AIAA 80-1196R

CF6-50 Short Core Exhaust Nozzle

Donald J. Dusa*
General Electric Company, Cincinnati, Ohio
and
Frank J. Hrach†
NASA Lewis Research Center, Cleveland, Ohio

The General Electric CF6-50 engine nacelle was originally equipped with both fan nozzle and core nozzle thrust reversers. Many airline operators later deactivated the core reverser. Elimination of the core reverser enabled design changes to be made to help improve performance. A reduction in core nozzle length of approximately 2 ft was possible. This concept, defined as the short core exhaust nozzle, was evaluated in engine ground tests, including performance, acoustic, and endurance tests under the NASA Lewis Engine Component Improvement Program. The test results verified the performance predictions from scale model tests. The short core exhaust nozzle provides an internal cruise SFC reduction of 0.9% without an increase in engine noise. The nozzle hardware successfully completed 1000 flight cycles of endurance testing with no signs of distress.

Introduction

IN the interest of energy conservation, NASA is sponsoring the Aircraft Energy Efficiency (ACEE) Program aimed at reducing fuel consumption of commercial transports. The NASA Lewis Engine Component Improvement (ECI) Program is the element of the ACEE program directed at improving the fuel efficiency of current engines. The ECI program consists of two parts: engine diagnostics and performance improvement. The engine diagnostics effort is to provide information to identify the sources and causes of engine deterioration. The performance improvement (PI) effort is directed at developing components which improve engine performance and increase performance retention for new production engines and retrofit. The initial work effort under the PI program consisted of a feasibility analysis which was conducted in cooperation with the aircraft companies and airline operators. From the results of the feasibility analysis, reported in Ref. 1, one of the concepts selected for development on the PI part of the ECI program was the General Electric CF6-50 engine short core nozzle (SCN). This paper presents the results of the development work on the SCN concept.

Background

The CF6-50 engine was initially designed to provide both fan nozzle and core nozzle thrust reversing; however, many airline operators subsequently deactivated the core reverser or adopted a fixed nozzle system that had the same aerodynamic flow path, but without the reverser hardware/function. The elimination of the core nozzle thrust reverser thus provided the flexibility for design changes aimed at performance improvements through reduced internal core nozzle pressure losses, reduced core cowl scrubbing drag, and a weight reduction. A reduction in core nozzle length of approximately 2 ft was possible.

Initial scale model isolated nacelle wind-tunnel tests were conducted in 1974/1975 which confirmed the potential for improvement with the SCN. As a result, preliminary design studies were carried out by General Electric and Douglas to get a better understanding of the impact of this design change on the installation and on the aircraft operating characteristics. A schematic illustrating a CF6-50 nacelle installation with both the long core nozzle (LCN) and SCN is shown on Fig. 1. Subsequent work effort included flow visualization evaluation by both airplane model tests and full-scale flight tests. These tests also indicated that there was a potential installed performance improvement for the SCN over the current production LCN. Then in August of 1977, a scale model static performance test was conducted by General Electric to evaluate the performance of the final internal flow path and to define the desired nozzle flow areas for engine thermodynamic cycle matching. In addition, scale model isolated nacelle wind-tunnel tests were carried out by General Electric on the selected configuration. These tests confirmed the results of the initial investigation, which indicated a 0.9% reduction in SFC on an isolated nacelle basis for the DC-10-30 aircraft.

As a result of this work, in late 1977 the SCN performance improvement concept was selected for development and evaluation in ground test facilities by the NASA Lewis Engine Component Improvement Program because of its high fuel saving potential and short payback period for the DC-10-30.

Objectives

The objective of the program was to develop the technology of the SCN system and to verify the predicted fuel savings by full-scale engine ground tests. Mechanical, cycle, performance, acoustic, and installation design studies were conducted in support of the engine tests.

Description of Exhaust System

A schematic illustrating the comparison of the SCN to the LCN is provided on Fig. 2. By elimination of the core nozzle thrust reverser, it was possible to reduce the core nozzle duct length by approximately 2 ft. This reduction in core nozzle length enabled propulsion system performance improvements through reduced pressure drop in the core nozzle and reduced scrubbing of the core cowl. The core cowl scrubbed area was reduced by approximately 30%. In addition to the performance improvement, a weight reduction was also achieved. A weight reduction of 325 lb per engine was realized

---

Presented as Paper 80-1196 at the AIAA/SAE/ASME 16th Joint Propulsion Conference, Hartford, Conn., June 30-July 2, 1980; submitted July 25, 1980; revision received July 6, 1981.

*Manager, Installed Performance Subsection, Aircraft Engine Group. Member AIAA.

†Engine Component Improvement Project Engineer. Member AIAA.

for the SCN relative to the LCN with a core reverser. The 325 lb was made up of 225 lb for elimination of the core reverser and 100 lb for shortening the core nozzle.

An assessment of the SCN performance improvement was obtained from isolated nacelle model tests conducted at FluiDyne Engineering. The model test included evaluation of both the LCN and the SCN to obtain a direct measure of the improvement with the SCN. The gross thrust coefficients for these nozzles are presented in Fig. 3 for the static testing and in Fig. 4 for the external flow wind-tunnel testing. It can be seen from Fig. 3 that the static test demonstrated improvements in gross thrust coefficient with the SCN of 0.0036 at maximum cruise power pressure ratio and 0.0037 at normal cruise power pressure ratio. At lower nozzle pressure ratios, there is more scatter in the test data and the improvement is approximately 0.0035 in gross thrust coefficient. From Fig. 4, it can be seen that the improvement with the SCN is 0.0039 in gross thrust coefficient at Mach 0.82 cruise. This improvement in cruise gross thrust coefficient is equivalent to approximately 1% net thrust (~1% SFC) at 9000 lb of net thrust and 35,000 ft altitude and is exactly the improvement that was obtained in the 1975 model test of an earlier version of the SCN. At lower Mach numbers (Mach 0.6 and 0.25 on Fig. 4), there is more data scatter, but the SCN shows an improvement at all conditions.

Installation of the SCN is readily adaptable to all CF6-50 series engines on the A300B, DC-10-30, and 747 airplanes. In addition to a new core nozzle, other modifications required to implement utilization of the SCN are a new core cowl, a core cowl hinge line modification on the pylon, and modification to the lower pylon fairing (reference Fig. 2).

Engine Performance Test

The test vehicle was the CF6-50 engine. Figure 5 shows the long fixed core nozzle configuration including the pylon. The long fixed core nozzle configuration has the same flow path as the LCN, but does not incorporate a core reverser. Figure 6 shows the SCN configuration with the SCN core cowl doors. The long fixed core nozzle test hardware consisted of

1) fan reverser
2) core cowl doors
3) long fixed core nozzle: outer cowl, centerbody
4) pylon/nozzle fairing (LCN)

Changes made to install the short core nozzle were

1) core cowl doors
2) short core nozzle: outer cowl, centerbody
3) pylon/nozzle fairing (SCN)

At sea-level test cell operating conditions, the performance indicator for the SCN improvement is primarily the difference in overall gross thrust coefficient. The thrust coefficient is defined as follows:

$$C_T = \frac{F_{\rm GM}}{(Fi_{\rm FAN} + Fi_{\rm CORE})}$$

where $F_{\rm GM}$ is the measured gross thrust. $Fi_{\rm CORE}$ is the ideal core nozzle thrust based on measured core stream total pressures and calculated core gas flow. $Fi_{\rm FAN}$ is the ideal fan nozzle thrust based on measured fan stream total pressures, inlet total airflow, and calculated core flow.

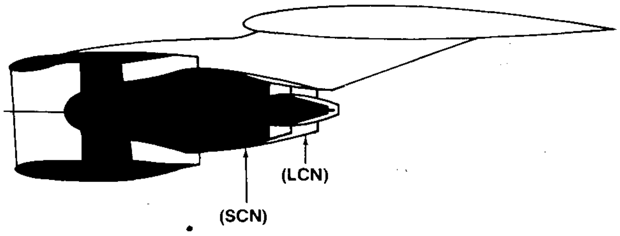

Fig. 1 CF6-50 long core nozzle (LCN) and short core nozzle (SCN) installation.

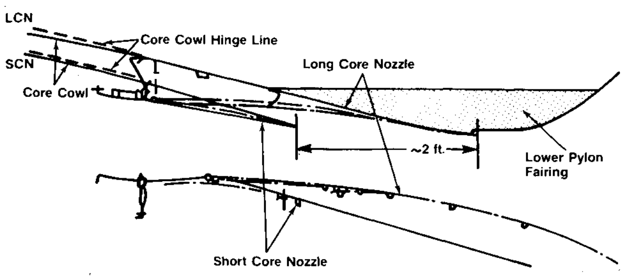

Fig. 2 Comparison of short core nozzle to long core nozzle.

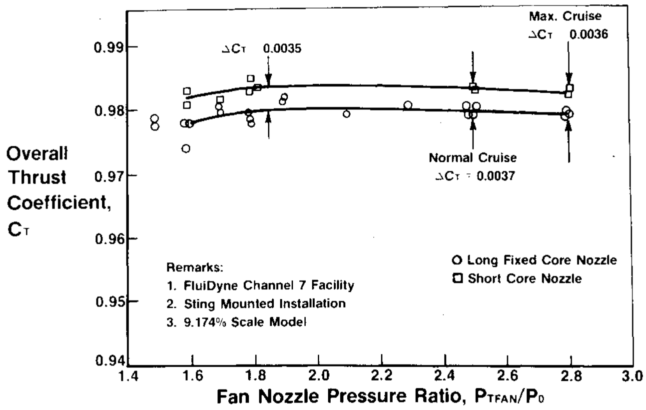

Fig. 3 Scale model isolated nacelle static test data.

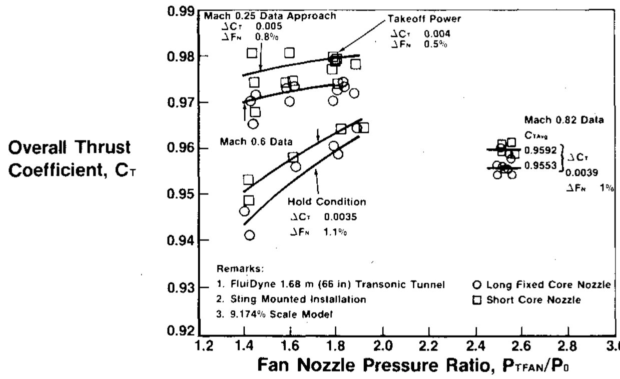

Fig. 4 Scale model isolated nacelle wind-tunnel test data.

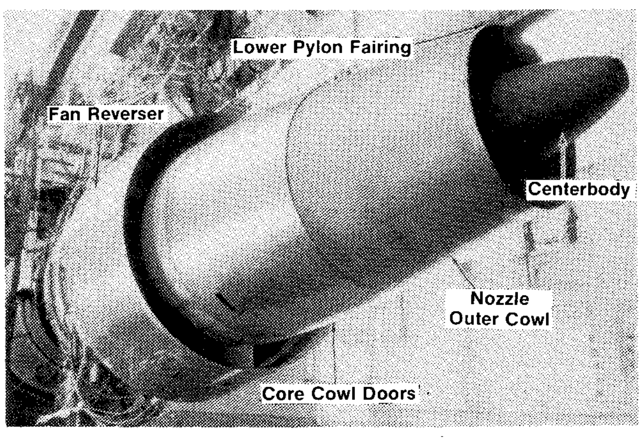

Fig. 5 Long core nozzle.

Two methods were used in calculating the overall gross thrust coefficient difference. The first method utilized nozzle flow coefficients from scale model data to determine core airflow, and the second method utilized the low pressure turbine effective area to determine this quantity. The fan flow was obtained by subtracting the calculated core flow from the total flow determined from the calibrated bellmouth inlet. Both methods indicated overall gross thrust coefficient improvements in the order of 0.003 as shown in Figs. 7 and 8.

A detailed description of the engine test procedure and results is provided in Ref. 2. The following summarizes the results of the performance test:

1) The full-scale engine, back-to-back LCN vs SCN testing indicates an improvement in overall thrust coefficient of approximately 0.3%. The close agreement between full-scale and model test data at sea level verified the 0.35% overall gross thrust improvement with the SCN as determined from scale model tests at sea-level operating conditions.

2) Based on the agreement of full-scale with model test results at sea level, the model test results simulating altitude operation can be used for projecting performance improvements for the SCN at other operating conditions.

3) The SCN does not require a power management change to meet minimum engine thrust at fan speed.

The above performance evaluation summary was made from data obtained through scale model static and isolated nacelle wind-tunnel tests and full-scale engine static tests. The next step is installed "on wing" performance evaluation through scale model airplane wind-tunnel tests and/or aircraft flight tests to determine the effect of the nacelle modification on airplane drag. Some of this work has already been accomplished (e.g., Ref. 3) through independent research and some investigation is being conducted under the ACEE Program on current and advanced airplanes.

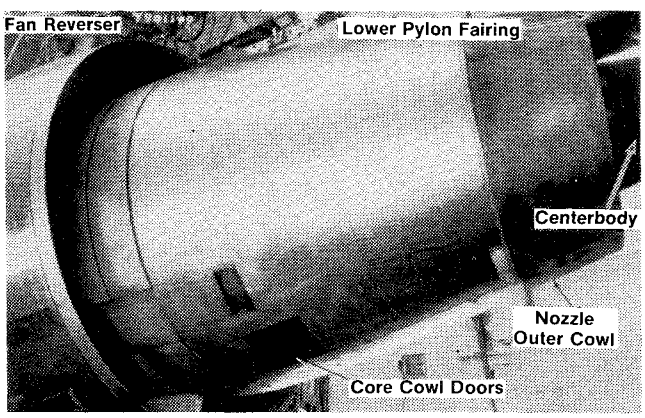

Fig. 6 Short core nozzle.

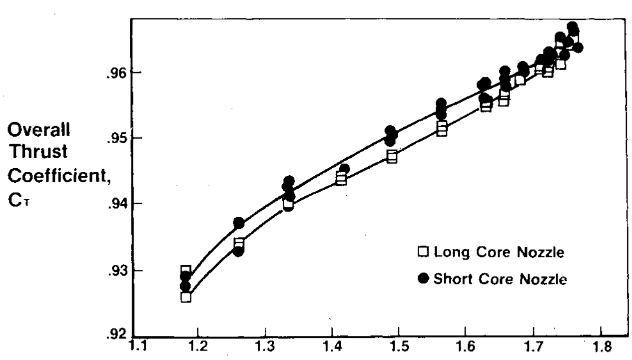

Fig. 7 Test cell data, overall gross thrust coefficient, and core flow obtained using measured full-scale areas; flow coefficients derived from model data.

Acoustic Test

A series of back-to-back acoustics tests were conducted on a CF6-50 engine with the SCN and the LCN in which the following items were evaluated for both exhaust systems; cycle effect on noise, low pressure turbine (LPT) noise, and jet noise. From the results of the data taken, an assessment of the core nozzle modification on community noise level was also made. A sketch of the sound field layout is shown in Fig. 9.

A comparison of the flow lines and the amount of acoustic treatment between the two core nozzle exhaust systems is shown on Fig. 10. Even though the nozzle is much shorter for the SCN, the elimination of the reverser allowed for more acoustic treatment, as shown in Fig. 10.

Prior to testing, it was postulated that changing from the LCN to the SCN could modify the engine noise through the following principle mechanisms: change in the thermodynamic cycle (fan speed/thrust relationship); change in suppression of low pressure turbine noise (effect of treatment for different nozzle shapes); and, change in jet noise (effect of geometry change on turbulence).

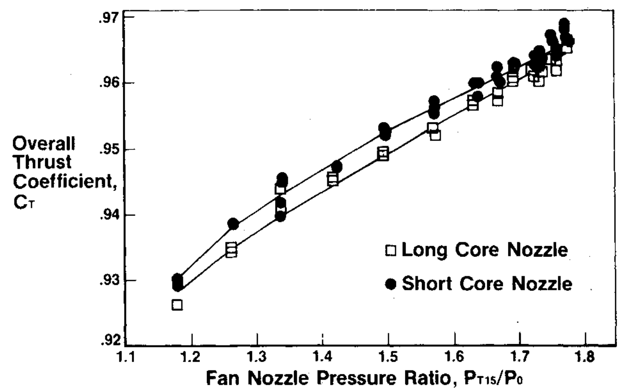

Fig. 8 Test cell data, overall gross thrust coefficient, and core flow obtained from low pressure turbine flow function.

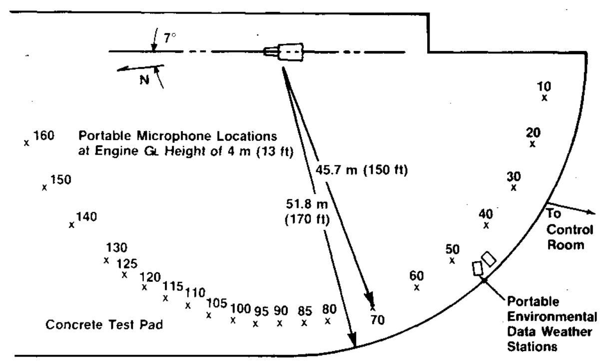

Fig. 9 CF6-50 sound field layout.

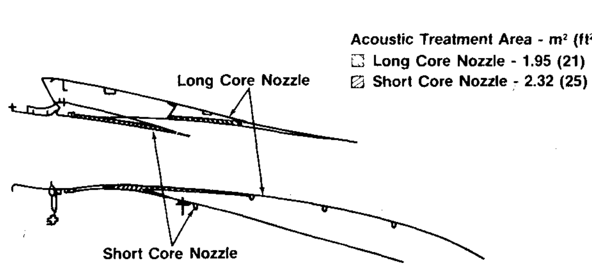

Fig. 10 Comparison of core nozzle acoustic treatment.

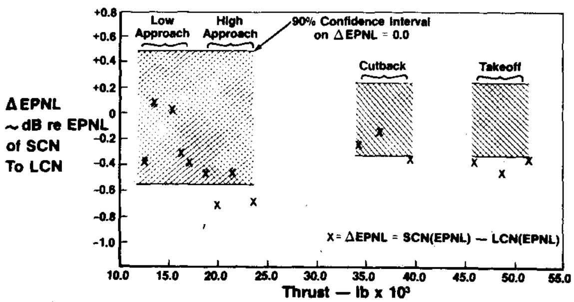

Fig. 11 Change in community noise of short core nozzle vs long core nozzle.

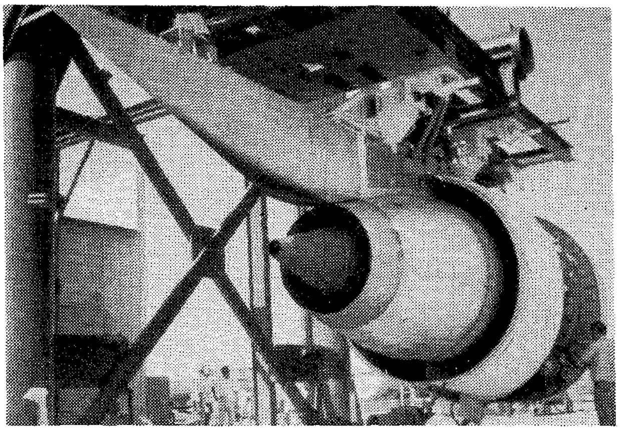

Fig. 12 CF6-50 engine with short core nozzle endurance test setup.

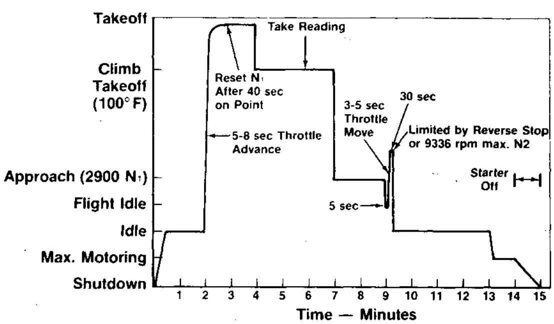

Fig. 13 CF6-50 simulated service *C* cycle.

Based on the results of the back-to-back testing of the SCN and LCN on the CF6-50 engine, it was concluded that the dominant noise components of the CF6-50 engine (fan, LPT, and core jet) were not significantly different for the two core exhaust systems. Figure 11 presents an evaluation of the community noise levels of the two core nozzles on a statistical basis. All of the data for the SCN is within or below the 90% confidence band limits. These results imply the community noise levels for the SCN are equivalent to or less than the LCN. This information is discussed in much more detail in Ref. 2.

Endurance Test

Endurance testing of the SCN was also conducted on the CF6-50 engine. In endurance testing of the engine cowling, it has proven more representative to perform these tests in an outdoor test site rather than an enclosed test cell to avoid pressure/noise perturbations from the cell walls. The exhaust system, with SCN, installed on the engine at the outdoor test site is shown on Fig. 12.

Following the mechanical checkout, break-in run, and short engine performance analysis test, the engine was put through "*C*" cycle endurance testing. A *C* cycle is a 15-min cycle that simulates the transient movements made during a typical airline flight (see Fig. 13). A detailed visual inspection of the SCN upon completion of 1000 endurance cycles of testing indicated that there were no signs of distress. A formal dye-penetrant inspection corroborated these findings. A detailed discussion of the endurance test may be found in Ref. 2.

Conclusions

From the results of the CF6-50 engine tests as described in this paper and Ref. 2, the following conclusions are made:

1) The SCN provides an isolated nacelle cruise SFC reduction of 0.9% relative to the production LCN.

2) There is no significant change in engine noise for the SCN relative to the LCN.

3) The endurance test successfully demonstrated the life capability of the SCN hardware in 1000 simulated flight cycles without any indication of distress.

The short core nozzle concept has been selected for installation on the DC-10-30 and A300B airplanes. Approximately 25 DC-10-30 airplanes are in service with the SCN installation and all new deliveries will have the SCN. Approximately 20 A300B airplanes have been delivered with the SCN. A significant portion of the fleet in the field is scheduled to be refit with the SCN and all new airplanes will have the SCN. The feasibility study[1] indicated a substantial payoff in fuel savings and return on investment for the SCN on the DC-10-30. Subsequent flight tests of the DC-10-30 tended to substantiate this early assessment. Flight test analysis is currently in progress for the A300B. The feasibility study[1] did not show as big a payoff for the 747 because early wind-tunnel tests indicated an airplane drag increase for the SCN installation as reported in Ref. 3. Additional scale model airplane wind-tunnel tests are in progress to investigate pylon modifications aimed at eliminating this adverse effect on airplane drag and thereby realizing the total SCN improvement on the 747 airplane.

References

[1]Fasching, W.A., "CF6 Jet Engine Performance Improvement Program, Task 1—Feasibility Analysis," NASA CR-159450, March 1979.

[2]Fasching, W.A., "CF6 Jet Engine Performance Improvement Program—Short Core Exhaust Nozzle Performance Improvement Concept," NASA CR-159564, Sept. 1979.

[3]McKinnon, M.I. and Mehta, B.K., "Factors Influencing Nacelle Design on 747," AIAA Paper 79-1236, June 1979.