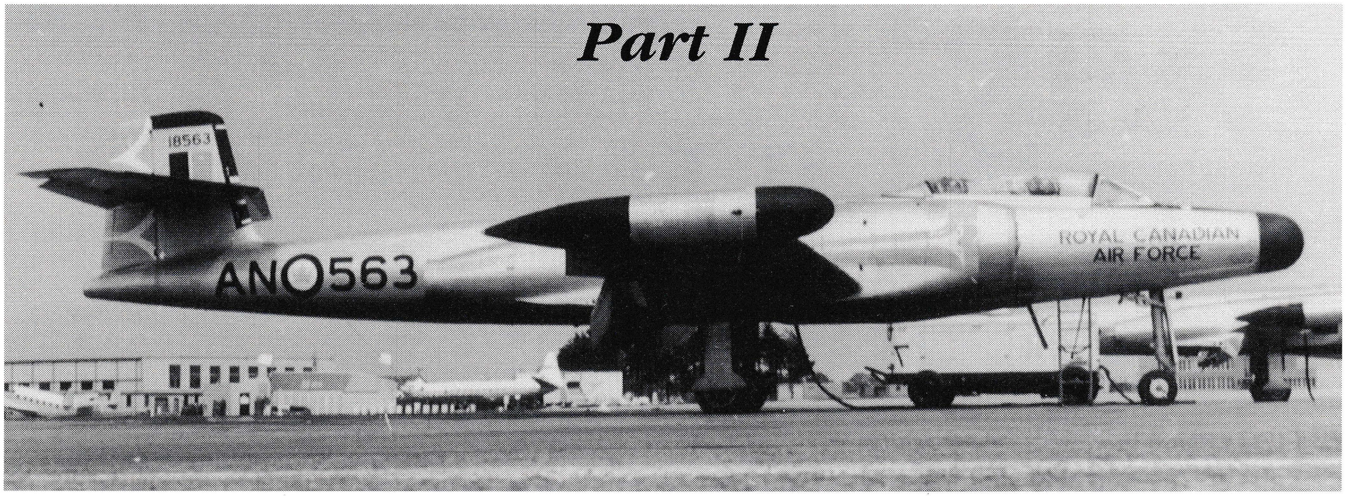
Part II



AB INITIO TO WORLD CLASS

CANADA'S BID AS A JET ENGINE LEADER

Paul B. Dilworth

Following His Introduction to UK Jet Engine Development, the Author Returned to Canada to Organize Cold Weather Testing.

Our meeting with Frank Whittle was followed by a tour of the engineering and development facility at Lutterworth and the production plant at Whetstone. At the former we saw both of the current Power Jets engines on test, the W,2B and W.2-500. Shown also were a design layout and components of the latest model W2-700. All were essentially evolutionary improvements based on Whittle's original flight engine, the W.1 and aimed at achieving successively greater performance with thrusts in the 2,000 to 3,000 pound range and total weight of 700 to 800 pounds. Rotor speeds were from 16,000 to 17,000 rpm. Work at Power Jets had also produced designs for both by-pass fans and turbine driven thrust augmentors. One of our guides was Dennis ("Dick") Shepherd who later joined the A. V. Roe Canada Gas Turbine Division at Malton.

We also visited the British Thomson Houston plant at nearby Rugby. They had manufactured and provided test space for Whittle's first experimental engine, the WU. BTH were then making turbine disks under contract to Power Jets. Long overdue for delivery, one such experimental unit had been seriously damaged by falling from a hoist. PJs gave up in frustration. A related progress report contained the laconic observation "this project has been dropped."

Armstrong Siddeley Motors at Coventry were at that time developing an axial flow gas turbine engine designated ASX. It was rated at 2,600 pounds static thrust as a jet engine. An alternative configuration was as a shaft power turbine of 6,500 horsepower. In the jet configuration it was later tested in Canada at the Cold Weather Test Station. Although not too favourably impressed with the rather convoluted design configuration of the ASX we met and formed a high opinion of ASM's Deputy Chief Engineer J.H. (Pat) Lindsey who was in charge of all work on gas turbine development.

Later, in Canada, we had reason to owe Lindsey a debt of deep gratitude for the loan of ASM vibration experts in helping to solve Orenda's plague of compressor blade failures. ASM later developed their axial flow Sapphire jet engine, rated at 7,200 pounds thrust. Under Ministry pressure its compressor aerodynamics were later made available to and used by Rolls-Royce to redesign the compressor aerodynamics of the RR AJ65 Avon -- the original design, having been inadequate, was causing serious delay in the engine's development. This was the engine with which the prototype Avro CF-100s were powered. It was succeeded by the Orenda engine in all production units.

Initial visits to Rolls were at the main works at Derby, their turbine development section at Sinfin and flight test facility at Hucknell. At Derby we met A.G. Elliot, Chief Designer and Stanley (later Sir Stanley) Hooker. Most of our time was spent with Hooker who showed us around Sinfin where we saw new designs for Rolls-Royce version of the W.2B, named Welland, and their later, and much larger WR.1 (Nene) designed for 5,000 pounds thrust for a weight of but 1,200 pounds. It was later reported to have produced a thrust of 4,500 pounds on initial test and, soon thereafter achieved its design performance of 5,000 pounds. The WR.1 featured a straight through combustion system as distinct from the Whittle's folded configuration. Rolls later produced a scaled down version of the Nene, named Derwent. The latter engines were used in AVRO Canada's world-pioneering Jetliner. The Jetliner was originally designed to use two RR.AJ65 Avon engines. Jim Floyd was forced to redesign the Jetliner, substituting four Derwents following Rolls's notification that the Avon could not be developed to a stage suitable for commercial airline use in time to meet the Jetliner's project schedule.

Also at Derby we were shown a novel contra-rotating axial flow engine designed by Dr Griffith. This featured independent rotor discs, each with turbine blades at the outer periphery supported by compressor blades at the inner disc periphery. The air and gas flow paths were opposite in direction. Rolls had been unable to find a means to start this engine and, it was apparently later abandoned.

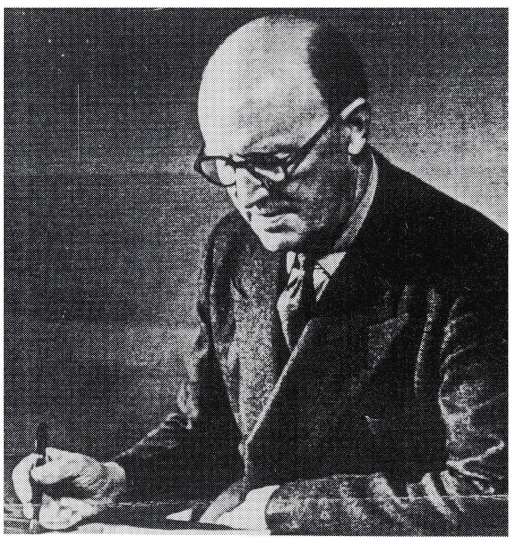
Another engine design, by Haworth, was also on the drawing board. It was an axial flow engine with three independent contra-rotating compressor-turbine rotors on concentric shafts. Haworth had also produced a layout of a twin-spool version. To the best of my knowledge, neither of these designs was ever built. Years later, however, Haworth's basic design configuration became the basis of virtually all major jet engines, including the Rolls RB series, US Pratt and Whitney J75, and the Orenda Iroquois.

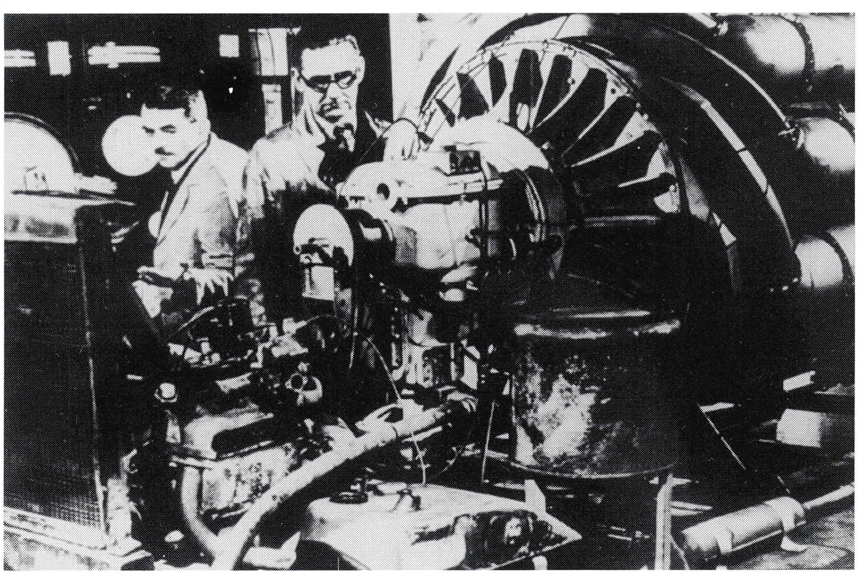
At Hucknell we inspected a Wellington bomber outfitted for flight testing of W.2B engines. The engine installation replaced the tail gun turret (See photograph, P. 57).

Reflecting the Air Ministry's policy of having Whittle's organization, Power Jets, concentrate on basic design and development they had commissioned the Rover Motor Car company to undertake second stage development of the Whittle W.2B at a plant in Clitheroe in Lancashire. Rovers also built a production plant for these engines at nearby Barnoldswick. Any redesigns by Rovers were, however, to be approved by Power Jets.

Over repeated and strenuous objections from Power Jets, Rovers were introducing some design innovations without getting Power Jets approval. This, among other factors, lead to a take-over by Rolls-Royce of these two plants and all of Rover's jet engine contracts with the Ministry.

To Rover's credit, they were the first to initiate design, construction and testing of a straight through combustion configuration of the W.2 series, later adopted by Rolls-Royce on the Nene and Derwent engines.





Heading: *the Avro CF-100 Mk 5 fitted with two Canadian-designed and -built Orenda engines was, at its peak, among the world's finest all-weather interceptors. RCAF 18563 flew with 433 Squadron. R .JUNIPER.* ***Left:*** *Willoughby (Bill) Lappin, "Lp" of Rolls-Royce. Bill was our guide and "limo service" between London and Derby. W. BRIAN LAPPIN.* ***Below:*** *Engine WU reconstructed (1938) with new multi-chamber reverse-flow combustion system on test with Whittle at the controls.* R-R HERITAGE TRUST.

Nearby, at Burnley in Yorkshire, the Joseph Lucas company, whose longstanding basic business was in automotive electrics, were engaged on development and production of combustion chambers. They were suppliers to Power Jets, Rolls-Royce, de Havilland and Armstrong Siddeley. Later, Lucas developed and supplied the combustion chambers for both the Chinook and Orenda jet engines at A.V. Roe Canada. Both functioned extremely well.

At Stag Lane we found de Havilland at an advanced stage of developing the H.1 Goblin, a single-side entry centrifugal compressor engine with straight through combustor configuration. The H.1 design rating was 3,000 pounds thrust but initially cleared for flight at 2,000 pounds. It was destined for their small Vampire jet fighter, but was also a possible alternate to R-R engines for the Gloster F.9/40 (Meteor) fighter.

The Metropolitan Vickers Company at Manchester were well along with testing their F.2 axial flow jet engine. Additionally, we were shown the design of a thrust augmentor unit for operation with it. The F.2 was rated at 2,100 pounds thrust for a weight of 1,570 pounds and a specific fuel consumption of 1.12. It had a nine-stage compressor, two-stage turbine and, in contrast to all other engines under development at the time, a single annular chamber combustor. The latter type became standard equipment on all later jet engines, including the Orenda "Iroquois".

After a heavy lunch in the Director's dining room we were given an erudite lecture on the F.2 development by Dr. D.M Smith, its designer. The lunch proved too soporific for Ken who dozed off during the discourse. Fortunately, his nodding head, bushy eyebrows and merciful absence of snoring conveyed an aura of rapt attention.

Smith's breadth of knowledge was most impressive as were Vickers' accomplishments in developing what appeared to be a very fine light weight aero engine -- this by a firm whose experience was exclusively with very heavy industrial machinery. Had they, like the American General Electric Company later on, set up a separate aero engine division there is little doubt that they could have become a serious world competitor.

On our following visit to the Gloster Aircraft Company at Cheltenham we were shown the first British experimental jet propelled aircraft to fly, the Gloster E,28/39. It was first flown in 1941 with an early Whittle engine -- the W.1 at a de-rated thrust of but 850 pounds. Its designer being W.G. Carter, it was irreverently dubbed "Carter's Farter." On its initial flight the E.28/39 had achieved a top speed of 407 miles per hour at 18,000 feet altitude. Local citizens reported having seen a very fast aeroplane flying "without any propeller!"

Also shown was the design layout for the F9/40 twin jet fighter which became Britain's first operational jet fighter, the Meteor. It was to be powered by two Rolls-Royce W.2B engines. The Meteor entered service late in the war and was restricted to shooting down Buzz Bombs. Another Gloster concept seen at the time was a fighter, named the "Ace," employing a single de Havilland H.1 (Goblin) engine aft of the pilot.

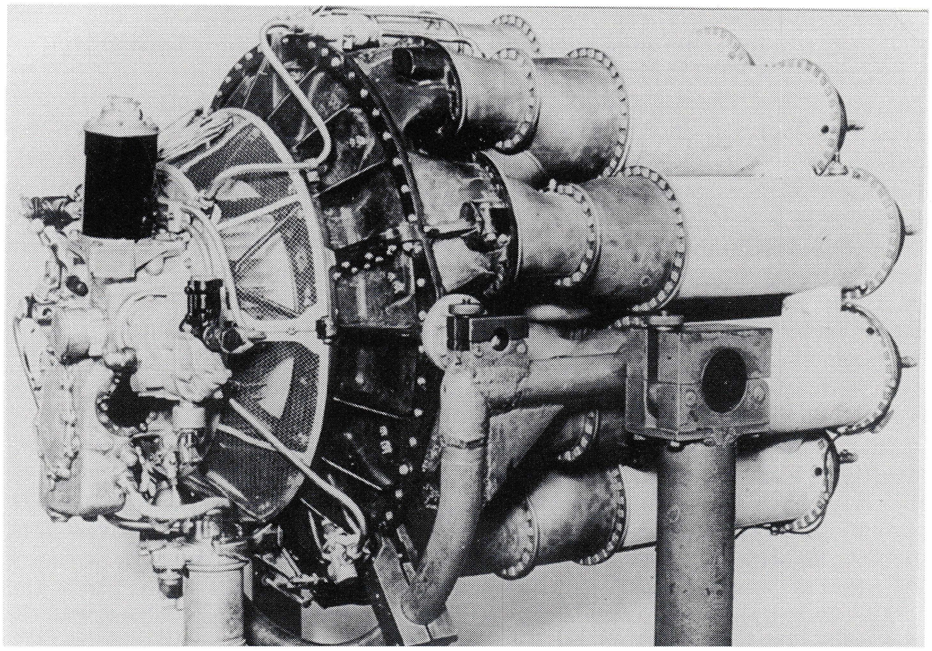
A considerable amount of time and attention was devoted to learning all possible about the work of principal suppliers of key components and materials. As previously noted, Joseph Lucas at Burnley in Yorkshire were developing and manufacturing combustors for Power Jets, de Havillands and, Rolls-Royce. They were also contributing to the development of fuel pumps and fuel injectors supplied by CAV.

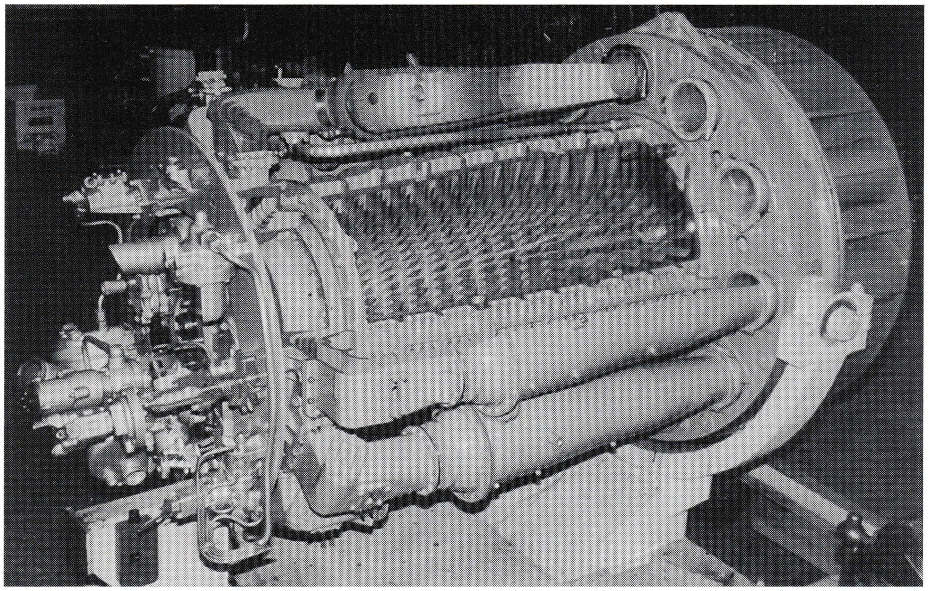
The work of High Duty Alloys at Slough in developing high strength aluminium and magnesium alloys and making these into forgings and castings for engine compressor rotors and casings was very impressive.

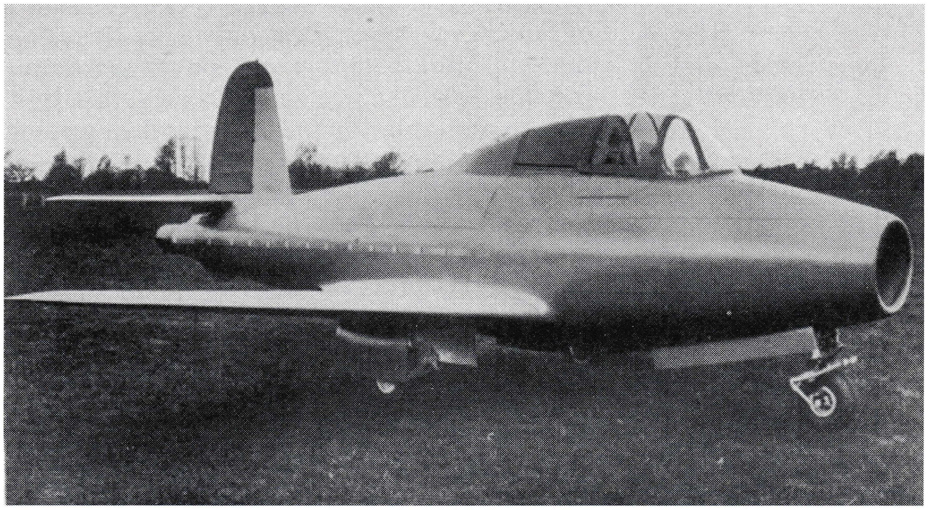
Circumventing the strict food control system, one of a herd of HDA's prize Black Angus steers kindly obliged us by falling into a ditch and breaking its leg. As a result, we were treated to a most excellent roast beef dinner as guests of Mr Devereaux, the Managing Director.

At Birmingham both the Henry Wiggin and Mond Nickel companies were deeply immersed in developing improved high temperature alloys for turbine blades and combustors. Every degree added to the temperature at inlet to the turbine of a gas turbine engine confers significant improvement in both performance and efficiency. The process of developing and testing such alloys is very time-consuming and costly. Each new experimental alloy is subjected to long term tensile tests to measure its rate of elongation or creep. The pay-off from a few extra degrees in sustainable operating temperature, however, fully justifies the effort and cost of such work.

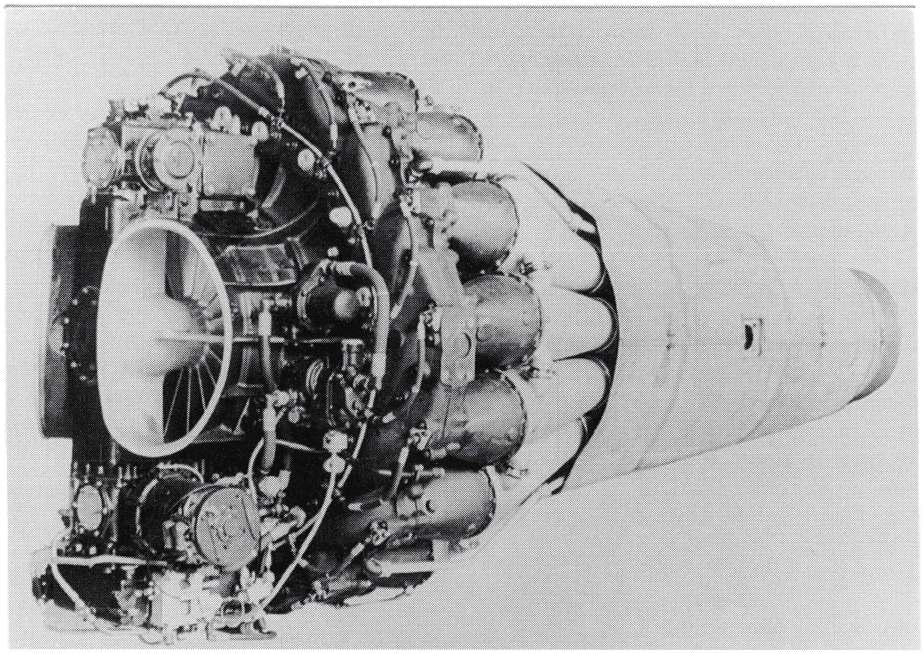
CAV in London, was the chief source of supply for fuel pumps, barostats (altitude flow controllers) and burners (fuel injection nozzles) for all engine companies. They relied heavily, however, on Lucas at Burnley for operational testing of the burners and on the engine firms for their other components.



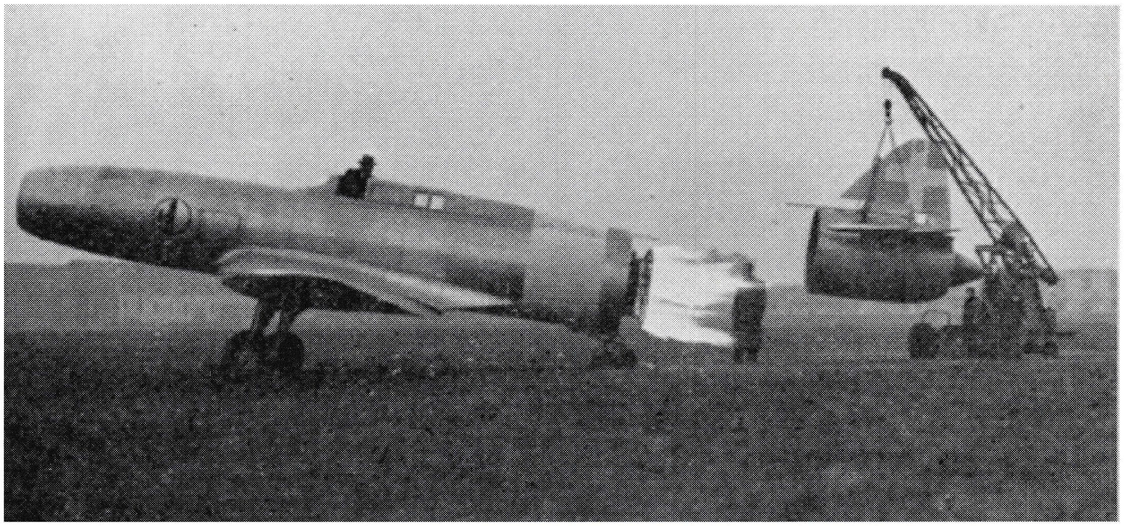


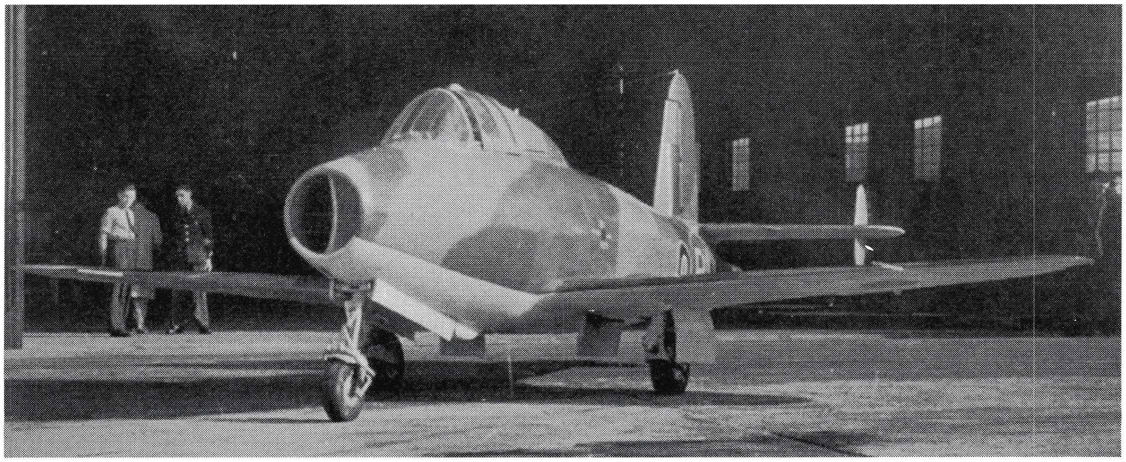


Without doubt, of greatest impact among all these visits was the personal introductory lecture at Brownsover Hall by Frank Whittle. He had first conceived the concept of using a gas turbine for jet propulsion in 1929. He was then 22 years old and a student at Cranwell, the RAF technical college. It was not until 1937, however, that he was able to secure financing help from friends to build and test his first experimental engine, the WU. The huge "elephant trunk" combustor was later replaced by multiple reverse flow chambers arranged peripherally around the outer diameter of the engine. This configuration survived throughout the succeeding W.1, W.2B, W.2-500 and W.2-700 engine series. Indeed, apart from being replaced by the straight-through configurations first introduced by Rover and de Havilland, and adopted by Rolls-Royce on the Nene and Derwent engines, the basic configuration of Whittle's first flight engine was reflected in all those later engines. Even de Havilland's H.1 was very similar in layout, the main new features being a single sided compressor impeller and a straight-through combustion system. The single chamber annular combustor, initiated in the F.2 by Metrovicks, was later universally adopted by Armstrong Siddeley, Rolls-Royce, General Electric, Pratt & Whitney and by Orenda for the Iroquois, but only after very substantial investments of time and money.



Whittle's lucid discourse for our benefit at Brownsover Hall in February 1943 on both British jet engine design and development and his perception as to how this would revolutionize the design of both military and commercial aircraft in future was mind boggling. Furthermore, his creative wizardry and obvious mastery of the basic principles of both mechanical design and of aero and thermo dynamics stamped him as one of the greatest aeronautical innovators and engineers of his era. Devotees of his German counterpart, Hans von Ohain may take exception to this statement. Ohain and his sponsors, the Heinkel aircraft company, assuredly deserve credit for first getting a jet engine into flight. It was Whittle, nevertheless, who first conceived and published the concept of gas turbine jet propulsion. To him also belongs credit for the great entrepreneurial initiative





Opposite, top: *Rolls-Royce W.2B, similar to first two engines tested in Canada in 1944.* R-RHT. ***Opposite, middle:*** *Armstrong Siddeley ASX with axial-flow compressor.* R-RHT. ***Opposite, bottom:*** *The Gloster-Whittle E.28/39 powered by the Whittle W.1 engine, the first British jet aircraft to fly (15 May 1941), in its initial unmarked configuration.* CROWN ***Top:*** *the deHavilland Goblin with "straight-through" combustion system and single entry compressor.* TAYLOR. ***Middle:*** *the unsuccessful Italian Caproni-Campini C.P.-1which used a conventional aero engine to drive its compressor.* TAYLOR. ***Left:*** *the E.28/39 in its final configuration with fins added for better stability at high speeds.* CROWN.

and effort in translating his concept into reality without any assistance from and, indeed, in the face of much scepticism and even obstruction, from people in high places. For these as well as an in-depth history of his early work his book titled Jet is must reading for those interested in jet engine history.

Ultimately Whittle's monumental achievements were given public recognition, first by a monetary award of 100,000 pounds sterling and followed shortly thereafter by a Knighthood.

Sir Frank died in the USA on 8 August 1996 at age 89.

REPORT AND RECOMMENDATION

Toward the end of May, Tupper and I spent many days in collating the material we had garnered and in preparation of a formal report. With some editorial finishing touches by Banks, the report was finally completed and copies despatched to C.D. Howe, and Ralph Bell about 20 May 1943. They, in turn, sent copies to Air Marshall Breadner, The Hon. C.G. Power, Canadian Minister for Air, and to Dean C. J. Mackenzie, Acting President of the NRC.

Although better known as "The Banks Report" its formal title was "Report on Development of Jet Propulsion Engines in the United Kingdom" by C.A. Banks, K.F. Tupper and P.B. Dilworth.

The principal recommendations, responding to our terms of reference, were that:

1. Canadian personnel be sent to England to aid in various jet propulsion developments already in progress;
2. Work be undertaken in Canada directed towards the development of high temperature resistant materials suitable for gas turbine construction;
3. A cold-weather ground test station be established in Canada and staffed for experimental operations on gas turbine engines;
4. A fully staffed flight test establishment be created in Canada and equipped with a flying-test bed aircraft, preferably a York or Lancaster, with provision in the fuselage for installation of gas turbine engines;
5. A compressor test rig be installed for testing gas turbine compressors, particularly under conditions of low air temperatures.

Tupper and I returned to Canada by sea toward the end of May. Our ship was the Empress of Scotland, formerly Empress of Japan. A German submarine having just mined Halifax Harbour, we were diverted for a three day cruise in the sunny mid Atlantic. Being lowly civilians we were outclassed by returning service men in chatting up returning CWAAFs. Our retreat was the chess board.

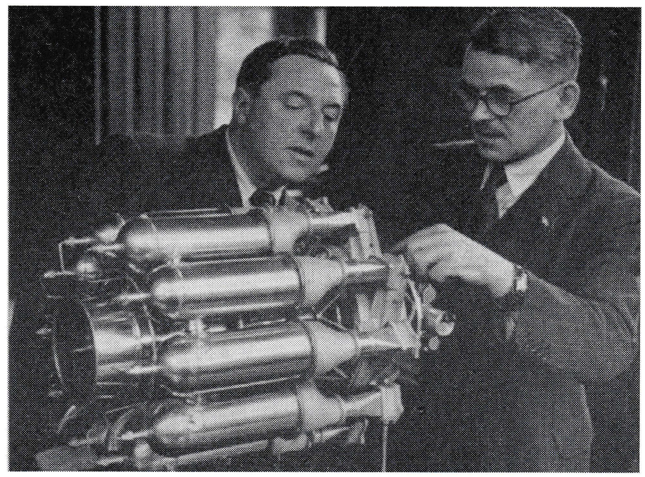
IMPLEMENTATION

The Banks report and its recommendations were the subject of an early meeting attended by R.P. Bell, Director-General and Fred.T. Smye, Director of the Aircraft Branch of DM&S; Dean C.J. Mackenzie and J.H.Parkin, representing NRC, A/V/Ms E.W. Steadman, and Alan Ferrier of the RCAF, K.F. Tupper and myself.

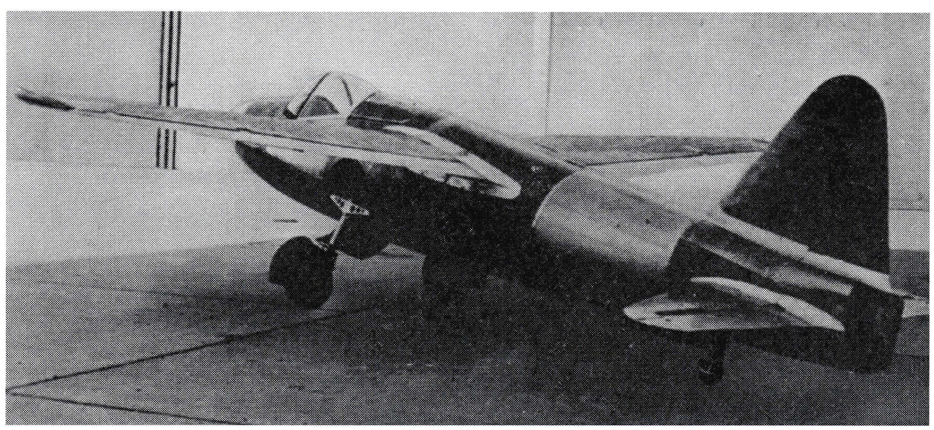
A consensus favoured recommending to the Minister of CDM&S immediate implementation of the cold weather test station and related training of personnel for its operation under the aegis of NRC. It was concluded that other recommendations should be left in abeyance.

In anticipation of a positive decision on the CWTS, Ken and I were directed by Parkin, our NRC Director, to organize and manage its execution. Dan McLean, Head of Meteorology for the Mines Branch, was first consulted on cold temperature records in various centres across Canada. The two most likely centres, reasonably accessible by rail and air, were Kapuskasing and Winnipeg. Churchill and Edmonton were considered but rejected. The former lacked both ready access to personnel and necessary infrastructure and the latter entailed unacceptable travel time for anticipated rail shipment of special test gear from eastern Canada and the USA.

In June, I undertook an inspection trip by TCA to both Kapuskasing and



Right: *Frank Whittle examines a chromed model of one of his engines.* ***Below:*** *the Heinkel He. 178 powered by Pabst von Ohain's 1,100 lb thrust He.S.3B.* TAYLOR. ***Opposite:*** *the Gloster F. 9/40 Meteor powered by two Rolls-Royce Whittle W.2B engines.* RAF.



Winnipeg. We decided on Winnipeg because of its larger population centre and related larger pool of personnel and auxiliary facilities, such as machine shops and hardware stores upon which we could draw.

We took rooms in a Winnipeg boarding house on Westgate, operated by a Mrs. Hunt and referred to by her boarders as the "Westgate Hunt Club." My introduction there, during the trip in June, was through my brother-in-law, Cy Williams. He was serving in the RCAF at Brandon but was on leave in Winnipeg. There I also met Alex and Peggy Loomis who became lifelong close friends. Alex was also in the RCAF.

Architects, Moody & Moore of Winnipeg, were retained and set about making designs and specifications for the basic building structures for the CWTS. Concurrently we prepared sketches and specifications for special test gear and instrumentation. Some of these were designed by George Klein of the NRC and made in their experimental machine shop at the Montreal Road Laboratories of the Division of Mechanical Engineering in Ottawa. Others were purchased under wartime priority orders from suppliers in Canada and the USA. As noted below, some of the more specialized items were secured from the British while on my second trip to the UK in September.

"A German submarine having just mined Halifax Harbour, we were diverted for a three-day cruise in the sunny mid-Atlantic."

Notification that funding of $300,000 and formal approval for construction and operation of the CWTS for one year was received at the end of August 1943. The contract for construction of the buildings was let on 3 September.

Immediately following this final approval of the project, we travelled to Ottawa and Toronto to recruit personnel. We managed to get two engineers, Douglas W. Knowles from Meadows Engineering Consultants in Toronto, then engaged on designing army gun and armoured personnel carriers, and Bruce N. Torell who had recently joined the NRC Engine Lab under Mac Kuhring. On my strong recommendation, on the eve of my departure to the UK, Ken sought out my classmate Winnett Boyd.

An initial cadre of technicians was also recruited, including Bert Marcouillier, Willy Wilson and Ray Joyce from the NRC shops in Ottawa; Art Pearce and Norm Bickell from Standard Aero Engines in Winnipeg; Carson Crigger, Ken Hedges, Bruce Watters and Fred Tarnowetski all, if I recall correctly, from the technical school in Winnipeg. There followed another two engineers, Bob Whitelaw and Berk Roden. Most of these were recruited by Ken while I was absent on a second trip to England.

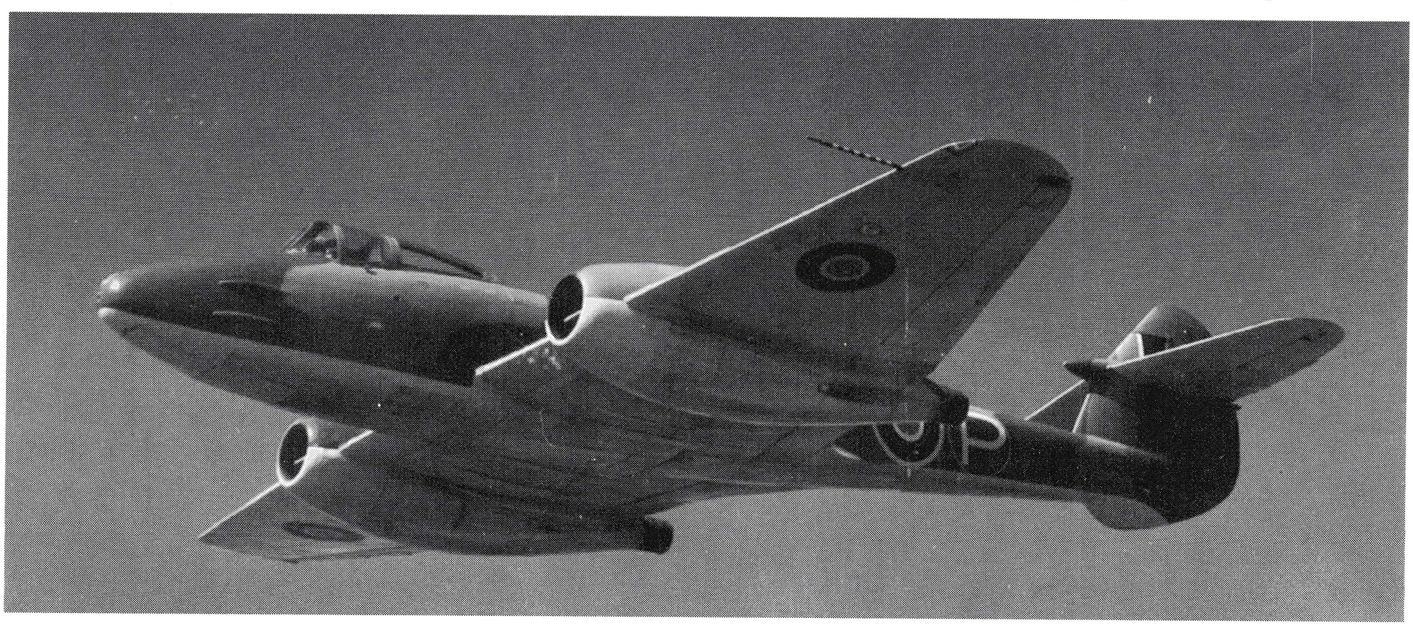
Winn Boyd, and later, Doug Knowles were stationed at Power Jets where Winn initiated a design study for a full scale compressor test plant. All of the others were stationed at Rolls-Royce, Barnoldswick, under Bruce Torell whom I placed in charge of the team during my second UK visit in September 1943.

This second trip was again by Liberator to Prestwick. The journey from Prestwick to London was in an RAF Dominie (militarized D.H. 89 Dragon Rapide). Return was, again by sea from Liverpool. The trip spanned some five weeks from early September to early October.

The main purpose of this visit was to finalize arrangements for allocation and transport of engines for the initial winter's tests, to define the related program of tests and to secure some of the more specialized test instrumentation, notably for thrust measurement and tachometers, there being some doubt that we could secure these from the US or Canada in the short time available. This visit entailed extensive meetings with senior people at MAP, notably Dr Roxbee-Cox who held responsibility for overall direction of the jet engine programmes, and with Stanley Hooker of Rolls-Royce at Barnoldswick. MAP had assigned Rolls first place in sending engines (R-R W.2Bs) for test as these were to be installed in Britain's first operational jet fighter, the Gloster Meteor.

NRC COLD WEATHER TEST STATION (CWTS)

In under four months from date of approval to proceed, 3 September 1943, the CWTS was constructed, equipped, staff trained in England and returned to Winnipeg and the first engine test performed on 4 January 1944. The engine, a Rolls-Royce W2B, had been flown by USAAF Transport Command via Dakar and Brazil to Edmonton. It arrived at Winnipeg by CNR Express from



Edmonton, in an unmarked shipping crate, just before year end 1943,

After a brief dummy run, using its starting motor, and with Art Pearce at the controls, the engine ignition was turned on and RR W2B No131 started and ran without a hitch. This was 4 January 1944, an occasion for celebration -- when the characteristic start-up whine and ensuing exhaust roar of a jet engine was first heard in Canada. It also set an example, later emulated by the first two jet engines designed and built in Canada at Malton, for coming to life and operating without any hitch, on the first attempted start.

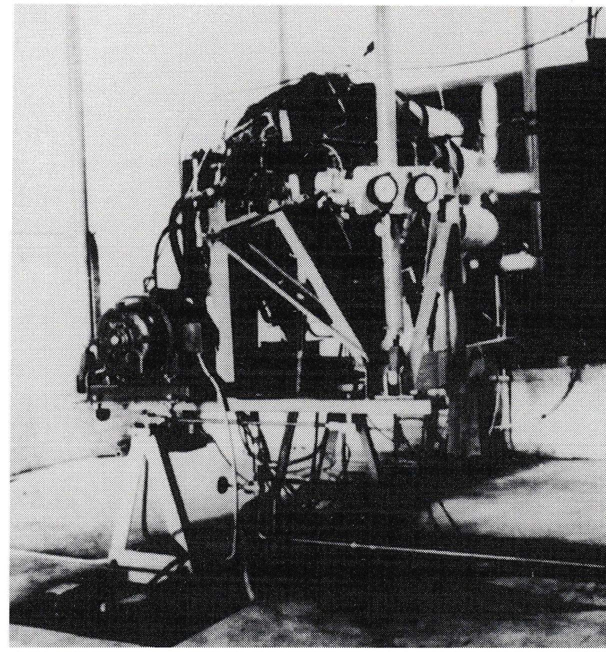
Although designated a Hack Engine, since it was not completely up to date in all details, the W2B proved itself in both performance and reliability throughout that first winter's test program. Regrettably, its fully updated successor, a RR W2B 23, which arrived very late in the cold season, suffered a rear bearing failure. By the time a replacement bearing was shipped and installed, the cold test season was over until the following December.

The CWTS continued operation throughout the balance of 1944, through 1945 and to May 1946, albeit having been transferred to a new Crown Corporation, Turbo Research Ltd on 1 September 1944. With this transfer Ken Tupper moved to Toronto as Turbo's Chief Engineer and it was left for me to manage the CWTS operations in Winnipeg until it ceased operations in May 1946 and was turned back to the NRC.

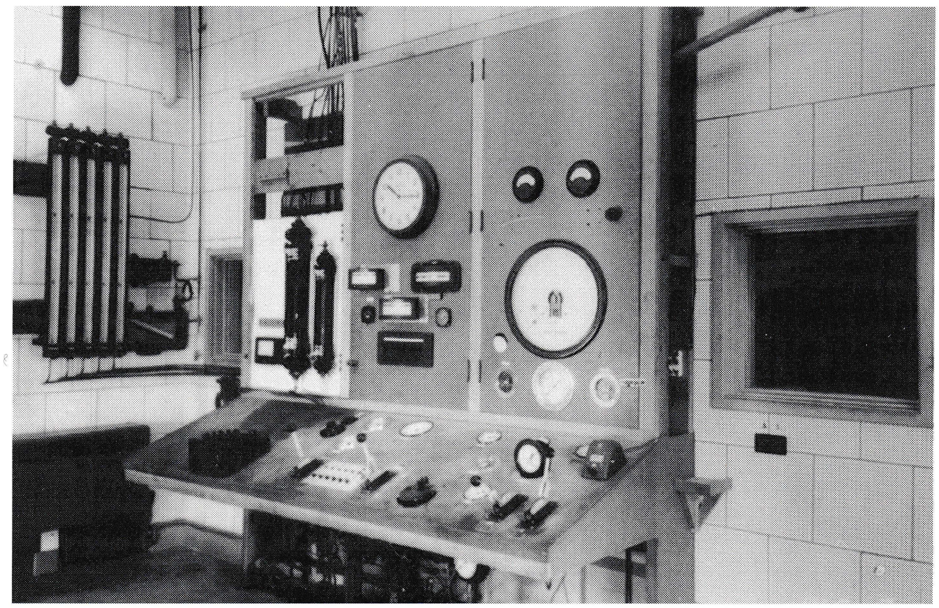
During the balance of 1944 and through 1945 and 1946, we caried out tests on the latest models of the Rolls-Royce W2B, Power Jets Ltd. W2-700 and the Armstrong Siddeley ASX (forerunner of the Sapphire). These engines were accompanied by technicians from their respective firms in order to observe the tests at first hand and also assist with any mechanical problems. Several of these enterprising visitors managed to smuggle back such items as silk stockings and lingerie and many boxes of chocolates and cigarettes in the shipping cases. Some items were secreted internally inside the engines. Wives and girl friends were the lucky recipients in war starved Britain.

During this period additional personnel were recruited and sent to England for training. By December,1945 a total of 18 Canadian engineers and technicians were on training in England. Most came to the CWTS for further training and familiarization. Some remained to augment the station's manpower resource. Others returned East and took up duties with Turbo at Toronto.

Ken also made a second trip to the UK, in 1944, in an effort to assess the prospect for improving the supply of engines for test and generally to ascertain the level of policy support by MAP and the engine firms for continuing on with the CWTS program. This evidently had some positive results, particularly in assurances that the British were still very definite that such tests should continue. While the supply of W2B engines remained very tight, due to priority of engines for the Meteor Fighters on Buzz-Bomb patrol, other engines did materialize, as previously noted, namely the Power Jets W2-700 and Armstrong Siddeley ASX.



Right: the first jet engine to run in Canada, the R-R Whittle Type W.2B at CWTS, Winnipeg, Manitopba, on 4 January 1944. NATIONAL ARCHIVES of CANADA. ***Below:*** *the control panel of the CWTS cell.* NAC. ***Opposite, top:*** *RAF DG206/G was the first of the Meteor prototypes to fly, on 5 March 1943 at Cranwell piloted by Michael Daunt.* RAF. ***Opposite, middle:*** *the NRC Cold Weather Test Station (CWTS) at Stevenson Field, Winnipeg, Manitoba. The test house is at left.* NAC. ***Opposite: bottom:*** *CWTS staff photo taken in 1946, K. F. Tupper and the writer are absent.* S. G. RAHMER.



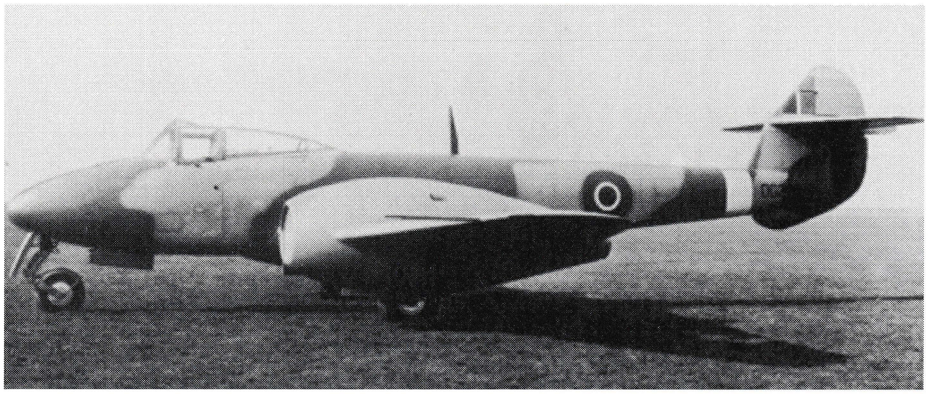
Tupper and I made our final UK visit concerning the mission in late April and early May 1945. Fortuitously, the timing of this visit put us in the UK for VE Day where we participated in the immensely emotional and happy celebrations in London.

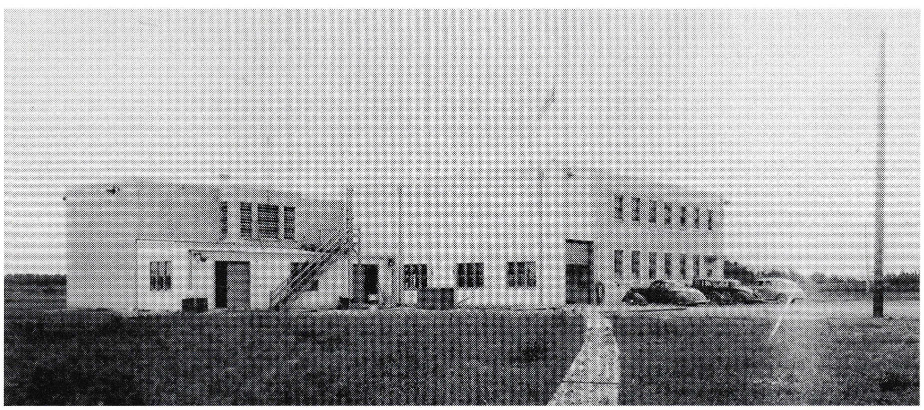
The business purpose of this visit centred largely on determining basic policy and attitudes of both the British Government and the engine firms on commercial use by Canada of British Jet Engine technology and on-going technical exchange. It transpired that a for-

". . an occasion for celebration -- when the characteristic start-up whine and ensuing exhaust roar of a jet engine was first heard in Canada."

mal agreement was consummated between Canada and Britain whereby, inter alia, there would be a royalty-free exchange of technical information between Turbo Research and Power Jets.

Although quite incidental to the main story I include here an unanticipated byproduct of the UK Trainee program which inured to the benefit of the USA. It concerns the first of our NRC UK trainees, Bruce N. Torell. Following his return to Canada, Bruce joined the CWTS staff at Winnipeg where he was engaged on the test programme on British jet engines. Subsequently, along with most of the Turbo Research staff, he joined the A.V. Roe Canada Gas Turbine Division, working under Winnett Boyd. Shortly thereafter he resigned to take up employment with US Pratt & Whitney at Hartford. Although this was regarded as a breach of good faith at the time, he nevertheless deserves credit for carving out a most distinguished career. Torell participated in developing P&W's highly successful military jet engines and on special assignment to P&W Canada, he played a key role in developing the famous PT6 gas turbine aero engine which has enjoyed such spectacular world wide commercial success. To his further credit Torell completed his career at P&W as President of the parent firm.





CWTS SUMMARY

As to the value of the tests performed on the British engines at the CWTS, this turned out to be more confirmatory than constructive. In terms of performance, acceleration, starting and operation in cold temperatures, all engines functioned well and essentially to design performance. An exception was in combustors. Some of these suffered failures under the higher pressures resulting from ground level low temperature operation. This led to corrective design modification.

While the British seemed well satisfied with the results of the test programme the major beneficiary was undoubtedly Canada. The CWTS project laid a foundation in recruiting, training and practical experience for the cadre of personnel who later formed the backbone of Canada's jet engine design and development team at Malton. It also encouraged federal government officials, notably C.D. Howe and R.P. Bell and later, Air Marshall W.A. Curtis, Chief of Air Staff of the RCAF, to support the launching of Canada's jet engine design and development industry.

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To be continued