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INLET/NACELLE/EXHAUST SYSTEM INTEGRATION
FOR THE
QCSEE PROPULSION SYSTEMS

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SUMMARY

The QCSEE UTW and OTW propulsion systems provide advanced technology by the introduction of the integrated engine/nacelle installation. This technology is a critical ingredient in achieving the objectives of high installed performance and high installed thrust to weight ratio for the extremely low noise, low fan pressure ratio short haul propulsion systems. The key features of the integrated propulsion systems are discussed in this paper including the high Mach number, fixed geometry near sonic inlet, the variable area nozzles, thrust reversing systems and aircraft accessory location. The roles and interplay of each element are discussed and comparisons made with conventional state-of-the-art technology.

INTRODUCTION

The General Electric Company is currently under contract to NASA to develop, design, build and test two engine systems complete with inlet, ducting and nacelles for future short haul powered-lift aircraft that may enter service in the 1980's. The two engine systems are the under the wing (UTW) based on the principle of the externally blown flap (EBF) STOL aircraft similar to the YC15, and the over the wing (OTW), based on the principle of the upper surface blowing (USB) STOL aircraft similar to the YC14. The General Electric task was to develop the complete propulsion system, integrating all aspects of engine cycle, structure, acoustics, and aerodynamics into a balanced design to meet the program objectives. To assist in this task, Douglas, Boeing and American Airlines were subcontractors to the General Electric Company with the general assignment of reviewing program plans, installation features and performance characteristics. In particular, Douglas was funded for specific assistance in the high Mach inlet design based on their data base and Boeing provided guidance for the OTW exhaust system internal and external aero line definitions.

The General Electric Company design approach provided the first application of the integrated engine/nacelle propulsion system. Some of the key aerodynamic elements of this system, the inlet and exhaust systems, involved advancements in propulsion design technology not normally found in conventional designs. Extensive analysis and component testing were required to provide the timely solution for the best overall design. These tests were conducted at the NASA Lewis and Langley wind tunnel facilities.

A description of the integrated propulsion system and the role played by the key components is presented in this paper as well as the significant results from the experimental programs.

DISCUSSION

The extremely low noise goals of the QCSEE program present a major challenge in the aerodynamics of nacelle integration in order to provide propulsion systems with minimum performance penalties. The magnitude of the task is vividly portrayed by reference to Figure 1. This analysis illustrates the sea level takeoff thrust per unit frontal area as a function of the fan pressure ratio. The analysis is presented relative to todays CTOL high bypass ratio systems with a nominal fan pressure ratio of 1.6. The figure shows that the QCSEE UTW propulsion system with its fan pressure ratio of 1.27 has a decrease in thrust per unit frontal area relative to the reference CTOL system of 85% and the QCSEE OTW with its fan pressure ratio of 1.35 is in the order of 65%. This perspective portrays the significant need to achieve the lowest installed diameter and length practical with the system requirements.

INLET SELECTION

The inlet is the single largest component of the nacelle installation and has particular significance because it generally defines the nacelle maximum diameter.

The QCSEE UTW and OTW propulsion systems employ a high (0.79) throat Mach number fixed geometry inlet system. Figure 2 illustrates the comparison of the QCSEE high Mach inlet and nacelle and conventional design low Mach inlet of 0.6 The low Mach inlet results in a nacelle diameter 9% larger and a nacelle cowl 10% longer. The low Mach inlet which is representative of conventional state-of-the-art of design technology does indeed define the maximum nacelle diameter and plays a large role in defining the overall nacelle length.

The QCSEE M=.79 throat inlet, however, with its reduced throat area does not set the maximum nacelle diameter since the inlet internal and external geometry diameter design results in a diameter less than that for the integrated nacelle structure.

For the QCSEE propulsion system, the inlet must also provide by its design a large measure of front end noise suppression to meet the low noise goals and also achieve a much higher angle of attack for aircraft operation. The 0.79 throat Mach number inlet with its near sonic flow characteristics is able to achieve its significant front end noise suppression in an inlet length to diameter ratio of 1.0 compared to a 20% increase for the low Mach inlet.

Numerous aero/acoustic tests have demonstrated the significant front end noise suppression of near sonic inlets. The QCSEE propulsion systems are the first to use this characteristic in a practical propulsion design which meets all the QCSEE program objectives.

The QCSEE inlet was designed for a throat Mach number of 0.79 because this was the highest Mach number practical considering inlet engine matching requirements. Typical subsonic inlet performance characteristics follow the recovery/Mach number relationship shown on Figure 3. These data obtained at static conditions show a precipitous fall off in recovery at a Mach number of 0.82. The Mach number of 0.79 was selected by consideration of tolerances required for engine airflow variation, transient engine operational requirements, throat corrected flow variations due to aircraft operational effects and inlet manufacturing tolerances, and then backing off from the limit value of 0.82.

In addition to the required integration for noise and minimum diameter, the QCSEE inlet had another most stringent requirement.

The QCSEE inlet system needed to operate at unusually high angles of attack because of anticipated STOL airplane characteristics and crosswind conditions. The angle of attack condition defined by the NASA requirement was satisfactory engine operation to 50 degrees angle of attack at 80 knots forward velocity. This compares to the more normal maximum angles of attack of conventional CTOL aircraft of 20 to 22 degrees. The NASA defined crosswind requirement was for satisfactory engine operation with 35 knots crosswind at 90 degrees. This is consistent with conventional CTOL type operation.

The selected QCSEE inlet geometry as demonstrated in a scale model verification test program did achieve the desired inlet recovery versus Mach number characteristics. The detailed lip geometry and diffuser shape to achieve the non-separated flow with its attendant low distortion characteristics at the high angles of attack required by QCSEE received much attention in the scale model program. The test data show that the selected QCSEE inlet does not have separation and resultant high distortion until approximately 63 degrees, well beyond the 50° requirement. This assures the engine/airframe compatibility.

The ability of the QCSEE UTW engine/propulsion system to achieve the relatively high takeoff throat Mach number for a fixed geometry inlet is a significant advancement in aero/acoustic integration as evidenced by the flight placard airflow characteristics shown on Figure 4. This analysis portrays the resultant throat Mach number of conventional CTOL systems and the QCSEE UTW system at the takeoff, maximum climb, cruise and approach conditions. The conventional aircraft propulsion system is shown to have its highest throat Mach number at maximum climb conditions and, due to its fixed geometry fan and non-variable nozzle, the Mach number at takeoff and approach falls to 0.57 and .40, respectively. As a result, the CTOL system has no inherent accelerating flow noise suppression benefit at the critical takeoff and approach conditions. The present QCSEE design estimate for the inlet/nozzle/cycle match results in the relatively high inlet throat Mach number of 0.71 at approach conditions also producing some noise suppression. This is made possible by the unique aerothermodynamic UTW engine cycle operating characteristics with the UTW variable pitch fan and variable exhaust fan nozzle.

CONFIGURATION DESCRIPTION

The UTW propulsion system is shown on Figure 5 as it would be installed on a typical EBF aircraft wing arrangement. The overall nacelle geometry is shown to be compatible with the aircraft pylon, wing and nacelle location requirements. The major nacelle components consist of the high Mach inlet, upper pylon mounted accessories, fan duct, the multi-function flare nozzle, core cowl and plug. All nacelle components are axisymmetric and have acoustic treatment as an integral part of the structural walls. The inlet is not drooped as is the case on most CTOL aircraft because the inlet location is far enough forward of the wing to be out of the upwash flow field. The nacelle maximum diameter is 200 cm (78.7 in) with an overall length of 536 cm (211 in). Attention is directed to the accessory pylon location. This upper pylon location does not produce any unusual maintenance problems for the high wing aircraft but does provide a reduced projected frontal area by allowing the accessories to fit within the silhouette of the pylon. The upper accessory location shortens configuration hardware (tubes, ducts, cables, wires, etc.) since there is a minimum distance from the engine to the engine accessories and then on to the aircraft interconnect points. The upper accessory location eliminates the characteristic lower bulge which results in local supervelocities and attendant lower static pressures and hence downward force and loss of aircraft lift. In addition, the accessory sidewise bulge in the pylon is located in front of the wing for a favorable impact on overall aircraft area ruling. The upper pylon accessory location eliminates the need for fan casing hardware on the typical bottom mounted accessory arrangement and permits integration of the fan cowl into the engine structure. This permits thinner nacelle walls - approximately 10 cm (4 in) all around compared to 25 cm (10 in) on the top and sides of the CF6 and 50 cm (20 in) on the bottom of the CF6/DC10 nacelle.

The conventional bottom - mounted accessory arrangement is shown in Figure 6. The nacelle structure is no longer symmetrical and a potential drag producing fairing is required to cover the accessories. In order to maintain low boattail angles, the fairing must be extended aft of the normal nacelle exit with potential negative impact on internal flow characteristics.

EXHAUST SYSTEM

The requirement for low fan pressure ratio to achieve low noise introduces another installation design complexity in the exhaust system. These low pressure ratio systems require variable area exhaust nozzles with the cruise area being reduced relative to takeoff area in order to maintain fan efficiency and increase altitude cruise thrust. The QCSEE UTW engine cycle requires an area increase of 31% while the OTW needs 21% as shown on Figure 7. Conventional CTOL systems being in the higher fan pressure ratio range of 1.5 and over do not employ variable area nozzles.

The QCSEE UTW propulsion system employs a 4 flap arrangement as shown on Figure 8. The 4 flaps are arranged to provide the 31% area change required for takeoff to cruise operations while maintaining acceptable low boattail angles for cruise conditions. In addition, those flaps are actuated outward to provide the flow inlet for reverse mode operation for the variable pitch UTW fan. Testing at NASA Lewis during wind on conditions has demonstrated recovery levels during reverse tests of 95% at simulated aircraft landing conditions and low pressure distortion levels of 7% at the fan face. This UTW multi-function exhaust system was designed to fit within the overall nacelle envelope defined for the integrated propulsion system.

The QCSEE OTW exhaust system had the additional requirements of efficient flow turning for the over the wing nacelle arrangement (the target was 60° of turning for approach conditions), exit area variability of 21% and a thrust reverser producing 35% reverse thrust.

Since the QCSEE OTW effort involved the development of a ground test engine only, and the nacelle integration with the wing would need to be very intimately tailored to the fuselage and wing flow field, the design thought process specifically excluded any detailed external and internal aerodynamic iterations and no plans were put into place for tradeoff studies or wind tunnel cruise drag investigations. Overall general guidance on the nozzle geometry was received from the Boeing Company.

The QCSEE OTW exhaust system was developed with the assistance of the NASA Langley Dynamic Stability Branch. The aft views on Figure 9 show the means of achieving the required 21% area variation. Two side doors are opened up for takeoff mode and the doors closed for the cruise mode to provide continuous flow surfaces. The side doors provide the required 21% area change and in addition, enhance the sidewise flow spreading characteristics to achieve the desired jet turning for USB Propulsive Lift Systems. The detailed internal and external contours of the nozzle are called out on Figure 10. The combination of the nacelle lines produces a very significant impingement angle of the flow on the wing surface resulting in 59 degrees of jet turning and efficiency of 87%.

The manner in which the nozzle integrates with the overall OTW nacelle and the target type thrust reverser is shown on Figure 11. The reverser geometry was also developed at NASA Langley. The reverse thrust objective of 35% was achieved. The combination of the nacelle duct area and reverser location does restrict the reverse airflow to about 85% of the forward mode level. However, under these conditions, the QCSEE OTW engine has adequate stall margin for satisfactory engine operation in the reverse mode for ground test purposes.

CONCLUDING REMARKS

The QCSEE integrated propulsion system design provides technology advancements in the areas of the high Mach fixed inlet, integrated low drag nacelle with unique upper pylon accessories, and variable area nozzle arrangements. These components have been integrated to fully meet the objectives of the QCSEE short haul transport requirements. The inlet, cycle and exhaust system, nozzle and reverser for both the UTW and OTW are matched efficiently to provide a balanced aero/acoustic design.

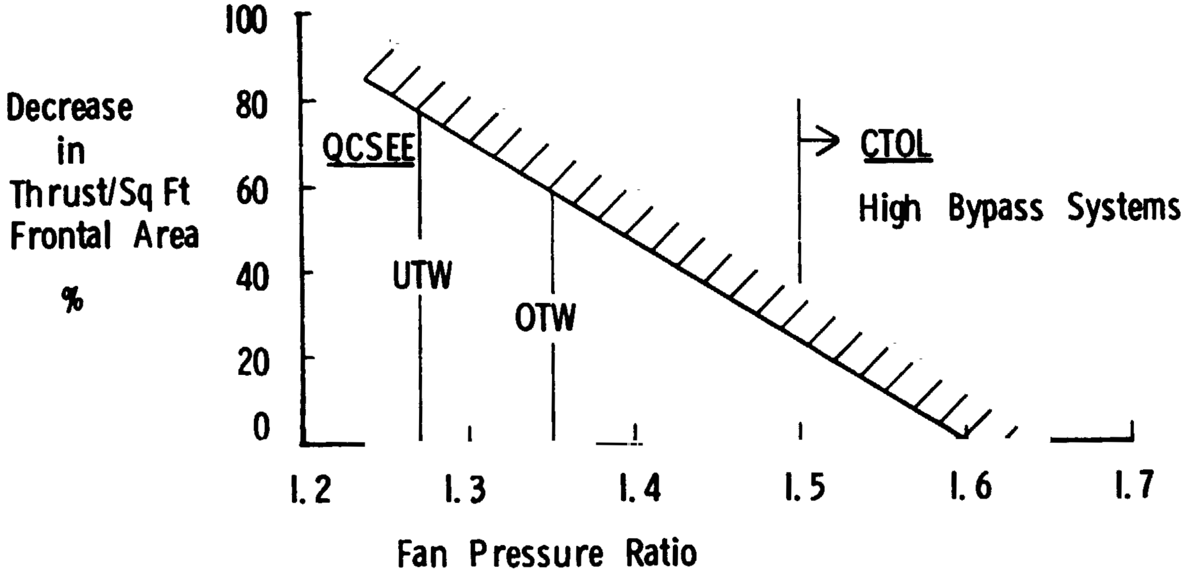

Figure 1.- Effect of fan pressure ratio on thrust per square foot of frontal area.

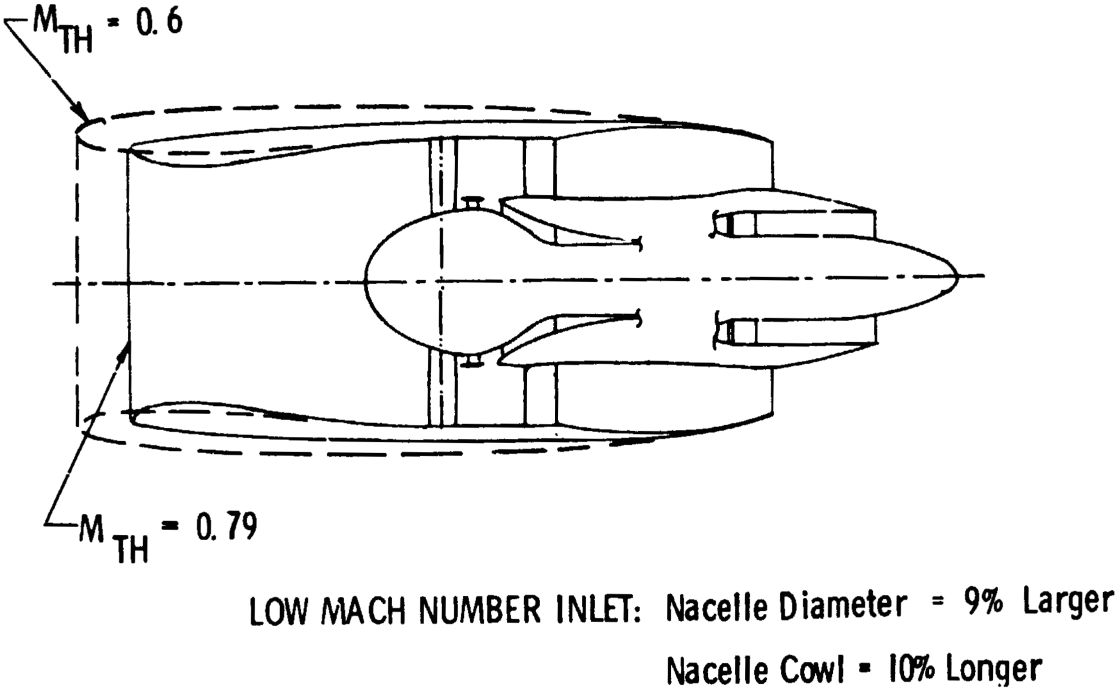

Figure 2.- Nacelle comparison of high throat Mach number with low throat Mach number.

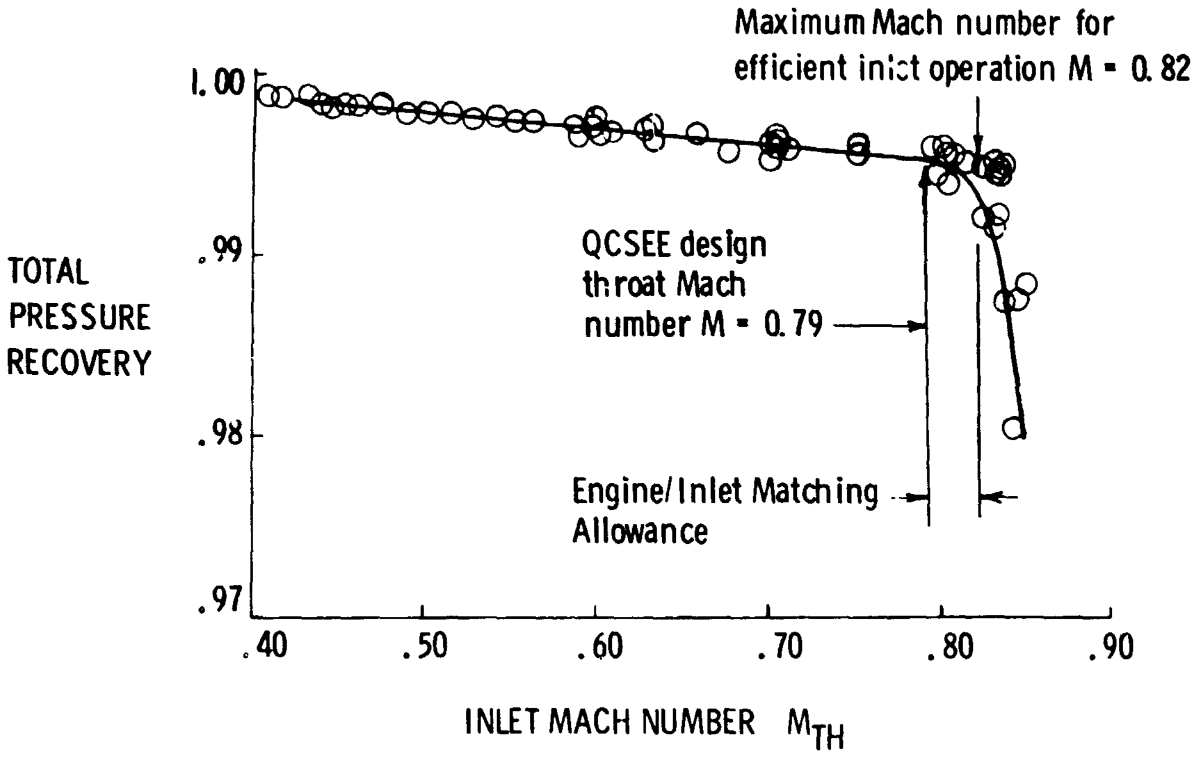

Figure 3.- Inlet throat Mach number selection.

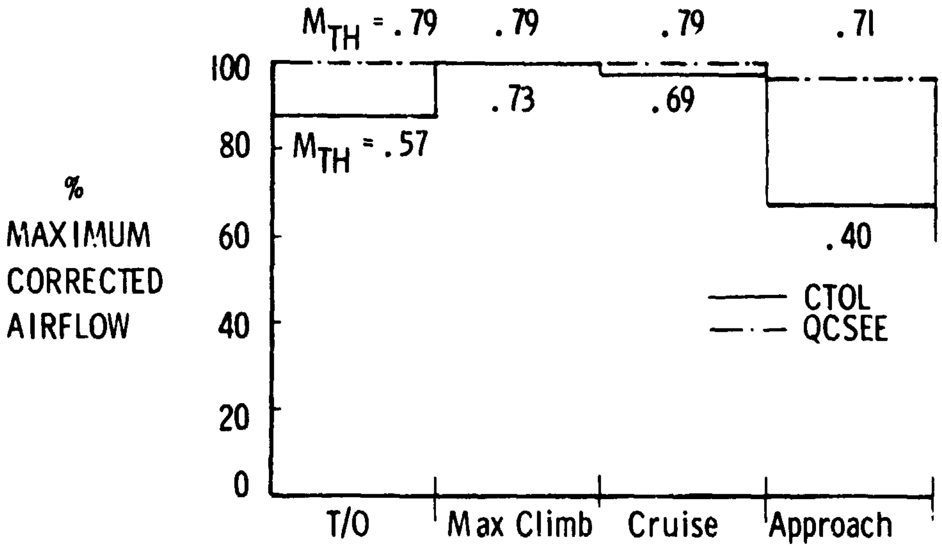

Figure 4.- Flight placard airflow characteristics for QCSEE UTW and CTOL aircraft.

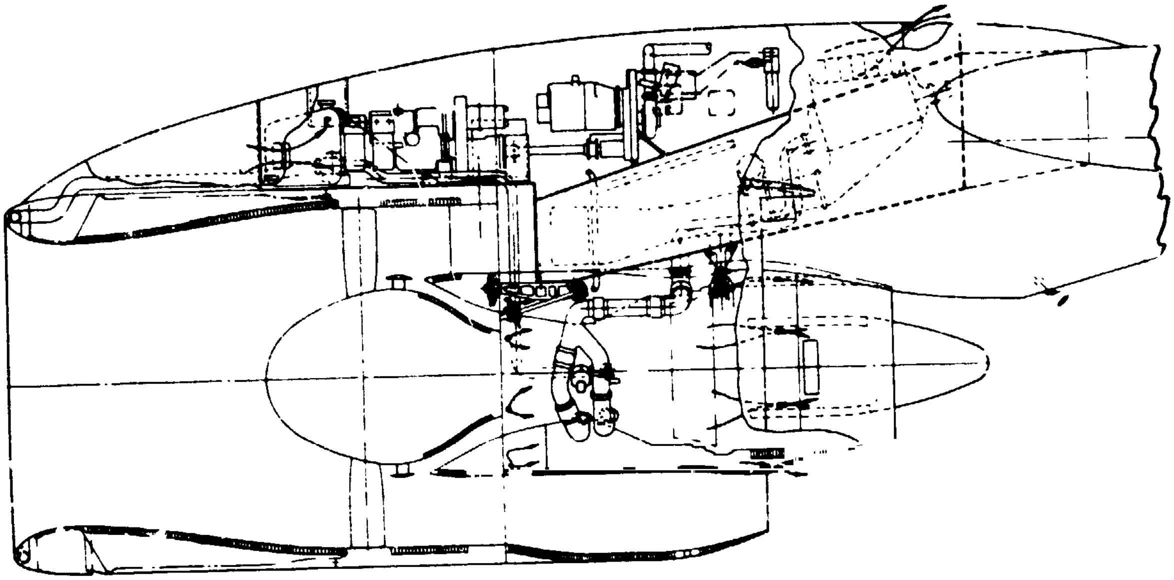

Figure 5.- QCSEE UTW baseline propulsion system, upper pylon accessories.

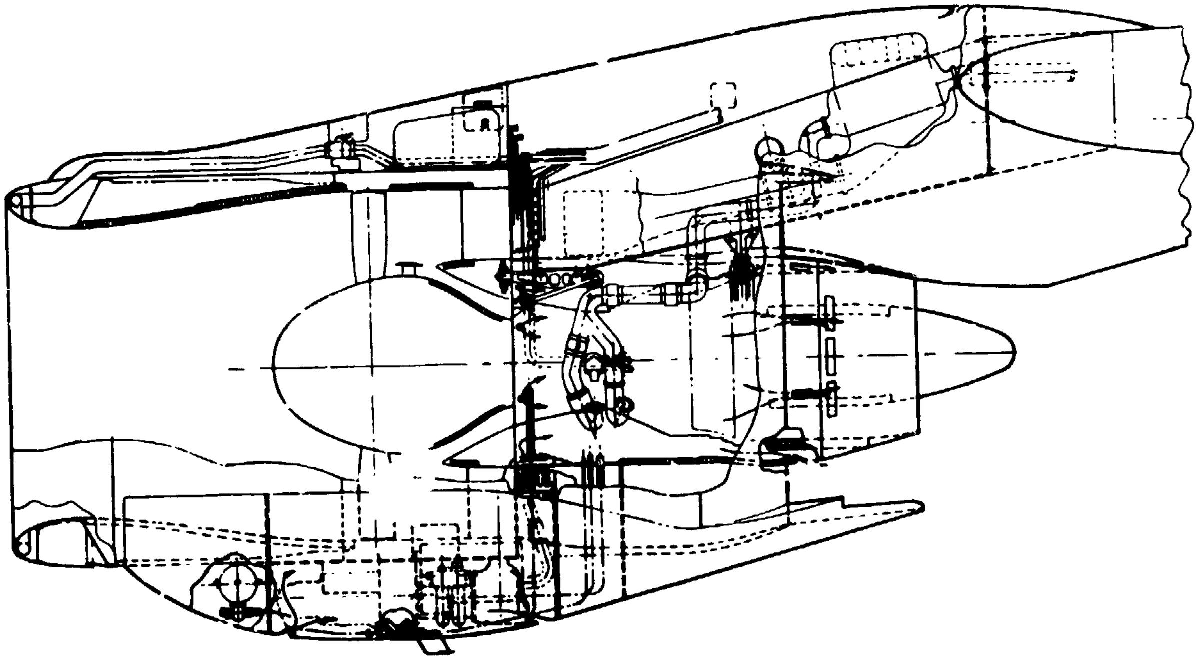

Figure 6.- QCSEE UTW study propulsion system, bottom mounted accessories.

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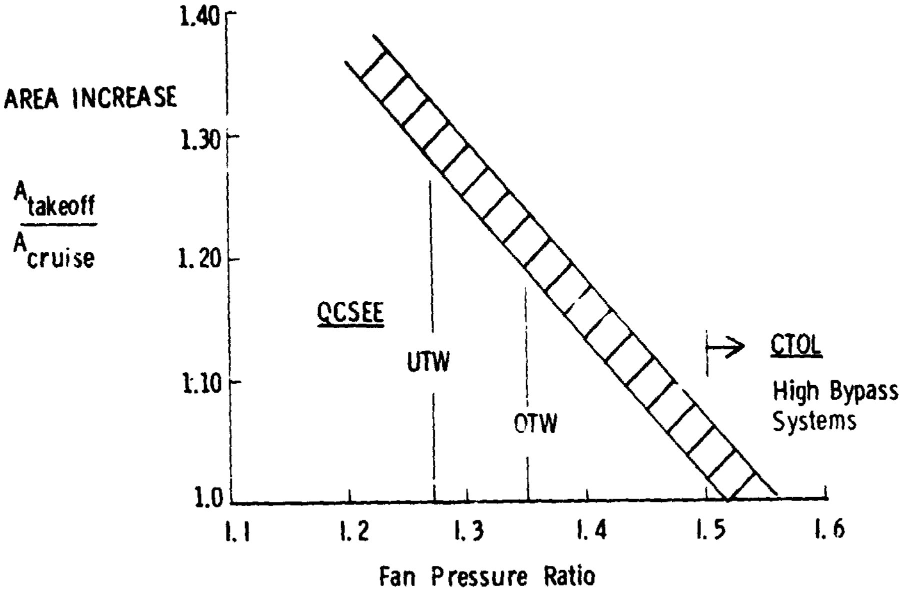


Figure 7.- Effect of fan pressure ratio on nozzle area to maintain fan efficiency at cruise.

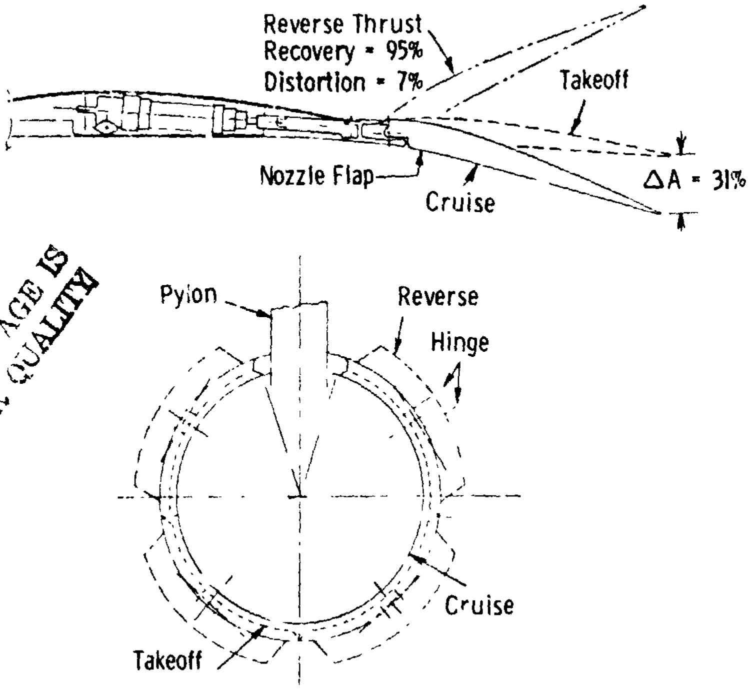
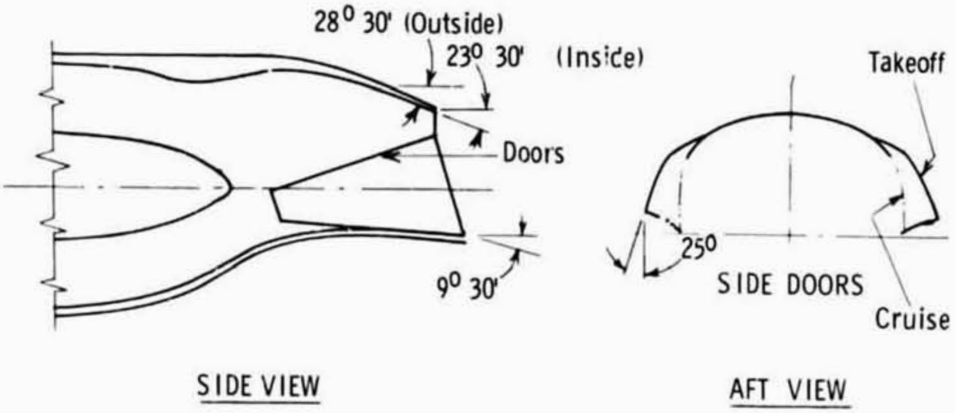


Figure 8.- Exhaust nozzle for QCSEE UTW.

Figure 9.- Exhaust nozzle for QCSEE OTW aft view.



Jet Turning Angle = 59°, Efficiency = 87%

Takeoff to Cruise

Nozzle Area Change = 21%

Figure 10.- QCSEE OTW exhaust nozzle.

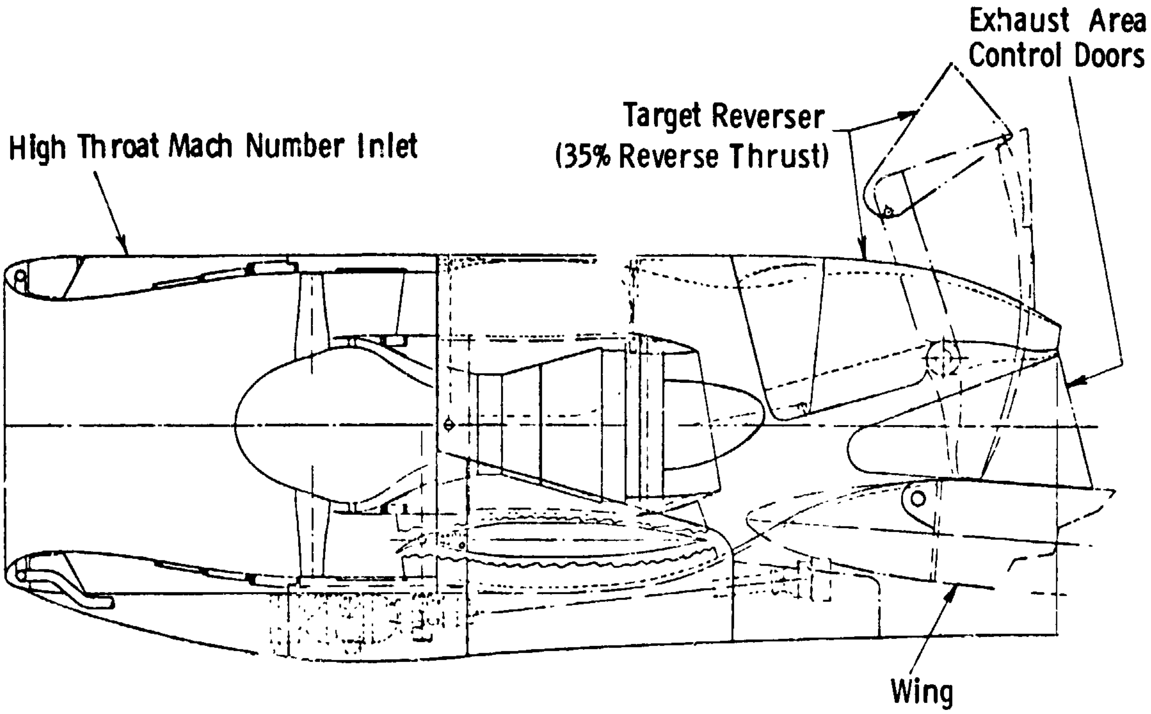


Figure 11.- QCSEE OTW nacelle - sideview variable nozzle and thrust reverser.