O R E N D A   I R O Q U O I S

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INTRODUCTION

The Iroquois began in September, 1953, with a long look into the future. . .a look at operational requirements five years hence. In the normal cycle of engine development, this meant skipping one generation of engines.

Several factors dictated this decision. Chief among them was the fact that the next generation of engines already was being developed in other countries. It was thus economically unsound for Orenda, with a substantial time disadvantage, to try to compete in this area.

The decision was made with full awareness of the magnitude of the task. Apart from the imposing specification, the design and development team, by skipping one engine generation, was foregoing much knowledge and experience which normally would have been applied to development of the Iroquois.

Thus there was more than the normal allotment of risk. It has been estimated that about 20% of the engine called for work in completely unknown areas or, as engineers put it, "beyond the state of the art."

Finally, engineering considerations aside, there was the financial risk. The project was without military sponsorship in the beginning. In fact, some $8 million in private funds was spent before a development contract was received from the Royal Canadian Air Force.

HISTORY AND DEVELOPMENT

The Iroquois concept was based primarily on a Royal Canadian Air Force interceptor requirement for a successor to its CF-100. This called for maximum performance of Mach 1.5 at 50,000 feet.

In just 20 days the design team came up with the basic layout; an engine with two compressors, high velocity combustion chamber, close-coupled afterburner, with modulated convergent nozzle, the package delivering 20,000 lbs. of thrust without afterburner at sea level and weighing not more than 4,500 lbs. Titanium alloys, relatively new in the aircraft industry, would be used extensively throughout the front end. The project was labelled PS-13 ("project study 13").

PS-13 was placed before the Hawker Siddeley Group's Design Council, composed of the technical heads of the various Hawker Siddeley companies of which Orenda is one through A.V. Roe Canada Limited. The project was thoroughly discussed during the council's visit to Malton in October, 1953, and unanimously endorsed.

The Orenda design team realized at the outset that the utmost enterprise would be demanded to stay within the weight limit imposed. The basic design gave a thrust-to-weight ratio of just under 5-to-1, and there was every intention of boosting this if at all possible.

At the outset, titanium offered the greatest single opportunity for keeping the weight down. Using it to replace aluminum in the front end of the engine (where temperatures would be too high for aluminum) it was estimated the engine would be lighter by 850 lbs. than if steel (the alternative material) were used.

However, there were other ways too. The two-compressor, or two-spool, arrangement was lighter than a single compressor designed for the same duty. (This of course, was not the sole consideration in the compressor design; the two-spool design was considered more flexible for engine performance and handling characteristics.)

The combustion chamber was made smaller, and consequently lighter, as a result of studies which showed that airflow velocities through the combustion chamber could be increased considerably over normal practice without penalizing combustion performance. Finally, afterburner design was tied closely to the basic engine so that it became an integral part of the design and was a smaller and lighter unit than it otherwise would have been.

While titanium appeared to be very attractive, it was not without its hazards. It was in a critical position at that time. Quality of the material varied from batch to batch; it was said to be difficult to weld and to machine; and it was in short supply.

To overcome these disadvantages, the Orenda team set out to learn as much as possible about titanium. In the laboratory, characteristics of physical properties were established. In the machine shop, investigations were undertaken to learn how to fabricate the material and many new techniques were devised, particularly in the welding field.

The lack of knowledge about titanium was to be expected at that time. Only a few pounds of ingot had been produced in 1946 and that in a U.S. Bureau of Mines laboratory. Output had grown to 150 lbs. in 1951, and in 1953, the then current year, to 2,000 lbs. Five thousand tons were expected in the next year and 12,000 tons in 1955. However, it was still not enough to satisfy demand. Order books were virtually closed for 1953 and were tight up to 1956. But one source disclosed the availability of sufficient material for 12 engine sets if ordered immediately.

On the design side the picture was bright. It was known that other engine companies were planning to use titanium but only as a substitute after an engine had been designed for steel. While some weight savings were obtained by exchanging a steel part for a titanium part, it was reasoned that if a part were designed in titanium at the outset, then all its related supporting structure could also be lightened and in this way total weight savings would be much greater.

A specific study on titanium and steel discs and blades designed for the same duty showed the titanium disc weighed 16 lbs., the steel disc 48 lbs. Titanium blades carried by the disc weighed 17 lbs., steel blades 29 lbs.. Total was 33 lbs. for titanium, 77 lbs. for steel, while the density of titanium was about 60 per cent.

It was in fact this considerable reduction in the weight of dynamic parts that permitted the use of a simplified rotor bearing arrangement. This arrangement was simpler by virtue of fewer bearings, hence less supporting structure and a total weight saving of significant proportion. The engine casing was designed to carry the stresses that would have been absorbed by the supporting structure which was now eliminated.

Notwithstanding these major advantages, the high cost of titanium was a factor to be reckoned with and for this reason a parallel program of development was carried out using other available materials as possible alternatives.

As a result of this program, the original concept of an all-titanium front end was modified without any weight penalty. Methods devised for fabrication of hollow steel turbine blades led to the replacement of the titanium compressor stator blades with their counterpart in hollow steel, with no weight increase. The low pressure compressor casing was changed to magnesium alloy and the high pressure compressor casing to steel.

Stator rings, which constituted a potential rubbing area for the compressor blade tips, were converted to steel for another reason -- to eliminate a fire hazard. Titanium is a poor heat conductor, and experience showed that where a local hot spot developed it could result in a hole burning through the material. Then air from the compressor, feeding through the hole, might create a blow-torch effect, endangering the entire structure.

Early in 1955 came a reminder, if one were needed, of the high stakes being played for. A serious weakness found in the titanium compressor blades was traced to an excess of hydrogen in the raw material as received from the supplier. Instead of a maximum of 25 parts in a million, 140 parts in a million were found. This in no way was due to negligence or otherwise on the part of the supplier. Rather it was because no satisfactory process has yet been found to give fault-free production.

To salvage the blades, which represented a fair sum in development funds, arrangements were made to have them degassed in a vacuum. The hydrogen was successfully "bubbled" out but not before many anxious days of wondering whether the entire titanium concept would have to be abandoned.

Orenda engineering enterprise showed up well in arriving at a final afterburner design. The basic design called for a proportionate throttle/thrust characteristic with a nozzle fully variable as opposed to the two-position, on-off type of afterburner then in a wide use. Because the Orenda team felt insufficiently experienced in afterburner work detail design of this component was given to another company which specialized in combustion design. This led to a four-segment type of afterburner in which each segment was lit one after the other to provide successive boosts in power.

However, this did not provide the flexibility of operation sought, and the system suffered other technical shortcomings as well. At this stage an Orenda team undertook a program of afterburner investigation which led to a satisfactory design giving full afterburning with smooth, full modulation.

Another major development occurred in the turbine section where the original design requirements were studded with complex problems. At the outset there was no material available, or likely to be available in the near future, capable of withstanding the temperatures of the turbine section without some form of induced cooling. Hollow, air-cooled blades were indicated for at least some stages of the turbine.

Toward this end investigations began on techniques for producing hollow steel blades. Once successfully fabricated, the turbine design was subjected to many hours of test rig running to perfect the air-cooling system, which involved bleeding air from the compressor and directing it through the hollow, rotating blades of the turbine.

Meantime progress was being made by the International Nickel Company on research and development which had been requested by Orenda. INCO came up with a material that required casting (up until this time Iroquois blades were forged) and with temperature limits within 25 degrees of the air-cooled blades' limit. Calculations showed that the 25 degree temperature advantage (desirable because the higher the turbine temperature the higher the thrust) of the air-cooled blades was cancelled by the loss of power resulting from the bleeding of air from the compressor to cool the blades. Therefore, the decision was made to use this new material and a simpler design was drawn up.

Significant performance achievements were recorded in December, 1955, just one year after the first running. A maximum thrust in excess of 20,000 lbs. was recorded during a sustained run at maximum speed. Indications were that high speed operation was satisfactory both aerodynamically and mechanically.

On June 24, 1956, the first official 50 hour Pre-Flight Rating Test was successfully carried out. The afterburner operated for the first time July 3. By September 19, engine development running time had reached 1000 hours.

By early 1957 the many aerodynamic and mechanical "unknowns" of the original design had been virtually eliminated and modification of a B-47 bomber, which had been allocated by the United States Air Force to the RCAF for Orenda's use, was going ahead. The plan here was to hang a seventh engine pod on the right rear side of the fuselage below the horizontal tail-plane.

During this period further test facilities required for the program were being constructed. These consisted mainly of new development test cells, a high altitude facility, and full-scale afterburner and rotating blade cooling test rigs.

Meantime, arrangements were being made for simulated high altitude running tests in The National Advisory Committee for Aeronautics laboratories in the United States, and for cold weather testing at the National Research Council laboratories in Ottawa.

As general mechanical reliability continued to improve at the expected rate, so further milestones were passed. On July 27, 1957, the first official 100-hour endurance test was successfully carried out at a reduced thrust rating of 18,750 lbs.

A demonstration run at over 20,000 lbs. dry thrust was carried out for Canadian Government representatives on November 1, and 12 days later the Iroquois was run at altitude in the B-47 for the first time.

A high point was reached in January, 1958, when the first phase of testing at simulated altitude and forward speed conditions was completed at the NACA laboratories in Cleveland, Ohio. The engine was run successfully for two hours in an atmosphere heated to over 240 degrees Fahrenheit with a peak of five minutes at 349 degrees (equivalent to Mach 2.3)

Over 100 hours running was achieved during this test phase during which time the Iroquois recorded what was probably the highest dry thrust ever achieved by turbojets on the North American continent. An Orenda-patented relight method proved entirely successful, giving normal relights at designed Mach numbers up to 60,000 feet, the altitude capability of the tunnel.

At this point the Iroquois had completed more than 5,000 hours of bench running. In addition, many thousands of hours more had been accumulated in rig-testing such principal components as main bearings, compressors, combustion and afterburner systems, and air-cooled turbine blades.

Initial flight testing has been carried out in the modified B-47 bomber simultaneously with extensive running under conditions of simulated altitude environments in high altitude test cells. Final proving of the engine will be done in an Avro CF-105 where the full potential of the engine can be exploited.

Some mention should be made here of the willing and generous co-operation of United States authorities in connection with the Iroquois program. This had revolved mainly around the provision of time in U.S. test facilities until Orenda's own facilities came into operation, the provision of the B-47 and its related equipment on loan, and the training of Orenda personnel to fly and service the U.S. aircraft.

Performance of the engine to day completely justifies the faith of those who put the project in motion and certainly proves the far-seeing theory of the original concept.

Important though the current record-making performance of the engine is, the potential built into it is even more significant. Further development guarantees its continued existance for some years to come.

The future of the Iroquois is full of possibilities. It is now ideally suited for missions calling for supersonic speeds whether in fighter, bomber, interceptor, or missile. By dropping the afterburner and de-rating the engine for increased reliability, engine life and lower fuel consumption, a first-class powerplant is available for airliner applications.

IROQUOIS AT A GLANCE

- The Orenda Iroquois is an axial flow turbojet design based on an RCAF requirement for a supersonic interceptor.
- Among large turbojets the Iroquois has an unprecedented 5:1 power-to-weight ratio.
- The Iroquois ran for the first time in December, 1954, just 11 months after release of the first drawings to the manufacturing shop.
- The Iroquois with afterburner has fewer parts than its predecessor, the 7,500 lbs. -thrust Orenda, without afterburner.
- The Iroquois' main bearing arrangement, its combustion chamber and afterburner are highlights of the mechanical design.
- Main bearings of the Iroquois run cooler than the air surrounding them.

Following are the main specifications released to date:

Length, with afterburner	231 in.
without afterburner	208 in.
Intake diameter	42 in.
Afterburner diameter	47 in.
Thrust	over 20,000 lbs.
Thrust/Weight ratio	5:1
Specific Fuel Consumption	under 1.0 (dry) under 2.0 (afterburner)
Compressor	two spool
Compression ratio	moderate
Combustion system	annular, high velocity, vaporizing.
Afterburner	close-coupled.

TIMETABLE OF DEVELOPMENT

1953	September 14	Initial design begun.
1954	January	First drawings issued.
	May 1	Design completed.
	December 15	First light-up achieved.
1956	June 24	First official 50-hour Pre-Flight Rating test completed.
	July 3	First afterburner light-up achieved.
	September 19	1,000 hours of development running completed.
1957	February 15	Cold weather testing started at National Research Council, Ottawa.
	April 22	First engine shipped to National Advisory Council for Aeronautics, Cleveland, for high altitude testing.
	July 27	First official 100-hour test completed.
	November 1	Demonstration run completed at over 20,000 lbs. for both dry and afterburner ratings.
	November 13	First in-flight light-up achieved with Iroquois installed in B-47.
1958		First engine delivered to Avro Aircraft Limited for installation in Arrow.