Interceptor Rex --- The Avro CF-105 Arrow

Written By Emmanuel Gustin

This is the second revision of this text. Emmanuel writes:

I received some detail critique from a former engineer who worked on the Avro Arrow project. So I made small modifications to the text. Here is the new version.

Emmanuel Gustin

Design and Development

Avro Canada was created in December 1945, when the British Avro acquired the National Steel Car factory that had been building its Lancaster bombers during WWII. After WWII, Avro Canada designed a number of aircraft. The CF-100 "Canuck" a transsonic straight-wing all-weather fighter was the most successful one and 692 were built, including 53 for Belgium, between 1950 and 1958. In 1954 Avro Canada came under governement control, with an aircraft division and an engine division. The latter would later become Orenda engines.

It was inevitable that Avro Canada would try to design a replacement for the CF-100. Initially, these designs resembled CF-100s with swept wings and supersonic performance. Later a number of designs with swept and delta wings were studied, but the effort began in earnest in April 1953, when the RCAF announced it requirement Air-7-3. It wanted a twin-engined, two-seat interceptor with a radius of action of at least 1000km, a ferry range of no less than 6000 nautical miles (11000km) and a maximal speed of more than Mach 1.5. It was to be equipped with a sophisticated fire control system, and to have an all-missile armament. A need for 600 such aircraft was initially envisaged. No such aircraft was available elsewhere, and the RCAF was unwilling to comprise by adopting a less than 100% satisfactory aircraft. So a new type would have to be designed. In the end, the RCAF would adopt one of the alternative designs it had studied, but rejected --- the McDonnell F-101 Voodoo.

It is interesting to note that when the USAF formulated its requirement for a modern interceptor, it did choose a single-engined, single-seat fighter. This reflected the confidence of the USAF in automatized systems, as had already been used by the F-86D, for the all-weather interception mission. The RCAF may have felt, probably wisely, that the workload for a single pilot in bad weather or at night was too high. The preference for twin-engined aircraft may have been based on the assumption that these are safer for long patrol flights over the vast unpopulated regions of Canada. The requirements of the USAF were also less demanding in other important aspects: Radius of action was required to be only 600km, and the bomb bay of the F-102 and F-106 was tailored for only four Falcon missiles. All this resulted in a smaller aircraft. The USAF adopted a two-stage development program, in which the F-106 was to be preceded by an interim model, the F-102. In this way the USAF limited the risks of the development process.

The armament of the new fighter was to be all-missile, and the missiles were to be stored in an internal missile bay. This protected them for the elements and reduced drag, but in combination with the range requirement it called for a large and roomy fuselage. To make access for maintenance easier, and to reduce structural problems with the wing spars and the missile bay, a shoulder wing configuration was adopted. The chosen wing was a large, very thin delta wing with marked anhedral. When this design was submitted to the RCAF in 1953, it was immediately accepted. Wind tunnel tests, as well as tests with rocket-powered scale models, produced favourable results.

However, the choice of the engines was to be a problem. Originally, the Rolls Royce RB106 engine was chosen, but it was soon recognized that this would not be available. Then the Wright J67 was chosen, but this engine was cancelled in 1955. Finally, it was decided to use an indigenous engine, the Orenda PS-13 Iroquois. Because this engine would not be available for the first prototypes, it was decided to use the Pratt & Whitney J75 to power the Mark 1 prototypes and pre-series aircraft. The thrust of the J75-P-3 with full afterburner was 8390kg, equivalent to the maximal dry thrust of the Iroquois. The Arrow Mk.2 would have the Orenda engines. The Mk.2A would have more fuel and redesigned jet intakes and nozzles. The final Mk.3 version, with uprated engines, would be able to fly at Mach 2.5.

Structure

The delta wing was thin and had considerable anhedral. In plan view, the leading edge was swept at 60 degrees and straight, apart from a dogtooth at half-span. Internally, the spars of the outboard wing panel were swept at almost the same angle as the leading edge, while those of the inboard panels had much less sweep. This was reflected by the leading edges of the big control surfaces. The Arrow had separate elevators and ailerons on its delta wing. The leading edges were drooped, more strongly on the outboard wing sections. The wing contained six integral fuel tanks: in the inboard wing panel behind the landing gear compartiment, in the wing roots, and a small tank in the part of the wing on top of the fuselage, inboard of the landing gear compartiment.

The fuselage was large and box-like, preceding that of the MiG-25 and F-15. A compartiment in the nose was designed for the Astra radar and fire control system, that in the end never was installed. The CF-105 would probably have been able to be fitted with a larger radar antenna, and the nosecone tapered sharply. The engines intakes were rectangular, with large splitter plates to divert the boundary layer. They were far forward of the wing leading edge and the engines, so that considerable volume was occupied by the intake ducting. Two fuel tanks were installed in the fuselage, between the engine intakes. The armament bay, which was larger than that of a Lancaster or B-29, was installed below the intake ducts. It was 16ft 1in long, 9ft 6in wide, and 3ft high. The projected armament consisted of a version of the AIM-7 Sparrow, known as Sparrow II, and the Hughes Falcon. The doors of the missile bay could be opened in 0.3 seconds. Launch tests were performed at speeds up to Mach 1.5.

The engines were installed at the extremeties of the aft fuselage, with the engine nozzles projecting well beyond the wing trailing edge and the tail. The engines could be changed in 30 minutes, by extracting them backwards.

Engines

The Arrow Mk.2 was to be powered by two Orenda PS-13 Iroquois engines. Development of the PS-13 began in 1953. It was a twin-spool engine, designed to deliver 8720kg dry trust and 11800kg with afterburner. The high-pressure spool had two compression and two turbine stages; the low- pressure spool had three compression stages and a single turbine stage. The then still very scarce and expensive titanium was used for a number of parts, to keep the weight down. Of a total weight of about 2000kg, 30% was accounted for by titanium parts.

The PS-13 was run at full dry power during ground tests in 1955. In 1957, the RCAF received a B-47E Stratojet on loan from the USA to test the Iroquois engine. The cooperation of the USA also extended to giving the Canadian crew of the aircraft a SAC training course, and offering the facilities of NACA to test the engine. The Iroquois was installed at the right side of the tail, under the tailplane of the B-47. The first flight was made in November 1957.

Testing was not entirely without problems, including an in-flight failure of the turbine, luckily without any serious consequences for aircraft or crew. But in general the engine was progressing well. The Iroquois was the most powerful engine of the American continent, it had a very good weight-to-trust ratio, and it was fuel efficient. Development costs had not exceeded 90 million dollar --- cheap, even for that time.

Crew accomodation

The two crewmembers sat under clamshell-type canopies. They opened on the top, the two side panels folding left and right. The panels of the pilot's cockpit had a relatively large cutout in them, but the aft compartiment only had two small windows. The windscreen was of V-type with a frame in the middle. A similar type of canopy was fitted to the American F-106, until 1972. This canopy design betrayed a preoccupation with the high-speed bomber interception mission, being obviously less suitable for dogfights with enemy fighters, because it offered a relatively poor view.

However, the cockpit layout was excellent, and praised as one of the best by a group of USAF visitors. The pilot and radar operator sat on Martin-Baker C5 ejection seats. For many test flights, there was only a single crewmember.

Landing Gear

The landing gear of the CF-105 was supplied by Dowty. The three undercarriage legs each had two wheels. On the mainwheel legs, the wheels were set in tandem, to fit withing the wing. The nosewheel leg retracted to the front. The mainwheel legs were attached close to the leading edge, near the dogtooth extension at half-span. They legs retracted diagionally inwards and to the front, and folded into the inboard wing panels. Behind the wheel wells there was enough room for an external pylon.

Because the Arrow was a shoulder-wing design, this meant that the mainwheel legs were very long. Especially because the Arrow stood very high above the ground, with a nosewheel leg that was 3.65 meters long! The nosewheel leg was attached just behind the cockpit, under the jet intakes.

Powerful brakes were provided, as well as a braking parachute. This was installed in the tail cone, between and just above the engines.

Controls and Equipment

The CF-105 relied to a much higher degree on electronic systems for control than any previous aircraft, although it was not a true fly-by-wire design. An AFCS (Automatic Flight Control System) was installed. This worked in three modes: In "normal" mode it assisted the pilot by stabilizing the aircraft. In "automatic" mode the AFCS controlled the aircraft completely, serving as autopilot and blind-landing aid. In theory, fully automatic landings were possible. The "emergency" mode was entered in case of a serious failure, e.g. an engine failure, and served to prevent the CF-105 from entering a stall or another dangerous condition.

The controls were all hydraulically boosted. The thin wing had created some problems for the designers of the hydraulically powered controls. They finally decided to have the hydraulic lines running through the wing fuel tanks.

Special problems were also posed by the Canadian environment. The CF-105 was designed to operate in very cold weather, but also to resist the heat generated by sustained high-speed flight. Some key parts were made from titanium, and an environmental control system was installed to protect the crew and the instruments.

Armament

One of the key features of the Arrow project --- which also contributed to its end --- was its armament system. This was as ambitious as the Arrow fighter itself. There were numerous problems with the Astra radar and fire control system, designed by RCA-Victor. This was complex and expensive. In addition, a new missile was being developed for the Arrow, and this was a very ambitious one: Sparrow II. In fact, this missile had already been abandoned by the US Navy because it was too ambitious.

Canada had already had an unpleasant experience with its only serious indigeneous air-to-air missile program, Velvet Glove. This was a short-range (8km) missile with IR guidance. It had been initially intended for the CF-100, but development was so slow that it still was unavailable when the last CF-100s were being delivered. Velvet Glove was finally cancelled in 1954, and was no longer considered for the Arrow.

As a long-range missile for the Arrow, the RCAF chose Sparrow II. This missile was developed between Sparrow I, a beam-riding missile and the Sparrow III with semi-active radar homing. Sparrow III is still in service, but Sparrow II was a much more ambitious project, because it featured active radar homing. The 8in fuselage diameter of Sparrow I was retained, and this required very careful engineering to fit the X-24 radar, developed by Westinghouse. The Sparrow II project was initiated by Douglas in 1955, and it was intended for its F5D Skylancer fighter. But in 1956 the US Navy cancelled both. The project was revived by the RCAF interest, with Canadair acting as a subcontractor for Douglas. However, communication between the two companies was extremely poor, and Sparrow II was not a successful project.

In addition, the Hughes AIM-4 Falcon was considered as short-range missile. Initially, it was planned that the Arrow would carry eight Falcons and three Sparrows in its immense missile bay. Later the number of Sparrow missiles was increased to four. After the cancellation of Sparrow II, the armament was changed to four Falcon missiles, and one or two unguided Genie missiles. Genie, unofficially designated MB-1 or (after 1962) AIR-2, was an unguided rocket with a 1.5kT nuclear warhead. This armament combination, Falcon and Genie, was the same as used by the F-106 and F-101B interceptors. Both missiles were designed for intercepting bombers, and in Vietnam it would be demonstrated that Falcon was nearly useless in fighter-versus-fighter combat.

Politics

During the development of the CF-105, there were some political evolutions that changed its intended role. The NORAD agreement that was signed in 1954, created a cooperation between the USA and Canada in the air defense of the North American continent. Although this made it in theory easier to sell the CF-105 to the USAF, in practice this was unlikely to happen, because the Americans preferred to develop their own aircraft.

In 1957, the conservatives replaced the liberals in governement. They and the new prime minister, John Diefenbaker, were much less supportive of the CF-105 project. The order for the CF-105 was reduced to 100, for a price of 781 million dollar. In combination with inflation, delays and development problems, this served to boost the unit price of the CF-105. The public animosity against the expensive interceptor increased, and every problem with the aircraft was published extensively by the press.

The most important problem was that the enemy that the Arrow had been designed to intercept, the high-flying supersonic or transsonic bomber, was perceived by many to be on its way out. Although new attack aircraft, optimized to fly at low altitudes, were on the drawing boards, the missile seemed to be the future both as vector for nuclear weapons and as air defence system. In 1957 the British aviation industry was dealt a sharp blow when Duncan Sandys cancelled all aircraft projects, except the English Electric Lightning, which was considered in a too advanced development stage to be cancelled. If anyone had announced then that the Tu-95 'Bear' would still be in service in 1995, he would probably have been put in a straightjacket immediately.

Meanwhile, the IM-99B Bomarc B surface-to-air missile had been ordered to reinforce the air defence. Bomarc B was more an unmanned interceptor aircraft than a missile in common sense: It was 13.3 meter long, weighed 7260kg, and had a range of 710km. Although Bomarc could ostensibly not replace the Arrow,it did contribute to the feeling that the Arrow was really unneccessary.

The prototypes

For the CF-105, a similar production plan was adopted as the Cook-Craigie plan adopted by the USAF for the F-102. The prototypes were built on production jigs. The first CF-105 Mk.1 was rolled out on 4 October 1957, four years after the definition of the RCAF requirement. This was certainly a notable achievement. The Minister of Defence, George R. Pearkes, announced with some pride a new age in Canadian aviation. The Chief of Air Staff used the opportunity to hint at a possible purchase of the Arrow by the USAF, and to point out that American subcontractors had contributed significantly to the Arrow. Probably this could have saved the Arrow from its final fate, but it was never much more than a faint possibility.

In preparation for the first flight, the design parameters of the CF-105 were fed to a computer --- still very limited, in 1958! --- to predict the behaviour of the aircraft in the air. The usefulness of this was probably small, because the computer predicted that the Arrow was unstable and would crash 13 seconds after take-off.

This did not deter the chief test pilot for the CF-105, Jan Zurakowski. He was born in Poland and flew combat missions in 1939, before he escaped to Britain. There he joined the RAF, and later became a test pilot for Gloster. He joined Avro Canada in 1952. The second test pilot was Spud Potocki, and for the RCAF Lt. Jack Woodman would test the CF-105.

During taxi tests all four mainwheel tires exploded, and the brakes had to be modified. On 25 March 1958 Zurakowski took the CF-105, number 25201 (coded RL-201) into air for the first time. Apart from a landing gear warning light, the flight was without problem. Zurakowski declared that the Arrow was easier to fly than the F-102 or the Gloster Javelin, two other delta-winged fighters. This would later be confirmed by other test pilots, who praised the handling of the CF-105 highly. Zurakoski complained about the high workload in the cockpit, despite the sophisticated AFCS (Automatic Flight Control System), but on the other hand the reliability of the electronic systems was better than expected.

On its third flight, the CF-105 reached Mach 1.1, at an altitude near 13000m. Mach 1.52 was reached on the seventh flight. But on its 11th flight, on 11 June, the left landing gear leg failed during landing, because it had not aligned itself properly with the axis of the aircraft. The landing gear broke off completely, and 201 skidded of the runway on its belly. Damage was not extensive, and on 5 October the aircraft flew again. Meanwhile, on 1 August, the 202 had joined the flight test program. But in November the landing gear of 202 failed when the brakes blocked.

Cancellation

The Arrow was to be cancelled in stages. First to go was the Astra radar and fire control system, and the associated Sparrow II missiles. These were cancelled on 23 September 1958, and replaced by American systems. It was announced that the entire project would be reviewed again in March 1959.

On 11 hours, 20 February 1959, John Diefenbaker announced that the CF-105 was to be cancelled. On the same day, Avro was instructed to immediately halt all work on the CF-105. That included the completion of the first Mk.2 prototypes, which were nearly complete. Employees were sent home, and were told that Avro could not garantuee them a job in the future. Indeed, about 14000 were fired.

It was ordered that all five prototypes, the nearly complete first four Arrow Mk.2's, and the tools would be destroyed. Although the Arrow could now have been a political liability, this scrapping of everything seems to have been the standard procedure. Suggestions that one of the Arrows could be kept flying as an engine test bed, or that RL-206 should be used to set a new speed record, were dismissed. The only remains now is the nose of a single Arrow, RL-206, the sixth prototype. This one was the first Mk.2 prototype, but it has never flown.

A might have been

For all purposes, the Avro Arrow had remained one of the greatest 'night have beens' of the aviation industry, competing only with the BAC TSR.2 strike aircraft. Despite being a considerable technical achievement, the Arrow failed to reach the production stage because of problems with the project management and political support.

It would be unfair to blame only the governement that cancelled the Arrow. The RCAF itself was probably unwise in putting its demands so high. Everything it demanded was technically achievable, as was proven by the existence of the Arrow itself. However, it should have been clear from the start that such an expensive aircraft was not affordable, except in the unlikely case that there would be large export orders. The simultaneous development of aircraft, engines, radar system and missiles was a high-risk affair, with a large probability that at least one of these programmes would be a failure. The Sparrow II project may have been the least well-advised of all, because the missile had already been abandoned by the US Navy. A less ambitious project, with more off-the-shelf parts, would have been more realistic. For example Sweden developed several generations of excellent fighter aircraft, but always used derivatives of existing engines.

The RCAF can also be blamed for being too inflexible in planning. The Arrow was hailed as the definitive interceptor, and the projected future versions were intended to fly faster and higher, to carry even more expensive electronics, and to be more effective in killing bombers. One could compare this to the career of the F-101: Derived from a long-range escort fighter, the F-101 evolved into a fighter-bomber with nuclear weapons, an interceptor and a reconnaissance aircraft. Such changing requirements were an inevitable consequence of the longer development time of more complex aircraft. Some of the money spent on the development of radar and armament could have been used better to make the Arrow more flexible and more cost- effective. As an air superiority fighter, the Arrow had the disadvantage of being a very large aircraft, but because of its large wing area and powerful engines it could have been effective. Because of its high performance, the Arrow would probably also have been an good reconnaissance platform. Because of its large bomb bay, generous wing area and ample ground clearance it could also have been an effective fighter bomber. On the other hand, its enormous wing area was a disadvantage for operations at very low altitude. The main problem of the Arrow was its size. Almost any job, except that of a long range interceptor, could have been done more effectively by a smaller aircraft. If the RCAF had accepted external missile carriage, and had taken into account the development of in-flight refuelling, even that task could have been undertaken by a smaller aircraft.

Statistics

Data for the Arrow Mk.2 are estimates, because the aircraft never flew.

TypeArrow	**Mk.1Arrow**	**Mk.2F-101B**	**MiG-25P**
Engines	P & W J75-P-3	Orenda PS-13 Iroquois P&W J75-P-55	Tumansky R-31
Dry Thrust	5670kg	8390kg	6750kg
Full thrust	8390kg	11790kg	12250kg
Wing Span	15.24m	15.24m	12.09m\14.01m
Length	25.3m	24.83m	20.54m\19.75m
Height	6.25m	6.4m	5.94m\6.10m
Wing Area	113.8m2	113.8m2	34.19m2\61.40m2
Empty Weight	13141kg	20000kg	

Max. Weight	31117kg	23768kg	36720kg
Max. Speed	Mach 1.98	Mach 2.4+1965km/h	Mach 2.83
Climb	13565m/min		
Ceiling	18290m	16705m	20700m
Action rad.	483km		
Range	2500km		1730km

Sources:

• Avro CF-105 "Arrow". Bernard Custeau, Le Fana de l'Aviation No.270, 271 and 272, starting in May 1992. Published by Editions Lariviere, Paris.
• Airplane, Nr.95. Published by De Agostini (Netherlands).
• McDonnell F-101 Voodoo. Robert F. Dorr, Osprey, 1987.
• The complete book of Fighters. William Green and Gordon Swanborough. Salamander, 1994.
• The illustrated Encyclopedia of the World's Rockets & Missiles. Bill Gunston, Salamander Books, 1979.
• E-mail from Darrell A. Larose (ad607@freenet.carleton.ca), Russell Isinger (isingerr@herald.usask.ca), Maury Markowitz (maury@softarc.com), Bill Zuk (bzuk@minet.gov.mb.ca), Thomas Dugelby (jwmhans@hookup.net).

Emmanuel Gustin
gustin@uia.ua.ac.be

Created: March 5, 1996
Last Update: October 16, 1996