIR ENTHUSIAST FOUR) would require a supersonic replacement by that time.

In September 1951, Avro Aircraft, the airframe division of Avro Canada Ltd, submitted to the RCAF a brochure outlining three proposals for an advanced supersonic fighter. One proposal seemed to be heralding the future, incorporating as it did, a delta planform, two engines (Armstrong Siddeley ASSa 4 Sapphires were suggested), all weather capability and a two-man crew. When, in March 1952, the RCAF issued to Avro its "Final Report of the All-Weather Interceptor Requirements Team", covering the requirements determined by the RCAF for a supersonic interceptor to replace the CF-100, it was found, therefore, that Avro was already in line with RCAF thinking. Two engines were considered essential because of the need for increased reliability over the vast stretches of uninhabited wilderness which make up most of Canada, and a two-man crew was equally necessary. Most of Canada's population is in the south, along the US border, but interceptors must fly over the northern regions, which lacked a developed ground environment. These requirements are still influencing Canadian procurement decisions today.

The supersonic requirement was comparatively unusual for the period — the CF-100 was subsonic — but considered absolutely necessary because of the expected development of jet bombers. At that time, the Mid-Canada Line was the main radar "fence" for North America — the Distant Early Warning (DEW) line was not completed until 1958 — and RCAF interceptor stations were located relatively close to it. To intercept the bombers, following their detection and before they reached the interceptor stations, supersonic speed was required as soon after take-off as possible.

Ultimately, the Arrow "system" consisted of four main components: the airframe, the turbojet powerplant, the fire-control system and the armament. Originally, the only component planned for development in Canada was the airframe, but Canada eventually assumed responsibility for the other components also, although the aircraft itself remained the first and most important part of the system.

In June 1952, Avro submitted to the RCAF brochures entitled "Designs to Interceptor Requirements". The first of these outlined the C-104/1 and C-104/2 projects, both delta-wing, two-man interceptors with provision for rockets and missiles. The C-104/2, however, had two engines, whereas, to keep the options open, the C-104/1 had only one. Avro was considering three different engines for the C-104 at this time: the Curtiss-Wright J67, the Bristol Olympus BOl3 and the Avro Canada TR9. Several months later, in October, the National Aeronautical Establishment completed its analysis of the prospective C-104 designs and the C-104/2 was considered preferable, with many desirable features. As proposed by Avro, however, the design was too heavy and it was recommended that the company should make further studies of the C-104/2. The RCAF also made adjustments to its requirements, calling mainly for an increase in operating altitude.

Discussions between the RCAF and Avro on the size and design of the aircraft continued until April 1953. In that month, the RCAF issued its specification AIR 7-3, calling for a twin-engined, two-crew aircraft, and the next month Avro turned out a report, "Design Study of Supersonic All-Weather Interceptor Aircraft", outlining the major features of a redesigned C-104/2 which was by then known as the C-105. This would have a high wing, since this resulted in the lowest weight of the positions considered and because it provided the best access to the powerplants, electronics and armament. The aircraft 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.

As foreshadowed in the early proposals, a delta wing was selected. There were several reasons for this choice — a thin wing was required for supersonic flight and the delta was the lightest structure available for a low thickness chord ratio, but the large root chord allowed adequate thickness for fuel and for stowing the undercarriage. Although the report listed five aircraft sizes, the one with a wing area of 1,200 sq ft (111 m^2) was selected as the happy medium between the high-altitude performance of larger wing areas and the weight-saving advantages of smaller areas. The powerplant for the aircraft was not finally decided in the report, with the Rolls-Royce RB.106 now included as one of the possibilities, in addition to those types projected earlier (all with afterburners). For armament, Avro recommended the Hughes MX1179 system, with six Falcon guided missiles and fifty 2-in (5,1-cm) folding-fin rockets.

In this configuration, the proposal met the original requirements. In addition, the complexity of the fire-control system and the desire to be able to make a manual attack should the automatic system fail, reinforced the original decision in favour of a crew of two. The two engines were retained for safety reasons and because, although the project team was pursuing weight-savings wherever possible, the C-105 was still too heavy for any one engine then envisaged.

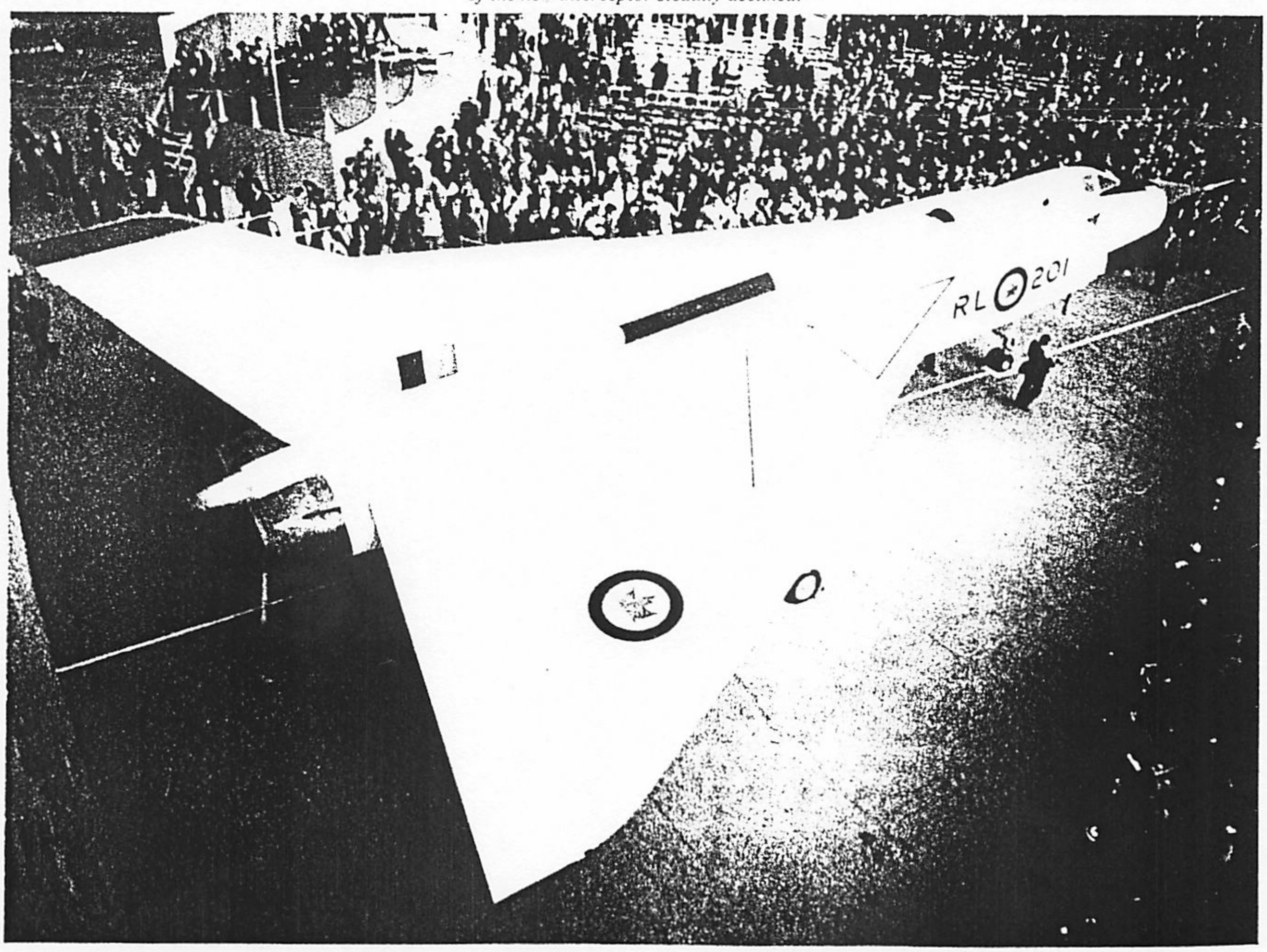
The report also included three more proposals for the purposes of comparison, all considerably smaller than the design selected. Two had wing areas of 900 sq ft (83,6 m^2) — one of these with engines located outboard — and the third had 750 sq ft (69,7 m^2) and only one engine. The RCAF rejected these as not being practical.

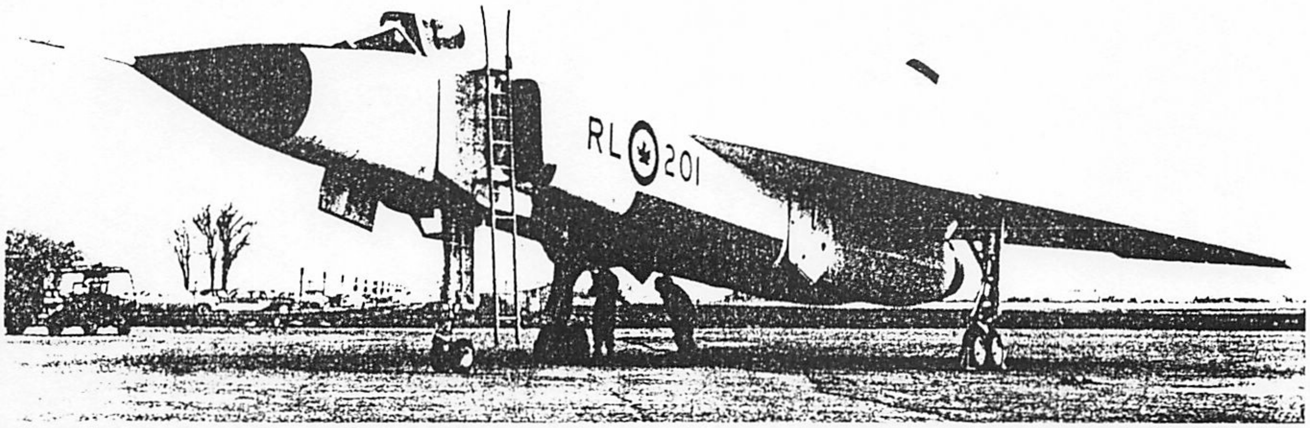
Early developments

In July 1953, a ministerial directive from the Department of Defence Production authorised a design study to meet specification AIR 7-3. This was the signal for Avro to go ahead with the development of the CF-105 — as the C-105 project now became — and in December, an order for two development prototypes was approved. By this time, plans were being formulated for full-scale procurement by the RCAF, the anticipated date for the operational introduction of the aircraft being 1958. Numbers expected to be required ranged between 500 and 600 at a cost of \$1·5 to \$2m per aircraft. The RCAF's plan for employment of the CF-105 envisaged nine regular squadrons and 11 auxiliary squadrons; use of the new aircraft in Europe was never formally proposed, but was under consideration in RCAF circles.

The Arrow, as the CF-105 was eventually to be named, presented the Avro designers and engineers with many challenges, only a few of which, and the means to meet them,

The first Avro Arrow, 25201, was rolled out at Malton on 4 October 1957 with due ceremony and in the presence of some 12,000 spectators, including the company's work force. Hopes for the Arrow were still high but first flight was delayed for almost six months, in which time prospects for future production of the new interceptor steadily declined.





Above: The Arrow was no midget, as this photo of the prototype shows: note the two groundcrew under the fuselage and the length of the ladder giving access to the cockpit. (Below) Arrow 25201 on its first flight on 25 March 1958, when the landing gear was not retracted.

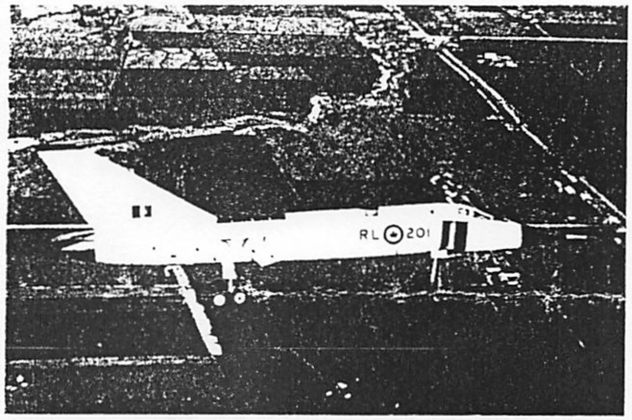
can be mentioned in this article. It was to be among the first of the operational supersonic aircraft, and many problems of supersonic flight had still to be solved.

The aerodynamic loads had to be established and, although the aerodynamics department of Avro worked these out, the effect of manoeuvrability on the structure required further investigation. A number of stressing cases were, therefore, fully investigated. The problem of frictional heating also required close examination. Amongst the many items of information periodically issued by Avro's publicity department was this example of high speed heat: "At 1,200 mph (1 931 km/h), air friction raises the temperature of an aircraft's skin by 300°F (165°C). Even at high altitudes, with the outside air temperature at around 50°F (43°C) below zero, the skin temperature is still 40°F (27°C) above the boiling point of water". Another problem was that of sound. Both aerodynamic and engine noise could damage skin panels and loosen rivets. To assist the designers and engineers in solving many of these and related problems, the wind-tunnel programme was one of the most important tools.

The first tests in the wind-tunnel development programme were run in September 1953 and by the time the aircraft was rolled out for public display in 1957, Avro had completed an exhaustive series of wind-tunnel studies. The National Aeronautical Establishment tunnel in Ottawa was used for both low- and high-speed testing, while transonic and supersonic tests were carried out respectively at the Cornell Aeronautical Laboratories in Buffalo and at the NACA tunnel at Langley Field, Virginia. 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 an extensive programme designed to investigate, test and confirm the theories and designs. Between December 1954 and January 1957, Avro conducted a programme in which large, heavily-instrumented, free-flight models were mounted on 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 range in Virginia. In every case, the launch and the subsequent separation of the model and booster were successful, and much valuable information was gathered.

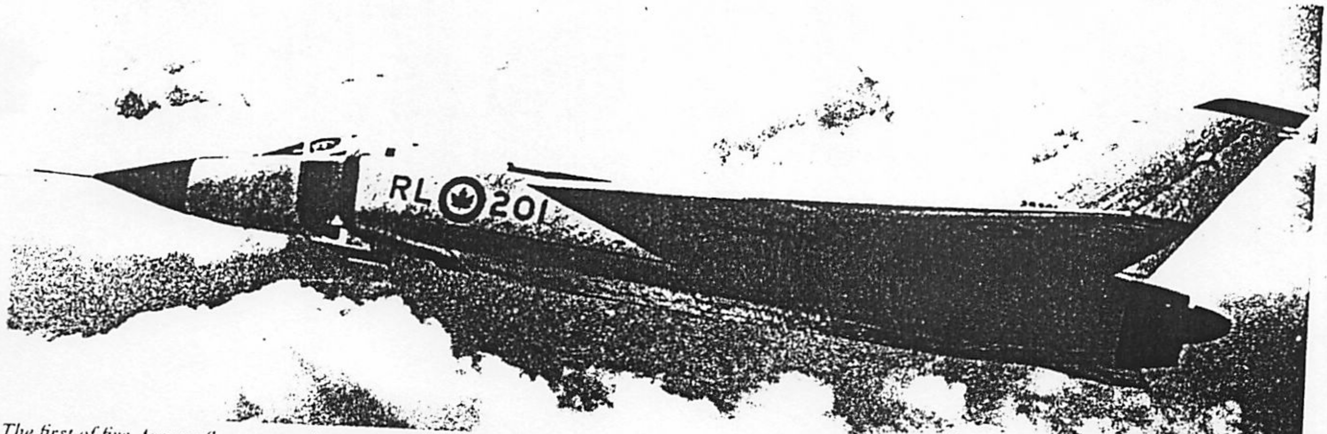
At the Avro factory, a mock-up was prepared to provide a three-dimensional check on installation clearances and general accessibility. One of the first tasks of the mock-up was to check



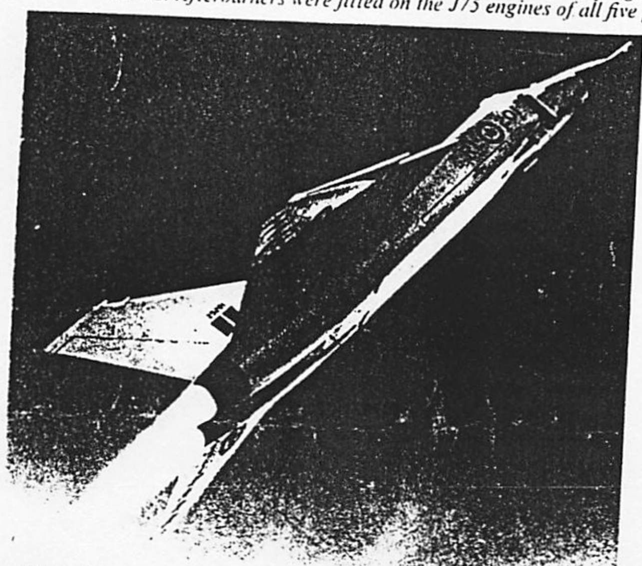
the clearance of the Curtiss-Wright J67 turbojets, that had been nominated to power the CF-105, many changes being required when the J67 was later replaced by the Pratt & Whitney J75.

Another important component in the development programme 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, Sqn Ldr 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 including Avro's chief development pilot, Janusz Zurakowski (also ex-Gloster) together with "Spud" Potocki and the RCAF's leading test pilot, Flt Lt Jack Woodman.

A test pilot's tasks begin, of course, long before a prototype is ready for flight. In the case of the Arrow, the pilots worked in co-operation with the engineers on electrical and fuel systems, hydraulics and such essentially pilot-related areas as control systems and emergency features. Flight simulators controlled by an analogue computer were constructed 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 taxying — 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 Gen Joseph Caldara, of the USAF's Office of the Director of Flight Safety, considered the Arrow's cockpit layout to be "the best he had seen".



The first of five Arrows flown up to the time of cancellation of the programme was in flight test for almost a full year, but made only 24 flights, totalling 25 hrs. Afterburners were fitted on the J75 engines of all five prototypes, bestowing a Mach 2 performance potential on the Arrow.



The pilots prepared for the Arrow flight-test programme by being posted to Convair's test facility at Palmdale, California, where they flew the single-engined, delta-winged F-102. In addition to those on the Arrow programme, other pilots were conducting tests for Avro's sister company, Orenda, which was developing the Iroquois engine.

Production of the prototype

With initial designs under way and development proceeding, Avro now had contracts for 37 pre-production Arrows: five Mk 1s and 32 Mk 2s. The Mk 1 referred to prototypes equipped with Pratt & Whitney J75 turbojets and without armament. The Mk 2 was the fully developed version, to be powered by the indigenous 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 invested in new machinery and developed new techniques, among which were: a new glass-cloth process; an electronically-controlled skin-mill for machining large integrally-stiffened wing panels, as well as smaller cutters; a 15,000-ton 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.

The complexity of the new aircraft can be judged by comparing it to its predecessor, the CF-100. The CF-100 Mk 5 weighed 23,100 lb (10 478 kg) empty, while the CF-105 Mk 1 weighed 49,040 lb (22 244 kg). The CF-100 had approximately 13,000 parts compared with 38,000 for the CF-105. In addition to the aircraft itself, ground-handling and maintenance equipment involved an important production effort: an Avro-RCAF Maintenance Engineering Group designed 200 separate pieces of equipment for the Arrow.

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

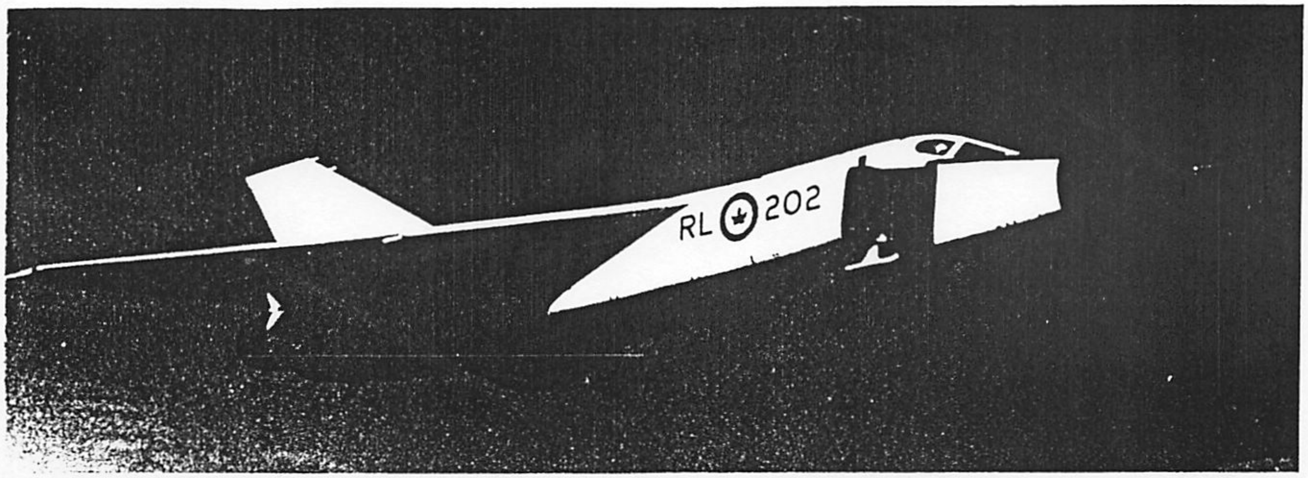
Associated programmes

The first of the associated programmes to be undertaken was that involving the powerplant. The Rolls-Royce RB.106 had been the first choice for the engine, but when this was abandoned early in 1954, the Curtiss-Wright J67 was selected as a replacement. Meanwhile, in September 1953, A V Roe Canada had started, through its subsidiary Orenda Company, to design a new turbojet engine, financing the development from its own funds.

The progress of this project was encouraging and, with rumours of the J67's imminent abandonment by the USAF, the Canadian government undertook the funding of production of the Orenda engine. The Curtiss-Wright J67 would be used as an interim powerplant in the five Mk 1 aircraft, while Mk 2 pre-production and all production aircraft would be fitted with the Orenda engine, designated the PS-13 and later named Iroquois. When the J67 succumbed in 1955, the Pratt & Whitney J75 was substituted as the "interim" engine in the Mk 1s, such a step being considered necessary because of the risks involved in testing a new aircraft and a new engine simultaneously.

The Iroquois was intended to give 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 hrs of bench running in test cells at Malton and in flight tests; some 2,000 hrs of additional testing had been completed by the time the Iroquois was cancelled and the turbojet had been installed in a CF-105 Mk 2 in preparation for flight testing.

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 lightness and simplicity. For example, Orenda pioneered new territory in the field of titanium. Twenty per cent by weight of the completed Iroquois consisted of titanium. The earlier Orenda turbojet, which then powered



The second Arrow, 25202, joined the flight test programme on 1 August 1958 and in six months this aircraft totalled 22 flights and nearly 24 hrs, only slightly less than the first aircraft. There were no external differences between the five prototypes completed.

Canadair Sabres and Avro CF-100s, had more parts while producing less power: the Iroquois weighed 5,900 lb (2 675 kg) dry by comparison with the Orenda 9's 2,560 lb (1 160 kg). These comparisons take into account the American Marquardt afterburner of the Iroquois; the early Orenda did not have an afterburner. The Iroquois rating was reported to be 30,000 lb st (13 608 kgp) with reheat for take-off, while the maximum rating of the Orenda 9 was 6,355 lb st (2 883 kgp).

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 were invaluable, revealing, among other things, the engine's successful operation under sustained high inlet temperatures; the ability to make normal relights up to 60,000 ft (18 290 m), the limit of the tunnel, and probably the highest dry thrusts recorded in North America for a turbojet.

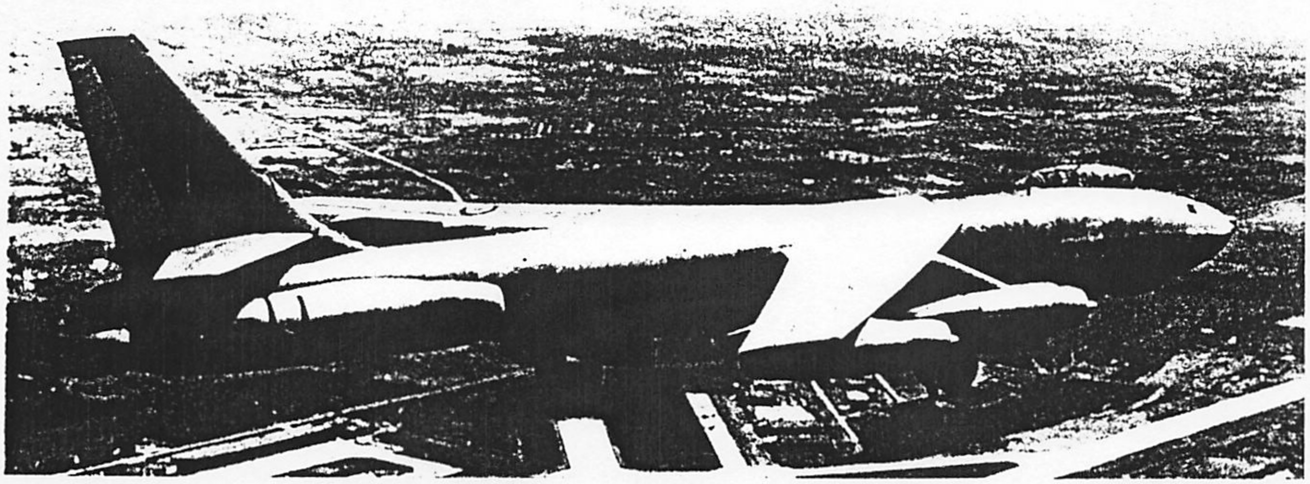
The Iroquois flight test programme was conducted with a Boeing B-47 loaned by the USAF to the RCAF, which loaned it in turn to Orenda. Canadair, at Cartierville, Quebec, near Montreal, spent more than a year modifying the B-47 for its task, fitting a large nacelle to the starboard rear fuselage to house the Iroquois, and adding approximately 20 tons of ballast and instrumentation. 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 change of engine to allow for testing at full power would have meant a month's delay, but all went well within these limitations.

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 fire-control system. Had this course been followed, the outcome of the Arrow controversy might have been very different. The RCAF wished to have a 40-in (1,02-m) 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

Avro Arrow Specification (1955)

Power Plant: Two Pratt & Whitney J75 (Model JT4A-23) turbojet engines with afterburners.
Performance: Max speed, Mach = 1·99 at 50,000 ft (15 240 m); cruising speed, 610 mph (981 km/h); service ceiling, 57,200 ft (17 435 m); time to climb to 50,000 ft (15 240 m), 3·7 min; normal range, 230 mls (370 km); cruising radius, 466 mls (750 km); maximum range, 2,058 mls (3 312 km).
Weights: Empty, 41,839 lb (18 978 kg); normal loaded, 58,975 lb (26 750 kg); max, 67,730 lb (30 722 kg).
Dimensions: Span, 50 ft 0 in (15,2 m); length, 79 ft 0 in (24,1 m); height, 21 ft 2·4 in (6,46 m); wing area, 1,225 sq ft (113,8 m^2).
Accommodation: Two crew (pilot and radar operator) in tandem, pressurised, air-conditioned cockpits with automatic ejection seats.
Armament: To consist of air-to-air missiles in a removable pack housed in an interior armament bay.

As part of the Arrow programme, the Orenda Iroquois engine intended for the definitive Arrow 2 was test flown on this Boeing B-47, slung in a nacelle on the rear fuselage. The conversion was handled by Canadair Ltd (as the CL-52) and the first flight (with a mock-up Iroquois installed) was made from Montreal to Malton in April 1957.



for the new radar — its systems were standard in the CF-100 — but the American company rejected the proposed contract on the grounds that the dish could not be used in USAF interceptors, thus restricting its marketability to a relatively small batch of Canadian aircraft. Avro, it was said later, was willing to manage with a smaller Hughes dish, but RCAF's insistence caused the contract to be awarded to the Radio Corporation of America (RCA), with its associates Minneapolis-Honeywell.

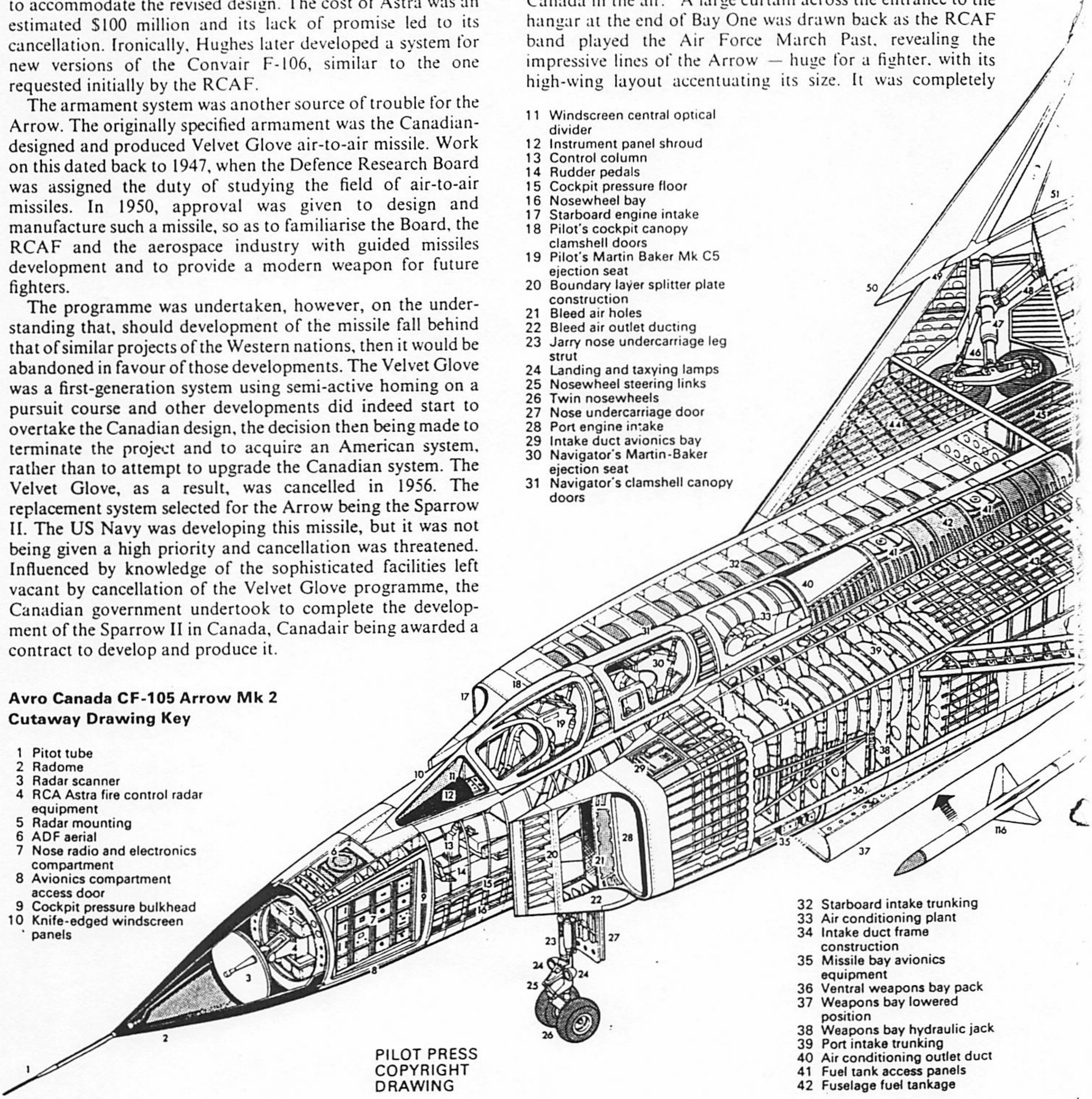
Astra I was adopted as the name for RCA's electronic system responsible for automatic flight, fire control, communications and navigation in the Arrow. Unfortunately, it proved to be a failure. Changes led to more changes, and costs mounted. Constant alterations initiated at RCA also affected Avro, since the Arrow airframe had to be modified each time to accommodate the revised design. The cost of Astra was an estimated $100 million and its lack of promise led to its cancellation. Ironically, Hughes later developed a system for new versions of the Convair F-106, similar to the one requested initially by the RCAF.

The armament system was another source of trouble for the Arrow. The originally specified armament was the Canadian-designed and produced Velvet Glove air-to-air missile. Work on this 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 was given to design and manufacture such a missile, so as to familiarise the Board, the RCAF and the aerospace industry with guided missiles development and to provide a modern weapon for future fighters.

The programme 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 system using semi-active homing on a pursuit course and other developments did indeed start to overtake the Canadian design, the decision then being made to terminate the project and to acquire an American system, rather than to attempt to upgrade the Canadian system. The Velvet Glove, as a result, was cancelled in 1956. The replacement system selected for the Arrow being the Sparrow II. The US Navy was developing this missile, but it was not being given a high priority and cancellation was threatened. Influenced by knowledge of the sophisticated facilities left vacant by cancellation of the Velvet Glove programme, the Canadian government undertook to complete the development of the Sparrow II in Canada, Canadair being awarded a contract to develop and produce it.

Tangible results

The CF-105 programme came to the forefront of the news in 1957. Early that year, the name "Arrow" had been officially adopted and public interest and anticipation grew as the roll-out 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 them) released from work for the ceremony — gathered at Malton. After the preliminaries, the Minister of National Defence, the Hon George R Pearkes, VC, addressed the gathering, extolling the virtues of the aircraft and emphasising 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." A large curtain across the entrance to the hangar at the end of Bay One was drawn back as the RCAF band played the Air Force March Past, revealing the impressive lines of the Arrow — huge for a fighter, with its high-wing layout accentuating its size. It was completely



Avro Canada CF-105 Arrow Mk 2 Cutaway Drawing Key

1 Pitot tube
2 Radome
3 Radar scanner
4 RCA Astra fire control radar equipment
5 Radar mounting
6 ADF aerial
7 Nose radio and electronics compartment
8 Avionics compartment access door
9 Cockpit pressure bulkhead
10 Knife-edged windscreen panels
11 Windscreen central optical divider
12 Instrument panel shroud
13 Control column
14 Rudder pedals
15 Cockpit pressure floor
16 Nosewheel bay
17 Starboard engine intake
18 Pilot's cockpit canopy clamshell doors
19 Pilot's Martin Baker Mk C5 ejection seat
20 Boundary layer splitter plate construction
21 Bleed air holes
22 Bleed air outlet ducting
23 Jarry nose undercarriage leg strut
24 Landing and taxying lamps
25 Nosewheel steering links
26 Twin nosewheels
27 Nose undercarriage door
28 Port engine intake
29 Intake duct avionics bay
30 Navigator's Martin-Baker ejection seat
31 Navigator's clamshell canopy doors
32 Starboard intake trunking
33 Air conditioning plant
34 Intake duct frame construction
35 Missile bay avionics equipment
36 Ventral weapons bay pack
37 Weapons bay lowered position
38 Weapons bay hydraulic jack
39 Port intake trunking
40 Air conditioning outlet duct
41 Fuel tank access panels
42 Fuselage fuel tankage

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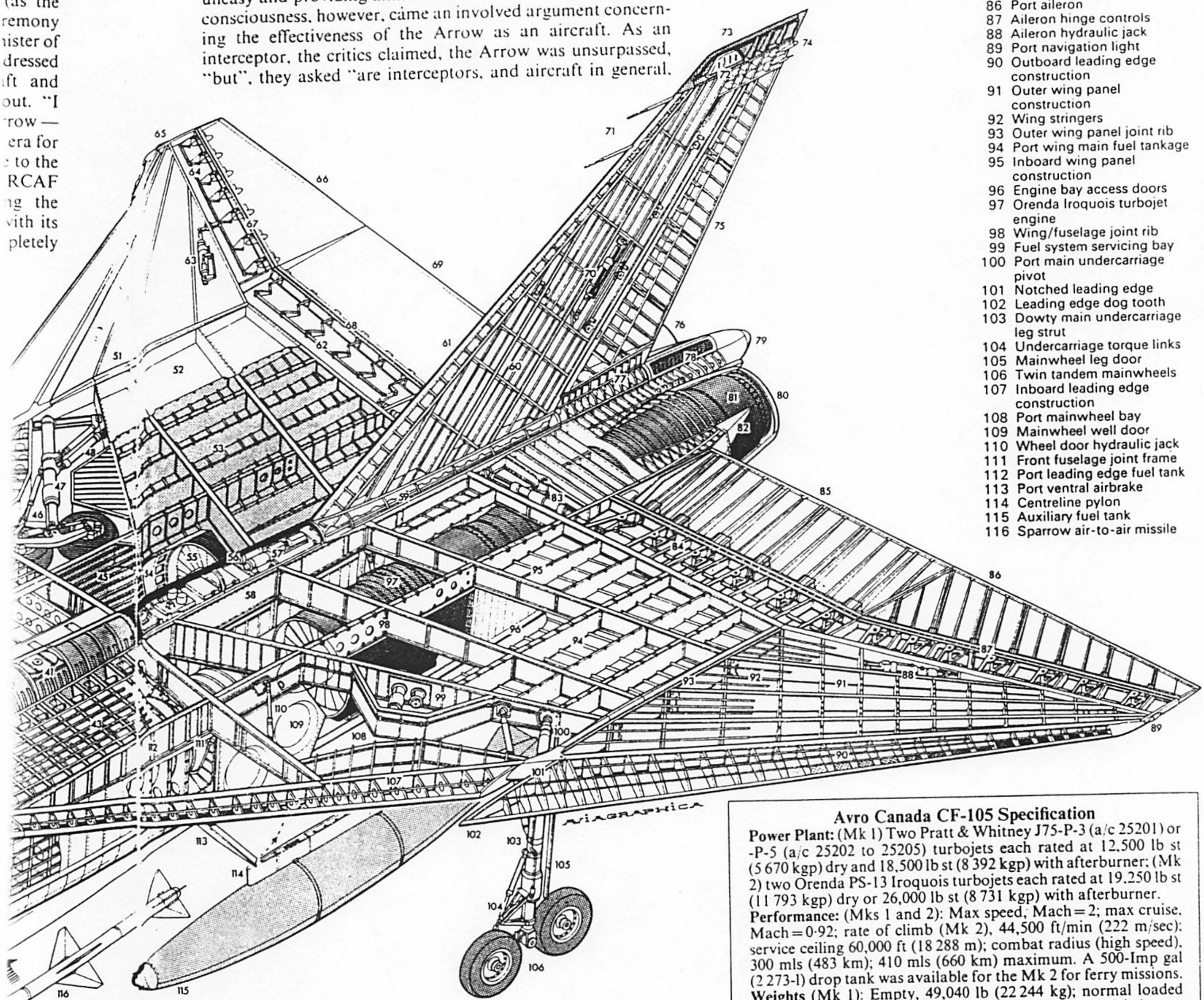
white (with the exception of the radome) for anti-radiation flash protection. The moment of roll-out was dramatic and it was difficult for anyone to be disappointed that day.

On the same day, the Soviet Union launched its first Sputnik. This was an unfortunate coincidence, since it highlighted the growing controversy concerning the fate of the Arrow. Steadily rising costs were making the Government uneasy and providing ammunition for critics. With this cost-consciousness, however, came an involved argument concerning the effectiveness of the Arrow as an aircraft. As an interceptor, the critics claimed, the Arrow was unsurpassed, "but", they asked "are interceptors, and aircraft in general,

65 Starboard navigation light
66 Starboard aileron
67 Aileron upper surface hinge
68 Elevator upper surface hinge
69 Starboard elevator
70 Rudder hydraulic jack
71 Pitot tubes
72 Communications aerial
73 Fin tip antenna fairing
74 Tail navigation light
75 Rudder construction
76 Starboard engine exhaust nozzle
77 Dorsal spine fairing
78 Brake parachute housing
79 Tailcone
80 Port engine exhaust nozzle
81 Afterburner exhaust duct
82 Trailing edge fillet
83 Elevator hydraulic jack
84 Elevator hinge controls
85 Port elevator
86 Port aileron
87 Aileron hinge controls
88 Aileron hydraulic jack
89 Port navigation light
90 Outboard leading edge construction
91 Outer wing panel construction
92 Wing stringers
93 Outer wing panel joint rib
94 Port wing main fuel tankage
95 Inboard wing panel construction
96 Engine bay access doors
97 Orenda Iroquois turbojet engine
98 Wing/fuselage joint rib
99 Fuel system servicing bay
100 Port main undercarriage pivot
101 Notched leading edge
102 Leading edge dog tooth
103 Dowty main undercarriage leg strut
104 Undercarriage torque links
105 Mainwheel leg door
106 Twin tandem mainwheels
107 Inboard leading edge construction
108 Port mainwheel bay
109 Mainwheel well door
110 Wheel door hydraulic jack
111 Front fuselage joint frame
112 Port leading edge fuel tank
113 Port ventral airbrake
114 Centreline pylon
115 Auxiliary fuel tank
116 Sparrow air-to-air missile



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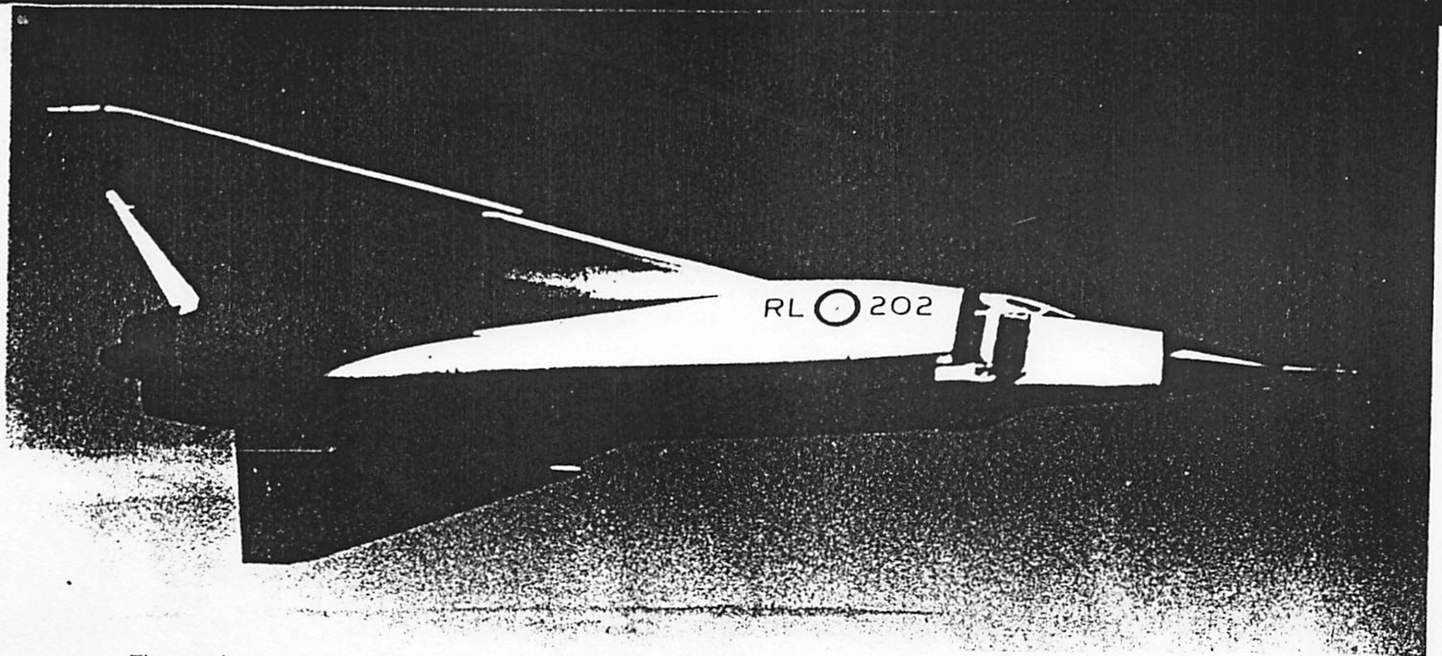
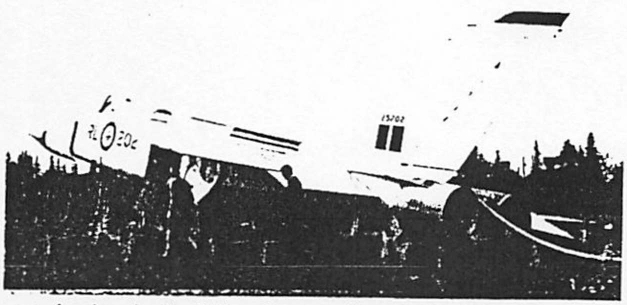
43 Forward fuselage stringer construction
44 Starboard leading edge fuel tank
45 Auxiliary wing fuel tank
46 Starboard main undercarriage bay
47 Starboard undercarriage retracted position
48 Retraction jack
49 Notched leading edge
50 Leading edge dog tooth
51 Outer wing panel joint rib
52 Wing skin plating
53 Main wing fuel tanks
54 Intake duct spill doors
55 Starboard engine compressor face
56 Dorsal aerial antenna fairing
57 Aerial transmitting and receiving equipment
58 Wing spar centre section joint rib
59 Fin root attachment
60 Tailfin construction
61 Fin leading edge
62 Elevator hinge controls
63 Aileron hydraulic jack
64 Aileron hinge controls

Avro Canada CF-105 Specification

Power Plant: (Mk 1) Two Pratt & Whitney J75-P-3 (a/c 25201) or -P-5 (a/c 25202 to 25205) turbojets each rated at 12,500 lb st (5 670 kgp) dry and 18,500 lb st (8 392 kgp) with afterburner; (Mk 2) two Orenda PS-13 Iroquois turbojets each rated at 19,250 lb st (11 793 kgp) dry or 26,000 lb st (8 731 kgp) with afterburner.
Performance: (Mks 1 and 2): Max speed, Mach=2; max cruise, Mach=0·92; rate of climb (Mk 2), 44,500 ft/min (222 m/sec); service ceiling 60,000 ft (18 288 m); combat radius (high speed), 300 mls (483 km); 410 mls (660 km) maximum. A 500-Imp gal (2 273-l) drop tank was available for the Mk 2 for ferry missions.
Weights (Mk 1): Empty, 49,040 lb (22 244 kg); normal loaded (Mk 1) 57,000 lb (25 855 kg), (Mk 2) 62,431 lb (28 319 kg); max overload (Mk 1), 68,602 lb (31 117 kg), (Mk 2), 68,847 lb (31 228 kg); combat weight (Mk 1), 64,000 lb (29 056 kg), (Mk 2), 53,796 lb (24 423 kg); landing weight (Mk 1), 65,000 lb (29 510 kg), (Mk 2), 47,743 lb (21 675 kg).
Dimensions (Mks 1 and 2): Span, 50 ft 0 in (15,24 m); length (Mk 1), 83 ft 0 in (25,3 m), (Mk 2), 80 ft 0 in (24,38 m); height (Mk 1), 20 ft 6 in (6,25 m), (Mk 2), 21 ft 0 in (6,4 m); wing area (Mks 1 and 2), 1,225 sq ft (113,8 m^2); anhedral, 4°; sweepback: 61 deg on leading edge.
Accommodation: Two (pilot and radar operator) for all versions.
Armament: None fitted to Mk 1; six Falcon air-to-air missiles in Mk 2. Hughes MA-1 fire control system selected for operational versions.



The second Arrow came to grief on 11 November 1958, when the brakes seized as it touched down after a flight on which it had only just failed to achieve Mach 2. As tyres and magnesium wheel hubs were shed, the aircraft slewed off the runway and the starboard leg broke, the aircraft coming to rest on its starboard wing-tip. Five months earlier, on 11 June and on its 11th flight, the first Arrow had similarly come to grief when, unknown to the pilot, the undercarriage had failed to extend and lock down properly. Zurakowski touched down with the port wheels at a 30-deg angle to the line of flight and the aircraft slewed, broke its port leg and suffered damage that took four months to repair.



not obsolete in the light of recent developments in missiles?". Pearkes attempted to calm these fears in his speech at the roll-out, saying, in part:

"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."

Such views were not necessarily shared by others. Gen Guy Simonds, who had been Chief of the General Staff in 1953 — when the decision to undertake the CF-105 project had been made — was among 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 replace bombers and all combat aircraft would be obsolete. That an enemy might retain both missiles *and* aircraft, or that the marginal period might be quite long, or that the complementary nature of aircraft and missile systems might be proved, and thus require the maintenance of both, were possibilities that the missile proponents never adequately considered.

The opponents of the pro-missile view were more impressive. Air Marshal Hugh Campbell, Chief of Air Staff, stressed "an inherent flexibility in operations and promising future development potential". Former AVM John L Plant, who was the Air Member for Technical Services when the Arrow go-ahead was given and was now president and general manager of Avro Aircraft, condemned the convenient use of the term "obsolete" as indiscriminate, since there is always "a better airplane on the drawing board behind". Wg Cdr 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" — usually involving straying airliners or private aircraft.

The argument that the Arrow programme was beyond the financial means of a "middle" power like Canada would have been a more realistic (though not incontestable) one to have applied, since the project was running up huge costs for the Canadian taxpayers. The additions of powerplant, fire-control system and armament to the original airframe programme 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 price might have been more acceptable. The financial aspects of the controversy, which had some basis in reality, were always accompanied by the arguments concerning the obsolescence of the Arrow as an aircraft.

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 of that year. Among the planks in Diefenbaker's platform was a promise to reduce government expenditure, and the Arrow programme was obviously a prime target. The estimated cost per aircraft was variable according to the parameters being used, but was inevitably increased by any reduction in the numbers likely to be ordered. From the early projections of 500 to 600, the number required had first slipped to 400 — still enough to equip nine regular and 11 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 100 aircraft. A 1955 estimate was $2·6 million per copy, but figures between $8 and $13 million were officially quoted later.

After several postponements, the Arrow's first flight was made on 25 March 1958. The armament bay of the Arrow (s/n 25201, code RL), which was as large as the bomb bay of a B-29, was packed with instrumentation for the transmission of signals to a telemetry van. Flown by Zurakowski, the aircraft was accompanied by two chase aircraft — one a CF-100 piloted by "Spud" Potocki, with Avro photographer Hugh MacKechnie and his still and ciné cameras, in the navigator's seat, and a Sabre flown by Flt Lt Jack Woodman, whose helmet had been fitted with a special adapter to allow for the mounting of another ciné camera.

At 0949 hrs, 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 3,000 ft (915 m) of the 11,000 ft (3 353 m) available to become airborne.

The speed of the Arrow was increased cautiously to 300 mph (480 km/h) and the height to 10,000 ft (3 050 m). After flying over Malton at different altitudes, with the undercarriage retracted or lowered, Zurakowski set the aircraft down on runway 32. The drag-chute billowed and filled, slowing 25201 almost to a stop before being jettisoned. "It handled nicely", Zurakowski commented on leaving the cockpit. "There was no unexpected trouble."

The flight test programme for the Arrow was to have been divided into eight phases, of which the first three were for contractors test and development and the other five for RCAF test and evaluation. In the event, only a part of Phase I testing was completed, with a total of 64 flights aggregating 68 hrs 45 min made in just under a year. This total was spread over all five Mk I airframes, the remainder of which had made their first flights, respectively, on 1 August, 22 September and 27 October 1958 and 11 January 1959. By the time the programme was cancelled, the first Arrow, 25201, had made 24 flights; 25202, 22 flights; 25203, 11 flights; 25204, six flights and 25205 one only. "Spud" Potocki had succeeded Zura as chief development pilot and actually flew more Arrow hours than any of the other pilots, who, in addition to Zura, were Avro's Pete Cope and the RCAF's Flt Lt Jack Woodman. On one flight, a test observer flew in the rear seat; all other flights were made solo or with pilots in both cockpits.

The Arrow achieved supersonic speed on its third flight and on its seventh, reached Mach = 1·5 at 50,000 ft (15 250 m). The highest speed recorded, Mach = 1·97/1·98, was just short of the design max of Mach = 2·0. About 95 per cent of the flight envelope was explored and handling was found to be generally satisfactory, although not flawless. The following recollections come from 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 I 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 optimised 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 glideslope; 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."

The final chapter

With the coming of summer, the air defence controversy was approaching the proportions of a full-scale battle. The cost of the Arrow was obviously back-breaking, and there seemed to be two methods of making it bearable: by foreign sales and by a replanning of the components of the aircraft. Discussions were held with the UK and the USA about possible sales. The

Fifth and last Arrow to fly, 25205 took to the air on 11 January 1959 (eleven seems to have been a significant number for the Arrow — see caption on opposite page). It made only one flight before being broken up the following month.

The Arrow Airframe and Systems

Wings: High-wing, delta-planform monoplane. All-metal structure. Sweep-back 61 deg on leading edge. Anhedral 4 deg.
Fuselage: All-metal, bonded.
Landing Gear: Retractable, tricycle type. Forward gear consisted of dual wheels and retracted forward. Main gears had two-wheeled bogies and retracted inboard and forward into the wing. An emergency system allowed extension of the landing gear by means of pneumatic pressure from a 5,000 lb/sq in (351.5 kg/cm²) 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 nosewheel was steered with the rudder pedals, which were mechanically linked to a steering control valve. The steering angle was approximately ±55 deg which permitted a 180 deg turn to be made on about a 21 ft (6.4 m) radius. The Arrow's wheel track was 30 ft 2½ in (9.21 m).
Accommodation: The crew members were seated in separate tandem cockpits. Each cockpit was pressurised and air-conditioned. Cabin pressure remained the same as the outside air up to 10,000 ft (3 050 m). Above this altitude, the differential between cabin pressure and aircraft pressure increased linearly until a differential pressure of 4·5 to 5 lb/sq in (0.32 to 0.35 kg/cm²) would be reached at 60,000 ft (18 290 m). 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 min 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: 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 to be three modes of control for the final Arrow configuration. The *normal* mode was characterised by a damping system, automatically stabilising the aircraft in all three axes and co-ordinating rudder movement with movement of the ailerons and elevators. The *automatic* mode was never fitted to the aircraft. The *emergency* mode's rôle is self-explanatory: the hydraulic components for operating the ailerons and elevators were controlled mechanically. Yaw stability and turn co-ordination 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, spring feel was provided.
Hydraulic System: The Arrow Mk 1 had two independent hydraulic systems of 4,000 lb/sq in (281 kg/cm²). 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. A utility hydraulic system, as distinct from the flying-control hydraulic system described above, consisted of two pumps, one on each engine-driven gear-box, rated at 4,000 lb/sq in (281 kg/cm²). The landing gear, wheel-brakes, nosewheel steering, and speed brakes were all operated by this system.
Fuel System: Fuel was carried in two bladder-type tanks in the fuselage and six integral tanks in each wing. Total capacity was 2,508 Imp gal (11 401 l). A long-range tank of 500 Imp gal (2 273 l) was planned for later aircraft and would have been carried under the fuselage for ferry missions.
Speed Brakes: 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.
Navigation and Communication: Navigation equipment in the Arrow Mk I consisted of Radio Magnetic Indicator, UHF Homer, ARN-6 Radio Compass, and J4 Gyro Compass. The communications equipment consisted of ARC-34 UHF and AIC-10 Intercom.

UK was not interested in buying the Arrow, but actually wanted the RCAF to buy the TSR-2, which was then being threatened with a similar fate. The discussions with the USA were no more successful, for the American aerospace lobby was strong, and determined to defend US markets; the range of the Arrow at supersonic speeds — some 400 mls (645 km) without ferry tankage — was considered insufficient for US operations; and the Americans were in any case similarly worried about the coming missile age.

With these possible solutions gone, Diefenbaker and his government had to consider some hard alternatives, although even at this late date it could not be assumed that the Arrow was a "dead duck". *Time* magazine's Canadian edition stated that up to a week before Diefenbaker's 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.

On 23 September 1958, the Canadian premier 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 system and the Sparrow II were cancelled immediately, to be replaced by the Hughes MA-1 and the Falcon; Bomarcs, SAGE (Semi-Automatic Ground Environment) and gap-filler radar would be introduced into the Canadian air-defence system; and finally, negotiations would begin with the USA on the subject of defence production.

The address was not interpreted the same way by everybody. To Gen Simonds — already known as an opponent of the Arrow — it meant that the formal cancellation of the programme was merely postponed until March. The views of the media were divided, some still anticipating eventual production, while others accepted the September statement as tantamount to a cancellation. All doubts were settled on 20 February 1959, when the axe fell, when the Prime Minister made an announcement in the House of Commons of Government policy on air defence. Of the Arrow, 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."

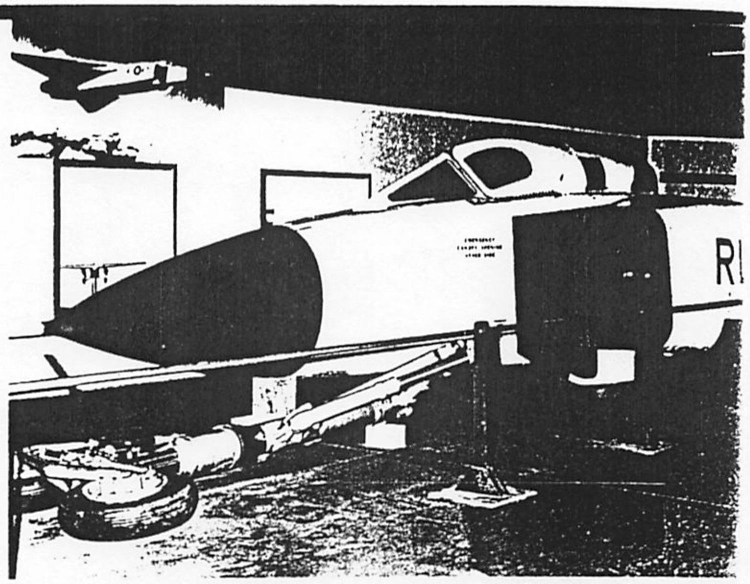
The Arrow story was over. Avro dismissed some 14,000 workers immediately, as there was no work for the company. The last CF-100 Mk 5 had been delivered in December 1958 and the guided missile-armed CF-100 Mk 6 had been shelved in 1957. It has since been suggested that the mass dismissal was a pressure tactic designed to force the Government either to reconsider its decision or to find other contracts for the company, but if this was so, the tactic failed.

Controversy over the Arrow inevitably continued for a while, however, and it is difficult even today to sort out the rights and wrongs of the situation. Certainly, Diefenbaker's position on replacing manned interceptors with missiles proved fallacious, as the CF-100 was replaced in 1961 by the CF-101B Voodoo. His insistence that the decision was based solely on strategic, not economic, considerations does not today carry much weight.

The threat of manned bombers and the value of the investigatory capacity of RCAF fighters could not be simply and finally dismissed in 1959. The possibility of ICBM predominance was partially valid, but the idea of discounting manned bombers, reconnaissance aircraft and any other intruders does not make sense. Had the argument been based on the high cost of fighters relative to the smaller threat of bombers, then there would have been credibility in the argument. To gamble on the possibility of an all-ICBM/no-bomber enemy was very questionable, since there would, in any case, have been a period when ICBMs *and* bombers would be used. The cost of the Arrow was, on the other hand, far too high for a "middle" power and to believe that economics did not have a predominant place in the cancellation decision is hard to accept. Moreover, the Boeing MIM-10B (or IM-99B) Bomarc missile adopted for Canadian defence when the Arrow was cancelled was and is an anti-*bomber* weapon, with application against air-breathing missiles. It was designed as a different approach to conventional threats, not as an anti-*ballistic missile* (ABM) weapon — and North America still lacks a comprehensive ABM defence even today.

In conclusion, it can be said that the cancellation of the Arrow was justified by some economic reasons, but that this justification was denied by the decision-makers. It does seem sensible, as suggested by a later defence minister, Paul Hellyer, that the aircraft should have been retained at least for completion of a development programme, and the lessons learned, as the money had been spent anyway: but the Government ordered all the aircraft — those completed as well as those under construction, Mk 1 and Mk 2 — to be broken up. Over the next few months, all the aircraft, tooling, jigs and fixtures were scrapped. The completed Iroquois engines and some tooling associated with them were kept, but in 1962 these, too, were ordered to be scrapped. Many had hoped that the Arrow would be able to compete for the world speed record, and there was loud criticism when it was learned that the five completed Mk 1s (25201 to 25205), all of which had flown by the time of cancellation, were also to be broken up. Of the $407,388,964 spent (according to current CAF information), some of the value of at least these five functioning aircraft could surely have been salvaged.

Avro Aircraft soon ceased to exist. Orenda survived, but the days when it designed powerplants like the Orenda and the Iroquois were over. A V Roe Canada Ltd, the parent company of Avro and Orenda, changed its name to Hawker Siddeley Canada Ltd on 1 May 1962, in order to reflect the move away from its original aviation basis. Jan Zurakowski gave up his test-pilot duties after the Arrow debacle and left to live in northern Ontario. In 1959, he was awarded Canada's coveted McKee Trophy for his work as a test pilot — particularly on the CF-105 programme.



The only surviving components of the Arrow are this front fuselage and main undercarriage leg of the sixth airframe, which had been destined to be the first Mk 2 and was close to first flight when the axe fell (all too literally) on the entire programme. When rediscovered in 1967, this relic still clearly bore the legend "cut here" on the fuselage just aft of the intakes.

In 1967, the front fuselage of 25206, the first Mk 2, was found at the Aviation Medical Unit in Toronto. News of the find was immediately passed on to the aviation museum in Ottawa, which acquired the structure, washed off the dust and placed it on display along with an undercarriage leg and tyre. This front fuselage is at present in the possession of the National Museum of Science and Technology in Ottawa — apparently the sole surviving artifact of the Arrow programme. □