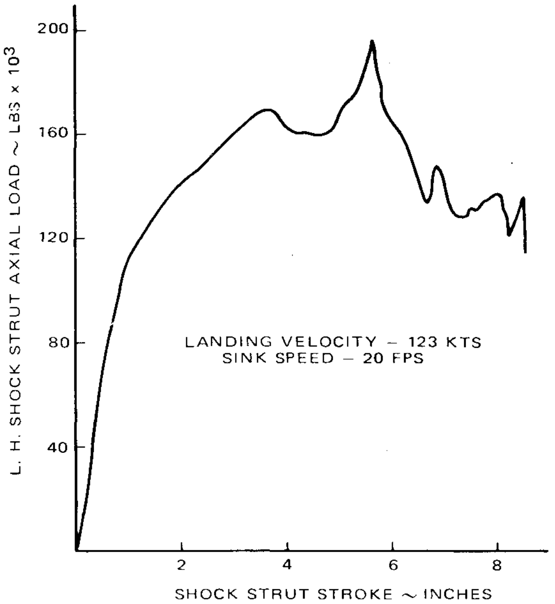

Fig. 21 Flight test data—shock strut.

Figures 18–21 are plots of some data recorded during the flight tests. These data are typical of the flight test data and are included to show the similarity with the laboratory data. These plots cannot be compared directly with any of the other data presented here for the same reasons given in the paragraph on drop tests. They do show, however, that similar data is obtained from the three test methods (roller plate platforms, shuttle plate, and flight test) so long as there is no requirement for running over deck obstructions. When this requirement is present, the shuttle plate provides the better and more economical method.

Conclusions

Construction of the facility provided VSD with the most accurate method known for dynamic simulation of aircraft landings. It provided precise control of the parameters necessary to verify design loads and conditions and, for the first time, the design loads for a navy aircraft resulting from encountering deck obstructions during landing impact have been accurately simulated in the laboratory. Flight testing has not and cannot be expected to serve this purpose because of the inability to accurately control the initial conditions at touchdown such as encountering the obstruction at the critical stroke position. Furthermore, the facility is an improvement on former methods of drop testing disregarding the deck obstruction encounter capabilities. This is because certain critical member loads are not accurately simulated using the roller plates or other past methods, especially in the case of tripod type landing gears.

Utilization of the facility to date, however, has been limited to verification testing of a single landing gear design and, though excellent simulation has been achieved, much more testing needs to be done. Member loads and shock absorption capabilities are affected not only by the geometrical arrangement but also by such variables as landing velocity, lift to weight ratio at touch down, tire size and inflation pressure, and of course the shape and size of obstructions encountered. The facility provides an excellent tool for the study of such variables with or without an airplane. As has been shown in this brief description of tests performed, very valuable data can be obtained by means of relatively simple tower drops of single gear assemblies as well as by means of full scale airplane drops.

It is to be noted also that the facility has other applications. Already it has been used in development tests of a linear induction motor for a ground transportation vehicle and in the study of the effects of velocity on the characteristics of some rather large permanent magnets and electromagnets. Other applications in tests requiring a moving ground plane are being considered.

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Advanced Technology Thrust Vectoring Exhaust Systems

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Systematic studies of a series of candidate thrust vectoring exhaust nozzle systems were performed to identify the best system for an advanced VTOL fighter/interceptor. The investigation used generalized nozzle and installation data in finding that a nozzle arrangement featuring a "trap door" thrust vectoring device was competitive with other types for nonaugmented vertical operation and offered superior installation qualities. A three-bearing rotating elbow nozzle was best when partial afterburning was employed for deflected thrust. Nozzle selections were based on study results as well as subjective appraisals by aircraft companies.

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Index categories: VTOL Aircraft Design; VTOL Mission and Transportation Systems; VTOL Powerplant Design and Installation.

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Introduction

AS the military effectiveness of a single aircraft is increased through improvement in all systems involved in weapons delivery, conventional aircraft carriers can be supplemented by smaller "sea control ships" which carry a much reduced complement of aircraft, yet provide a major contribution to fleet defense and surface attack capability. With effective defense at low cost as a prime objective, deck space and ship size will be kept small by using vertical and short takeoff and landing (V/STOL) aircraft.

Many propulsion and aircraft studies have shown that one of the most effective ways to provide VTOL for a fighter aircraft is to use vectored thrust from the main engines plus lift engine thrust. Thus, in a sense, the launch and retrieval capability conventionally represented by the steam powered catapult and the canted deck with the arresting gear will be nicely tucked away aboard this new fighter in the form of an advanced technology thrust vectoring exhaust system supplemented by compact lightweight special purpose lift engines. The goal of the airframe designer is to provide this VTOL capability with minimum penalty.

A limited choice of exhaust systems capable of thrust deflection is available for the VTOL fighter aircraft where efficient supersonic flight and high maneuverability are required. To relieve this situation, the Navy has initiated an advanced development program which includes the definition and initial development of thrust vectoring exhaust systems applicable to an advanced V/STOL fighter /interceptor. The following discussion presents the results of a survey and analytical study of several thrust vectoring nozzles plus a discussion of the best nozzles for a selected mode of operation.

Approach

Studies of a series of candidate thrust vectoring exhaust nozzle systems were performed for typical mission requirements for an advanced VTOL fighter/interceptor. The nozzles were installed on an afterburning mixed flow turbofan engine with performance characteristics basically suited to the mission. The studies used generalized exhaust system performance derived from 1) basic test data, 2) engine performance adjusted for cooling air requirements of the nozzle, 3) estimated nozzle weight and geometry based on preliminary sketches, analyses, and prior nozzle designs, and 4) parametric installation factors applied through the rationale of an aircraft sizing and mission analysis computational system. Nozzle selections were based on the results of these studies.

The payoff parameter for the in-house analytical studies was minimum aircraft gross weight required to accomplish the design mission, while the participating aircraft companies provided comments and ratings on factors related to performance, installation, and over-all suitability.

Aircraft Operating Requirements

For the analytical studies, a typical set of requirements were postulated which served to determine the engine thrust size, aircraft gross weight, and the internal fuel requirement.

Thrust Size

The aircraft flight performance requirements are shown in the Mach number versus altitude envelope of Fig. 1. Hot-day vertical capability (VTO) was required with total vertical installed thrust exceeding aircraft weight by 5% for condition 1. Acceleration, turn, maximum speed, and maneuver requirements reached satisfactory levels at con-

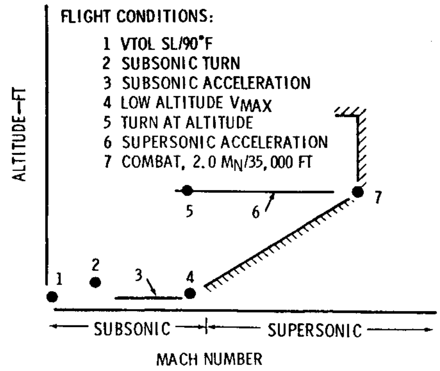


Fig. 1 Typical operating requirements.

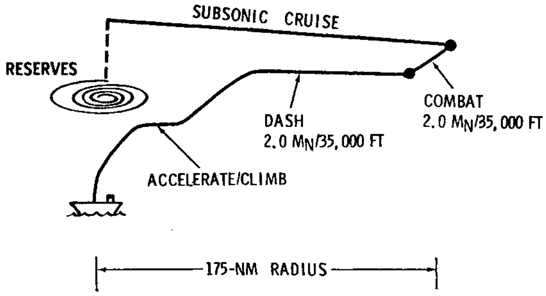


Fig. 2 Typical deck-launched interceptor mission.

ditions 2-6 if the engines provided sufficient excess thrust (P_s = 625 fps) for combat at Mach 2 and 35,000 ft with maximum afterburning thrust (condition 7). This combat requirement established the size of the main engines and, thus, the thrust available from the main engines for the VTO condition. The additional thrust required for VTO established the size of the lift engines.

Design Mission

The deck launched interceptor (DLI) mission used is shown in Fig. 2. The radius is 175 nm with a vertical takeoff and landing. The mission radius includes an accelerate/climb to 35,000-ft altitude, Mach 2 dash-out and best cruise return subsonically. A midpoint combat is required for a specific energy gain equivalent to 2 min at maximum thrust.

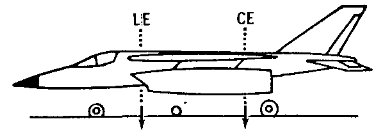
Basepoint Aircraft

A sketch of the basepoint aircraft appears in Fig. 3. The aircraft features podded nacelles and four externally mounted missiles. Static balance is assumed, and thrust balance is obtained from relative placement of the main engines and lift engines. External compression, two-dimensional, variable geometry inlets are sized for engine flow at Mach 2 and 35,000 ft. A wing loading of 80 lb/ft^2 was used to provide good subsonic turn capability. No attempt is made to estimate changes in interference drag or wave drag as effected by engine configuration and placement.

Basic Engine Characteristics

Advanced technology cruise and lift study engines were applied. The cruise engine is an afterburning turbofan se-

Fig. 3 Base-point aircraft.



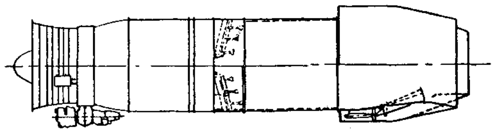


Fig. 4 Basic cruise engine.

lected for a balance in high supersonic thrust and good subsonic fuel economy. The engine is typical of an IOC 1980 to 1983 fixed-geometry turbofan which performs well in an interceptor role and also provides reasonable subsonic alternate mission capability. Design characteristics for the cruise engine are shown in Fig. 4.

The lift engine is a turbojet capable of supplying the aircraft attitude control system with compressor discharge bleed air up to 15% of engine inlet flow. Technology assumed in this design is equivalent to a thrust-to-weight ratio of 22:1 for a zero bleed design.

Turbofan Engine Matrix

Twelve basic vectoring exhaust nozzle systems were processed through preliminary design and mated to the turbofan engine. The matrix features four types of thrust vectoring systems, i.e., ventral or "trap door" system, three-bearing pipe, folding elbow, and swivel cascade nozzle systems. Various cruise nozzles were employed including convergent and convergent-divergent types. The cruise nozzles were designed to work in a maximum afterburning temperature environment throughout the flight envelope. Two gas temperature limits were investigated for the lift nozzle systems. Lift systems employing partial augmentation in the deflected gas stream were limited to a common temperature selected as a practical limit consistent with material constraints and reasonable cooling flows. Lift systems operating without augmentation were subjected to the temperature of the mixed exhaust flow of the turbofan engine. Thus, study engines were configured to be fully augmented at cruise and either partially augmented or nonaugmented for lift. One completely nonaugmented engine was included with a swivel cascade nozzle system to complete the matrix.

Exhaust System Design Features for Lift

The trap door vectoring nozzle shown in Fig. 5 consists of a cylindrical casing with a rectangular opening in the bottom. Fixed-side plates and movable front and rear vanes extend from the opening. In the lift mode, the entire engine flow is exhausted through the trap door opening. Trap door thrust may be vectored from a "reverse" position forward of vertical to the "lift off" position which extends to an intermediate aft position all with full engine flow. In the "high vector" operating mode which extends to the horizontal, the flow is divided between the trap door nozzle and the cruise nozzle. In the transition between the lift and cruise conditions, the effective flow areas of the two nozzles are varied inversely so as to maintain essentially constant turbine speed and back pressure and substantially constant total thrust. Either a blocker valve or a star closure device is required to divert the exhaust gas from the cruise nozzle to the trap door nozzle. The star closure consists of a series of triangular sections hinged together to a cylindrical casing. This device forms the convergent cruise nozzle.

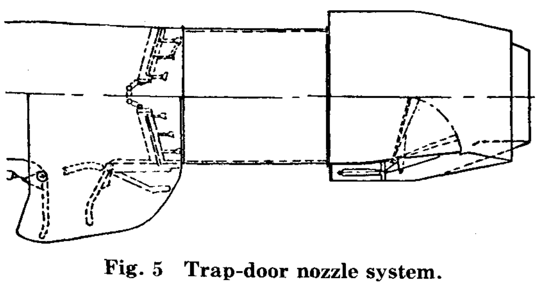


Fig. 5 Trap-door nozzle system.

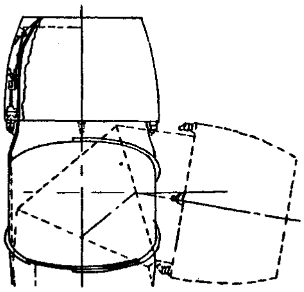


Fig. 6 Three-bearing pipe deflector.

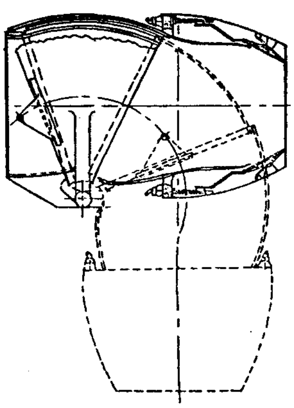


Fig. 7 Folding elbow deflector.

The three-bearing pipe nozzle shown in Fig. 6 consists of a cylindrical casing in which one peripheral bearing is placed at right angles to the engine centerline followed by two equal oblique peripheral bearings. Flow-path deflection is obtained by relative rotation of the segments. The relative rotation of the right-angle bearing can be scheduled to eliminate lateral thrust components during vector angle changes.

The folding elbow nozzle shown in Fig. 7 consists of a series of telescoping concentric segments of tori of graduated diameters. These segments are assembled and mounted such that straight-through cruise mode flow is obtained in the retracted condition. Any desired jet deflection angle up to the maximum can be obtained by extension of the segments.

The swivel cascade nozzles as shown in Fig. 8 are composed of a bifurcated pipe represented by two "elbow"

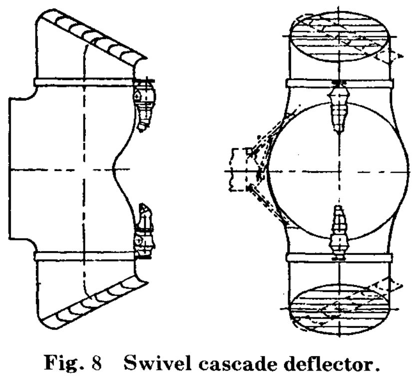


Fig. 8 Swivel cascade deflector.

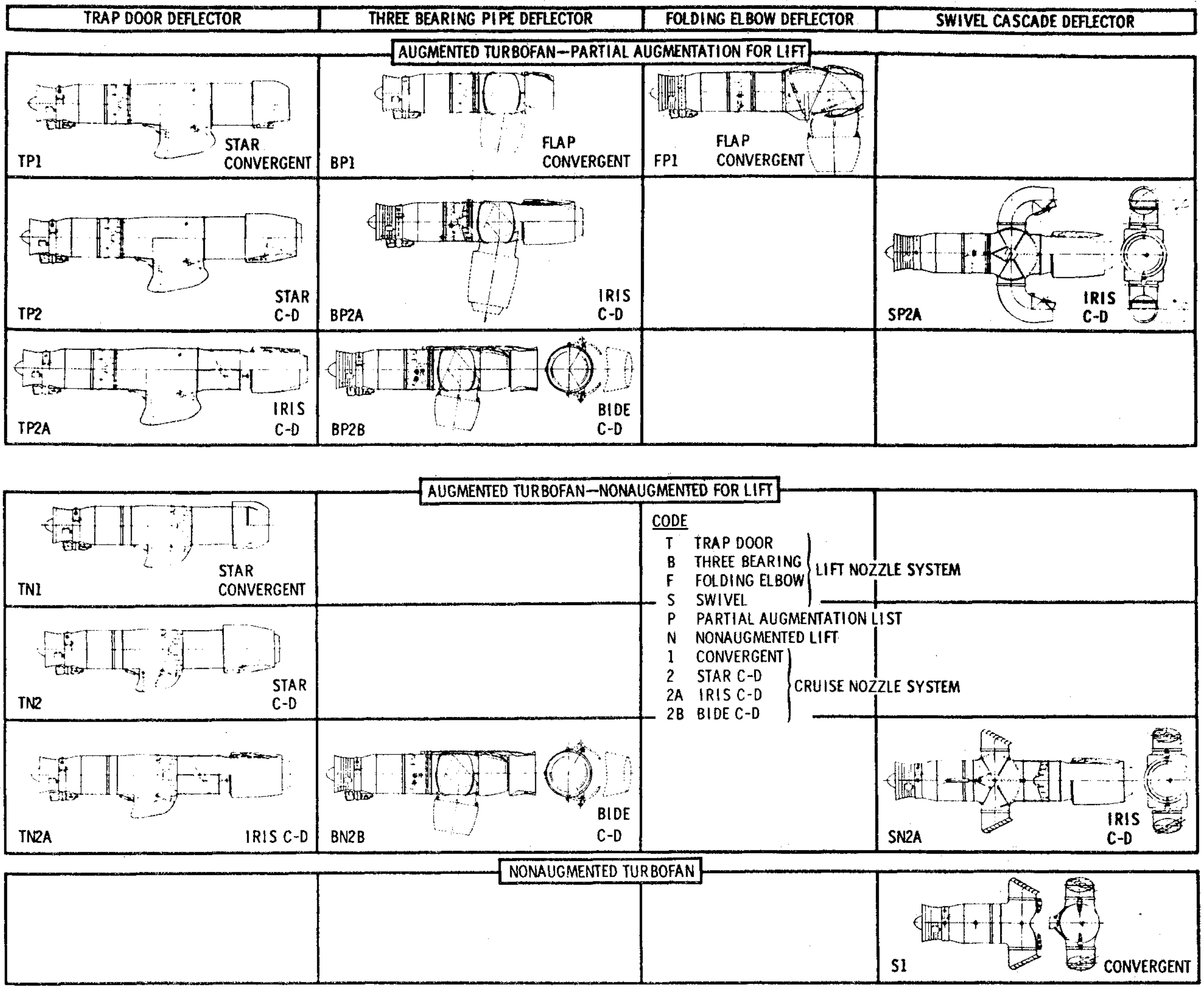


Fig. 9 Turbofan engine matrix.

stream tubes with each tube turning approximately 90°. These elbows are mounted on a bearing such that the exhaust can be rotated from straight aft to vertical.

Candidate Thrust Vectoring Systems

The candidate thrust vectoring exhaust system components include the lift nozzles previously described plus various arrangements of flow blockers, augmentors, and cruise nozzles. Each configuration was selected to test the effect of certain design features in a pattern to minimize the total number of configurations required to select the most desirable systems.

As shown in Fig. 9, the trap door deflector was used in six different arrangements, all with afterburners. Configurations TP1 and TN1 used a star closure convergent nozzle with a fixed shroud. Configuration TP1 has augmented lift, so the afterburner is located forward of the trap door. Configurations TP2 and TN2 are similar except that a divergent exhaust nozzle is added for cruise operation. In configurations TP2A and TN2A, the star cruise nozzle system is replaced with a convergent-divergent iris exhaust nozzle and a butterfly diverter valve.

Configurations BP1, 2A, and 2B employ the three-bearing pipe deflector. Configuration FP1 uses a conceptually similar folding elbow deflector. These units are designed for augmented cruise and partial augmentation for lift. Configurations BP1 and FP1 are compared with a convergent nozzle; BP2A has a C-D iris nozzle; and BP2B has a convergent nozzle mounted on the pipe and a blow-in door ejector nozzle which is airframe mounted.

Configurations SN2A, SP2A, and S1 employ the swivel cascade deflector principal. Configuration SN2A has two swivel cascade nozzles and a deflector valve followed in the flow path by the augmentor and a C-D cruise exhaust nozzle. With this system, the deflector valve rotates to provide unaugmented flow through the swivel cascade nozzles for lift or directs flow through the augmentor to the cruise nozzle for cruise operation. Thus, unaugmented thrust is vectored for lift, and full augmentation is available for cruise. Configuration SP2A is operationally similar to Configuration SN2A except that partial augmentation is used for lift. Here the deflector valve supplies two rotating pipe elbows equipped with variable area convergent nozzles to provide lift thrust. The afterburner is located forward of the diverter valve to allow augmentation for lift. Configuration S1 features the base-line turbofan engine without augmentation equipped with two convergent swivel cascade nozzles.

Engine Design Definition

Detailed preliminary design and analysis were performed on each of the engine configurations previously described. Cooling was provided each component to maintain specified metal temperatures to ensure structural integrity to all operating conditions. Sealing systems were selected for all sliding and rotating joints of the exhaust components and leakage estimates made. The cooling and leakage effects for each nozzle system were included in the engine performance estimates for that system.

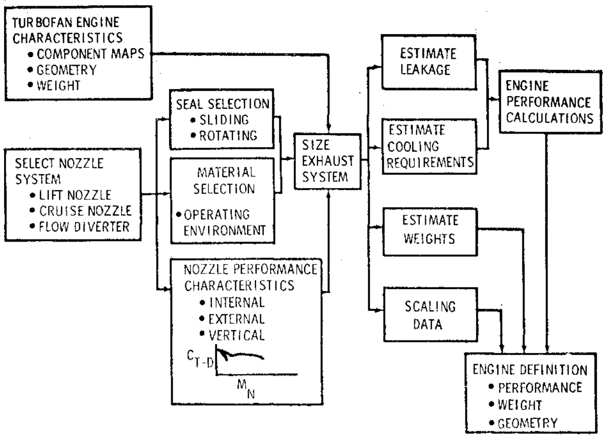


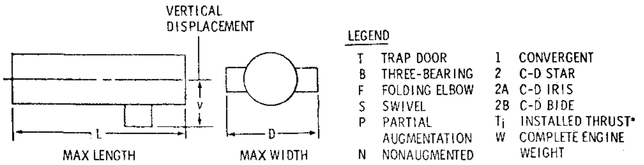
Fig. 10 Engine preliminary design matrix.

Each nozzle component was sized for the baseline turbofan engine and weight estimates based on similar nozzle designs from previous studies. A detailed weight breakdown of each component and each exhaust system was generated. Where the same component was used in several exhaust systems, its weight was appropriately adjusted to maintain a consistently comparable engine matrix.

Nozzle performance estimates were made for each nozzle in the subsonic and supersonic cruise modes and in the lift and transition modes to provide a further adjustment to the engine performance for each nozzle configuration. A general flow diagram of the design process is shown in Fig. 10.

Summary of Turbofan Engine Characteristics

Some of the significant characteristics of the turbofan engines are presented in Fig. 11 for comparative purposes. Dimensions which influence the nacelle wrap up of the engine and the ground clearance requirements are given in the upper half of the chart. These dimensions are divided by an arbitrary constant to provide a relative rather than absolute comparison. The lower half of the chart shows complete engine thrust-to-weight ratios at two conditions, i.e., combat at Mach 2, 35,000 ft, and maximum trthrust and VTO at sea level, hot day at lift off thrust. In this study, the former is a measure of the weight of the system as sized for combat, and the latter is a measure of the thrust available for VTO. Again, the actual ratios are divided by an arbitrary constant to show a relative comparison. A comparison of these data will show that the nozzle selection can be quite dependent on the aircraft system requirements.



VERTICAL TYPE	TRAP-DOOR						THREE-BEARING				FOLDING ELBOW	SWIVEL CASCADE		
AUGMENTATION	PAB			DRY			PAB			DRY	PAB	PAB	DRY	NO A/B
CODE	TP1	TP2	TP2A	TN1	TN2	TN2A	BP1	BP2A	BP2B	BN2B	FP1	SP2A		S1
L	1.32	1.42	1.48	1.13	1.23	1.32	0.91	1.09	1.05	1.05	1.07	1.15	1.24	0.63
D	—	—	—	—	—	—	—	—	—	—	—	0.73	0.55	0.48
V	0.28	0.28	0.28	0.23	0.23	0.23	0.32	0.50	0.32	0.32	—	—	—	—
$(T_i/W)_{COMBAT}$	0.85	0.94	0.96	1.09	1.19	1.23	1.25	1.32	1.16	1.16	1.18	1.02	1.28	0.44
$(T_i/W)_{VTO}$	0.82	0.79	0.83	0.70	0.67	0.70	1.20	1.07	1.00	0.67	1.15	0.88	0.73	1.07

*INSTALLATION EFFECTS INCLUDE NOZZLE/DEFLECTOR LOSSES AND MIL-E INLET RECOVERY.

Fig. 11 Relative turbofan engine characteristics.

1) Swivel cascade Configuration S1 has no afterburner and thus low-supersonic thrust. It is two to three times heavier than the other engines at the Mach 2 combat condition on the basis of thrust per pound of engine weight. Yet, the VTO thrust-to-weight ratio can be used to show the engine one of the lightest in providing lift thrust.

2) Convergent nozzle configurations (TN1, TP1, BP1, and FP1) tend to give lower thrust-to-weight ratio at combat than engines with C-D nozzles. Not shown in Fig. 11 is the fact that specific fuel consumption at high thrust supersonic conditions is also sacrificed.

3) Significantly higher thrust-to-weight ratios at VTO are prevalent when partial augmentation is used.

4) The trap door configurations tend to be heavier than the other types but have less vertical length.

5) It is apparent from the vertical length of Configuration BP2A that the movable tailpipe systems have a significant ground clearance problem if the convergent-divergent nozzle rotates with the tailpipe. Configurations BP1 and BP2B rotate with a convergent nozzle only and are much shorter.

6) The three-bearing pipe systems are generally shorter in over-all length than the other types.

Study Considerations

The effectiveness of each engine in satisfying the requirements of the vehicle was measured in terms of aircraft gross weight—the best engine producing the lightest aircraft by virtue of achieving a minimum installed propulsion system weight and fuel weight. The aircraft gross weight was influenced primarily by changes in engine design characteristics, i.e., thrust, fuel flow, geometry, and weight.

The process involved sizing the basepoint aircraft to perform all requirements of the design mission for each engine configuration. Basically, the cruise was sized for the critical thrust requirement. This permitted sizing of the lift engine to provide the additional thrust for vertical operation over that furnished by vectored thrust from the cruise engine. The aircraft fuel system was sized for the total fuel required by the lift and main engines to complete the flight plan. The process was iterative because drag and weight adjustments for engine, fuel, tankage, landing gear, wing, tail, and fuselage were made as each engine and scalable aircraft component reached the size required to meet the mission objectives. Some of the detail considerations involved in the analytical treatment of each engine in terms of engine, nacelle, and aircraft related factors involved in the installation of each engine configuration in the aircraft are as follows:

1) Engine/Deflector Nozzle Related Factors.
   a) Cruise nozzle internal and external performance.
   b) Deflector performance at VTO.
   c) Deflector and cruise nozzle cooling and leakage requirements.
   d) Weights.
2) Nacelle Related Factors
   a) Inlet size and weight.
   b) Maximum engine diameter including any fairings (swivel cascade).
   c) Aft doors for vectored thrust.
   d) Support structure for engine.
   e) Support structure for exhaust nozzle configuration.
3) Aircraft Related Factors.
   a) Lift engine thrust size.
   b) Fuselage volume.
   c) Landing gear length for lift nozzle ground clearance.

Summary of Results

In Fig. 12, relative aircraft gross weight for all afterburning engines is related to a lift system thrust-to-weight

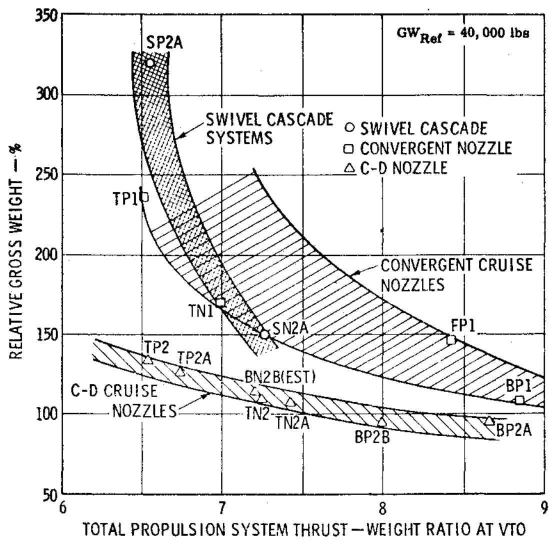


Fig. 12 Gross weight trends for the augmented turbofan with thrust vectoring exhaust systems.

ratio, i.e., the ratio of the total main and lift engine hot day vertical thrust to the total basic weight of the engines. The results fall in three general groups: 1) engines with swivel cascade nozzle systems, 2) convergent nozzle systems, and 3) C-D nozzle systems. The swivel cascade systems are indicated as unacceptable because of the high drag associated with projection of the swivel elbow into the external flowfield. The convergent nozzle systems are not as good as their C-D counterparts. The lower efficiency of the convergent nozzle decreases thrust at the sizing condition and increases specific fuel consumption during climb/acceleration and dash requirements of the DLI mission. These performance losses were not offset by the convergent nozzle size and weight advantages. In the examination of the convergent nozzle systems, the three-bearing design (BP1) was better than the folding elbow (FP1) as a result of lower lift system weight and less vertical length in the rotated position.

Figure 13 shows the result of the competing three-bearing and trap door designs with C-D nozzle systems. The three-bearing type is significantly superior to the trap door for augmented lift configurations, but the two types are competitive for nonaugmented lift systems with this analysis favoring the trap door design.

For augmented lift systems, the trap door configurations were penalized by high-cooling requirements which adversely effect combat and intercept climb fuels. Although cooling requirements were modulated with AB flame temperature and further reduced by using a star closure in place of a blocker valve, the trap door location downstream of the burner resulted in additional cooling losses. The most significant factor, however, was the heavy weight of the trap door designed to operate at the

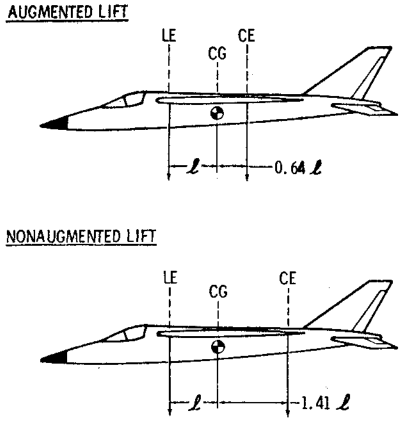


Fig. 14 Relative engine replacement-augmented versus nonaugmented.

partial augmentation gas temperature common to this group.

When the gas temperature was reduced to the level for nonaugmented lift operation, significant reduction in nozzle weight and cooling requirements were made in the trap door configurations. Gross weights were slightly lower than for the three-bearing design because of these factors and because of the absence of a ground clearance problem. Increase in normal landing gear length to provide adeaute nozzle ground clearance was necessary with the three-bearing design. Also, the increased size of the engine bay cut-out required for rotation of the three-bearing pipe caused additional weight penalties.

Engine Placement

The fundamental factor affecting engine placement is thrust balance. Figure 14 shows a comparison of thrust vector placement for vertically augmented and nonaugmented lift/cruise engines. Assuming the geometry of the forward section of the aircraft is relatively fixed to enclose avionics, crew, nose gear, and the lift engine bay and that the aircraft c.g. is maintained the the same longitudinal location by rearrangement of equipment, thrust balance in the vertical mode dictates that the augmented lift thrust vector must be closer to the c.g. of the aircraft than the nonaugmented lift. The augmented lift case then is more appropriate for nacelle or wing root mounted main engines. With a short, swivel, tailpipe, this position may cause difficulty in meeting area rule conditions for efficient supersonic flight. For aft mounted engines, thrust balance may dictate reduced power operation and nonaugmented operation. This is more likely to occur when flight maneuver requirements force high-main engine thrust loadings on the aircraft, causing a relatively large amount of deflected thrust without augmentation.

Figure 15 shows the effect of engine placement on gross

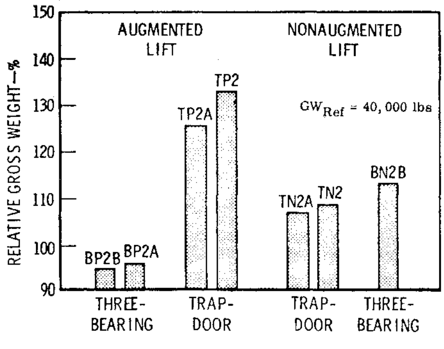


Fig. 13 Comparison of trap-door and three-bearing exhaust systems.

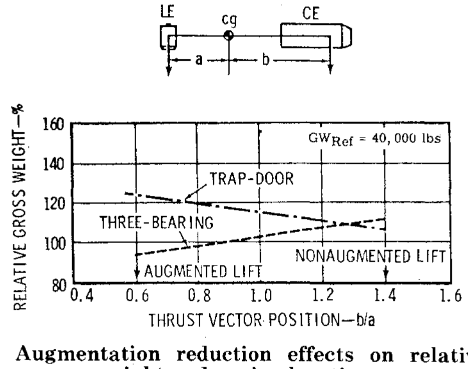


Fig. 15 Augmentation reduction effects on relative gross weight and engine location.

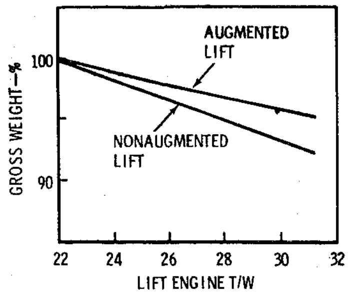


Fig. 16 Effect of improved lift engine thrust-to-weight ratio.

weight for the three-bearing and the trap door configurations. If a rear engine placement is desired, gross weight tends to improve for the trap door configuration because of reduced gas temperatures but increase for the three-bearing configuration because of decreased vertical thrust.

Another factor involved in the nozzle selection is lift engine technology level. The sensitivity of aircraft gross weight for augmented lift and nonaugmented lift in the cruise engine is shown in Fig. 16 for increase in lift engine thrust-to-weight ratio. The nonaugmented lift system is benefited more by improvements in lift engine thrust-to-weight than the augmented system. This results because larger lift engines are required with the nonaugmented lift system.

Installation Performance Observations

The selection of the optimum deflector nozzle system for an advanced supersonic VTOL interceptor will require detailed and highly configuration oriented system integration studies performed jointly by engine and airframe company design teams. However, some general observations related to selecting the best candidate systems for additional development effort can be made as a result of this and prior investigations.

Interference with Aircraft Structure

The vectoring system should minimize the structural penalties imposed on the airframe. The trap door design offers minimum interference with the tail carry-through structure when the engine is mounted in the aft fuselage. The forward placement of the vectoring nozzle and relatively small size of the ventral cut-out permits a more conventional rear fuselage design. Vectoring tailpipe configurations require a large underbody opening to permit vertical movement which leads to special construction techniques and added airframe weight.

Minimum External Drag

Minimum increase in external aerodynamic drag because of installation of a thrust vectoring system is desired, particularly for a supersonic application. The three-bearing, folding elbow, and trap door systems provide aerodynamic lines which are similar to conventional cruise engine installations. The trap door system offers the added advantage of a fixed cruise nozzle position which could simplify the problem of aft and engine/airframe integration by allowing a tighter, cleaner installation devoid of space requirements for door actuating mechanisms and related equipment.

Adequate Ground Clearance

The vertical offset below the engine centerline should be minimized. Minimum ground clearance of at least one nozzle diameter must be provided to prevent loss in engine performance. The vectoring tailpipe designs droop well below the engine centerline during vertical operation. The required landing gear lengths to achieve ground clearance may cause difficult problems in gear stowage, payload hardpoint locations, and internal space priorities. Carrier height restrictions may also impose additional structural penalties. Ground clearance problems are less apt to occur with the trap door system because of the reduced centerline offset.

Carrier Suitability

Exhaust gas velocity as affected by exit temperature and pressure must be limited as consistent with operating restrictions. In general, augmented vertical thrust systems are less desirable from this standpoint than nonaugmented systems. Flight deck noise and forward base ground erosion design constraints are also involved in the selection of augmented or nonaugmented lift and the type of nozzle system used.

Lift Vector Location

The lift vector should be positioned as far forward as possible. This tends to permit the use of a higher percentage of cruise engine deflected thrust for VTOL. For example, it is not uncommon to find that the cruise engine must be throttled during deflected thrust operation to maintain balance along the longitudinal axis. The trap door and swivel cascade exhaust systems allow a more forward location of the thrust vector.

Aircraft Maneuverability

For aircraft designs using thrust vectoring to obtain increased maneuverability in combat and attack situations, the swivel cascade and trap door systems offer a more attractive approach. The three-bearing and folding elbow designs present a problem of high drag in the deflected position.

Summary and Conclusions

Many installation and performance considerations pertinent to a nozzle selection have been considered. The final choice is dependent on the mission, the airframe configuration, and the operating constraints in ground proximity. Of the nozzles investigated, the trap door nozzle has been found to have the most attractive features with regard to installation ease and overall suitability and is judged best for nonaugmented deflected thrust engines. Where augmentation is required in the vectoring mode, the three-bearing pipe deflector is favored. The three-bearing nozzle concept also has the added advantage of having been demonstrated in an engine environment.

Some form of convergent-divergent nozzle appears necessary for a Mach 2 supersonic VTOL interceptor. The best configuration is dependent on many factors, but it is apparent that the trap door nozzle arrangement allows the most freedom in selection and integration of the cruise nozzle with the airframe.

The competitive potential of the trap door nozzle system has been indicated by these studies and the airframe company survey. The objective of the advanced technology components program sponsored by the Naval Air Systems Command is to increase the data base available to weapon system designers to use in definition of an optimal system for advanced VTOL fighter/interceptors. In support of this objective, it is concluded that the trap door nozzle concept merits continued design and development to obtain a more complete definition of the design characteristics of the system and to provide documented data for future systems selection studies.