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ABSTRACT

A study of supersonic vertical takeoff or landing (VTOL) fighter aircraft employing two engine types, a conventional medium bypass ratio turbofan, and a turbine bypass turbojet was carried out. The aircraft assumed was a clipped delta wing with canard configuration. A VTOL deck launched intercept, DLI, mission with Mach 1.6 dash and cruise segments was used as the design mission. Several alternate missions requiring extended subsonic capabilities were analyzed. Comparisons were made between the turbofan (TF) and the turbine bypass turbojet (TBE) engines in airplane types using a Remote Augmented Lift System, RALS and a Lift plus Lift Cruise system (L+LC). The figure of merit was takeoff gross weight for the VTOL DLI mission.

The results of the study show that the turbine bypass turbojet and the conventional turbofan are competitive engines for both type of aircraft in terms of takeoff gross weight and range. However, the turbine bypass turbojet would be a simpler engine and may result in more attractive life cycle costs and reduced maintenance. The RALS and L+LC airplane types with either TBE or TF engines have approximately the same aircraft takeoff gross weight.

NOMENCLATURE

AB	Afterburner
BPR	bypass ratio
DLI	deck launched intercept
FPR	fan pressure ratio
ft	feet
g	gravitational gas constant
lb	pound
L+LC	lift plus lift-cruise
M	Mach number
max	maximum
min	minimum
n.mi.	nautical mile
OPR	overall pressure ratio
opt	optimum
R	degrees Rankine
sec	second
SFC	specific fuel consumption
SL	sea level
TBE	turbine bypass engine
temp	temperature
TF	turbofan
TOGW	takeoff gross weight
$W\sqrt{\theta}/\delta$	corrected airflow rate

Subscripts

m	mass
f	force

I. INTRODUCTION

Providing a vertical takeoff or landing (VTOL) capability to high speed aircraft posses many challanges in aircraft/propulsion system integration. This is especially true for supersonic aircraft. This type of aircraft requires a low frontal area whereas lift systems tend to increase the frontal area. Some of the concepts that have been studied thus far[1,2] are shown in figure 1. The VATOL concept requires the aircraft to takeoff and land in a vertical attitude and may be objectionable from the pilot's viewpoint. The lift plus lift-cruise (L+LC) system carries dedicated lift engines. This would tend to improve engine performance at cruise. Since they would not be oversized for takeoff, they need not be throttled back drastically at cruise with resulting penalties in specific fuel consumption. However, unless the lift engines can be used for other flight conditions they represent a weight penalty. Also, the two engine types may result in higher life cycle costs.

The remote augmentor lift system (RALS) in figure 1 is powered by a turbofan engine. The engine duct flow is directed to the remote burners during vertical takeoff and landing. This system is less compact than the L+LC system because of the RALS ducting. Also, it would have a hot footprint during VTOL operation.

The tandem fan system is similar to remote lift fan systems. Separate air intakes are provided for the front fan and for the main engine when in VTOL operation. An attractive feature of this system is that the front fan is used during both VTOL and cruise flight.

The turbojet would be a compact engine for a VTOL aircraft. However, an undesirable problem in using the turbojet is that part of the hot exhaust gas must be ducted to the forward lift point. A means of avoiding this problem is provided by the turbine bypass engine (TBE). This concept was first reported by Boeing in their supersonic cruise airplane studies contracted by NASA-Langley. In this conceptual turbojet some of the compressor discharge air is bypassed around the burner and turbine and reinjected into the nozzle. For aircraft requiring wide variations in engine power, the turbine bypass provides a better cycle match and improved performance. Studies have been made of the turbine bypass turbojet (TBE) for a commercial supersonic transport.[3]

Since the compressor discharge air of the TBE provides an attractive air supply for the

RALS during VTOL, in-house studies of this concept have been carried out at NASA-Lewis. In these studies, the TBE and a conventional mixed flow turbofan were analized in both the RALS and L+LC airplane systems. Engine performance and missions studies were performed for these engine concepts. The potential of the engines was assessed in terms of the performance of an advanced supersonic VTOL fighter. This paper provides the results of these studies.

II. METHOD OF ANALYSIS

The airplane used for the study is shown in figure 2. The baseline aircraft has two main engines. For the RALS, main engine air is ducted forward to a remote augmentor for vertical thrust in addition to the vectored thrust of the two main engines. For the L+LC system, one scaled XL99 lift engine is located forward for the front thrust. The location of the front thrustor was adjusted for center of gravity. Reaction controls powered by main engine air are located at the wing tips. These provide pitch, yaw and roll control by modulating thrust vectors. As shown in figure 2 the airplane is a clipped delta wing with canard configuration. The weight and dimensions of the airplane vary with propulsion system type and mission constraints.

The five missions included in the study are shown in figure 3 and 4. As indicated in the figures, the deck launched intercept and combat air patrol missions are for VTOL. The other three missions are for short takeoff or landing (STOL). The airplane was designed for the deck launched intercept (DLI) mission (figure 3). The design was held fixed for the remaining missions and the takeoff weight adjusted for the fuel and weapons required for each mission. A fuel reserve of 5 percent was assumed in the study.

The airplane/mission calculations were performed with the NASA Lewis Airplane Mission Analysis Code (AMAC) which computes the volumes, dimensions, weight, and aerodynamics of the airplane and "flies" it over the prescribed mission. The airplane and engine were sized to meet the design constraints listed in figure 3. The first three constraints are satisfied by engine sizing. The specific excess power (PS) goal and the one minute acceleration from Mach 0.8 to Mach 1.6 at 35000 feet are usually the most critical constraints and engines sized for these two met the other constraints including VTO. The last constraint (6.2 g's at Mach 0.6, 1000 feet) was satisfied by adjusting the wing loading.

The uninstalled engine performance was first calculated without inlet and nozzle drags using the Navy-NASA Engine Program (NNEP).[4] The engine component aerodynamic characteristics, efficiencies, and cooling requirements used in the program are compatible with a mid-1990's technology level. The installed engine performance is the uninstalled performance adjusted for the inlet and nozzle drags. The inlet drags include cowl pressure drag, bypass drag, and spillage drag. Nozzle performance includes the boattail drag.

The installed propulsion system weight includes the engine, inlet, and nozzle. The propulsion system weight was calculated using an engine weight computer code.[5]

III. DISCUSSION

The Turbine Bypass Engine

For most aircraft turbine engines the turbine is choked for nearly all operating conditions. Therefore, for a fixed turbine, the turbine corrected airflow will be constant for nearly all operating conditions. In a conventional turbojet, the compressor will operate at pressure ratios and airflows to match the constant value of turbine corrected airflow. This places limitations on the throttle excursions the turbojet can achieve. At high throttle (high turbine inlet temperature) the compressor operating point moves toward the surge region. At low throttle the compressor operates at low pressure ratios which deteriorate engine performance. One means of reducing these restrictions is a variable area turbine. This permits the turbine corrected airflow to vary, permitting wider excursions in throttle without affecting the compressor operating point. The objective of the turbine bypass concept is very similar to that of the variable area turbine. However, instead of varying the turbine area, the turbine airflow is varied. Figure 5 shows a schematic of this concept for a single-spool turbojet. The compressor is matched to an undersized turbine and provision is made for bypassing some compressor discharge air around the burner and turbine and into the nozzle. As shown in the figure, the turbine inlet temperature for zero bypass is 2100°R. As the turbine inlet temperature is increased, the bypass airflow is increased. The actual turbine airflow is reduced to maintain a constant turbine corrected airflow. In this example, the compressor operates at a single point for turbine inlet temperature variations from 2100°R to 3260°R. In addition to the engine performance benefits provided by the TBE, this concept is an attractive alternative for the remote augmentor lift system for VTOL aircraft.

Propulsion Systems

As mentioned before, the TBE and a conventional, mixed flow turbofan were studied for both the RALS and L+LC airplane types. The engine cycle characteristics for these engines are provided in Table I. Schematics of the propulsion system arrangements for the RALS systems are shown in figure 6. For the RALS/turbofan system the bypass air is supplied to the remote burner where the air is heated to 3260°R during VTOL operation. For this system the RALS supplied 30 to 50 percent of the total lift. For other flight conditions the engines operate as mixed flow turbofans. For the RALS/TBE system the compressor bypass air is directed to the remote burner for VTOL and to the engine nozzle at other flight conditions. During vertical takeoff the engines are operated at maximum power and the amount of bypass air going to the remote burner is a maximum. This amounts to about 20 percent of the engine airflow in this example. The RALS provides about 17 percent of the total lift in the RALS/TBE system. For other flight conditions where high power is required such as acceleration and combat the bypass air is injected into the engine nozzle. As indicated in figure 6, the duct sizes for the RALS/TBE would be about 1/3 the size of those for the RALS/turbofan system.

For the L+LC propulsion systems, the TBE or turbofan engines are the main engines and the performance and weight characteristics of the XL99 are used for the lift engine. The lift engine is sized to provide 30 percent of the total lift for VTOL operation.

Figure 7 shows a comparison of the turbine bypass engine (TBE) and turbofan engine (TF) performance at Mach 1.6 and 0.8. Some typical operating points for a DLI mission are also shown in the figure. The indicated climb thrust is the climb throttle setting at Mach 1.6. About 65% of the usable fuel is consumed during the three flight segments at Mach 1.6. For climb and combat the TBE has about 13% lower fuel consumption than the turbofan. For dash and the Mach 0.8 cruise the fuel consumption of the two engines is about the same. The better supersonic SFC's of the TBE lead to lower overall fuel consumption compared to the turbofan. As shown in Table I, the dry thrust/engine weight (FN/W) ratios of the TBE is better than that of the TF and the afterburning FN/W ratios are nearly the same. It will be shown later that the heavier engine weight of the TBE compared to the turbofan (for the same airflow) offsets this advantage to some extent.

Mission Results

Figure 8 shows a comparison of the TBE and turbofan engines in L+LC aircraft in terms of takeoff gross weight (TOGW). Both dry and afterburning engines are shown. As indicated in the figure, the aircraft are sized for the VTOL DLI mission and the comparisons in this figure are for this mission. The climb thrust of the dry turbofan is marginal for this mission resulting in large engines and excessive fuel consumption. The aircraft with dry turbofans is about 85% heavier than the dry TBE aircraft. Afterburning does not improve the TBE aircraft significantly (about 8% reduced TOGW), but results in large improvements to the turbofan aircraft. This shows that the turbofan requires afterburners, but the TBE may not need afterburners resulting in a much simpler propulsion system. However, when both engines are compared with afterburners the TOGW of the turbofan aircraft is only slightly larger than the TBE aircraft.

Figure 9 shows a comparison of aircraft TOGW for RALS and L+LC systems with TBE and turbofan engines. All of these engines except the XL99 lift engine are equipped with afterburners. The high thrust/weight ratio of the XL99 lift engine (about 14 installed) provides a lightweight lift system competitive with the RALS. As seen in the figure the RALS and the L+LC propulsion system result in about the same TOGW. It should be emphasized that the turbofan requires afterburners for both RALS and the L+LC aircraft to perform the DLI and CAP missions while the TBE does not. This is due to the climb to supersonic speed segment of this mission.

Figure 10 compares the propulsion systems for the alternate missions. Since the large TOGW of the airplanes with dry turbofans (figure 8) indicate dry turbofans are not suitable for this type of airplane, only afterburning turbofans are considered in this comparison.

In comparing the dry TBE with the afterburning TBE for both RALS and L+LC aircraft, it is seen that the dry TBE is better than the afterburning TBE for Combat Air Patrol VTOL (CAP) and Strike. Engines sized for the supersonic Deck Launched Intercept mission give adequate power without afterburning for the subsonic CAP and Strike missions. The afterburning engines are smaller and lighter and operate at better SFC's during dry operation (not throttled back as far) than the dry TBE's. However, the use of afterburning during climb and combat results in excessive fuel consumption and less range. For Subsonic Surveillance about 50% of the mission fuel is used during loiter and for the Ferry mission about 85% of the mission fuel is used for subsonic cruise. Both the dry and afterburning TBE's operate dry for these missions and the loiter time and range about the same.

In comparing the turbofan with the TBE, it is seen that the turbofan does somewhat better that the TBE on all of the alternate missions. Since these mission are all subsonic, the SFC's of the turbofan are better than those of the TBE (figure 7) resulting in better range and loiter capabilities.

In comparing the RALS and L+LC aircraft for the alternate missions both systems provide about the same alternate mission capabilities.

CONCLUDING REMARKS

The turbine bypass engine and a medium bypass ratio mixed flow afterburning turbofan are competitive engines for a VTOL aircraft in terms of takeoff gross weight. Afterburning provides a small benefit for the TBE, but is required in the turbofan to make it competitive with the TBE. For the RALS system the TBE would result in smaller duct sizes and lead to less complexity. Since the TBE does not need an afterburner for either the RALS or the L+LC aircraft and being a simpler engine than the turbofan it may be a more attractive engine in terms of life cycle costs. Comparisons of the RALS and L+LC systems show that both provide about the same takeoff thrust/weight ratios and result in about the same aircraft takeoff gross weight.

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2. R. W. Luidens, G. E. Turney and J. Allen, "Comparison of Two Parallel/Series Flow Turbofan Propulsion Concepts for Supersonic V/STOL," AIAA Paper 81-2637, December 1981.

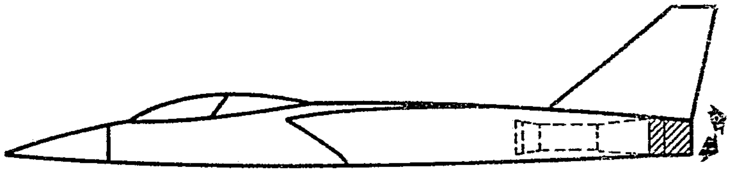
3. L. C. Franciscus, "Turbine Bypass Engine - A New Supersonic Cruise Propulsion Concept," National Aeronautics and Space Administration TM-82608 (1981).

4. L. H. Fishbach and M. J. Caddy, "NNEP - The Navy-NASA Engine Program," National Aeronautics and Space Administration TM X-71857 (1975).

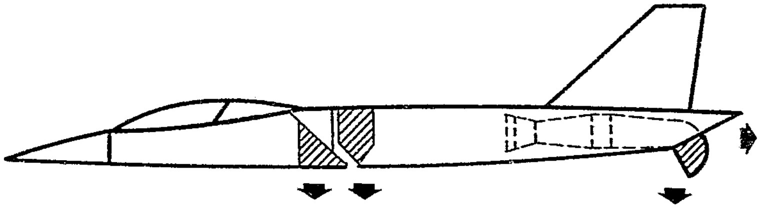
5. E. Onat and G. W. Klees, "A Method to Estimate Weight and Dimensions of Large and Small Gas Turbine Engines Final Report," National Aeronautics and Space Administration CR-159481 (1979).

TABLE I - ENGINE CHARACTERISTICS

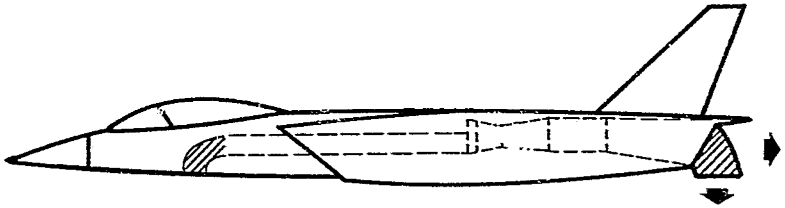
	TBE	TF
ENGINE CYCLE DESCRIPTION		
$W\sqrt{\theta}/\delta$, lbm/sec	175	175
FPR	---	3
OPR	15	15
BPR	---	1.0
MAX CET, °R	3260	3260
MAX AB, °R	3260	3260
MAX RALS TEMP., °R	3260	3260
ENGINE WEIGHT		
Engine + Nozzle + RALS, lbm	2755	2329
THRUST TO WEIGHT - DRY/AB	6.2/7.5	5.3/8.0



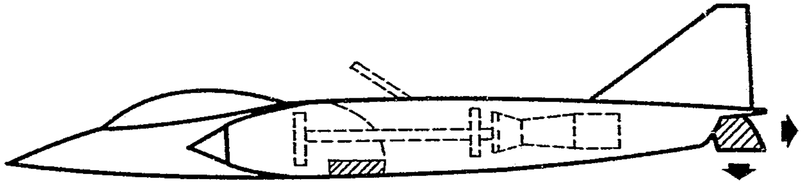
VATOL CONFIGURATION



LIFT + LIFT/CRUISE CONFIGURATION



REMOTE FAN BURNING CONFIGURATION



TANDEM FAN CONFIGURATION

Figure 1. - VTOL airplane concepts.

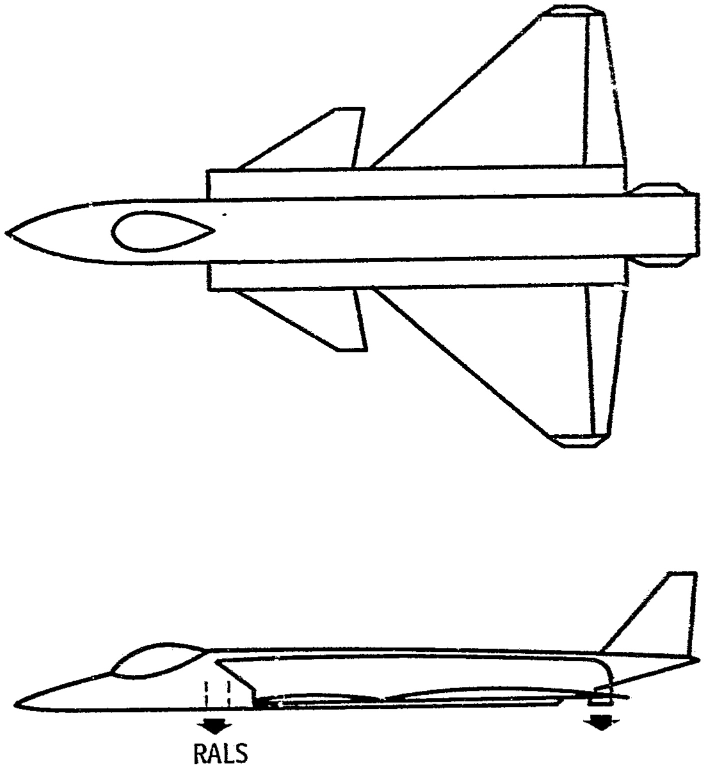
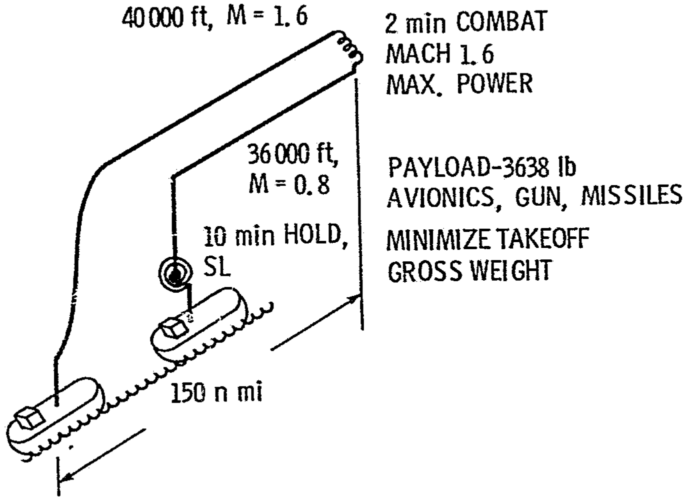


Figure 2. - Aircraft configuration.



DESIGN CONSTRAINTS

1. 2 minute combat at M = 1.6; max power
2. Excess specific power - 900 ft/sec
3. 1 minute acceleration from M = 0.8 to M = 1.6 at 36 000 ft
4. 6.2 g load at M = 0.6, 10 000 ft

Figure 3. - Deck launched intercept mission; design mission.

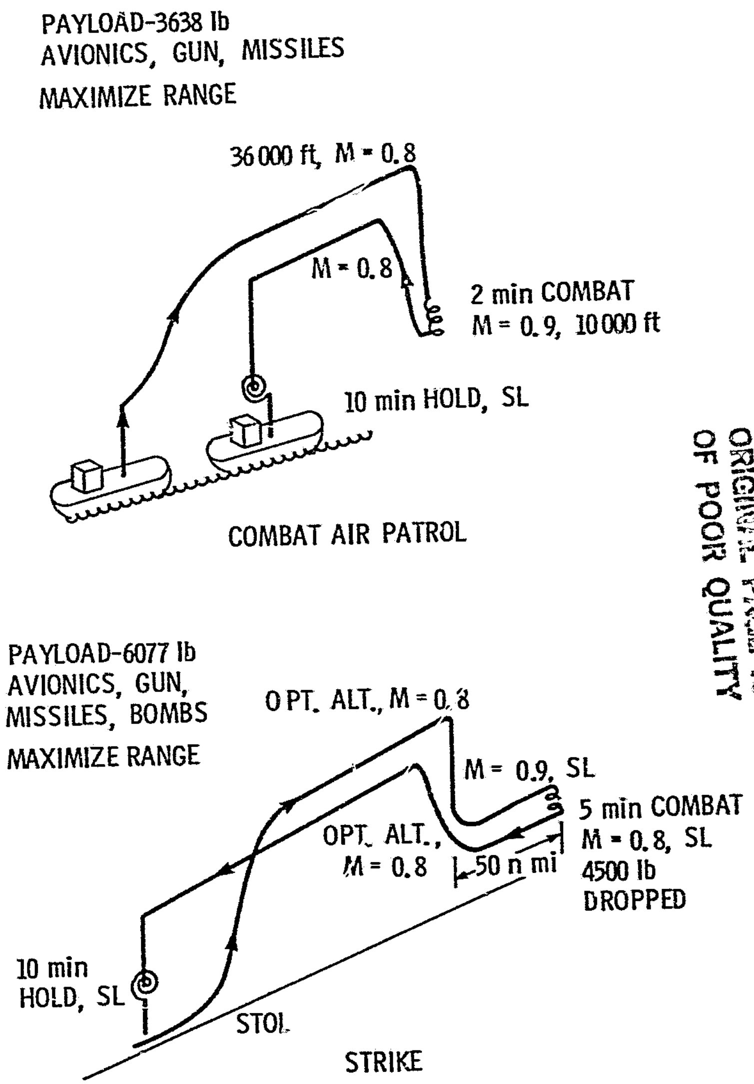


Figure 4. - Alternate missions.

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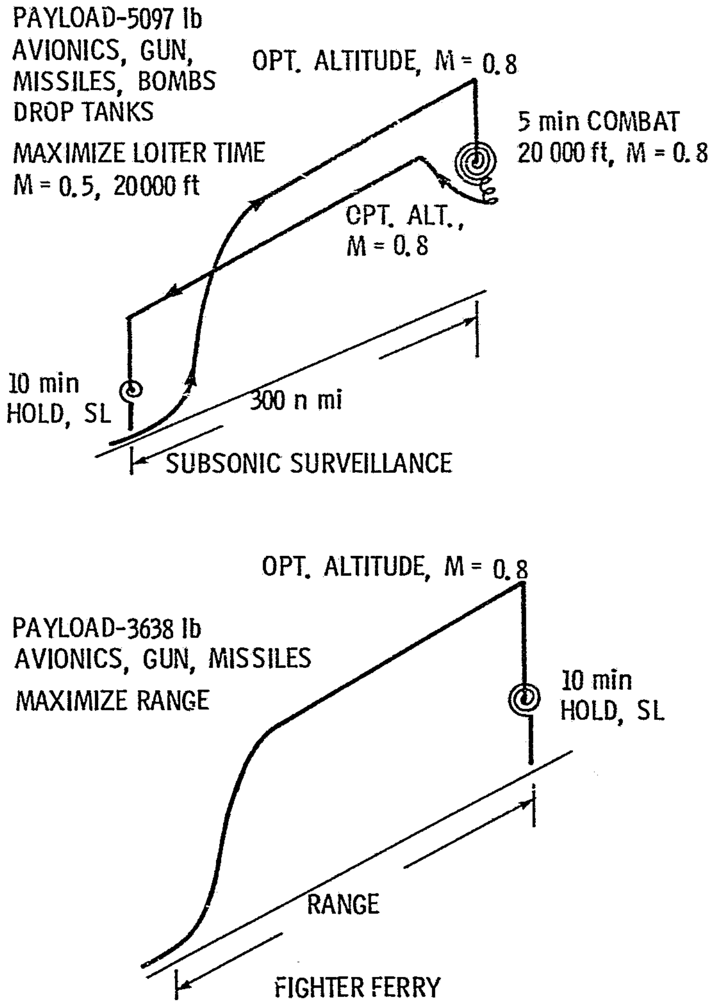

Figure 4. - Concluded.

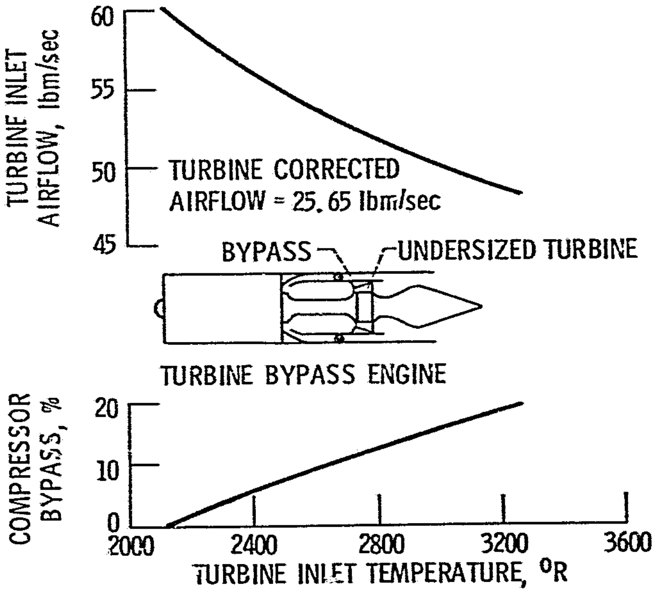

Figure 5. - Variation of bypass air and turbine inlet air with turbine inlet temperature; Mach 0.8; altitude - 36000 ft; engine corrected airflow - 175 lbm/sec.

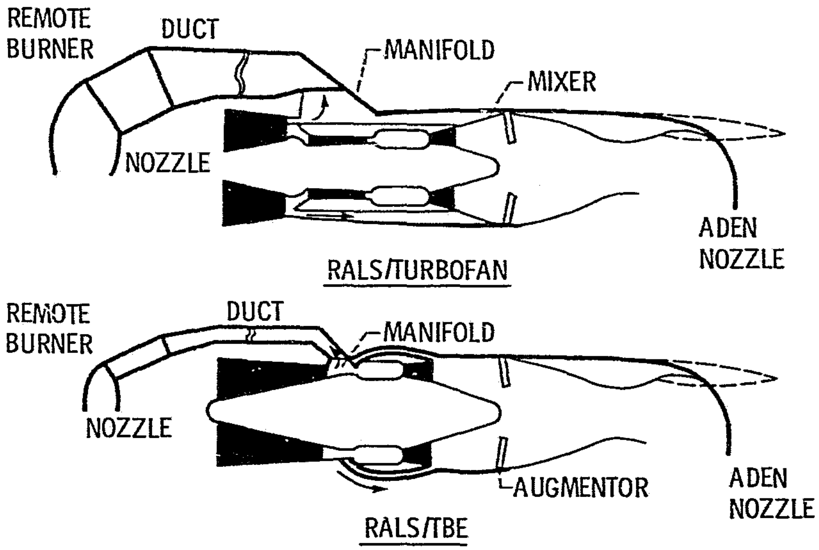

Figure 6. - RALS propulsion systems.

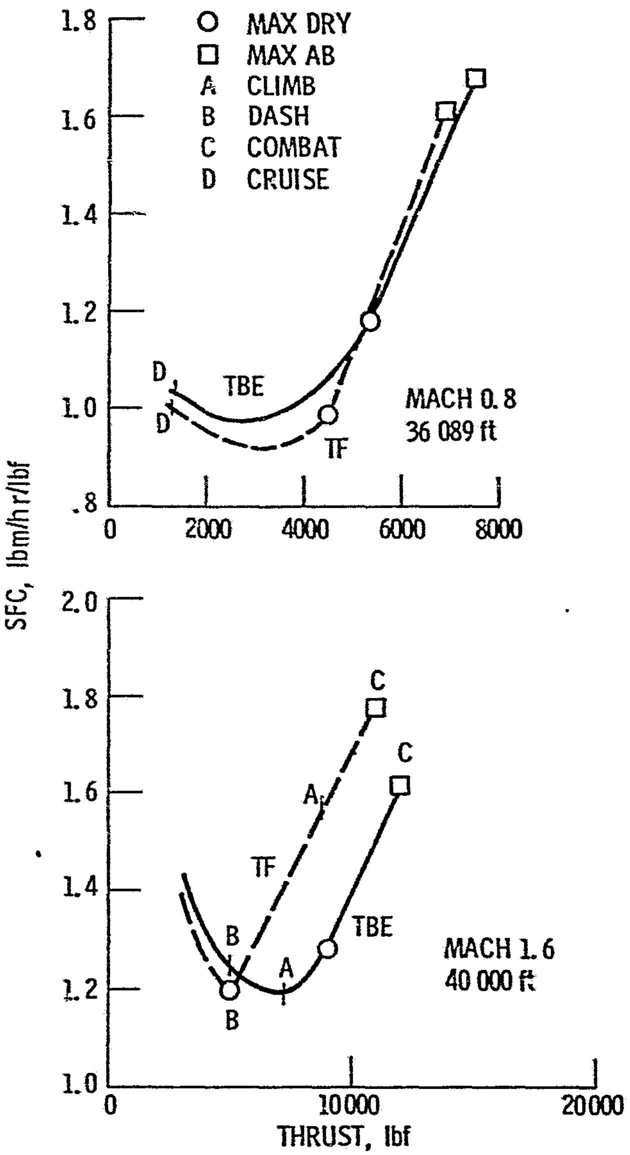

Figure 7. - Comparison of engine performance of the TBE and the turbofan engine; sea level static airflow - 175 lbm/sec.

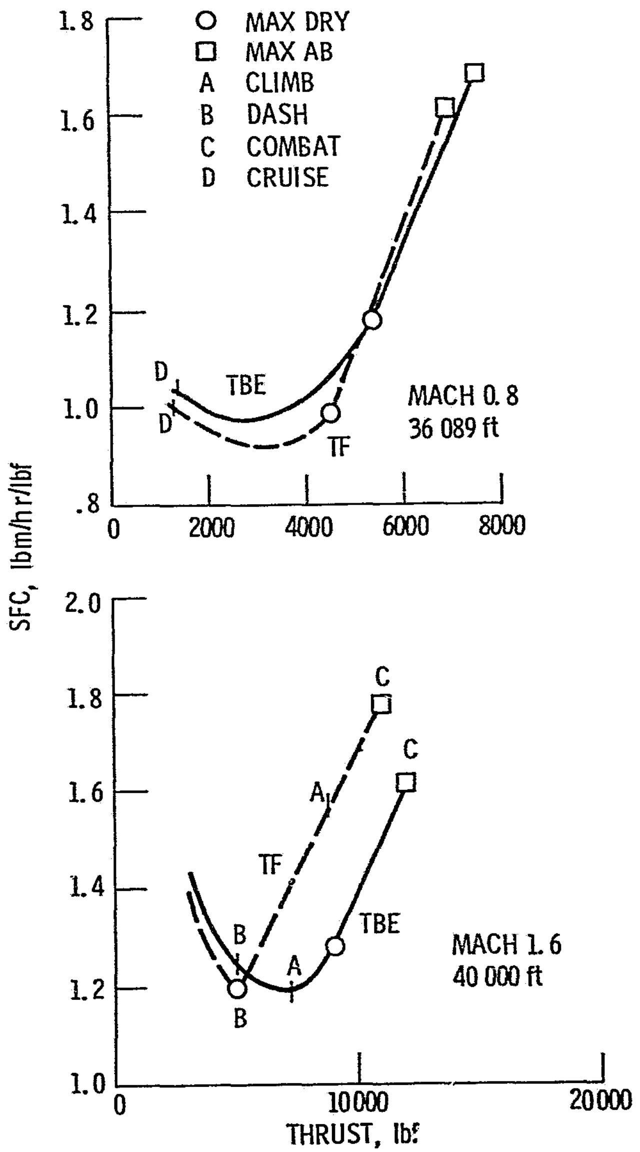

Figure 7. - Comparison of engine performance of the TBE and the turbofan engine; sea level static airflow - 175 lbm/sec.

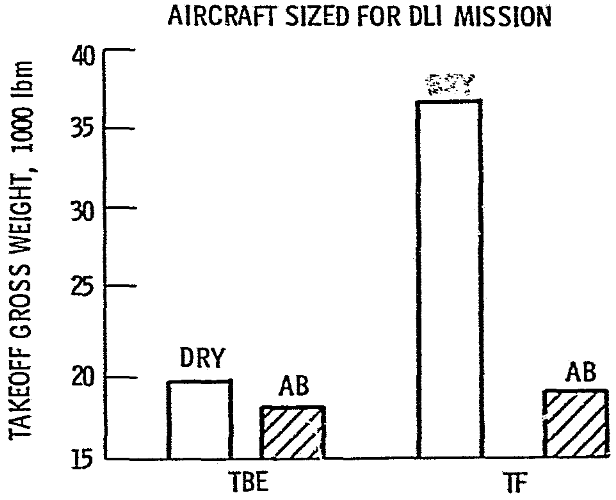

Figure 8. - Comparison of the aircraft takeoff gross weight of the TBE and turbofan aircraft sized for the deck launched intercept mission.

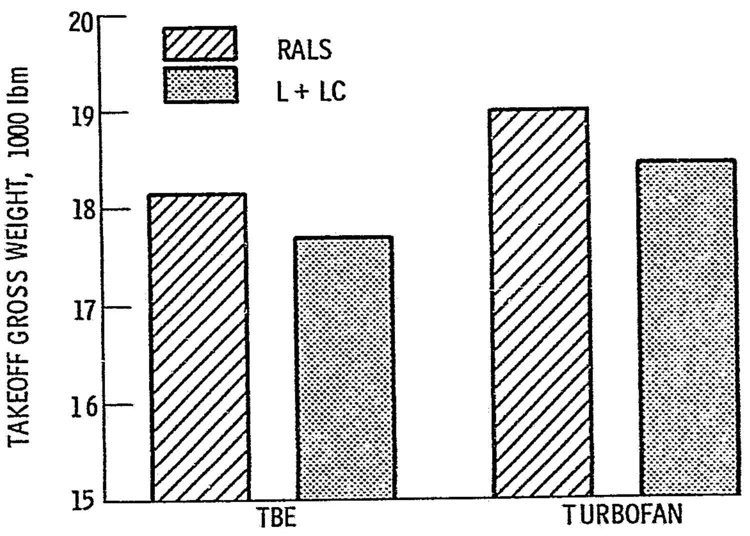

Figure 9. - Comparison of the aircraft takeoff gross weight of RALS and L + LC systems; aircraft sized for the deck launched intercept mission; all main engines equipped with afterburners.

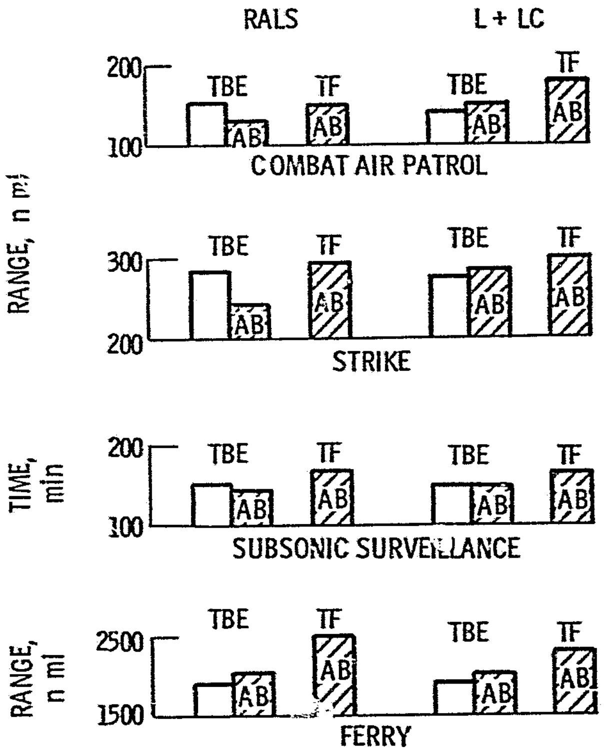

Figure 10. - Propulsion system comparisons for alternate missions; aircraft sized for the deck launched intercept mission; all with VTOL capability.