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# NOISE IMPACT OF ADVANCED HIGH LIFT SYSTEMS

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# PREFACE

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# 1. INTRODUCTION

In addition to meeting FAA FAR Part 36 / ICAO Annex 16 certification noise standards, commercial airplanes are also subject to specific noise limits for operations at many airports. Noise limits are established to reduce the noise exposure in communities around the airports. Noise abatement flight procedures are in turn used by operators to comply with these noise limits. These procedures, however, often result in lower noise levels in some parts of the community but higher noise levels in other parts.

The incorporation of advanced technologies such as improved high lift systems, automated flight management systems, and automated thrust management systems could have a significant impact upon aircraft certification noise levels and upon community noise levels around airports. The present study evaluates the noise impact of advanced high lift systems by focusing on two aircraft categories, a short-to-medium range, 150 passenger and a medium-to-long range, 275 passenger aircraft. Two engine types were considered for both aircraft categories, a high bypass ratio (HBPR) direct drive turbofan with a bypass ratio of 6 and a very high bypass ratio (VHBPR) geared variable pitch ducted fan with a bypass ratio of 16.

Sizing trade studies were carried out for each aircraft engine combination with both conventional and advanced high lift systems. Certification and community noise levels were evaluated for each of these combinations. The community noise assessments evaluated various flight procedures designed to alleviate noise for communities close to and farther away from airports.

In addition to the sizing and noise evaluations, direct operating cost (DOC) was also computed for each of the aircraft configurations considered in this study.

## 2. SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| ADP | Advanced ducted propeller |
| APU | Auxiliary power unit |
| ASL | Average stage length |
| ATM | Advanced technology multipliers |
| CASES | Computer Aided Sizing and Evaluation System |
| CET | Combustor exit temperature |
| CG | Center of Gravity |
| $C_{Lmax}$ | Maximum lift coefficient |
| $C_L$ | Lift coefficient |
| CPA | Closest point of approach |
| CWEP | Conceptual Weight Estimation Program |
| DFBR | Distance from brake release |
| DOC | Direct Operating Cost |
| EIS | Entry Into Service date |
| EPNL | Effective Perceived Noise Level |
| $F_n$ | Engine net thrust |
| $Fn/\delta$ | Corrected net thrust |
| HBPR | High bypass ratio |
| HPC | High pressure compressor |
| HPT | High pressure turbine |
| L/D | Aerodynamic lift to drag ratio |
| LPC | Low pressure compressor |
| LPT | Low pressure turbine |
| MAC | Mean aerodynamic cord |
| MTOGW | Maximum takeoff gross weight |
| NPD | Noise-power-distance table |
| OEW | Operating Empty Weight |
| OPR | Overall pressure ratio |
| PD | Differential cabin pressure |
| SEL | Sound Exposure Level |
| $S_W$ | Wing area |
| T3 | Compressor exit total temperature |
| T4 | Combustor exit temperature |

| | |
|---|---|
| T41 | Turbine inlet temperature |
| VD | Maximum speeds in a dive |
| VHBPR | Very high bypass ratio |
| $V_{min}$ | Minimum aircraft speed |
| WER | Weight estimating relationships |
| WMPL | Maximum payload |
| WPPL | Performance payload |
| $V_{true}$ | True airspeed |
| $\delta_F$ | Flap deflection angle |

# 3. AIRCRAFT DESIGN

## 3.1 Mission Definitions

Noise impact of commercial passenger aircraft varies markedly depending on aircraft type. For this reason two categories of aircraft were selected to assess the impact of advanced high lift systems in future aircraft designs. The two types were a short-to-medium range aircraft and a medium-to-long range aircraft. The short-to-medium range aircraft type was selected because it best represents aircraft operations out of small noise sensitive airports. For small airports the area affected by aircraft noise is small but the frequency of operations is increased. The medium-to-long range aircraft was chosen to give a good representation of aircraft operations at medium and large airports that have large impacted areas but fewer operations. In order to maximize synergy with other technology assessment studies, the two airframe configurations used in the present study were chosen from the four airframe configuration definitions analyzed under NASA Contract NAS3-25965, (Propulsion Airframe Integration Technology (PAIT)), Task 9 -- "Advanced Subsonic Aircraft Design and Economic Study" (see Table 1).

## 3.2 Aircraft Configuration

### 3.2.1 Definitions / Rules

A conventional aircraft configuration was used throughout this study with engines mounted on wing pylons and the horizontal and vertical tail mounted on the aft fuselage. The fuselage was sized to accommodate 150 and 275 passengers respectively for the two configurations.

The short-to-medium range aircraft fuselage was configured for a two class seating arrangement with a single aisle with 8% in first class and the remainder in economy class (32 inches seat pitch). The flight crew requirements are derived from the FAR Part 121, subpart R, paragraph 121.480, see Reference 1.

The fuselage for the medium-to-long range aircraft was configured for a three class seating arrangement with 6% in first class, 19% in business class, and the remaining 75% in economy class. The seat pitch in economy class is 33 inches.

Once the fuselages were sized they were fixed for this study. When high lift system technology was incorporated the wing and empennage geometry and weights, and engine were re-sized and the fuel requirements were adjusted.

3.2.1 Descriptions

The small-to-medium range aircraft configuration has two turbofan engines mounted on pylons forward and below the wing. The wing has an aspect ratio of 11 with a taper ratio of 0.275 and were mounted low on the fuselage. Figure 1 shows a general arrangement drawing of this configuration. The fuselage is circular in cross section and accommodates one LD-W container below the floor forward and aft of the wing box and main landing gear bay. The interior arrangement provides 150 seats. A common empennage design, consisting of a horizontal and vertical tail mounted on the rear fuselage, was used for both the short-to-medium range and the medium-to-long range aircraft. The medium-to-long range aircraft configuration also has two turbofan engines mounted on pylons forward and below the wing. The wing has an aspect ratio of 11 with a taper ratio of 0.30 and was mounted low on the fuselage. Figure 2 shows a general arrangement drawing of this configuration. The fuselage is circular in cross section and will accommodate two LD-3 containers below the floor forward and aft of the wing box and main landing gear bay. The interior arrangement provides 282 seats (even though the mission requirement was for 275 seats).

### 3.3 Propulsion

In order to span the range of engines that will most likely be used on future aircraft, two distinctly different engine types were analyzed with each configuration. A high bypass ratio (HBPR) turbofan engine and a very high bypass ratio (VHBPR) turbofan engine cycles were developed for both the short-to-medium and the medium-to-long range configurations.

The McDonnell Douglas Aerospace (MDA) Douglas Turbo-Fan #22 (DTF022) and #23 (DTF023) engine cycle models, used in previous 225 passenger aircraft studies, were re-sized for both the 150 passenger and the 275 passenger aircraft. The cycle models of both engines used bleed flow and horsepower extraction adjusted to meet the PAIT Task 9 requirements. Zero bleed flow is used since the PAIT Task 9 airplanes are all-electric (with advanced power by wire technology). Horsepower extraction is 379 HP, which is the requirement for a 225 passenger airplane. Both engines were designed with similar high pressure core and technology limits (i.e., T3, T4, and T41).

The DTF023 engine is a high bypass ratio (HBPR), bypass ratio of 6.0 at the design point, direct drive turbofan engine with a conventional wide chord fan. This engine consists of three compression systems - a fan, a low pressure compressor (LPC), and a high pressure compressor (HPC). A two spool arrangement was employed where the high pressure turbine (HPT) powers the HPC and the low pressure turbine (LPT) powers both the fan and the LPC. DTF023 engine cycle parameters at the design point are listed in Table 2.

The DTF022 engine is a very high-bypass ratio (VHBPR), bypass ratio of 16.0 at the design point, geared turbofan engine with variable pitch fan blades. The engine also consists of three compression systems - a fan, a LPC, and HPC. Just like the DTF023, the components are powered by two turbines and a two spool arrangement is again employed where the HPT powers the HPC and the LPT powers the fan and the LPC. Because of the large bypass ratio of the DTF022 engine, a reduction gearbox between the fan and the LPC is incorporated to allow both the fan and LPC-LPT rotational speed to be optimized. This results in a reduction in the number of stages required for the LPC and LPT. It uses variable pitch fan blades. This ensures adequate fan surge margin across the engine operating envelope. The use of variable pitch fan blades makes it possible to achieve reverse thrust through a blade pitch change mechanism, eliminating the need for a thrust reverser. The weight penalty associated with the variable pitch mechanism is offset by the weight reduction attained by removing the thrust reverser. This also in turn, allows a thinner "slimline" nacelle to be incorporated, reducing drag and weight. The DTF022 engine cycle parameters at the design point are listed in Table 3.

A comparison of the engine performance at top of climb, cruise, and takeoff for the DTF023 and DTF022 engines at the reference conditions (sized for a 225 passenger aircraft) is shown in Table 4. Figure 3a and 3b show the flow paths of the two engines drawn to the same scale. Table 5 shows a comparison of the weights and dimensions at the reference condition. The DTF022 has an engine thrust-to-weight ratio of 3.79 at takeoff and 0.80 at top-of-climb. The DTF023 has an engine thrust-to-weight ratio of 4.82 at takeoff and 1.15 at top-of-climb.

### 3.3.1 Engine Nacelle

The engine nacelle design is a slimline short duct nacelle that is lined with acoustic treatment throughout to minimize engine noise from the fan inlet, fan exhaust, and turbo-machinery. This ensures good comparison of high lift impact. Acoustic parameters are shown in Table 6 for both engines. Table 7 shows the relevant nacelle geometry, used in determining nacelle drag effects and nacelle -- wing interference effects.

## 3.4 Aerodynamics

### 3.4.1 High Lift Systems

One conventional and one advanced high lift system configuration has been developed for each of the airplane configurations. A definition of the these systems and the estimates of their low speed aerodynamic characteristics are given below.

For the short-to-medium range aircraft the conventional high lift system consists of a full span leading edge slat and an MD-80 type vane/flap. The slat has a single position for both takeoff and landing. The trailing edge vane is fixed relative to the flap; maximum flap setting is 40°. The advanced high lift system uses a slat that is sealed at takeoff and fully open at landing. The trailing edge system is a Fowler-motion flap in two spanwise segments. Inboard of the trailing edge break the flap is a two element (main / auxiliary) type with the auxiliary flap remaining stowed at takeoff. Outboard of the wing break the flap is a single element design. Additionally, the ailerons are drooped for takeoff and landing thereby providing a full span high lift system. The maximum flap setting is 35° and refers to the deflection of the inboard main flap. Figure 4 shows a comparison of the design features of the conventional and advanced high lift systems.

For the medium-to-long range aircraft the conventional high lift system uses a full span leading edge slat with a single deflected position. The trailing edge vane/flap uses a simple external hinge system like that of the McDonnell Douglas MD-11 airplane and has a maximum flap setting of 50°. The advanced high lift system is basically the same as that for the short-to-medium range aircraft; a two position full span slat, Fowler-motion flaps, and drooped ailerons for takeoff and landing. The inboard flap has two elements; the auxiliary flap remains stowed at takeoff. The midspan and outboard flaps are both single element. The maximum flap setting is 30°. An auto slat system is assumed for this study which opens the slats from the takeoff (sealed) position to the landing position near stall to improve the takeoff stall speeds. Figure 5 shows a comparison of the conventional and advanced high lift system designs for the medium-to-long range aircraft.

#### 3.4.1.1 Trimmed Aerodynamic Characteristics

The low speed aerodynamic characteristics of both aircraft were estimated using a combination of flight and wind tunnel test data as well as conceptual handbook methods. The lift and drag data were assembled and trimmed using MDC's proprietary 'Computer-Aided Sizing and Evaluation System [CASES] computer program. aircraft sizing program.

A summary of the final aerodynamic characteristics are plotted in Figures 6, 7, and 8 for the short-to-medium range aircraft and in Figure 9, 10, and 11 for the medium-to-long range aircraft. The results shown are for the configurations with the VHBPR engines. Figure 6 and Figure 9 show a comparison of $C_{L_{max}}$ for the conventional and advanced high lift systems and include both tail-off at 1-g conditions as well as trimmed $V_{min}$ levels. Figures 7 and 10 are plots of takeoff lift-to-drag (L/D) ratios as a function of lift coefficient. These plots represent envelope L/D curves i.e., the maximum L/D using the best flap setting at a given $C_L$. Figures 8 and 11 show L/D ratios for the landing condition at the landing flap setting only. All takeoff data as well as $C_{L_{max}}$ were trimmed at the forward CG limit, -0.3% of the mean aerodynamic cord (MAC) for the short-to-medium range aircraft and 10.5% MAC for the meduim-to-long range aircraft. Landing data was trimmed at the mid CG position, 16.2% MAC and 21.2% MAC for the short-to-medium and medium-to-long range aircraft respectively.

The high speed aerodynamic data were estimated using a combination of standard advanced design methods and empirical data, based on wind tunnel results of advanced design aircraft. The wing design incorporated supercritical airfoils with divergent trailing edge technology. The short-to-medium range and medium-to-long range aircraft wings were designed to cruise at Mach equal to 0.78 and 0.83 respectively. The aircraft were trimmed at a center of gravity location of thirty percent of the mean aerodynamic chord. Aircraft performance is discussed later in this report.

### 3.5 Weights

MDC's proprietary Conceptual Weight Estimation Program (CWEP) was used in this study to predict aircraft weights. The program requires inputs such as geometrical parameters, design criteria, and advanced technology multipliers. CWEP uses a series of weight estimating relationships (WERs) and a modified Breguet range equation to develop the initial aircraft sizing parameters, which are then processed by the CASES sizing code. The sizing parameters (shown in Table 8) consist of the partial derivatives of Operational Empty Weight

(OEW) with respect to gross weight, wing area ($S_W$), and thrust ($F_n$) plus a constant weight. To obtain the final aircraft weight, the $S_W$, $F_n$, and gross weight calculated in CASES are input to CWEP. The resulting group weight statement was used for cost estimation.

### 3.5.1 Design Criteria

The aircraft's maximum takeoff gross weight (MTOGW) is defined by the requirement to transport the maximum design passenger capacity over the design range. The full complement of passengers and bags at 210 lbs each defines the performance payload (WPPL), which is shown in Table 9. The maximum payload (WMPL) reflects the heaviest payload that the aircraft must carry and influences the structural weight. As is typical for commercial aircraft, these configurations are designed for a 2.5 limit load factor and a 10 ft/sec limit landing sink rate.

The short-to-medium range aircraft is designed to provide 8000 ft cabin pressure at 39,000 ft, and the medium-to-long range aircraft provides 8000 ft cabin pressure at 43,000 ft. This results in a limit differential cabin pressure (PD) of 8.1 psig for the short-to-medium range aircraft and 8.6 psig for the medium-to-long range aircraft. The maximum speeds in a dive (VD) for the aircraft are also presented in Table 9.

### 3.5.2 Advanced Technology Weight Impacts

CWEP reflects various technology levels by varying advanced technology multipliers (ATMs). The ATMs based on an entry into service date (EIS) of 2005 as referenced to a database of operational aircraft were used. The structural weight increments of advanced composites in newer operational transports have been factored out in order to normalize the database.

The wing and tail incorporate maximum use of advanced composites, but metallics are assumed for leading edges, aerodynamic surface hinges, and at critical joints. More dramatic weight reductions may be feasible, but commercial transports must emphasize low cost of manufacturing and maintenance. The fuselage uses Glare skins, Aluminum-Lithium longerons, and advanced composite secondary structure. The landing gear utilizes carbon brakes, radial tires and steel struts with a moderate improvement material properties.

The fixed equipment ATMs are empirically derived trends that reflect numerous weight reductions due to technology improvements, many of which are offset by increased capabilities and improved functionality. The term "fixed equipment" refers to those items whose weight is insensitive to changes in MTOGW and includes furnishings, APU, pneumatics, air conditioning, electrical, instruments and avionics. The weight of fixed equipment items tend to scale with fuselage size.

Although a EIS 2005 transport may be all-electric, there is scant empirical data on such systems and no reliable rationale for identifying related weight increments, therefore none are assumed.

### 3.5.3 High-Lift System Weights

The conventional high-lift system is similar to those installed on the McDonnell Douglas MD-80 and MD-11 aircraft. The advanced Fowler trailing edge flaps weigh nearly twice as much as the hinged MD-11 flaps. The drooped ailerons, that are proposed for the advanced high-lift system are assumed to be 10 percent heavier than conventional ailerons due to their higher unit aerodynamic loads. The slat's weight is assumed to be not affected by the two-position requirement since the maximum slat extension is the same as that for one-position slats. Also, no penalty was applied to the upper surface spoilers. The flight control and hydraulic systems weights are factored up by 4.3 percent for the advanced high-lift concept.

### 3.5.4 Propulsion System Weights

Propulsion system engine pod weight and nacelle weight were described in Section 2.5. Lacking detailed engine pylon drawings, all pylons were assumed to weigh 16 % of the pod weight, a value that is typical of the highly cantilevered pylons on modern commercial transport aircraft.

The pod plus pylon weights are scaled with $F_n$ using the following relationships. The first pair of equations were applied to the short-to-medium range aircraft, and the latter pair were utilized for the medium-to-long range aircraft.

$$\underline{18{,}000 \text{ lbs} < F_n < 45{,}000 \text{ lbs}}$$

$$Rt = F_n / 30{,}000 \text{ lbs}$$

HBPR Engine: $7{,}006 \text{ lbs } [\, 0.33 + 0.66\, Rt + 0.01\, Rt^2 ]$

VHBPR Engine: $9{,}650 \text{ lbs } [\, 0.33 + 0.66\, Rt + 0.01\, Rt^2 ]$

$$\underline{30{,}000 \text{ lbs} < F_n < 100{,}000 \text{ lbs}}$$

$$Rt = F_n / 60{,}000 \text{ lbs}$$

HBPR Engine: 12,000 lbs [ $0.17 + 0.82\,Rt + 0.02\,Rt^2$ ]

VHBPR Engine: 16,470 lbs [ $0.17 + 0.82\,Rt + 0.02\,Rt^2$ ]

### 3.6 Economics

The economic criteria used for evaluating and comparing the effect of advanced high-lift systems and engine cycles on airplane design and operation was Direct Operating Cost (DOC). The study's economic focus was on the first-level effects of advanced high-lift system technology, with respect to airplane performance (block time, block fuel) and airplane economics (DOC for a typical average stage length (ASL)).

The DOC method used for this study was based on the combination of ground rules and assumptions developed collectively by McDonnell Douglas Corporation (MDC) and its commercial aircraft component, Douglas Aircraft Company (DAC), the Boeing Commercial Airplane Group (BCAG), and NASA's Lewis Research Center (LeRC) for the PAIT Task 9 study. In the PAIT Task 9 study, the method was referred to as the "DOC+I" method, since the interest cost element was added. In addition, cabin crew costs, landing fees and navigation fees, usually considered to be indirect operating costs, were also added to the old Air Transport Association (ATA) DOC cost element structure. For purposes of this study, the conventional acronym DOC will be used, even though it will include the other cost elements just noted.

The DOC cost element structure included the following: (1) Flight Crew, (2) Cabin Crew, (3) Landing Fees, (4) Navigation Fees, (5) Maintenance - Airframe, (6) Maintenance - Engine, (7) Fuel, (8) Depreciation - Aircraft and Spares, (9) Insurance, and (10) Interest. Elements (1) through (7) are commonly referred to as "cash costs"; whereas elements (8) through (10) are referred to as "ownership costs".

The DOC process shown in Figure 12 is typical of the process used for this study. The block 'standard economic rules sets' includes the ten cost elements just discussed and the specific ground rules and assumptions to calculate each one. Airplane study prices for the airframe and engine were calculated using parametric methods. Airplane (airframe and engine) maintenance values were also parametrically determined from a historical database.

The short-to-medium range airplane was evaluated using U.S. domestic DOC rules at an average stage length (or average trip distance) of 500 NM. The medium-to-long range airplane was evaluated at an average stage length of 3000 NM using international DOC rules. The DOC ground rules used for the study are summarized in a Table 10. The economic results using the DOC method just described are shown and discussed in Section 3.1.2.

### 3.7 Acoustics

Acoustic analysis for this study was carried out using a method which is based on the construction of noise vs. power and distance (NPD) tables for each airframe / engine configuration design. These tables were created using MDC's proprietary source noise prediction computer program, "PAPER ENGINE", for a matrix of level flyovers at ten altitudes and at each altitude for six engine thrust levels and all at a reference flight Mach number. The six thrust settings spanned the range of expected conditions during the takeoff and landing portions of flight.

The PAPER ENGINE program models aircraft noise by integrating the contributions of several noise sources which include jet, core, fan inlet, fan exhaust, turbine, and airframe. Atmospheric absorption and ground reflections were also included in the modeling. The component sources predictions were based on engine cycle conditions and engine / aircraft geometry parameters. Attenuation of fan inlet and exhaust noise due to treatment (typical of current liner technology) was also included. The predictions methodology was calibrated with available flight data for similar sized aircraft.

A standard noise abatement flight procedure was used to generate flight paths for noise analysis. The procedure followed the general rules of FAR Part 25 safety procedures illustrated in Figure 13. This noise abatement procedure was used to evaluate all eight configurations. For the four short-to-medium range aircraft, cutback altitudes of 800 feet and 1,500 feet, typical of smaller airport procedures designed to reduce the close-in (less than 3 miles from the airport) community noise and the farther-out community noise respectively, were used. For the four medium-to-long range aircraft cutback altitudes of 1,000 feet and 1,500 feet, typical procedures utilized at larger airports to reduce close-in and farther-out community noise, were used.

The noise levels for the certification conditions - sideline, cutback, and approach were obtained by interpolation in the NPD tables for the appropriate minimum distance to the aircraft and engine thrust from the takeoff and landing flight profiles of the aircraft. Corrections for aircraft speed and lateral attenuation were then applied, when applicable according to the methods described in Reference 2. Noise contours were generated from a matrix of ground locations where noise levels were calculated using the same procedure.

# 4. ANALYSIS AND RESULTS

## 4.1 Sizing Trades

The sizing of aircraft was performed following the criteria stated in Table 1. In all cases, payload, range and takeoff field length were critical sizing parameters. Initial cruise altitude was never a critical parameter. Approach speed was critical only for the short-to-medium range aircraft with advanced high lift systems, but had a negligible effect on MTOGW. All other aircraft were sized by the combination of $S_W$ and $F_n$ which yielded the minimum MTOGW while meeting the takeoff field length requirements. As described in section 3, four short-to-medium range aircraft and four medium-to-long range aircraft were sized according to this ground rule. Each group of four similar aircraft consisted of configurations that had conventional high lift systems with HBPR engines and VHBPR engines as well as advanced high lift systems with HBPR engines and VHBPR engines.

We notice that the use of advanced high lift systems results in a decrease in the $S_W$ and $F_n$, but increases the MTOGW and fuel burned. The operating empty weight (OEW) is also higher for the configurations with the advanced high lift system (except for the short-to-medium configuration with HBPR engines). The weight increases are due to the higher weight of the advanced high lift systems themselves. The effect of engine change from HBPR to VHBPR is an increase of OEW and a decrease of fuel burned. $S_W$, $F_n$, and MTOGW decrease significantly due to engine change to VHBPR engine for the medium-to-long range aircraft, but generally increase for the short-to-medium range configurations. The longer range of the larger aircraft allows the higher fuel efficiency of the VHBPR to overcome it's higher weight and drag.

### 4.1.1 Aerodynamic Performance

A comparison of the aerodynamic performance parameters for the four short-to-medium range aircraft sized to minimize MTOGW area shown in Table 11. A similar comparison of the aerodynamic performance parameters for the four medium-to-long range aircraft sized for minimum MTOGW area shown in Table 12.

Flight paths generated using the standard noise abatement procedure with a cutback altitude of 800 feet for all four short-to-medium configurations are shown in Figures 14a, 14b, and 14c in terms of altitude, $F_n/\delta$, and true airspeed ($V_{true}$), respectively. When comparing the configurations with the advanced high lift systems to the corresponding configurations that have the conventional high lift systems, it can be noticed that the thrust required at cutback decreased by 3% for the HBPR powered configuration and by 6% for the VHBPR powered configuration. The corresponding altitudes attained over the certification takeoff location, a distance from brake release (DFBR) of 21,325 feet, decreased by 22 feet for the configuration with HBPR engines and 34 feet for the configuration with VHBPR engines.

### 4.1.2 Direct Operating Cost

The direct operating cost method described in Section 3.6 was used to evaluate and compare the economic impact of high-lift system technology. DOCs were calculated only for the final sized airplanes in each case.

The DOC values for the short-to-medium range aircraft with the conventional and advanced high-lift systems are shown in Figure 15. The summary results indicate that for the HBPR powered aircraft use of the advanced high-lift system results in 0.8% reduction in DOC relative to the conventional high-lift system. For the VHBPR powered aircraft, the slight DOC advantage of the advanced high-lift system is even lower (0.4%). The advanced high-lift system did not change the overall aircraft design and operational characteristics enough to produce a large change in DOC.

The DOC results for the medium-to-long range configurations are shown in Figure 16. The impact of incorporating an advanced high-lift system in either the VHBPR-powered or the HBPR-powered medium-to-long range configuration produced results similar to those for the short-to-medium range configuration. In this case, the advanced high lift system reduced the DOC by 0.2% for the HBPR powered configuration and by 0.5% for the VHBPR powered configuration. In the case of the medium-to-long range configurations, the reduction in engine size (thrust) afforded by the advanced high-lift system did produce a sizable reduction in engine maintenance cost, but that cost element comprised such a small percentage of the total DOC that its impact was not significant.

### 4.1.3 Noise

The NPD curves generated for the short-to-medium range configurations are shown in Figure 17 and Figure 18 for the HBPR and VHBPR engines, respectively. The noise metric shown in these NPDs is Sound Exposure Level (SEL). Similar NPDs for Effective Perceived Noise Level (EPNL) noise metric were also generated. SEL NPD curves for the medium-to-long range configurations are shown in Figure 19 and Figure 20 for the HBPR and VHBPR engines, respectively. The power variable used was corrected net thrust ($Fn/\delta$).

The smallest two $Fn/\delta$ values in the NPDs, 8,402 lbs and 6,424 lbs in Figure 17 for example, cover thrust range experienced during approach, whereas the other four values cover the takeoff cutback thrusts. The slant range values extend to 25,000 ft in order to allow noise contours to be calculated during takeoff and the approach phases of flight. A comparison of noise versus engine thrust for the two different engine types can be seen in Figure 21. It can be noticed that the VHBPR engine is around 9 EPNdB quieter than the HBPR engine in the takeoff and cutback thrust range, as expected with the increased bypass ratio. This benefit, however diminishes in the approach thrust region.

A comparison of the four short-to-medium range aircraft in terms of certification noise levels is given in Table 13. All of the aircraft shown were sized for minimum MTOGW. Significant noise reduction, as much as 24 cumulative EPNdB, was obtained from the utilization of VHBPR engines in place of HBPR engines. The additional benefit seen by including the advanced high lift system in the configuration was only 0.8 cumulative EPNdB (primarily at sideline). The approach and sideline noise benefit of the VHBPR engines on the short-to-medium range aircraft is slightly less for the advanced high lift system configurations than for the conventional high lift system configurations. Thus if the sizing criteria is minimum MTOGW for a specified mission, the noise benefit of advanced high lift systems is limited. Table 14 shows the benefit that switching from a HBPR to a VHBPR engine has on community noise. The noise exposure area can be reduced by as much as 13.15 square miles or 400% for the 80 SEL contour. Again, the VHBPR engine seems to show more noise reduction benefit on the short-to-medium range configuration with the conventional high lift system than with the advanced high lift system for all the contours shown except for the 80 SEL contour area with a cutback at an altitude of 800 feet. The percent reduction of this contour area shown in Table 14 is larger for the configuration with the advanced high lift system than for the configuration with the conventional high lift system. This is an indication that a tradeoff is occurring in the noise exposure between communities close to and those farther away from the airport. The benefit of greater contour area reduction from cutting back power earlier, with the advanced high lift configuration, offsets the increase in contour area incurred from higher thrust at sideline and approach. Figure 22 shows a comparison of the 85 EPNdB contour area for the short-to-medium range configuration with advanced high lift systems using HBPR and VHBPR engines.

A comparison of the four medium-to-long range aircraft in terms of certification noise levels is given in Table 15. Again, all of the aircraft shown were sized for minimum MTOGW. The benefit achieved by including the advanced high lift system in the medium-to-long range configuration was only 0.1 cumulative EPNdB. Table 16 shows that the incorporation of the advanced high lift system was beneficial at lower contour levels. Using the flight procedure with a cutback altitude of 1,000 feet, the 80 SEL contour area for the advanced high lift configuration with VHBPR engine is 298% higher compared to the HBPR engine case. For the conventional high lift configuration the corresponding change in contour area is 267%. Similarly the 85 SEL contour area changes are 531% and 505% respectively for the advanced high lift and conventional high lift configurations. Figure 23 shows a comparison of the 85 EPNL contour area for the medium-to-long range configuration with advanced high lift systems using HBPR and VHBPR engines.

4.1.3.1 Wing Oversizing and Reduced Approach $\delta_F$

As observed above, if the aircraft is resized for minimum MTOGW, the noise benefit of advanced high lift system is limited. However, the wing area, $S_W$, and the required engine thrust, $F_n$, do decrease. This led to an investigation of configuration design trades which would improve the noise benefit. The first approach was to increase the $S_W$ of the advanced high lift configuration up to the baseline $S_W$ (or increase the $S_W$ of the baseline conventional high lift configuration by a similar percentage) and determine the resultant effect on noise. Another approach was to reduce the approach flap deflection angle ($\delta_F$) to further improve the L/D ratio. The results of both of these parameter changes are shown in Table 17 in terms of the resized aircraft characteristics and noise. This table also gives an indication of the relative contributions of the resized aircraft speed, thrust, and distance (height over the noise monitor) to the noise changes at the takeoff, sideline, and approach certification monitor locations relative to the baseline configuration represented by the aircraft with conventional high lift system with approach flap angle, $\delta_F = 40^o$ and sized for minimum MTOGW. These are computed as $10\log(V/V_{ref})$, $10\log(F_n/F_{nref})$, and $20\log(D/D_{ref})$ as listed in Table 17).

As shown for configuration S9 in Table 17, increasing $S_W$ of the advanced high lift system configuration to equal that of the baseline HBPR, conventional high lift system (minimum MTOGW) configuration and reducing the approach $\delta_F$ to $15^o$ yielded noise reductions of 0.4 EPNdB at the takeoff monitor for the 1,500 ft altitude cutback takeoff procedure, 1.4 EPNdB at sideline, and 2.1 EPNdB at approach. Even though the speed dropped in all three instances and the minimum distance to the monitor decreased (indicated by a positive

"+" noise impact), these effects were out-weighed by the reduction in the required thrust, $F_n$ (indicated by a negative "-" noise impact). Figure 24 shows the cumulative ΔEPNL ($\Delta EPNL_{takeoff} + \Delta EPNL_{sideline} + \Delta EPNL_{approach}$) due to various sizing criteria and other configuration variations for the short-to-medium range aircraft. All cumulative ΔEPNL values shown are with respect to the baseline configuration (S0), which has a conventional high lift system and is sized to minimize MTOGW. The cumulative noise reduction for a configuration (S4) with advanced high lift system but sized for minimum MTOGW is only 1.2 EPNdB. It is noted that the maximum approach $\delta_F$ was $40^o$ for the conventional high lift system and $35^o$ for the advanced high lift system. Sizing for minimum MTOGW yielded a 12% smaller wing area for the S4 configuration compared to the S0 configuration. The benefit of advanced high lift system can be taken in noise reduction rather than a wing area reduction, as was the case for configuration S2. Resizing the S2 configuration to the same $F_n$ and $V_2$ as the baseline S0 configuration resulted in a significant penalty in terms of cumulative noise reduction, as indicated for the S7 configuration. Reducing the MTOGW of the S7 configuration to equal that of the baseline (S0) yielded only a moderate noise improvement (configuration S8). In an effort to find the maximum noise reduction obtainable with the advanced high lift system, a resizing with a reduced approach $\delta_F$ was performed for configuration S5. Again further noise reduction was seen when the wing area of the S5 configuration was increased to equal that of the baseline in configuration S6.

The effect of simply increasing the wing area by roughly 12% can be seen in Figure 25. For the advanced high lift system configuration, the takeoff noise level with a cutback at 1500 feet decreases by 0.4 EPNdB, the sideline noise level decreases by 0.5 EPNdB, while the approach noise level increases by 0.2 EPNdB due to the decreased airspeed at approach. For the conventional high lift system configuration similar noise changes are obtained at sideline and approach but no noise benefit is obtained at cutback.

Figure 26 shows the effect of reducing the approach flap angle, $\delta_F$ on the advanced high lift system configurations in terms of $\Delta EPNL_{approach}$. The configurations of Figure 26 were all sized with the same wing area as the baseline configuration with conventional high lift system. The approach speeds of these configurations increased as $\delta_F$ was reduced but were all below 130 knots. The approach noise of the configuration with a $\delta_F$ of $15^o$ is 2 EPNdB lower than that for the configuration with a $\delta_F$ of $35^o$.

The approach noise of the aircraft configuration with the conventional high lift system can also be reduced by decreasing approach flap angle as shown for the configuration labeled

S10 in Figure 24. The S9 configuration can be compared to the S10 configuration in order to isolate the noise benefit of the advanced high lift system from that obtained by merely reducing $\delta_F$. As shown in Table 17, the S9 configuration with the advanced high lift system and $\delta_F$ of 15° has roughly the same approach speed as the S10 configuration with the conventional high lift system and $\delta_F$ of 25° but the approach thrust requirement has been reduced by 28%. The total noise benefit attributable solely to improved high lift system technology for this comparison was a reduction of 0.4 EPNdB at takeoff, 1.4 EPNdB at sideline, and 0.8 EPNdB at approach for a cumulative ΔEPNL of 2.6 EPNdB.

## 5. CONCLUSIONS AND RECOMMENDATIONS

The impact of advanced high lift systems on aircraft size, performance, DOC and noise was evaluated for a short-to-medium range and a medium-to-long range aircraft with HBPR and VHBPR engines. Two significant observations were made from this study. First, the advanced high lift systems provided a cumulative noise reduction of approximately 1 EPNdB (primarily at sideline) when the aircraft were sized to minimize MTOGW. The improvements in the high lift system resulted in aircraft with smaller wings and lower engine thrusts for the same mission. Secondly, implementation of advanced high lift system without reducing the wing size, and using lower flap angles that provide higher L/D at approach showed a cumulative noise reduction of as much as 4 EPNdB (including significant reduction at approach). Comparison of conventional and advanced high lift aircraft configurations that have similar approach speeds yielded a cumulative noise reduction of 2.6 EPNdB that is purely the result of incorporating an advanced high lift system in the aircraft design.

A logical follow on to this study is to determine optimum flight procedures for the best configurations of the short-to-medium range and medium-to-long range aircraft in order to minimize the community noise impact at specific airports. Consideration of only areas outside of airport boundaries should also be factored into the analysis. Additionally, system studies should be undertaken to quantify the changes in overall aircraft cost, performance, and reliability, resulting from reduced approach flap settings and hence approach thrust requirements to lower approach noise.

## REFERENCES

[1] Federal Aviation Regulation Part 121, subpart R, paragraph 121.480, "Flight Time Limitations".

[2] SAE Committee A-21, "Procedure for the Calculation of Airplane Noise in the Vicinity of Airports", Society of Automotive Engineering Aerospace Information Report 1845, March 1986.

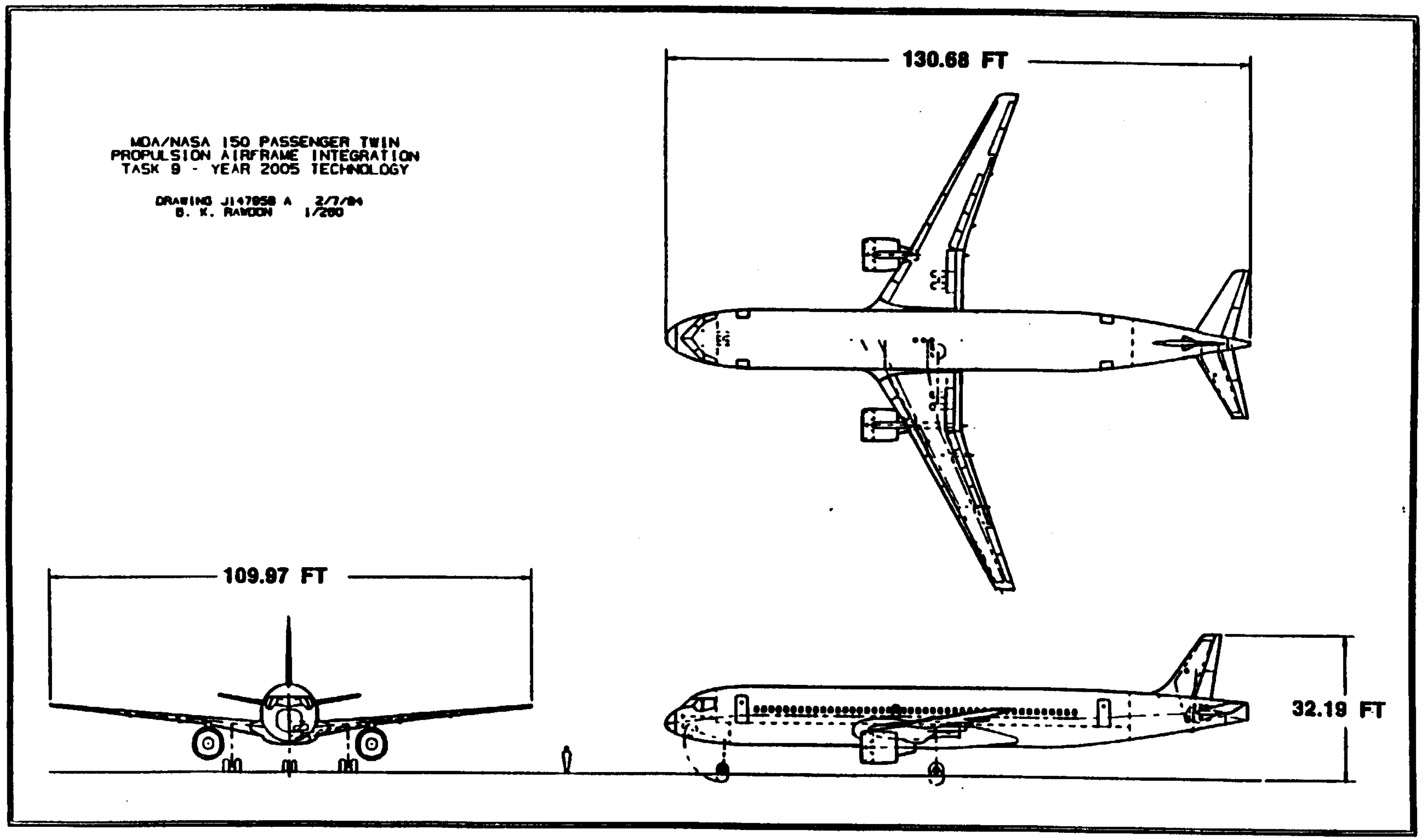



Figure 1 150 Passenger Aircraft Configuration

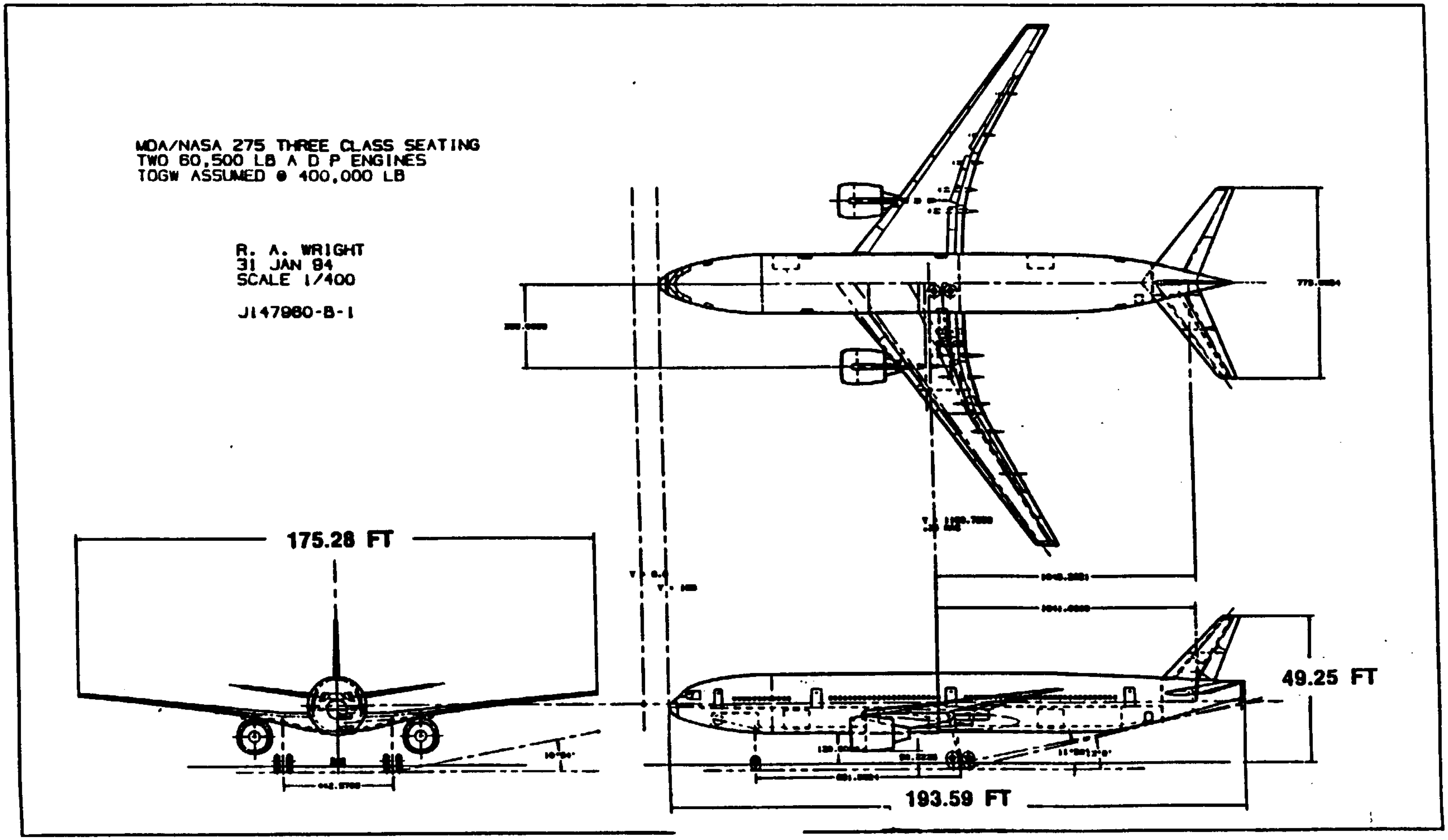



Figure 2   275 Passenger Aircraft Configuration

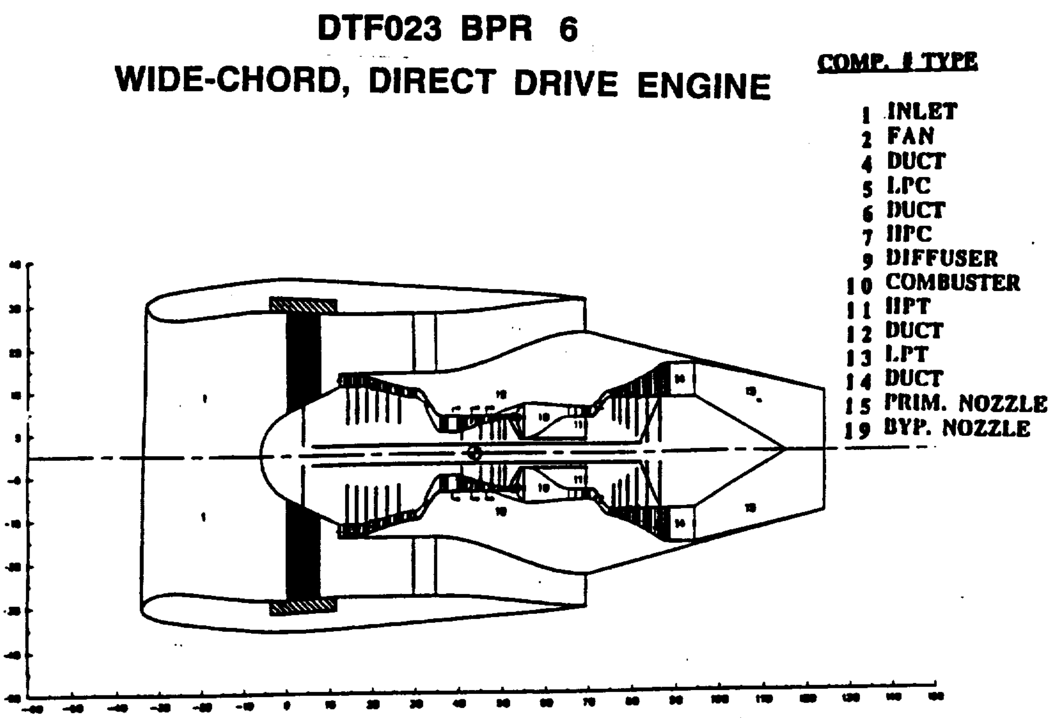



Figure 3a DTF 023 Engine Flow Path

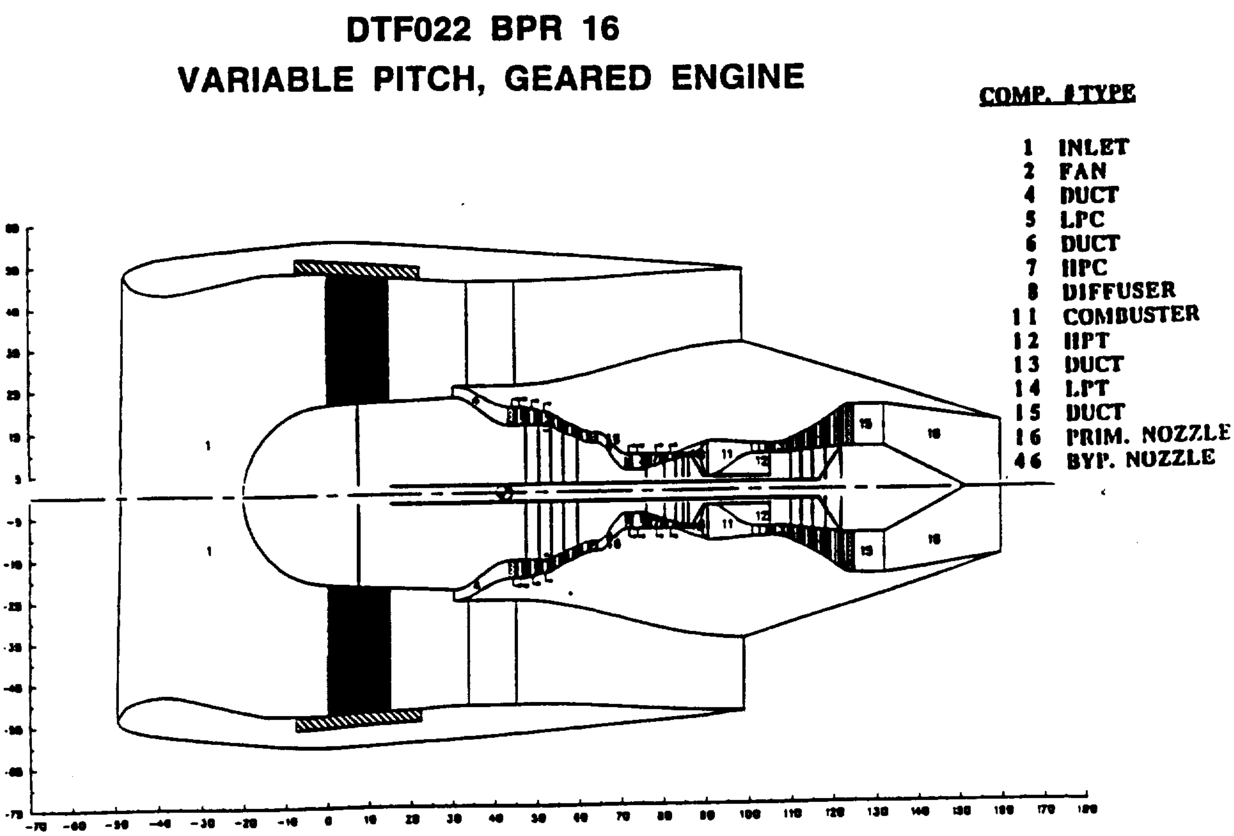
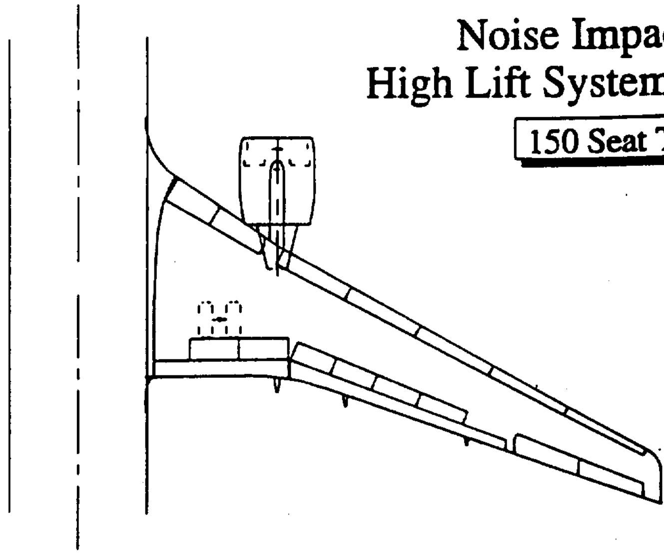



Figure 3b DTF022 Engine Flow Path

# Noise Impact Study
## High Lift System Definitions

**150 Seat Twin**



**Ref. Quant. from 3-view J147958:**

Sref = 1099.44 sq. ft.
AR = 11.0
Taper ratio = 0.275
c/4 sweep = 27.0°

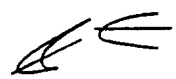
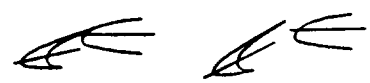
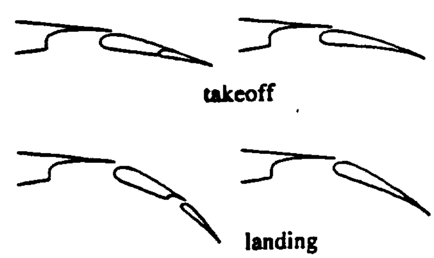
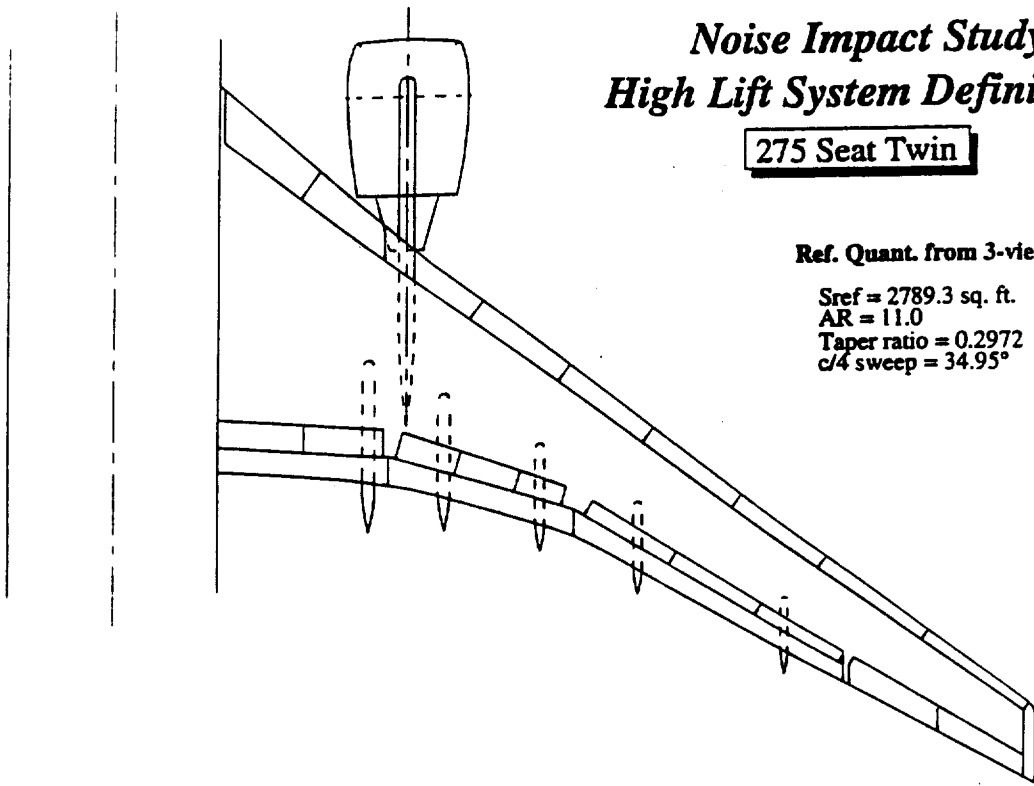
| | Conventional High Lift System | Advanced High Lift System |
|---|---|---|
| Leading edge device | Single position slat<br><br>(takeoff & landing) | Two position slat<br><br>takeoff (sealed) landing |
| Trailing edge device | MD-80 type vane/flap<br><br>landing | Fowler motion<br>2-seg inbd / 1-seg outbd<br><br>takeoff<br>landing |
| Additional features | | Drooped ailerons |

Figure 4. 150 Passenger Aircraft High Lift System Comparison



*Noise Impact Study*

***High Lift System Definitions***

275 Seat Twin

**Ref. Quant. from 3-view J147960:**

Sref = 2789.3 sq. ft.
AR = 11.0
Taper ratio = 0.2972
c/4 sweep = 34.95°

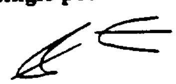
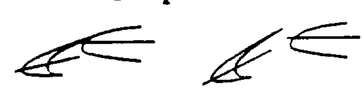
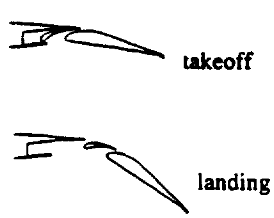
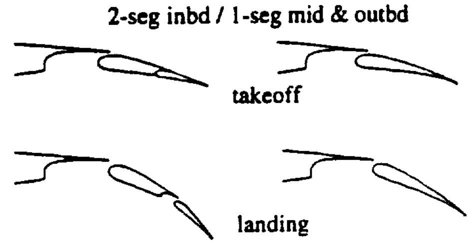
| | Conventional High Lift System | Advanced High Lift System |
|---|---|---|
| Leading edge device | Single position slat  (takeoff & landing) | Two position slat  takeoff (sealed) landing |
| Trailing edge device | MD-11 type vane/flap  | Fowler motion flap 2-seg inbd / 1-seg mid & outbd  |
| Additional features | | Drooped ailerons for takeoff & landing |

Figure 5. 275 Passenger Aircraft High Lift Systems Comparison

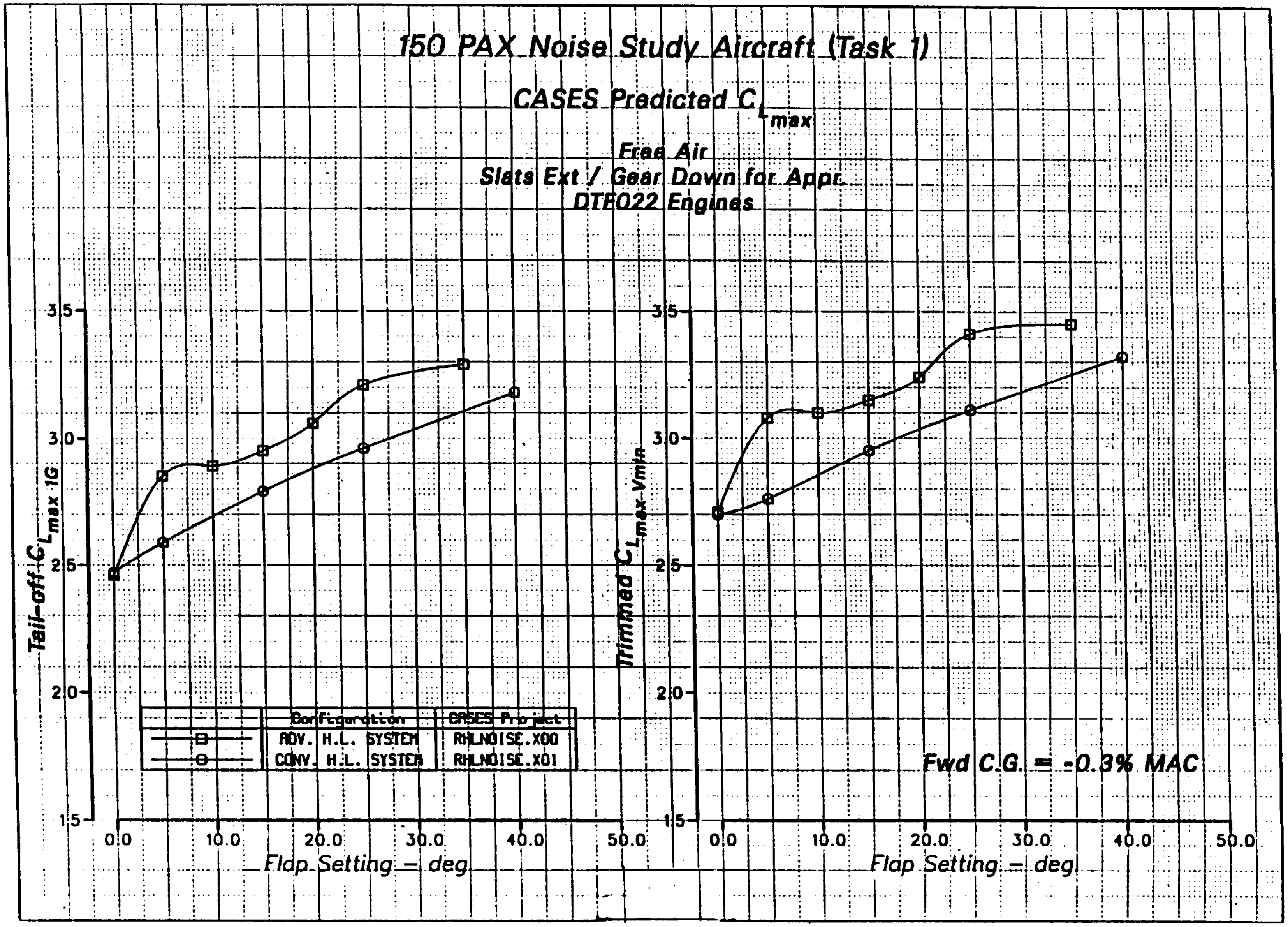



**Figure 6** 150 Passenger Aircraft Lift Coefficients

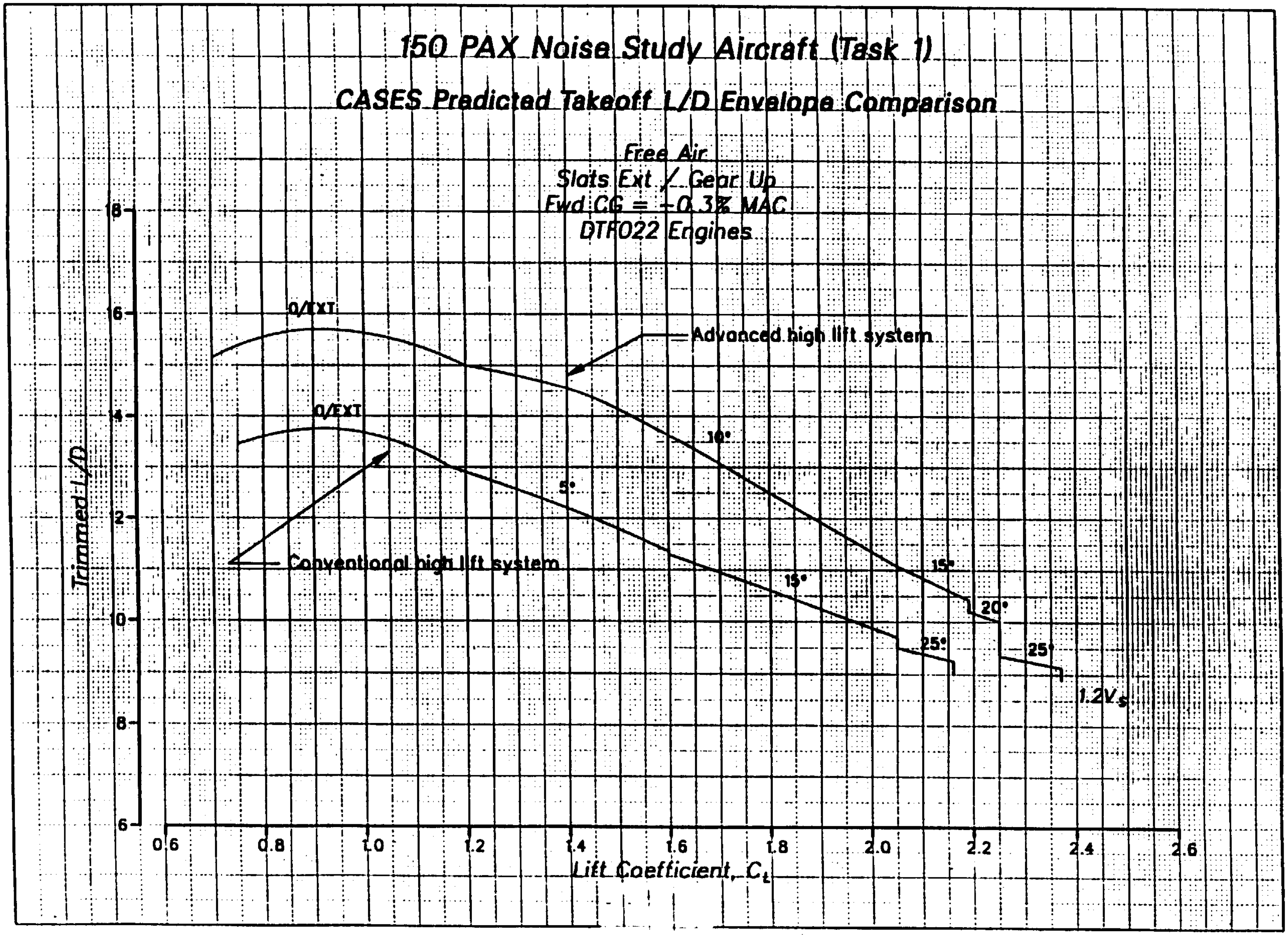



**Figure 7** 150 Passenger Aircraft Takeoff L / D

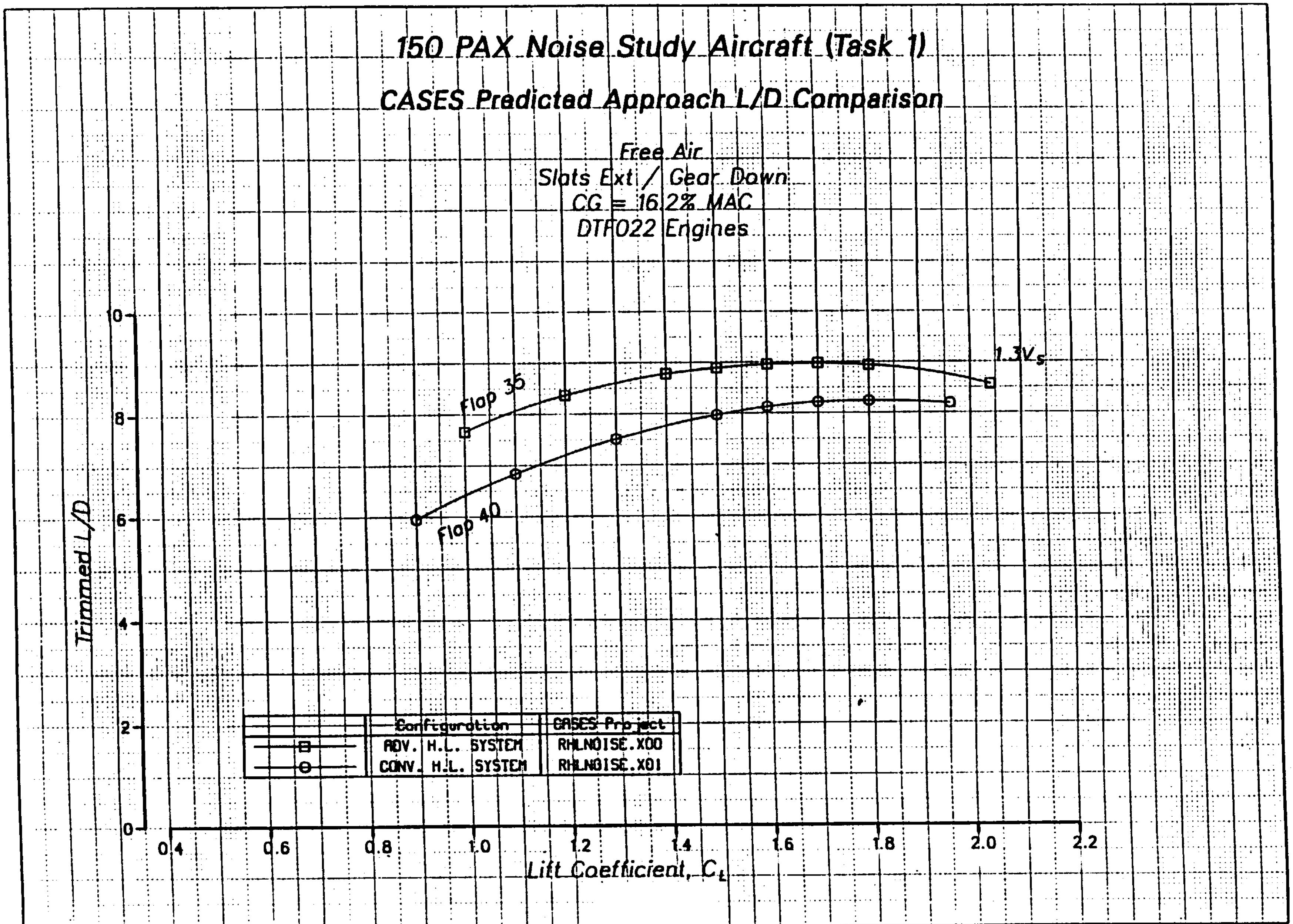



Figure 8 150 Passenger Aircraft Approach L/D

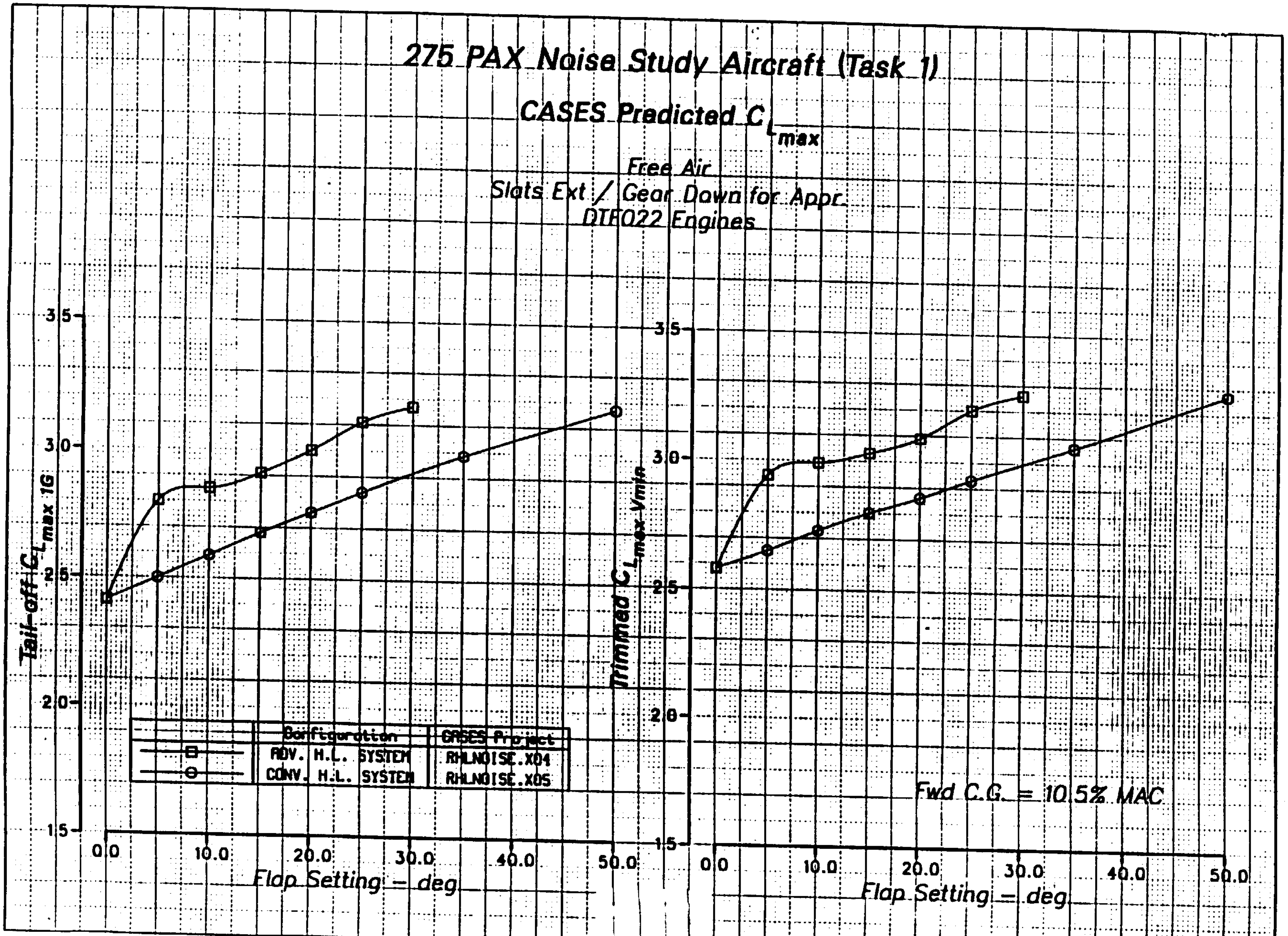



**Figure 9** 275 Passenger Aircraft Lift Coefficients

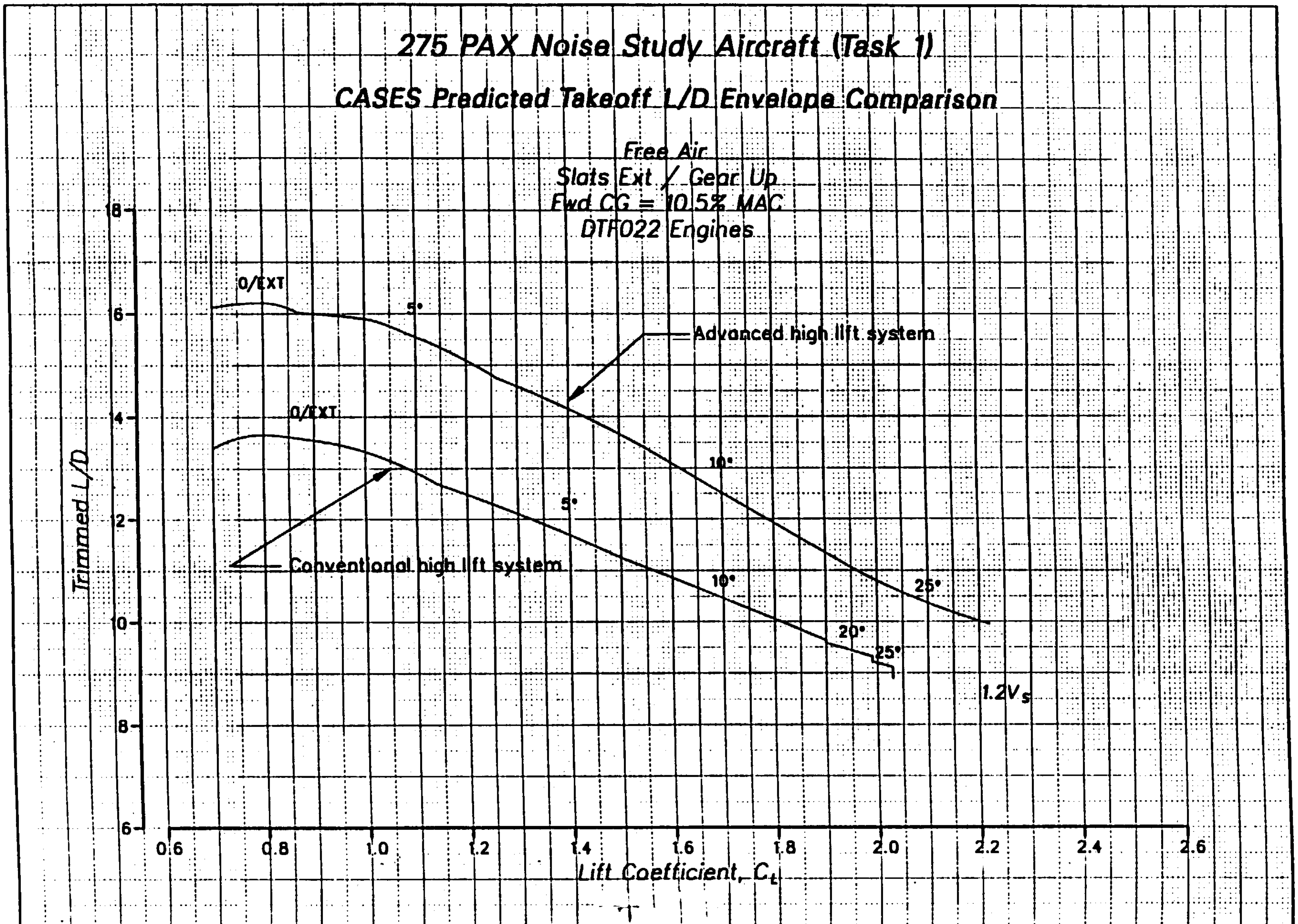



**Figure 10** 275 Passenger Aircraft Takeoff L/D

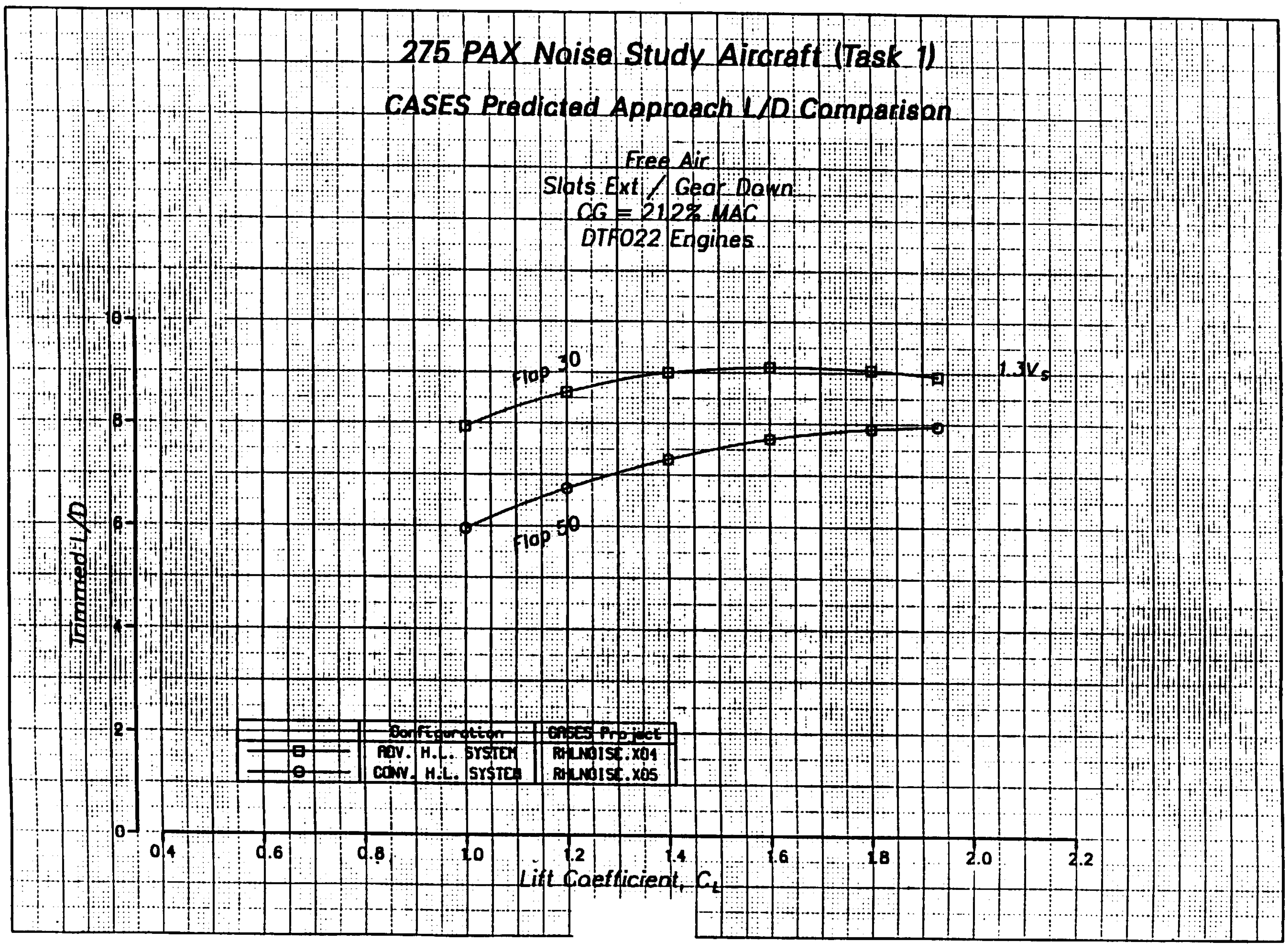



**Figure 11** 275 Passenger Aircraft Approach L/D

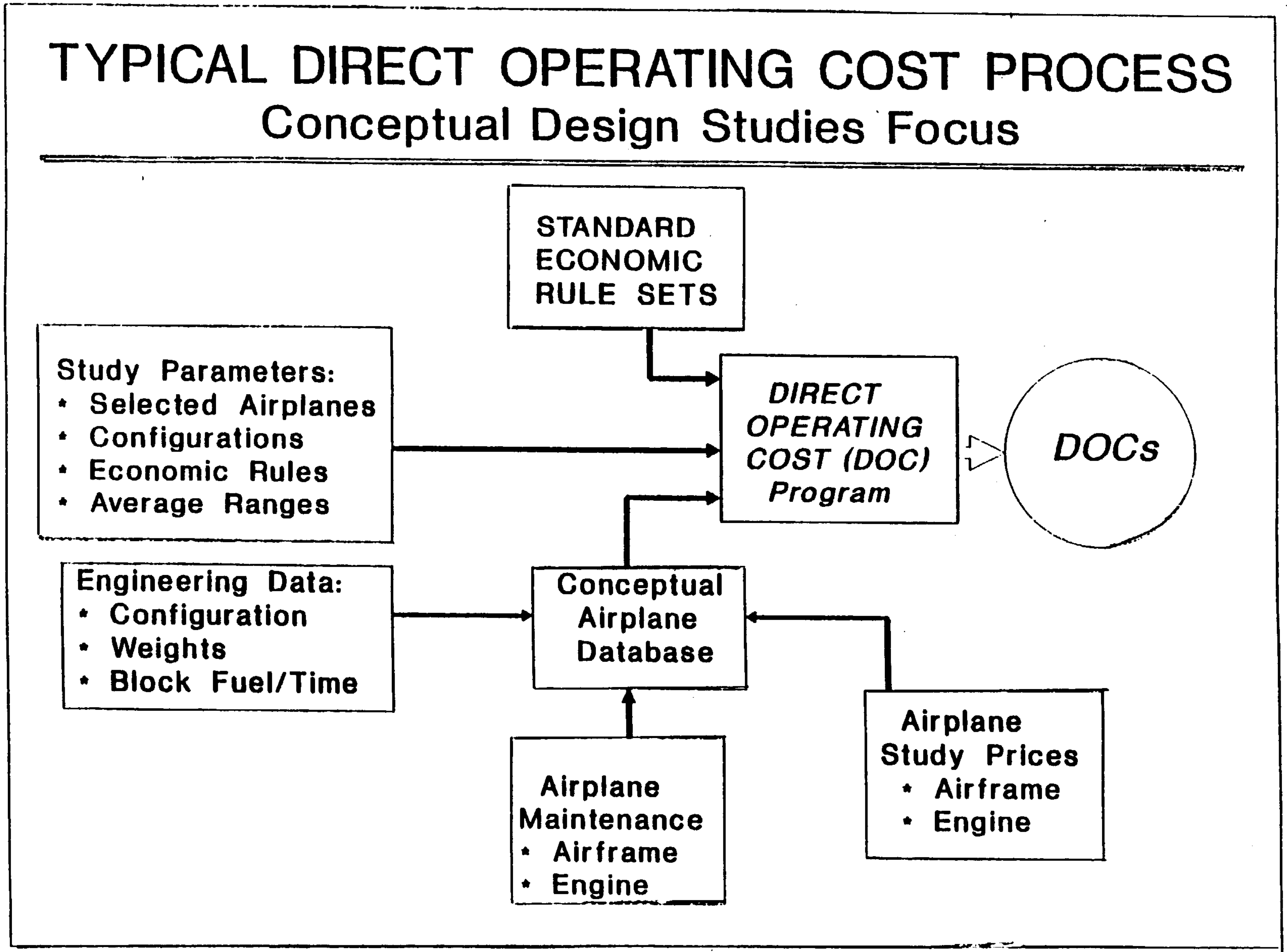



Figure 12. Typical Direct Operating Cost Process

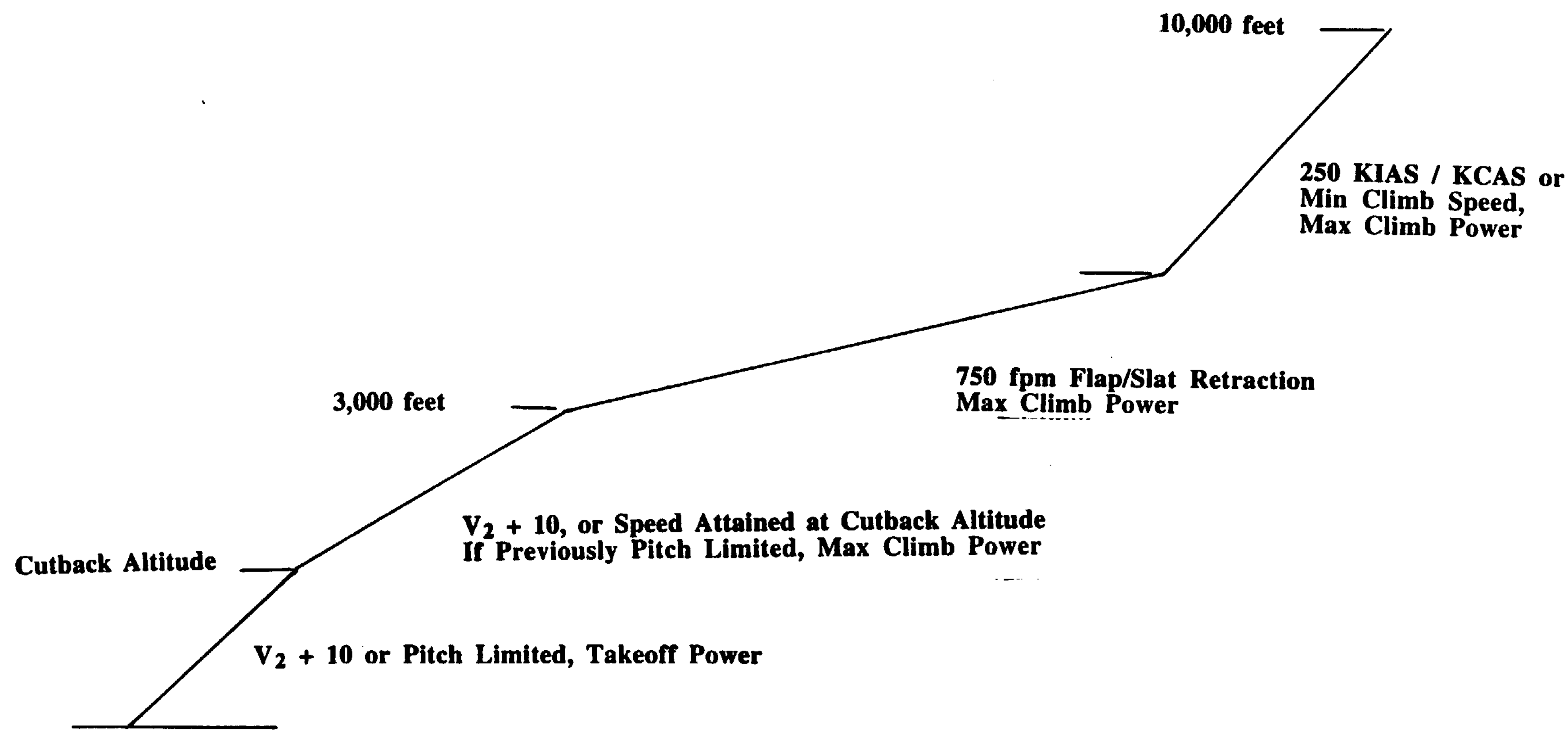



Figure 13. Noise Abatement Takeoff Flight Procedure

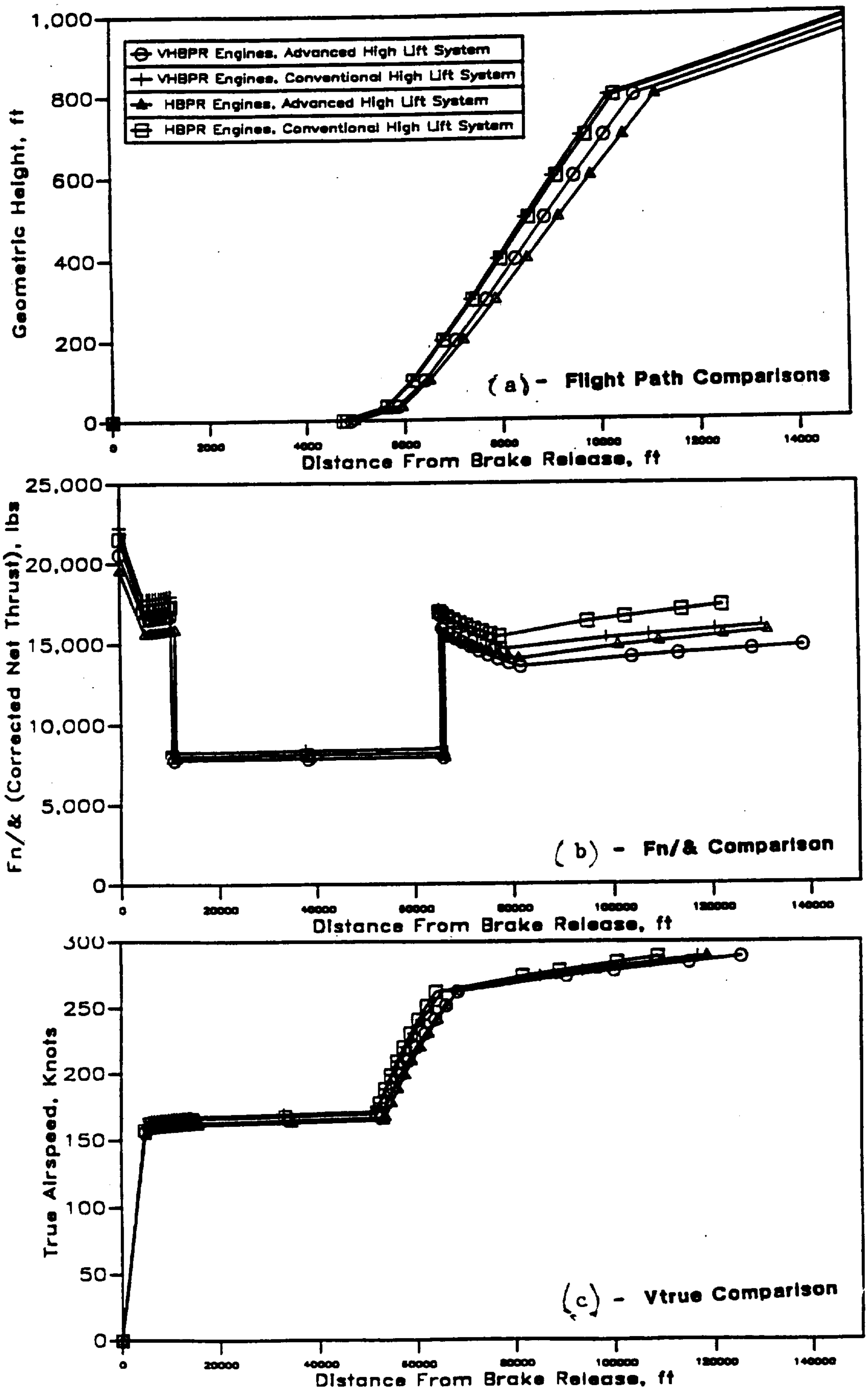



FIGURE 14. Short-to-Medium Range Aircraft Flight Path Comparison
Cutback to 4% All Engine Climb Gradient at a Height of 800 feet

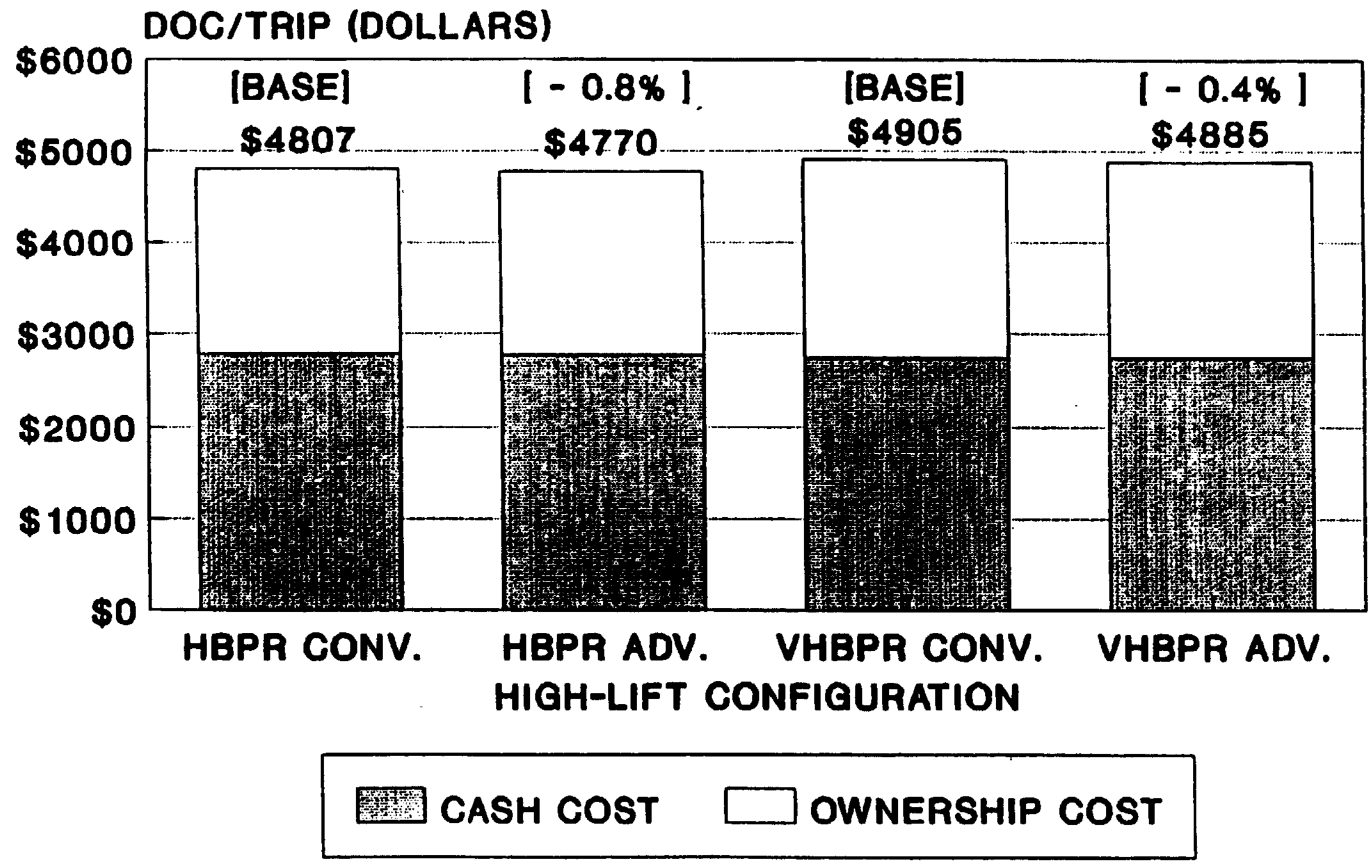



Figure 15. Impact of High Lift System on DOC; Short-to-Medium Range Aircraft

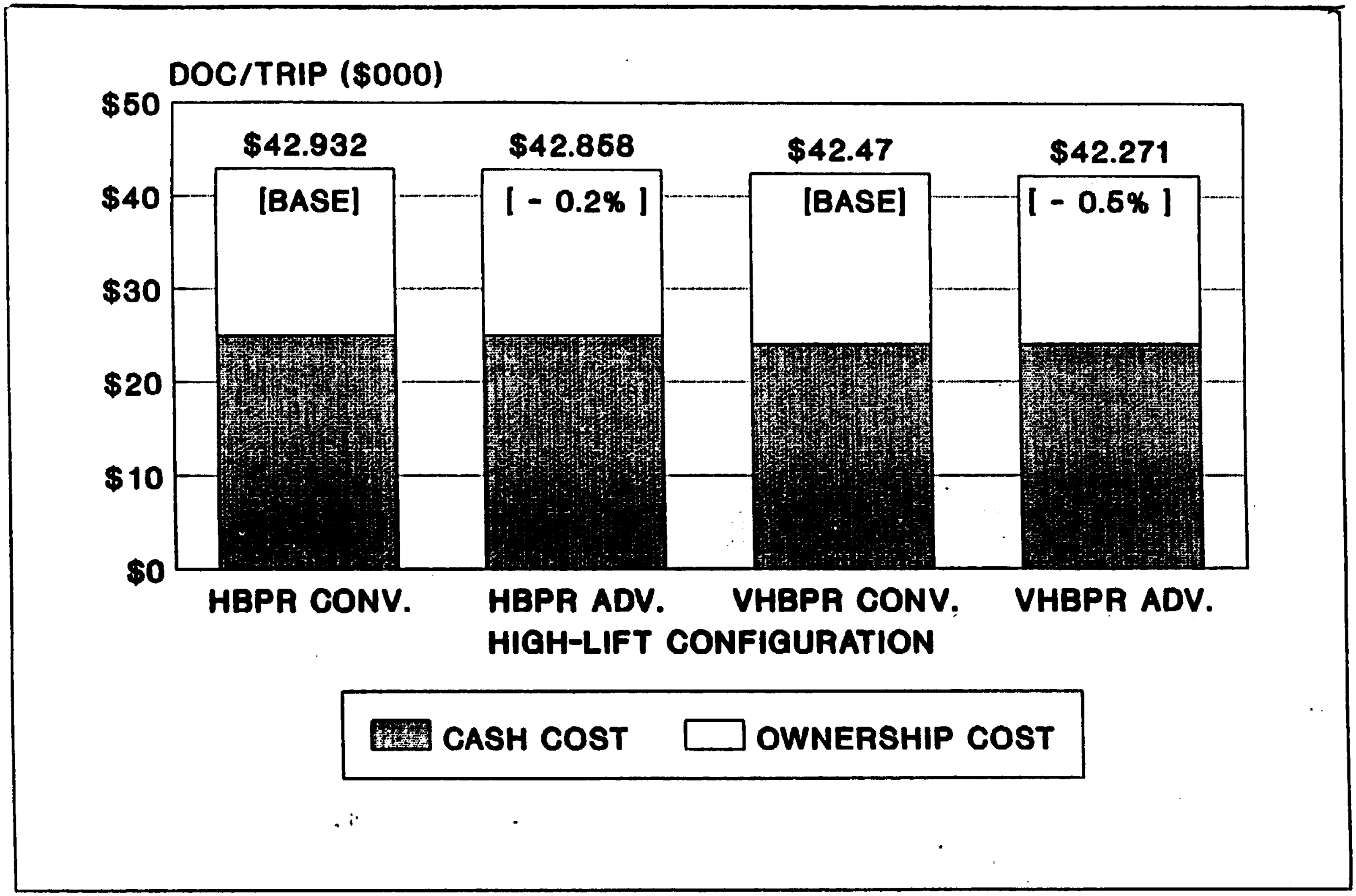



Figure 16. Impact of High Lift System on DOC; Medium-to-Long Range Aircraft

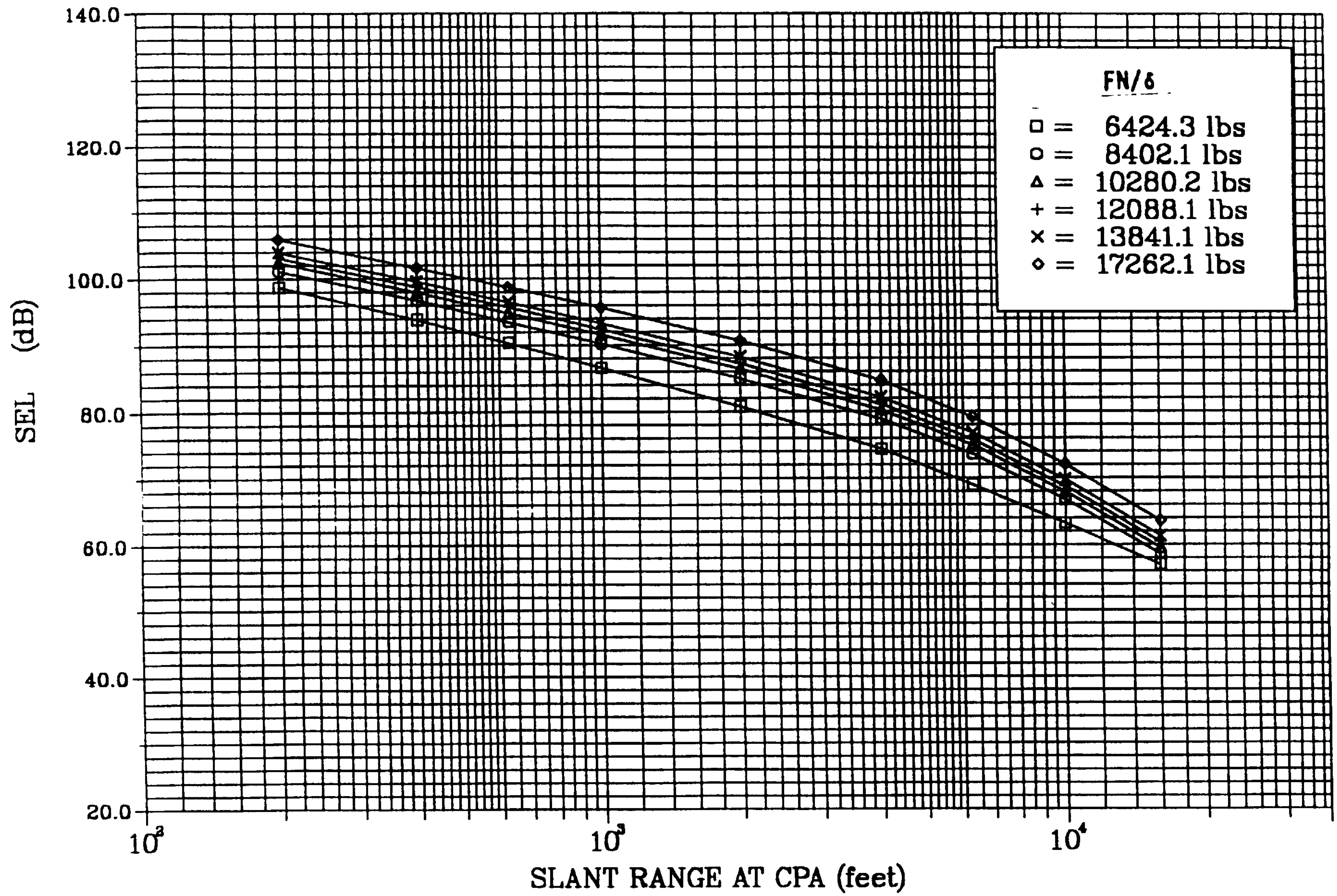



Figure 17. SEL Noise-Power-Distance Map; Short-to-Medium Range, HBPR Aircraft

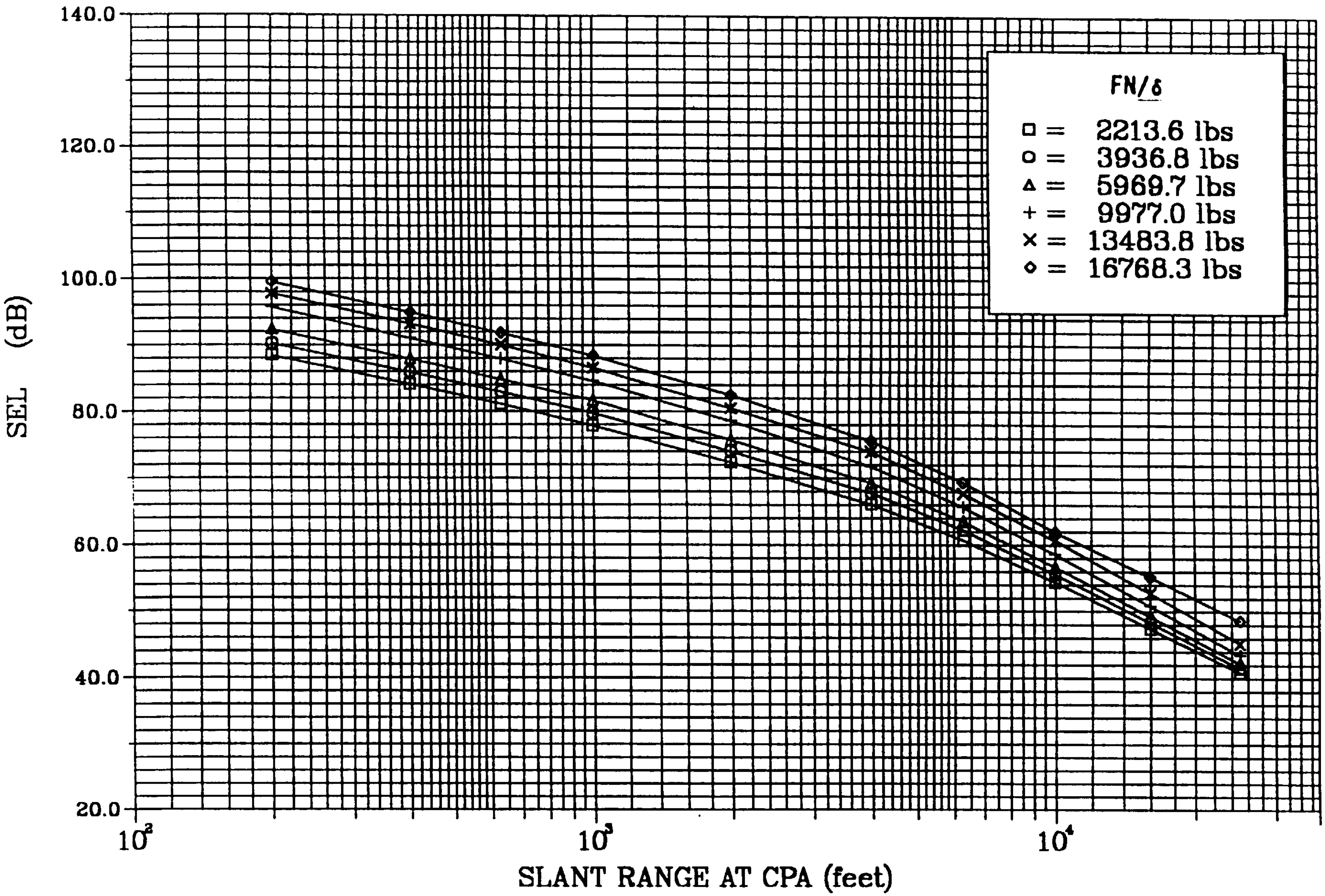



Figure 18. SEL Noise-Power-Distance Map; Short-to-Medium Range, VHBPR Aircraft

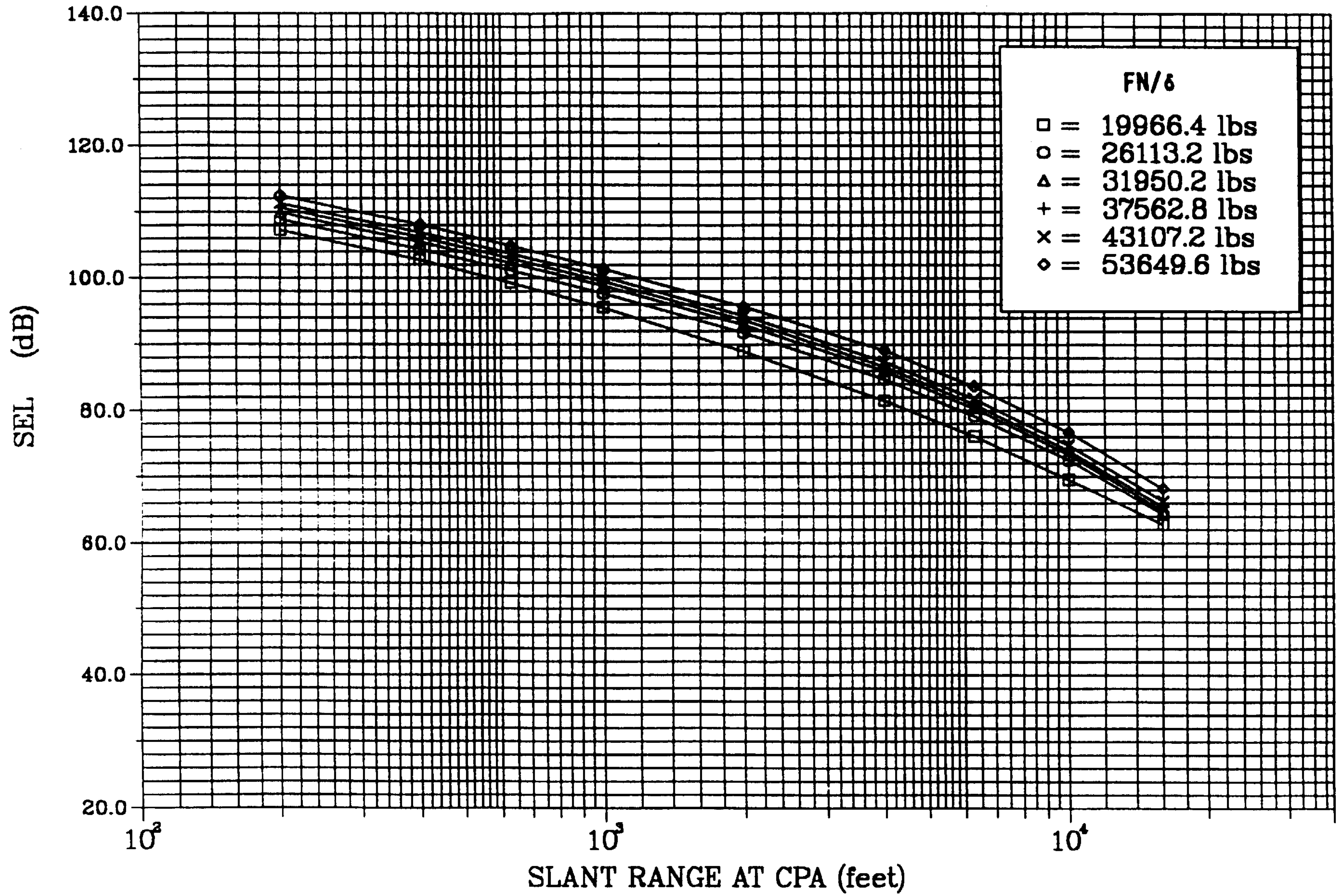



Figure 19. SEL Noise-Power-Distance Map; Medium-to-Long Range, HBPR Aircraft

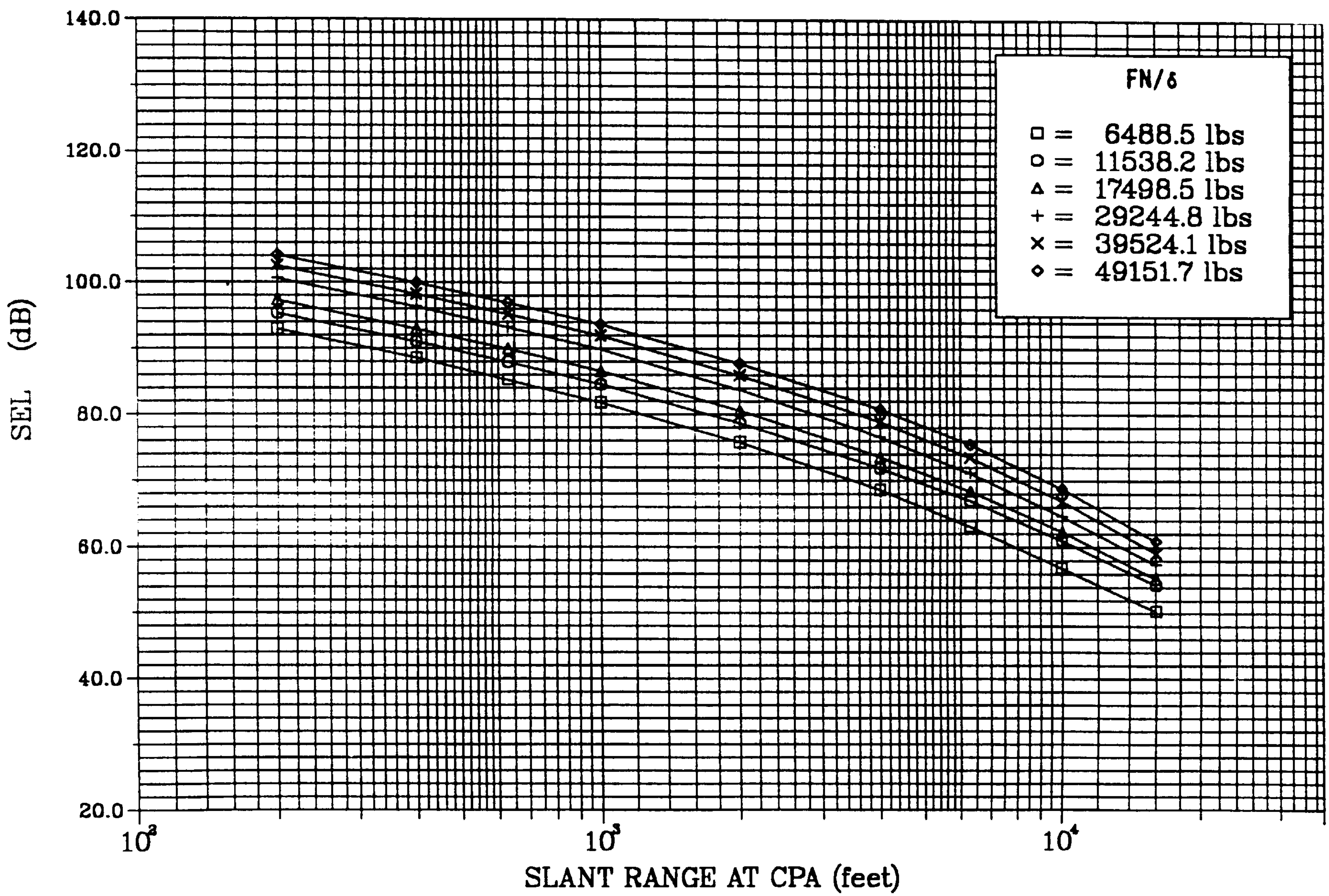



Figure 20. SEL Noise-Power-Distance Map; Medium-to-Long Range, VHBPR Aircraft

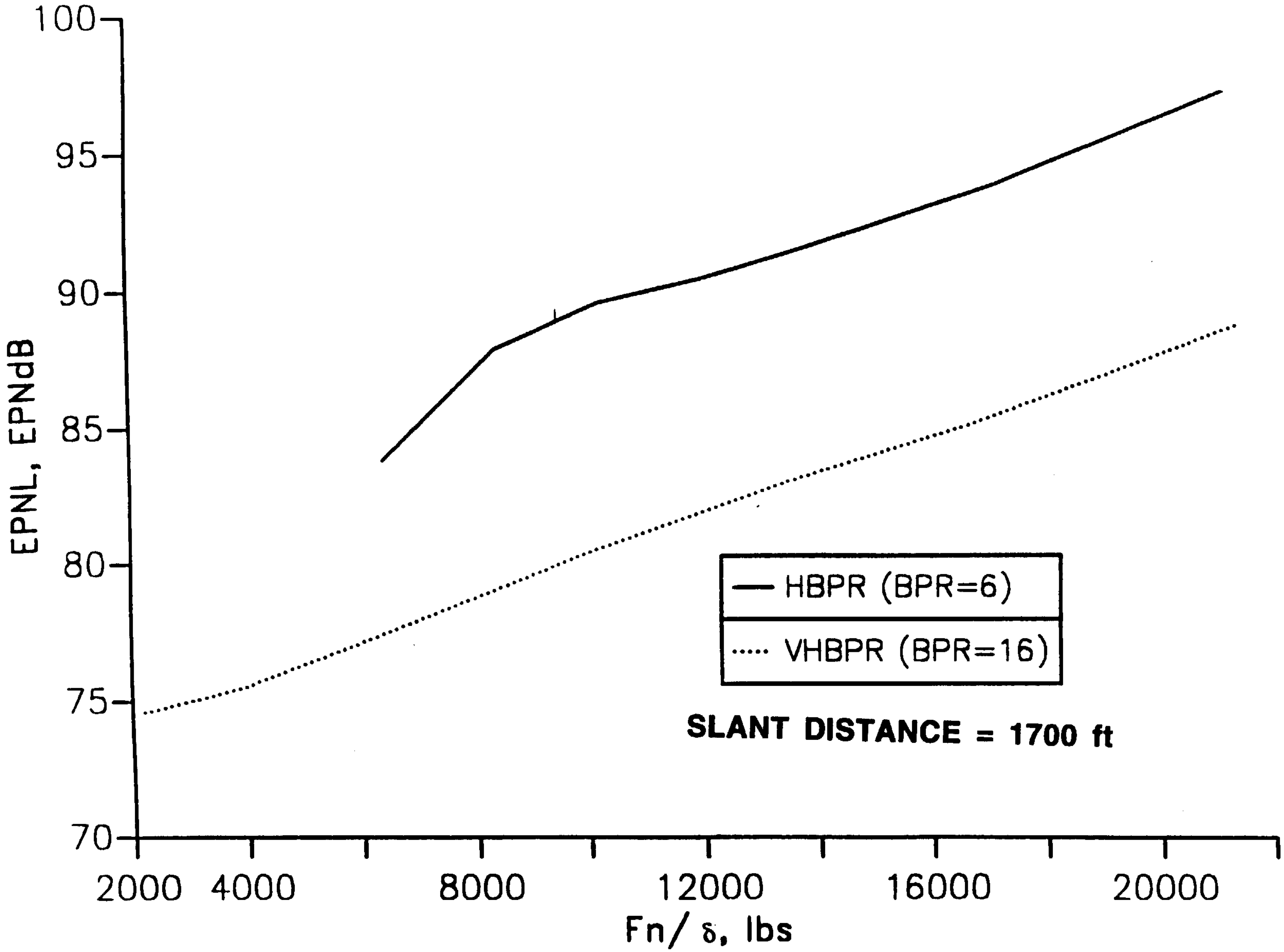



FIGURE 21. EPNL Versus $F_n/\delta$ For The HBPR And VHBPR Engines

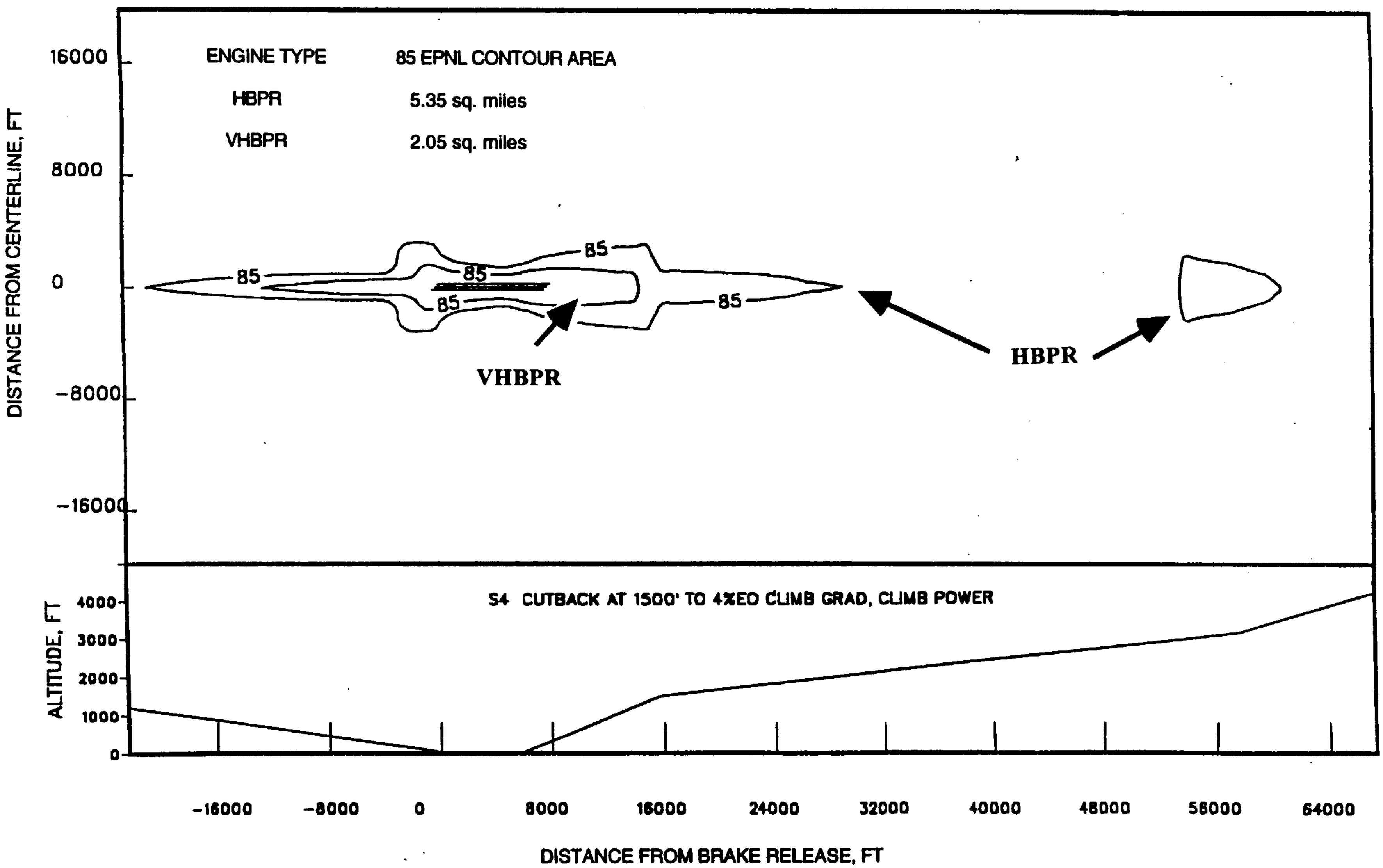



FIGURE 22. 85 EPNL Noise Contours For The Short-To-Medium Range Aircraft With Advanced High Lift Systems

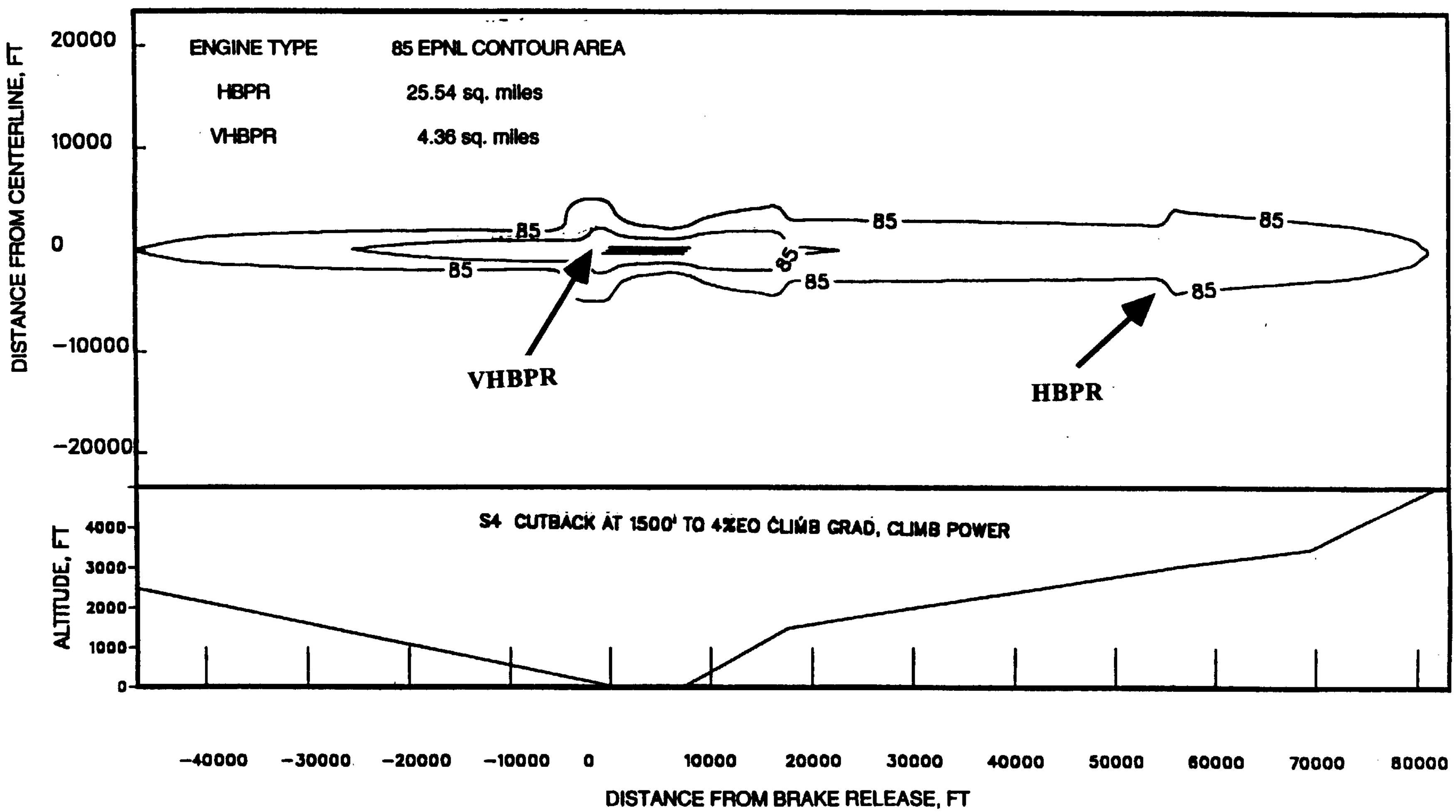
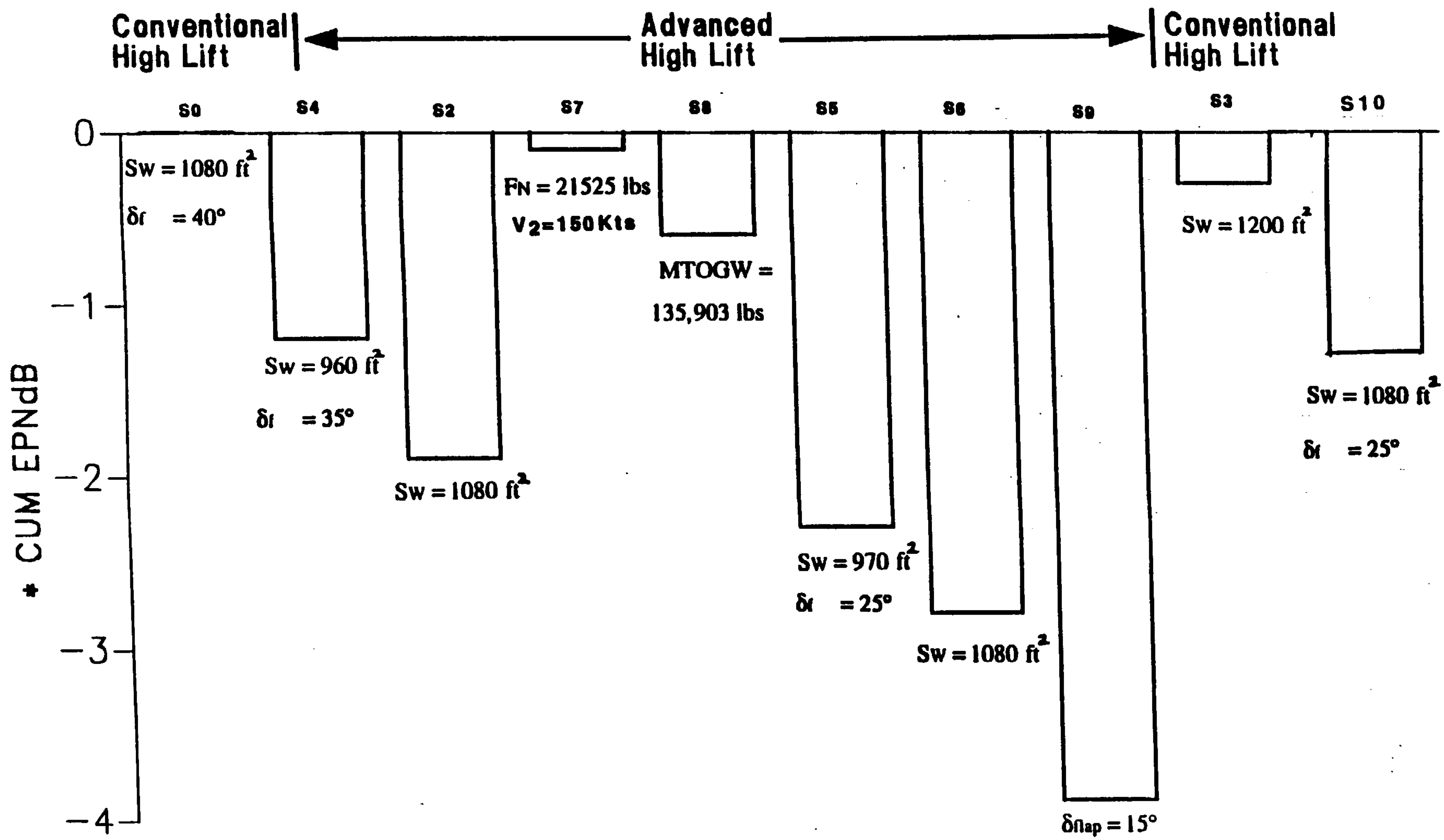



FIGURE 23. 85 EPNL Noise Contours For The Medium-To-Long Range Aircraft With Advanced High Lift Systems

SHORT-TO-MEDIUM RANGE ; 31,000lb PAYLOAD; 7,000ft TOFL; 2,500 NM MISSION




* SUM OF EPNdB CHANGES AT SIDELINE, TAKEOFF, AND APPROACH

SHORT-TO-MEDIUM RANGE AIRCRAFT ; 31,000lb PAYLOAD; 7,000ft TOFL; 2,500 NM MISSION

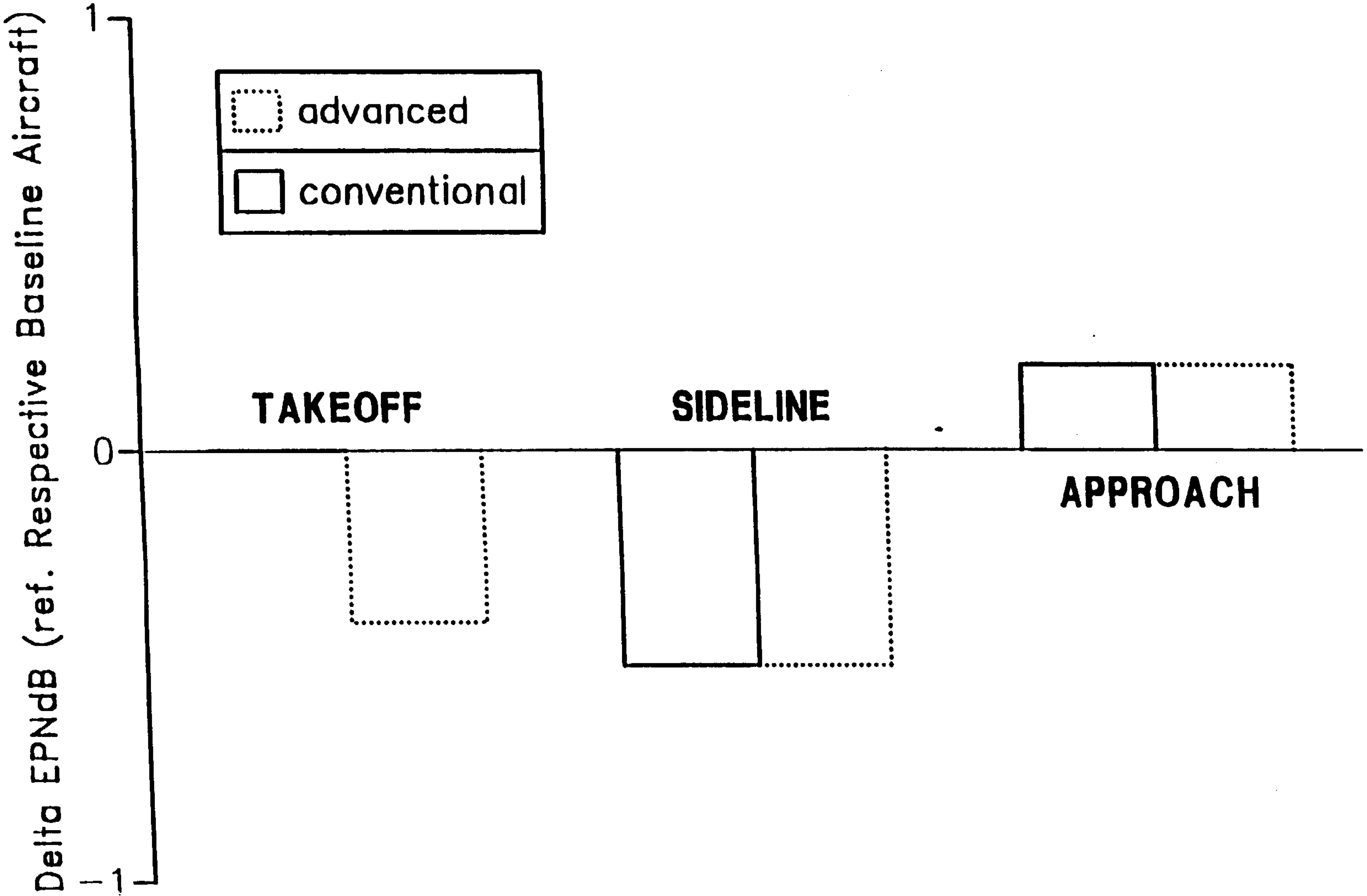



FIGURE 25 Effect Of Wing Oversizing On Noise

SHORT-TO-MEDIUM RANGE AIRCRAFT; 31,000lb PAYLOAD; 7,000ft TOFL; 2,500 NM MISSION

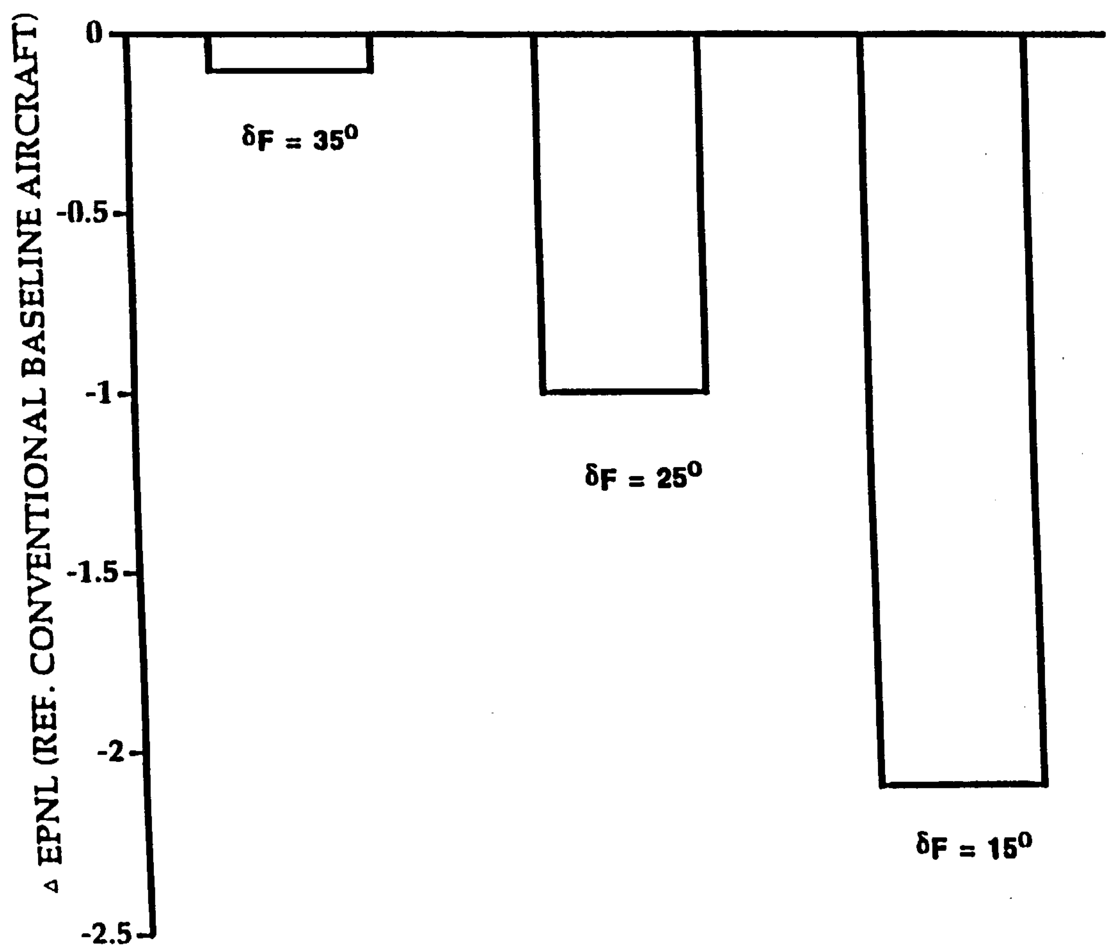



FIGURE 26 Effect Of Approach Flap Angle On Noise

## TABLE 1 - PAIT TASK 9 Airplane Missions

| | Category | Seats | Rules | Range (N.Mi.) | Cruise Mach No. | ICA (Ft) | VAP (Kt) | TOFL (Ft) |
|---|---|---|---|---|---|---|---|---|
| * | Short Range | 150 | 2 Class Narrow Body | 2500 | .78 | 31,000 | 130 | 7000 |
| | Medium Range | 225 | 2 Class Twin Aisle | 4500 | .80 | 35,000 | 120 | 6000 |
| * | Medium Range | 275 | 3 Class International | 6000 | .83 | 35,000 | 140 | 9000 |
| | Long Range | 600 | 3 Class International | 8000 | .85 | 35,000 | 155 | 11,000 |

* Missions Definitions For The RESEARCH IN AIRPLANE ACOUSTICS AND NOISE CONTROL TASK 1 - NOISE IMPACT OF ALTERNATIVE OPERATIONAL PROCEDURES

TABLE 2. - HBPR (DTF023) ENGINE CYCLE PARAMETERS AT THE DESIGN POINT

| PARAMETER | DESCRIPTION | DTF023 |
|---|---|---|
| W2AR | Corrected airflow at inlet exit (lb/sec) | 944 |
| W3R | Corrected airflow at HPC exit (lb/sec) | 4.85 |
| T3 | HPC exit temperature (°R) | 1,383 |
| T4 | Combuster exit temperature (°R) | 2,760 |
| T41 | Turbine rotor inlet temperature (°R) | 2,579 |
| BPR | Bypass ratio | 6.0 |
| FPR | Fan pressure ratio | 1.8 |
| OPR | Overall pressure ratio | 37.0 |

TABLE 3. - VHBPR (DTF022) ENGINE CYCLE PARAMETERS AT THE DESIGN POINT

| PARAMETER | DESCRIPTION | DTF022 |
|---|---|---|
| W2AR | Corrected airflow at inlet exit (lb/sec) | 2,182 |
| W3R | Corrected airflow at HPC exit (lb/sec) | 4.85 |
| T3 | HPC exit temperature (°R) | 1,354 |
| T4 | Combuster exit temperature (°R) | 2,760 |
| T41 | Turbine rotor inlet temperature (°R) | 2,576 |
| BPR | Bypass ratio | 16.2 |
| FPR | Fan pressure ratio | 1.3 |
| OPR | Overall pressure ratio | 34.2 |

## TABLE 4. - CYCLE PERFORMANCE OF ENGINES COMPARISON

| CONDITION | DTF022 | | DTF023 | |
|---|---|---|---|---|
| | NET THRUST (lbs.) | TSFC (lb/hr/lb) | NET THRUST (lbs.) | TSFC (lb/hr/lb) |
| Top of Climb<br>M0.8, h=36,089 ft, RC=40 | 7,383 | 0.515 | 6,598 | 0.593 |
| Max. Cruise<br>M0.85, h=36,089 ft, RC=35 | 6,685 | 0.528 | 6,248 | 0.594 |
| Takeoff<br>M0.0, h=0.0 ft, RC=50 | 35,008 | 0.224 | 27,732 | 0.320 |
| Takeoff<br>M0.2, h=0.0 ft, RC=50 | 29,188 | 0.304 | 22,823 | 0.394 |

1. Includes bleeds and extractions for 225 passenger twinjet
2. Inlet and nozzle performance based on P&W STS998

TABLE 5. - WEIGHTS AND DIMENSIONS OF ENGINES COMPARISON

| WEIGHTS: | DTF022 | DTF023 |
|---|---|---|
| BARE ENGINE (including core cowl) | 7286 | 3974 |
| BYPASS NOZZLE (with or without reverser) | 278 | 836 |
| PRIMARY NOZZLE | 117 | 125 |
| NACELLE | 863 | 436 |
| ACCESSORIES | 700 | 388 |
| TOTAL (lbs.) | 9,244 | 5,759 |

| DIMENSIONS (inches): | DTF022 | DTF023 |
|---|---|---|
| MAXIMUM FAN DIAMETER | 105.9 | 67.0 |
| MAXIMUM NACELLE DIAMETER | 121.1 | 81.2 |
| TOTAL LENGTH (inlet to core nozzle exit) | 209 | 158 |
| ENGINE LENGTH (fan face to LPT exit frame) | 132 | 124 |

TABLE 6. - ENGINE GEOMETRY AND ACOUSTIC INFORMATION COMPARISON

| | DTF022 | DTF023 |
|---|---|---|
| No. of Fan Blades | 16 | 22 |
| No. of Fan Stators | 34 | 54 |
| Fan Tip Diameter (in) | 105.9 | 67.0 |
| Fan Hub Diameter (in) | 42.4 | 20.1 |
| Fan Rotor/Spacing at 75%Rotor Radial Length | 1.26 | 2.72 |
| Fan Efficiency | 91.68 | 89.81 |
| Fan RPM at design point | 1669 | 4803 |
| Gear Box Ratio | 0.2381 | 1.0 |
| No. of Rotor Blades for LPT Last 2 Stages | 109/105 | 161/143 |
| No. of Vanes for LPT Last 2 Stages | 107/102 | 157/138 |
| Rotor/Stator Spacing for LPT Last 2 Stages | 3.0/3.5 | 3.75/2.5 |
| LPT Tip Diameter (in) Last 2 Stages | 30.2/34.2 | 35.1/38.0 |
| LPT Hub Diameter (in) Last 2 Stages | 19.1/19.7 | 26.2/26.2 |
| Primary/Fan Nozzle Exit Area ($in^2$) | 768.5/4856.2 | 630.4/1449.3 |
| Primary Nozzle Exit Diameter (in) | 31.2 | 28.4 |
| Fan Nozzle Exit Diameter (in) | 105.4 | 71.0 |

TABLE 7. - ENGINE NACELLE GEOMETRY COMPARISON

| | DTF022 | DTF023 |
|---|---|---|
| Total Nacelle Length (in) | 148.2 | 103.8 |
| Ratio of Stream Tube/Highlight Areas | 0.536 | 0.543 |
| Nacelle Max X-sectional Area ($ft^2$) | 80.0 | 36.0 |
| Fan Exit Area ($ft^2$) | 33.7 | 10.0 |
| Core Exit Area ($ft^2$) | 5.3 | 4.4 |
| Exposed Planform Area ($ft^2$) | 96 | 41 |
| Fan Cowl Wetted Area ($ft^2$) | 343 | 156 |
| Fan Pressure Ratio | 1.3 | 1.8 |
| Fan Cowl Length (in) | 148.2 | 103.8 |

**TABLE 8. - Aircraft Sizing Derivatives**

$$OEW = W_c + \frac{dOEW}{dW_g}[W_g + W_{go}] + \frac{dOEW}{dS_w}[S_w - S_{wo}] + \frac{dOEW}{dT}[F_n - F_{no}]$$

$$W_g = OEW + W_{pl} + W_{fuel}$$

Where:

OEW = Operational Empty Weight (lb)

$\frac{dOEW}{dSw}$ = Partial derivative of OEW with respect to wing area $\left(\frac{lb}{ft^2}\right)$

$\frac{dOEW}{dT}$ = Partial derivative of OEW with respect to Thrust $\left(\frac{lb}{lb}\right)$

$\frac{dOEW}{dW_g}$ = Partial derivative of OEW with respect to MTOGW $\left(\frac{lb}{lb}\right)$

$S_w$ = Wing area ($ft^2$)

$S_{wo}$ = Base wing area ($ft^2$)

$F_n$ = Thrust per engine, sea level static rated ($lb_f$)

$F_{n_o}$ = Base thrust per engine, sea level static rated ($lb_f$)

$W_c$ = Base constant weight (lb)

$W_g$ = Maximum Takeoff Gross Weight (lb)

$W_{go}$ = Base Maximum Takeoff Gross Weight (lb)

$W_{fuel}$ = Fuel weight (lb)

$W_{pl}$ = Payload weight (lb)

**TABLE 9. - Design Criteria**

| CONFIGURATION | WPPL (lb) | RANGE (nm) | WMPL (lb) | PD (psig) | VD (KEAS) |
|---|---|---|---|---|---|
| Short-To-Meduim Range | 31,500 | 2,500 | 43,000 | 8.1 | 400 |
| Meduim-To-Long Range | 57,750 | 6,000 | 100,000 | 8.6 | 415 |

TABLE 10. - Direct Operating Cost (DOC) Ground Rules

| | DOMESTIC | INTERNATIONAL |
|---|---|---|
| **DESIGN MISSION** | 2,500 NM | 6,000 NM |
| **ECONOMIC MISSION** | 500 NM | 3,000 NM |
| **UTILIZATION** | 2,100 Trips/Year | 625 Trips/Year |
| **DOLLAR YEAR** | 1993 | 1993 |
| **FUEL PRICE** | $.65/U.S. Gallon | $.70/U.S. Gallon |
| **MAINTENANCE**: LABOR | $25.00/Hour | |
| BURDEN | 200% Direct Labor | |
| **COCKPIT CREW** | 2 | |
| **CABIN CREW** | 1/35 Seats | 1/30 Seats |
| **LANDING FEES** | $=f$(MLGW) | $=f$(MTOGW) |
| **NAVIGATION FEES** [First 500 NM] | None | $=f$(MTOGW) |
| **ANNUAL HULL INSURANCE** [% of Total Airplane Price] | .35 | |
| **DEPRECIATION**: PERIOD [Years] | 15 | |
| RESIDUAL [% Price] | 10 | |
| **SPARES**: AIRFRAME [% Price] | 6 | |
| ENGINES [% Price] | 23 | |
| **INTEREST**: AMOUNT FINANCED | 100% | |
| PERIOD [Years] | 15 | |
| RATE [%] | 8 | |

TABLE 11. - SIZING PARAMETER COMPARISON OF SHORT-TO-MEDIUM RANGE AIRCRAFT

| | Conventional High Lift System | | Advanced High Lift System | |
|---|---|---|---|---|
| Engine | MDA DTF023 | MDA DTF022 | MDA DTF023 | MDA DTF022 |
| Bypass Ratio | 6 | 16 | 6 | 16 |
| Sw (Sq Ft) | 1,080 | 1,080 | 960 | 1,005 |
| Fn (Lb) | 21,525 | 22,225 | 19,550 | 20,550 |
| MTOW (Lb) | 135,918 | 138,656 | 136,162 | 139,143 |
| OEW (Lb) | 76,087 | 81,067 | 75,915 | 81,316 |
| Block Fuel (Lb) | 24,017 | 22,221 | 24,426 | 22,463 |
| Block Time (Hr) | 6.052 | 6.033 | 6.044 | 6.031 |
| Wt/Sw (Lb/Sq Ft) | 125.85 | 128.38 | 141.84 | 138.45 |
| Fn/Wt | 0.317 | 0.321 | 0.287 | 0.295 |
| ICA (Ft) | 38K+(Buffet) | 37K+(Cl Ceil) | 35K+(Buffet) | 36K+(Cl Ceil) |
| Vappr (KEAS) | 125.2 | 127.6 | 130.1 | 129.9 |
| Fn appr - 2 engines (Lb) | 8,159 | 8,553 | 7,875 | 8,233 |
| TOFL (Ft) | 7,000 | 7,000 | 7,000 | 7,000 |
| 1st Seg Grad (%) | 1.34 | 1.34 | 1.50 | 1.44 |
| 2nd Seg Grad (%) | 2.40 | 2.40 | 2.40 | 2.40 |
| V2 (KEAS) | 148.9 | 150.7 | 144.4 | 146.2 |
| L/D | | | | |
| Start Cruise @ 35000 | 17.9 | 17.5 | 17.7 | 17.4 |
| End Cruise @ 39000 | 17.8 | 17.4 | 17.4 | 16.8 (35000) |
| SFC | | | | |
| Start Cruise @ 35000 | 0.580 | 0.511 | 0.577 | 0.509 |
| End Cruise @ 39000 | 0.578 | 0.506 | 0.575 | 0.513 (35000) |

## TABLE 12 - SIZING PARAMETER COMPARISON OF MEDIUM-TO-LONG RANGE AIRCRAFT

| | Conventional High Lift System | | Advanced High Lift System | |
|---|---|---|---|---|
| Engine | MDA DTF023 | MDA DTF022 | MDA DTF023 | MDA DTF022 |
| Bypass Ratio | 6 | 16 | 6 | 16 |
| Sw (SQ FT) | 3,240 | 3,126 | 3,045 | 2,900 |
| Fn (LB) | 69,350 | 65,630 | 64,600 | 61,000 |
| MTOW (LB) | 449,500 | 433,000 | 453,300 | 435,300 |
| OEW (LB) | 224,900 | 230,200 | 227,900 | 231,700 |
| Block Fuel (LB) | 148,600 | 131,600 | 149,600 | 132,400 |
| Block Time (Hr) | 13.1 | 13.07 | 13.1 | 13.07 |
| Wt/Sw (LB/SQ FT) | 138.75 | 138.51 | 148.87 | 150.09 |
| Fn/Wt | 0.3085 | 0.3031 | 0.285 | 0.2803 |
| ICA (FT) | 39.7K (CLMB) | 37.8K+(CLMB) | 38.2K+(CLMB) | 36.1K+(CLMB) |
| Vappr (KEAS) | 119.24 | 121.49 | 123.29 | 126.17 |
| Fn appr - 2 engines (lb) | 22,150 | 22,650 | 21,200 | 21,500 |
| TOFL (FT) | [redacted] | | | |
| 1st Seg Grad (%) | 0.67 | 0.62 | 0.79 | 0.73 |
| 2nd Seg Grad (%) | 2.40 | 2.40 | 2.40 | 2.40 |
| V2 (KEAS) | 164.2 | 163.9 | 160.7 | 160.7 |
| L/D | | | | |
| Start Cruise @ 35000 | 20.114 | 19.478 | 19.822 | 19.165 |
| End Cruise @ 43000 | 19.625 | 18.999 | 19.273 | 18.729* |
| SFC | | | | |
| Start Cruise @ 35000 | 0.6069 | 0.5368 | 0.6015 | 0.5311 |
| End Cruise @ 43000 | 0.6166 | 0.5388 | 0.6101 | 0.5362* |

* at 39,000 Ft

TABLE 13. - CERTIFICATION NOISE COMPARISON FOR SHORT-TO-MEDIUM RANGE AIRCRAFT

| | Conventional High Lift System | | Advanced High Lift System | |
|---|---|---|---|---|
| | **S0** HBPR Engine Min MTOGW | **S0** VHBPR Engine Min MTOGW | **S4** HBPR Engine Min MTOGW | **S4** VHBPR Engine Min MTOGW |
| Sw, sq ft | 1,080 | 1,080 | 960 | 1,005 |
| Fn, lbs | 21,525 | 22,225 | 19,550 | 20,550 |
| MTOGW, lbs | 135,918 | 138,656 | 136,162 | 139,151 |
| OEW, lbs | 76,087 | 81,067 | 75,915 | 81,316 |
| Block Fuel, lbs | 24,017 | 22,221 | 24,426 | 22,463 |
| Block Time, hrs | 6.052 | 6.033 | 6.044 | 6.031 |
| Wt/Sw, lbs/sq ft | 125.85 | 128.38 | 141.84 | 138.45 |
| Fn/Wt | 0.317 | 0.321 | 0.284 | 0.295 |
| ICA, ft | 38K+(Buffet) | 37K+(Buffet) | 35K+(Buffet) | 36K+(CL) |
| Vapp (KEAS), kts | 125.2 | 127.6 | 130.1 | 129.9 |
| Fnapp, lbs | 8,159 | 8,553 | 7,875 | 8,233 |
| L/Dapp | 8.00 | | 8.16 | |
| TOFL, ft | 7,000 | 7,000 | 7,000 | 7,000 |
| 1st Seg Grad, % | 1.34 | 1.34 | 1.50 | 1.44 |
| 2nd Seg Grad, % | 2.40 | 2.40 | 2.40 | 2.40 |
| V2(KEAS), Kts | 148.9 | 150.7 | 144.4 | 146.2 |
| L/D beg of cruise | 17.9 | 17.5 | 17.7 | 17.4 |
| L/D end of cruise | 17.8 | 17.4 | 17.4 | 16.8 (35,000) |
| SFC beg of cruise | 0.580 | 0.511 | 0.577 | 0.509 |
| SFC end of cruise | 0.578 | 0.506 | 0.575 | .513 (35,000) |
| | | **Takeoff Noise With Cutback at 800 ft Altitude** | | |
| Δ EPNL | Baseline | -8.0 | Baseline | -8.1 |
| 10Log(V/Vref) | Vref=165 Kts | - | Vref=160 Kts | - |
| 10Log(Fn/Fnref) | Fnref= 8072 lbs | + | Fnref= 7860 lbs | - |
| D/Dref) | Dref=1239 ft | - | Dref=1206 ft | - |
| | | **Takeoff Noise With Cutback at 1,500 ft Altitude** | | |
| Δ EPNL | Baseline | -8.4 | Baseline | -9.5 |
| 10Log(V/Vref) | Vref=166 Kts | - | Vref=161 Kts | - |
| 10Log(Fn/Fnref) | Fnref=8107 lbs | + | Fnref= 7881 lbs | - |
| D/Dref) | Dref=1775 ft | - | Dref=1722 ft | - |
| | | **Sideline Noise With a 1,476 ft Sideline Distance** | | |
| Δ EPNL | Baseline | -8.0 | Baseline | -7.8 |
| 10Log(V/Vref) | Vref=164 Kts | - | Vref=159 Kts | - |
| 10Log(Fn/Fnref) | Fnref= 17274 lbs | + | Fnref=15783 lbs | + |
| D/Dref) | Dref=1629 ft | - | Dref=1630 ft | + |
| | | **Approach Noise at 394 ft Altitude** | | |
| Δ EPNL | Baseline | -7.5 | Baseline | -7.4 |
| 10Log(V/Vref) | Vref=125 Kts | - | Vref=130 Kts | + |
| 10Log(Fn/Fnref) | Fnref= 4080 lbs | + | Fnref= 3839 lbs | + |
| ΔCUM EPNL | | -23.9 | | -24.7 |

TABLE 14. - COMMUNITY NOISE COMPARISON FOR SHORT-TO-MEDIUM RANGE AIRCRAFT

| | Conventional High Lift System | | Advanced High Lift System | |
|---|---|---|---|---|
| | S0 HBPR Engine Min MTOGW | S0 VHBPR Engine Min MTOGW | S4 HBPR Engine Min MTOGW | S4 VHBPR Engine Min MTOGW |
| Sw, sq ft | 1,080 | 1,080 | 960 | 1,005 |
| Fn, lbs | 21,525 | 22,225 | 19,550 | 20,550 |
| MTOGW, lbs | 135,918 | 138,656 | 136,162 | 139,151 |
| OEW, lbs | 76,087 | 81,067 | 75,915 | 81,316 |
| Block Fuel, lbs | 24,017 | 22,221 | 24,426 | 22,463 |
| Block Time, hrs | 6.052 | 6.033 | 6.044 | 6.031 |
| Wt/Sw, lbs/sq ft | 125.85 | 128.38 | 141.84 | 138.45 |
| Fn/Wt | 0.317 | 0.321 | 0.284 | 0.295 |
| ICA, ft | 38K+(Buffet) | 37K+(Buffet) | 35K+(Buffet) | 36K+(CL) |
| Vapp (KEAS), kts | 125.2 | 127.6 | 130.1 | 129.9 |
| Fnapp, lbs | 8,159 | 8,553 | 7,875 | 8,233 |
| L/Dapp | 8.00 | | 8.16 | |
| TOFL, ft | 7,000 | 7,000 | 7,000 | 7,000 |
| 1st Seg Grad, % | 1.34 | 1.34 | 1.50 | 1.44 |
| 2nd Seg Grad, % | 2.40 | 2.40 | 2.40 | 2.40 |
| V2(KEAS), Kts | 148.9 | 150.7 | 144.4 | 146.2 |
| L/D beg of cruise | 17.9 | 17.5 | 17.7 | 17.4 |
| L/D end of cruise | 17.8 | 17.4 | 17.4 | 16.8 (35,000) |
| SFC beg of cruise | 0.580 | 0.511 | 0.577 | 0.509 |
| SFC end of cruise | 0.578 | 0.506 | 0.575 | .513 (35,000) |
| 85 EPNL | Approach and Takeoff Noise With Cutback at 800 ft Altitude | | | |
| Δ area, sq. mi. | | -6.53 | | -6.03 |
| % area change | | -353% | | -347% |
| 90 EPNL | Baseline | | Baseline | |
| Δ area, sq. mi. | | -1.59 | | -1.51 |
| % area change | | -139% | | -134% |
| 85 EPNL | Approach and Takeoff Noise With Cutback at 1500 ft Altitude | | | |
| Δ area, sq. mi. | | -5.26 | | -3.30 |
| % area change | | -248% | | -161% |
| 90 EPNL | Baseline | | Baseline | |
| Δ area, sq. mi. | | -1.74 | | -1.67 |
| % area change | | -144% | | -139% |
| 80 SEL | Approach and Takeoff Noise With Cutback at 800 ft Altitude | | | |
| Δ area, sq. mi. | | -13.22 | | -13.15 |
| % area change | | -380% | | -400% |
| 85 SEL | | | | |
| Δ area, sq. mi. | Baseline | -3.18 | Baseline | -2.90 |
| % area change | | -222% | | -210% |
| 90 SEL | | | | |
| Δ area, sq. mi. | | -0.66 | | -0.62 |
| % area change | | -70% | | -66% |
| 80 SEL | Approach and Takeoff Noise With Cutback at 1500 ft Altitude | | | |
| Δ area, sq. mi. | | -11.76 | | -10.44 |
| % area change | | -364% | | -322% |
| 85 SEL | | | | |
| Δ area, sq. mi. | Baseline | -2.39 | Baseline | -1.93 |
| % area change | | -146% | | -119% |
| 90 SEL | | | | |
| Δ area, sq. mi. | | -1.12 | | -0.98 |
| % area change | | -118% | | -102% |

## TABLE 15. - CERTIFICATION NOISE COMPARISON FOR MEDIUM-TO-LONG RANGE AIRCRAFT

| | Conventional High Lift System | | Advanced High Lift System | |
|---|---|---|---|---|
| | S0 | S0 | S4 | S4 |
| | HBPR Engine Min MTOGW | VHBPR Engine Min MTOGW | HBPR Engine Min MTOGW | VHBPR Engine Min MTOGW |
| Sw, sq ft | 3,240 | 3,126 | 3,045 | 2,900 |
| Fn, lbs | 69,350 | 65,630 | 64,600 | 61,000 |
| MTOGW, lbs | 449,500 | 433,000 | 453,300 | 435,300 |
| OEW, lbs | 224,900 | 230,200 | 227,900 | 231,700 |
| Block Fuel, lbs | 148,600 | 131,600 | 149,600 | 132,400 |
| Block Time, hrs | 13.10 | 13.07 | 13.10 | 13.07 |
| Wt/Sw, lbs/sq ft | 138.75 | 138.51 | 148.87 | 150.09 |
| Fn/Wt | 0.3085 | 0.3031 | 0.2850 | 0.2803 |
| ICA, ft | 39.7K+(CL) | 37.8K+(CL) | 38.2K+(CL) | 36.1K+(CL) |
| Vapp (KEAS), kts | 119.24 | 121.49 | 123.29 | 126.17 |
| Fnapp, lbs | 22,150 | 22,650 | 21,200 | 21,500 |
| L/Dapp | | | | |
| TOFL, ft | 9,000 | 9,000 | 9,000 | 9,000 |
| 1st Seg Grad, % | 0.67 | 0.62 | 0.79 | 0.73 |
| 2nd Seg Grad, % | 2.40 | 2.40 | 2.40 | 2.40 |
| V2(KEAS), Kts | 164.2 | 163.9 | 160.7 | 160.7 |
| L/D beg of cruise | 20.114 | 19.478 | 19.882 | 19.165 |
| L/D end of cruise | 19.625 | 18.999 | 19.273 | 18.729 (39,000) |
| SFC beg of cruise | 0.6069 | 0.5368 | 0.6015 | 0.5311 |
| SFC end of cruise | 0.6166 | 0.5388 | 0.6101 | 0.5362 (39,000) |
| | | Takeoff Noise With Cutback at 800 ft Altitude | | |
| Δ EPNL | | -10.3 | | -10.2 |
| 10Log(V/Vref) | Vref=181 Kts | + | Vref=178 Kts | - |
| 10Log(Fn/Fnref) | Fnref= 14,285 lbs | - | Fnref= 13,178 lbs | - |
| D/Dref) | Dref=1,301 ft | + | Dref=1,283 ft | + |
| | | Takeoff Noise With Cutback at 1,500 ft Altitude | | |
| Δ EPNL | | -10.2 | | -10.3 |
| 10Log(V/Vref) | Vref=182 Kts | + | Vref=178 Kts | - |
| 10Log(Fn/Fnref) | Fnref=14,477 lbs | - | Fnref= 13,358 lbs | - |
| D/Dref) | Dref=1,669 ft | + | Dref=1,645 ft | + |
| | | Sideline Noise With a 1,476 ft Sideline Distance | | |
| Δ EPNL | | -9.9 | | -10.0 |
| 10Log(V/Vref) | Vref=181 Kts | + | Vref=177 Kts | - |
| 10Log(Fn/Fnref) | Fnref= 27,429 lbs | - | Fnref=25,664 lbs | - |
| D/Dref) | Dref=1,771 ft | | Dref=1,777 ft | |
| | | Approach Noise at 394 ft Altitude | | |
| Δ EPNL | | -8.5 | | -8.4 |
| 10Log(V/Vref) | Vref=119 Kts | - | Vref=123 Kts | - |
| 10Log(Fn/Fnref) | Fnref= 5,538 lbs | + | Fnref= 5,300 lbs | + |
| ΔCUM EPNL | | -28.6 | | -28.7 |

## TABLE 16. - COMMUNITY NOISE COMPARISON FOR MEDIUM-TO-LONG RANGE AIRCRAFT

| | Conventional High Lift System | | Advanced High Lift System | |
|---|---|---|---|---|
| | S0 HBPR Engine Min MTOGW | S0 VHBPR Engine Min MTOGW | S4 HBPR Engine Min MTOGW | S4 VHBPR Engine Min MTOGW |
| Sw, sq ft | 3,240 | 3,126 | 3,045 | 2,900 |
| Fn, lbs | 69,350 | 65,630 | 64,600 | 61,000 |
| MTOGW, lbs | 449,500 | 433,000 | 453,300 | 435,300 |
| OEW, lbs | 224,900 | 230,200 | 227,900 | 231,700 |
| Block Fuel, lbs | 148,600 | 131,600 | 149,600 | 132,400 |
| Block Time, hrs | 13.10 | 13.07 | 13.10 | 13.07 |
| Wt/Sw, lbs/sq ft | 138.75 | 138.51 | 148.87 | 150.09 |
| Fn/Wt | 0.3085 | 0.3031 | 0.2850 | 0.2803 |
| ICA, ft | 39.7K+(CL) | 37.8K+(CL) | 38.2K+(CL) | 36.1K+(CL) |
| Vapp (KEAS), kts | 119.24 | 121.49 | 123.29 | 126.17 |
| Fnapp, lbs | 22,150 | 22,650 | 21,200 | 21,500 |
| L/Dapp | | | | |
| TOFL, ft | 9,000 | 9,000 | 9,000 | 9,000 |
| 1st Seg Grad, % | 0.67 | 0.62 | 0.79 | 0.73 |
| 2nd Seg Grad, % | 2.40 | 2.40 | 2.40 | 2.40 |
| V2(KEAS), Kts | 164.2 | 163.9 | 160.7 | 160.7 |
| L/D beg of cruise | 20.114 | 19.478 | 19.882 | 19.165 |
| L/D end of cruise | 19.625 | 18.999 | 19.273 | 18.729 (39,000) |
| SFC beg of cruise | 0.6069 | 0.5368 | 0.6015 | 0.5311 |
| SFC end of cruise | 0.6166 | 0.5388 | 0.6101 | 0.5362 (39,000) |
| **85 EPNL** | **Approach and Takeoff Noise With Cutback at 1,000 ft Altitude** | | | |
| Δ area, sq. mi. | Baseline | -23.87 | Baseline | -22.71 |
| % area change | | -486% | | -486% |
| **90 EPNL** | | | | |
| Δ area, sq. mi. | Baseline | -11.49 | Baseline | -10.27 |
| % area change | | -527% | | -475% |
| **85 EPNL** | **Approach and Takeoff Noise With Cutback at 1,500 ft Altitude** | | | |
| Δ area, sq. mi. | Baseline | -22.47 | Baseline | -21.17 |
| % area change | | -499% | | -485% |
| **90 EPNL** | | | | |
| Δ area, sq. mi. | Baseline | -9.95 | Baseline | -8.98 |
| % area change | | -420% | | -387% |
| **80 SEL** | **Approach and Takeoff Noise With Cutback at 1,000 ft Altitude** | | | |
| Δ area, sq. mi. | Baseline | -32.17 | Baseline | -32.21 |
| % area change | | -267% | | -298% |
| **85 SEL** | | | | |
| Δ area, sq. mi. | Baseline | -18.64 | Baseline | -18.32 |
| % area change | | -505% | | -531% |
| **90 SEL** | | | | |
| Δ area, sq. mi. | Baseline | -6.43 | Baseline | -5.84 |
| % area change | | -380% | | -346% |
| **80 SEL** | **Approach and Takeoff Noise With Cutback at 1,500 ft Altitude** | | | |
| Δ area, sq. mi. | Baseline | -30.46 | Baseline | -30.79 |
| % area change | | -274% | | -315% |
| **85 SEL** | | | | |
| Δ area, sq. mi. | Baseline | -16.97 | Baseline | -16.36 |
| % area change | | -474% | | -467% |
| **90 SEL** | | | | |
| Δ area, sq. mi. | Baseline | -5.45 | Baseline | -4.97 |
| % area change | | -294% | | -277% |

## TABLE 17 - EFFECTS OF SIZING VARIATIONS FOR SHORT-TO-MEDIUM RANGE AIRCRAFT

| HBPR | Conventional High Lift System | | | Advanced High Lift System | | | |
|---|---|---|---|---|---|---|---|
| | S0<br>Baseline<br>δ = 40°<br>Min MTOGW | S3<br>δ = 40°<br>Increased<br>Sw | S10<br>δ = 25°<br>Min MTOGW | S4<br>δ = 35°<br>Min MTOGW | S2<br>δ = 35°<br>Increased<br>Sw | S6<br>δ = 25°<br>Increased<br>Sw | S9<br>δ = 15°<br>Increased<br>Sw |
| Sw, sq ft | 1,080 | 1,200 | 1,080 | 960 | 1,080 | 1,080 | 1,080 |
| Fn, lbs | 21,526 | 20,550 | 21,530 | 19,550 | 18,425 | 18,400 | 18,400 |
| MTOGW, lbs | 135,918 | 136,292 | 135,893 | 136,162 | 136,807 | 136,777 | 136,775 |
| OEW, lbs | 76,087 | 76,849 | 76,086 | 75,915 | 76,966 | 76,954 | 76,951 |
| Block Fuel, lbs | 24,017 | 23,734 | 23,993 | 24,426 | 24,157 | 24,140 | 24,121 |
| Block Time, hrs | 6.052 | 6.061 | 6.052 | 6.044 | 6.057 | 6.057 | 6.057 |
| Wt/Sw, lbs/sq ft | 125.85 | 113.58 | 125.83 | 141.84 | 126.67 | 126.64 | 126.62 |
| Fn/Wt | 0.317 | 0.302 | 0.317 | 0.284 | 0.269 | 0.269 | 0.269 |
| ICA, ft | 38K+(Buffet) | 39K+(Buffet) | 38K+(Buffet) | 35K+(Buffet) | 37K+(CL) | 37K+(CL) | 37K+(CL) |
| Vapp (KEAS), kts | 125.2 | 119.0 | 129.2 | 130.1 | 123.1 | 123.7 | 128.9 |
| Fnapp, lbs | 8,159 | 8,100 | 6,036 | 7,875 | 7,801 | 6,166 | 4,346 |
| L/Dapp | 8.00 | 8.06 | 9.43 | 8.16 | 8.24 | 9.36 | 11.02 |
| TOFL, ft | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 |
| 1st Seg Grad, % | 1.34 | 1.38 | 1.35 | 1.50 | 1.49 | 1.49 | 1.49 |
| 2nd Seg Grad, % | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 |
| V2(KEAS), Kts | 148.9 | 146.5 | 148.2 | 144.4 | 140.7 | 140.8 | 140.8 |
| L/D beg of cruise | 17.9 | 18.4 | 17.9 | 17.7 | 18.0 | 18.0 | 18.0 |
| L/D end of cruise | 17.8 | 17.8 | 17.8 | 17.4 | 17.8 | 17.8 | 17.8 |
| SFC beg of cruise | 0.580 | 0.576 | 0.580 | 0.577 | 0.577 | 0.577 | 0.577 |
| SFC end of cruise | 0.578 | 0.576 | 0.578 | 0.575 | 0.575 | 0.575 | 0.575 |
| | Baseline | Takeoff Noise With Cutback at 800 ft Altitude | | | | | |
| Δ EPNL | | 0.0 | -0.1 | 0.0 | -0.3 | -0.3 | -0.3 |
| 10Log(V/Vref) | Vref=165 Kts | + | + | + | + | + | + |
| 10Log(Fn/Fnref) | Fnref= 8,072 lbs | - | - | - | - | - | - |
| 20 Log(D/Dref) | Dref=1,239 ft | + | + | + | + | + | + |
| | Baseline | Takeoff Noise With Cutback at 1,500 ft Altitude | | | | | |
| Δ EPNL | | 0.0 | 0.0 | 0.0 | -0.4 | -0.4 | -0.4 |
| 10Log(V/Vref) | Vref=166 Kts | + | | + | + | + | + |
| 10Log(Fn/Fnref) | Fnref= 8,107 lbs | - | | - | - | - | - |
| 20 Log(D/Dref) | Dref=1,775 ft | + | | + | + | + | + |
| | Baseline | Sideline Noise With a 1,476 ft Sideline Distance | | | | | |
| Δ EPNL | | -0.5 | 0.0 | -0.9 | -1.4 | -1.4 | -1.4 |
| 10Log(V/Vref) | Vref=164 Kts | + | | + | + | + | + |
| 10Log(Fn/Fnref) | Fnref= 17,274 lbs | - | | - | - | - | - |
| 20 Log(D/Dref) | Dref=1,629 ft | + | | - | - | - | + |
| | Baseline | Approach Noise at 394 ft Altitude | | | | | |
| Δ EPNL | | 0.2 | -1.3 | -0.3 | -0.1 | -1.0 | -2.1 |
| 10Log(V/Vref) | Vref=125 Kts | + | - | - | + | + | + |
| 10Log(Fn/Fnref) | Fnref= 4,060 lbs | - | - | - | - | - | - |
| Δ EPNL (CUM) | | -0.3 | -1.3 | -1.2 | -1.9 | -2.8 | -3.9 |

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13. ABSTRACT *(Maximum 200 words)*

The impact of advanced high lift systems on aircraft size, performance, direct operating cost and noise were evaluated for short-to-medium and medium-to-long range aircraft with high bypass ratio and very high bypass ratio engines. The benefit of advanced high lift systems in reducing noise was found to be less than 1 EPNdB when the aircraft were sized to minimize takeoff gross weight. These aircraft did however, have smaller wings and lower engine thrusts for the same mission than aircraft with conventional high lift systems. When the advanced high lift system was implemented without reducing wing size and simultaneously using lower flap angles that provide higher L/D at approach a cumulative noise reduction of as much as 4 EPNdB was obtained. Comparison of aircraft configurations that have similar approach speeds showed cumulative noise reduction of 2.6 EPNdB that is purely the result of incorporating advanced high lift system in the aircraft design.

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