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Engine Case Externals Challenges and Opportunities

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Engine externals and accessories are subject to significant thermal exposure. Performance constraints and penalties of cowl leakage place increased emphasis on improved technology of component capabilities and ventilation analysis. For example, reliable wiring and connectors qualified for 700°F are needed for the next-generation engines. Zonal flow prediction is also necessary to minimize fire-extinguishing testing and many other functions. The challenges and opportunities are clear.

Introduction

BETWEEN the engine case and the nacelle cowling there exists a complex space overflowing with pipes, wires, components, and challenges (Fig. 1). This is the world of engine externals, a cramped, noisy, hot, high-vibration world where the engine controls and engine-powered services are located. Engine externals are seldom discussed, researched, or understood by the aerospace technical community. This is the realm of the maintenance engineer, airline mechanic, and the systems design engineer.

Several reasons support technology investment in engine externals and the engine externals environment. Combined, externals cause the majority of engine in-flight shutdowns (IFSDs) (Fig. 2). One airline estimated that 40% of their unscheduled line maintenance costs are linked to the propulsion systems, and 80% of that maintenance fraction is tied up in engine externals. This translates to almost one-third of that airline's total line maintenance budget that is being spent on maintaining engine externals (Fig. 3).

The challenges are complex and require innovation, value engineering, and technology development. Functionality, reliability, maintainability, performance, and other challenges must be met (Fig. 4), but the opportunity for payback is real (Fig. 5). To illustrate this payback, this paper presents a discussion of four examples of externals development opportunities and identifies both the technical challenges and paybacks.

Cowl Seals and Leakage Through Cowling

Modern commercial transport nacelles include components that open or move to allow maintenance to be carried out and to allow thrust reversal during landing. Because these moving components can open into the fan stream flow path, it is necessary to provide sealing to prevent excessive flow leakage when the airplane is in normal operation. Loss of flow from the fan stream results in the loss of fan gross thrust in proportion to the leakage flow effective area. The target level of fan duct leakage for a typical 777 is 6.8 in.^{2} per nacelle, which translates into an operating empty weight penalty of 2040 lb and a thrust-specific fuel consumption (TSFC) increase of 0.38% for the airplane. Because leakage without seals would be many times the target level and the seal weight is much less than 100 lb per nacelle, the tradeoff in seal weight vs performance gain is very much in favor of sealing.

Leakage goals for current nacelles have been reduced for newer airplane models, as shown in Table 1. Goals of effective leakage area relative to the fan nozzle area have ranged as high as 0.4% for older nacelle designs to a very aggressive target of 0.1% for modern nacelles.

A typical 777 fan duct seal arrangement is shown in Fig. 6, with all of the nacelle hardware removed. The total length of the fan duct seals for one nacelle is ~81 ft. All of the seals involve moving surfaces in some way or another, and they are impacted very strongly by the design of the seals and seal lands, surface deflections in operation, rigging, and tolerances. Good seal performance is heavily dependent on good design practices, but our experience has been that obtaining the low target leakage requires that development testing be carried out on nacelle hardware.

For this reason, test procedures have been developed to evaluate nacelle leakage on initial pre-production or production hardware, so that refinements in seal design, if required, can be incorporated very early in the production cycle.

Tests to two levels of sophistication have been used on the 777, which have different costs and impacts on the production cycle. The cost and complexity are primarily determined by the pressure level at which the tests are carried out. The high-pressure and low-pressure tests that have been used on 777 nacelle hardware are described next.

Nacelle Leakage Tests

High-pressure leakage tests attempt to match the fan duct pressures that will occur in normal operation. Figure 7 shows the test rig that was used for the 777. The data obtained from this type of test can be of great value because they cover the pressure range of interest and are carried out in a laboratory setting where leakage flow can be metered carefully and sealing fixes can be tested easily. However, the cost is very high and test hardware is removed from the manufacturing flow for a week or more.

Use of the low-pressure test technique was prompted by the cost and schedule problems of the high-pressure method. In this test, pressure is limited to a few tenths of a pound per square inch, so that pressurizing equipment and nozzle sealing plates can be very simple. Although the data obtained covers only a small portion of the operating pressure range, this test has been quite effective in identifying and correcting seal problems.

Opportunities for Improvement in Seal Design

The payoff for sealing is such a benefit, it will continue to be a necessary task for future nacelle designs. Based on our recent experience, some of the improvements that appear to be worth pursuing are discussed as follows:

1) Seal design: this is the most important part of the nacelle sealing process. Review of past experience and close attention to seal retention and seal compression are very important. Seal bends, seal ends, moving seals or seal lands, and engine/nacelle deflections have all been problem areas in the past.

2) Seal gaps: a technique for interrogating a completed seal and structure design for gaps would be very useful. The use of solid models for seals, seal lands, and nacelle structure may offer the

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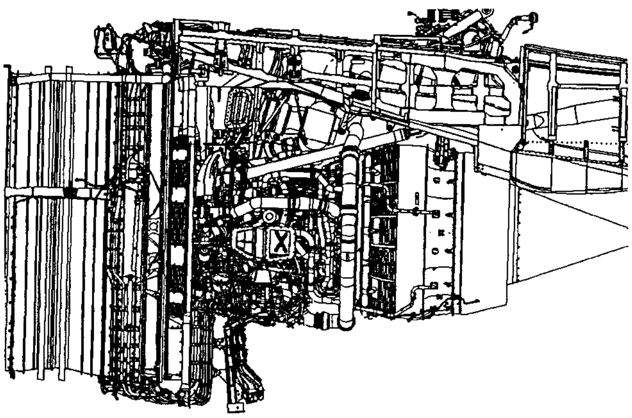

Fig. 1 Typical 777 engine with strut and externals installed.

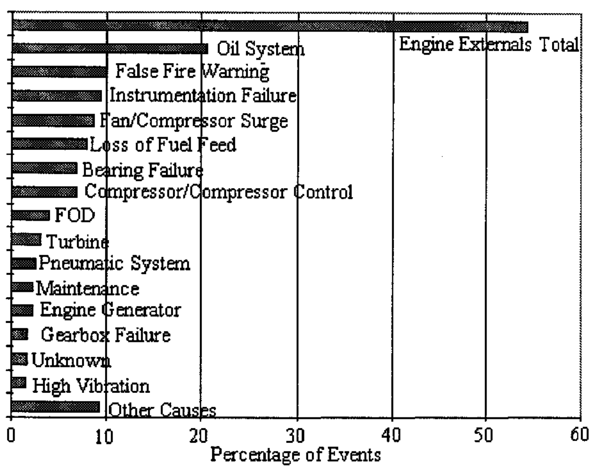

Fig. 2 In-flight shutdowns Boeing twin engine airplane fleet 1980 and on.

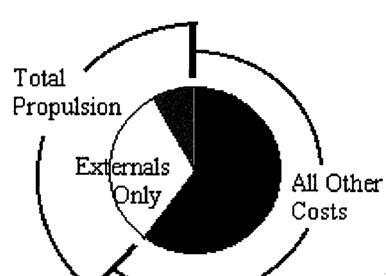

Fig. 3 Typical unscheduled line maintenance costs.

possibility of an automated process for sniffing out gaps. This technique would be enhanced by the addition of a dynamic model of bulb seal behavior that uses digital design models and considers seal friction and scrubbing.

3) Testing: the current low-pressure test method is a cost-effective way to obtain leakage data, but a test that is more integrated into the manufacturing process would be desirable. An opportune time for leakage testing would be when the thrust reverser halves are mounted on a test fixture for fit checks. A low-pressure test could be applied at this point with little impact on manufacturing flow.

Engine Externals Cooling Analysis

Engine externals and accessories are required by specification to perform their intended function within vibration, temperature, and pressure constraints intended to be representative of the propulsion system environment. Compliance to these limits must be shown as part of the airplane and engine certification process. Predicted component temperatures are used for the qualification of components. Flight-test measurements are corrected to adverse hot day conditions and are compared with component qualification levels. Usually, most flight-test component temperatures are found to be within temperature limits. However, there are always a few components that are exceptions and require corrective action. These actions may include requalification of that component to higher temperatures and/or redesign of the installation thermal protection and cooling hardware. The process is costly due to component requalifications and the repeated flight tests (recent programs required from 2 to 25 test attempts before success). Moreover, additional costs are incurred in reworking the cooling configuration of production airplanes prior to delivery. The ideal process would be a single flight test that demonstrates positive margins in the range of 25°F for all components. Unfortunately, current analytical methods are subject to significant inaccuracy. Errors of ±50°F in cool regions and ±100°F in hotter regions of the nacelle are commonplace (Fig. 8).

The present analysis method employs a simple steady-state axisymmetric model that oversimplifies cowling and case heat transfer, cowling and case leakage, seal leakage, zone ventilation, externals cooling flows, and exhaust vent flow. Overcooling externals with fan flow to minimize repeated flight tests is an option, but the excessive performance penalties would be a burden to the airlines for the life of the airplane. The deficiencies of the analysis method are understood. The problem is very complex with irregular geometry, three-dimensional flow, transient heat transfer, and a myriad of material properties.

Recent advances in the digital definition of components provide an opportunity to advance the cooling analysis method. However, the integration of heat transfer models, fluid dynamic models, and design models presents a significant challenge. The resulting model must give reasonably accurate predictions of local temperatures (around ±25°F) and be economic and timely in computation procedures. The costs of analysis must not approach the costs of flight tests with the current methods.

The integration process will require participation by experts from several disciplines from the diverse organizations that produce and install engine externals. Experts from engine manufacturers, cowling manufacturers, airframe manufacturers, external components manufacturers, airline engineers, FAA certification experts, and NASA technology specialists will be needed to provide guidance to criteria selection, technology readiness assessment, and program direction.

Core Cowl Vent Design

Fan flow is used to cool various nacelle components, engine oil, cooling oil for the airplane's electrical generators, and the environmental control system (ECS) compressor bleed that is used for environmental control in the cabin. The ECS cooling and most other cooling flows are exhausted into the nacelle core compartment and must find their way overboard through the vent system. The level of flow into the core compartment and the need for an exhaust provision has led to the design of a core cowl vent nozzle that can accommodate the exhaust flow requirements and also recover some thrust. A properly sized vent with the flow levels experienced on current nacelles can result in a thrust recovery equivalent to −0.25 to −0.5% fuel flow at cruise.

Figure 9 shows the location of the core cowl vents for a typical 777 installation. This is a difficult design problem because ventilation flow is exhausted into the fan stream that is operating at a pressure ratio that is much higher than the core cowl vent. Small changes in fan stream pressure ratio can have very large effects on the flow from the core cowl exit. Conversely, the low-energy stream from the vent can adversely affect the downstream boundary layer on the fan nozzle afterbody and can disturb the supersonic fan stream flow such that an undesirable flow compression wave forms near the vent exit.

The design goal for the core cowl vent is to pass the necessary flow at the highest flow condition and to maintain the highest possible core compartment pressure at cruise conditions to maximize thrust recovery. These are conflicting requirements because increasing the

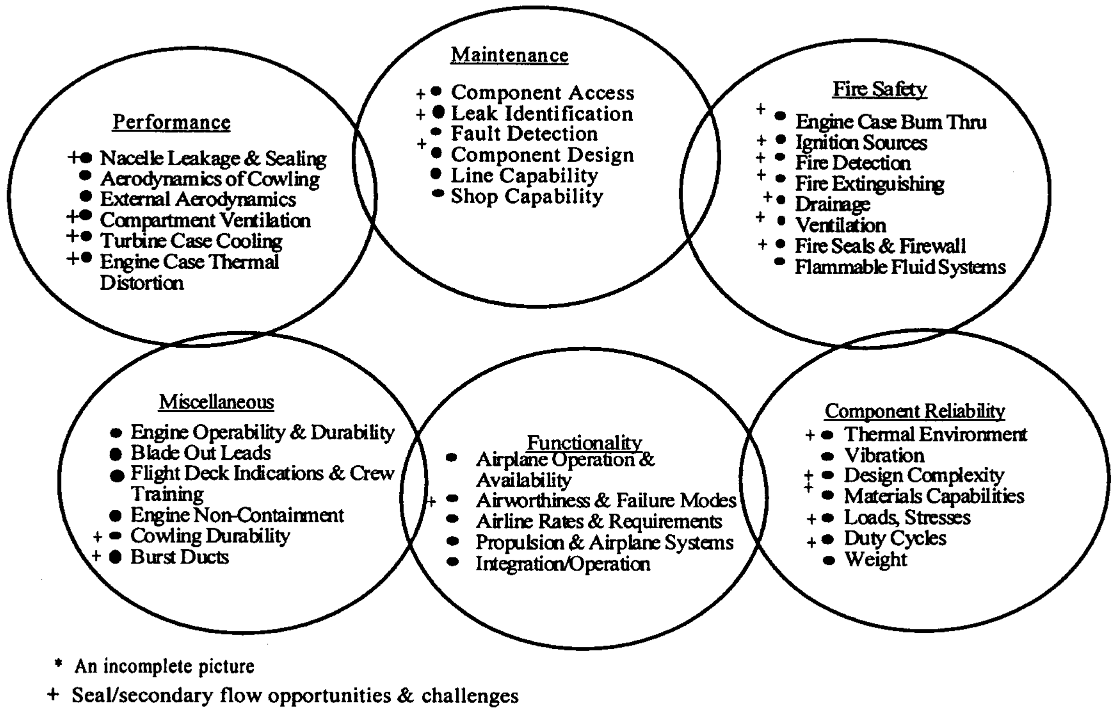

Fig. 4 Externals pressures and constraints.

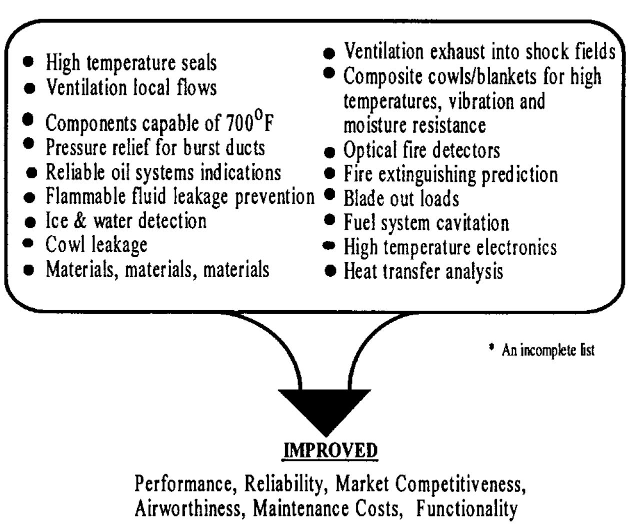

Fig. 5 Engine external design challenges and technology opportunities.

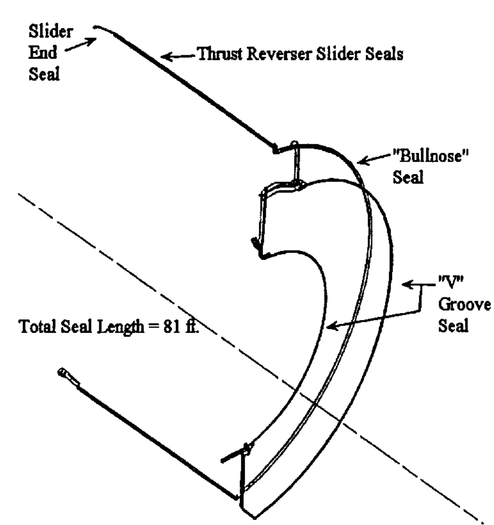

Fig. 6 Typical 777 fan duct seals.

Table 1 Leakage goals for current nacelles (typical)

Airplane	Nominal fan nozzle area, in.^{2}	Target leakage area (% of nozzle area)
737-300/400/500	1160	4.64 (0.40%)
757-200	2143	3.2 (0.15%)
767-200/300	2783	4.2 (0.15%)
777-200/300	4533	6.8 (0.15%)
737-600/700/800	1200	1.2 (0.10%)

vent area to cover the highest flow condition will reduce core compartment pressure and thrust recovery at cruise.

The use of flow analysis in the design of the vent is an attractive approach, but the complex nature of the flow requires that fully viscous methods be used. The PARC[1] code was used for the flow analysis of the 777 vent designs, and results were useful, but only axisymmetric geometries could be analyzed at the time the designs were finalized.

Opportunities for Improvement in Vent Exhaust Design

The vent design process suffers from two conflicting requirements. The first problem is that the vent flow is very sensitive to the local external flow environment and the required flow rates, which may not be well known early in the program, and the second requirement is that lines must be defined early in a development program to meet manufacturing schedules. Further study in the following areas would aid in achieving optimum vent exhaust designs:

1) Flow requirements: any effort that helps to define the design flow requirements earlier in the development program would be very beneficial. This would involve any system that puts flow into the core compartment such as precooler flow, component cooling, or heat exchangers.

2) Flow analysis: three-dimensional viscous analysis methods that can account for the nacelle installation in the presence of the wing are needed. A high level of accuracy is needed because of the sensitivity of vent flow to local pressure.

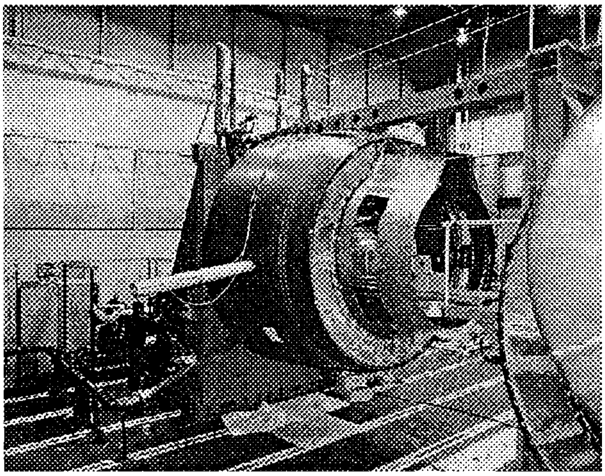

Fig. 7 High-pressure 777 nacelle leak test rig.

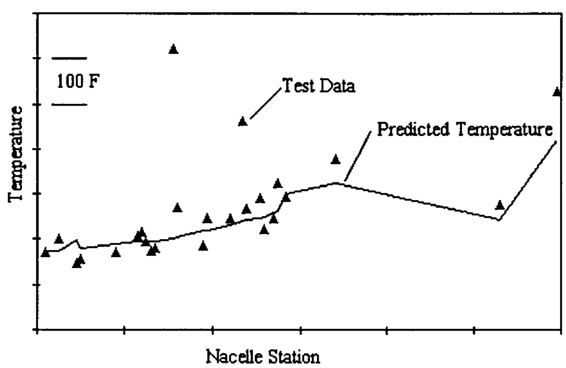

Fig. 8 Comparison of predicted ambient temperatures and test data.

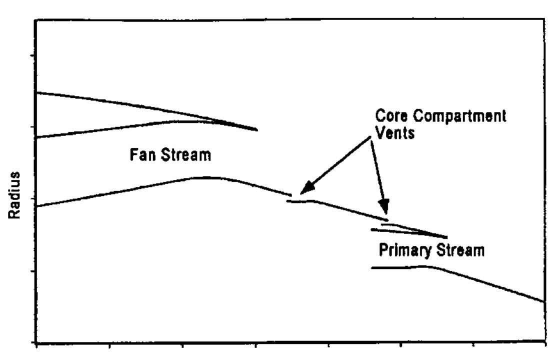

Fig. 9 Core compartment vents for 777 nacelle.

3) Alternate locations for vent exit: one of the major problems in vent design is the fan stream flow, where changes in engine power setting and freestream Mach number both affect the vent exit conditions, and thus, the flow coefficient. Locating the vent exhaust outside of the fan stream, e.g., the strut, would reduce the impact of engine power on the vent exit condition and would make the prediction of local conditions easier.

4) Trimming capability: standard practice in vent exit design should include the ability to trim the hardware late in the manufacturing cycle, so that changes can easily be made after airplane operating requirements are known.

5) Active vent area: the vent exit area should be increased to aid in pressure relief or even in meeting maximum normal flow requirements for the nacelle results in performance penalties through lower vent thrust recovery. Trade studies that look at alternate methods of relieving high-pressure operating conditions, such as doors that open at high pressure and then close when the pressure is reduced, would be helpful in maximizing thrust recovery.

Engine Indications

Reliable sensors for critical engine parameters are essential for proper engine operation and engine health monitoring. The cockpit display of these engine parameters allow the flight crews to make informed decisions and diagnoses regarding the health of the engines. These are the requirements for cockpit engine indications. However, the instrumentation errors and the false fire warnings are second and third at causing IFSDs (Fig. 2).

Today's indication systems are designed to accommodate single sensor failure without the loss of the cockpit display by using redundant sensors. This approach masks a poor sensor reliability with an acceptable system availability. Instead of improving sensor reliability, we design systems that require extra sensors for redundancy and fault accommodation. Such design philosophy requires logic to manage redundancy, wiring to interconnect redundant sensors, and therefore the part count increases. More parts also means more failures, more maintenance costs, and more spare inventory for our customers.

What is required is a single, reliable sensor able to operate for extended periods in the hostile environment of engine externals. The challenge is to design a sensor whose availability is the same as today's redundant system. To do this, the sensor reliability must improve an order of magnitude.

High-Temperature Wire Requirement

Electrical wiring that can tolerate high temperatures is an area where component manufacturers could play an important role in reliability and ownership costs of airplane propulsion systems. The engine externals environment presents wiring requirements that are much more demanding than the environment for wiring in other airplane zones. Moreover, higher engine cycle temperatures have rendered the existing wiring standards obsolete. Current engine harnesses are capable of 500°F continuous temperatures. The next generation of engines will be expected to require up to 700°F capable wiring.

This requirement exceeds the capability of elastomerics insulation of today's harnesses. There is ample evidence that harnesses of in-service airplanes need improvement because many airlines routinely replace engine harnesses during engine maintenance. However, higher temperature capability must not compromise other characteristics. For example, moisture resistance must be maintained so that insulation resistance is not degraded.

Harness connectors that employ elastomerics present a similar challenge. Many connectors employ metallic shells that offer high-temperature and low-absorption capabilities, but the internal insulation is temperature limited. The challenge is to produce a flexible internal insulator rated at 700°F, with no degradation in other characteristics.

These wiring and connector opportunities require the consideration of new materials technology and new design solutions. Clearly, new basic and applied technology initiatives are appropriate.

Conclusions

Engine externals provide many challenges and opportunities for the application of advanced technologies. Several specific examples have been presented and discussed in this paper. Engine externals have a major impact on propulsion-system reliability, which affects airline schedule and service performance. Several problems increase flight tests and manufacturing costs. Many areas relate to sealing and secondary flows with associated performance impacts.

A comprehensive study of the costs/benefits associated with each item of Fig. 5 would provide focus for the prioritization of resources in solving the problems and improving the propulsion systems. A steering group drawn from engine manufacturers, ariframers, airlines, and government experts would be appropriate.

Reference

[1]Cooper, G. K., and Sirbaugh, J. R., "The PARC Code: Theory and Usage," Arnold Engineering Development Center, AEDC-TR-89-15, Arnold AFB, TN, Dec. 1989.