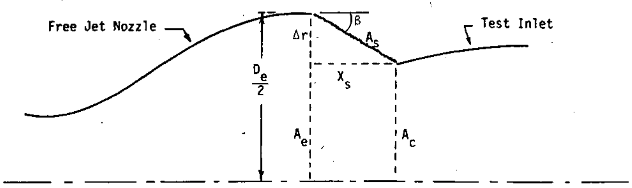

Fig. 1 Free jet test facility nomenclature.

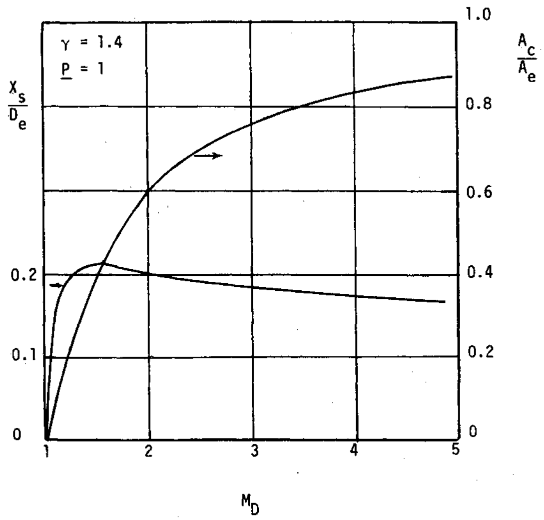

Fig. 2 Axial distance and capture area vs design Mach number.

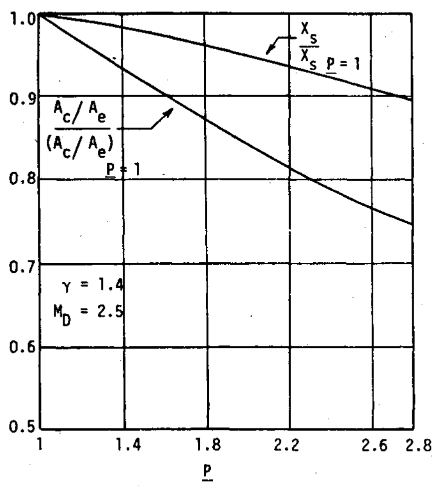

Fig. 3 Axial distance and capture area vs pressure ratio.

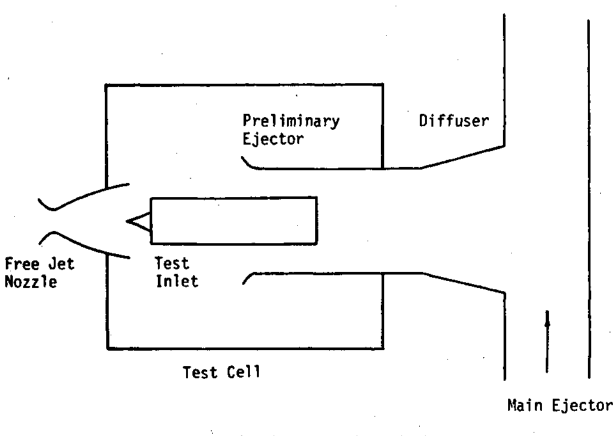

Fig. 4 Schematic diagram of preliminary ejector.

Enhancement of Facility Pumping Capability

The required low backpressure, P_a, must be supplied by the facility pumping capability. This capability is usually supplied by an air or steam[1] driven ejector. In cases where large model sizes are to be tested, facility pumping capability can become limiting, and the requirement to enhance such capability can be imperative. When large test models with high-pressure recovery inlets are utilized, the test model flow itself can have significant pumping capability. Thus, as suggested in Fig. 4, the model exhaust flow can be utilized as the primary flow of a preliminary ejector to raise the pressure at entry to the main ejector. The preceding calculations provide the necessary mass flows in the primary and secondary streams of the preliminary ejector. Estimates of the delivery stagnation pressure from the test model should be available, and it has been found a reasonable lower estimate of the secondary stream stagnation pressure to simply take it equal to the static backpressure, P_a.

With the approximations suggested above, the combined system capability can be estimated in a straight-forward fashion utilizing established theories.[6,7] When high Mach number tests are to be conducted, considerable pumping enhancement occurs when a preliminary ejector is utilized.

References

[1] Myers, T. D. and Stromberg, G., "Ground Test Facility for Integral Rocket Ramjet Engines," AIAA Paper 78-938, AIAA/SAE 14th Joint Propulsion Conference, July 25-27, 1978.

[2] Dunsworth, L. C. and Reed, G. J., "Ramjet Engine Testing and Simulation Techniques," *Journal of Spacecraft and Rockets,* Vol. 16, Nov.-Dec. 1979, pp. 382-388.

[3] Summerfield, M., Foster, C. R., and Swan, W. C., "Flow Separation in Over-Expanded Supersonic Exhaust Nozzles," *Jet Propulsion,* Vol. 24, Sept.-Oct. 1954, pp. 319-321.

[4] Kantrowitz, A. and Donaldson, C. du P., "Preliminary Investigation of Supersonic Diffusers," NACA ACR L5D20, 1945.

[5] Ames Research Staff, "Equations, Tables and Charts for Compressible Flow," NACA Report 1135, 1953 [p. 9, Eq. (128)].

[6] Fabri, J. and Paulon, J., "Theory and Experiments on Supersonic Air-To-Air Ejectors," NACA TM 1410, 1957.

[7] Taylor, D. and Toline, F. R., "Summary of Exhaust Gas Ejector-Diffuser Research," AEDC-TR-68-84, Oct. 1968.

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Effect of Cross-Shafting on Landing Reliability of V/STOL Aircraft

William S. Willis*
General Electric Company, Cincinnati, Ohio

Introduction

THE desired capability of completing a vertical landing with one core engine inoperative has been a major driver in configuring subsonic V/STOL propulsion systems. The approach generally used to achieve this capability involves the addition of bevel gears and cross-shafting to the engines. In a two-turbofan system, either core can thus drive both fans at a balanced thrust level to allow vertical landing at reduced gross weights.

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*Manager, Advanced Military System—Preliminary Design.

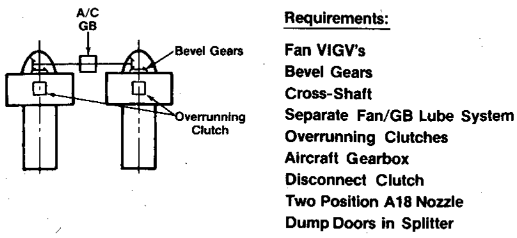

Fig. 1 Cross-shaft systems.

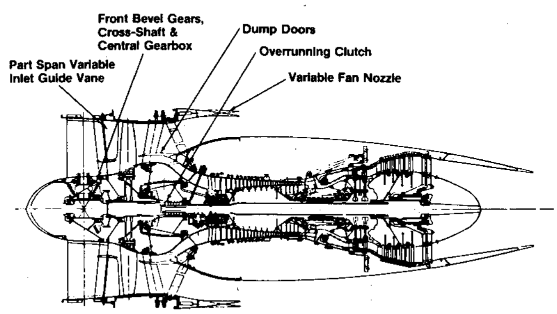

Fig. 2 TF34-V/STOL.

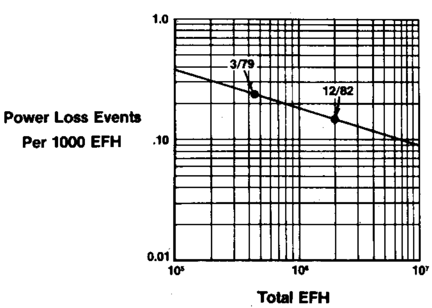

Fig. 3 TF34 reliability growth.

The addition of bevel gears and cross-shafting also requires the addition of a number of other system elements, as shown in Fig. 1. Variable inlet guide vanes (VIGV's) are needed to balance the system thrust. The engine lubrication systems must be split so that fan lube services can be provided when the core is inoperative. Over-running clutches are required in the low-pressure shafts to disengage the low-pressure turbine when the fan is being driven through the cross-shaft. A central gearbox would be added to drive aircraft accessories from the cross-shaft, and this gearbox would contain a disengagement clutch to provide single engine operating capability. In addition, a two-position fan exhaust nozzle and dump doors in the splitter must be provided to bypass the fan hub airflow when the core is inoperative. These features are shown on a V/STOL version of the TF34 engine in Fig. 2.

The extent of these modifications to a mature engine raises questions as to the merit of the cross-shaft approach. With real constraints on development cost and timing, the added equipment can be expected to be far less mature, and less reliable than the basic engine when the system enters service. It is therefore possible that the cross-shaft may actually detract from, rather than improve engine-out landing capability.

This study was an attempt to assess the probability of completing successful vertical landings with and without cross-shafting, considering realistic reliability levels of the components. Comparisons were made for the operational flight system and also for a Research Technology Aircraft (RTA) designed to provide a proof of concept much earlier than the operational system.

Unreliability, $Q = \lambda t$

Where λ = **Instantaneous Failure Rate Per EFH**

t = **Hours Per Mission**

Reliability, $R = 1 - Q$

For Series System:

$R_s = R_1 \times R_2 \times R_3 \ldots R_N$

For Parallel System:

$Q_s = Q_1 \times Q_2 \times Q_3 \ldots Q_N$

Fig. 4 Analytical approach.

Table 1 Estimated failure rate/1000 EFH

	Non-cross-shafted	Cross-shafted
Operational aircraft (1990 IOC)	0.188	0.118
RTA (1984 flight test)	1.399	3.026

Approach

The TF34 engine has been under consideration for use in several subsonic V/STOL aircraft designs. This engine has demonstrated an excellent reliability record in the S-3A aircraft. As of March 1979, the engine had reached a total of 427,000 equivalent flight hours (EFH), and had achieved an in-flight power loss rate of 0.249/1000 EFH. By definition a power loss event represents 10% or greater loss of thrust. The reliability growth rate of the engine is progressing satisfactorily as shown in Fig. 3. By the end of 1982, the engine is expected to reach two million EFH and a power loss rate of only 0.154/1000 EFH.

To predict the failure rates of cross-shafted and non-cross-shafted V/STOL engines, historical data were used for the TF34 components. Estimates were made for the new components based on available sources such as helicopter data. The failure rates were then adjusted to reflect the expected usage and time period for both the operational and Research Technology Aircraft. The analytical approach used with this data was to apply probability logic as outlined in Fig. 4.

The non-cross-shafted system is a series analysis where the failure of any element can prevent a vertical landing. In the case of the cross-shafted system, the added equipment provides redundancy in the core engine so that either core can fail without preventing the vertical landing. This parallel path increases the core reliability to essentially 100%. But, in exchange for this benefit, all of the added components show up as additional series elements. Of course, there are many other elements in the aircraft system that affect the overall system reliability, but these are similar in either case and were therefore neglected.

Results

The results of the reliability calculation are shown in Table 1.

Concluding Remarks

The study results indicate that cross-shafting will provide a small improvement in engine-out vertical landing reliability in an operational aircraft. To achieve this improvement, however, an extensive (and expensive) development program would be required. The equivalent of 200,000 engine flight hours might be needed with the entire cross-shaft system tested in a supporting structure that simulates the stiffness and dynamic characteristics of an airplane.

The results also show clearly that mixing very immature cross-shaft components with a mature engine in a RTA can seriously detract from the system reliability. Moreover, the weight of this added equipment represents a 10% increase in engine weight. Elimination of this equipment would permit a substantial reduction in VTO thrust requirements, permitting the engines to be down-sized, or derated to further enhance reliability.