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PRELIMINARY QCSEE PROGRAM TEST RESULTS

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ABSTRACT

The QCSEE (Quiet, Clean, Short-Haul Experimental Engine) program has entered the engine test phase. This paper describes the overall design and advanced technology incorporated into the two engines in the program. In addition, preliminary engine test results are presented and compared to the technical requirements the engines were designed to meet.

STAR Category 07

IN 1974 NASA INITIATED AN EXPERIMENTAL PROGRAM designed to develop propulsion system technology suitable for powered-lift, short-haul type of aircraft. The goal was to have the technology available for application to new aircraft of this type in the 1980's time period. This program has now progressed well into the engine test phase, and the purpose of this report is to present an overview of the program including some of the significant test results that have been recently obtained.

The technical emphasis in the QCSEE (Quiet, Clean, Short-Haul Experimental Engine) program is directed toward minimizing environmental impact while maintaining good performance. Environmental concerns are, of course, low noise, particularly in the case of short-haul aircraft which will operate out of small airports that are close to metropolitan areas, and low exhaust pollutants. Providing good propulsion system performance is necessary in order to produce economically viable short-haul aircraft.

Although the QCSEE program is directed toward short-haul commercial applications, it is evident that the technology being developed in this program has the potential for benefiting a much broader range of applications. For example, the low noise and pollution technology are certainly of interest for application to conventional takeoff and landing aircraft for both the short- and long-haul types. Secondly, the recent interest in energy conservation enhances the importance of advanced technology aimed at improving propulsion system performance. Indeed, several of the QCSEE advanced performance concepts could well find their way into future low energy consumption propulsion systems. And finally, much of the QCSEE propulsion system technology base is applicable to a number of the propulsion concepts being considered for powering the U.S. Navy V/STOL type aircraft which are currently under study.

This report describes the QCSEE propulsion concepts and their major design features, discusses the technical performance requirements set down for them, and summarizes the progress made and test results obtained to date. Inasmuch as the intent of this report is to summarize progress made in the program, further details can be found in the references published and noted herein and in those to be published in the near future.

PROPULSION SYSTEMS OVERALL DESIGN

PROPULSION CONCEPTS - The QCSEE program is investigating technology applicable to two powered-lift propulsion concepts for short-haul aircraft. They are illustrated in Figs. 1 and 2 and the engines associated with these concepts are referred to as the "under-the-wing" (UTW) and "over-the-wing" (OTW) propulsion systems. Each of these approaches has its advantages. In the UTW powered-lift concept, the engine location is more conventional and, therefore, it is a more straightforward approach from both aerodynamic and mechanical standpoints. Whereas in the OTW powered-lift approach, the engine installation offers a noise advantage. This is due to the shielding benefit that the wing surface provides for engine aft-end noise. The data being developed in the QCSEE program will help to choose between these alternative powered-lift approaches for future applications.

DESIGN REQUIREMENTS - The technical requirements that the propulsion systems were designed to meet, and which are essentially the goals of the QCSEE program, are listed in Table I. The noise limits for takeoff and approach power conditions are quite low. To illustrate this, a comparison to current FAA regulations shows that the QCSEE takeoff sideline noise limit is about 23 EPNdB lower when extrapolated to the same FAA sideline distance. Although no noise regulation currently exists for reverse thrust or noise footprint area, a correspondingly stringent requirement has been set in both these areas. In regard to exhaust pollutants, the engines are being designed to meet the proposed EPA 1979 emission standards. The engine thrust levels are a result of the desire to be in the 20 000-pound thrust class, which is a size of practical interest for short-haul aircraft, and the availability of the advanced technology F101 engine core, which has the capability for this thrust class of engine. The higher thrust level of the OTW is not of technical significance, and in an actual application either engine would have to provide a specific thrust level. The thrust difference is a result of designing the engines for the same airflow; this allows for use of common nacelle hardware and conserves program funds. With similar engine airflows the thrust of the OTW engine is higher because of its higher fan pressure ratio.

A challenging requirement of the QCSEE engine is the high installed thrust-to-weight ratios. High thrust-to-weight engines reduce aircraft weight and size and accordingly, reduce fuel consumption. The degree of improvement in thrust-to-weight ratio being sought can be illustrated when the QCSEE requirements are compared to that for the CF-6 engine which is used in the DC-10. The installed thrust-to-weight ratio of this modern high bypass ration engine is 3.5. And finally, we have set relatively short thrust response times for the QCSEE engines because short response time is important for control of powered-lift type of aircraft.

OVERALL DESIGN - In Fig. 3 a cross section of the UTW engine is presented which illustrates the advanced technology components in the engine and the engine characteristics during takeoff. As mentioned earlier, the engine uses the General Electric F101 engine core. The core engine employs a PV (product verification) combustor. In order to meet the stringent pollution goals in the QCSEE program, a double annular, dome combustor is being adapted to the F101 combustor envelope. This adaptation is being done in combustor rig tests. The double annular, dome combustor concept is one of the more successful types that are under development in the NASA Clean Combustor program.

A variable pitch fan is used in this engine because it results in a much lower weight thrust reversing system than the usual target type of reverser for low pressure ratio fans. It also has other advantages, such as increased thrust response, reduced engine noise, and improved engine performance over the wide range of engine operating conditions encountered. Extensive use of lightweight composite materials is made in the engine. Composite components include the fan frame, fan blades, and the nacelle. The weight of these components is projected to be 25 to 35 percent lower than the usual metal components and this is a major factor in reaching the thrust-to-weight goals in the program.

The engine uses lightweight speed reduction gears between the low-pressure turbine and the fan. This produces a smaller and, therefore, lighter weight turbine operating at a relatively high speed. The fan inlet employs a combination of high Mach number flow and wall acoustic treatment for fan inlet noise suppression. In addition, wall treatment is built integrally into the composite nacelle in the fan flow discharge duct walls and splitter. The core nozzle also contains wall acoustic treatment.

And, finally, the engine is controlled by an engine-mounted digital electronic control. This advanced control technique is necessary for the complex UTW engine control problem. The engine has four variables to control; they are the usual fuel valve and variable compressor stators and, in addition, the variable pitch fan and variable area fan nozzle.

Significant in the engine characteristics shown in Fig. 3 is the relatively high (about 12) engine bypass ratio. The fan pressure ratio and tip speed are relatively low which is customary for high bypass ratio engines. These characteristics are all a result of the low noise requirement imposed on the propulsion system. The key factor here was lowering the engine exhaust velocity so that the noise associated with exhaust impingement on the wing flaps during powered-lift operation can be maintained at tolerable levels. The engine overall pressure ratio is low, and it would be increased in an actual flight application by introducing core booster stages. This was not done in QCSEE because of the cost involved and because it would not add significantly to the program technical output.

Further details of the UTW propulsion system design can be found in (1).*

A cross section of the OTW propulsion system is shown in Fig. 4. The significant differences between it and the UTW propulsion system are in the fan, nozzle and thrust reverser areas. The OTW propulsion system employs a fixed-pitch higher pressure ratio fan. The core and fan flow are combined and discharged through a single nozzle because this approach lends itself to designing an efficient exhaust system for OTW installations. The target-type thrust reverser is used in this engine because the higher fan pressure ratio results in a lighter, and more tolerable, weight system and the OTW installation allows for upward discharge of reverse flow which is advantageous from engine exhaust and foreign object reingestion standpoints. The digital control contains an advanced feature referred to as the "failure indication and corrective action" system. It allows the control to continue functioning in the event one or two engine sensors should fail, thus improving control system reliability. The engine also employs the high Mach number inlet, reduction gears, and a composite material frame much the same as the UTW engine. A preflight-rating-test (PFRT) combustor is used in the core engine. Additional details of this engine can be found in (2).

PROGRAM SCHEDULE

An overall program schedule is shown in Fig. 5. The major part of the program is being done under

*Numbers in parentheses designate References at end of paper.

contract to NASA by the General Electric Company. Curtiss-Wright, Hamilton Standard, Douglas, Boeing, and American Airlines are also contributing to the program as subcontractors. General Electric's task is to design, develop component technology for, fabricate, and test two experimental engines. As of this date, all work on the OTW engine has been completed and only the testing of the UTW composite nacelle propulsion system remains to be accomplished.

General Electric testing consists of tests of the engine alone; that is, without any wing/flap segment which is required to produce powered-lift. Testing of the engine with a wing/flap system included will be performed at the Lewis Research Center. In addition, there may be additional engine acoustic, dynamic or controls tests performed at Lewis if determined to be useful as a result of analysis of the results of the General Electric tests.

TEST RESULTS

Reported herein are the overall results of the General Electric Company engine testing that have been completed to date. This includes all the OTW engine testing but only the aerodynamic tests of the UTW engine. Inasmuch as detailed analysis has not been complete, the results presented are considered to be preliminary in nature. However, the prospects for significant changes in the information presented are small.

In Figs. 6 and 7 the OTW and UTW engines with boilerplate nacelles are shown installed in the General Electric, Peebles test facility. The unique "D" nozzle geometry of the OTW engine can be seen in Fig. 6. This nozzle shape (shown inverted from aircraft orientation) is a result of the necessity to interface with the wing upper surface and also provide for good powered-lift characteristics.

NOISE - Measurements of the OTW propulsion system noise levels in the fully suppressed configuration were projected to the conditions for which the noise requirements were established; namely, 500 foot sideline distance and a four-engine aircraft with a thrust level of 90 000 pounds. A comparison of these OTW engine aircraft projected noise levels with the required levels from Table I is shown below:

	OTW powered-lift aircraft noise	
	Required	Projected
Approach, EPNdB	95	92
Takeoff, EPNdB	95	96
Reverse, PNdB	100	106
95 EPNdB contour area, sq mile	.5	.33

As is evident, the approach and 95 EPNdB contour area requirements were easily met by an OTW engine powered aircraft while the takeoff requirement was exceeded by only 1 dB and the reverse thrust requirement by 6 dB. The significance of the projected noise levels for the OTW powered aircraft can be illustrated with the following comparisons. The OTW powered aircraft takeoff noise level, if extrapolated to the FAA sideline condition, would be about 22 EPNdB below the FAA limit. It would also be about 12 EPNdB lower than the DC-10 aircraft, which is representative of the modern wide body jet aircraft. In terms of noise contour area (or footprint), the OTW powered aircraft has a projected area only 1/38 of that of the standard Boeing 727 aircraft. The significantly lower noise contour area for the OTW powered aircraft is due to steeper climb and approach angles common in short-takeoff and landing aircraft as well as the significantly lower engine noise levels. The relatively high reverse thrust noise level was a result of the higher than expected engine speed necessary to obtain the required reverse thrust level. This higher engine speed was a result of reverser back-pressure, which reduced engine airflow, and pressure loss effects. These factors could be improved, but at a cost of increased engine weight. Accordingly, since reverse thrust noise is primarily an airport concern and also because the measured re[illegible]rse thrust noise level is still significantly lower than that of operational engines, it was decided to accept the higher reverse thrust noise level rather than penalize engine weight.

Powered-lift aircraft noise is composed of two major components; one is the engine machinery noise and the other is the jet/flap interaction or powered-lift noise. The contribution these two noise components make to the OTW engine total system noise at takeoff power and how well the machinery noise was predicted is shown in Fig. 8. The OTW engine machinery perceived noise was obtained by removing an estimated value for jet noise. The jet/flap noise levels are estimated values, confirmation of these levels will be made in the Lewis tests. It is apparent that the measured OTW engine machinery noise sources (unsuppressed) are exceedingly close to pretest predictions in both the front and rear quadrants. The machinery noise sources include the fan, turbine, compressor, and combustor. Noise suppression was 11 and 8 PNdB compared to predicted values of 13 and 12 PNdB for the front and rear quadrants, respectively. The combined high Mach and wall treatment inlet suppression appears to be doing quite well. The lower suppression effectiveness in the rear quadrant resulted in a total system noise level increase of about 2 dB above prediction. The reduced effectiveness of the aft machinery noise suppression is the reason that the aircraft requirement of 95 EPNdB for takeoff conditions was exceeded by 1 dB.

In summary, the overall acoustic performance of the OTW engine was found to be very good.

POLLUTION - As was indicated previously, the engine exhaust emissions reduction effort is being done in a combustor rig. A 90° sector of the QCSEE combustor has been set up and tests have been initiated. The effort is currently concentrating on reducing the engine idle emissions (CO and H_xC_y). This is because the relatively short length of the combustor and the low-cycle pressure ratio is expected to make the idle emission requirements very difficult to meet. The test program has not progressed to the point at this time where significant results are available.

THRUST - A comparison of the installed thrust requirements and the measured thrust performance for both the UTW and OTW propulsion systems is shown below:

	Required	Measured
Forward OTW	20 300 lb	20 300 lb
Forward UTW	17 400 lb	17 400 lb
Reverse, percent OTW	35	35
Reverse, percent UTW	35	25

As can be seen, the forward thrust requirement was met by both engines. The reverse thrust requirement was also achieved by the OTW engine, but the UTW engine failed to meet the 35-percent requirement. However, testing of the UTW engine at higher anticipated reverse thrust levels has not been completed. Thus, the prospects are good for increasing the UTW engine reverse thrust level, but whether or not the requirement can be reached will have to await completion of engine tests.

Important to the engines thrust performance was the performance of the fans. These fans are relatively low-pressure ratio designs. The design pressure ratio for each fan was selected at a point between the low-pressure ratio required for low noise at takeoff and the higher pressure ratio desired at cruise for improved engine performance. The airflow at takeoff and cruise were similar because of the airflow limitations of the high Mach number inlet. The aero performance of the fixed pitch OTW fan was generally good as can be seen in Fig. 9. The takeoff airflow and pressure ratio was attained at a slightly lower than predicted fan speed. Fan efficiency met or exceeded predictions, particularly in the hub region. This is particularly significant in view of the relatively high (2.6) work coefficient in the fan hub region.

The performance of the UTW fan is presented in Fig. 10. The UTW fan has variable pitch capability and this results in a relatively low blade solidity. A 20-inch model of the UTW fan was built and tested during the program. The results of the model fan tests indicated (Fig. 10) generally good performance in comparison to predictions and no modifications (although some bypass flow efficiency improvements appeared possible) were undertaken in the full-scale engine version. The aero design point airflow and pressure ratio were obtained at about a 6-percent higher fan speed on the 20-inch model fan. Performance of the full-scale engine fan was generally very close to the 20-inch model fan. In order to reduce the fan speed in the engine and still provide the required takeoff airflow and pressure ratio, the UTW fan pitch was opened slightly by 2.8 degrees from design.

THRUST/WEIGHT RATIO - Complete evaluation of the UTW and OTW propulsion systems installed thrust-to-weight ratios cannot be made at this time. Although the capability of the engines to meet their required thrust levels has been confirmed, several component weights have not been finalized. One of these is the composite nacelle. Fabrication of the nacelle has not been completed, and accordingly, final evaluation of its weight can not be made. Another area of uncertainty is the composite fan blades. The QCSEE composite fan blades have not demonstrated adequate FOD resistance and accordingly, an improvement in blade design is required in order to demonstrate a greater degree of confidence in meeting flight requirements. There are a number of composite blade technology programs currently in progress and prespects are reasonably good that these programs will uncover a blade design that is acceptable from an FOD standpoint for the QCSEE type application.

THRUST RESPONSE - The approach to takeoff thrust transient requirement of 1 second for the OTW engine was successfully demonstrated during engine tests. The thrust response results are shown in Fig. 11. In order to meet this requirement, advantage had to be taken of resetting the compressor stators. By closing the compressor stators at approach thrust levels, the core speed can be kept near or at the takeoff value, this significantly shortens the time required to accelerate the high-speed rotor during thrust transients. It can be seen that a 25° compressor stator reset reduces response time by almost a factor of two. Further, these results were obtained with a heavy fan rotor since composite blades were not used in the OTW engine. With a lightweight rotor, response time could be decreased by about another 0.2 second. In the OTW engine the thrust reverser was not automated and, therefore, the approach-to-reverse thrust transient will not be evaluated. However, based on the forward thrust transient results, it appears that this requirement could also be met.

The digital control performance was, in general, very good, except for one area. Complete checkout of the "failure indication and corrective action" (FICA) system was not accomplished. This system provides for continued operation of the engine should one or more of the sensors fail. This improves control system reliability. It is anticipated that further testing of this feature of the control at Lewis Research Center will demonstrate this capability.

MAIN REDUCTION GEARS - The main reduction gears on both the OTW and UTW engines have performed without difficulty. Total engine test time on each gear set is about 50 hours. This is in addition to about 50 hours of testing accumulated on each set in a gear test rig. The UTW engine gear set was thoroughly inspected after the engine testing with boilerplate nacelle and the gears were found to be in good condition.

CONCLUSIONS

The QCSEE program is investigating a wide range of advanced propulsion system technology. The technology emphasis is in the areas of propulsion system noise reduction, improved performance, or fuel economy and emissions reduction. Initial engine test results indicate that the majority of the technical requirements layed down for the engines are being met or exceeded. Although the thrust of the program is directed toward providing technology for powered-lift, short-haul aircraft, many of the individual advanced technology elements in the program should be useful in a much broader range of future aircraft.

REFERENCES

1. "Quiet, Clean, Short-Haul Experimental Engine (QCSEE) Under-the-Wing (UTW) Final Design Report," General Electric Co., Cincinnati, Ohio, May 1977; also NASA CR-134847.
2. "Quiet, Clean, Short-Haul Experimental Engine (QCSEE) Over-the-Wing (OTW) Final Design Report," R75AEG443, General Electric Co., Cincinnati, Ohio, June 1977; also NASA CR-134848.

TABLE I. - QCSEE TECHNICAL REQUIREMENTS

Noise	
500-foot S.L., four-engine 90 000-pound thrust aircraft	
Approach, EPNdB	95
Takeoff, EPNdB	95
Reverse, PNdB	100
95 EPNdB contour area, sq mile	0.5
Pollution	EPA 1979 emission levels
Installed thrust	
Forward, UTW, lb	17 400
Forward, OTW, lb	20 300*
Reverse, percent	35
Installed thrust/weight	
UTW	4.3
OTW	4.7
Thrust response	
Approach to takeoff, sec	1.0
Approach to reverse, sec	1.5

*With conic nozzles.

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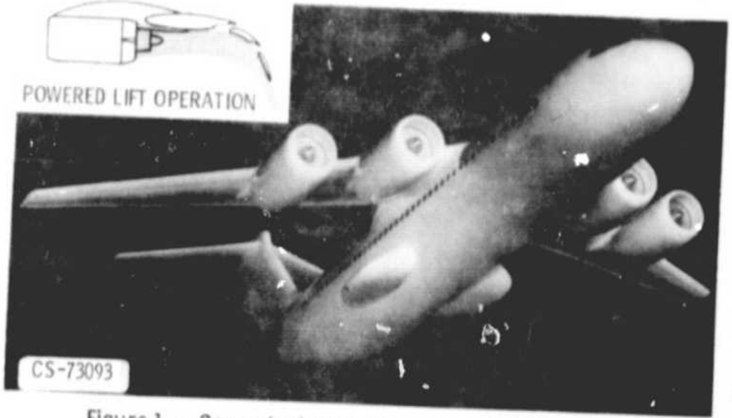

Figure 1. - Conceptual under-the-wing short-haul aircraft.

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Figure 2. - Conceptual over-the-wing short-haul aircraft.

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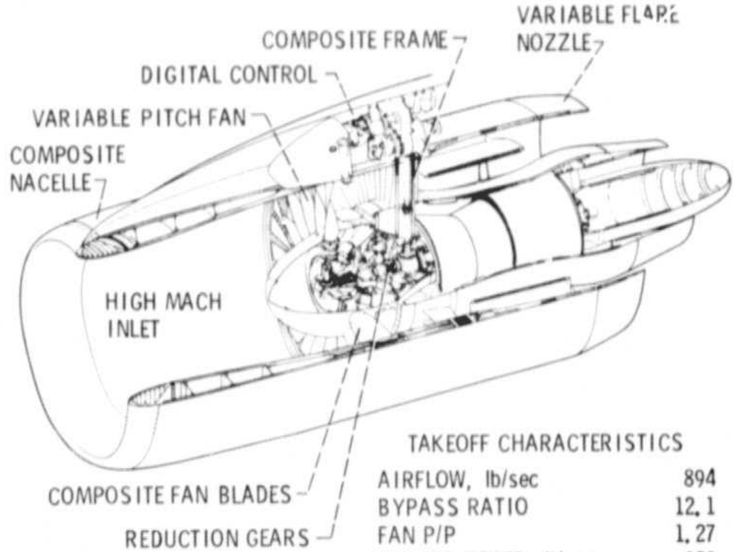
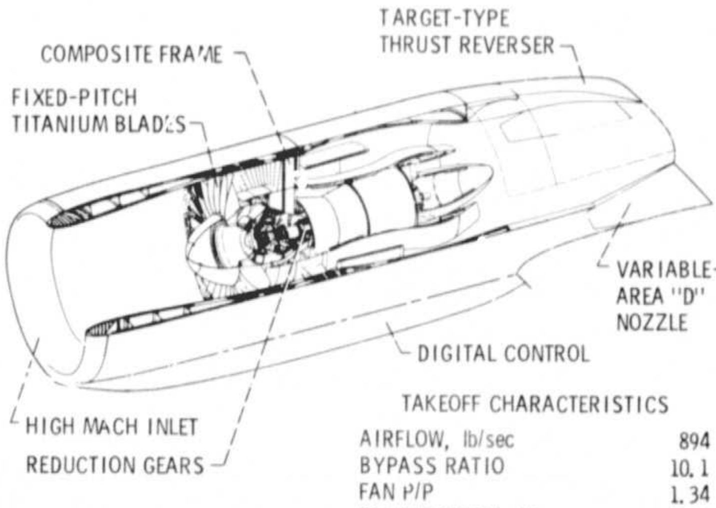


TAKEOFF CHARACTERISTICS

AIRFLOW, lb/sec	894
BYPASS RATIO	12.1
FAN P/P	1.27
FAN TIP SPEED, ft/sec	950
OVERALL P/P	14.3
THRUST, lb	17 400

Figure 3. - QCSEE UTW engine.



TAKEOFF CHARACTERISTICS

AIRFLOW, lb/sec	894
BYPASS RATIO	10.1
FAN P/P	1.34
FAN TIP SPEED, ft/sec	1162
OVERALL P/P	17.3
THRUST, lb	20 000

FIGURE 4. - OCSEE OTW engine.

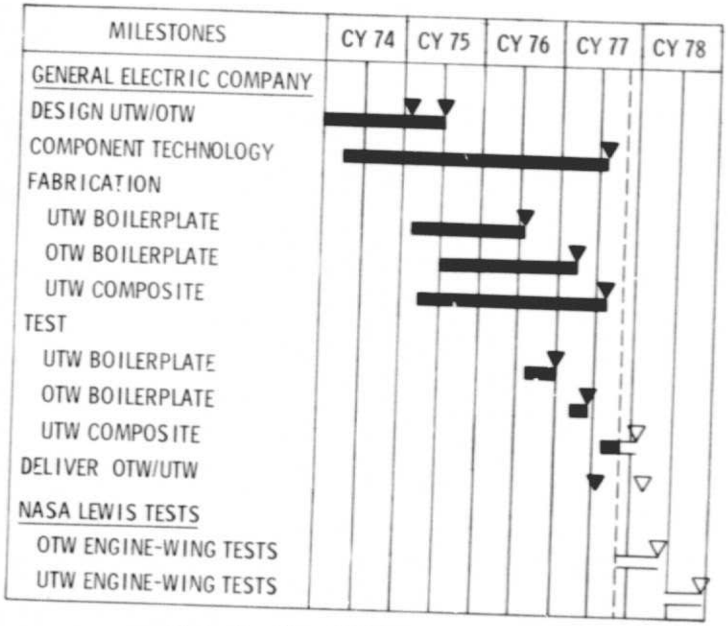


Figure 5. - Overall QCSEE program schedule.

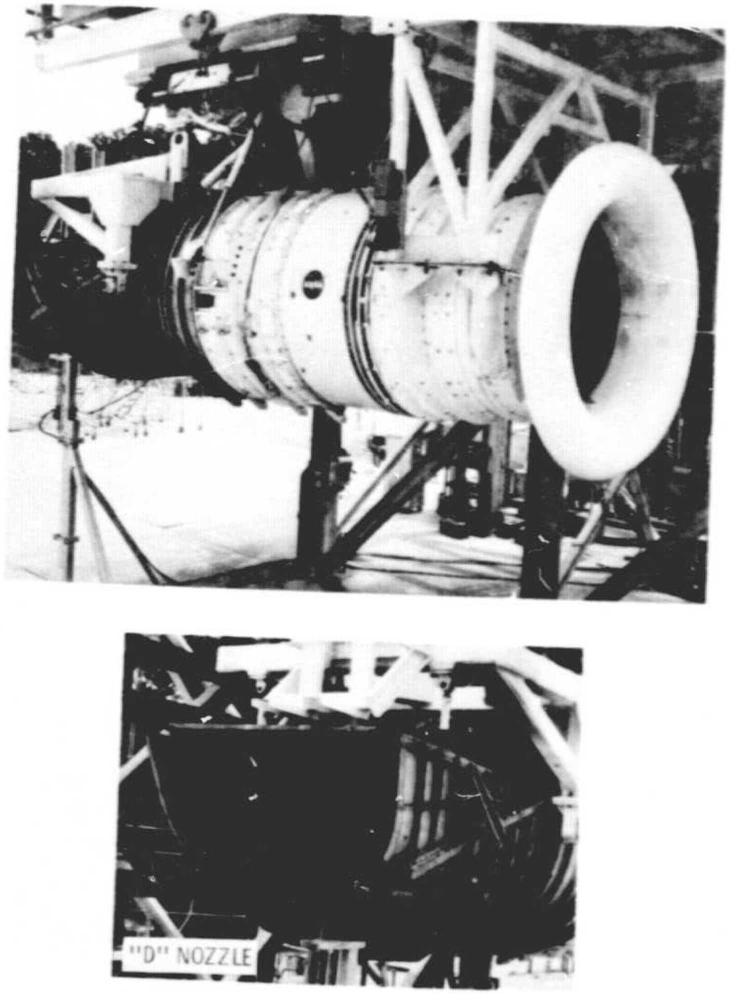


Figure 6. - Over-the-wing engine in General Electric test facility.

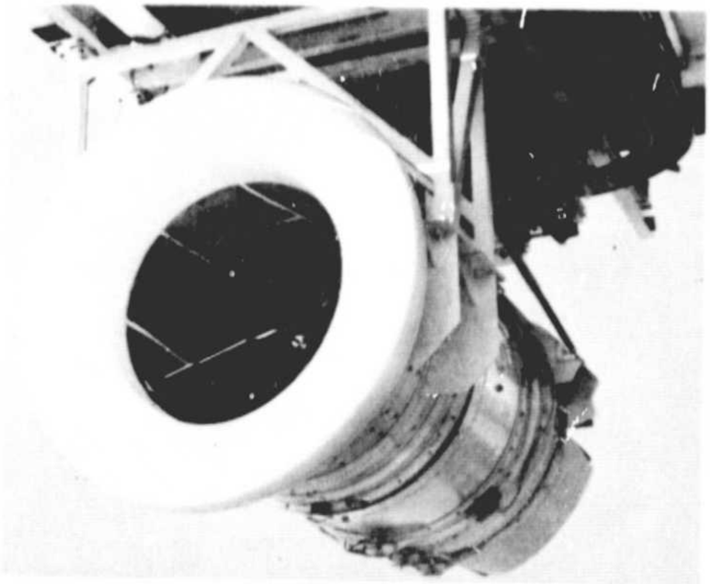


Figure 7. - Under-the-wing engine in General Electric test facility.

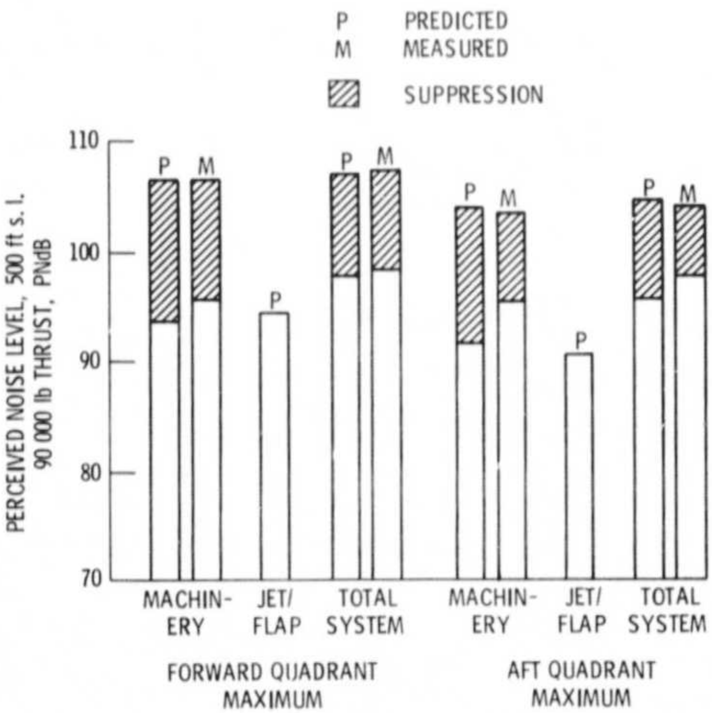


Figure 8. - OTW powered-lift component noise levels, takeoff.

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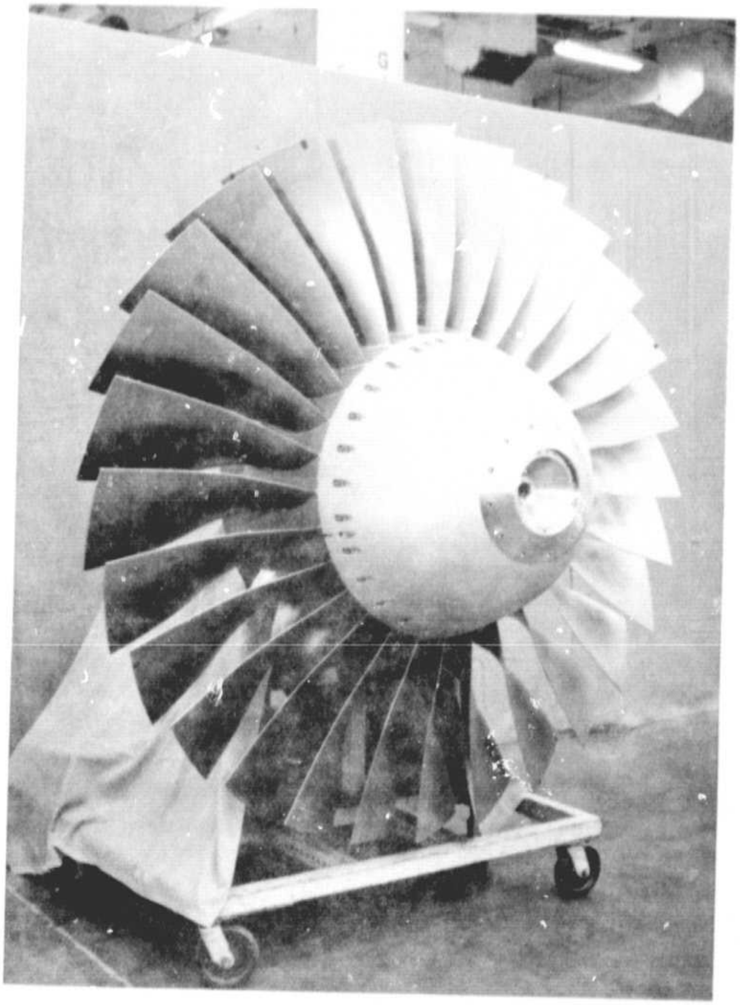
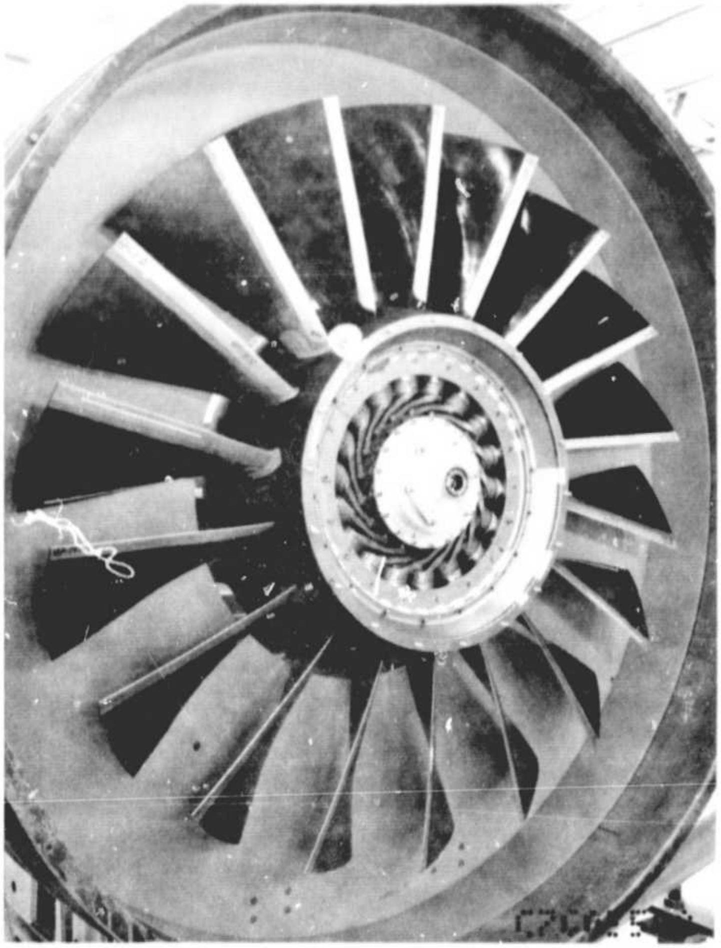


	AERO DESIGN POINT	TAKEOFF	
		PREDICTED	MEASURED
FLOW, lb/sec	900	894	896
PRESSURE RATIO			
BYPASS	1.36	1.34	1.33
CORE	1.43	1.43	1.46
EFFICIENCY, %			
BYPASS	88	86.7	86.8
CORE	78	75.5	84.3
TIP SPEED, ft/sec	1175	1162	1135

Figure 9. - OTW fan performance.



	AERO DESIGN POINT		TAKEOFF	
	PREDICTED	MEASURED 20" MODEL FAN	PREDICTED*	MEASURED ENGINE
FLOW, lb/sec	900	900	894	894
PRESSURE RATIO				
BYPASS	1.34	1.34	1.27	1.27
CORE	1.23	1.23	1.20	1.22
EFFICIENCY, %				
BYPASS	88	86	83.4	83.5
CORE	78	84	78.9	78
TIP SPEED, ft/sec	1005	1065	950	952
BLADE PITCH, deg	0	0	3(OPEN)	2.8(OPEN)

*BASED ON 20" MODEL FAN PERFORMANCE.

Figure 10. - UTW fan performance.

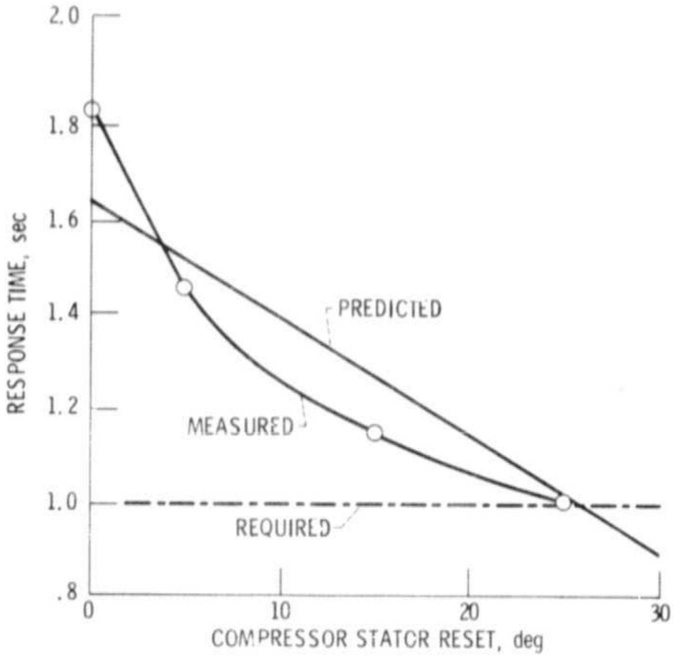


Figure 11. - OTW engine thrust response for an approach to takeoff transient.

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