NASA Technical Memorandum 81577

IMPROVED COMPONENTS FOR ENGINE FUEL SAVINGS

Robert J. Antl and John E. McAulay
Lewis Research Center
Cleveland, Ohio

Prepared for the
Aerospace Congress
sponsored by the American Society of Automotive Engineers
Los Angeles, California, October 13-16, 1980

NASA

IMPROVED COMPONENTS FOR ENGINE FUEL SAVINGS

by

Robert J. Antl and John E. McAulay

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

SUMMARY

NASA is currently involved in the Aircraft Energy Efficiency Program (ACEE) which is directed toward developing technology for more fuel efficient aircraft. As part of this overall program, the Engine Component Improvement (ECI) Project was formulated to address near-term improvements for current engines. One part of this effort is Engine Diagnostics which is directed at investigating the causes for in-service performance deterioration of the CF6 and JT9D high bypass ratio turbofan engines. The other part is Performance Improvement, which is directed at development of component technologies to reduce the fuel consumption of CF6, JT9D and JT8D engines. This paper discusses the Performance Improvement part. Nine of sixteen concepts being developed under the ECI project are now complete and four are in service. The remaining five are being offered to the airlines. Earlier feasibility studies have established their technical and economical acceptability and tests have demonstrated their fuel saving potential. Descriptions of these concepts, results of testing, and the status as to entering airline service are presented. Also presented is the status of the remaining concepts still under development.

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION has initiated several programs directed at developing technology for more fuel efficient aircraft as part of the Aircraft Energy Efficient Program (ACEE). These programs deal with the world-wide energy crisis as it affects the aviation industry. One such effort is the Engine Component Improvement Project (ECI) managed by the Lewis Research Center. This effort has been divided into two parts: Engine Diagnostics and Performance Improvement. The Engine Diagnostics part of the program consists of analysis and test of the CF6 and JT9D high bypass ratio turbofan engines to isolate and quantify the causes of performance deterioration with time. The data is expected to be used to reduce the fuel consumption of current engines about 1 percent and will also aid in future engine design. The Performance Improvement (PI) part (1)*, which is the subject of this paper, has an objective to provide for technological advances specifically aimed at improving the fuel efficiency for new production and retrofit of CF6, JT9D, and JT8D turbofan engines, shown in Figure 1.

The Performance Improvement effort started with a Feasibility Study, conducted by General Electric and Pratt & Whitney, which evaluated promising performance improvement concepts using a cost/benefit methodology (2,3). This was done to insure that the concepts would be technically sound and economically acceptable to the airlines. Results of the Feasibility Study were used by NASA to determine those concepts which were to be funded for development. A total of sixteen concepts were selected and included seven for the CF6, four for the JT9D, three for the JT8D, and two aircraft related concepts. To date, nine of these have been developed and tested. And, these concepts, or the technology derived, have been offered to the airlines in new models or retrofit. These are:

CF6 Fan
CF6 Front Mount
CF6 High Pressure Turbine Aerodynamics
CF6 Short Core Exhaust Nozzle
Compressor Bleed Reduction for DC-10
JT9D High Pressure Turbine Active Clearance Control
JT9D Fan Technology
JT8D High Pressure Turbine Outer Air Seal Technology
JT8D High Pressure Turbine Blade

*Numbers in parentheses designate References at end of paper.

It should be noted that at the time the study was conducted, fuel prices of 11 cents per liter were typical. However, as shown in Figure 2, the average price is currently up to about 21 cents per liter. An important factor for airline acceptability is the payback period projected for each concept. The payback period is defined as the actual cash outlay divided by the annual cash savings. With fuel prices escalating substantially more than the consumer price index, the payback period will most probably be reduced thus enhancing the airline acceptance of the performance improvement concepts.

Of the concepts offered, four have already been accepted by the airlines and are in service. These are the new fan, front mount, and short core exhaust nozzle for the CF6, and an active clearance control for the JT9D high pressure turbine.

Concepts for which development has been completed will be described, and, technical and economical results will be shown along with the in-service status. Also, a description of concepts still under development will be presented and include:

CF6 High Pressure Turbine Roundness Control
CF6 High Pressure Turbine Active Clearance Control
CF6 Low Pressure Turbine Active Clearance Control
JT9D High Pressure Turbine Vane Thermal Barrier Coating
JT9D High Pressure Turbine Ceramic Outer Air Seal
JT8D High Pressure Compressor Trenched Blade Tip
JT8D Nacelle Drag Reduction for DC-9

The status of the development of these concepts will be presented along with the predicted technical and economic results.

CONCEPTS COMPLETED

DEVELOPMENT RESULTS - The concept development efforts included design, analysis, fabrication, and testing activities. Actual improvement potential for each concept was demonstrated by engine performance tests and/or flight testing. Also, where applicable, mechanical integrity was demonstrated with various component tests and engine endurance testing. Results of the various tests provided the manufacturers, NASA, and the airlines with performance data for each concept. A description and representative performance data for the concepts completed for the CF6, JT9D, and JT8D engine follows.

General Electric CF6 Engines - Concepts for which development has been completed for the General Electric CF6 engine include an improved fan, a new front mount, an improved high pressure turbine and a short core exhaust nozzle. Also, a cabin air recirculation scheme to reduce compressor bleed was developed for the DC-10 aircraft. The CF6 engine was used for the development; however, the technology is applicable to DC-10 aircraft with Pratt & Whitney JT9D engines.

An improved fan package for the CF6 engine, shown in Figure 3, features improved blade aerodynamic design and a fan case stiffener. The improved fan design has a single part span shroud further rearward on the blade and the blade camber has been modified. The original and improved fan blades have identical dovetails and are completely interchangeable in the same fan disk in sets. Both fan blades are common to both CF6-6 and CF6-50 engine models. The fan case stiffener (Figure 3) raises the critical interaction frequencies of the fan and fan case above the maximum operating fan speed. This permits a fan blade tip clearance reduction which leads to increased fan efficiency.

The results of the fan package development (4) indicate a significant performance improvement. This is shown in the comparison of the original and improved fan effects on thrust in Figure 4. With the improved fan, the fan airflow increased for a given speed resulting in more thrust. Or, for a given thrust level, the fan speed could be reduced thereby reducing the amount of fuel burned. These results translated into a cruise specific fuel consumption (SFC) reduction of 1.8% for the improved fan for both the CF6-6 and CF6-50 engines. Results of noise testing indicated no increase in effective perceived noise level. This is illustrated in the comparison of takeoff noise levels for the original and improved fans in Figure 5.

A redesigned front mount, shown in Figure 6, effectively reduced the point loading in the compressor casing by applying load reactions at two points 30 degrees from the top vertical centerline (0° position). Engine thrust, and vertical and side forces are transmitted through a series of links connected tangentially to the compressor casing forward flange. Case distortion is reduced allowing the compressor blade tip clearances to be decreased.

Results of the development of the new front mount demonstrated that the mechanical aspects are satisfactory (5). This is illustrated by the typical exaggerated cardiod deflection curves for one stage in Figure 7. When subjected to loads (takeoff rotation shown), the original mount resulted in a single point compressor case deflection. The basically two point reaction of the new mount results in a reduced clearance loss at the 0° position. The effect of the mounts are further illustrated in Figure 8 which compares 0° position radial deflection for each compressor stage. Test results have indicated that the maximum radial deflection obtained with the new mount is reduced 29% for takeoff rotation and 42% for maximum static thrust. The decreased clearances in the compressor should produce a 0.1 percent cruise SFC reduction and a substantial increase in compressor stall margin.

A drawing depicting the main features of the improved CF6-6 high pressure turbine is presented in Figure 9. Included are: single shank turbine blades, reduced turbine exit swirl which lowers the turbine mid frame pressure losses, improved cooling techniques reducing the cooling flow requirements, aerodynamic refinements such as increased solidity and smoother blade surface finish, and shroud mechanical and cooling improvements allowing for reduced tip clearances.

The development program (6) engine testing results demonstrated the thermal effectiveness and mechanical integrity of the improved turbine. Improved blade leading and trailing edge temperatures compared to current blades are shown in Figure 10. As indicated, the stage 1 average temperature decreased significantly with a 6% reduction in cooling flow, while the stage 2 average temperature stayed about the same with a 50% reduction in cooling flow. Endurance testing simulating 2500-3500 hours of airline service established the basic integrity of the improved turbine design. An example of the condition of the stage 1 and 2 blades is shown in Figure 11.

Back-to-back engine tests indicated a 1.3% cruise SFC reduction and a 10°C reduction in exhaust gas temperature (EGT). Because of the improved performance retention characteristics, an additional reduction of 0.3% cruise SFC and 6°C in EGT is projected for long service engines.

A short core exhaust nozzle system, shown schematically in Figure 12, was developed for the CF6-50 engine. This concept involves replacing the current core engine reverser/exhaust nozzle system with a reduced length, fixed nozzle. Elimination of the core exhaust reverser allows for reduced diameter fan flow lines aft of the fan reverser, thereby reducing weight, pressure loss, and scrubbing drag. However, this necessitates recontouring of the engine core cowl as well as the core nozzle.

Sea level back-to-back engine performance and acoustic tests were conducted for direct comparison of the long and short-core nozzles (7). Figure 13 presents the overall gross thrust coefficient as a function of nozzle pressure ratio. These data indicate an uninstalled performance improvement of about 0.3% in thrust coefficient which translates to a cruise SFC reduction of about 0.9%. Flight tests validated these results. Acoustic tests demonstrated that the short core nozzle community noise levels are similar (within the data scatter) to those of the long core nozzle with reverser. Endurance testing, consisting of 1000 simulated flight cycles, were completed without any indication of distress.

A cabin air recirculation system developed for the DC-10 aircraft (8) will reduce the compressor bleed air usage when added to the existing air conditioning system. A schematic is shown in Figure 14. The primary components of the recirculation system are a fan, filter, and appropriate ducting and controls.

A recirculation system designed specifically to provide a wide range of fresh and recirculated air flows was installed on a DC-10 aircraft for flight testing. Fuel flow measurements obtained with normal and reduced bleed are shown in Figure 15. The data indicates the improvement potential with recirculation system operating. Analytical predictions show an SFC reduction of 0.8% for a 50% reduction in compressor bleed airflow. Correction and extrapolation of the flight test results compare favorably with the analytical results.

<u>Pratt & Whitney JT9D Engines</u> - Development of two concepts has been completed for the Pratt & Whitney JT9D engine. Included are improved fan technology and an improved active clearance control scheme for the high pressure turbine.

A comparison of the current and improved JT9D-7 fan blade is shown in Figure 16. Performance was improved by elimination of one of the part span shrouds, incorporation of improved blade aerodynamics (i.e., multiple circular arc airfoils), and increasing the blade chord which reduces the aspect ratio and the number of blades. The lower aspect ratio blade has better flutter and foreign object damage characteristics. Also, because of acoustic considerations, the reduced number of blades allows for a reduced number of fan exit guide vanes which improves overall performance.

Initial ground and flight testing verified the performance and stability expectations (9). Results of back-to-back engine testing indicated a fan efficiency increase of about 2.6 percentage points. This translates to an SFC improvement of 1.3 percent at the 90 percent of cruise thrust point, as shown in Figure 17. Ground and flight testing of the improved fan demonstrated distortion tolerances, stress levels, and noise levels equal to or improved over those for the current fan.

However, the requirement for a somewhat different fan for the JT9D engine model for the Boeing 767 airplane led to halting further development of this fan. Nevertheless, the increase in the data base from testing is directly applicable and is being used in fan development programs for the JT9D-7R4 fan (for the B-767).

Figure 18 shows the current and improved JT9D-70/59 high pressure turbine active clearance control systems. The high pressure turbine is encircled by perforated pipes which spray fan air on the turbine case during cruise shrinking the case and seals. This shrinkage tightens the tip clearances and improves the turbine efficiency. The air supply is off during takeoff, climb, and landing when the engine is subjected to the most severe thermal and structural loads. Since the case is hotter (without cooling air), thermal expansion of the case and seal supports provides larger clearances between the blade tips and the seals. The improved system incorporates an increased coolant air supply and an improved distribution system which results in a greater reduction in outer air seal diameter at cruise.

Simulated altitude engine testing of the improved active clearance control system demonstrated an average cruise SFC improvement of 0.65 percent over the current system (10). This improvement was constant over the entire cruise thrust range as shown in Figure 19. Also, the improved system showed no unusual deterioration effects after a 1000 cycle endurance test.

Pratt & Whitney JT8D Engines - Development for two related concepts improving the JT8D high pressure turbine has been completed. One provided improved outer air seal technology, and the other was a new turbine blade featuring root discharge of the blade cooling air.

In an effort to reduce the air seal leakage past the tip shrouds of the high pressure turbine, the first stage outer air seal and blade cooling scheme were redesigned. A schematic of the current and improved outer air seal is shown in Figure 20. The current blade discharges all the cooling air at the tip and, because of this and other considerations, has a large blade tip clearance with attendant high leakage. In the improved scheme, most of the cooling air discharge is relocated to the suction side of the blade by plugging and drilling the current blade. This allows for the addition of another knife edge seal at the blade tip and the extension of the honeycomb seal material to the trailing edge of the existing spoiler, thus reducing the seal leakage.

Sea level and simulated altitude back-to-back testing of the current and improved outer air seals established the turbine performance characteristics (11). At both sea level and altitude conditions, the improved turbine exhibited an improvement as can be seen in the HPT efficiency comparison in Figure 21. This improvement translates to an average cruise SFC reduction of 0.6 percent and a takeoff exhaust gas temperature reduction of 6°C.

A comparison of JT8D high pressure turbine blade cooling schemes is shown in Figure 22. The current blade uses a single pass, tip discharge cooling scheme while the improved blade uses a two pass, root discharge cooling scheme. Since this design required a new casting, updated materials, improved airfoil shape, and reduced trailing edge thickness were incorporated. When compared to the current blade, the improved blade has reduced contour losses, and has better cooling effectiveness thereby requiring about 0.6% less cooling air. The new blade also incorporates an extended honeycomb outer air seal similar to that previously developed for the improved outer air seal shown in Figure 20.

Sea level and simulated altitude engine testing was used to verify the design concept. Preliminary results indicate that the improved blade will provide about a 1.8 percent cruise SFC reduction and an 18°C reduction in takeoff exhaust gas temperature when compared to the current design.

FUEL SAVINGS - Based on the technical results of the development programs, economic results were determined in terms of fuel savings and payback period. Fuel savings estimates through the year 2005 considered the introduction date, fuel burned projections based on various engine/aircraft/mission combinations, the number of engines reflecting actual and projected sales, and an average engine life of 15 years for engines produced through 1990. The payback period determination also considered the cost of incorporating the concept into new and existing engines and the effect the concept had on maintenance and labor costs.

General Electric Engines - Figure 23 shows the projected fuel savings and status of the concepts completed for the CF6 engines. The projected fuel savings are a function of not only SFC reduction but the number of engines affected. This can be seen by comparing the SFC reduction and fuel savings for the fan and compressor bleed reduction concepts. All the concepts exhibit significant fuel savings potential with exception of the new front mount. However, this concept has significant performance retention potential. The fan, new front mount, and the short core exhaust nozzle are in airline service while the HPT aerondynamic improvements and the compressor bleed reduction concepts are going through an in-service evaluation.

Pratt & Whitney Engines - Projected fuel savings and status of concepts completed for the JT9D and JT8D engines are shown in Figure 24. The technology derived from the JT9D-7 new fan development will be applied to the development of a fan for the JT9D-7R4 engine. To date, the only JT9D performance improvement concept in service is the high pressure turbine active clearance control. The JT8D outer air seal has been offered to the airlines, and significant technology derived has been incorporated in the HPT root discharge blade concept. This concept has recently completed development. As can be seen, all the concepts offer significant fuel savings potential.

CONCEPTS IN DEVELOPMENT

CONCEPT DESCRIPTION AND STATUS - Development of several concepts is at various stages of design analysis, fabrication, and testing. A description, status, and the predicted fuel savings for concepts under development for the CF6, JT9D, and JT8D engine follows.

General Electric Engines - Three interrelated performance improvement concepts which involve improved control of the CF6 turbine clearances are under development. Included are a passive roundness control and an active clearance control for the high pressure turbine (HPT) and an active clearance control for the low pressure turbine (LPT).

Figure 25 shows the main features of the high pressure turbine roundness control (i.e., passive clearance control) for the CF6-50. The primary feature is an improved mechanical design including such considerations as added mass and mass distribution of the supporting structure, shielding the supporting structure from cavity air recirculation, solid shrouds, and modifications to the turbine midframe and struts. These provide for better rotor/stator thermal matching and a "round" turbine. The anticipated reduction in cruise SFC for this concept is 0.4 percent for new engines and 0.8 percent at 3000 hours.

The high pressure turbine (HPT) active clearance control concept for the CF6-6 engine is shown in Figure 26. Application of this system to the CF6-6 is feasible because of the roundness features developed in the HPT aerodynamic improvement concept. Cooling air from the aft fan duct is piped to manifolds circling the HPT and is directed to impinge at appropriate shroud support flanges. The air flow is controlled to provide maximum tip clearances at takeoff (minimum air flow) and minimum tip clearances at cruise (maximum air flow). The expected cruise SFC reduction for this concept is 0.3 percent for new engines and 0.6 percent at 3000 hours.

Antl
McAulay

10

The low pressure turbine (LPT) active clearance control system is schematically shown in Figure 27. Fan air that is continuously used to cool the LPT shroud supports is augmented with additional fan air at cruise to provide a reduction in blade tip clearance. The supplementary air flow is controlled by an on/off valve which is actuated by barometric pressure. An override actuated by the engine power level is provided to allow for increased clearances (less air flow) at flight idle in preparation for landing and reverse thrust operation. The predicted cruise SFC reduction using this system is about 0.3 percent.

All of the three turbine concepts are currently in the component and engine testing stages. Development of the HPT roundness control and the LPT active clearance control is scheduled for completion in early 1981, while the HPT active clearance control concept development is scheduled through 1981.

Pratt & Whitney Engines - There are four performance improvement concepts still under development for the P&W JT9D and JT8D engines. Two are for the JT9D engine and are directed at improving the high pressure turbine (HPT). Included are a vane thermal barrier coating and a ceramic outer air seal. Concepts concerned with the JT8D engine include a trenched tip high pressure compressor, and a DC-9 aircraft reverser stang fairing modification to provide a drag reduction.

A comparison of the current and thermal barrier coated JT9D HPT first stage vane end walls is shown in Figure 28. The zirconia ceramic coating provides a thermal barrier or insulating effect which allows for a reduction in cooling air. This results in a predicted cruise SFC reduction of 0.2 percent. There has been a considerable effort expended on investigating various coating chemistries and the devleopment of coating application techniques. Further development may allow thermal barrier application to vanes and blades in the future with potential additional reductions in fuel consumption.

The initial exposure of several thermal barrier coatings to an engine environment has been successfully concluded. Further development of the coatings based on this experience is underway.

Antl
McAulay

The JT9D HPT ceramic outer air seal concept under development is shown in Figure 29. The combination of a ceramic outer air seal and an abrasive blade tip provides a considerable improvement in abradability relative to current shroud/blade material combinations. This permits use of tighter tip clearances. Also, the ceramic shroud material acts as an insulator and reduces cooling air requirements. A potential cruise SFC improvement of 0.4 percent is estimated for this concept. Currently, results of material property and spray parameter tests are being evaluated to establish a seal composition suited for engine applications.

The JT8D trenched-tip high pressure compressor (HPC) configuration is shown in Figure 30. The use of abradable rub strips through the HPC permits running with tighter tip clearances. A sprayed Nichrome-polyester abradable rub strip appears most promising based on cost, erosion, and abradability considerations. The compressor outer case is also trenched so that the blade tip can run line-on-line with the outer flow path at cruise conditions. Also, rim seals have been added along the inner flow path to reduce inter-stage cavity recirculation, thereby improving stall margin. It is estimated that this blade-case configuration will provide a 2 percent improvement in compressor efficiency which corresponds to a 0.9 percent reduction in cruise SFC. Currently, trenched-tip compressor rig tests have been completed and will be followed by an engine demonstration.

The current and modified DC-9 thrust reverser stang is shown in Figure 31. As can be seen, the thrust reverser hinge assembly in the current configuration is only partially faired, leaving a significant base area. The modified configuration reduces the base area with a more complete fairing. The new fairing is made of Kevlar/PMR-15, an advanced composite material which will tolerate the 260°C environment created by the engine exhaust gas while providing improved fatigue strength over the current aluminum fairing. The development effort to date included several flight tests to determine the drag reduction. Initial tests incorporated static pressure measurements on the fairing as well as a tuft survey. The test results were used to develop the fairing contour. Later flight tests relied on an extensive tuft survey to detect the local flow conditions. From these results, a cruise drag (or SFC) reduction was calculated to be 1.2 percent. A one year in-service evaluation of the modified reverser stang fairing has just been initiated.

PREDICTED RESULTS - Using estimated SFC reductions, projected fuel savings and payback periods for the concepts still under development were determined. These results are summarized in Figure 32. Again, the effect of the number of engines affected can be seen by inspection of the SFC reductions and the attendant fuel savings. It should also be pointed out that even though the concepts concerned with the high pressure turbine indicate modest initial SFC reductions, they have significant performance retention potential. This is indicated by the 3000 hour SFC reduction shown for the CF6 high pressure turbine roundness control and active clearance control concepts.

CONCLUDING REMARKS

The development of fuel saving technology by NASA through the Engine Component Improvement (ECI) Project included technology aimed at near term propulsion improvements. Application of this technology to the CF6, JT9D, and JT8D turbofan engines aids in attaining several desirable goals. Besides saving energy, it maintains United States excellence in commercial aircraft and thus provides an impetus towards a favorable balance of payments. In addition, the airlines benefit in terms of reduced fuel costs which are a significant part of their operating costs.

Of the sixteen performance improvement concepts selected for development under NASA sponsorship, development of nine has been completed and four are in airline service saving fuel. If all sixteen concepts (or the technology derived) are successfully introduced into service, market projections indicate that over 24 billion liters (6 billion gallons) of fuel may be saved through the expected life of the engines affected. These performance improvement concepts have already started to provide, and will continue to provide, significant savings in operating costs for the commercial air transport fleet.

REFERENCES

1. John E. McAulay, "Engine Component Improvement Program - Performance Improvement". American Institute of Aeronautics and Astronautics 18th Aerospace Sciences Meeting, January 14-16, 1980. Also NASA TM 79304.
2. W. A. Fasching, "CF6 Jet Engine Performance Improvement Program - Task 1, Feasibility Analysis", General Electric Co., Cincinnati, Ohio, R79AEG295, March 1979. (NASA CR-159450).
3. W. O. Gaffin, and Webb, D. E., "JT8D and JT9D Jet Engine Performance Improvement Program - Task 1, Feasibility Analysis," Pratt & Whitney Aircraft Group, East Hartford, Conn., PWA-5518-38, April 1979. (NASA CR-159449).
4. W. A. Fasching, "CF6 Jet Engine Performance Improvement - New Fan," General Electric Co., Cincinnati, Ohio, R79AEG413, May 1980. (NASA CR-159699).
5. W. A. Fasching, "CF6 Jet Engine Performance Improvement - New Front Mount," General Electric Co., Cincinnati, Ohio, R79AEG366, December 1979. (NASA CR-159639).
6. W. A. Fasching, "CF6 Jet Engine Performance Improvement - High Pressure Turbine Aerodynamic Performance Improvement," General Electric Co., Cincinnati, Ohio, June 1980. (NASA CR-159832).
7. W. A. Fasching, "CF6 Jet Engine Performance Improvement - Short Core Exhaust Nozzle," General Electric Co., Cincinnati, Ohio, September 1979. (NASA CR-159564).
8. W. H. Newman and M. R. Viele, "Jet Engine Performance Improvement Program - Engine Bleed Air Usage Reduction In DC-10 Aircraft," Douglas Aircraft Company, Long Beach, California, ACEE-18-FR-0081, June 1980. (NASA CR-159846).
9. W. O. Gaffin, "Engine Component Improvement - Performance Improvement Program - JT9D-7 3.8 Aspect Ratio Fan," Pratt & Whitney Aircraft Group, East Hartford, Conn., PWA-5515-114, June 1980. (NASA CR-159806).
10. W. O. Gaffin, "JT9D-70/59 Improved High Pressure Turbine Active Clearance Control System," Pratt & Whitney Aircraft Group, East Hartford, Conn., PWA-5515-87C, September 1979. (NASA CR-159661).
11. W. O. Gaffin, "JT8D Revised High Pressure Turbine Cooling and Outer Air Seal Program, Pratt & Whitney Aircraft Group, East Hartford, Conn., PWA-5515-77, March 1979. (NASA CR-159551).

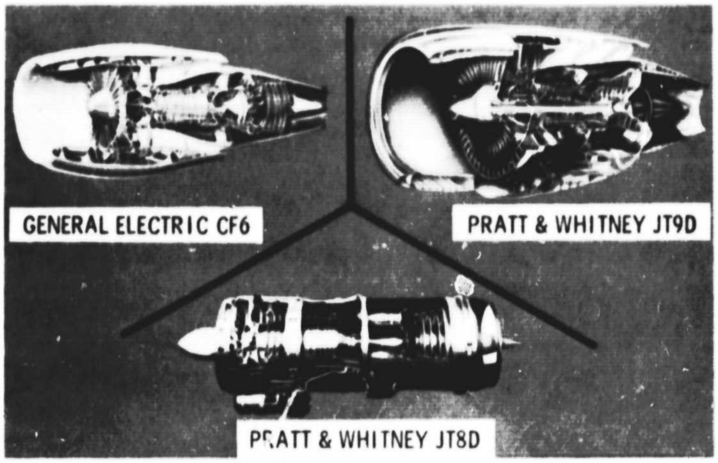


Figure 1. - Engines for which performance improvement concepts are being developed.

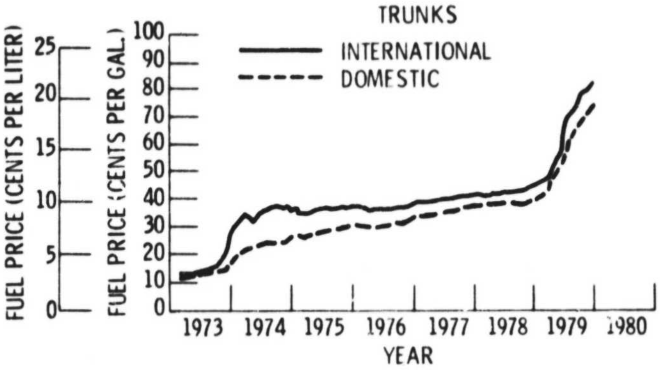


Figure 2. - U.S. Airline jet fuel price history. (Based on CAB monthly averages.)

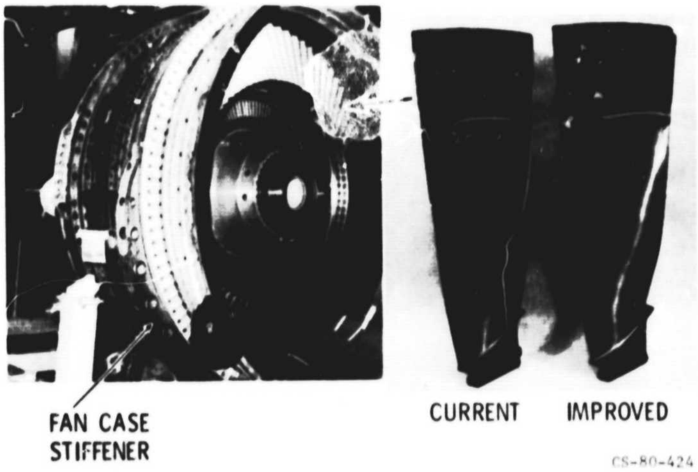


Figure 3. - CF6 fan.

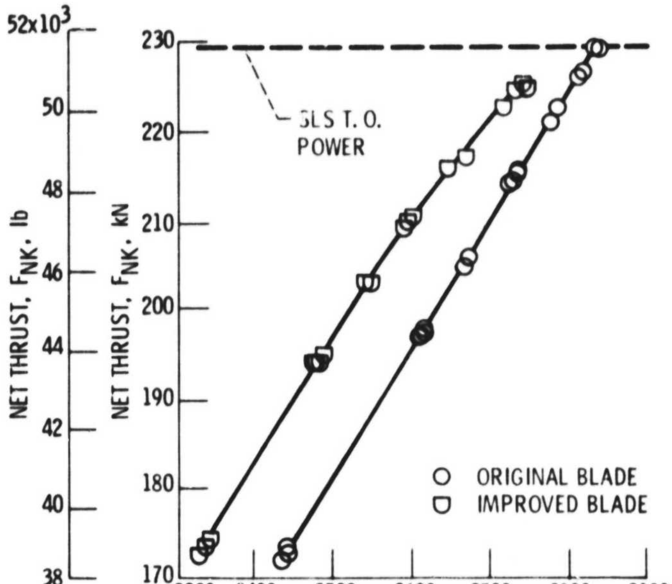


Figure 4. - Effects of fan configuration on thrust characteristics of CF6-50 engine. (Sea Level Static)

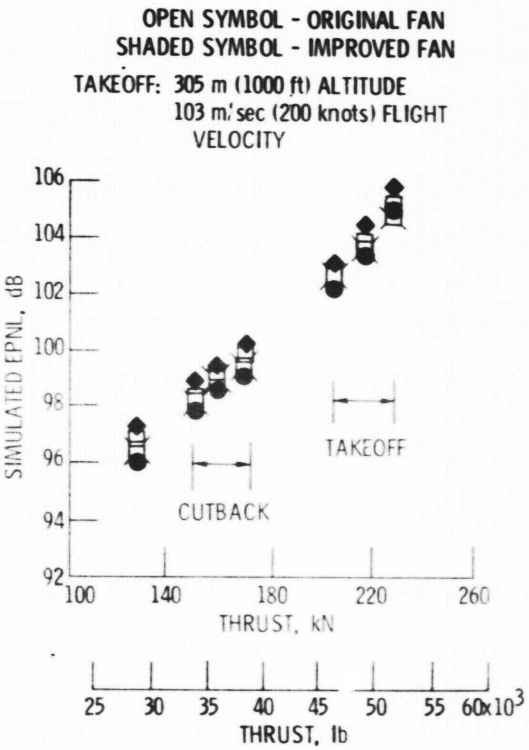


Figure 5. - CF6-50 engine noise comparison of original and improved fan configurations at takeoff flight conditions.

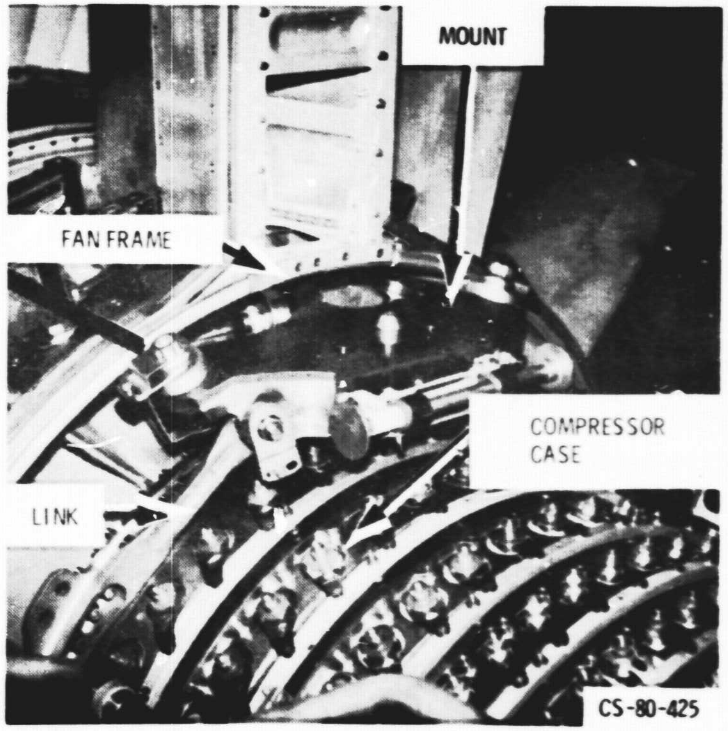


Figure 6. - New CF6 front mount.

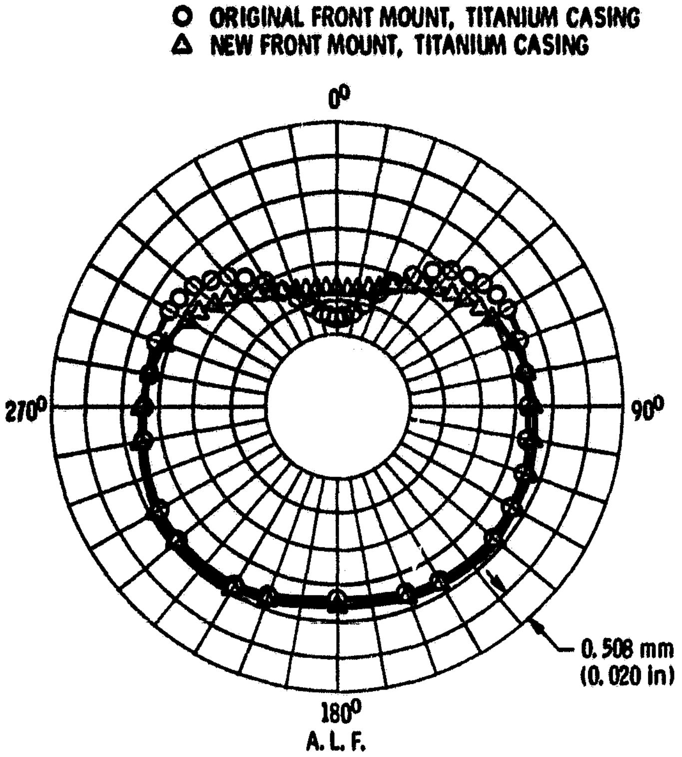


Figure 7. - CF6-50 original and new front mount - HPC casing radial deflection at stage 3, takeoff at rotation condition (including 1 G down).

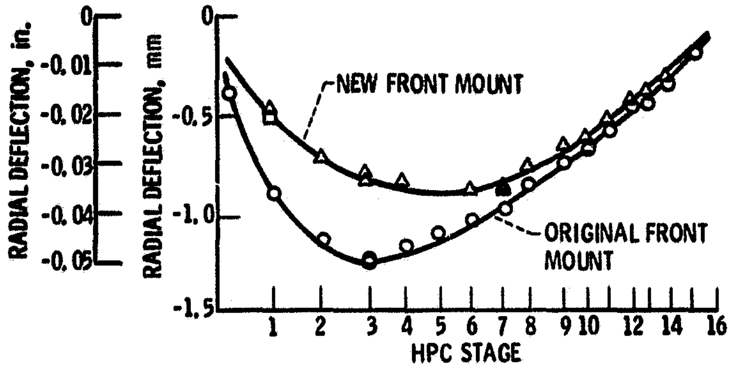


Figure 8. - Original and new front mount - HPC casing backbone radial deflection, takeoff at rotation condition (including 1 G down).

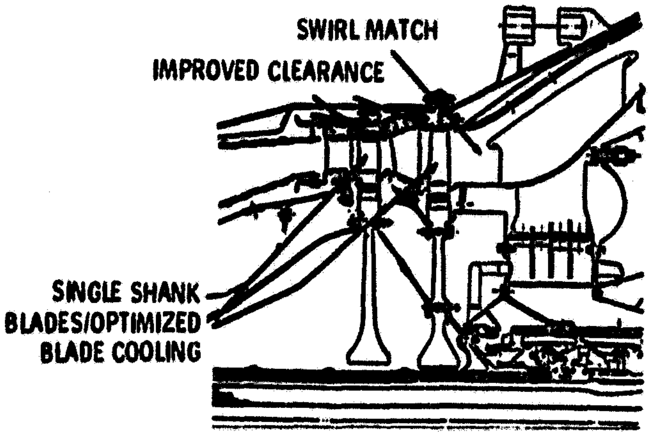


Figure 9. - Improved CF6-6 high pressure turbine.

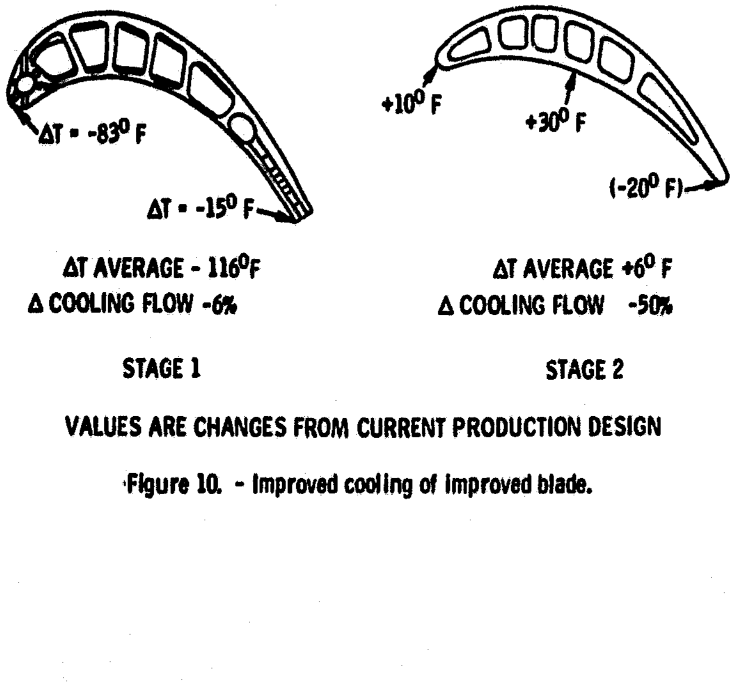


Figure 10. - Improved cooling of improved blade.

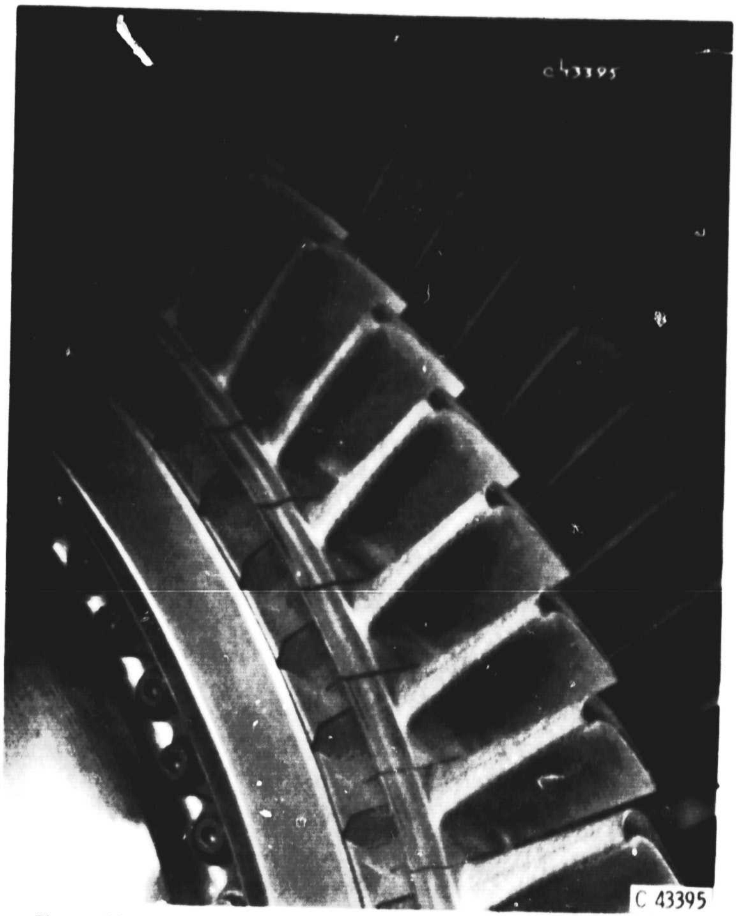


Figure 11. - Stage 1 and 2 blades in rotor assembly after 1000 cycles.

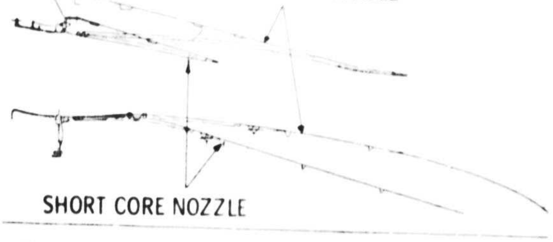


Figure 12. - CF6 core exhaust nozzle configurations.

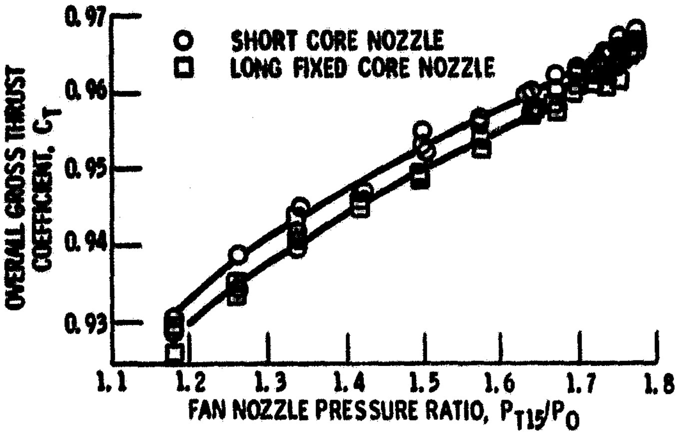


Figure 13. - Overall gross thurst coefficient data.

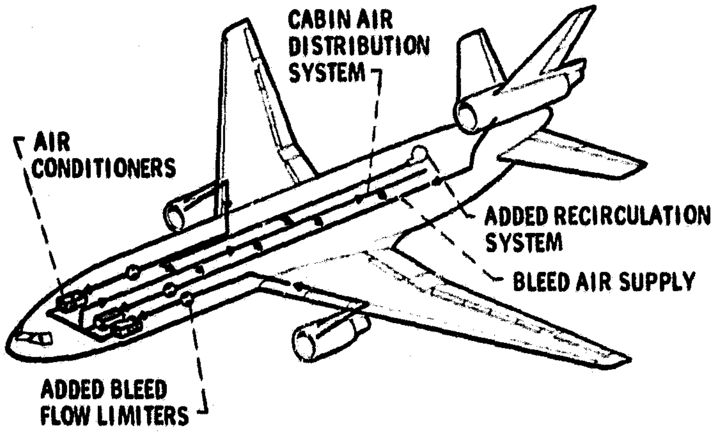


Figure 14. - DC-10 improved cabin air circulation system.

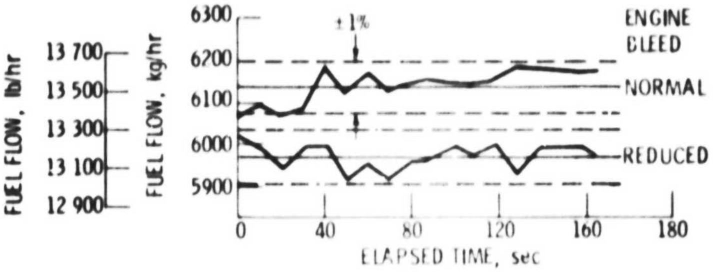


Figure 15. - Measured fuel flows with normal and reduced bleed.

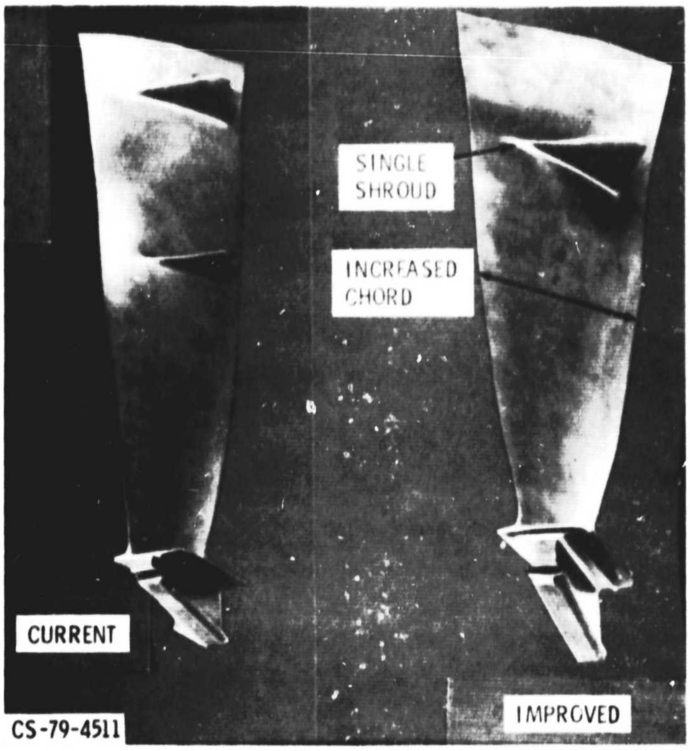


Figure 16. - JT9D-7 fan blade.

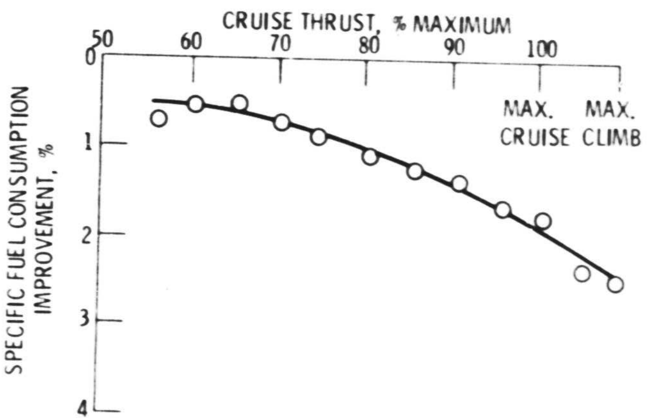


Figure 17. - Specific fuel consumption improvement of the improved fan relative to the current JT9D-7 fan. (Simulated altitude, 9 906 m (32 500 ft); Mach number, 0.84.)

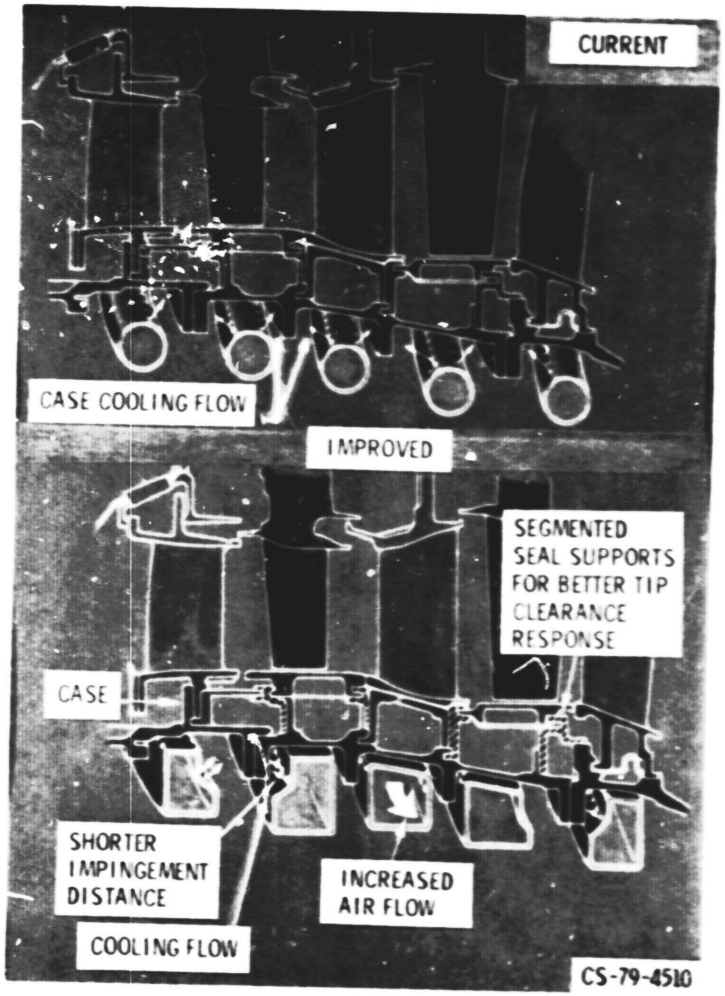


Figure 18. - JT9D-59/70 high pressure turbine active clearance control system.

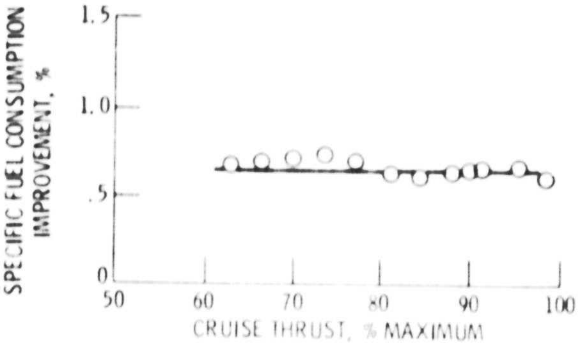


Figure 19. - Improvement in cruise SFC for the improved HPT active clearance control system relative to the current system. (JT9D-70/59.)

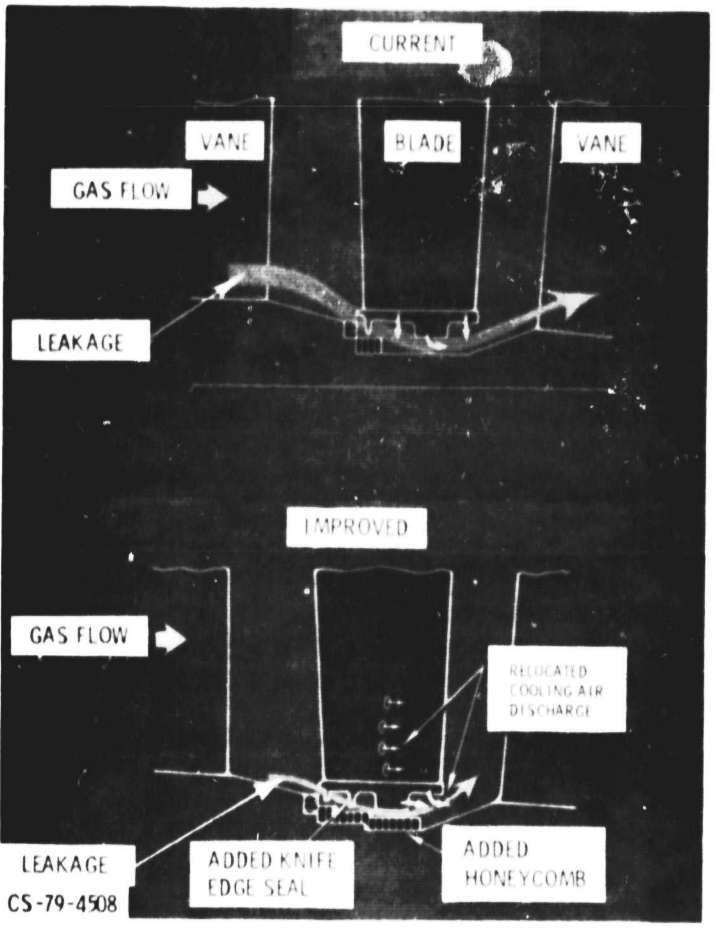


Figure 20. - JT8D high pressure turbine outer air seal.

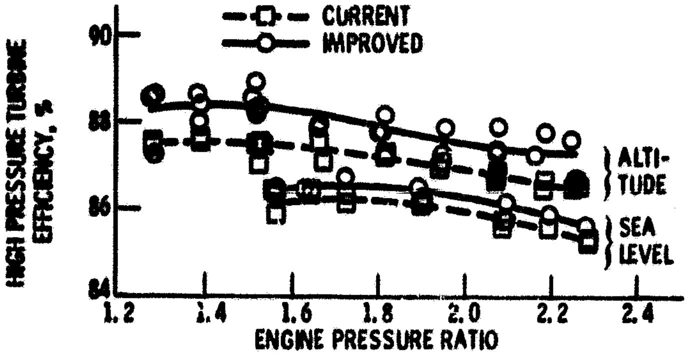


Figure 21. - JT8D high pressure turbine efficiency vs. engine pressure ratio for the current and improved HPT outer air seal. (Sea level and simulated altitude.)

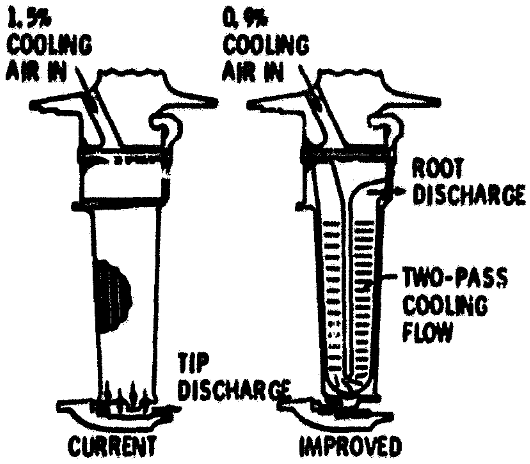


Figure 22. - JT8D high pressure turbine blade cooling.

CONCEPT	CRUISE SFC REDUCTION, %	CUMULATIVE FUEL SAVINGS THROUGH 2005		PAY BACK PERIOD NEW BUY YR[a]	STATUS
		10^6 LITERS	10^6 GAL.		
IMPROVED FAN	1.8	3997	1056	[b]0.8 - 1.4	IN SERVICE
NEW FRONT MOUNT	0.1	267	70	1.1	IN SERVICE
HPT AERODYNAMICS	1.3, [c]1.6	1120	296	0.2	IN SERVICE EVALUATION
SHORT CORE EXHAUST	0.9	1557	411	0	IN SERVICE
COMPRESSOR BLEED REDUCTION	0.8	3028	800	1.0	IN SERVICE EVALUATION

[a] BASED ON AVERAGE FUEL PRICES OF 12-15 ¢/LITER.

[b] DEPENDENT ON AIRCRAFT APPLICATION.

[c] 3000 HOUR ENGINE.

Figure 23. - Fuel savings and status of completed concepts for General Electric CF6 engines.

CONCEPT	CRUISE SFC REDUCTION, %	CUMULATIVE FUEL SAVINGS THROUGH 2005		PAY BACK PERIOD NEW BUY YR[a]	STATUS
		10^6 LITERS	10^6 GAL		
JT9D ENGINE					
FAN TECHNOLOGY	1.3	2650	70.0	1.3	TECHNOLOGY USED ON JT9D-7R4
HPT ACTIVE CLEARANCE CONTROL	0.65	1279	338	[b]1.4 - 2.9	IN SERVICE
JT8D ENGINE					
HPT OUTER AIR SEAL	0.6	767	203	[b]2.7 - 3.5	OFFERED TO AIRLINES
HPT ROOT DIS-CHARGE BLADE	1.8	934	247	0	DEVELOPMENT JUST COMPLETED

[a] BASED ON AVERAGE FUEL PRICES OF 10¢/LITER.

[b] DEPENDENT ON AIRCRAFT APPLICATION.

Figure 24. - Fuel savings and status of completed concepts for Pratt & Whitney engines.

IMPROVED MECHANICAL DESIGN

- ADDED AND REDISTRIBUTED SHROUD SUPPORT MASS
- CAVITY AIR RECIRCULATION SHIELD
- SOLID SHROUDS
- MODIFIED TMF MOUNTS AND STRUTS

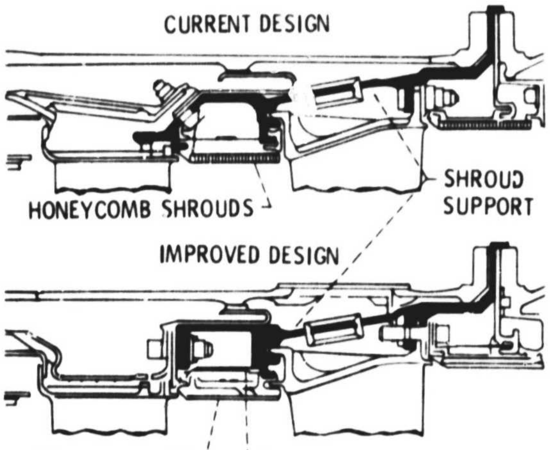


Figure 25. - CF6 high pressure turbine roundness control features.

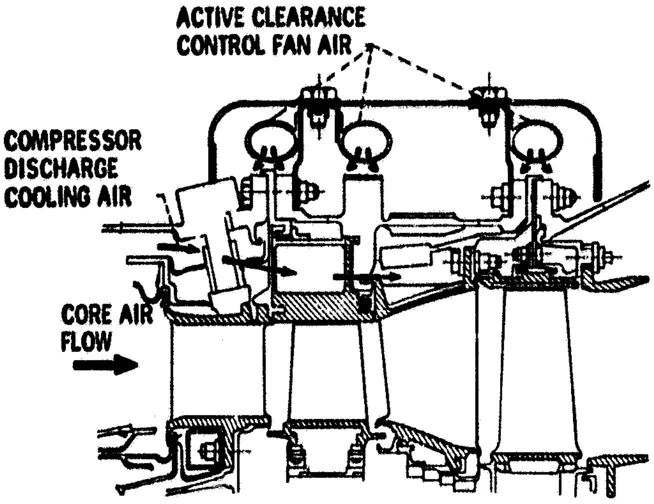


Figure 26. - CF6 high pressure turbine active clearance control system.

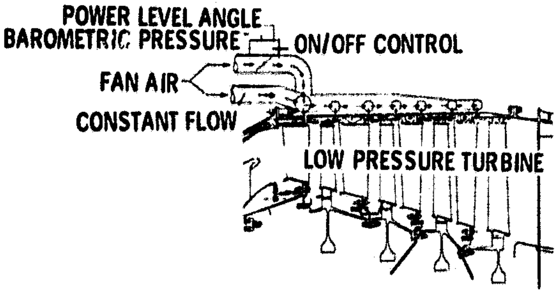


Figure 27. - CF6 low pressure turbine active clearance control system.

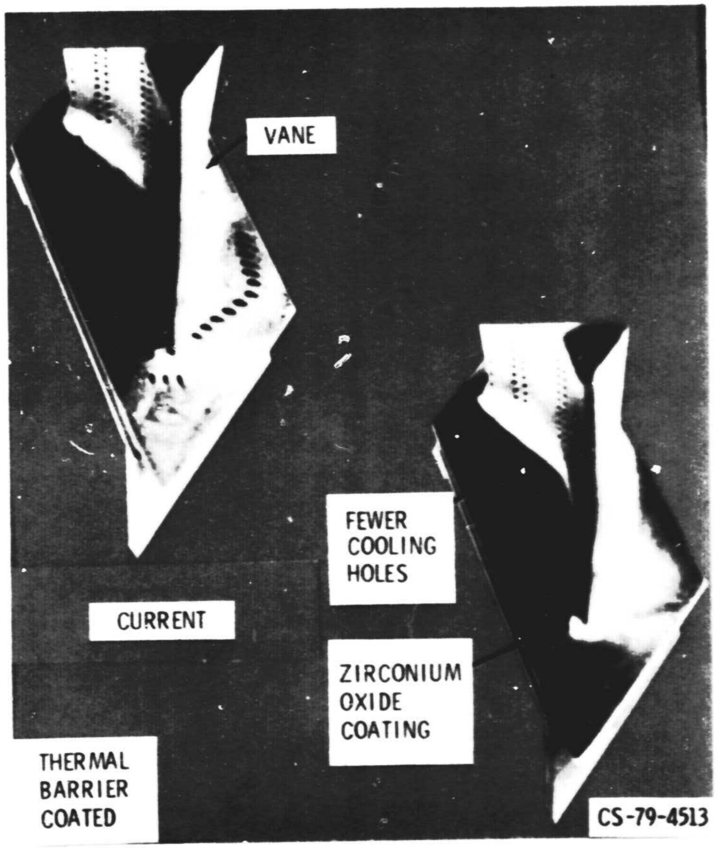


Figure 28. - JT9D high pressure turbine vane end wall.

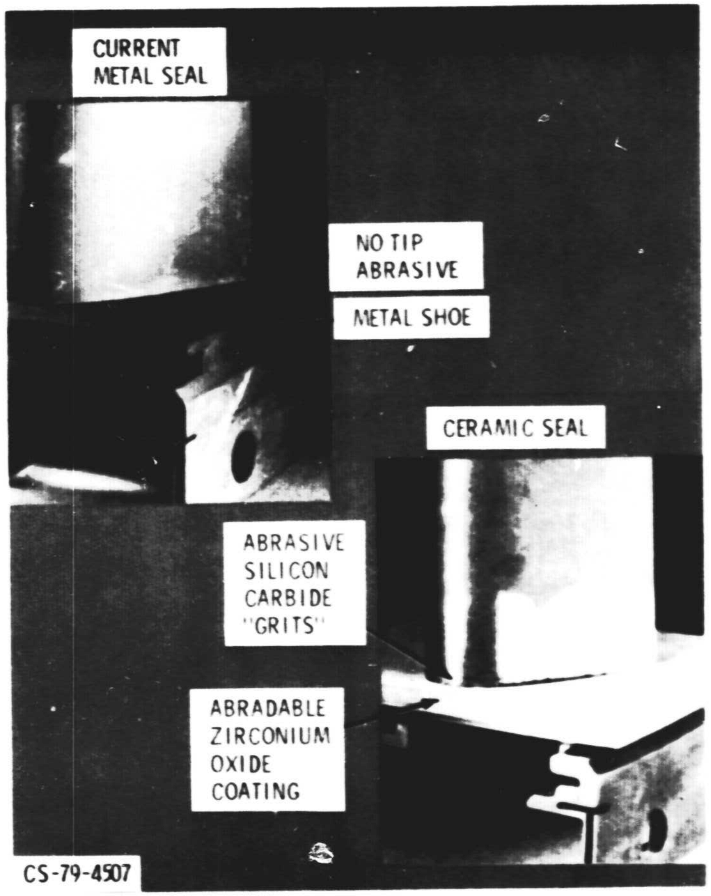
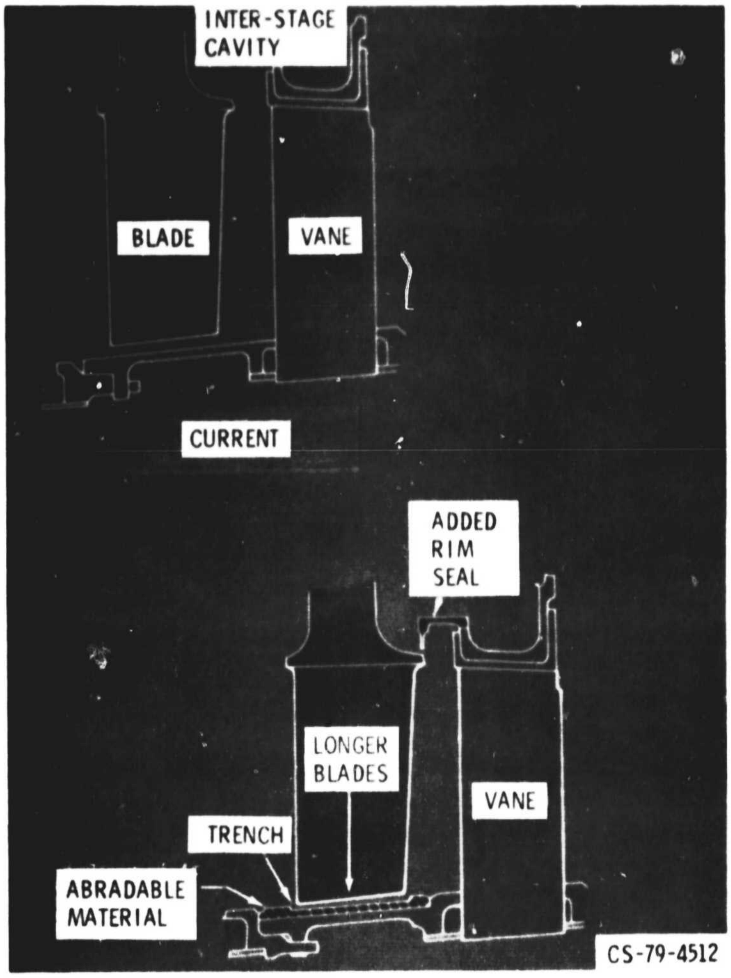


Figure 29. - JT9D high pressure turbine outer air seal.



Trenched-tip

Figure 30. - JT8D high pressure compressor stage.

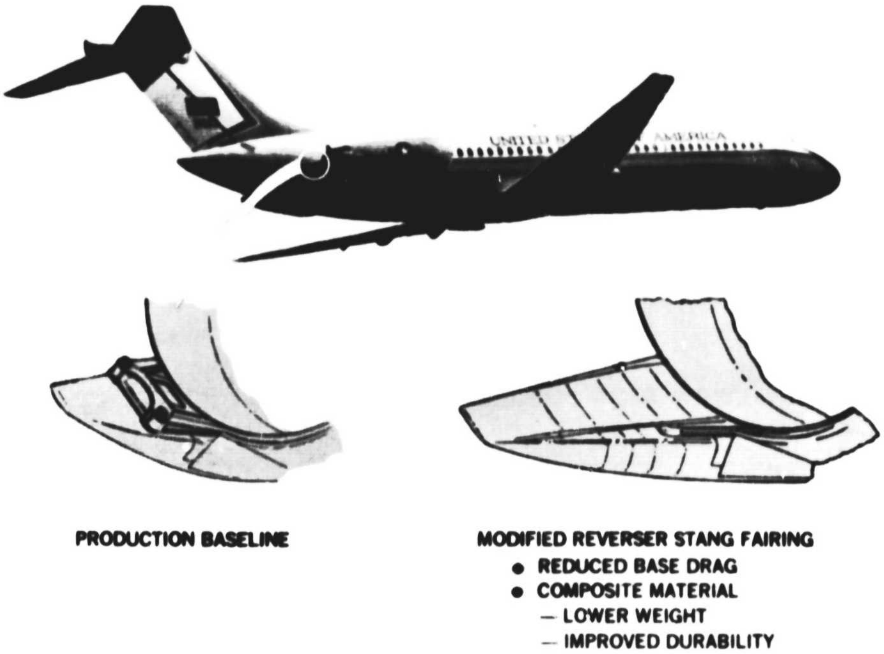


Figure 31. - DC-9 thrust reverser stang.

CONCEPT	PREDICTED CRUISE SFC REDUCTION %	CUMULATIVE FUEL SAVINGS THROUGH 2005		PAYBACK PERIOD NEW BUY, YR[a]
		10^6 LITERS	10^6 GAL	
CF6 ENGINE				
HPT ROUNDNESS CONTROL	0.4, [b]0.8	1506	398	0.8
HPT ACTIVE CLEARANCE CONTROL	0.3, [b]0.6	916	242	4.4
LPT ACTIVE CLEARANCE CONTROL	0.3	348	92	4.1
JT9D ENGINE				
HPT VANE THERMAL BARRIER COATING	0.2	980	259	0
HPT CERAMIC OUTER AIR SEAL	0.4	1953	516	0.3
JT8D ENGINE				
HPC TRENCHED BLADE TIP	0.9	2229	589	1.2
DC-9 NACELLE DRAG REDUCTION	1.2	634	168	1.7

[a] BASED ON FUEL PRICES OF 10-15 ¢/LITER.

[b] 3000 HOUR ENGINE.

Figure 32. - Estimated results for concepts under development.

1. Report No.
NASA TM-81577

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
IMPROVED COMPONENTS FOR ENGINE FUEL SAVINGS

5. Report Date

6. Performing Organization Code

7. Author(s)
Robert J. Antl and John E. McAulay

8. Performing Organization Report No
E-506

9. Performing Organization Name and Address
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

10. Work Unit No.

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, D.C. 20546

13. Type of Report and Period Covered
Technical Memorandum

14. Sponsoring Agency Code

15. Supplementary Notes
Prepared for the Aerospace Congress sponsored by the American Society of Automotive Engineers, Los Angeles, California, October 13-16, 1980.

16. Abstract
NASA is currently involved in the Aircraft Energy Efficiency Program (ACEE) which is directed toward developing technology for more fuel efficient aircraft. As part of this overall program, the Engine Component Improvement (ECI) Project was formulated to address near-term improvements for current engines. One part of this effort is Engine Diagnostics which is directed at investigating the causes for in-service performance deterioration of the CF6 and JT9D high bypass ratio turbofan engines. The other part is Performance Improvement, which is directed at development of component technologies to reduce the fuel consumption of CF6, JT9D and JT8D engines. This paper discusses the Performance Improvement part. Nine of sixteen concepts being developed under the ECI project are now complete and four are in service. The remaining five are being offered to the airlines. Earlier feasibility studies have established their technical and economical acceptability and tests have demonstrated their fuel saving potential. Descriptions of these concepts, results of testing, and the status as to entering airline service are presented. Also presented is the status of the remaining concepts still under development.

17. Key Words (Suggested by Author(s))
Turbofan engines
Fuel savings
Energy conservation
Improved components

18. Distribution Statement
Unclassified - unlimited
STAR Category 07

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages

22. Price*

* For sale by the National Technical Information Service, Springfield, Virginia 22161