NASA Contractor Report 195077

Noise Exposure Reduction Of Advanced High–Lift Systems

Stephen W. Haffner
Boeing Commercial Airplane Company, Seattle, Washington

Contract NAS1–20090
Task 3

May 1995

National Aeronautics and
Space Administration
Langley Research Center
Hampton, Virginia 23681–0001

TABLE OF CONTENTS

SUMMARY

NASA and the commercial aviation industry have defined a goal of providing technology to reduce subsonic aircraft noise 7–10 EPNdB by the end of the decade. Most of this reduction would likely be achieved through improvements to engine and airframe technologies. Additional noise reductions might be obtained by optimizing aircraft high–lift performance for noise. For example, if an aircraft's lift–to–drag ratio could somehow be increased without increasing the gross weight, there would be an attendant noise benefit due to reduced thrust on approach and improved climb performance on takeoff.

Three classes of subsonic aircraft were examined: small twin engine, medium sized twin engine, and large quad engine aircraft. The estimated noise levels of production aircraft were compared to the estimated noise levels that would result from increasing the lift–to–drag ratio up to 15%. It was found that a 15% increase in L/D can reduce approach noise by up to 2 EPNdB, and takeoff with cutback by up to 1.5 EPNdB. Sideline EPNL would not be affected. A 15% increase in L/D reduces the 80 dBA contour areas by 0% to 22% on approach, and from 5% to 10% on takeoff with cutback.

1. INTRODUCTION

The objective of the noise reduction element of the Advanced Subsonic Technology (AST) program is to provide technology to reduce aircraft noise levels 7–10 EPNdB (relative to 1992 technology) by the year 2000. This 10 dB decrease includes a 6 dB reduction in engine noise and a 4 dB reduction in airframe noise, with additional noise reductions to be obtained from improvements to other technology areas. One technical area, apart from working directly on noise sources themselves, which offers potential for aircraft noise reduction is the performance of the aircraft's high–lift system. Since aircraft lift–to–drag ratio (L/D) determines thrust required on approach, as well as climb performance, high–lift system performance affects aircraft noise both on approach and takeoff.

Under NASA Contract NAS1–20090 Task 3, a study was conducted to determine the potential noise reduction for subsonic jet transports that would result from increases in airplane lift–to–drag ratio. The results of that study are contained in this document.

2. BACKGROUND

The relationship between aircraft noise and L/D is contained in the equation that governs the basic aerodynamics of flight:

$$\sin(\gamma) = T/W - 1/(L/D)$$

where γ is the climb angle or angle of descent, T is the aircraft thrust, W is the aircraft weight, and L/D is the aircraft lift–to–drag ratio.

It can be seen that during takeoff, for a given thrust and weight, the climb angle increases with increasing L/D, resulting in greater altitudes above the fixed measurement points, and lower noise levels. During landing approaches thrust required to maintain stable flight decreases with increasing L/D, thus resulting in lower noise levels.

In Reference 1, Howe reported that the airplane climb/sink angle was second only to engine by–pass ratio as a determinant of noise footprint areas. Olson showed in Reference 2 that for a High Speed Civil Transport, a 15% increase in L/D could reduce takeoff noise by 1.4 EPNdB, and reduce the 100 EPNdB takeoff contour area by 5%. Sideline noise actually increased about 0.25 EPNdB. A Boeing internal study of an HSCT had similar findings. Preliminary noise level estimates for the Airbus A340 transport are lower than expected for the state of technology believed to exist on that plane. The A340 is known to have a higher aspect ratio wing than most subsonic commercial jetliners. This high aspect ratio wing will have unusually low induced drag, and and unusually high L/D. It is possible that a higher L/D accounts for some of the A340's reduced noise levels.

3. BASIC METHOD

The noise levels of several airplanes were correlated with postulated changes to lift–to–drag ratio. For each airplane, three L/D's were examined: the production airplane, a moderately improved L/D (5% increase), and a greatly improved L/D (15%). The 15% figure is an estimate of an achievable increase in L/D that might be realized without a significant increase in airplane gross weight.

Existing noise databases and airplane performance prediction software were used to predict the noise characteristics of each configuration. Three noise measures were predicted, FAR Part 36 EPNL's, 95 EPNdB noise contours, and 80 dBA noise contours. FAR Part 36 requires the measurement of EPNL's at three locations: takeoff, sideline, and approach, as shown in Figure 1.

4. SELECTION OF BASELINE AIRCRAFT AND CONFIGURATIONS

The contract specified that three airplane configurations were to be studied, a small twin, a medium twin, and a large quad. The following factors were considered in selection of the aircraft:

1. airplanes that were already in service
2. a significant member of fleet mix
3. availability of aero and propulsion data

The subject aircraft should already be in service, so that reliable estimates of noise performance can be made. Also, the relevance of the study is enhanced if the selected airplanes comprise a significant portion of the U.S. airline fleets. Finally, it was necessary that aerodynamic and engine performance data be readily available in order to make realistic estimates of the airplanes' flight profiles. The selected aircraft are summarized in table 1.

Configuration	Airplane	Engine
Small Twin	737–300/400/500 Family	CFM56–3
Medium Twin	767–300 Family	CF6–80
Large Quad	747–400 Family	PW4000

Table 1 – Summary of Aircraft Configurations

4.2 TAKEOFF PROCEDURES

A postulated reduction in drag for takeoff conditions could influence operational procedures and noise levels in three ways:

1) For full power takeoffs, a reduced drag airplane would climb out more quickly, thereby achieving a higher altitude at the takeoff measurement point, with a consequent reduction in measured noise levels.

2) For conventional cutback takeoffs, the drag reduction would be manifested in both a higher measurement point altitude (though not as large an increase as with the full power takeoff), and in a lower thrust required to maintain the specified climb gradient.

3) Reduced drag could also be exploited by maintaining a reduced power setting throughout the takeoff procedure. This takeoff procedure was not examined in this study.

4.2 APPROACH PROCEDURES

Approaches are typically flown in configurations deliberately designed to have moderately high levels of drag. Approach engine speeds are kept as high as necessary to minimize engine spoolup time to provide maneuvering thrust in emergency situations. Extra drag is desirable in normal approach operations, to counteract the extra thrust, allowing the airplane to descend on a reasonable glide slope.

The obvious benefit of reduced airplane drag is the lower thrust required to maintain the approach glide slope. There are two limitations on the amount that drag, and therefore thrust, can be reduced. First, the airplane lift–to–drag ratio must not be allowed to get too high, or the airplane will have a tendency to float. For safety reasons, an airplane that is above the normal glide slope must be able to achieve a glide slope of as much as 6 degrees in order to capture the 3 degree approach path. This corresponds to a maximum L/D of about 9.5. Secondly, it is known that engine operation becomes less stable at the lower thrust settings. It is possible that the lower approach thrust associated with a given increase in L/D could actually cause an engine noise increase due to engine instabilities (e.g., surge bleed operation).

5. RESULTS

A summary of the FAR Part 36 results is given in Tables 2–4. Figures 2 through 6 show the trends for individual flight configurations.

Results for the approach case are shown in Table 2 and Figure 2. It can be seen that for all airplanes studied, FAR Part 36 noise levels decrease with increasing L/D. For the maximum

L/D improvement studied, 15%, the EPNL reduction of all airplanes was approximately 2 EPNdB. This level of noise improvement is encouraging, but it must be emphasized that the L/D's are nearing 9, and the airplane will have a definite tendency to float. Designers are reluctant to build aircraft with such large L/D's. Also, as the thrust levels drop lower and lower, there is an increasing probability of engine instability developing. Some engines have markedly higher noise levels when surge bleed valves are opened to maintain engine stability.

Airplane	Thrust Change, %	EPNL Change, dB
Small Twin	−22.9	−2.34
Medium Twin	−22.0	−1.87
Large Quad	−21.7	−1.99

Table 2 – Summary of Impact of 15% L/D increase – FAR Part 36 Approach Conditions

Results for the full power takeoff case at the centerline measurement point are shown in Table 3 and Figure 3. As L/D is increased, airplane rate of climb, and hence overhead altitude also increase. All airplanes show EPNL reductions of approximately 0.5 EPNdB at the maximum L/D increase of 15%.

Results for the full power sideline case are shown in Figure 4. Because of the large slant angle in the sideline EPNL measurement, the modest altitude increase shown in Figure 4 does not contribute significantly to the sound propagation path of the peak sideline noise levels. Hence, no reduction in sideline EPNL is observed for full power takeoffs.

Airplane	Altitude Change, %	EPNL Change, dB
Small Twin	6.81	−0.46
Medium Twin	6.16	−0.43
Large Quad	9.55	−0.68

Table 3 – Summary of Impact of 15% L/D increase – FAR Part 36 Full Power Takeoff Conditions

Results for the cutback–power takeoff case at the centerline measurement point are shown in Table 4 and Figure 5. It can be seen that for the maximum assumed increase in L/D of 15%, the thrust required to maintain the FAR Part 36 climb gradients is lowered by up to 12%, and the overhead altitude is increased by 4% to 9%. Both of these changes tend to reduce the noise levels. The maximum reduction in EPNL was approximately 1.4 EPNdB at the maximum L/D increase of 15%.

Results for the cutback power sideline measurement case are shown in Figure 6. Reduced sideline noise levels might be expected due to reduced engine thrust. However, FAR Part 36 requires that the maximum sideline noise level be reported. Boeing's experience has shown that the peak sideline noise levels invariably occur while the airplane is near or below a 1000 feet altitude. For twin engine aircraft, cutback initiation is not allowed below an altitude of 984 feet. In addition, FAR Part 36 requires that thrust be stabilized before the initial 10 dB down point is reached. Because of these additional measurement constraints, the expected noise reduction is never realized in FAR Part 36 cutback EPNL's. Therefore, as with full power takeoff, we do not observe a noise reduction for the cutback power takeoff sideline case.

Airplane	Altitude Change, %	Thrust Change, %	EPNL Change, dB
Small Twin	4.42	−12.7	−1.14
Medium Twin	4.24	−12.6	−1.34
Large Quad	9.29	−8.63	−1.44

Table 4 – Summary of Impact of 15% L/D increase – FAR Part 36 Takeoff with Cutback Conditions

A summary of noise contour area reductions is shown in Tables 5 and 6. Figures 7 through 12 show contours for individual airplanes. The takeoff and approach contours have been combined, with the approach footprint appearing on the left side of the plot, and the takeoff on the right side. On each plot, the outer contour line is for the baseline airplane, and the inner contour line, when visible, is the contour for the 15% L/D increase.

	Contour Area Change, %		
Airplane	**Approach**	**ICAO−A**	**ICAO−B**
Small Twin	−22	−7	−8
Medium Twin	−11	−7	−5
Large Quad	0	−10	−5

Table 5 – Summary of 80 dBA Contour Area Reductions Resulting from 15% L/D Increase

	Contour Area Change, %		
Airplane	**Approach**	**ICAO−A**	**ICAO−B**
Small Twin	−54.2	−2.7	−2.7
Medium Twin	−36.3	−3.6	−3.9
Large Quad	−27.4	−7.3	−5.6

Table 6 – Summary of 95 EPNdB Contour Area Reductions Resulting from 15% L/D Increase

There is a significant reduction in the areas of most contours. One noticeable exception is the 80 dBA contour for the approach case for the large quad airplane, shown in Figure 9. The dBA versus thrust curve for this airplane was exceptionally flat in the range of thrusts being studied.

6. CONCLUSIONS

This study has shown that airplane certification and community noise levels might be reduced by designing airplanes with high lift–to–drag ratios. A 15% increase in L/D can reduce approach noise by up to 2 EPNdB, and takeoff–with–cutback noise levels by up to 1.5 EPNdB. No certification sideline noise reduction would be observed.

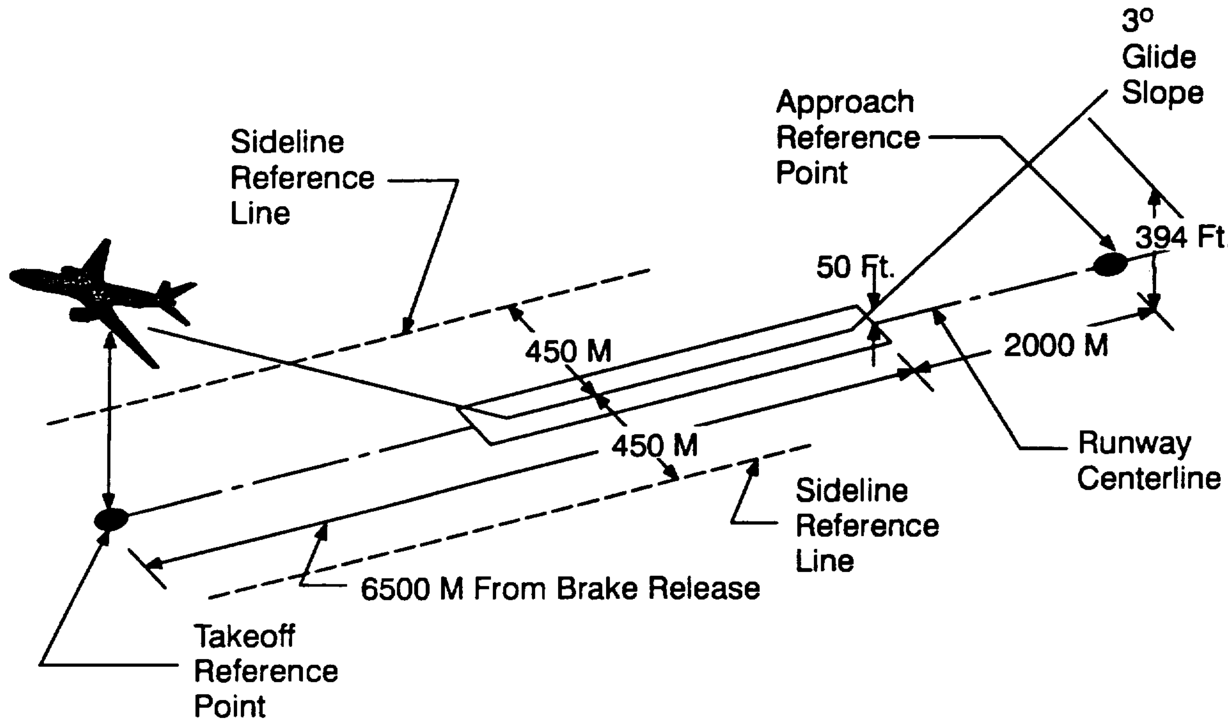
Noise contour areas will generally be reduced by L/D improvements. A 15% increase in L/D reduces the 80 dBA contour areas by 0% to 22% on approach, and from 5% to 10% on takeoff with cutback.

Despite the potential noise benefits, it is unknown to what extent real airplanes could be designed or operated with the increased L/D. On approach conditions, the likelihood of engine surge (with resulting noise increase) increases with the reduced thrusts that result from increased L/D. Also, as the L/D increases to values much above 9, the aircraft has a tendency to float, making glide slope capture more difficult. On takeoff conditions, there is a tradeoff between using the increased L/D to increase the lift capability of the airplane, and reducing the noise level of the airplane at a fixed takeoff weight.

REFERENCES

1. Subsonic Jet Transport Noise – The Relative Importance of Various Parameters, D. Howe, Cranfield Report Aero No. 25 N75–14763, Cranfield Institute of Technology, July, 1974.

2. SAE Technical Paper Series 921939, "Advanced Takeoff Procedures for High–Speed Civil Transport Community Noise Reduction", E.D. Olson, October, 1992.



- Thrust cutback permitted during takeoff
- Sideline -- maximum noise level along reference line during takeoff

Figure 1 – Far Part 36 Noise Certification Reference Points

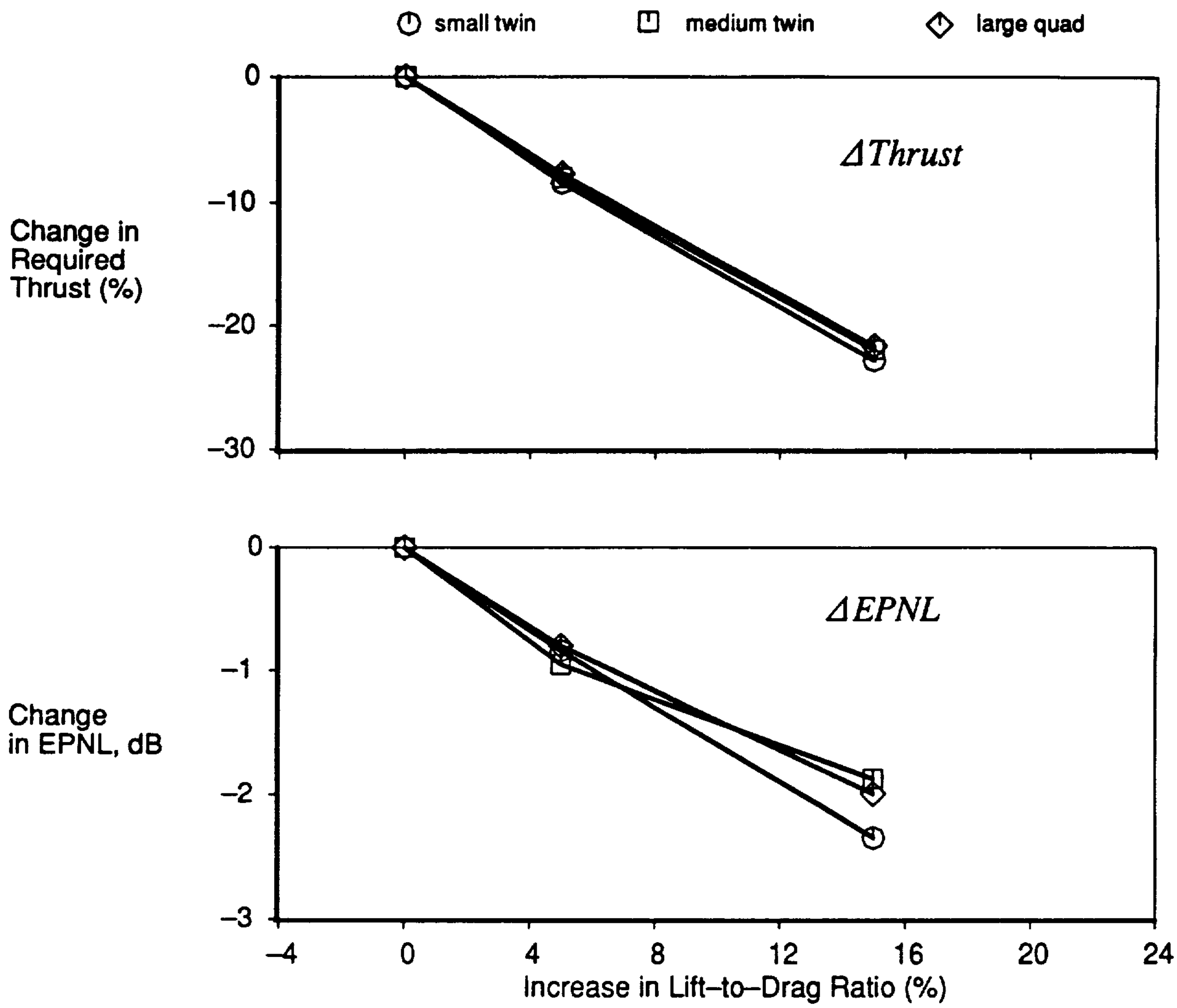


Figure 2 – Impact of L/D Increases on Aircraft Noise Certification Parameters – Landing Approach

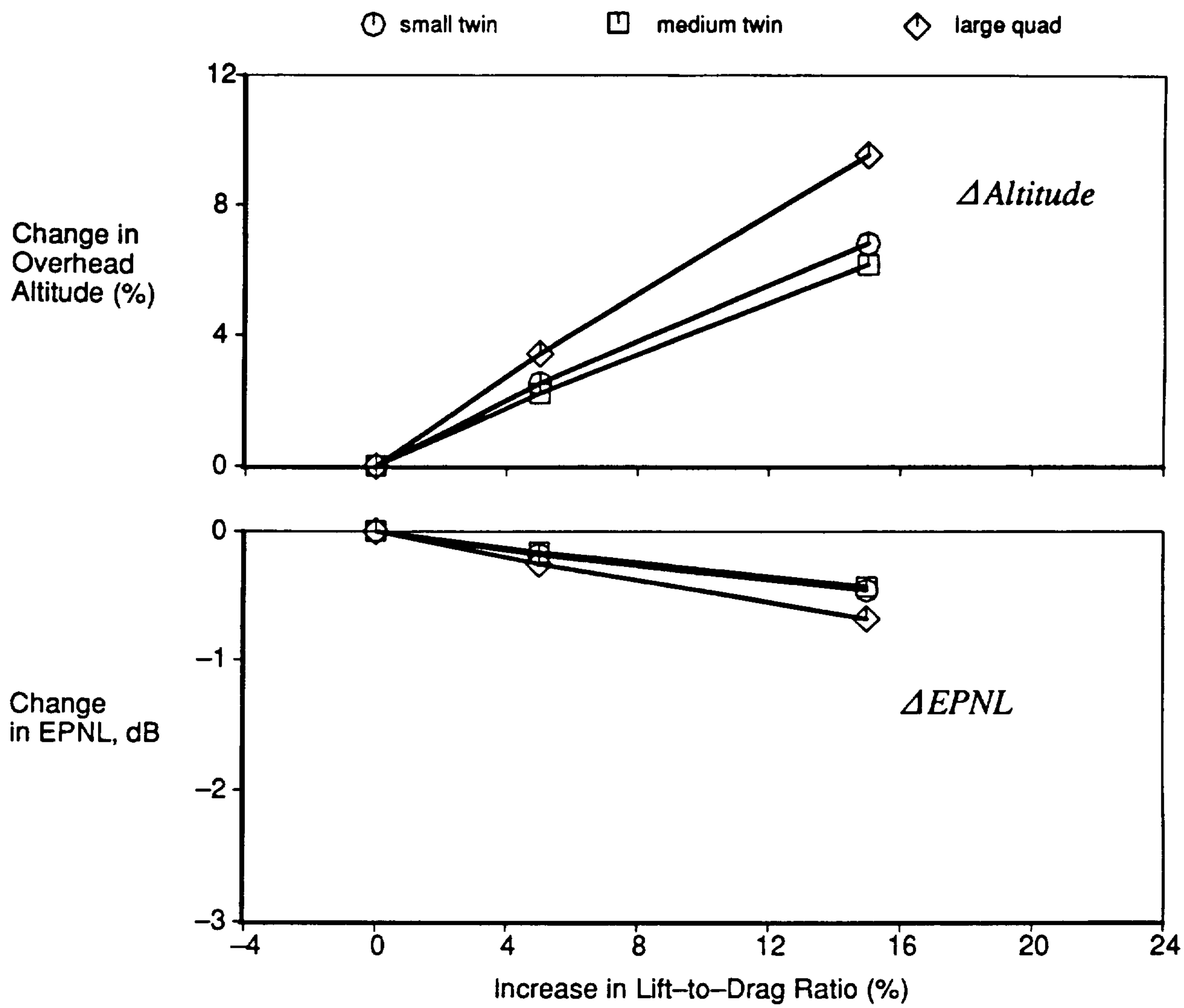


Figure 3 – Impact of L/D Increases on Aircraft Noise Certification Parameters – Full Power Takeoff (Centerline)

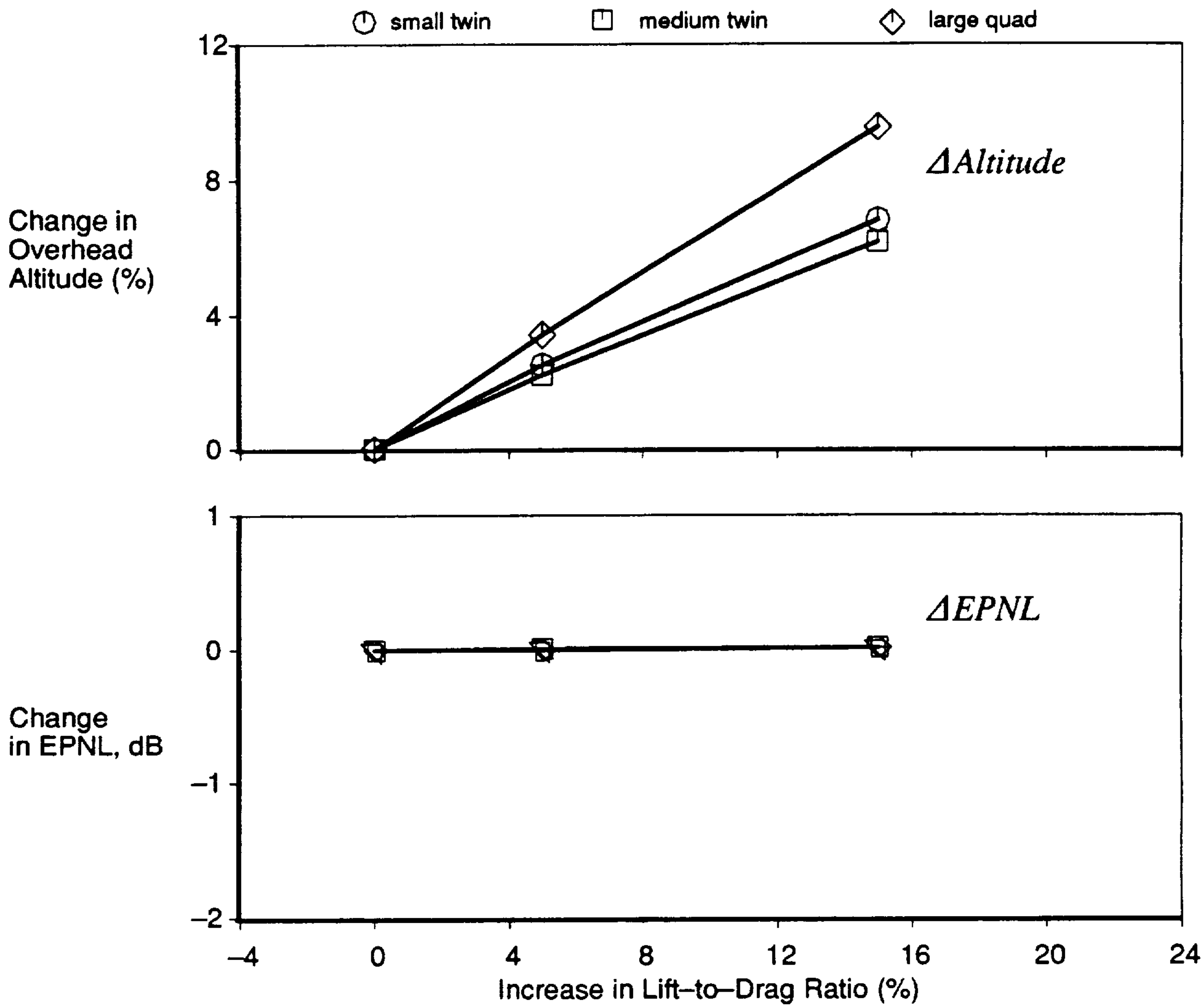


Figure 4 – Impact of L/D Increases on Aircraft Noise Certification Parameters – Full Power Takeoff (Sideline)

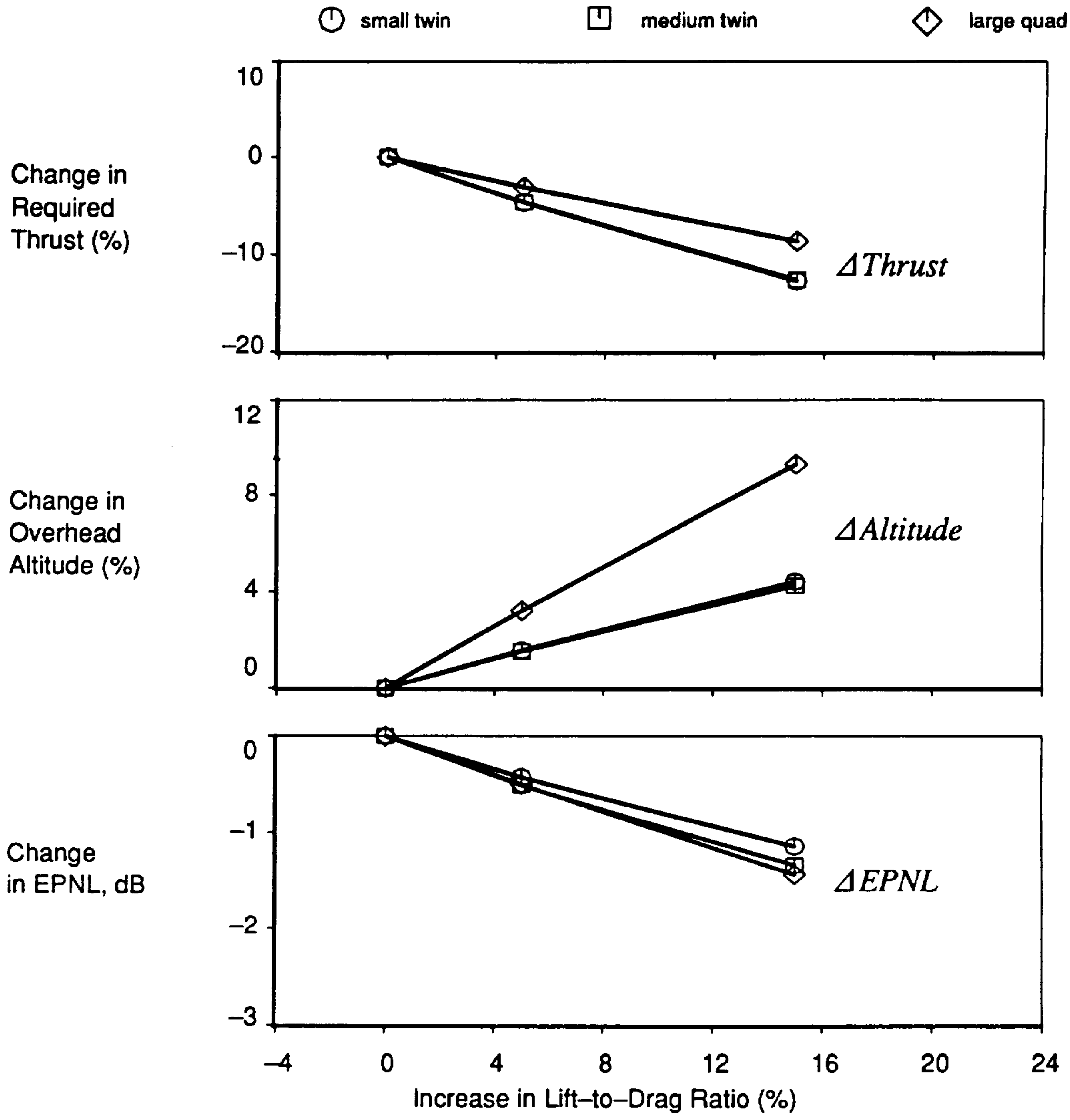


Figure 5 – Impact on L/D Increases on Aircraft Noise Certification Parameters – Cutback Power Takeoff (Centerline)

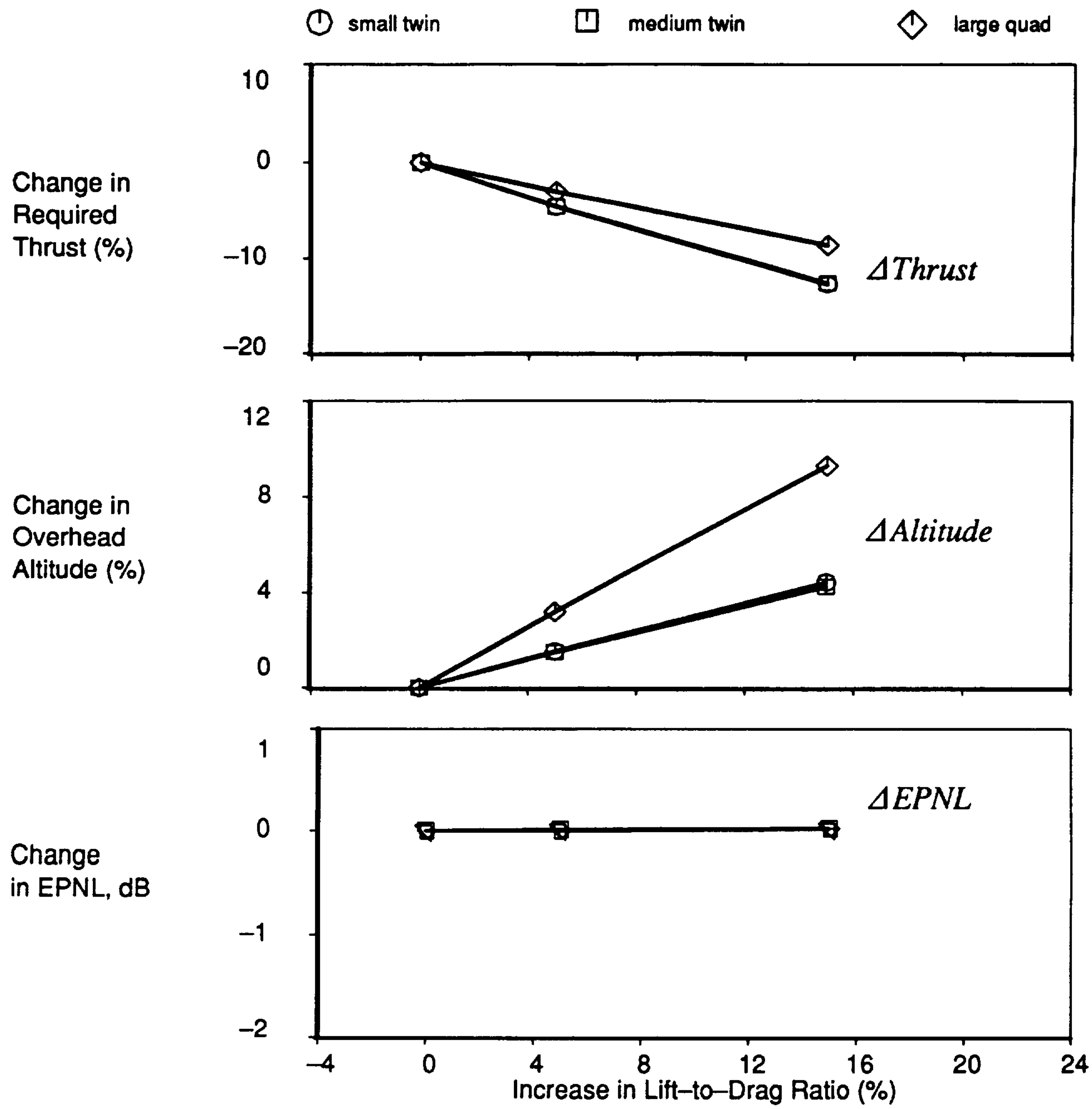


Figure 6 – Impact of L/D Increases on Aircraft Noise Certification Parameters – Cutback Power Takeoff (Sideline)

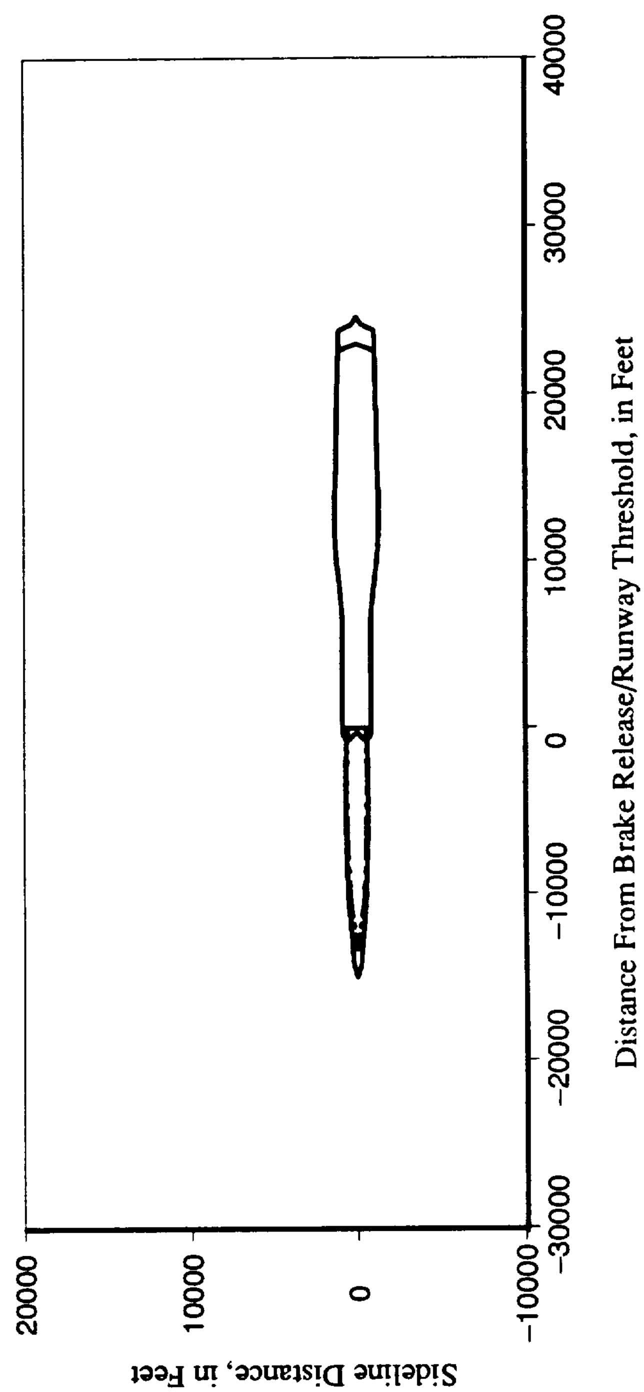


Figure 7 – Small Twin 80 dBA Contour

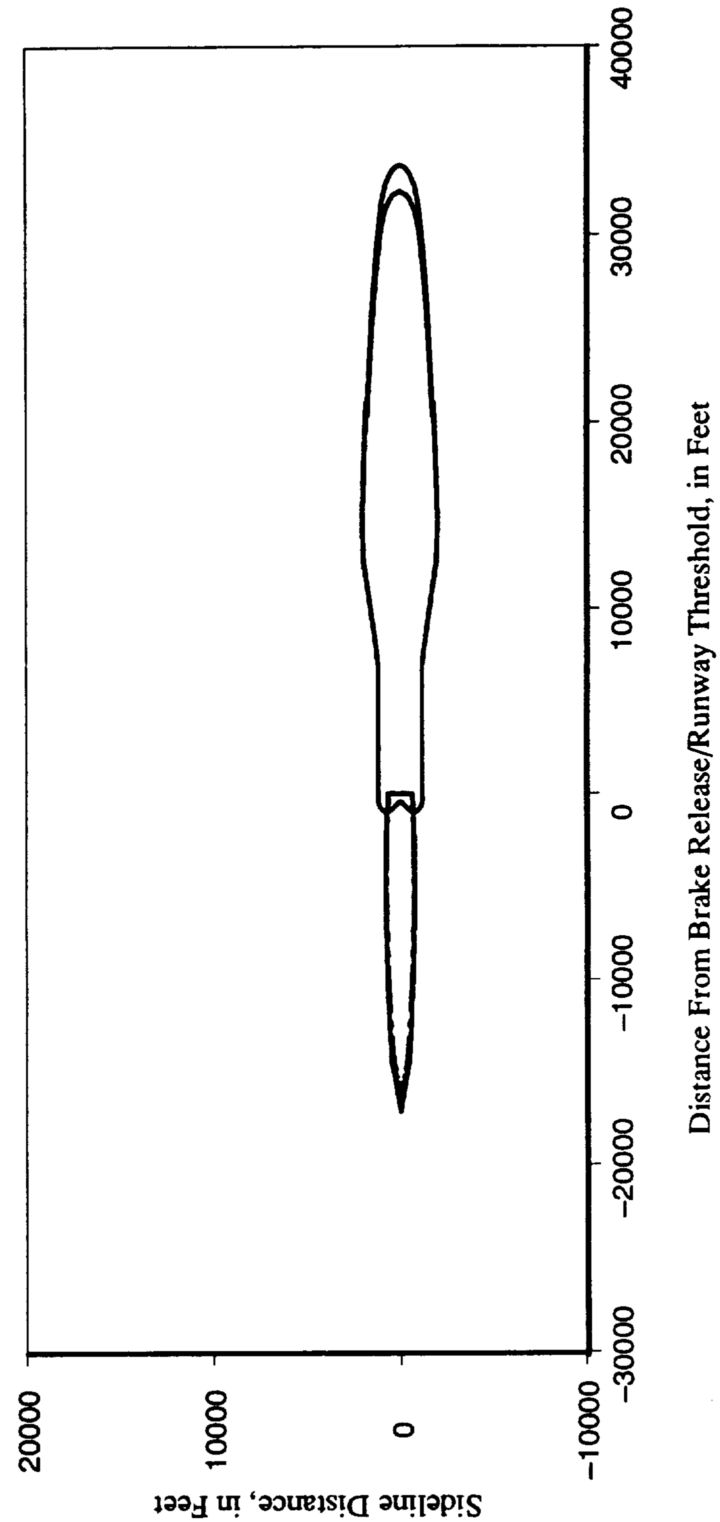


Figure 8 – Medium Twin 80 dBA Contour

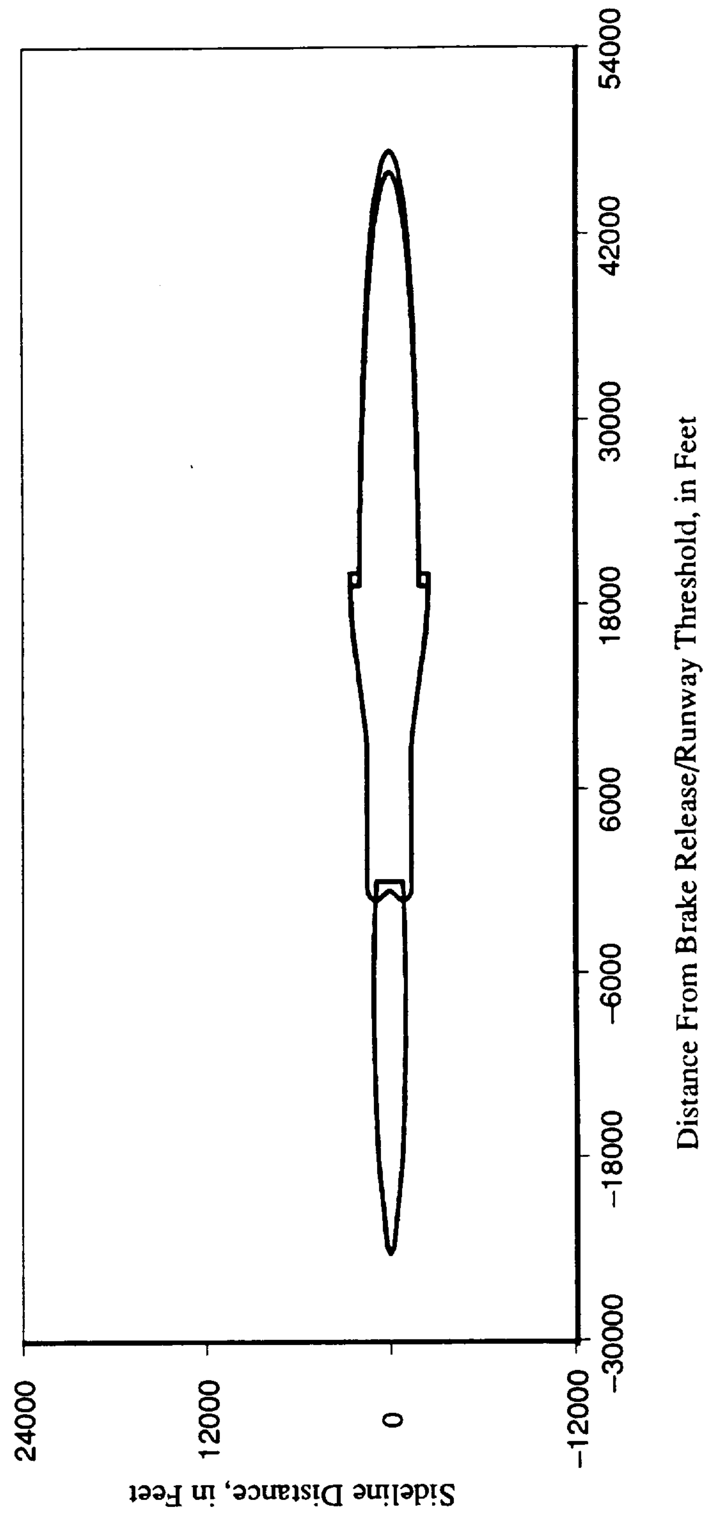


Figure 9 – Large Quad 80 dBA Contour

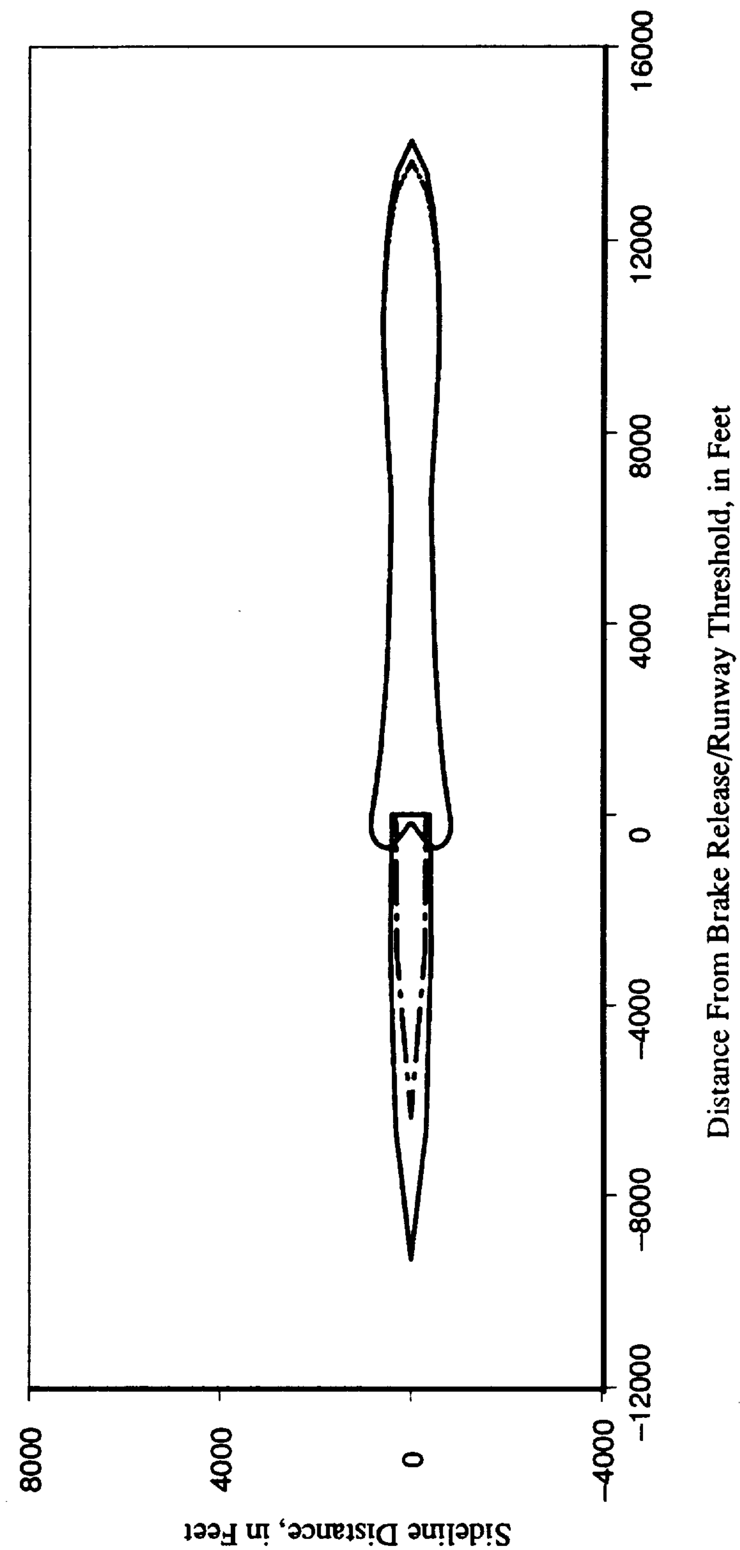


Figure 10 – Small Twin 95 EPNdB Contour

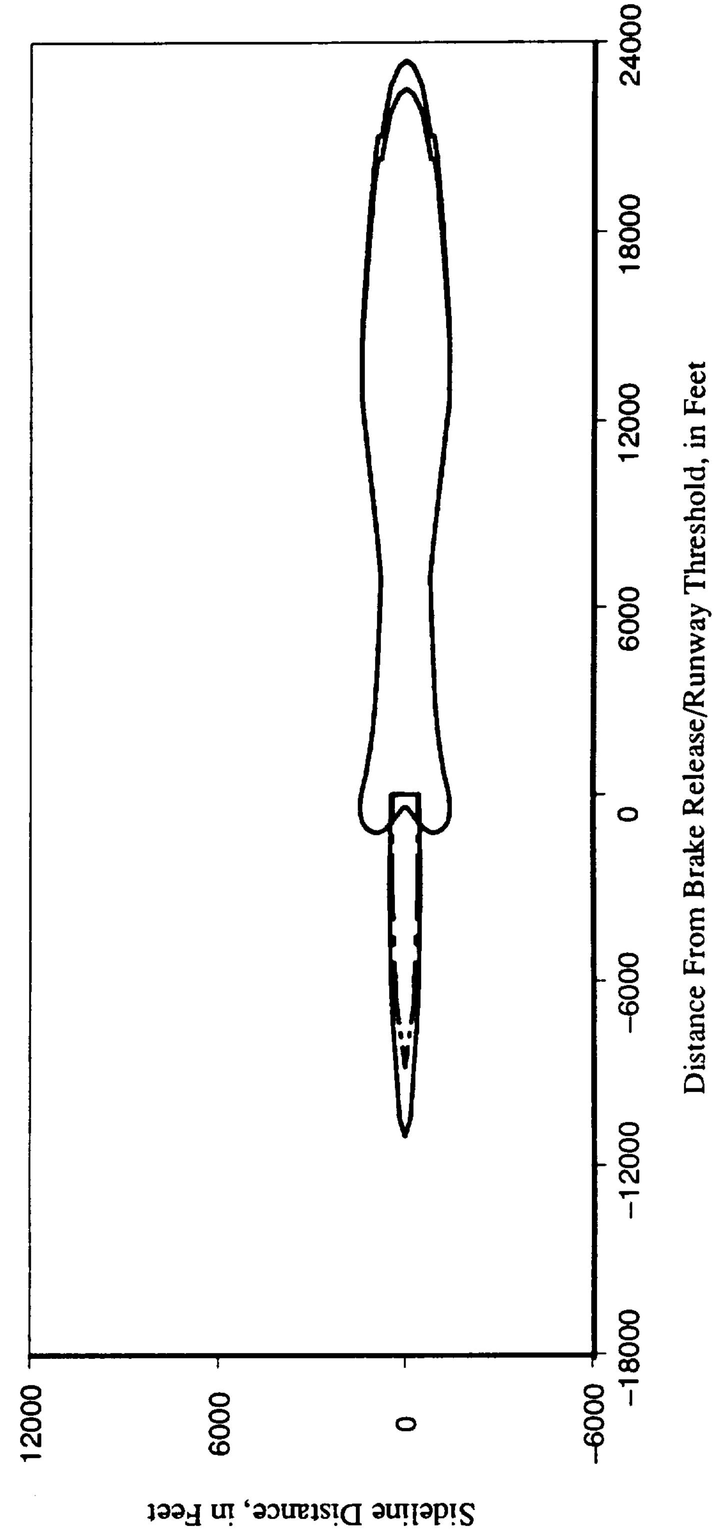


Figure 11 – EPNL Twin 95 EPNdB Contour

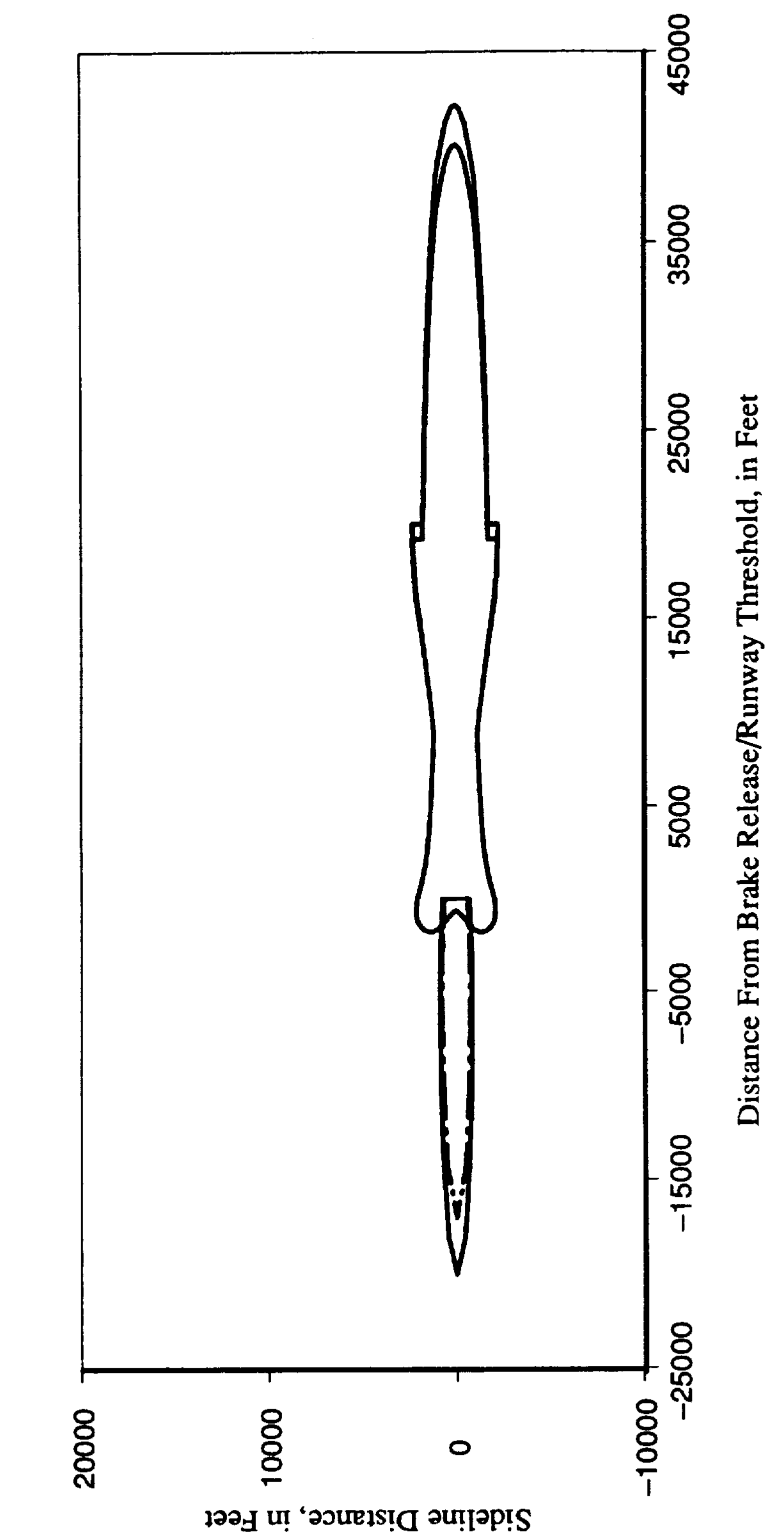


Figure 12 – Large Quad 95 EPNdB Contour

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
May 1995

3. REPORT TYPE AND DATES COVERED
Contractor Report

4. TITLE AND SUBTITLE
Noise Exposure Reduction of Advanced High–Lift Systems

5. FUNDING NUMBERS
NAS1–20090 Task 3
538–03–15–01

6. AUTHOR(S)
Stephen W. Haffner

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Boeing Commercial Airplanes
P.O. Box 3707
Seattle, Washington 98124–2207

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23681–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA CR–195077

11. SUPPLEMENTARY NOTES
Langley Technical Monitor: Kevin P. Shepherd

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified–Unlimited
Subject Category – 71

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
The purpose of NASA Contract NAS1–20090 Task 3 was to investigate the potential for noise reduction that would result from improving the high–lift performance of conventional subsonic transports. The study showed that an increase in lift–to–drag ratio of 15% would reduce certification noise levels by about 2 EPNdB on approach, 1.5 EPNdB on cutback, and zero EPNdB on sideline. In most cases, noise contour areas would be reduced by 10 to 20%.

14. SUBJECT TERMS
Acoustics, Community Noise, High–Lift, Aircraft Performance

15. NUMBER OF PAGES
21

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT