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AN INTRODUCTION TO THE JT15D ENGINE

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ABSTRACT

An analysis of the market potential for a small turbofan engine intended for business aircraft has led to the design of the JT15D. The main design objectives were low initial cost, low fuel consumption, high reliability, low maintenance costs, ease of installation and operation, and good growth potential. These objectives have been achieved using a minimum number of components and providing a simple layout. Mounting of the engine is highly flexible, and operation is straightforward. Extensive component testing has been carried out. Guaranteed engine performance was achieved early in the development programme.

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Introduction

The business aircraft market has shown steady and impressive growth since its inception. Initially, piston engine-powered medium and light aircraft were modified for executive use. The first aircraft expressly designed for this market were turbojet powered. They won quick acceptance because of the high speed which they offered. Also the decreased noise and vibration, with the resulting reduction in travel fatigue, focussed the attention of the users of smaller aircraft on the virtues of the gas turbine engine. These aircraft were relatively expensive and sophisticated however, and at first only large corporations were able to justify their acquisition. The increasing demand for executive mobility led to the design of the turboprop powered business aircraft. Compared with the turbojet, the turboprop aircraft offered lower initial and operating costs, equal comfort, and greater flexibility of operation. The penalty was a loss in speed, although the speed increment over the piston engined aircraft was considerable. The success of this class of aircraft is evidenced by the production figures for the Pratt & Whitney PT6. Close to 3,000 of these engines have been produced, and a steady backlog of orders is maintained. A new type of operation, the commuter airline, has grown from the experience gained with this class of aircraft. In the commercial airline business, the turbofan engine has gained universal acceptance as a result of its improved fuel economy. Studies of the application of the small turbofan to potential business aircraft showed this to be a promising avenue.

The JT15D - The Raison d'Etre

Studies related to the use of turbofan engines for business aircraft were carried out at United Aircraft of Canada Limited as far back as 1960. Various layouts and thrust levels were studied. Cost analyses showed clearly the gains available from the use of the centrifugal compressor, particularly if the pressure ratio capability could be raised and efficiency maintained or increased. Subsequent research into centrifugal compressor technology at United Aircraft of Canada Limited led to the development of this capability. Optimization studies identified the cycle parameters which would best utilize the centrifugal compressor.

The requirement for specific definition of power level led to consultation with the aircraft manufacturers in order to better understand their needs and future planning. Market surveys were conducted encompassing the spectrum of aircraft types under consideration. A gap in the business aircraft market existed which was generating considerable interest. This area of interest is shown in Figure 1.

It appeared that the aircraft that would fill this gap would be 6 to 10 place and would travel at between 375 and 500 mph. They would weigh between 7000 and 12,000 lb., would have an IFR range of over 1,000 miles, and would offer turboprop field performance. A medium bypass ratio turbofan engine was required of about 2,000 lb. thrust. This became the basic definition of the JT15D.

Contact with potential customers led to more serious aircraft project studies. These indicated a need for more power. As a result the engine was uprated to 2,200 lb. thrust, thus conforming to a tradition of the engine business. The present engine ratings are shown in Figure 2, along with general engine data.

Design Objectives and Criteria

The overall design objectives for a small turbofan engine were chosen. The criteria which had to be satisfied, in order that the objectives be met, were then defined. These objectives and criteria are tabled in Figure 3.

Engine Description

The JT15D is a two-spool, medium bypass ratio turbofan engine. Figure 4 shows a cross-section of the engine. The single stage fan, which has no inlet guide vanes, produces an average pressure ratio of just under 1.5. The titanium fan blades incorporate a part-span shroud to eliminate vibration. The titanium disc carries the rotating nose bullet, which is anti-iced on a full-time basis by compressor delivery air, which is subsequently used for seal pressurization. The air flow splits behind the rotor, the bypass ratio being 3.2. The bypass flow whirl is removed by a stator, and the air passes down a full length duct. The initial section of the duct is formed by the cast magnesium intermediate casing. The main part of the bypass duct is formed externally by an aluminum casing.

The primary flow passes through the inner stator and down an inter-compressor duct into the high compressor. The high compressor is a single stage centrifugal compressor which produces a pressure ratio of approximately 7. The vanes on the titanium impeller are designed to be flank milled, to minimize cost. The diffuser is of the patented pipe type developed at United Aircraft of Canada Limited (1). This single centrifugal stage replaces the 6 or 7 stages of axial compressor which would be designed into an all-axial engine.

The air is discharged from the diffuser through a cascade, after which it reverses direction and enters the fully annular combustion chamber. The fuel is injected through dual orifice nozzles from the dome end of the flame tube. Ignition is effected by a medium energy spark system. The hot gas turns through 180 degrees to pass through the single stage high turbine. The cast integral vane ring is cooled. The disc and blades are of conventional construction.

The gas is discharged from this highly loaded stage with some residual whirl and passes along a short inter-turbine duct. The low turbine is a two stage, shrouded blade design. Both the vanes and wheels are integrally cast, using materials with which extensive satisfactory service has been accumulated. The hot exhaust gas is then discharged past vanes which incorporate the exhaust temperature thermocouples in the leading edges. The tail bullet is an integral part of the exhaust casing.

Each of the high and low rotors is supported on two main bearings. There is one inter-shaft bearing at approximately mid length. The outer races of both thrust bearings run in a pressurized oil film to give maximum tolerance to unbalance loads. A single pressure pump supplies all engine oil. Bearing compartments are scavenged by air pressure and gravity except for the aft low turbine bearing, which uses a jet pump. All oil is scavenged to the integral oil tank via the accessories gearbox. All seals are labyrinth type except for one inter-shaft seal, where a controlled gap carbon seal is used.

(1) D.P. Kenny, "A Novel Low Cost Diffuser for High Performance Centrifugal Compressors," ASME 68-GT-38.

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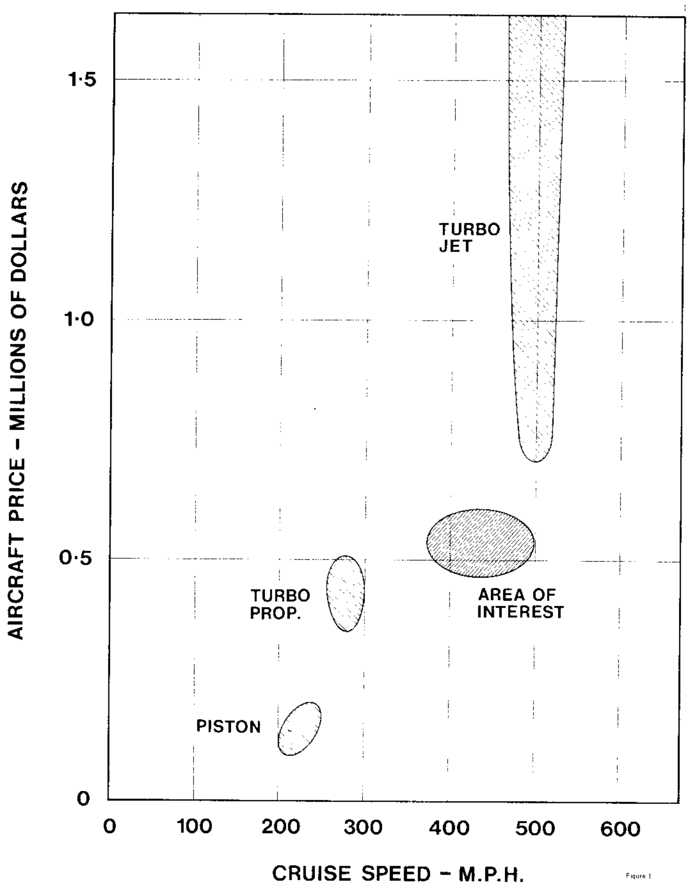

Figure 1

JT15D-1

Figure 2

RATING	NET THRUST - lb	SPECIFIC FUEL CONSUMPTION LB/HR/LB
SEA LEVEL STATIC		
TAKE-OFF	2,200	0·504
MAXIMUM CONTINUOUS	2,090	0·503
MAXIMUM CLIMB	2,090	0·503
MAXIMUM CRUISE	1,980	0·501
ALTITUDE 30,000 ft. MACH No. 0·6		
MAXIMUM CRUISE	636	0·789

ENGINE DIAMETER - in.	27·55
DRY WEIGHT - lb.	480

Figure 3

LOW INITIAL COST

MINIMUM NUMBER OF COMPONENTS
NO VARIABLE GEOMETRY
CONSERVATIVE TURBINE INLET TEMPERATURE
MAXIMUM USE OF TECHNOLOGY ALREADY IN DEVELOPMENT
SIMPLE CONTROL SYSTEM

LOW FUEL CONSUMPTION

OPTIMUM BYPASS RATIO BETWEEN 2.5 AND 3.5
OPTIMUM PRESSURE RATIO - GAINS DIMINISH ABOVE R=10
HIGH COMPONENT EFFICIENCY

HIGH RELIABILITY AND LOW MAINTENANCE COSTS

MINIMUM NUMBER OF COMPONENTS
NO VARIABLE GEOMETRY
CONSERVATIVE TURBINE INLET TEMPERATURE
MINIMUM SUSCEPTIBILITY TO F.O.D.
MAXIMUM USE OF PROVEN MECHANICAL DESIGN CONCEPTS

EASY AND CONVENIENT INSTALLATION

MOUNT FROM EITHER SIDE OR TOP WITHOUT HANDING
ACCESSORIES READILY ACCESSIBLE
AIRCRAFT CONNECTIONS GROUPED
ENGINE DESIGNED TO SUPPORT NACELLE
INTEGRAL OIL TANK
BLEED AIR AND POWER EXTRACTION AVAILABLE
MINIMUM FIREWALL REQUIREMENTS

EASY AND PLEASANT TO OPERATE

SINGLE LEVER OPERATION
SEMI-AUTOMATIC STARTING ON AIRCRAFT BATTERY
LOW NOISE LEVEL
GOOD RESPONSE

GROWTH POTENTIAL BY PROVIDING SCOPE FOR

INCREASED AIR FLOW, BOTH BYPASS AND PRIMARY
INCREASED COMPONENT EFFICIENCY
INCREASED CYCLE PRESSURE RATIO
INCREASED TURBINE INLET TEMPERATURE

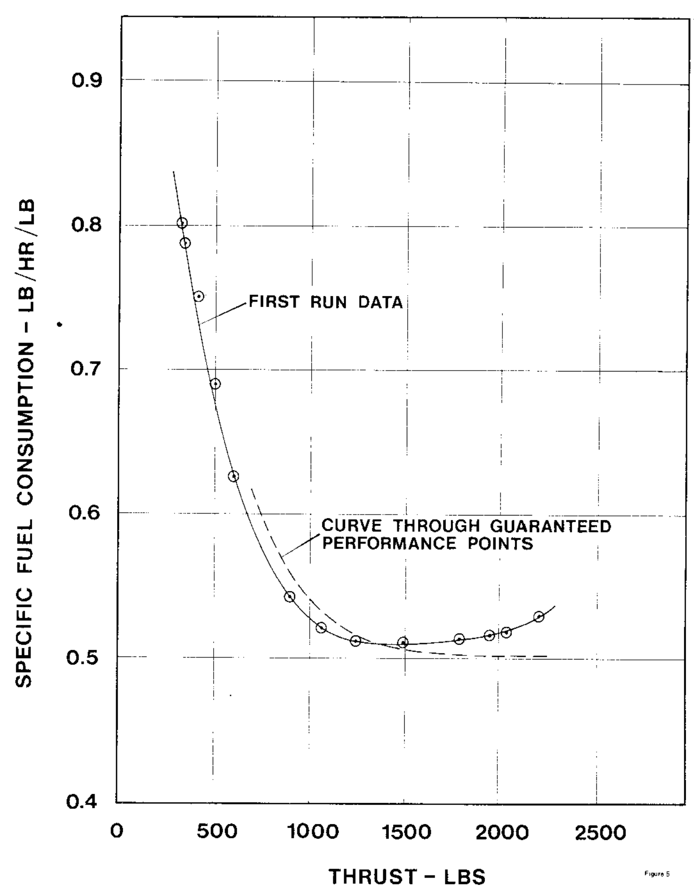

Figure 5

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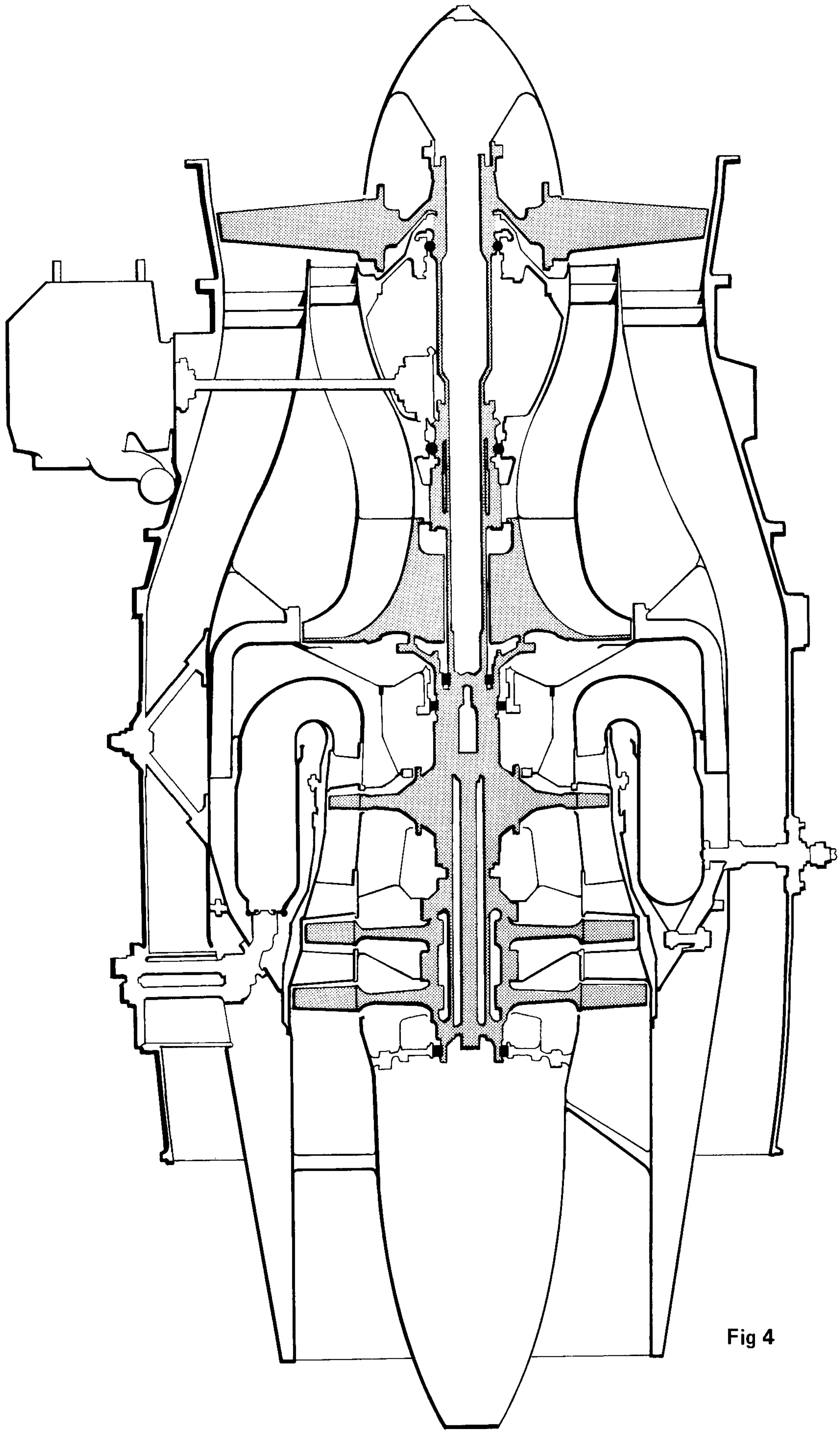

Fig 4

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The accessories drive is taken from the high rotor. The accessories gearbox provides a starter generator drive and an aircraft accessory drive. Also mounted on the accessories gearbox are the tachometer, the oil pumps and the fuel pump. The fuel control, a pneumatic/mechanical unit essentially the same as that used on the PT6, is mounted directly on the fuel pump. Metered fuel is carried aft to a unit which provides the semi-automatic start function, divides the fuel between the primary and secondary manifolds, along with several other functions.

Design Features

Now let us return to the items of Figure 3 and see how the programme objectives are accomplished by the JT15D design.

The compressor comprises a single stage fan and a single stage high compressor, the utmost in simplicity. This provides for low cost, high reliability and ease of maintenance. Modifications for growth affect a minimum number of components. Both the fan and high compressor had been aerodynamically tested before the engine design was finalized. The lack of inlet guide vanes, choice of number of stator vanes, and axial spacing of the fan components provide a low noise level and minimum susceptibility to F.O.D. Most foreign objects entering the fan will be centrifuged outward to pass down the bypass duct. All discs in the JT15D are designed to give a large number of speed cycles and long life.

The average turbine inlet temperature for a production engine at final test will be approximately 1760°F at Take-Off Rating. This allows the choice of standard turbine materials at minimum cost. It will also minimize deterioration of the hot section with time, and provides scope for uprating. Here, as throughout the engine design, the Field Service department has been integrated into the design team to ensure maximum benefit from operating and overhaul experience. The objective is to equal or better the record of the PT6, which has a premature removal rate record equal to the best airline engines.

The single stage high turbine is quite heavily loaded, but turbine rig testing on uprated PT6 stages had shown that good efficiency could be maintained at these higher loadings. Thus the high rotor or core gas generator contains the minimum number of components possible. The only departure from single stage components is in the low turbine. Studies and test data showed that a larger diameter single stage would do the job satisfactorily, but engine length and weight would be adversely affected. The growth potential is also enhanced with the two stage arrangement. The low average jet velocity of the turbofan yields low exhaust noise.

Engine mounting is straightforward. Four mount pads are provided on the intermediate casing. Any two adjoining mounts can be used to mount from either side or from above. The aft mount is designed to be readily moved to the appropriate circumferential position. The installation is simplified by the integral oil tank and the ability to integrate the oil cooler in the engine plumbing. All accessories and engine connections are grouped under the engine for ease of accessibility. The main forward and aft engine flanges are designed to carry the nacelle, which cowls very close to the bypass duct. The position of the accessories outside of the bypass duct and the full length shrouding of the engine by cool bypass air reduce the need for firewalls to a minimum.

The starting and operation of the JT15D are very simple. The engine is intended to be operated by a single lever. Once minimum light-off speed is reached, the lever is set into the idle position. Fuel flow is automatically metered on the run-up by a compressor delivery pressure signal. The starter and igniters can be integrated into the single lever motion. Power is set for the Maximum Cruise and Take-off Ratings, temperature being a limit only. The Maximum Climb rating is obtained by temperature setting. The temperature indicated in the cockpit is inter-turbine temperature, with a single limiting valve for up-trimmed Take-off temperature. All jet fuels can be used in the JT15D, and Aviation gasoline can be used as an emergency fuel.

Early Development Experience

The engine first ran in September 1967. The first run was temporarily interrupted by a seal rub, but when recommenced the engine was taken to above the thrust which was 100% at that time. The performance results from the first run are shown in Figure 5. For the initial run of a new engine the agreement is considered very good. Since that time optimization of the component matching has yielded specific fuel consumption below guarantee. Performance evaluation of modified components will naturally be continued throughout the development period.

Traversing at the fan rotor and stator outlet showed the fan design efficiency to have been exceeded. Difficulty was encountered in maintaining the balance of the fan wheel, and this was traced to small shifts of individual blades or blade groups. The blade axial location tolerances were tightened and the problem eliminated. The fan characteristic showed a satisfactory stall margin. Measurement of static and dynamic stresses on the fan blades was carried out very early in the programme. Measured stresses corresponded quite closely to the analytical values except in the hub area where the effect of the hub slope was stronger than forecast and resulted in lower stresses. Icing tests of the nose bullet zone were carried out in February 1968 and revealed the need for it to be heated.

Early running was hampered by an inability to decelerate the engine rapidly without flameout. Investigation traced this to the flame tube rather than the fuel system, and it was identified as a high lean limit blowout fuel/air ratio. Rig testing led to a reduction in this parameter by one third, which eliminated the flameouts. Slam accelerations have been carried out in approximately 3 seconds without encountering either stability or temperature limitations. The ground idle thrust is less than 4% of the Take-off thrust at present, which will ensure satisfactory aircraft brake life.

From the first evaluation the expansion system has performed at design efficiency. Initial engine running has been without the cooled high turbine vanes. The turbine inlet temperatures have not been limited by the lack of cooled vanes. However the life of the uncooled vanes would obviously be shorter than with cooling. It is expected that the cooled vanes will have essentially infinite life.

Supporting Component Testing

A number of components have undergone rig testing, some before the engine ran, others concurrently. A scale model of the high compressor was tested before the design was completed, and development is continuing on a full scale unit. Combustion system testing started with water tunnel work, then moved to the hot

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testing phase. Inter-compressor and inter-turbine ducts were model tested. The high and low turbines are both under development on the turbine test rig. Other small rigs have been used extensively. Examples are an oil system rig which allowed rapid elimination of an instability in the engine oil system, and a rig to develop the jet pump for oil scavenging. Over 2,000 hours of rig testing have been accumulated.

Flight Testing

The decision was taken to flight test the engine as early as possible in the programme to check out altitude performance and to check systems function under extremes of the flight envelope in which the engine would normally operate. The flight test vehicle chosen was the Avro CF-100, an all-weather interceptor with Mach number capability of over 0.8, and a ceiling of upwards of 45,000 ft. The aircraft was loaned to United Aircraft of Canada Limited by the Canadian Armed Forces. The design and installation of the test pod and instrumentation package was undertaken by the Helicopter Division of the company. Figure 6 shows the aircraft with the JT15D nacelle mounted under the fuselage, offset to the port side to gain ground clearance. For take off and landing, debris doors are actuated to cover the test pod inlet. The choice was made to use in-flight automatic recording onto magnetic tape for steady state data and oscillograph recording for transient data. The magnetic tape is fed directly into the computer and reduced data are quickly available for analysis. The engine and instrumentation system are controlled by the flight test engineer from the back seat in the CF-100. A sound survey was carried out on the engine in the aircraft, both near field and far field sound being recorded. Both were found to agree well with the forecast values, showing the noise reduction expected relative to a turbojet. The exhaust of the engine has been observed to be essentially smoke-free.

Current Status and Programme Schedule

Eight engines have been built and run to date. By mid 1969 the total will be ten. Approximately 1,000 hours of development engine running have been accumulated. The early running concentrated on verification of design assumptions and identification of problem areas and potential problems. Useful endurance running was then able to be initiated with considerable confidence.

The first application of the JT15D was announced last fall when Cessna Aircraft presented the Model 500 turbofan aircraft. This aircraft is shown in Figure 7. Flight prototypes will be shipped to Cessna in August of this year. Prototypes will be available to other customers shortly after.

The JT15D engine programme was undertaken in response to a rapidly developing market for a small turbofan. The engine ran on schedule, giving excellent performance right from the start. The programme has continued to meet scheduled milestones. The major milestone, engine civil certification, is expected to be completed by the end of 1970. Production engines will start to flow out the door a month later.

Acknowledgments

The author wishes to express his thanks to his various colleagues who have contributed to the work on the JT15D thus far, and to acknowledge the efforts of those who made helpful comments on this paper.

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Figures