APPLICATION OF ADVANCED EXHAUST NOZZLES FOR TACTICAL AIRCRAFT

by

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Abstract

Advanced exhaust nozzles play an important role in the system design for advanced tactical aircraft and offer attractive design options which contribute to total aircraft performance. These exhaust nozzles can improve aircraft cruise performance if integrated carefully. Thrust vectoring attainable with these exhaust nozzles adds significantly to aircraft maneuver performance. STOL performance is obtained by thrust reversing or a combination of thrust reversing and thrust vectoring. The significant aircraft performance improvements which lie in advanced exhaust nozzle technology will be determined by past, ongoing and future programs investigating the best application of advanced exhaust nozzles for tactical aircraft.

1. Introduction

During the past 40 years, the technology of the jet engine exhaust nozzle and its integration into military aircraft have been tailored to meet the requirements of the aircraft. The importance of this technology in industry and government is evident in References 1-39 which describe programs in this area in the last few years only. In light of these aircraft requirements, the exhaust nozzle has been tasked with an increasingly more difficult role in total vehicle performance and exhaust nozzle integration has become "an exercise in the art of compromise", Reference 27. In Figure 1, the evolution of exhaust system design has developed from a simple engine control valve in 1940-1950, to an aircraft control device in the 1980's and beyond. This increasing nozzle role in aircraft mission performance is the challenge to advanced exhaust nozzle integration in the next generation aircraft.

1950	1965	1990
ENGINE CONTROL VALVE	ENGINE CONTROL VALVE	ENGINE CONTROL VALVE
	THRUST EFFICIENCY	THRUST EFFICIENCY
	MINIMIZE DRAG	MINIMIZE DRAG
		THRUST REVERSING
		THRUST VECTORING PITCH
		THRUST VECTORING YAW
		THRUST VECTORING ROLL
		ACOUSTICS

FIGURE 1. EVOLUTION OF EXHAUST SYSTEM DESIGN REQUIREMENTS (REFERENCE 27)

As exhaust nozzle integration developed over the years, some early integration concepts were complex, as shown in the Horten 229 of the early 1940's, Figure 2, but the main concern up through the 70's was designing configurations where the installed exhaust system did not cause excessive drag or thrust loss. Configurations such as the F-16 and F-18 are examples of aircraft with nozzle installations that are very efficient. Other aircraft however did not fare as well. Reference 37 points out that while the aftbodys of some twin engine fighter aircraft are only 20 to 35 percent of the total aircraft length, this area produces up to 50 percent of the total aircraft drag. In addressing this problem, the more promising design schemes proposed to minimize the drag were concepts incorporating nonaxisymmetric or two-dimensional nozzles. Wind tunnel data from exploratory research models indicates that it might be possible to reduce aftbody/nozzle drag of twin engine aircraft with nonaxisymmetric nozzles due to a reduction in separated flow regions.

FIGURE 2. ADVANCED EXHAUST NOZZLE INTEGRATION- HORTEN 229-1945

Other experimental data, reported in a 1976 summary of related research conducted at the NASA Langley Research Center, Reference 2, indicated that vectoring the flow of a nozzle near the trailing edge of a wing generated a lift increment similar to that obtained from experiments with jet flaps. It was concluded that induced effects from thrust vectoring generally resulted in increases in lift and decreases in drag at constant angle of attack. This lift increment was caused in part by a component of the thrust and in part by the exhaust jet favorably influencing the flow over the lifting surface. In general the research indicated that the higher the aspect ratio or width of the nozzle, the greater the increment of induced lift. With these improvements in lift, discussion in the technical literature began to reflect possible improvements in fighter aircraft manueverability and agility, particularly in the flight regime away from the design point of the wing.

A related development was the emergence of the vectored-engine-over-wing (VEO) concept, an adaptation of upper surface blowing to a fighter aircraft. This scheme, reported in Reference 3, uses a vectored exhaust to change the wing aerodynamics improving the lift. Once again, the improved wing aerodynamics are attributable to a favorable influence on the wing flow field and the reduction of separated flow on the wing flap. The coupling of spanwise blowing with the VEO concept gave promise of further improvement of lift at low speeds and high angles of attack.

Until the last three or four years most of the interest in advanced nozzles has been how they might be used to improve cruise performance and aircraft agility or manueverability. More recently, operational considerations have generated an increased interest in short takeoff and landing (STOL) capability where it appears propulsive lift concepts utilizing vectorable and/or reversable advanced nozzles might be of benefit. Initial assessment of the STOL performance requirements indicates that the vectoring capability may be used both on takeoff and landing.

This paper discusses some of the more pertinent attributes of advanced nozzles (both axisymmetric and nonaxisymmetric) and their integration into tactical aircraft to improve cruise performance, manueverability and STOL operation. While most of the discussion will address the installed aerodynamic performance of the nozzles, a complete discussion would include information on structural integrity, materials, controls and actuation, reliability and maintainability, cooling requirements and the difference in weights for the various concepts.

2. Advanced Exhaust Nozzle Integration For Cruise Performance

As indicated in the introduction the aftbody nozzle area can contribute as much as 50% of the total aircraft drag. While historically the emphasis has been on optimum thrust and not necessarily minimum drag, as in the F-111 aftbody/nozzle shown in Figure 3, current research is being directed toward aircraft life cycle cost and especially reducing aircraft fuel use by reducing aircraft drag. The success of these efforts have been mixed. The F-15 aftbody/nozzle, Figure 4, appears to be an aerodynamically tailored area, but from the predominately negative pressure coefficent contours shown in Figure 5, it is evident that the F-15 nozzle boattail forces in cruise are essentially in the drag direction.

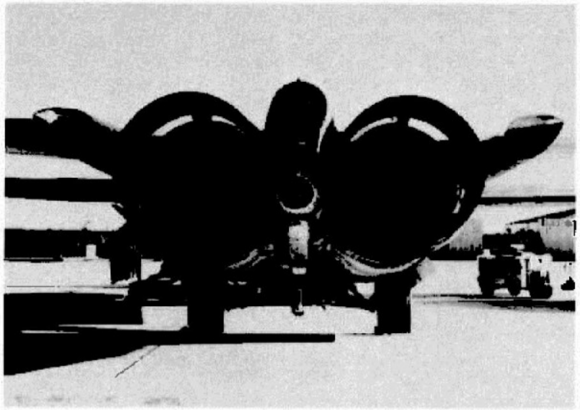


FIGURE 3. F-111 AFTBODY/NOZZLE

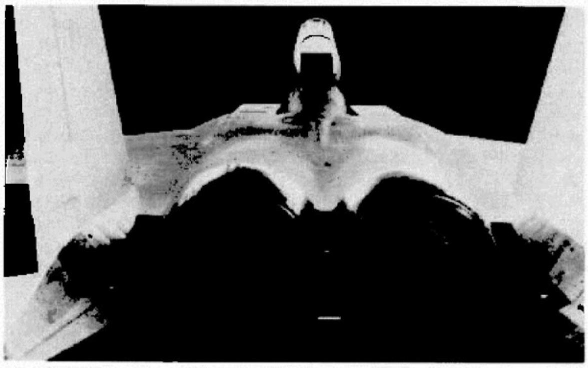


FIGURE 4. F-15 AFTBODY/NOZZLE

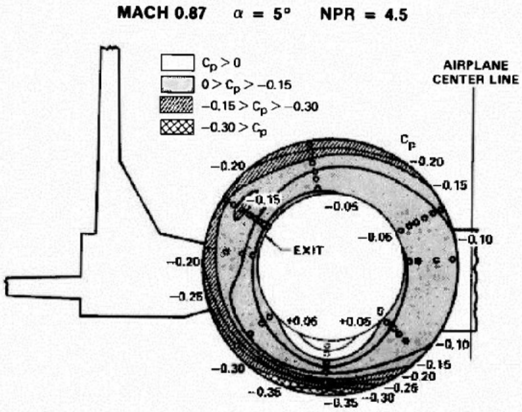


FIGURE 5. F-15 NOZZLE PRESSURE CONTOURS AT SUBSONIC CRUISE

With advanced multifunction exhaust nozzles playing an important role in aircraft manuever and STOL, these nozzles now need to be evaluated relative to their impact on efficent aircraft cruise. The incorporation of the thrust vectoring/thrust reversing capability may require a contour compromise in the boattail region to accomodate these functions. This may translate into a cruise drag impact in an area of the aircraft which already claims a disproportionate amount of total aircraft drag. On the other hand, the use of the thrust vectoring with a canard may reduce aircraft drag by using both devices for trimming. This section will discuss the impact of advanced multifunction nozzles on aircraft cruise both geometrically and in conjunction with other aircraft systems.

For the high fineness ratio air-to-surface aircraft, Figure 6, which is designed for a cruise Mach number of 2.0, the installation of advanced exhaust nozzles definitely impacts aircraft total drag from a geometric integration perspective. As identified in Reference 24, the design for nozzle integration for this aircraft were: "(1) achieve comparable locations for the effective point of vector application, (2) minimize subsonic interference drag between the twin nozzles, and (3) minimize supersonic wave drag by tailoring the area distribution". The axial location of the nozzle exits was held constant and the lateral spacing was selected to provide a horizontal knife-edge interfairing with minimum interference. The aftbody/nozzle contours and the resulting pressure distributions for the axisymmetric and two advanced axisymmetric nozzles are shown in Figure 7. The aftbody contouring of the advanced axisymmetric nozzle is gradual on the aftbody with rapid change near the nozzle exit to give a final boattail angle of 24 degrees. The contours of the two advanced exhaust nozzle installations also change slowly on the aftbody and close down to a 23 and 18 degree final boattail angle, respectively, for the aspect ratio 3.6 and 7 nozzles. These contours, while not radically different, produce total aircraft drag levels as shown in Figure 8. The difference in basic drag at 0.9 Mach number is 23 drag counts (C_D = .0023) for the low aspect nozzle and 11 drag counts (C_D = .0011) for the higher aspect ratio nozzle. When the aircraft is trimmed and other nozzle attributes such as thrust vectoring and the nozzle lift generated at angle of attack are considered the total aircraft drag for all advanced nozzles in this study varies from 10 counts less than the baseline axisymmetric nozzle aircraft to 32 counts more, see Figure 9.

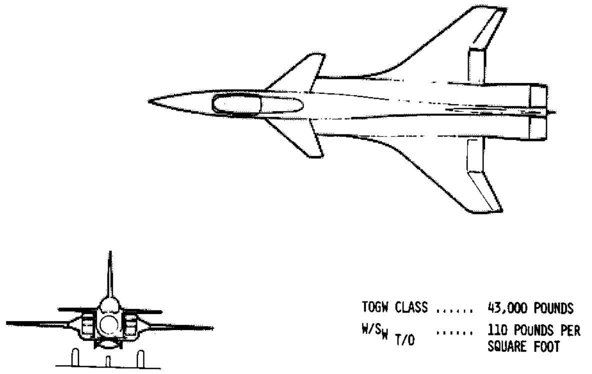


FIGURE 6. AIR-TO-SURFACE AIRCRAFT (REFERENCE 24)

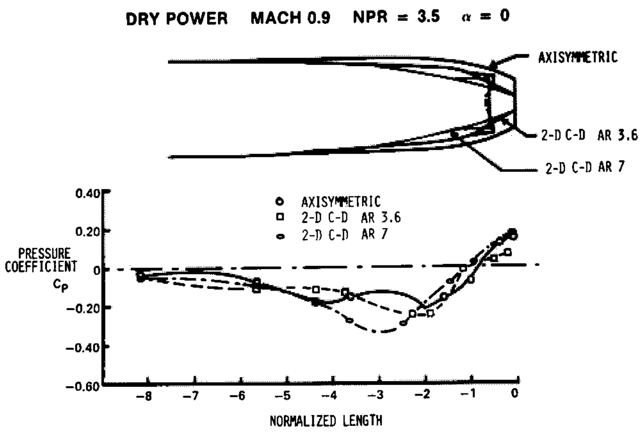


FIGURE 7. AFTBODY/NOZZLE CONTOURS AND PRESSURE DISTRIBUTIONS (REFERENCE 24)

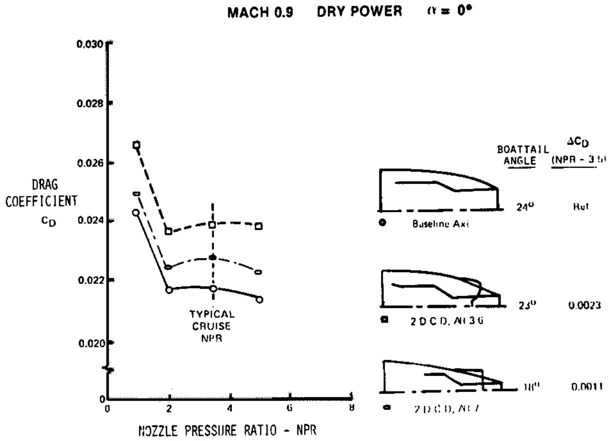


FIGURE 8. SUBSONIC CRUISE DRAG COMPARISON (REFERENCE 24)

NOZZLES	SUBSONIC CRUISE M = 0.9 $\Delta C_{D_{TOTAL}}$
BASELINE AXI	REF
2D CD AR 7	- 0.0010
SERN AR 7	- 0.0003
TV/TR AXI	0.0006
2D CD AR 7.2	0.0027
2D CD AR 3.6	0.0032

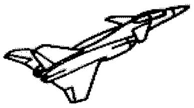


FIGURE 9. ADVANCED NOZZLE AIRCRAFT DRAG COMPARISIONS (REFERENCE 24)

Another example of advanced nozzle installation is the F-18 system work described in References 19, 25, and 36. For the F-18, the advanced "nozzle shape blends well with airframe contours and the nozzle aspect ratio... was selected to fill the area behind the engine. In addition, sidewall thickness has been minimized by locating actuation hardware in available area on top of the exhaust duct.... The result is a nozzle installation that minimizes drag producing base regions.", Reference 36. Each of the aftbody/nozzles was tested in a water tunnel to identify areas of flow separation. In one instance, the aftbody for the 2-D C-D nozzle was lengthened to eliminate an area of flow separation. The consequence of this configuration refinement was equivalent or higher thrust-minus-drag performance for the advanced nozzle configurations compared to the axisymmetric configurations.

Installed drag for advanced exhaust nozzles on aircraft with pod mounted engines with the nozzle exit at or near a lifting surface are discussed in References 3,5,10,12,15, and 16. An aircraft configuration of this type is shown in Figure 10 (Reference 10). Compared to an axisymmetric nozzle, the single expansion ramp nozzle (SERN) installed on this aircraft reduced drag at the cruise condition leading to a large improvement in specific range, Figure 11. The cruise benefits are primarily due to a favorable lift/drag relation for the SERN nozzle. With the integration of this nozzle near the wing trailing edge, the total aircraft lift becomes a function of the engine power setting. Since the influence of the exhaust flow on the wing flow field is not easily understood and is often confused, a short discussion of the phenomenon may be helpful. The preponderance of the experimental data obtained to date indicates there is a positive contribution to lift from vectorable nozzles when they are integrated near the trailing edge of a lifting surface. Upstream of the nozzle exit, the upper wing pressures decrease and the lower wing pressures increase due to the presence of the nozzle jet. This change in wing pressures, both upper and lower surface and the contribution to increased lift is verified in Reference 11 and 14. The jet induced effects are attributed to boundary layer control of the flow in and around the nozzle and the trailing-edge wing flap plus some induced circulation.

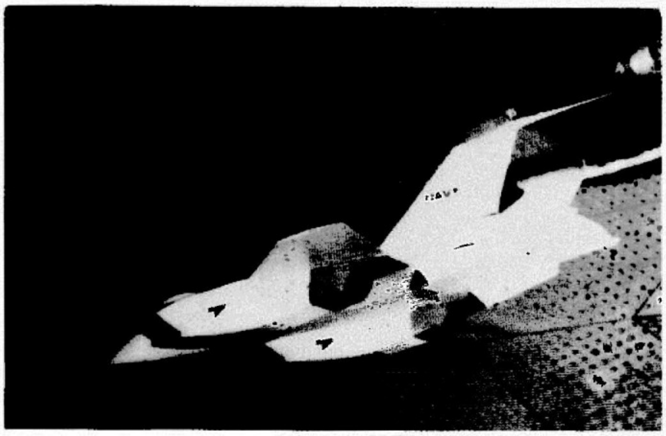


FIGURE 10. ADVANCED AIRCRAFT WITH POD MOUNTED ENGINES (REFERENCE 10)

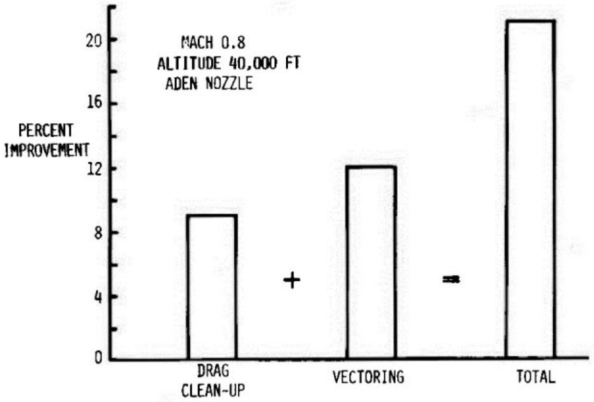


FIGURE 11. RANGE IMPROVEMENT RELATIVE TO AXISYMMETRIC BASELINE (REFERENCE 10)

More recent data on an aircraft with a podded engine near a wing, Figure 12, is presented in Reference 39. A series of advanced exhaust nozzles were installed on this aircraft with guidelines similar to those identified in Reference 24. For this highly maneuverable aircraft, all nozzle installations produced total trimmed aircraft drag values within a competitive range except the high aspect ratio single expansion ramp nozzle, see Figure 13.

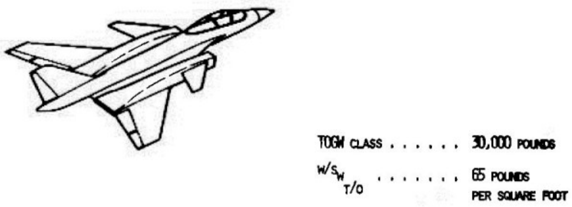


FIGURE 12. AIR-TO-AIR AIRCRAFT (REFERENCE 39)

	SUBSONIC CRUISE M = 0.9	SUPERSONIC MAXIMUM M = 1.8
NOZZLE	$\Delta C_{D_{TOTAL}}$	$\Delta C_{D_{TOTAL}}$
BASELINE AXI	REF	REF
MULTIFUNCTION NOZZLES		
2D CD AR 3.2	0.0014	0.0010
ALBEN AR 3.6	0.0016	0.0006
TV/TR AXI	0.0020	0.0001
SERN AR 27	0.0046	0.0033

FIGURE 13. ADVANCED NOZZLE AIRCRAFT DRAG COMPARISIONS (REFERENCE 39)

For a given mission profile an aircraft cruises at a nearly constant lift coefficient. When the aircraft lift is supplemented by a favorable nozzle flow/wing interaction the required wing lift can be reduced, thereby reducing the angle of attack for cruise, and subsequently reducing the cruise drag. For the aircraft shown in Figure 10, an exhaust nozzle with a 10 degree thrust vector supplemented the lift through the favorable wing interaction and direct jet lift, to reduce the cruise angle of attack by 1.3 degrees. The reduction of cruise drag, partially offset by the axial thrust loss due to vectoring, results in a 10.5 percent increase in specific range.

The integration of advanced exhaust nozzles must be done very carefully to avoid an aircraft drag impact. The aftbody/nozzle contouring for a low drag efficient installation may require advanced analytical techniques and configuration screening efforts to identify and correct problem areas. As will be apparent in the subsequent sections, the utilization of thrust vectoring and thrust reversing not only modifies the aftbody contour but also the aircraft aerodynamics. The design approaches for these multi-function nozzles will probably be different than for the basic nozzle integrated in the past.

As a general statement concerning installed aircraft drag of different nozzle types, the reader should keep in mind that not only aftbody/nozzle considerations determine the success of a particular installation. Items such as aircraft stability and control, weight and balance, installed engine performance and most of all aircraft mission requirements are as important as a particular aftbody/nozzle installation. In summary when considering installed cruise drag of advanced exhaust nozzles in tactical aircraft, the following lessons have been learned to date:

1. The installed drag of advanced exhaust nozzles for tactical aircraft can be competitive with basic axisymmetric nozzle installations if done carefully.

2. For propulsion installations where the nozzle exit is near a lifting surface, the lift required for aircraft cruise can be partially obtained by the direct jet lift and the jet induced lift. The reduced lift required of the wing allows a reduced cruise angle of attack and reduced cruise drag.

3. Advanced Exhaust Nozzle Integration For Aircraft Maneuver

Aircraft size often depends on the maneuver requirement levied on the vehicle. Consequently, designers have developed efficient aircraft lift systems to meet the maneuver requirement. Through improved wing design, variable camber, high lift devices, close-coupled canards, reduced static margin, aeroelastic tailoring, and integrated controls (Reference 37), the aircraft can have the desired maneuver performance but often at the expense of other mission legs. The best maneuver lift system, for example, may create a penalty in supersonic cruise. The advanced exhaust nozzle can offer an alternative to a wing compromise. An efficient cruise wing with lower maneuver capability may be coupled with a thrust vectoring exhaust nozzle to supplement the maneuver capability and improve overall mission performance. These exhaust nozzles can be used to increase the maneuver capability or can be used to reduce aircraft size and maintain capability. This section will address several different aspects of the contribution of advanced exhaust nozzles to enhance aircraft maneuver.

The influence of the jet exhaust on a lifting surface is the basis for some of the maneuver benefits of installed exhaust nozzles. This phenomenon produces lift and drag (though not as much proportionally as to lift) by changing the overall wing flowfield, and, depending on the location of the jet a change to the pitching moment. The vectored jet has been related to a mechanical aerodynamic flap which varies in length with power setting, but does not have separated flow as on metal flap. As a result, there are greater lift increments and a reduced drag penalty.

The maneuvering benefit for vectoring advanced exhaust nozzles is primarily evident at higher angles of attack corresponding to a point where the wing flow separates (Reference 9,37). The current industry practice of sizing the wing and engine to the sustained turn requirement where thrust equals drag means the instantaneous maneuver point at thrust less than drag can utilize thrust vectoring to increase aircraft maneuverability and agility. Figure 14 presents the powered polar improvements as the nozzle deflection increased from 0 to 30 degrees. The air-to-surface aircraft with a forward canard and a thrust vectoring nozzle showed improved vehicle trim characteristics at maneuver conditions. This vehicle uses thrust vectoring in conjunction with the canard across the angle of attack range. The respective schedules for the canard and nozzle vector angle is shown in Figure 15. Note that with the nozzle vectoring, the

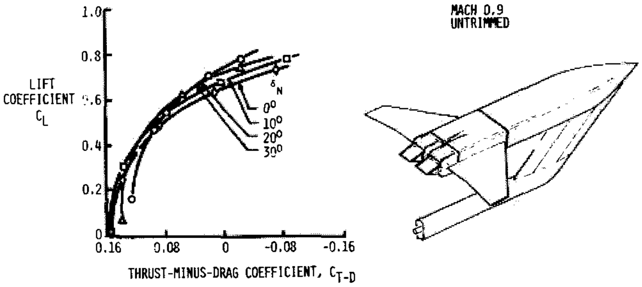


FIGURE 14. POWERED POLAR IMPROVEMENT WITH THRUST VECTORING (REFERENCE 8)

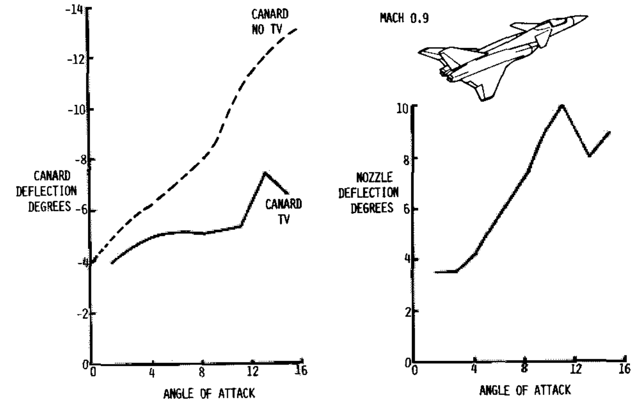


FIGURE 15. REDUCTION OF CANARD DEFLECTION FOR TRIM USING THRUST VECTORING (REFERENCE 24)

canard deflection is less than eight degrees while the deflection increases to 14 degrees with no thrust vectoring. The beneficial impact of this function on the aircraft at maneuver is shown in Figure 16 for an aircraft with and without a thrust vectoring nozzle. The aircraft drag at maneuver was reduced by 7 to 10 percent compared to the canard trim only of the baseline aircraft.

	SUBSONIC MANEUVER M = 0.9
NOZZLE	$\Delta C_{D_{TOTAL}}$
BASELINE AXI	REF
MULTIFUNCTION NOZZLES	
2D CD AR7	- .0137
SERN AR7	- .0127
TV/TR AXI	- .0111
2D CD AR 3.2	- .0089
2D CD AR 7.2	- .0085

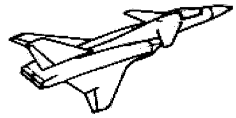


FIGURE 16. ADVANCED AIRCRAFT DRAG COMPARISONS (REFERENCE 24)

For the air-to-air aircraft (Reference 39), the use of thrust vectoring near the wing trailing edge demonstrated a significant contribution to aircraft performance at the maneuver condition. The additional lift generated by two of the advanced nozzles when installed on this configuration is shown in Figure 17. At high angles of attack as much as 0.2 increase in lift coefficient is produced by the vectoring nozzle. The use of the canard and the vectoring nozzle contribution of lift and pitching moment at high angles of attack for trim is shown in Figure 18. Note that the trimmed powered polar for the optimum combination of thrust vector angle and canard angle is much better at high angle of attack than the powered polar based on canard minimum drag. The aircraft drag values for the thrust vectoring exhaust nozzles with the optimum vectoring relative to the baseline axisymmetric nozzle aircraft is shown in Figure 19. A maximum thrust vector angle of 21 degrees was used by the configuration.

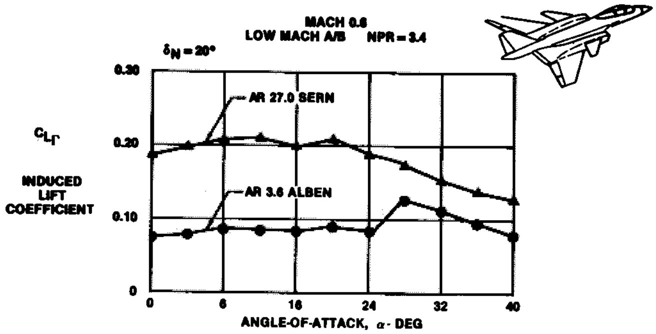


FIGURE 17. INDUCED LIFT ATTRIBUTABLE TO EXHAUST NOZZLE/WING INTERACTION (REFERENCE 39)

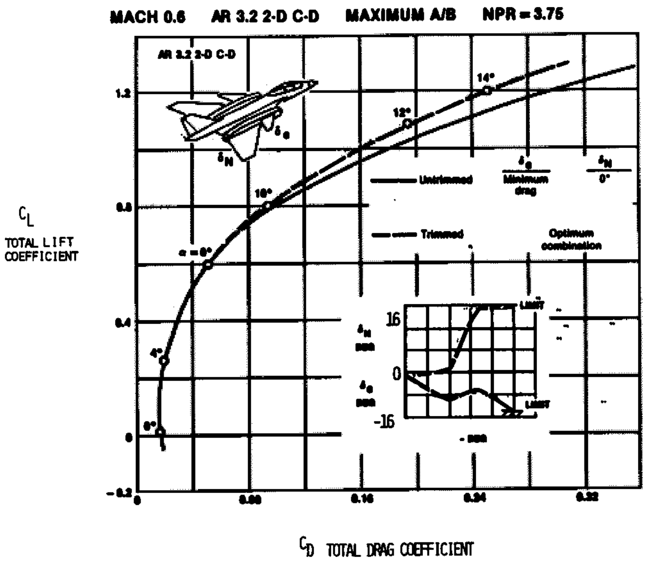
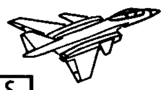


FIGURE 18. THRUST VECTORING/CANARD UTILIZATION FOR MANEUVER (REFERENCE 39)



	SUBSONIC MANEUVER M = 0.6		SUBSONIC MANEUVER M = 0.9	
NOZZLE	$\Delta C_{D_{TOTAL}}$	δ_V (DEG)	$\Delta C_{D_{TOTAL}}$	δ_V (DEG)
BASELINE AXI	REF	0	REF	0
MULTIFUNCTION NOZZLES				
SERN AR 27	-0.0426	12.1	- 0.0002	2.7
2D CD AR 3.2	-0.0401	21.4	- 0.0036	7.5
TV/TR AXI	-0.0375	20.0	- 0.0078	10.6
ALBEN AR 3.6	-0.0247	15.5	- 0.0031	1.13

FIGURE 19. ADVANCED AIRCRAFT DRAG COMPARISON (REFERENCE 39)

Another benefit for advanced exhaust nozzles is the ability to utilize the aircraft maximum lift coefficient after the canard control limit has been reached. Using high angle of attack data for this aircraft, thrust vectoring of 30 degrees could be utilized to trim the aircraft at its maximum lift coefficient after the canard control power limit has been reached at a negative 18 degrees deflection. This use of thrust vectoring, Figure 20, translates into a 40 percent improvement in turn rate at 0.6 Mach number.

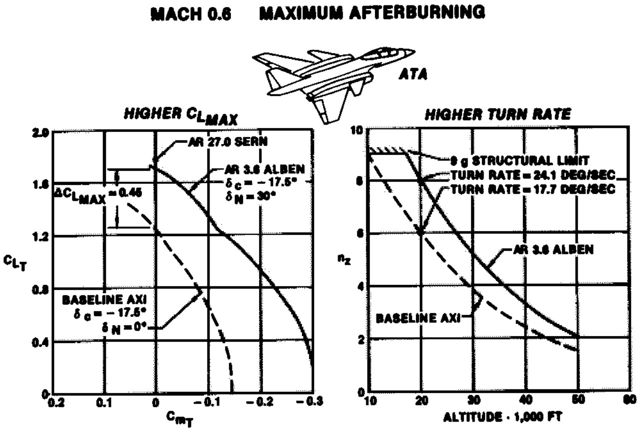


FIGURE 20. IMPROVEMENT IN $C_{L_{MAX}}$ AND TURN RATE WITH THRUST VECTORING (REFERENCE 39)

An additional benefit of advanced exhaust nozzles is maneuverability and agility at high lift and/or low dynamic pressure conditions. The pitch and roll control available when aerodynamic surfaces lose control power provide added aircraft flexability and survivability.

In summary, when considering the impact of advanced exhaust nozzles on aircraft maneuver, the following lessons have been learned to date:

1. Advanced exhaust nozzles show the most benefit for aircraft maneuver when used in conjunction with canards.
2. The benefit derived from advanced exhaust nozzles at maneuver angles of attack is reduced trim drag and increased pitch control to utilize the total lift capability.

4. Advanced Exhaust Nozzle Integration For STOL Performance

Recent emphasis on STOL has evolved from an anticipated requirement to operate from bomb damaged runways and/or unprepared areas. The goal of current efforts is to develop capability for high performance tactical aircraft at nominal STOL distances of 1000 feet. While some current fighter aircraft can achieve this goal if lightly loaded, none can approach this balanced length under normal loads (Reference 22).

Technology areas being investigated to improve STOL capability include high lift aerodynamics, thrust vectoring, thrust reversing, and integrated aircraft propulsion controls. A combination of these may be needed to obtain the desired low approach speeds and to overcome the resultant trim and control problems. The demands on advanced exhaust nozzles for STOL depend heavily on aircraft type and field length requirement. For example, for a 750 foot balanced field length, the approach speed for an air-to-surface aircraft decreases to 105 knots from a nominal 145 knots for a conventional approach. Thrust vectoring of less than 45 degrees, and thrust reversing are required. For a 300 foot balanced field length, the approach speed required is less than 70 knots. Thrust vectoring is now a thrust spoiling function and more propulsive moment balancing and reaction controls (like the Harrier control system) are required. Figure 21 gives a summary of nozzle requirements for both takeoff and landing. Other studies have shown for a 50,000 pound aircraft a 1000 foot landing distance is possible with a thrust reverser and a vectoring nozzle at the wing trailing edge utilizing 10 degrees of thrust vectoring and a good high lift system (Reference 31). Still other efforts have indicated a need for large amounts of forward trim to offset the vectored nozzle moments to achieve STOL goals. Reference 38, for example, shows that for an air-to-surface tactical aircraft 38 degrees of thrust vectoring plus a forward jet or burned bleed air (with no major wing change) is required to obtain a critical 1000 foot takeoff distance.

The information shown in Figures 22 and 23 was generated under a current program investigating advanced exhaust nozzles for improved STOL performance and gives an indication of the total lift required as a function of takeoff and landing distance for the air-to-surface aircraft being considered. A 1000 foot takeoff distance is possible due to approximately equal parts aerodynamic and jet lift plus an increment of lift enhancement to obtain the required lift coefficient.

FIELD LENGTH REQM'T	1900 FT	1200 FT	700 FT
TAKEOFF			
NOZZLE DEFLECTION	15.6°	15.0°	29.5°
LIFTOFF SPEED (KTS)	126	119	85
LANDING:			
NOZZLE DEFLECTION	37°	16.1°	62.9°
TOUCHDOWN SPEED (KTS)	101	76	61
GLIDE SLOPE ANGLE	3.4°	4.4°	5.6°

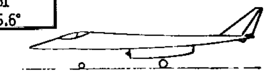


FIGURE 21. STOL REQUIREMENTS (REFERENCE 32)

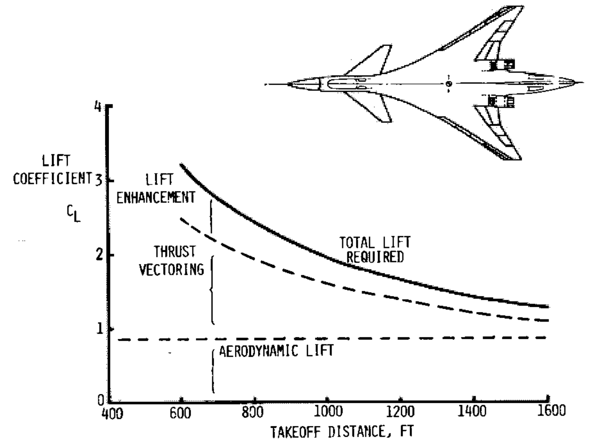


FIGURE 22. LIFT COEFFICIENT REQUIRED FOR TAKEOFF

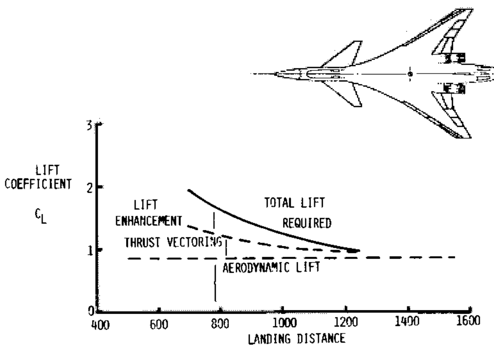


FIGURE 23. LIFT COEFFICIENT REQUIRED FOR LANDING

A recent propulsive lift research program investigating thrust vectoring in conjunction with spanwise wing blowing shows promise in increasing the aircraft lift coefficient on approach. An underwing cascade on the nacelle of an air-to-surface aircraft directs some of the exhaust flow out along the wing like an externally blown flap. The configuration achieves a total lift coefficient of 2.18 with an induced lift contribution (.4 C_L) of 20 percent of the total lift. Note in Figure 24, the effect of simultaneous operation of cascade blowing and the vectored primary jet is much greater than the sum of the two blowing schemes operated separately. This is an indication of a favorable interaction of the two devices increasing the total lift.

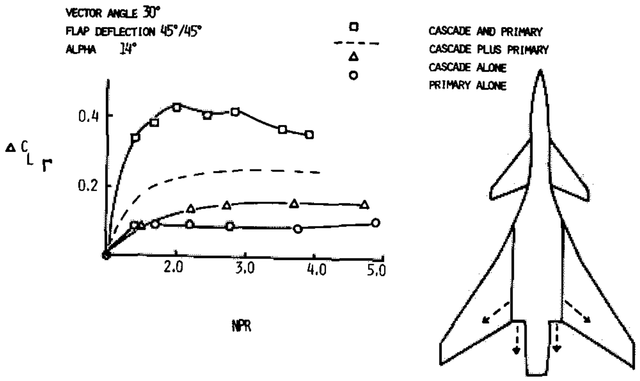


FIGURE 24. LIFT INCREMENT FOR VECTORED NOZZLE AND UNDERWING BLOWING (REFERENCE 30)

Systems studies for current and advanced aircraft are showing large STOL payoffs for thrust reversers on landing and in some cases thrust vectoring or spoiling on approach. From Reference 29, the F-15 with an advanced thrust reverser could have a balanced field length capability of approximately 1500 feet. The study also showed that the thrust reverser was more efficient than aerodynamic braking devices such as a large wing and a parabrake, and could show a 50 to 75 percent reduction in F-15 brake wear. For the air-to-air aircraft discussed previously, the landing ground roll was reduced from 2830 feet to 980 feet, Figure 25. The improvement is even more significant for a wet runway. This aircraft, given an axisymmetric exhaust nozzle, a drag chute and a speed brake, would have a comparable takeoff distance but would have a landing roll approximately 67 percent greater than the advanced nozzle with a reverser.

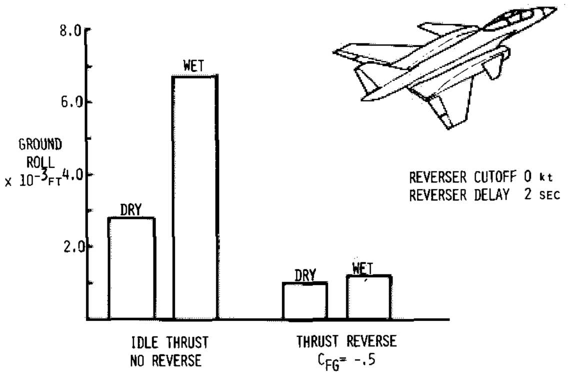


FIGURE 25. REDUCTION OF GROUND ROLL USING THRUST REVERSER (REFERENCE 39)

A continuing area of concern for STOL aircraft with thrust reversers is aircraft stability and control during thrust reverser operation. Losses in lift, pitching moment changes, and interactions of the reversed jet with the horizontal and vertical tails all impact longitudinal and lateral stability. It can not be emphasized too strongly that the impact of the thrust reverser operation on stability and control is highly configuration dependent. Several ongoing research programs are currently addressing this important area.

Many other factors govern the effectiveness of the nozzle as a contributor to STOL performance. For example, optimum STOL performance can be realized when approach speeds are minimized, the engine is maintained at maximum dry power, and the reverser is deployed on approach and landing. The mechanical and control complexity of these advanced nozzles will also impact their utilization in a STOL mission. As thrust reversers are refined, difficult design problems must be solved which will determine the best nozzle type. Both axisymmetric and nonaxisymmetric exhaust nozzles must be investigated for their application to advanced aircraft STOL.

In summary, for the application of advanced exhaust nozzles for STOL in advanced tactical aircraft, the following lessons have been learned to date:

1. Balanced field length for advanced tactical aircraft can be obtained by utilizing the advanced nozzle functions of thrust vectoring and thrust reversing on approach and landing.
2. As STOL distances are reduced, the required exhaust nozzle functional capability is increased.

5. Concluding Remarks

Some of the impacts of advanced exhaust nozzles on tactical aircraft have been discussed for cruise, maneuver, and STOL mission requirements. While current and projected US government and industry efforts are continuing in the advanced exhaust nozzle area, the emerging trends are as follows:

1. The aftbody/nozzle installation for advanced airframes and exhaust nozzles must be approached very carefully to optimize installed performance at cruise.
2. For maneuver, advanced thrust vectoring exhaust nozzles show advantages at high angle of attack demonstrating improved turn rate and instantaneous maneuver performance.
3. For STOL, advanced exhaust nozzles with thrust vectoring and/or thrust reversing may be necessary.

The choice of exhaust nozzle for a tactical aircraft is driven by aerodynamic characteristics, mission requirements, and many other factors. Nozzles are also classified by total weight, cooling flow, internal performance, control system, and reliability and maintainability. The requirement for thrust reversing and vectoring will also influence nozzle selection. Promising nozzle technologies include advanced composites to reduce nozzle weight and other factors associated with advanced nozzles, now unquantified, including reduced cost, simplicity, and a reduced structural penalty by mounting the nozzles directly to the airframe. Consideration of all these factors and the aerodynamic performance determine the best advanced nozzle for a particular tactical aircraft. The potential for significant aircraft performance improvements lies in the proper utilization of advanced exhaust nozzle technology in concert with the total aircraft system.

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