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Optimum Climb to Cruise Noise Trajectories for the High Speed Civil Transport

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Optimum Climb to Cruise Noise Trajectories For the High Speed Civil Transport

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By entraining large quantities of ambient air into advanced ejector nozzles, the jet noise of the proposed High Speed Civil Transport (HSCT) is expected to be reduced to levels acceptable for airport-vicinity noise certification. Away from the airport, however, this entrained air is shut off and the engines are powered up from their cutback levels to provide better thrust for the climb to cruise altitude. Unsuppressed jet noise levels propagating to the ground far from the airport are expected to be high. Complicating this problem is the HSCT's relative noise level with respect to the subsonic commercial fleet of 2010, which is expected to be much quieter than it is today after the retirement of older, louder, domestic stage II aircraft by the year 2000. In this study, the classic energy state approximation theory is extended to calculate trajectories that minimize the climb to cruise noise of the HSCT. The optimizer dynamically chooses the optimal altitude-velocity trajectory, the engine power setting, and whether the ejector should be stowed or deployed with respect to practical aircraft climb constraints and noise limits. *(This report was written in 1996 for NASA's High Speed Research Program.)*

Nomenclature

D	drag
E	energy
g	gravitational acceleration
h	height
h_e	energy height
L	lift
L_A	A-weighted sound pressure level
L_N	arbitrary noise level metric
$L_{N\,acc}$	accumulated noise level
L_P	perceived noise level
L_S	sound exposure level
m	mass
M	Mach number
$\mathcal{O}$	optimization objective function
t	time
T	thrust
v	velocity
w_f	fuel weight
W_F	weighting factor
x	distance
α	angle of attack
γ	flight path angle
ε	angle between thrust and zero lift axes

Introduction

Jet noise, caused by the turbulent mixing of a jet engine's exhaust with the surrounding air, will be much higher for the proposed High Speed Civil Transport (HSCT) than the jet noise of today's subsonic commercial aircraft. Advanced mixer ejector nozzles are expected to reduce HSCT jet noise to airport certification levels by entraining and mixing large quantities of ambient air with the primary jet stream. Away from the airport, however, as the HSCT gains speed and climbs, poor ejector inlet recovery and ejector ram drag contribute to poor thrust, making it advantageous to turn off the ejector. Doing so at full power, however, will create noise levels propagating to the ground as much as 25 dBA greater than typical current subsonic commercial aircraft. Complicating this problem is the HSCT's relative noise level with respect to the subsonic commercial fleet of 2010, which is expected to be much quieter than it is today after the retirement of older, louder, domestic stage II aircraft by the year 2000. Unlike sideline, community, and approach noise, climb to cruise noise is currently unregulated by the Federal Aviation Administration. Some cities with large populations in outlying areas, however, have local noise regulations that restrict the operations of loud aircraft. Airlines with vested interest in these cities may find it necessary to pay HSCT operating fees, restrict their operations, or may even be reluctant to purchase any HSCTs at all. Without noise abatement climb trajectories, the HSCT has the potential to be a wolf in the fold of tomorrow's aircraft.

In the early days of aviation, climb trajectories for relatively low-speed subsonic aircraft were uncomplicated. The problem amounted to simply climbing to the desired altitude at the best available rate of climb. The advent of high-speed supersonic aircraft, however, where kinetic energy comprises a significant portion of the total energy required at the top of the climb path, necessitated the development of more sophisticated methods. In 1953, Rutowski (Ref. 1) graphically considered the first minimum time and minimum fuel climb trajectories. Other studies followed (e.g., refs. 2, 3, 4, 5), including the gradient-based computer solutions of Bryson, et al. (refs. 6, 7). This technique, based on the energy state approximation, is expanded in this study to provide solutions to the minimum noise trajectory problem for the HSCT. More accurate variational calculus techniques may be used, but the simpler, less computationally intensive energy state approximation solutions show good agreement with more precise calculations (ref. 7).

An optimizer, based on the energy state approximation noise analysis described below, is programmed into NASA's Flight Optimization System (ref. 8). The current joint Boeing-McDonnell Douglas Technology Concept Aircraft HSCT is modeled and its climb trajectories are analyzed using the optimizer. The program dynamically chooses the best altitude-velocity trajectory, the best engine power setting, and whether the ejector should be stowed or deployed with respect to practical aircraft climb constraints and noise limits.

This study does not consider overland climb trajectories outbound from any particular city, nor does it consider specific population densities or noise abatement trajectories out of the vertical plane. The purpose of this study is to use the best available methods to quantify the climb to cruise noise levels produced by the most current proposed HSCT configuration relative to the subsonic fleet and to conduct trajectory studies of operational procedures used to minimize noise.

Method of Analysis

The classical treatment of the energy state approximation theory begins with defining the total energy of the aircraft. Assuming that energy contributions due to aircraft rotation and structural deflections are negligible, the total energy of the aircraft at a point in altitude-velocity space is given by

$$E = mgh + \frac{mv^2}{2}$$

Dividing through by the aircraft weight mg, the specific energy, or *energy height*, is given by

$$h_e = h + \frac{v^2}{2g}$$

Using properties of the standard atmosphere, contours of constant energy height are plotted in Figure 1 as a function of altitude and Mach number. The energy height represents the theoretical altitude that an aircraft could achieve if all of its kinetic energy were converted to potential energy. Such a climb along a contour of constant energy height is known as a zoom to zero velocity. The reverse, a dive to maximum speed at zero altitude, is also possible, and the notion that variable amounts of kinetic and potential energy can be traded back and forth in zero time without total energy loss is the foundation of the energy state approximation. Total energy is considered to be the state variable of the system.

Minimum Time to Climb

The classical derivation of the minimum time trajectory, necessary for the minimum noise trajectory analysis, is reviewed below. Using the energy height as the independent variable, the time required to climb from one energy height, $h_{e,o}$, to another, $h_{e,f}$, may be expressed as

$$t = \int_{h_{e,o}}^{h_{e,f}} \frac{1}{d\hat{h}_e / dt} d\hat{h}_e \ ,$$

where $\hat{h}_e$ is a dummy energy height variable used for integration. For a minimum time trajectory, the above integral must be minimized. The rate of change of energy height with respect to time is

$$\frac{dh_e}{dt} = \dot{h} + \frac{v}{g}\dot{v}$$

To resolve this relationship into a more convenient form, the equations of motion for the system are required.

$$\begin{aligned} m\dot{v} &= T\cos(\alpha + \varepsilon) - D - mg\sin\gamma \\ mv\dot{\gamma} &= T\sin(\alpha + \varepsilon) + L - mg\cos\gamma \\ \dot{h} &= v\sin\gamma \\ \dot{x} &= v\cos\gamma \\ \dot{m} &= -\dot{w}_f \end{aligned}$$

If α and ε are small, the small angle approximation may be used, giving

$$\begin{aligned} m\dot{v} &= T - D - mg\sin\gamma \\ mv\dot{\gamma} &= T(\alpha + \varepsilon) + L - mg\cos\gamma \\ \dot{h} &= v\sin\gamma \\ \dot{x} &= v\cos\gamma \\ \dot{m} &= -\dot{w}_f \end{aligned}$$

Substituting,

$$\frac{dh_e}{dt} = \frac{v(T - D)}{mg}$$

This grouping is often referred to as the potential rate of climb or the excess specific power. The minimum time trajectory is one that maximizes this parameter at every point in the climb path as the energy height increases.

Minimum Noise to Climb

To extend this analysis to minimum noise trajectories, the following noise level metric is defined:

$$L_{N\,acc} = \int_{t_o}^{t_f} L_N \, d\hat{t}$$

$L_{N\,acc}$ is the *accumulated* noise level of an arbitrary noise metric L_N source propagated vertically to the ground along the flight track for a given time interval. The choice of the noise level metric used for L_N is important in order to accurately model the subjective perception of flyover noise to ground-based observers. The metric used for L_N is discussed in the next section. Using the reasoning developed for the minimum time analysis, the minimum noise trajectory is one that maximizes $dh_e/dL_{N\,acc}$ at every point in the climb path. It is important to note that, in this analysis, momentarily high or low noise levels are less important than the overall noise levels accumulated throughout the climb path. Maximizing $dh_e/dL_{N\,acc}$ yields the greatest increase of energy height with respect to noise along the ground track. Arranging terms, the rate of change of energy height with respect to accumulated noise may be written as

$$\frac{dh_e}{dL_{N\,acc}} = \frac{dh_e/dt}{dL_{N\,acc}/dt} = \frac{v(T - D)}{mgL_N}$$

For optimization purposes, an overall objective function O may now be defined which combines minimum time, noise, and fuel (ref. 1) trajectories:

$$O = O\left(\frac{dh_e}{dt}, \frac{dh_e}{dL_{N\,acc}}, \frac{dh_e}{dw_f}\right);$$

$$O = \frac{v(T - D)}{mg\left[W_{F\,time} + W_{F\,noise}\dfrac{L_N}{L_{No}} + W_{F\,fuel}\dfrac{\dot{w}_f}{\dot{w}_{fo}}\right]}$$

The weighting functions W_{Fi} allow for choosing optimum time, noise, or fuel trajectories either singly or in combination. The L_N and $\dot{w}_f$ variables are normalized with their initial values at the start of the climb path, allowing O to retain units of velocity.

Programming this method into the Flight Optimization System code requires stepping through discrete intervals of energy height and calculating all relevant parameters at every point. The distance traveled between each point along the ground track is given by

$$x_i - x_{i-1} = \sqrt{\left[\frac{1}{2}(v_i + v_{i-1})(t_i - t_{i-1})\right]^2 - \left[h_i - h_{i-1}\right]^2}$$

where the time interval is approximated by

$$t_i - t_{i-1} = \int_{h_{e,i-1}}^{h_{e,i}} \frac{1}{d\hat{h}_e/dt}\, d\hat{h}_e = \frac{h_{e,\,i} - h_{e,\,i-1}}{\frac{1}{2}\left[\left.\frac{dh_e}{dt}\right|_i + \left.\frac{dh_e}{dt}\right|_{i-1}\right]}$$

Since the noise constraints in this analysis (discussed below) are a function of x, additional distance calculations are added to the Flight Optimization System code. And since x is a function of dh_e/dt, which is in turn a function of throttle setting and any noise constraints involved, additional iteration loops are necessary and are programmed into the optimizer.

Noise Metrics

The noise level metric L_N used for climb noise optimization should be one that accurately reflects the subjective annoyance levels of ground-based observers along the flight path. A variety of noise metrics are available (e.g., ref. 9); many of which are practical for airport-vicinity aircraft noise certification. Unlike airport-vicinity noise, however, the HSCT's climb noise will be propagated through a more attenuative atmosphere from relatively high altitudes. Because of this, the HSCT's climb noise signature will be characterized by relatively low noise levels, long durations, and low-frequency spectra. Due to the attenuating atmosphere, the higher frequency turbomachinery and ejector mixing noise sources may be effectively neglected. Low-frequency broadband jet noise will dominate.

McCurdy (ref. 10) reviews a variety of noise level metrics for turbofan aircraft en route cruise noise applications. McCurdy conducted a laboratory experiment to quantify the annoyance response of people subjected to recordings of turbofan aircraft en route noise. In an anechoic listening room, the laboratory subjects ranked various aircraft flyover recordings in order of perceived annoyance and statistical means were computed. McCurdy recommends that the maximum flyover perceived noise level L_P be used to most accurately predict subjective noise annoyance levels. Interestingly, duration and tonal corrections to L_P do not significantly improve the annoyance prediction. In this study, the HSCT's peak jet flyover L_P level is used as the optimization noise level metric L_N.

Noise Analysis

The HSCT's flyover jet noise levels are computed by NASA's Aircraft Noise Prediction Program (ANOPP, refs. 11, 12). This computer program has been demonstrated to be an effective and accurate tool in evaluating the en route jet noise levels of DC-9 JT8D-7 turbofan aircraft (ref. 13). The HSCT's 3570.80 mixed flow turbofan thermodynamic jet properties, calculated jointly by the partnership of General Electric and Pratt & Whitney, are used as inputs to both the "SGLJET" (refs. 14, 15) and the Boeing "JN8" jet noise prediction modules.

SGLJET is a model of SAE's widely-used jet mixing noise prediction procedure for simple, single stream jets. It is used in this study to compute the HSCT's jet noise in both stowed and deployed ejector configurations. For configurations where the ejector is deployed, simple mixed jet properties are used as inputs to the model, effectively ignoring any higher-frequency internal mixing noise that may be generated within the ejector chutes. As discussed above, this is not a bad assumption, since most of the higher-frequency internal mixing noise will be attenuated by the atmosphere. Indeed, in the DC-9 jet noise example of reference 13, nearly all of the sound above 1000 Hz is attenuated at an altitude of only 5000 feet. The effect of forward flight jet noise reduction is calculated using the method described in reference 15. The forward flight effect term, which accounts for reduction of the jet's mean-square acoustic pressure, is experimentally derived from relatively low speed flight data. This term may not accurately predict forward flight attenuation at higher subsonic aircraft speeds. In addition, jet shock cell noise is not calculated in this study. The jet noise levels in this study may be underestimated if the jet contains shock noise due to imperfect nozzle expansion.

JN8 is a relatively new mixer-ejector jet noise prediction procedure based on scale model ejector nozzle acoustic tests. It is used as an alternative to the SGLJET model and generates some of the results in this study. The SGLJET results, however, are emphasized, since the JN8 model is used to predict ejector jet noise in high speed, high altitude conditions far outside of the range of its database.

For SGLJET computations, the point source jet noise spectra are modified in a propagation analysis, which accounts for spherical spreading and atmospheric attenuation (refs. 16, 17). Three typical minimum absorption, mean absorption, and maximum absorption atmospheres, based on FAA temperature and humidity profiles (ref. 13), are used in this study. Unless otherwise specified, the results below are calculated using the mean absorption atmosphere. The JN8 model uses its own internal propagation analysis based on the methods described in reference 18. Other atmospheric propagation effects, such as acoustic refraction, wind, and turbulence are not considered in this study.

A program is prepared to read the thermodynamic jet properties from the manufacturer's data packs, modify the jet definition inputs of steady flyover template input files (e.g., table 1), and execute ANOPP via system batch calls. The resulting noise data are gathered into tabular form. L_S, peak L_A, and peak L_P noise levels are available to the trajectory optimizer throughout the mission as a function of Mach number, altitude, throttle setting, atmosphere type, and ejector configuration via tabular lookup. Samples of full-power maximum flyover L_A levels for deployed and stowed ejector configurations are shown in figures. 2 through 8. The symbols indicate where the manufacturer's jet data are provided.

Aircraft Analysis

The Technology Concept Aircraft HSCT is modeled on the modified Flight Optimization System using current, 1996 data provided by the aircraft industry. Propulsion performance, aerodynamics, weight, sizing methods, airframe geometry, physical constraints, and mission definition data are among the modeling requirements. Calculations are performed for two separate HSCT missions. The 5000 nm range design mission, flown at maximum takeoff gross weight and full payload, is shown in figure 9. A reduced range, reduced payload "economic" mission that is more representative of a typical mission is illustrated in figure 10. Optimized trajectories are flown for both missions. The measures of merit used in this study for the design and economic missions are range and block fuel, respectively.

Results and Discussion

Ideal Trajectories

To illustrate the use of the climb path optimizer, ideal trajectories that are unrestricted by realistic physical aircraft and propulsion constraints are considered. Without regard for dynamic pressure loads, heating loads, aeroelastic flutter limits, and stability and control limits, the HSCT's minimum time trajectory is calculated and shown in table 2 and figure 11. The trajectory and objective function data in each table and figure are multiplied by a nonlinear "warping" function in both altitude and velocity dimensions. This is done to prevent disclosure of wing flutter boundaries, dynamic pressure limits, and other industry-proprietary information. The design missions, rather than the economic missions, are plotted in all of the figures.

Note that, in figure 11, the transonic drag rise splits the contours of dh_e/dt into two distinct regimes. The values of the dh_e/dt contours are arranged into 1000 ft/min intervals with zero-valued contours bounding the upper and lower edges of the operating envelope. For plotting purposes, the contours shown are calculated using the full power throttle setting with the ejector stowed, the drag corresponding to the required lift, and the average HSCT weight during the climb. Within the optimizer, however, the throttle setting, aircraft weight, and ejector configuration are variables. Since the trajectory is constrained by the obvious requirement $h > 0$, the HSCT flies a path along ground level until better values of dh_e/dt become available at Mach 0.86. The HSCT climbs until it becomes advantageous to perform a dive along an energy height contour into the supersonic regime. The aircraft continues to increase its energy height at the best available dh_e/dt until approximately Mach 2.7, where a zoom along an energy height contour is performed to reach cruise conditions. As expected for a minimum time trajectory, the throttle setting remains fixed at full power with the ejector stowed. Neglecting takeoff operations time, the time required for this climb path is 17.4 minutes, which is much less than the 49.0 minutes required for the baseline mission described below where realistic constraints are imposed.

The ideal minimum fuel trajectory is shown in table 3 and figure 12. Note that the additional fuel flow term in the objective function produces quite different dh_e/dw_f contours and alters the altitude-velocity path relative to the ideal time trajectory. Like the ideal minimum time path, the ideal fuel path is also flown at full power with the ejector stowed.

The ideal minimum noise trajectory is shown in figure 13. Tables 4 and 5 contain the data for this trajectory where the SGLJET and JN8 noise models are used for the deployed ejector configuration, respectively. Note that, for each mission, the optimizer found it advantageous to climb at full power with the ejector stowed at all times. The contours of $dh_e/dL_{N\,acc}$ and the trajectory shown in figure 13 are therefore the same despite the use of two different jet noise models for the ejector deployed condition. Although flying first at ground level and stowing the ejector creates more initial noise than climbing immediately and leaving the ejector deployed, the trajectory shown maximizes $dh_e/dL_{N\,acc}$ and more effectively reduces noise at points farther from the airport. It is, of course, impossible to fly such trajectories, and noise constraints will further limit the throttle settings used during the climb path. Therefore, the following more realistic possibilities are presented.

Baseline Trajectory

The current proposed baseline trajectory for the HSCT is shown in table 6 and figure 14. The ejector is stowed and maximum thrust is used throughout the climb. The HSCT climbs from 1500 ft and 250 kts calibrated airspeed to 10,000 ft and the speed corresponding to the wing flutter boundary. Equivalent airspeed increases linearly with altitude in this portion of the climb path. It is assumed that HSCTs will be vectored away from all subsonic traffic during climbout, and will not be restricted to 250 kts calibrated airspeed below 10,000 ft. The HSCT then climbs along its flutter boundary at constant equivalent airspeed until it reaches the transonic regime. Equivalent airspeed then once again increases linearly with altitude until the maximum dynamic pressure boundary is reached. As before, all data shown are multiplied by the warping function to prevent disclosure of industry-proprietary information.

Since the baseline trajectory is flown with the ejector stowed and at full throttle, it is one of the louder trajectories possible within a 50 nm radius of the airport. To reduce these noise levels, noise constraints and throttle limits may be imposed. The following constrained trajectories are presented.

Noise Constraint Relative to Stage III Aircraft

The climb noise measured from typical subsonic commercial aircraft may be used to constrain the HSCT's noise levels. The peak flyover L_A levels for stage II and III subsonic aircraft are shown in figure 15 (ref. 19). These levels represent the loudest measurements taken from many stage II and III subsonic aircraft under a variety of conditions, so any noise constraints using these measurements would result in HSCT noise levels higher than those of average stage II and III subsonic aircraft.

One way to immediately reduce climb noise to satisfy a local noise constraint is to gain altitude as rapidly as possible, but not so rapidly that higher, louder, throttle settings are required. These *lofted* trajectories, which are flown at lower dynamic pressure levels than those in the baseline climb path, are calculated by the optimizer for maximum $dh_e/dL_{N\,acc}$ effectiveness with respect to the noise constraints. Lofted trajectories are assumed to be allowed in this study as long as the indicated airspeed at altitude is greater than the minimum aircraft control velocity at sea level. Further stability and control analyses and air traffic control considerations are needed to confirm this assumption. In any case, both lofted and conventional baseline trajectories are considered and compared.

A lofted trajectory using a noise constraint based on the stage III aircraft peak L_A data plus 7 dBA is shown in figure 16. For plotting purposes, the contours of $dh_e/dL_{N\,acc}$ shown in the figure are calculated using the average throttle setting used during the subsonic climb and therefore appear different than the maximum power contours shown in figure 13. It is assumed in this study that lofting is not allowed under 10,000 ft, where air traffic is heavy and traffic control is most difficult. The HSCT therefore follows the conventional baseline linear altitude-velocity path under 10,000 ft. In this portion of the climb, only throttle manipulation and ejector configuration changes are allowed. This additional trajectory constraint, which sends the aircraft into higher dynamic pressure regimes, has the added benefit of keeping the airplane within its minimum control indicated airspeed during higher-speed lofted trajectories. The HSCT climbs at full power with ejectors stowed at speeds greater than Mach 0.9.

Peak L_A and altitude traces as a function of distance from brake release are shown in figures. 17 and 18, respectively. Five lofted trajectories, using noise constraints relative to stage III subsonic aircraft and the mean absorption atmosphere, are shown. The quietest, most restrictive trajectory possible is one limited to 7 dBA greater than the stage III aircraft constraint. Any trajectory using a constraint less than approximately 8 dBA requires too little thrust and either violates the four percent climb gradient requirement (ref. 20) or even drives dh_e/dt to negative values. The discontinuities shown in figure 17 for the unlimited, 20 and 15 dBA trajectories are caused by the ejectors being stowed. The loudest trajectory occurs when the HSCT climbs at full power with ejectors stowed, creating over 20 dBA more than the stage III aircraft constraint at a distance of 10 nm from the airport. Detailed data for these trajectories are shown in tables 7 through 11.

The climb time and range penalties due to the noise constraints for the design mission are shown in figures 19 and 20, respectively. The block fuel penalties for the economic mission are shown in figure 21. Note that, regardless of the measure of merit used, the penalties of throttling and ejector deployment due to the noise constraints are small. HSCTs using lofted trajectories and constrained by the climb gradient limit experience only 7.5, 0.9, and 0.7 percent penalties in climb time, range, and block fuel, respectively.

Noise Constraint Relative to the 747-400

Another interesting metric to use as a noise constraint is the climb noise produced by the HSCT's primary long-haul market future partner: the Boeing 747. Typical flyover altitude and L_S data for the 747-400/PW4056 are reported in further research by Mortlock (ref. 19) and is reproduced in figures 22 and 23. The L_S noise metric is similar to the L_A metric used above, but contains an additional duration component that usually increases the absolute level of the noise (See, e.g., ref. 9). L_S constraints are mathematically handled by the optimizer as easily as the previous L_A constraints. Using the 747 L_S trace as a noise constraint poses some concerns. Although the initial L_S level near the airport is relatively high, the levels quickly become more restrictive farther downrange, where reduced excess specific power levels at higher speeds and altitudes unfortunately limit the HSCT's ability to cope with the constraint. This is in contrast with the gently-sloping L_A constraint used above, where the HSCT is able to give up great amounts of excess specific power near the airport to satisfy the constraint, but is not required to do so farther downrange when less power is available.

A lofted trajectory using a noise constraint based on the 747 L_S track plus 5 dBA is shown in figure 24. As before, the contours of $dh_e/dL_{N\,acc}$ shown in the figure are calculated using the average throttle setting used during the subsonic climb. The HSCT again follows the conventional baseline linear altitude-velocity path under 10,000 ft and climbs at full power with ejectors stowed at speeds greater than Mach 0.9.

L_S and altitude traces as a function of distance from brake release are shown in figures 25 and 26, respectively. Five lofted trajectories, using L_S noise constraints relative to the 747 and the mean absorption atmosphere, are shown. The quietest trajectory possible is one limited to 5 dBA greater than the 747 constraint. Any trajectory using a constraint less than approximately 4 dBA either violates the climb gradient requirement or lacks sufficient thrust to climb. When the maximum absorption atmospheric profile is used, trajectories can be flown to within 2 dBA of the 747 constraint. Detailed data for the mean absorption atmosphere trajectories are shown in tables 12 through 16.

The climb time, range, and block fuel penalties due to the noise constraints are shown in figures 27, 28, and 29, respectively. Note that, due to the more restrictive 747 noise constraint, the penalties of throttling and ejector deployment are slightly more significant than in the case of the stage III aircraft L_A noise constraints. For example, a trajectory using a constraint based on the 747 L_S plus 5 dBA can result in a 12 percent increase in climb time. As before, however, the penalties in range and block fuel are small. Because some headway is made during the subsonic climb, the HSCT experiences only 0.9 percent penalties in range and block fuel for climb gradient limited, lofted trajectories. Due to the irregularly-shaped 747 noise constraint, the optimizer forces the HSCT through highly variable throttle changes, producing convolutions and crossings in the curves shown in figures 27 through 29. To avoid this, the following trajectories are examined.

Restricted dh_e/dt Trajectories

Another type of trajectory of interest is one which places a maximum limit on the potential rate of climb, dh_e/dt. This procedure not only effectively throttles the engines to reduce noise, but also allows the aircraft to fly at a practical, consistent subsonic potential climb rate without widely-variable throttle manipulations. For these trajectories, the optimizer still calculates the best altitude-velocity path (where applicable) and whether the ejector should be stowed or deployed for the best available $dh_e/dL_{N\,acc}$. The throttle setting, however, is now fixed by the dh_e/dt constraint.

A lofted trajectory using a maximum allowed dh_e/dt of 2500 ft/min is shown in figure 30. L_S and altitude traces as a function of distance from brake release are shown in figures 31 through 34. Nine lofted trajectories, using various maximum allowed potential rates of climb and three atmospheric absorption profiles, are shown. The effect of the three atmospheric absorption profiles on L_S levels is small at low altitudes, but becomes more significant as the HSCT climbs. Note that the maximum allowed potential climb rate must be greater than 2000 ft/min or the HSCT will lack sufficient thrust to climb. Detailed data for these trajectories are shown in tables 17 through 22. The climb time, range, and block fuel penalties due to the climb rate constraints are shown in figures 35, 36, and 37, respectively. There is little effect for climb rate restrictions greater than 3000 ft/min.

Conclusions

Based on the jet noise and trajectory analyses presented in this study, the following conclusions are given:

1. Trajectory optimization using the classic energy state approximation may be extended to minimize climb to cruise noise. The peak flyover perceived noise level L_P is the metric used to most accurately predict subjective noise annoyance levels.
2. The performance and jet acoustics of the latest Technology Concept Aircraft HSCT are modeled and analyzed using this technique. Noise levels for ejector deployed conditions may be calculated using either the SGLJET or JN8 jet noise prediction models. The SGLJET noise model results, however, are emphasized and presented.
3. The unconstrained minimum noise climb path for the HSCT is impractical because many aircraft physical and operational constraints are violated. More interesting results are obtained when operational and noise constraints are imposed on the HSCT.
4. Typical measured Stage III subsonic aircraft peak L_A levels may be used as noise constraints. Ejector nozzle deployment, throttling, and trajectory lofting optimization are used as noise abatement techniques. Using these techniques with a mean absorption atmosphere profile, the HSCT can at best expect to be 7 dBA louder than the Stage III aircraft noise constraint.
5. A noise constraint based on typical measured 747-400/PW4056 L_S levels is also used in this study. Using the above noise abatement techniques with a mean absorption atmosphere profile, the HSCT can at best expect to be 5 dBA louder than the 747 noise constraint.
6. Significant noise reduction may be obtained by climbing at reduced excess specific thrust levels.
7. The performance penalties brought about by these noise abatement techniques are generally small.

At maximum unsuppressed power, the HSCT will be appreciably louder than the subsonic commercial fleet with which it will coexist. With its ejector deployed and its engines throttled, however, the HSCT can be expected to climb approximately at 747 noise levels without significant performance penalties. These preliminary results are encouraging, since they suggest that excessive restrictions need not be imposed on HSCT operations. Further investigation is necessary to determine how accurate these analytical noise predictions are. A better understanding of forward flight effects on jet noise attenuation at high subsonic speeds is particularly important. Analytical noise predictions at these speeds may be calibrated with actual flight test noise data (See, e.g., ref. 21). Specific city pairs, population statistics, takeoff and climbout operations, geography, and anticipated local noise restrictions also need to be considered in future studies.

.

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```
$
$    Steady flyover using a single noise source applying
$    atmospheric absorption and ground effects
$
ANOPP $
STARTCS $
$
$    Load SAE table from the ANOPP permanent data base LIBRARY:
$
LOAD /LIBRARY/ SAE $
$
$    Specify the frequency and directivity angles:
$
UPDATE NEWU=SFIELD SOURCE=*  $
   -ADDR OLDM=* NEWM=FREQ FORMAT=4H*RS$ $
          50.    63.      80.    100.    125.    160.
         200.    250.    315.    400.    500.    630.
         800.   1000.   1250.   1600.   2000.   2500.
        3150.   4000.   5000.   6300.   8000.  10000.  $
   -ADDR OLDM=* NEWM=THETA FORMAT=4H*RS$ $
          10.  20.    30.   40.    50.   60.    70.    80.    90.
         100.  110.  120.  130.  140.   150.   160.   170.        $
   -ADDR OLDM=* NEWM=PHI FORMAT=4H*RS$ $
          90. $
   END* $
$
$ These two input parameters will be used by every module executed
$ in this template.  Since they will not be modified, they are
$ defined once before the module is executed.
$
PARAM IUNITS   = 7HENGLISH $  Use English units
PARAM IPRINT   =   3       $  printed output option code
$
$=====================================================================
$  Atmospheric Module - ATM
$
$   The purpose of this module is to build a table of atmospheric model
$   data as functions of altitude.  Input required includes the user
$   parameters listed below and the unit member ATM(IN).  Output
$   consists of the table ATM(TMOD) which is a table of atmospheric
$   model values in dimensionless units.  The model values include
$   pressure, density, temperature, speed of sound, average speed of
$   sound, humidity, coefficient of viscosity, coefficient of thermal
$   conductivity, and characteristic impedance all as a function of
$   altitude.  This table will be used as input to several modules that
$   will be subsequently executed.
$
$----------------------------------------------------------------------
$
$      Define the input unit member ATM(IN), each record defines the
$      temperature and relative humidity at a specific altitude.
```

$ Table 1: Sample SGLJET ANOPP Input

```
$      Three atmospheric profiles from FAA Office of Environment
$      and Energy data are used:  maximum, minimum, and mean
$      absorption models.
$
$      Mean absorption model:
$          0.   510.     70.  $
$       7500.   495.     40.  $
$      18000.   450.     23.  $
$      34000.   420.     20.  $
 $
$      Maximum absorption model:
$          0.   506.     60.  $
$       7500.   478.     10.  $
$      18000.   465.     10.  $
$      34000.   425.     35.  $
$
$      Minimum absorption model:
$          0.   535.     90.  $
$       7500.   505.     70.  $
$      18000.   465.     60.  $
$      34000.   402.     10.  $
$
UPDATE NEWU=ATM SOURCE=* $
   -ADDR OLDM=* NEWM=IN FORMAT=4H3RS$ $
           0.   535.     90.  $
        7500.   505.     70.  $
       18000.   465.     60.  $
       34000.   402.     10.  $
    END* $
$
$ Define input parameters for the Atmospheric Module
$
PARAM DELH      =       1000.   $  altitude increment for output, ft
PARAM H1        =          0.   $  ground level altitude, ft
PARAM NHO       =         51    $  number of altitudes for output
PARAM P1        =    2116.22    $  atmospheric pressure at ground
                                $  level, psf
$
$   Execute the Atmospheric Module
$
EXECUTE ATM  $
$
$=====================================================================
$  Atmospheric Absorption Module - ABS
$
$   This module computes average absorption/wavelength as a function of
$   altitude and frequency.  Input data units required include
$   SFIELD(FREQ), which has been generated using the UPDATE control
$   statement, and ATM(TMOD), which has been generated by the
$   Atmospheric Module.  The Atmospheric Absorption Module generates
$   the data table ATM(AAC) as output.
```

Table 1: Sample SGLJET ANOPP Input (Continued)

```
$   This table contains atmospheric absorption coefficients as a
$   function of altitude and frequency.  It will be used by the
$   Propagation Module to apply atmospheric absorption effects to the
$   noise sources.
$
$-----------------------------------------------------------------------
$
$   Define input user parameters for the Atmospheric Absorption Module
$
PARAM ABSINT     =       5      $  number of integration steps
PARAM ISAE       =       1      $  method option - use SAE ARP 866
                                $  method
$
$   Execute the Atmospheric Absorption Module
$
EXECUTE ABS  $
 $
$=======================================================================
$  Steady Flyover Module - SFO
$
$   The purpose of this module is to provide flight dynamics data in
$   the case of a steady state flyover.  One record of trajectory data
$   is written to a unit member at each time step.  This module
$   requires the user parameters listed below and the unit member
$   generated by the Atmospheric Module, ATM(TMOD), as input.  SFO
$   generates two unit members as output.  FLI(PATH) contains the
$   following flight trajectory data: time, aircraft position (x,y,z),
$   Euler angles from vehicle-carried to body axis and Euler angles
$   from body to wind axis.  FLI(FLIXXX) contains flight data in the
$   following order: time, Mach number, power setting, speed of sound,
$   density, viscosity, landing gear indicator, flap setting, and
$   humidity.
$
$-----------------------------------------------------------------------
$
$   Define input user parameters for the Steady Flyover Module
$
PARAM ZOPT       =          2    $
PARAM J          =          1    $  initial time step
PARAM TSTEP      =        0.5    $  time interval between step, s
PARAM ZGR        =        0.0    $  altitude at brake release, ft
PARAM ENGNAM     =      3HXXX    $  engine identifier name
PARAM DELTA      =        0.0    $  engine inclination angle, deg
PARAM TI         =        0.0    $  initial time, s
PARAM VI         =      933.8    $  aircraft velocity, ft/s
PARAM VF         =         VI    $
PARAM YI         =        0.0    $  initial lateral distance from
                                 $  origin, ft
PARAM ZI         =    25000.0    $  initial altitude, ft
PARAM FACTI      =      -1.60    $  Factor for initial distance
                                 $  calculation
```

Table 1: Sample SGLJET ANOPP Input (Continued)

```
EVALUATE ZIMOD  =ZI + 10000.    $
EVALUATE XI     =FACTI*ZIMOD    $  initial distance from origin, ft
PARAM THW       =        0.0    $  inclination of flight vector
                                $  with respect to horizontal, deg
PARAM ZF        =         ZI    $  final altitude limit, ft
PARAM FACTF     =       1.40    $  Factor for final distance
                                $  calculation
EVALUATE ZFMOD  =ZF + 10000.    $
EVALUATE XF     =FACTF*ZFMOD    $  final distance limit, ft
PARAM ALPHA     =        2.0    $  angle of attack, deg
PARAM THROT     =        1.0    $  power setting
$
$   Look up atmospheric data at flyover altitude
$
PARAM Z         =         ZI    $
EXECUTE APM $
$
$   Execute the Steady Flyover Module
$
EXECUTE SFO $
$======================================================================
$  Geometry Module - GEO
$
$   The purpose of the Geometry Module is to calculate the source to
$   observer geometry.  Input parameters are given below.  Input data
$   units include FLI(PATH) and OBSERV(COORD).  The unit FLI(PATH) was
$   generated as output from the Steady Flyover Module.  OBSERV(COORD)
$   is generated using the UPDATE control statement as shown below.
$   This unit member consists of a list of observer locations to which
$   the noise source will be propagated.  The data required are the x,
$   y, and z coordinates of the observer (i.e. microphone) locations.
$   The value of the user parameter ICOORD determines the output
$   generated by this module.  In this example, ICOORD has a value
$   of 1 which indicates that geometry associated with the body axis
$   will be output in a table called GEO(BODY).
$
$----------------------------------------------------------------------
$
$   Define the centerline ground observer coordinates
$
UPDATE NEWU=OBSERV SOURCE=* $
   -ADDR OLDM=* NEWM=COORD FORMAT=4H3RS$ $
           0.     0.    4.  $
   END* $
$
$   Define input user parameters for the Geometry Module
$
PARAM CTK       =        0.1    $  characteristic time constant
PARAM DELDB     =       20.0    $  limiting noise level down from
                                $  peak, dB
PARAM DELT      =        0.5    $  reception time increment, s
PARAM DELTH     =       10.0    $  maximum polar directivity
```

Table 1: Sample SGLJET ANOPP Input (Continued)

```
                                $  angle limit, deg
PARAM ICOORD    =          1    $  generate body axis output
PARAM DIRECT    =    .FALSE.    $  interpolate from FLI(PATH) observer
                                $  reception times based on user
                                $  parameters start, stop, delth,
                                $  and delt
$
$    Execute the Geometry Module
$
EXECUTE GEO  $
$=======================================================================
$  Single Stream Circular Jet Noise Module - SGLJET
$
$    This module predicts 1/3-octave band circular jet noise
$    incorporating forward flight effects with methods developed by the
$    SAE-A21 jet noise subcommittee.  Input user parameters required by
$    this module are listed below.  The input data units required are
$    SFIELD(FREQ), SFIELD(THETA), and SFIELD(PHI) which are the 1/3-
$    octave band center frequencies, the polar directivity angles, and
$    the azimuthal directivity angles, respectively.  These unit
$    members were created using the UPDATE control statement at the
$    beginning of this input deck.  The SAE data tables are also
$    required input to this module.  These tables were obtained from
$    the permanent data base using the LOAD control statement at the
$    beginning of this input deck.  The output generated by this module
$    is a table of mean-square acoustic pressure values as a function
$    of frequency, polar directivity angle and azimuthal directivity
$    angle.  The table is entitled SGLJET(XXXNNN) where the XXX is
$    replaced by the value of the user parameter SCRXXX and the NNN
$    is replaced by the value of the user parameter SCRNNN.
$-----------------------------------------------------------------------
$
$   Define ambient conditions
$
PARAM RHOA      =       .033    $  ambient density, slugs/ft3
PARAM TA        =      447.5    $  ambient temperature, R
PARAM CA        =     1038.7    $  ambient speed of sound, ft/s
$
$   Define  input parameters
$
PARAM AE        =     XX.XXX    $  engine reference area, ft2
PARAM AJ        =         AE    $  area of fully expanded primary
                                $  jet, ft2
PARAM RHOJ      =       .XXX    $  density of primary jet, slugs/ft3
PARAM TJ        =      XXX.X    $  jet total temperature, R
PARAM VJ        =     XXXX.X    $  jet velocity relative to
                                $  nozzle exit, ft/s
PARAM RS        =        1.0    $  radial distance from nozzle exit to
                                $  observer, ft
PARAM STIME     =        0.0    $  source noise calculation time, s
PARAM MA        =        .XX    $  aircraft Mach number
```

Table 1: Sample SGLJET ANOPP Input (Continued)

```
PARAM NENG      =          4    $  number of engines
PARAM DELTA     =        0.0    $  engine inclination angle, deg
PARAM SCRXXX    =      3HXXX    $  table unit member identifier
PARAM SCRNNN    =          1    $  table unit member identifier
PARAM IOUT      =          3    $  output code for table and
                                $  printed output
$
$   Nondimensionalize input parameters
$
EVALUATE AJ     =      AJ/AE    $
EVALUATE RHOJ   =  RHOJ/RHOA    $
EVALUATE TJ     =      TJ/TA    $
EVALUATE VJ     =      VJ/CA    $
$
$   Execute the noise module
$
EXECUTE SGLJET  $
$
$======================================================================
$  Propagation Module - PRO
$
$   The Propagation Module takes noise data which has been generated by
$   the noise source module(s) in the source frame of reference and
$   applies all of the appropriate computations to transfer it to the
$   observer frame of reference.  Input user parameters required by
$   this module are listed below.  Input data base units include the
$   following:
$      ATM(TMOD)      -  generated as output from the Atmospheric
$                        module
$      ATM(AAC)       -  generated as output from the Atmospheric
$                        Absorption Module and used only if
$                        atmospheric absorption effects are requested
$      GEO(GEOM)      -  generated as output from the Geometry Module
$      FLI(FLIXXX)    -  generated as output from the flight dynamics
$                        module - SFO in this template
$      YYYYYY(XXXNNN) -  output generated by the noise source
$                        module(s) where YYYYYY is the unit name
$                        associated with the noise module(s) used to
$                        calculate the source noise - SGLJET in this
$                        example
$   Output generated by this module includes the data unit
$   PRO(PRES) which contains dimensionless mean-square pressure
$   at the observer as a function of frequency and time.
$
$----------------------------------------------------------------------
$
$   Define input parameters for the Propagation Module
$
PARAM IOUT      =           3   $  print output in both SPL (dB) and
                                $  mean-square acoustic pressure
PARAM NBAND     =           5   $  number of subbands per
                                $  1/3-octave band
```

Table 1: Sample SGLJET ANOPP Input (Continued)

```
PARAM SURFACE   =      4HSOFT   $  type of surface to be used in
                                $  calculating
                                $  ground effects
PARAM COH       =        0.01   $  incoherence coefficient
PARAM PROTIME   =       3HXXX   $  3 letter id from unit
                                $  member FLI(FLIXXX)
PARAM PROSUM    =    6HSGLJET   $  name(s) of source unit(s) to
                                $  be summed
$
$   In order to include atmospheric absorption and ground effects,
$   these two input parameters are given a value of TRUE
$
PARAM ABSORP    =      .TRUE.   $  include atmospheric absorption
                                $  effects
PARAM GROUND    =      .TRUE.   $  include ground effects
$
$    Execute the Propagation Module - a name override is used to inform
$    the Propagation Module that the Geometry Module generated the unit
$    member GEO(BODY) while the Propagation Module is expecting
$    GEO(GEOM)
$
EXECUTE PRO GEOM=BODY  $
$
$======================================================================
$  Noise Levels Module - LEV
$
$   The Noise Levels Module computes overall sound pressure level,
$   A-weighted sound pressure level, D-weighted sound pressure level
$   perceived noise level, and tone-corrected perceived noise level as
$   a function of time and observer as requested by the user.  The
$   input user parameters required by this module are listed below.
$   The Noise Levels Module uses the data unit PRO(PRES), which was
$   generated by the Propagation Module, as input.  Also required as
$   input are the data units SFIELD(FREQ) and OBSERV(COORD) which both
$   were generated using the UPDATE control statement earlier in this
$   input deck.  If tone-corrected perceived noise levels calculations
$   are requested then the data unit LEV(PNLT) is generated as output.
$
$----------------------------------------------------------------------
$
$   Define input parameters for the Noise Levels Module
$
PARAM IAWT      =      .TRUE.   $  A-weighted sound pressure
                                $  level option
PARAM IDWT      =     .FALSE.   $  D-weighted sound pressure
                                $  level option
PARAM IOSPL     =      .TRUE.   $  overall sound pressure level option
PARAM IPNL      =      .TRUE.   $  perceived noise level (PNL) option
PARAM IPNLT     =      .TRUE.   $  tone-corrected PNL option
```

Table 1: Sample SGLJET ANOPP Input (Continued)

```
PARAM MEMSUM    = 4HPRO 4HPRES  $  unit name and member name of
                                $  the noise member to be summed
$
$   Execute the Noise Levels Modules
$
EXECUTE LEV $
$
$ EXECUTE EFF
$
ENDCS $
```

Table 1: Sample SGLJET ANOPP Input (Concluded)

Design Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_A (dBA)	L_{Alimit} (dBA)	T/T_{max}
.354	0	2922	5721	.0	4.0	149.63	137.33	na	1.0000
.458	0	4804	7587	.3	5.4	148.64	136.32	na	1.0000
.545	0	6685	8764	.5	6.8	147.83	135.71	na	1.0000
.624	0	8567	9869	.7	8.2	134.64	123.18	na	1.0000
.697	0	10448	10721	.9	9.6	120.67	109.90	na	1.0000
.767	0	12330	10918	1.1	11.0	117.41	106.80	na	1.0000
.833	0	14211	10746	1.2	12.6	117.26	106.66	na	1.0000
.862	1066	16093	10395	1.4	14.3	114.88	104.30	na	1.0000
.882	2511	17975	10079	1.6	16.1	111.78	101.21	na	1.0000
.882	4599	19856	9713	1.8	17.9	107.37	96.83	na	1.0000
.882	6715	21738	9312	2.0	19.8	102.94	92.42	na	1.0000

Range = 5024.0 nm
Climb Time = 17.4 min

Economic Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_A (dBA)	L_{Alimit} (dBA)	T/T_{max}
.354	0	2922	7756	.0	4.0	149.63	137.33	na	1.0000
.458	0	4804	10036	.2	5.0	148.64	136.32	na	1.0000
.545	0	6685	11328	.4	6.1	147.83	135.71	na	1.0000
.624	0	8567	12575	.6	7.2	134.64	123.18	na	1.0000
.697	0	10448	13541	.7	8.3	120.67	109.90	na	1.0000
.767	0	12330	13699	.8	9.5	117.41	106.80	na	1.0000
.833	0	14211	13392	1.0	10.7	117.26	106.66	na	1.0000
.862	1089	16093	12946	1.1	12.1	114.83	104.25	na	1.0000
.882	2508	17975	12548	1.3	13.5	111.78	101.22	na	1.0000
.882	4600	19856	12138	1.4	14.9	107.37	96.83	na	1.0000
.882	6716	21738	11685	1.6	16.4	102.96	92.44	na	1.0000
.882	8858	23619	11190	1.7	18.0	98.53	88.03	na	1.0000

Block Fuel = 204903 lb
Climb Time = 13.5 min

Table 2: Minimum Time Trajectory, No Noise Constraint, SGLJET Model,
Mean Atmospheric Absorption

Design Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_A (dBA)	L_{Alimit} (dBA)	T/T_{max}
.354	0	2922	5721	.0	4.0	149.63	137.33	na	1.0000
.458	0	4804	7587	.3	5.4	148.64	136.32	na	1.0000
.545	0	6685	8764	.5	6.8	147.83	135.71	na	1.0000
.624	0	8567	9869	.7	8.2	134.64	123.18	na	1.0000
.697	0	10448	10721	.9	9.6	120.67	109.90	na	1.0000
.714	1513	12330	10351	1.1	11.0	114.09	103.47	na	1.0000
.714	3518	14211	9637	1.3	12.5	109.57	98.95	na	1.0000
.734	4993	16093	9223	1.5	14.1	106.30	95.70	na	1.0000
.756	6407	17975	8873	1.7	15.9	103.25	92.67	na	1.0000
.779	7815	19856	8562	1.9	17.7	100.30	89.73	na	1.0000
.802	9212	21738	8294	2.1	19.6	97.44	86.89	na	1.0000
.827	10601	23619	8066	2.3	21.7	95.08	84.50	na	1.0000
.852	11981	25501	7830	2.6	23.8	93.30	82.62	na	1.0000
.879	13349	27382	7574	2.8	26.1	91.57	80.78	na	1.0000
.882	15438	29264	6913	3.1	28.5	88.74	77.78	na	1.0000
.882	17679	31145	6172	3.4	31.2	85.72	74.56	na	1.0000
.882	19942	33027	5377	3.7	34.2	82.70	71.35	na	1.0000
.882	22226	34908	4759	4.1	37.6	80.70	69.39	na	1.0000

Range = 5080.6 nm
Climb Time = 21.8 min

Economic Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_A (dBA)	L_{Alimit} (dBA)	T/T_{max}
.354	0	2922	7815	.0	4.0	149.63	137.33	na	1.0000
.458	0	4804	10105	.2	5.0	148.64	136.32	na	1.0000
.545	0	6685	11400	.4	6.1	147.83	135.71	na	1.0000
.624	0	8567	12653	.5	7.2	134.64	123.18	na	1.0000
.697	0	10448	13622	.7	8.3	120.67	109.90	na	1.0000
.714	1514	12330	13161	.8	9.4	114.09	103.47	na	1.0000
.714	3519	14211	12295	1.0	10.5	109.56	98.95	na	1.0000
.714	5536	16093	11416	1.1	11.8	105.06	94.46	na	1.0000
.725	7298	17975	10718	1.3	13.1	101.21	90.61	na	1.0000
.741	8894	19856	10185	1.5	14.6	97.82	87.23	na	1.0000
.741	10997	21738	9368	1.7	16.2	94.03	83.37	na	1.0000
.758	12670	23619	8950	1.9	17.8	91.79	81.00	na	1.0000
.780	14163	25501	8631	2.1	19.6	89.86	78.96	na	1.0000
.806	15605	27382	8313	2.3	21.5	88.04	77.03	na	1.0000
.830	17039	29264	7968	2.5	23.5	86.25	75.14	na	1.0000
.857	18459	31145	7596	2.8	25.7	84.51	73.29	na	1.0000
.882	19944	33027	7145	3.0	28.0	82.69	71.34	na	1.0000
.882	22229	34908	6440	3.3	30.5	80.71	69.40	na	1.0000
.882	24533	36790	5799	3.6	33.3	79.10	67.91	na	1.0000
.882	26844	38672	5124	4.0	36.4	77.36	66.31	na	1.0000

Block Fuel = 201542 lb
Climb Time = 20.6 min

Table 3: Minimum Fuel Trajectory, No Noise Constraint, SGLJET Model, Mean Atmospheric Absorption

Design Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_A (dBA)	L_{Alimit} (dBA)	T/T_{max}
.354	0	2922	5721	.0	4.0	149.63	137.33	na	1.0000
.458	0	4804	7587	.3	5.4	148.64	136.32	na	1.0000
.545	0	6685	8764	.5	6.8	147.83	135.71	na	1.0000
.624	0	8567	9869	.7	8.2	134.64	123.18	na	1.0000
.697	0	10448	10721	.9	9.6	120.67	109.90	na	1.0000
.767	0	12330	10918	1.1	11.0	117.41	106.80	na	1.0000
.802	917	14211	10616	1.2	12.6	115.30	104.70	na	1.0000
.826	2240	16093	10257	1.4	14.2	112.38	101.80	na	1.0000

Range = 4938.7 nm
Climb Time = 18.4 min

Economic Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_A (dBA)	L_{Alimit} (dBA)	T/T_{max}
.354	0	2922	6853	.0	4.0	133.50	120.85	na	1.0000*
.458	0	4804	9924	.2	5.1	148.64	136.32	na	1.0000
.545	0	6685	11212	.4	6.2	147.83	135.71	na	1.0000
.624	0	8567	12450	.6	7.3	134.64	123.18	na	1.0000
.697	0	10448	13411	.7	8.4	120.67	109.90	na	1.0000
.767	0	12330	13572	.9	9.6	117.41	106.80	na	1.0000
.789	1346	14211	13076	1.0	10.8	114.37	103.77	na	1.0000
.811	2680	16093	12627	1.1	12.1	111.43	100.85	na	1.0000
.835	3997	17975	12230	1.3	13.5	108.60	98.03	na	1.0000

Block Fuel = 210440 lb ("*" denotes ejector in operation)
Climb Time = 14.2 min

Table 4: Minimum Noise Trajectory, No Noise Constraint, SGLJET Model,
Mean Atmospheric Absorption

Design Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_A (dBA)	L_{Alimit} (dBA)	T/T_{max}
.354	0	2922	5721	.0	4.0	149.63	137.33	na	1.0000
.458	0	4804	7587	.3	5.4	148.64	136.32	na	1.0000
.545	0	6685	8764	.5	6.8	147.83	135.71	na	1.0000
.624	0	8567	9869	.7	8.2	134.64	123.18	na	1.0000
.697	0	10448	10721	.9	9.6	120.67	109.90	na	1.0000
.767	0	12330	10918	1.1	11.0	117.41	106.80	na	1.0000
.802	917	14211	10616	1.2	12.6	115.30	104.70	na	1.0000
.826	2240	16093	10257	1.4	14.2	112.38	101.80	na	1.0000

Range = 4938.7 nm
Climb Time = 18.4 min

Economic Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_A (dBA)	L_{Alimit} (dBA)	T/T_{max}
.354	0	2922	6853	.0	4.0	133.50	120.85	na	1.0000*
.458	0	4804	9924	.2	5.1	148.64	136.32	na	1.0000
.545	0	6685	11212	.4	6.2	147.83	135.71	na	1.0000
.624	0	8567	12450	.6	7.3	134.64	123.18	na	1.0000
.697	0	10448	13411	.7	8.4	120.67	109.90	na	1.0000
.767	0	12330	13572	.9	9.6	117.41	106.80	na	1.0000
.789	1346	14211	13076	1.0	10.8	114.37	103.77	na	1.0000
.811	2680	16093	12627	1.1	12.1	111.43	100.85	na	1.0000
.835	3997	17975	12230	1.3	13.5	108.60	98.03	na	1.0000

Block Fuel = 210440 lb ("*" denotes ejector in operation)
Climb Time = 14.2 min

Table 5: Minimum Noise Trajectory, No Noise Constraint, JN8 (Deployed) and SGLJET (Stowed) Noise Models, Mean Atmospheric Absorption

Design Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	5292	.0	4.0	137.16	125.41	na	1.0000
.392	2659	6208	5548	.3	5.5	126.63	118.99	na	1.0000
.431	3862	8096	5761	.7	7.1	116.10	112.64	na	1.0000
.471	5073	10044	5919	1.0	8.9	106.55	106.81	na	1.0000
.512	6292	12051	6059	1.3	10.8	103.58	104.30	na	1.0000
.555	7519	14118	6096	1.7	12.9	100.51	101.78	na	1.0000
.598	8756	16244	6295	2.0	15.2	97.83	99.62	na	1.0000
.644	10000	18429	6429	2.4	17.6	95.18	97.49	na	1.0000
.664	11523	20306	6232	2.7	19.7	93.05	95.57	na	1.0000
.686	13039	22182	6018	3.0	22.0	90.96	93.68	na	1.0000
.709	14546	24059	5786	3.3	24.5	88.90	91.82	na	1.0000
.733	16044	25935	5548	3.6	27.1	86.97	90.07	na	1.0000
.757	17531	27812	5292	4.0	29.9	85.10	88.38	na	1.0000
.781	19007	29689	5015	4.3	32.9	83.27	86.72	na	1.0000
.808	20470	31565	4715	4.7	36.1	81.49	85.10	na	1.0000
.834	21917	33442	4565	5.1	39.6	80.63	84.43	na	1.0000
.862	23350	35319	4387	5.5	43.3	79.81	83.78	na	1.0000

Range = 5000.0 nm
Climb Time = 49.0 min

Economic Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	7228	.0	4.0	137.16	125.41	na	1.0000
.392	2659	6208	7607	.2	5.1	126.63	118.99	na	1.0000
.431	3862	8096	7914	.5	6.3	116.10	112.64	na	1.0000
.471	5073	10044	8083	.7	7.5	106.55	106.81	na	1.0000
.512	6292	12051	8189	1.0	8.9	103.58	104.30	na	1.0000
.555	7519	14118	8180	1.2	10.5	100.51	101.78	na	1.0000
.598	8756	16244	8378	1.5	12.2	97.83	99.62	na	1.0000
.644	10000	18429	8495	1.8	14.0	95.18	97.49	na	1.0000
.664	11523	20306	8255	2.0	15.6	93.05	95.57	na	1.0000
.686	13039	22182	7994	2.2	17.4	90.96	93.68	na	1.0000
.709	14546	24059	7712	2.4	19.2	88.90	91.82	na	1.0000
.733	16044	25935	7420	2.7	21.1	86.97	90.07	na	1.0000
.757	17531	27812	7108	3.0	23.2	85.10	88.38	na	1.0000
.781	19007	29689	6768	3.2	25.4	83.27	86.72	na	1.0000
.808	20470	31565	6399	3.5	27.8	81.49	85.10	na	1.0000
.834	21917	33442	6220	3.8	30.4	80.63	84.43	na	1.0000
.862	23350	35319	6005	4.1	33.1	79.81	83.78	na	1.0000

Block Fuel = 203880 lb
Climb Time = 28.7 min

Table 6: Baseline Mission: No Noise Constraint, SGLJET Model, Mean Atmospheric Absorption

Design Mission:

M	*h (ft)*	h_e *(ft)*	dh_e/dt *(ft/min)*	*t (min)*	*x (nm)*	L_P *(PNdB)*	L_A *(dBA)*	L_{Alimit} *(dBA)*	T/T_{max}
.354	1464	4392	859	.0	4.0	91.31	79.84	79.84	.4138*
.392	2659	6208	1176	1.8	12.0	88.29	77.18	77.18	.4575*
.431	3862	8096	1655	3.1	18.5	85.83	75.01	75.01	.5231*
.471	5073	10044	2345	4.1	23.7	83.90	73.28	73.28	.6181*
.512	6292	12051	2528	4.9	28.4	82.29	71.70	71.70	.6496*
.555	7519	14118	2608	5.7	33.4	80.65	70.04	70.04	.6788*
.598	8756	16244	2463	6.6	39.0	78.83	68.19	68.19	.6656*
.644	10000	18429	2067	7.5	45.8	76.60	65.93	65.93	.6222*
.644	12069	20306	2349	8.4	51.9	75.09	64.50	64.50	.6973*
.644	14160	22182	3088	9.1	56.9	75.11	64.50	64.50	.8541*

Range = 4933.9 nm
Climb Time = 54.7 min

Economic Mission:

M	*h (ft)*	h_e *(ft)*	dh_e/dt *(ft/min)*	*t (min)*	*x (nm)*	L_P *(PNdB)*	L_A *(dBA)*	L_{Alimit} *(dBA)*	T/T_{max}
.354	1464	4392	1625	.0	4.0	91.31	79.84	79.84	.4138*
.392	2659	6208	2439	.9	8.0	89.64	78.51	78.51	.4996*
.431	3862	8096	3573	1.5	11.1	88.36	77.49	77.49	.6189*
.471	5073	10044	4998	2.0	13.5	87.36	76.68	76.68	.7763*
.512	6292	12051	5630	2.3	15.6	86.64	75.96	75.96	.8564*
.555	7519	14118	6219	2.7	17.8	85.95	75.25	75.25	.9421*
.598	8756	16244	6757	3.0	20.0	85.26	74.46	74.53	1.0000*
.644	10000	18429	6768	3.3	22.2	83.67	72.77	73.77	1.0000*
.664	11539	20306	6502	3.6	24.3	81.83	70.97	73.08	1.0000*
.686	13039	22182	6237	3.9	26.5	80.10	69.27	72.35	1.0000*
.707	14594	24059	5919	4.2	28.9	78.27	67.47	71.56	1.0000*
.719	16383	25935	5452	4.6	31.4	75.98	65.22	70.71	1.0000*
.757	17531	27812	5229	4.9	34.2	75.10	64.32	69.77	1.0000*
.781	19007	29689	4899	5.3	37.3	73.61	62.81	68.75	1.0000*
.808	20470	31565	4598	5.7	40.6	72.21	61.39	67.64	1.0000*
.834	21917	33442	4345	6.1	44.2	71.61	60.85	66.44	1.0000*
.862	23350	35319	4078	6.6	48.2	71.09	60.39	65.13	1.0000*

Block Fuel = 206123 lb ("*" denotes ejector in operation)
Climb Time = 31.1 min

Table 7: Stage 3 Aircraft Maximum Plus 7 dBA, Lofted Trajectory, SGLJET Model, Mean Atmospheric Absorption

Design Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_A (dBA)	L_{Alimit} (dBA)	T/T_{max}
.354	1464	4392	1480	.0	4.0	94.33	82.84	82.84	.5073*
.392	2659	6208	2163	1.0	8.5	92.52	81.36	81.36	.5993*
.431	3862	8096	3235	1.7	11.9	91.11	80.22	80.22	.7421*
.471	5073	10044	4473	2.2	14.6	89.98	79.32	79.32	.9065*
.512	6292	12051	5059	2.6	17.0	89.19	78.52	78.52	.9882*
.555	7519	14118	5021	3.0	19.5	87.01	76.31	77.67	1.0000*
.598	8756	16244	5055	3.5	22.3	85.26	74.46	76.75	1.0000*
.644	10000	18429	5107	3.9	25.3	83.67	72.77	75.74	1.0000*
.655	11768	20306	4761	4.3	28.1	81.33	70.49	74.82	1.0000*
.671	13433	22182	4464	4.7	31.1	79.24	68.45	73.82	1.0000*
.708	14578	24059	4413	5.1	34.3	78.31	67.50	72.75	1.0000*
.733	16044	25935	4135	5.5	37.8	76.70	65.90	71.59	1.0000*
.757	17531	27812	3844	6.0	41.6	75.10	64.32	70.33	1.0000*
.781	19007	29689	3574	6.5	45.7	73.61	62.81	68.94	1.0000*
.808	20470	31565	3326	7.1	50.3	72.21	61.39	67.50	1.0000*

Range = 4967.1 nm
Climb Time = 50.8 min

Economic Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_A (dBA)	L_{Alimit} (dBA)	T/T_{max}
.354	1464	4392	2411	.0	4.0	94.33	82.84	82.84	.5073*
.392	2659	6208	3530	.6	6.7	93.10	81.93	81.93	.6236*
.431	3862	8096	5111	1.0	8.9	92.12	81.22	81.22	.7876*
.471	5073	10044	6835	1.4	10.6	91.30	80.65	80.65	.9733*
.512	6292	12051	6990	1.7	12.2	89.42	78.74	80.09	1.0000*
.555	7519	14118	6775	2.0	14.1	87.01	76.31	79.48	1.0000*
.598	8756	16244	6766	2.3	16.2	85.26	74.46	78.79	1.0000*
.644	10000	18429	6778	2.6	18.4	83.67	72.77	78.03	1.0000*
.664	11523	20306	6521	2.9	20.5	81.87	71.00	77.35	1.0000*
.686	13039	22182	6246	3.2	22.7	80.10	69.27	76.61	1.0000*
.709	14546	24059	5952	3.5	25.1	78.38	67.56	75.83	1.0000*
.733	16044	25935	6964	3.8	27.3	86.10	75.07	75.07	.9585
.757	17531	27812	7112	4.0	29.5	85.10	73.92	74.35	1.0000
.781	19007	29689	6772	4.3	31.7	83.27	71.98	73.61	1.0000
.808	20470	31565	6404	4.6	34.1	81.49	70.09	72.82	1.0000
.834	21917	33442	6224	4.9	36.7	80.63	69.34	71.96	1.0000
.862	23350	35319	6009	5.2	39.4	79.81	68.60	71.06	1.0000

Block Fuel = 205006 lb ("*" denotes ejector in operation)
Climb Time = 29.8 min

Table 8: Stage 3 Aircraft Maximum Plus 10 dBA, Lofted Trajectory, SGLJET Model, Mean Atmospheric Absorption

Design Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_A (dBA)	L_{Alimit} (dBA)	T/T_{max}
.354	1464	4392	2685	.0	4.0	99.35	87.84	87.84	.6885*
.392	2659	6208	3860	.6	6.5	98.22	87.01	87.01	.8427*
.431	3862	8096	5099	1.0	8.5	96.44	85.52	86.33	1.0000*
.471	5073	10044	5159	1.4	10.5	91.83	81.17	85.66	1.0000*
.512	6292	12051	5141	1.8	12.8	89.42	78.74	84.91	1.0000*
.555	7519	14118	5014	2.2	15.3	87.01	76.31	84.08	1.0000*
.598	8756	16244	5048	2.6	18.1	85.26	74.46	83.15	1.0000*
.644	10000	18429	5100	3.0	21.1	83.67	72.77	82.14	1.0000*
.664	11523	20306	5814	3.3	23.6	92.03	81.30	81.30	.9536
.686	13039	22182	6032	3.7	26.0	90.96	80.12	80.51	1.0000
.709	14546	24059	5800	4.0	28.4	88.90	77.95	79.70	1.0000
.733	16044	25935	5561	4.3	31.0	86.97	75.90	78.83	1.0000
.757	17531	27812	5305	4.7	33.8	85.10	73.92	77.91	1.0000
.781	19007	29689	5028	5.0	36.8	83.27	71.98	76.91	1.0000
.808	20470	31565	4727	5.4	40.1	81.49	70.09	75.83	1.0000
.834	21917	33442	4577	5.8	43.5	80.63	69.34	74.67	1.0000
.862	23350	35319	4398	6.2	47.2	79.81	68.60	73.44	1.0000

Range = 4987.4 nm
Climb Time = 49.4 min

Economic Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_A (dBA)	L_{Alimit} (dBA)	T/T_{max}
.354	1464	4392	3926	.0	4.0	99.35	87.84	87.84	.6885*
.392	2659	6208	5553	.4	5.7	98.48	87.27	87.27	.8542*
.431	3862	8096	7045	.7	7.2	96.44	85.52	86.79	1.0000*
.471	5073	10044	7089	1.0	8.6	91.83	81.17	86.30	1.0000*
.512	6292	12051	6995	1.2	10.2	89.42	78.74	85.76	1.0000*
.555	7519	14118	6780	1.5	12.1	87.01	76.31	85.14	1.0000*
.598	8756	16244	6771	1.9	14.2	85.26	74.46	84.46	1.0000*
.644	10000	18429	8078	2.2	16.2	94.39	83.77	83.77	.9647
.664	11523	20306	8257	2.4	17.9	93.05	82.33	83.21	1.0000
.686	13039	22182	7996	2.6	19.6	90.96	80.12	82.64	1.0000
.709	14546	24059	7713	2.8	21.4	88.90	77.95	82.03	1.0000
.733	16044	25935	7422	3.1	23.4	86.97	75.90	81.38	1.0000
.757	17531	27812	7109	3.4	25.5	85.10	73.92	80.69	1.0000
.781	19007	29689	6770	3.6	27.7	83.27	71.98	79.95	1.0000
.808	20470	31565	6401	3.9	30.1	81.49	70.09	79.15	1.0000
.834	21917	33442	6221	4.2	32.6	80.63	69.34	78.30	1.0000
.862	23350	35319	6007	4.5	35.3	79.81	68.60	77.40	1.0000

Block Fuel = 204430 lb ("*" denotes ejector in operation)
Climb Time = 29.1 min

Table 9: Stage 3 Aircraft Maximum Plus 15 dBA, Lofted Trajectory, SGLJET Model, Mean Atmospheric Absorption

Design Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_A (dBA)	L_{Alimit} (dBA)	T/T_{max}
.354	1464	4392	4041	.0	4.0	104.37	92.84	92.84	.8923*
.392	2659	6208	4958	.4	5.8	101.51	90.29	92.24	1.0000*
.431	3862	8096	5098	.8	7.6	96.44	85.52	91.63	1.0000*
.471	5073	10044	5158	1.2	9.6	91.83	81.17	90.96	1.0000*
.512	6292	12051	5140	1.5	11.9	89.42	78.74	90.22	1.0000*
.555	7519	14118	5013	2.0	14.4	87.01	76.31	89.38	1.0000*
.598	8756	16244	6303	2.3	16.9	97.83	87.22	88.55	1.0000
.644	10000	18429	6438	2.7	19.3	95.18	84.58	87.75	1.0000
.664	11523	20306	6240	3.0	21.4	93.05	82.33	87.03	1.0000
.686	13039	22182	6026	3.3	23.7	90.96	80.12	86.27	1.0000
.709	14546	24059	5794	3.6	26.2	88.90	77.95	85.45	1.0000
.733	16044	25935	5556	3.9	28.8	86.97	75.90	84.59	1.0000
.757	17531	27812	5300	4.3	31.6	85.10	73.92	83.66	1.0000
.781	19007	29689	5023	4.6	34.5	83.27	71.98	82.67	1.0000
.808	20470	31565	4722	5.0	37.8	81.49	70.09	81.58	1.0000
.834	21917	33442	4572	5.4	41.3	80.63	69.34	80.42	1.0000
.862	23350	35319	4394	5.8	45.0	79.81	68.60	79.19	1.0000

Range = 4991.8 nm
Climb Time = 49.2 min

Economic Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_A (dBA)	L_{Alimit} (dBA)	T/T_{max}
.354	1464	4392	5629	.0	4.0	104.37	92.84	92.84	.8923*
.392	2659	6208	6832	.3	5.3	101.51	90.29	92.41	1.0000*
.431	3862	8096	7048	.6	6.6	96.44	85.52	91.97	1.0000*
.471	5073	10044	7092	.8	8.1	91.83	81.17	91.49	1.0000*
.512	6292	12051	6998	1.1	9.7	89.42	78.74	90.94	1.0000*
.555	7519	14118	8180	1.4	11.4	100.51	89.91	90.39	1.0000
.598	8756	16244	8379	1.6	13.1	97.83	87.22	89.82	1.0000
.644	10000	18429	8495	1.9	14.9	95.18	84.58	89.22	1.0000
.664	11523	20306	8256	2.1	16.5	93.05	82.33	88.68	1.0000
.686	13039	22182	7995	2.4	18.2	90.96	80.12	88.10	1.0000
.709	14546	24059	7712	2.6	20.0	88.90	77.95	87.49	1.0000
.733	16044	25935	7421	2.8	22.0	86.97	75.90	86.85	1.0000
.757	17531	27812	7108	3.1	24.1	85.10	73.92	86.16	1.0000
.781	19007	29689	6769	3.4	26.3	83.27	71.98	85.42	1.0000
.808	20470	31565	6400	3.7	28.7	81.49	70.09	84.62	1.0000
.834	21917	33442	6220	4.0	31.2	80.63	69.34	83.76	1.0000
.862	23350	35319	6006	4.3	34.0	79.81	68.60	82.86	1.0000

Block Fuel = 204216 lb ("*" denotes ejector in operation)
Climb Time = 28.9 min

Table 10: Stage 3 Aircraft Maximum Plus 20 dBA, Lofted Trajectory, SGLJET Model, Mean Atmospheric Absorption

Design Mission:

M	*h (ft)*	h_e *(ft)*	dh_e/dt *(ft/min)*	*t (min)*	*x (nm)*	L_P *(PNdB)*	L_A *(dBA)*	L_{Alimit} *(dBA)*	T/T_{max}
.354	1464	4392	4757	.0	4.0	106.75	95.21	na	1.0000*
.392	2659	6208	4958	.4	5.7	101.51	90.29	na	1.0000*
.431	3862	8096	5098	.8	7.5	96.44	85.52	na	1.0000*
.471	5073	10044	5158	1.1	9.5	91.83	81.17	na	1.0000*
.512	6292	12051	6064	1.5	11.6	103.58	92.93	na	1.0000
.555	7519	14118	6101	1.8	13.6	100.51	89.91	na	1.0000
.598	8756	16244	6299	2.2	15.9	97.83	87.22	na	1.0000
.644	10000	18429	6434	2.5	18.3	95.18	84.58	na	1.0000
.664	11523	20306	6237	2.8	20.5	93.05	82.33	na	1.0000
.686	13039	22182	6022	3.1	22.8	90.96	80.12	na	1.0000
.709	14546	24059	5791	3.4	25.2	88.90	77.95	na	1.0000
.733	16044	25935	5552	3.8	27.8	86.97	75.90	na	1.0000
.757	17531	27812	5297	4.1	30.6	85.10	73.92	na	1.0000
.781	19007	29689	5019	4.5	33.6	83.27	71.98	na	1.0000
.808	20470	31565	4719	4.9	36.9	81.49	70.09	na	1.0000
.834	21917	33442	4569	5.3	40.3	80.63	69.34	na	1.0000
.862	23350	35319	4391	5.7	44.0	79.81	68.60	na	1.0000

Range = 4995.2 nm
Climb Time = 49.1 min

Economic Mission:

M	*h (ft)*	h_e *(ft)*	dh_e/dt *(ft/min)*	*t (min)*	*x (nm)*	L_P *(PNdB)*	L_A *(dBA)*	L_{Alimit} *(dBA)*	T/T_{max}
.354	1464	4392	6528	.0	4.0	106.75	95.21	na	1.0000*
.392	2659	6208	6834	.3	5.2	101.51	90.29	na	1.0000*
.431	3862	8096	7049	.5	6.5	96.44	85.52	na	1.0000*
.471	5073	10044	7093	.8	8.0	91.83	81.17	na	1.0000*
.512	6292	12051	8189	1.1	9.5	103.58	92.93	na	1.0000
.555	7519	14118	8180	1.3	11.0	100.51	89.91	na	1.0000
.598	8756	16244	8379	1.6	12.7	97.83	87.22	na	1.0000
.644	10000	18429	8495	1.9	14.5	95.18	84.58	na	1.0000
.664	11523	20306	8255	2.1	16.2	93.05	82.33	na	1.0000
.686	13039	22182	7995	2.3	17.9	90.96	80.12	na	1.0000
.709	14546	24059	7712	2.5	19.7	88.90	77.95	na	1.0000
.733	16044	25935	7421	2.8	21.7	86.97	75.90	na	1.0000
.757	17531	27812	7108	3.0	23.7	85.10	73.92	na	1.0000
.781	19007	29689	6768	3.3	25.9	83.27	71.98	na	1.0000
.808	20470	31565	6400	3.6	28.3	81.49	70.09	na	1.0000
.834	21917	33442	6220	3.9	30.9	80.63	69.34	na	1.0000
.862	23350	35319	6005	4.2	33.6	79.81	68.60	na	1.0000

Block Fuel = 204134 lb ("*" denotes ejector in operation)
Climb Time = 28.8 min

Table 11: Unlimited Noise, Lofted Trajectory, SGLJET Model, Mean Atmospheric Absorption

Design Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	4200	.0	4.0	104.92	101.00	101.00	.9162*
.392	2659	6208	4343	.4	5.9	99.71	97.40	97.40	.9120*
.431	3862	8096	4371	.9	8.0	94.44	93.59	93.59	.8996*
.471	5073	10044	4201	1.3	10.4	89.27	89.58	89.58	.8708*
.512	6292	12051	4001	1.8	13.2	86.48	86.77	86.77	.8483*
.555	7519	14118	3841	2.3	16.5	84.09	84.40	84.40	.8446*
.598	8756	16244	3815	2.9	20.2	82.42	82.90	82.90	.8416*
.644	10000	18429	3288	3.5	24.5	79.78	80.30	80.30	.7757*
.644	12069	20306	3396	4.1	28.6	77.93	79.29	79.29	.8401*
.644	14160	22182	3121	4.6	32.7	75.27	77.39	77.39	.8632*
.644	16273	24059	2826	5.3	37.2	72.69	75.57	75.57	.8907*
.665	17845	25935	2629	6.0	42.1	71.02	74.15	74.15	.8963*
.682	19571	27812	2324	6.7	47.7	68.98	72.46	72.46	.8991*
.722	20702	29689	2075	7.6	54.1	67.83	71.17	71.17	.8682*
.733	22598	31565	1629	8.6	62.0	66.28	70.00	70.00	.8434*

Range = 4949.0 nm
Climb Time = 54.2 min

Economic Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	5802	.0	4.0	104.92	101.00	101.00	.9162*
.392	2659	6208	6410	.3	5.3	100.60	98.43	98.43	.9550*
.431	3862	8096	7017	.6	6.7	96.44	95.98	95.98	1.0000*
.471	5073	10044	7063	.9	8.1	91.83	92.63	93.35	1.0000*
.512	6292	12051	6970	1.1	9.8	89.42	90.23	90.41	1.0000*
.555	7519	14118	6756	1.4	11.6	87.01	87.84	88.37	1.0000*
.598	8756	16244	6748	1.8	13.7	85.26	86.22	86.30	1.0000*
.644	10000	18429	6644	2.1	16.0	83.49	84.60	84.60	.9886*
.645	12025	20306	6218	2.4	18.1	80.75	82.53	83.76	1.0000*
.658	13801	22182	5814	2.7	20.3	78.43	80.62	82.79	1.0000*
.692	15002	24059	5702	3.0	22.8	77.39	79.56	81.34	1.0000*
.713	16567	25935	5368	3.3	25.4	75.58	77.98	79.93	1.0000*
.716	18644	27812	4759	3.7	28.2	72.72	75.71	79.35	1.0000*
.734	20368	29689	4317	4.1	31.5	70.70	74.06	78.13	1.0000*
.739	22420	31565	3858	4.6	35.0	69.13	73.00	75.99	1.0000*
.748	24414	33442	3411	5.1	39.1	67.79	72.12	75.18	1.0000*
.761	26292	35319	3007	5.7	43.7	66.66	71.37	73.51	1.0000*
.788	27829	37195	2722	6.3	49.0	66.06	70.96	72.20	1.0000*
.815	29342	39072	2422	7.1	55.0	65.50	70.57	71.00	1.0000*

Block Fuel = 206058 lb ("*" denotes ejector in operation)
Climb Time = 31.2 min

Table 12: 747-400 L_S Plus 5 dBA, Lofted Trajectory, SGLJET Model, and Mean Atmospheric Absorption

Design Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	4757	.0	4.0	106.75	103.08	106.00	1.0000*
.392	2659	6208	4958	.4	5.7	101.51	99.51	102.81	1.0000*
.431	3862	8096	5098	.8	7.5	96.44	95.98	99.52	1.0000*
.471	5073	10044	5158	1.1	9.5	91.83	92.63	95.90	1.0000*
.512	6292	12051	5140	1.5	11.7	89.42	90.23	93.26	1.0000*
.555	7519	14118	5013	1.9	14.3	87.01	87.84	90.75	1.0000*
.598	8756	16244	5047	2.3	17.0	85.26	86.22	89.18	1.0000*
.644	10000	18429	5099	2.8	20.1	83.67	84.82	87.95	1.0000*
.664	11523	20306	4888	3.2	22.8	81.87	83.26	86.30	1.0000*
.664	13617	22182	4362	3.6	25.8	78.84	80.89	84.84	1.0000*
.684	15210	24059	4092	4.0	29.1	76.95	79.26	84.17	1.0000*
.714	16532	25935	3932	4.5	32.7	75.66	78.03	82.37	1.0000*
.751	17664	27812	3786	5.0	36.6	74.83	77.21	80.69	1.0000*
.780	19039	29689	3555	5.5	40.8	73.54	76.09	79.69	1.0000*
.808	20470	31565	3321	6.0	45.4	72.21	74.97	77.92	1.0000*
.834	21917	33442	3112	6.6	50.4	71.61	74.55	76.92	1.0000*
.862	23350	35319	2893	7.2	55.9	71.09	74.19	75.81	1.0000*

Range = 4966.6 nm
Climb Time = 50.1 min

Economic Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	6503	.0	4.0	106.75	103.08	106.00	1.0000*
.392	2659	6208	6808	.3	5.2	101.51	99.51	103.63	1.0000*
.431	3862	8096	7023	.6	6.5	96.44	95.98	101.25	1.0000*
.471	5073	10044	7068	.8	8.0	91.83	92.63	98.63	1.0000*
.512	6292	12051	6974	1.1	9.6	89.42	90.23	95.68	1.0000*
.555	7519	14118	6761	1.4	11.5	87.01	87.84	93.53	1.0000*
.598	8756	16244	6753	1.7	13.5	85.26	86.22	91.45	1.0000*
.644	10000	18429	6764	2.0	15.8	83.67	84.82	89.67	1.0000*
.664	11523	20306	6507	2.3	17.9	81.87	83.26	88.84	1.0000*
.665	13607	22182	5926	2.6	20.1	78.86	80.90	87.94	1.0000*
.709	14546	24059	5939	3.0	22.5	78.38	80.20	86.50	1.0000*
.709	16683	25935	5316	3.3	25.1	75.34	77.82	84.99	1.0000*
.727	18344	27812	4904	3.7	27.9	73.38	76.18	84.42	1.0000*
.761	19590	29689	4671	4.0	31.1	72.38	75.27	83.37	1.0000*
.808	20470	31565	4594	4.4	34.4	72.21	74.97	81.34	1.0000*
.834	21917	33442	4342	4.9	38.1	71.61	74.55	80.39	1.0000*
.862	23350	35319	4075	5.3	42.0	71.09	74.19	79.20	1.0000*

Block Fuel = 205746 lb ("*" denotes ejector in operation)
Climb Time = 29.9 min

Table 13: 747-400 L_S Plus 10 dBA, Lofted Trajectory, SGLJET Model, and Mean Atmospheric Absorption

Design Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	4757	.0	4.0	106.75	103.08	111.00	1.0000*
.392	2659	6208	4958	.4	5.7	101.51	99.51	107.81	1.0000*
.431	3862	8096	5098	.8	7.5	96.44	95.98	104.52	1.0000*
.471	5073	10044	5158	1.1	9.5	91.83	92.63	100.90	1.0000*
.512	6292	12051	5140	1.5	11.7	89.42	90.23	98.26	1.0000*
.555	7519	14118	5013	1.9	14.3	87.01	87.84	95.75	1.0000*
.598	8756	16244	5047	2.3	17.0	85.26	86.22	94.18	1.0000*
.644	10000	18429	5099	2.8	20.1	83.67	84.82	92.95	1.0000*
.658	11710	20306	4786	3.2	22.8	81.45	82.99	91.29	1.0000*
.682	13144	22182	4607	3.6	25.8	79.87	81.57	89.84	1.0000*
.707	14599	24059	4395	4.0	29.0	78.26	80.13	89.20	1.0000*
.733	16044	25935	4128	4.4	32.5	76.70	78.76	87.51	1.0000*
.757	17531	27812	3837	4.9	36.3	75.10	77.41	85.75	1.0000*
.781	19007	29689	3567	5.4	40.5	73.61	76.14	84.82	1.0000*
.808	20470	31565	3320	5.9	45.1	72.21	74.97	82.99	1.0000*
.834	21917	33442	3505	6.5	49.8	77.99	82.04	82.04	.8675

Range = 4969.6 nm
Climb Time = 50.0 min

Economic Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	6520	.0	4.0	106.75	103.08	111.00	1.0000*
.392	2659	6208	6825	.3	5.2	101.51	99.51	108.64	1.0000*
.431	3862	8096	7040	.5	6.5	96.44	95.98	106.27	1.0000*
.471	5073	10044	7085	.8	8.0	91.83	92.63	103.64	1.0000*
.512	6292	12051	6991	1.1	9.6	89.42	90.23	100.71	1.0000*
.555	7519	14118	6777	1.4	11.5	87.01	87.84	98.55	1.0000*
.598	8756	16244	6768	1.7	13.5	85.26	86.22	96.48	1.0000*
.644	10000	18429	6779	2.0	15.8	83.67	84.82	94.68	1.0000*
.664	11523	20306	6522	2.3	17.9	81.87	83.26	93.86	1.0000*
.686	13039	22182	7619	2.6	19.8	90.26	93.06	93.06	.9672
.709	14546	24059	7713	2.8	21.7	88.90	91.82	91.97	1.0000
.733	16044	25935	7422	3.1	23.7	86.97	90.07	90.81	1.0000
.757	17531	27812	7110	3.3	25.7	85.10	88.38	89.85	1.0000
.781	19007	29689	6770	3.6	27.9	83.27	86.72	89.41	1.0000
.808	20470	31565	6401	3.9	30.3	81.49	85.10	88.79	1.0000
.834	21917	33442	6221	4.2	32.9	80.63	84.43	87.26	1.0000
.862	23350	35319	6007	4.5	35.6	79.81	83.78	85.88	1.0000

Block Fuel = 204664 lb ("*" denotes ejector in operation)
Climb Time = 29.1 min

Table 14: 747-400 L_S Plus 15 dBA, Lofted Trajectory, SGLJET Model, and Mean Atmospheric Absorption

Design Mission:

M	*h (ft)*	h_e *(ft)*	dh_e/dt *(ft/min)*	*t (min)*	*x (nm)*	L_P *(PNdB)*	L_S *(dBA)*	L_{Slimit} *(dBA)*	T/T_{max}
.354	1464	4392	4757	.0	4.0	106.75	103.08	116.00	1.0000*
.392	2659	6208	4958	.4	5.7	101.51	99.51	112.81	1.0000*
.431	3862	8096	5098	.8	7.5	96.44	95.98	109.52	1.0000*
.471	5073	10044	5158	1.1	9.5	91.83	92.63	105.90	1.0000*
.512	6292	12051	5140	1.5	11.7	89.42	90.23	103.26	1.0000*
.555	7519	14118	5013	1.9	14.3	87.01	87.84	100.75	1.0000*
.598	8756	16244	5047	2.3	17.0	85.26	86.22	99.18	1.0000*
.644	10000	18429	6440	2.7	19.7	95.18	97.49	98.11	1.0000
.664	11523	20306	6242	3.0	21.9	93.05	95.57	96.87	1.0000
.686	13039	22182	6028	3.3	24.2	90.96	93.68	95.49	1.0000
.709	14546	24059	5796	3.7	26.6	88.90	91.82	94.68	1.0000
.733	16044	25935	5558	4.0	29.2	86.97	90.07	94.16	1.0000
.757	17531	27812	5302	4.3	32.0	85.10	88.38	92.81	1.0000
.781	19007	29689	5024	4.7	35.0	83.27	86.72	91.01	1.0000
.808	20471	31565	4723	5.1	38.2	81.48	85.10	90.35	1.0000
.834	21917	33442	4574	5.5	41.7	80.63	84.43	89.31	1.0000
.862	23350	35319	4395	5.9	45.4	79.81	83.78	87.92	1.0000

Range = 4989.8 nm
Climb Time = 49.2 min

Economic Mission:

M	*h (ft)*	h_e *(ft)*	dh_e/dt *(ft/min)*	*t (min)*	*x (nm)*	L_P *(PNdB)*	L_S *(dBA)*	L_{Slimit} *(dBA)*	T/T_{max}
.354	1464	4392	6528	.0	4.0	106.75	103.08	116.00	1.0000*
.392	2659	6208	6834	.3	5.2	101.51	99.51	113.64	1.0000*
.431	3862	8096	7049	.5	6.5	96.44	95.98	111.27	1.0000*
.471	5073	10044	7093	.8	8.0	91.83	92.63	108.65	1.0000*
.512	6292	12051	8189	1.1	9.5	103.58	104.30	105.95	1.0000
.555	7519	14118	8180	1.3	11.0	100.51	101.78	103.98	1.0000
.598	8756	16244	8379	1.6	12.7	97.83	99.62	102.29	1.0000
.644	10000	18429	8495	1.9	14.5	95.18	97.49	100.47	1.0000
.664	11523	20306	8255	2.1	16.2	93.05	95.57	99.54	1.0000
.686	13039	22182	7995	2.3	17.9	90.96	93.68	98.85	1.0000
.709	14546	24059	7712	2.5	19.7	88.90	91.82	98.12	1.0000
.733	16044	25935	7421	2.8	21.7	86.97	90.07	97.01	1.0000
.757	17531	27812	7108	3.0	23.7	85.10	88.38	95.77	1.0000
.781	19007	29689	6768	3.3	25.9	83.27	86.72	94.81	1.0000
.804	20552	31565	6344	3.6	28.3	81.36	85.00	94.33	1.0000
.834	21917	33442	6220	3.9	30.9	80.63	84.43	93.45	1.0000
.862	23350	35319	6005	4.2	33.6	79.81	83.78	91.82	1.0000

Block Fuel = 204134 lb ("*" denotes ejector in operation)
Climb Time = 28.8 min

Table 15: 747-400 L_S Plus 20 dBA, Lofted Trajectory, SGLJET Model, and Mean Atmospheric Absorption

Design Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	4757	.0	4.0	106.75	103.08	na	1.0000*
.392	2659	6208	4958	.4	5.7	101.51	99.51	na	1.0000*
.431	3862	8096	5098	.8	7.5	96.44	95.98	na	1.0000*
.471	5073	10044	5158	1.1	9.5	91.83	92.63	na	1.0000*
.512	6292	12051	6064	1.5	11.6	103.58	104.30	na	1.0000
.555	7519	14118	6101	1.8	13.6	100.51	101.78	na	1.0000
.598	8756	16244	6299	2.2	15.9	97.83	99.62	na	1.0000
.644	10000	18429	6434	2.5	18.3	95.18	97.49	na	1.0000
.664	11523	20306	6237	2.8	20.5	93.05	95.57	na	1.0000
.686	13039	22182	6022	3.1	22.8	90.96	93.68	na	1.0000
.709	14546	24059	5791	3.4	25.2	88.90	91.82	na	1.0000
.733	16044	25935	5552	3.8	27.8	86.97	90.07	na	1.0000
.757	17531	27812	5297	4.1	30.6	85.10	88.38	na	1.0000
.781	19007	29689	5019	4.5	33.6	83.27	86.72	na	1.0000
.808	20470	31565	4719	4.9	36.9	81.49	85.10	na	1.0000
.834	21917	33442	4569	5.3	40.3	80.63	84.43	na	1.0000
.862	23350	35319	4391	5.7	44.0	79.81	83.78	na	1.0000

Range = 4995.2 nm
Climb Time = 49.1 min

Economic Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	6528	.0	4.0	106.75	103.08	na	1.0000*
.392	2659	6208	6834	.3	5.2	101.51	99.51	na	1.0000*
.431	3862	8096	7049	.5	6.5	96.44	95.98	na	1.0000*
.471	5073	10044	7093	.8	8.0	91.83	92.63	na	1.0000*
.512	6292	12051	8189	1.1	9.5	103.58	104.30	na	1.0000
.555	7519	14118	8180	1.3	11.0	100.51	101.78	na	1.0000
.598	8756	16244	8379	1.6	12.7	97.83	99.62	na	1.0000
.644	10000	18429	8495	1.9	14.5	95.18	97.49	na	1.0000
.664	11523	20306	8255	2.1	16.2	93.05	95.57	na	1.0000
.686	13039	22182	7995	2.3	17.9	90.96	93.68	na	1.0000
.709	14546	24059	7712	2.5	19.7	88.90	91.82	na	1.0000
.733	16044	25935	7421	2.8	21.7	86.97	90.07	na	1.0000
.757	17531	27812	7108	3.0	23.7	85.10	88.38	na	1.0000
.781	19007	29689	6768	3.3	25.9	83.27	86.72	na	1.0000
.808	20470	31565	6400	3.6	28.3	81.49	85.10	na	1.0000
.834	21917	33442	6220	3.9	30.9	80.63	84.43	na	1.0000
.862	23350	35319	6005	4.2	33.6	79.81	83.78	na	1.0000

Block Fuel = 204134 lb ("*" denotes ejector in operation)
Climb Time = 28.8 min

Table 16: Unlimited Noise, Lofted Trajectory, SGLJET Model, Mean Atmospheric Absorption

Design Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	2000	.0	4.0	96.70	91.92	na	.5854*
.392	2659	6208	2000	.9	8.1	91.96	88.58	na	.5760*
.431	3862	8096	2000	1.9	12.7	87.30	85.33	na	.5716*
.471	5073	10044	2000	2.8	17.9	82.90	82.27	na	.5727*
.512	6292	12051	2000	3.8	23.6	80.80	80.38	na	.5805*
.555	7519	14118	2000	4.9	30.0	78.96	78.75	na	.5992*
.598	8756	16244	2000	5.9	37.1	77.60	77.68	na	.6069*
.644	10000	18429	2000	7.0	44.8	76.43	76.78	na	.6143*
.644	12069	20306	2000	8.0	51.6	74.12	75.25	na	.6512*
.644	14160	22182	2000	8.9	58.3	72.01	73.93	na	.6976*
.644	16273	24059	2000	9.8	65.0	70.14	72.84	na	.7558*
.644	18407	25935	2000	10.8	71.6	68.51	71.99	na	.8298*
.644	20562	27812	2000	11.7	78.2	67.20	71.50	na	.9249*
.680	21816	29689	2000	12.6	84.9	67.09	71.30	na	.9286*
.693	23683	31565	2000	13.6	91.8	67.04	71.71	na	.9924*
.730	24877	33442	2000	14.5	98.9	67.05	71.64	na	.9992*
.774	25921	35319	2000	15.5	106.3	67.23	71.73	na	.9996*
.822	26831	37195	2000	16.4	114.1	67.57	71.91	na	.9999*

Range = 4919.7 nm
Climb Time = 57.4 min

Economic Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	2000	.0	4.0	92.90	87.73	na	.4626*
.392	2659	6208	2000	.9	8.1	88.14	84.42	na	.4531*
.431	3862	8096	2000	1.9	12.7	83.50	81.25	na	.4486*
.471	5073	10044	2000	2.8	17.9	79.39	78.55	na	.4556*
.512	6292	12051	2000	3.8	23.6	77.75	77.16	na	.4722*
.555	7519	14118	2000	4.9	30.0	76.34	75.99	na	.4971*
.598	8756	16244	2000	5.9	37.1	75.37	75.34	na	.5129*
.644	10000	18429	2000	7.0	44.8	74.54	74.80	na	.5292*
.644	12069	20306	2000	8.0	51.6	71.97	73.04	na	.5520*
.644	14160	22182	2000	8.9	58.3	69.56	71.42	na	.5823*
.644	16273	24059	2000	9.8	65.0	67.28	69.92	na	.6207*
.644	18407	25935	2000	10.8	71.6	65.25	68.66	na	.6703*
.644	20562	27812	2000	11.7	78.2	63.55	67.71	na	.7350*
.644	22735	29689	2000	12.6	84.8	63.14	67.92	na	.7980*
.653	24675	31565	2000	13.6	91.3	63.05	68.25	na	.8572*
.664	26626	33442	2000	14.5	97.9	63.14	68.82	na	.9286*
.707	27756	35319	2000	15.5	104.6	63.27	68.74	na	.9320*
.726	29502	37195	2000	16.4	111.6	63.47	69.32	na	1.0000*
.777	30416	39072	2000	17.3	118.9	63.88	69.54	na	.9999*
.833	31162	40948	2000	18.3	126.6	64.49	69.89	na	.9999*

Block Fuel = 210280 lb ("*" denotes ejector in operation)
Climb Time = 41.8 min

Table 17: Maximum Subsonic dh_e/dt = 2000 ft/min, Lofted Trajectory, SGLJET Model, Mean Atmospheric Absorption

Design Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	3000	.0	4.0	100.55	96.24	na	.7358*
.392	2659	6208	3000	.6	6.7	95.37	92.47	na	.7195*
.431	3862	8096	3000	1.2	9.8	90.39	88.90	na	.7101*
.471	5073	10044	3000	1.9	13.2	85.87	85.65	na	.7083*
.512	6292	12051	3000	2.5	17.1	83.70	83.62	na	.7145*
.555	7519	14118	3000	3.2	21.3	81.80	81.85	na	.7326*
.598	8756	16244	3000	4.0	26.0	80.32	80.59	na	.7363*
.644	10000	18429	3000	4.7	31.2	79.04	79.52	na	.7393*
.644	12069	20306	3000	5.3	35.7	76.92	78.18	na	.7863*
.644	14160	22182	3000	5.9	40.2	74.93	77.02	na	.8446*
.644	16273	24059	3000	6.6	44.6	73.16	76.08	na	.9168*
.646	18333	25935	3000	7.2	49.1	71.76	75.49	na	.9999*
.687	19419	27812	3000	7.8	53.6	71.07	74.62	na	1.0000*
.733	20393	29689	3000	8.4	58.4	70.64	74.02	na	1.0000*
.775	21405	31565	3000	9.1	63.4	70.72	74.01	na	.9999*
.821	22287	33442	3000	9.7	68.7	71.06	74.20	na	.9999*
.862	23350	35319	2909	10.3	74.3	71.09	74.19	na	1.0000*

Range = 4954.5 nm
Climb Time = 52.7 min

Economic Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	3000	.0	4.0	96.58	91.79	na	.5808*
.392	2659	6208	3000	.6	6.7	91.67	88.26	na	.5657*
.431	3862	8096	3000	1.2	9.8	86.87	84.86	na	.5573*
.471	5073	10044	3000	1.9	13.2	82.60	81.95	na	.5622*
.512	6292	12051	3000	2.5	17.1	80.74	80.31	na	.5776*
.555	7519	14118	3000	3.2	21.3	79.02	78.82	na	.6022*
.598	8756	16244	3000	4.0	26.0	77.77	77.86	na	.6150*
.644	10000	18429	3000	4.7	31.2	76.71	77.07	na	.6276*
.644	12069	20306	3000	5.3	35.7	74.27	75.41	na	.6584*
.644	14160	22182	3000	5.9	40.2	72.02	73.94	na	.6979*
.644	16273	24059	3000	6.6	44.6	69.96	72.65	na	.7471*
.644	18407	25935	3000	7.2	49.0	68.13	71.59	na	.8095*
.644	20562	27812	3000	7.8	53.4	66.55	70.80	na	.8896*
.651	22552	29689	3000	8.4	57.8	66.34	71.13	na	.9518*
.669	24267	31565	3000	9.1	62.2	66.27	71.37	na	.9995*
.713	25360	33442	3000	9.7	66.8	66.30	71.18	na	1.0000*
.760	26337	35319	3000	10.3	71.7	66.58	71.32	na	.9995*
.811	27163	37195	3000	10.9	76.8	67.07	71.60	na	1.0000*

Block Fuel = 207520 lb ("*" denotes ejector in operation)
Climb Time = 35.2 min

Table 18: Maximum Subsonic dh_e/dt = 3000 ft/min, Lofted Trajectory, SGLJET Model, Mean Atmospheric Absorption

Design Mission:

M	*h (ft)*	h_e *(ft)*	dh_e/dt *(ft/min)*	*t (min)*	*x (nm)*	L_P *(PNdB)*	L_S *(dBA)*	L_{Slimit} *(dBA)*	T/T_{max}
.354	1464	4392	4000	.0	4.0	104.22	100.24	na	.8862*
.392	2659	6208	4000	.4	6.0	98.66	96.20	na	.8628*
.431	3862	8096	4000	.9	8.3	93.39	92.37	na	.8484*
.471	5073	10044	4000	1.4	10.9	88.73	88.95	na	.8436*
.512	6292	12051	4000	1.9	13.8	86.47	86.77	na	.8481*
.555	7519	14118	4000	2.4	17.0	84.50	84.87	na	.8656*
.598	8756	16244	4000	3.0	20.5	82.87	83.41	na	.8653*
.644	10000	18429	4000	3.5	24.4	81.43	82.14	na	.8637*
.644	12069	20306	4000	4.0	27.7	79.34	80.90	na	.9207*
.644	14138	22182	4000	4.4	31.1	77.50	79.92	na	.9889*
.678	15394	24059	4000	4.9	34.5	76.55	79.00	na	1.0000*
.721	16374	25935	4000	5.4	38.1	76.00	78.26	na	.9999*
.757	17531	27812	3842	5.9	41.9	75.10	77.41	na	1.0000*
.781	19007	29689	4000	6.3	45.9	80.68	84.44	na	.8770
.807	20486	31565	4000	6.8	49.9	79.71	83.53	na	.9112
.834	21925	33442	4000	7.3	53.9	79.26	83.23	na	.9281
.862	23350	35319	4000	7.8	58.0	78.87	82.95	na	.9489

Range = 4975.6 nm
Climb Time = 50.6 min

Economic Mission:

M	*h (ft)*	h_e *(ft)*	dh_e/dt *(ft/min)*	*t (min)*	*x (nm)*	L_P *(PNdB)*	L_S *(dBA)*	L_{Slimit} *(dBA)*	T/T_{max}
.354	1464	4392	4000	.0	4.0	99.63	95.22	na	.6998*
.392	2659	6208	4000	.4	6.0	94.42	91.38	na	.6791*
.431	3862	8096	4000	.9	8.3	89.43	87.78	na	.6668*
.471	5073	10044	4000	1.4	10.9	85.02	84.68	na	.6693*
.512	6292	12051	4000	1.9	13.8	83.03	82.87	na	.6835*
.555	7519	14118	4000	2.4	17.0	81.27	81.27	na	.7076*
.598	8756	16244	4000	3.0	20.5	79.92	80.17	na	.7173*
.644	10000	18429	4000	3.5	24.4	78.78	79.24	na	.7263*
.644	12069	20306	4000	4.0	27.7	76.49	77.72	na	.7650*
.644	14160	22182	4000	4.4	31.1	74.36	76.39	na	.8137*
.644	16273	24059	4000	4.9	34.4	72.39	75.23	na	.8736*
.644	18407	25935	4000	5.4	37.7	70.68	74.35	na	.9487*
.663	20076	27812	4000	5.9	41.1	69.64	73.70	na	.9999*
.707	21095	29689	4000	6.3	44.5	69.44	73.25	na	1.0000*
.751	22079	31565	4000	6.8	48.2	69.65	73.32	na	.9990*
.799	22964	33442	4000	7.3	52.0	70.03	73.54	na	.9999*
.852	23635	35319	3993	7.7	56.1	70.68	73.93	na	1.0000*

Block Fuel = 206315 lb ("*" denotes ejector in operation)
Climb Time = 32.3 min

Table 19: Maximum Subsonic dh_e/dt = 4000 ft/min, Lofted Trajectory, SGLJET Model, Mean Atmospheric Absorption

Design Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	4757	.0	4.0	106.75	103.08	na	1.0000*
.392	2659	6208	4958	.4	5.7	101.51	99.51	na	1.0000*
.431	3862	8096	5000	.8	7.5	96.17	95.66	na	.9865*
.471	5073	10044	5000	1.1	9.6	91.41	92.12	na	.9787*
.512	6292	12051	5000	1.5	11.9	89.06	89.81	na	.9814*
.555	7519	14118	5000	2.0	14.4	86.98	87.80	na	.9982*
.598	8756	16244	5000	2.4	17.2	85.15	86.09	na	.9939*
.644	10000	18429	5000	2.8	20.3	83.48	84.58	na	.9877*
.664	11523	20306	4888	3.2	23.1	81.87	83.26	na	1.0000*
.686	13039	22182	4662	3.6	26.0	80.10	81.72	na	1.0000*
.709	14546	24059	5000	4.0	29.0	86.95	90.12	na	.9109
.714	16543	25935	5000	4.4	31.9	85.61	89.00	na	.9732
.740	17987	27812	5000	4.7	34.9	84.35	87.82	na	.9989
.779	19088	29689	4980	5.1	38.0	83.14	86.63	na	1.0000
.808	20470	31565	4730	5.5	41.2	81.49	85.10	na	1.0000
.834	21917	33442	4580	5.9	44.7	80.63	84.43	na	1.0000
.862	23350	35319	4402	6.3	48.4	79.81	83.78	na	1.0000

Range = 4983.7 nm
Climb Time = 49.5 min

Economic Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	5000	.0	4.0	102.69	98.59	na	.8214*
.392	2659	6208	5000	.4	5.6	97.15	94.49	na	.7949*
.431	3862	8096	5000	.7	7.4	91.92	90.66	na	.7786*
.471	5073	10044	5000	1.1	9.5	87.41	87.41	na	.7787*
.512	6292	12051	5000	1.5	11.8	85.35	85.47	na	.7915*
.555	7519	14118	5000	1.9	14.3	83.51	83.74	na	.8152*
.598	8756	16244	5000	2.4	17.1	82.04	82.47	na	.8217*
.644	10000	18429	5000	2.8	20.2	80.76	81.38	na	.8270*
.644	12069	20306	5000	3.2	22.9	78.53	79.97	na	.8737*
.644	14160	22182	5000	3.5	25.6	76.48	78.75	na	.9317*
.647	16179	24059	5000	3.9	28.2	74.74	77.78	na	.9951*
.687	17258	25935	5000	4.3	30.9	74.11	77.01	na	1.0000*
.737	18074	27812	5000	4.7	33.8	73.96	76.59	na	.9998*
.781	19007	29689	4902	5.0	36.9	73.61	76.14	na	1.0000*
.808	20470	31565	5000	5.4	40.1	78.75	82.65	na	.8663
.824	22232	33442	5000	5.8	43.3	78.25	82.41	na	.8942
.862	23350	35319	5000	6.2	46.6	77.97	82.12	na	.9023

Block Fuel = 205547 lb ("*" denotes ejector in operation)
Climb Time = 30.7 min

Table 20: Maximum Subsonic dh_e/dt = 5000 ft/min, Lofted Trajectory, SGLJET Model, Mean Atmospheric Absorption

Design Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	4757	.0	4.0	106.75	103.08	na	1.0000*
.392	2659	6208	4958	.4	5.7	101.51	99.51	na	1.0000*
.431	3862	8096	5098	.8	7.5	96.44	95.98	na	1.0000*
.471	5073	10044	5158	1.1	9.5	91.83	92.63	na	1.0000*
.512	6292	12051	6000	1.5	11.6	103.40	104.13	na	.9924
.555	7519	14118	6000	1.8	13.7	100.23	101.52	na	.9883
.598	8756	16244	6000	2.2	16.0	97.06	98.92	na	.9669
.644	10000	18429	6000	2.5	18.6	94.15	96.56	na	.9539
.664	11523	20306	6000	2.9	20.9	92.49	95.08	na	.9745
.686	13039	22182	6000	3.2	23.2	90.91	93.64	na	.9975
.709	14546	24059	5791	3.5	25.7	88.90	91.82	na	1.0000
.733	16044	25935	5553	3.8	28.3	86.97	90.07	na	1.0000
.757	17531	27812	5297	4.2	31.0	85.10	88.38	na	1.0000
.781	19007	29689	5020	4.5	34.0	83.27	86.72	na	1.0000
.808	20470	31565	4719	4.9	37.3	81.49	85.10	na	1.0000
.834	21917	33442	4569	5.3	40.8	80.63	84.43	na	1.0000
.862	23350	35319	4391	5.7	44.5	79.81	83.78	na	1.0000

Range = 4995.1 nm
Climb Time = 49.1 min

Economic Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	6000	.0	4.0	105.41	101.55	na	.9382*
.392	2659	6208	6000	.3	5.3	99.59	97.26	na	.9062*
.431	3862	8096	6000	.6	6.9	94.16	93.27	na	.8859*
.471	5073	10044	6000	.9	8.6	89.53	89.89	na	.8837*
.512	6292	12051	6000	1.3	10.5	87.39	87.84	na	.8951*
.555	7519	14118	6000	1.6	12.6	85.51	86.04	na	.9183*
.598	8756	16244	6000	2.0	15.0	83.89	84.60	na	.9217*
.644	10000	18429	6000	2.3	17.5	82.44	83.33	na	.9234*
.644	12069	20306	6000	2.7	19.8	80.29	82.03	na	.9778*
.669	13489	22182	6000	3.0	22.1	79.12	81.07	na	1.0000*
.707	14601	24059	5922	3.3	24.4	78.26	80.13	na	1.0000*
.733	16044	25935	5590	3.6	27.0	76.70	78.76	na	1.0000*
.745	17877	27812	6000	3.9	29.6	82.82	86.48	na	.9176
.752	19834	29689	6000	4.2	32.1	81.54	85.38	na	.9789
.782	21205	31565	6000	4.6	34.6	80.71	84.65	na	.9972
.818	22392	33442	6000	4.9	37.3	80.21	84.22	na	1.0000
.862	23350	35319	6000	5.2	40.0	79.79	83.77	na	.9991

Block Fuel = 204999 lb ("*" denotes ejector in operation)
Climb Time = 29.7 min

Table 21: Maximum Subsonic dh_e/dt = 6000 ft/min, Lofted Trajectory, SGLJET Model, Mean Atmospheric Absorption

Design Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	4757	.0	4.0	106.75	103.08	na	1.0000*
.392	2659	6208	4958	.4	5.7	101.51	99.51	na	1.0000*
.431	3862	8096	5098	.8	7.5	96.44	95.98	na	1.0000*
.471	5073	10044	5158	1.1	9.5	91.83	92.63	na	1.0000*
.512	6292	12051	6064	1.5	11.6	103.58	104.30	na	1.0000
.555	7519	14118	6101	1.8	13.6	100.51	101.78	na	1.0000
.598	8756	16244	6299	2.2	15.9	97.83	99.62	na	1.0000
.644	10000	18429	6434	2.5	18.3	95.18	97.49	na	1.0000
.664	11523	20306	6237	2.8	20.5	93.05	95.57	na	1.0000
.686	13039	22182	6022	3.1	22.8	90.96	93.68	na	1.0000
.709	14546	24059	5791	3.4	25.2	88.90	91.82	na	1.0000
.733	16044	25935	5552	3.8	27.8	86.97	90.07	na	1.0000
.757	17531	27812	5297	4.1	30.6	85.10	88.38	na	1.0000
.781	19007	29689	5019	4.5	33.6	83.27	86.72	na	1.0000
.808	20470	31565	4719	4.9	36.9	81.49	85.10	na	1.0000
.834	21917	33442	4569	5.3	40.3	80.63	84.43	na	1.0000
.862	23350	35319	4391	5.7	44.0	79.81	83.78	na	1.0000

Range = 4995.2 nm
Climb Time = 49.1 min

Economic Mission:

M	h (ft)	h_e (ft)	dh_e/dt (ft/min)	t (min)	x (nm)	L_P (PNdB)	L_S (dBA)	L_{Slimit} (dBA)	T/T_{max}
.354	1464	4392	6528	.0	4.0	106.75	103.08	na	1.0000*
.392	2659	6208	6834	.3	5.2	101.51	99.51	na	1.0000*
.431	3862	8096	7049	.5	6.5	96.44	95.98	na	1.0000*
.471	5073	10044	7093	.8	8.0	91.83	92.63	na	1.0000*
.512	6292	12051	8189	1.1	9.5	103.58	104.30	na	1.0000
.555	7519	14118	8180	1.3	11.0	100.51	101.78	na	1.0000
.598	8756	16244	8379	1.6	12.7	97.83	99.62	na	1.0000
.644	10000	18429	8495	1.9	14.5	95.18	97.49	na	1.0000
.664	11523	20306	8255	2.1	16.2	93.05	95.57	na	1.0000
.686	13039	22182	7995	2.3	17.9	90.96	93.68	na	1.0000
.709	14546	24059	7712	2.5	19.7	88.90	91.82	na	1.0000
.733	16044	25935	7421	2.8	21.7	86.97	90.07	na	1.0000
.757	17531	27812	7108	3.0	23.7	85.10	88.38	na	1.0000
.781	19007	29689	6768	3.3	25.9	83.27	86.72	na	1.0000
.808	20470	31565	6400	3.6	28.3	81.49	85.10	na	1.0000
.834	21917	33442	6220	3.9	30.9	80.63	84.43	na	1.0000
.862	23350	35319	6005	4.2	33.6	79.81	83.78	na	1.0000

Block Fuel = 204134 lb ("*" denotes ejector in operation)
Climb Time = 28.8 min

Table 22: Unlimited Subsonic dh_e/dt, Lofted Trajectory, SGLJET Model, Mean Atmospheric Absorption

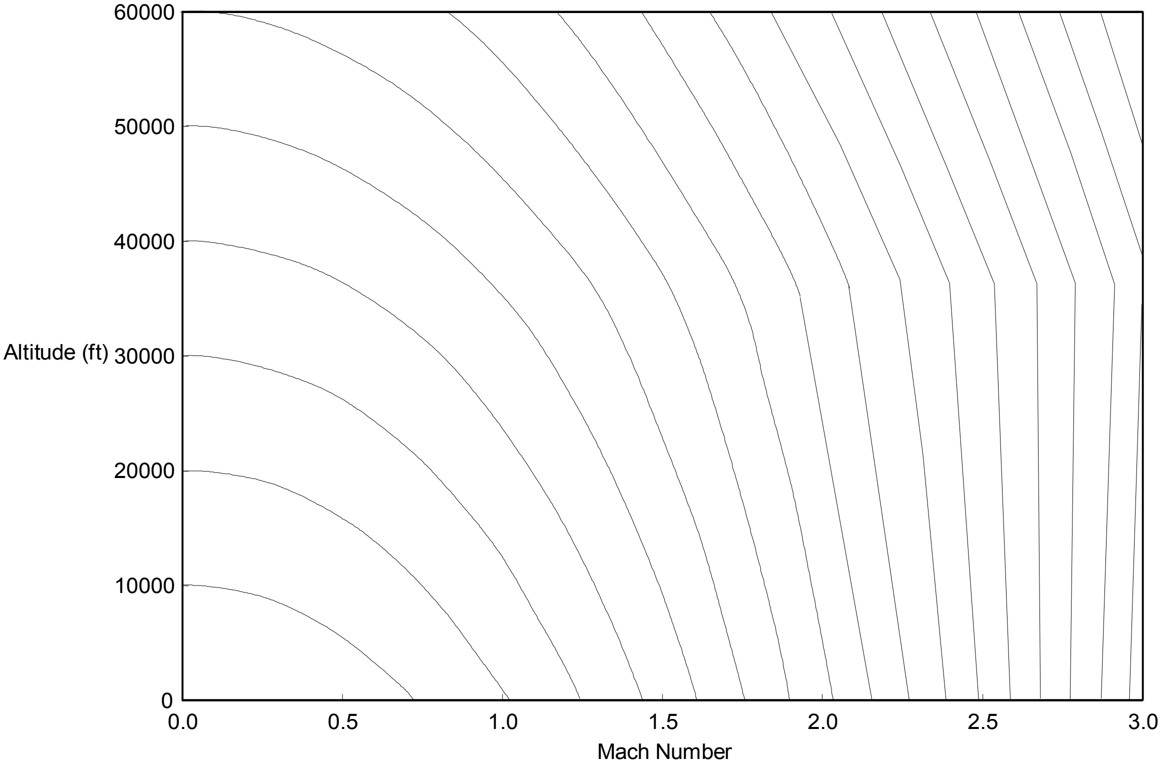

Figure 1: Energy Height Contours

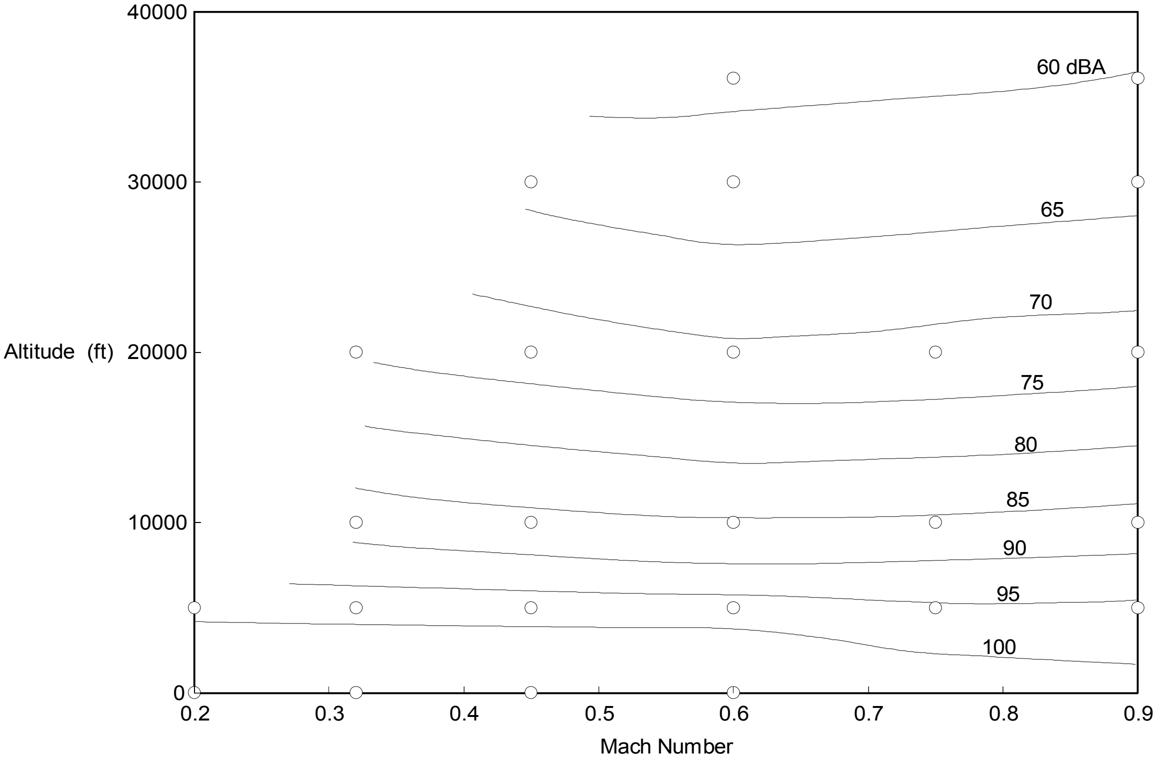

Figure 2: Peak Flyover L_A Levels: Ejector Stowed, Full Power, SGLJET Noise Model, Minimum Absorption

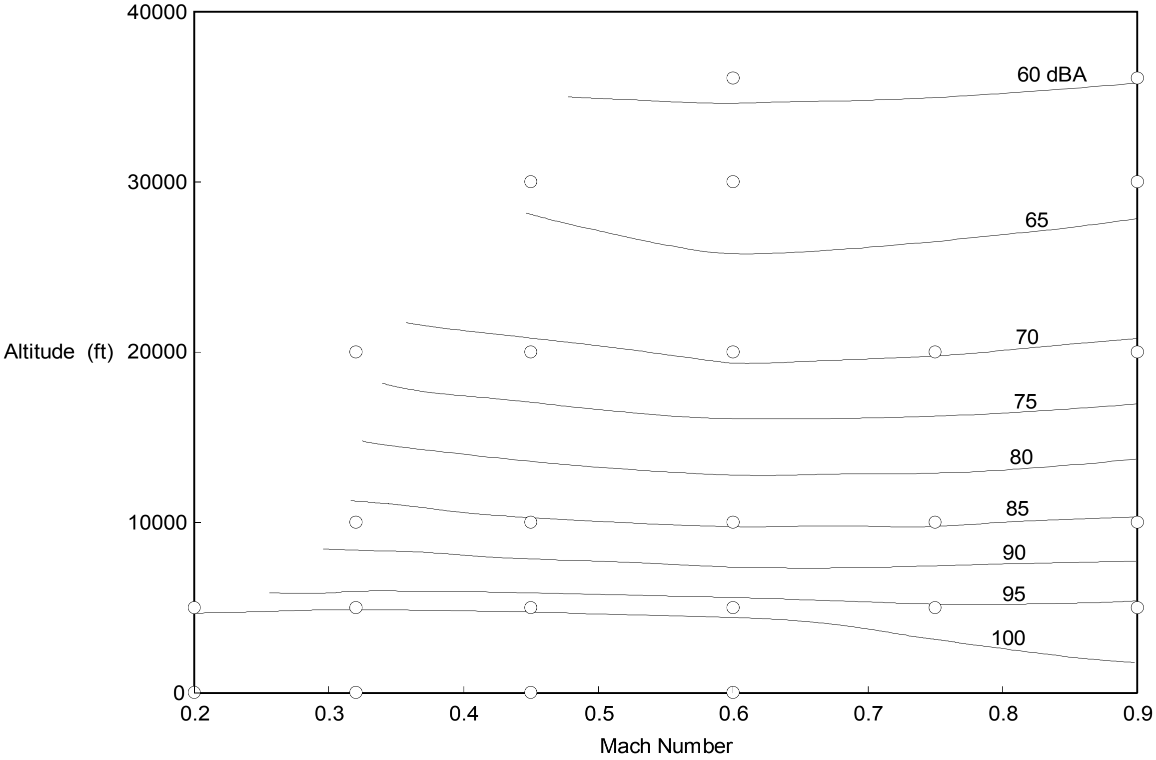

Figure 3: Peak Flyover L_A Levels: Ejector Stowed, Full Power, SGLJET Noise Model, Mean Absorption

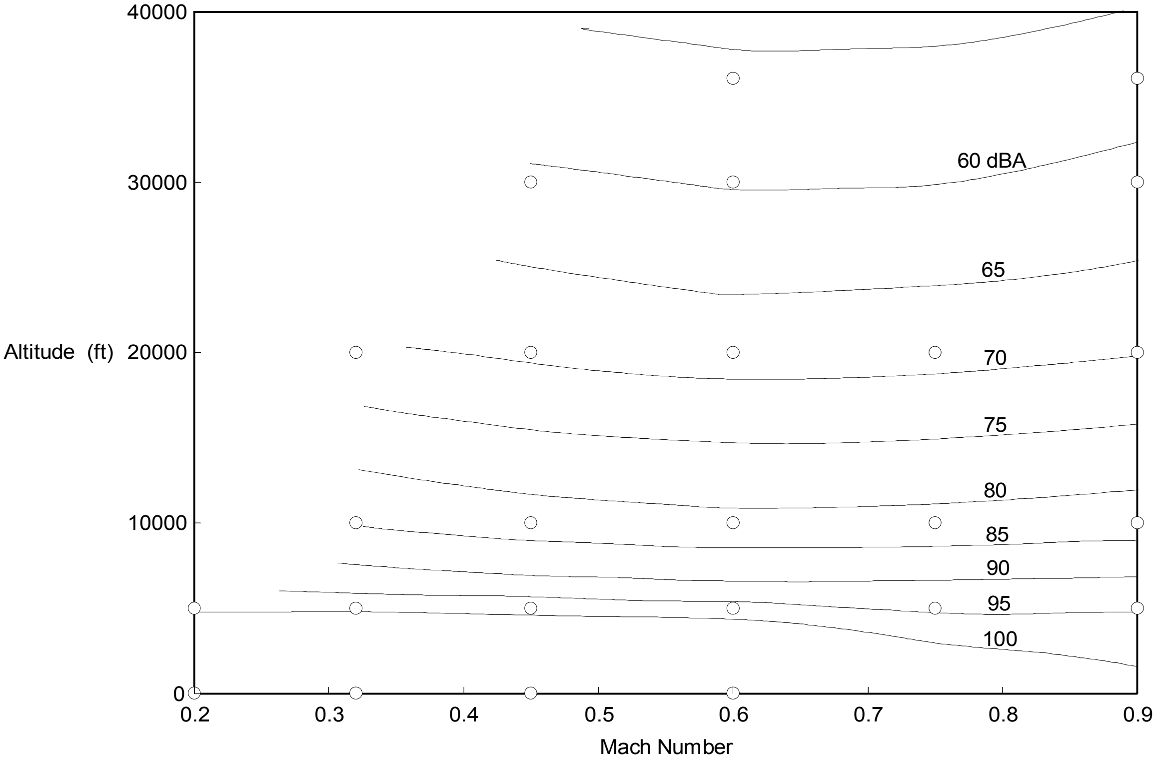

Figure 4: Peak Flyover L_A Levels: Ejector Stowed, Full Power, SGLJET Noise Model, Maximum Absorption

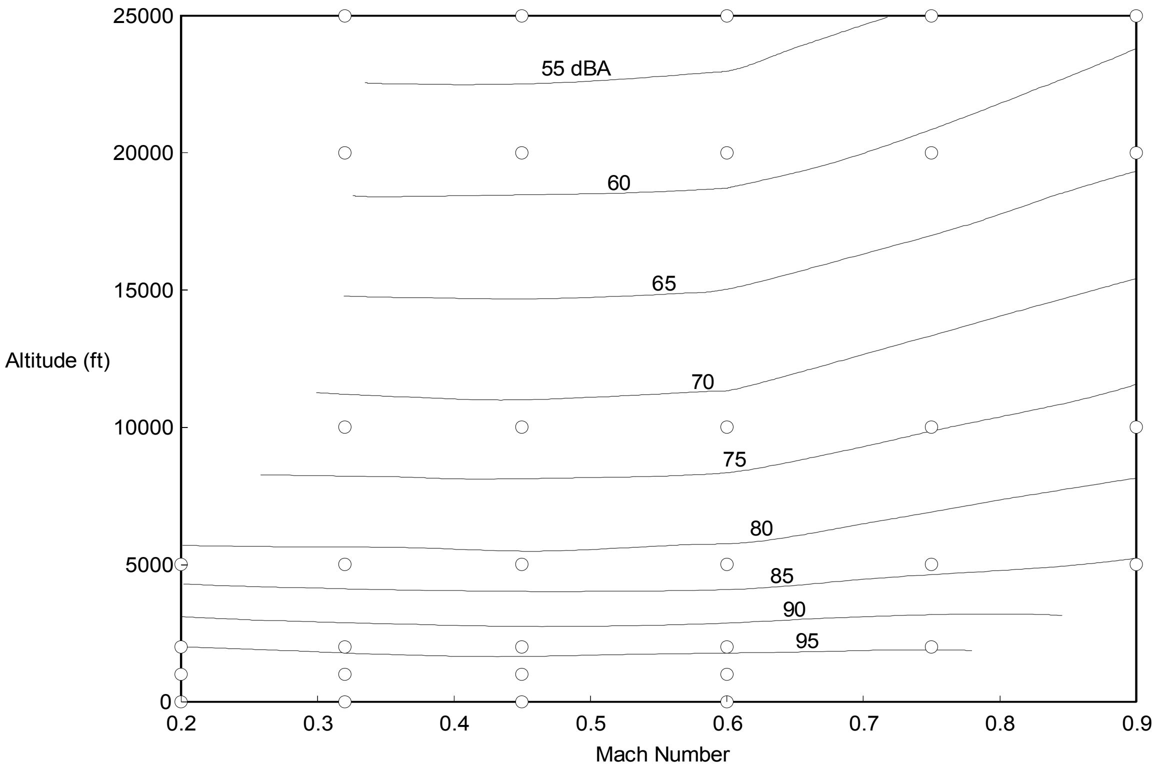

Figure 5: Peak Flyover L_A Levels: Ejector Deployed, Full Power, SGLJET Noise Model, Minimum Absorption

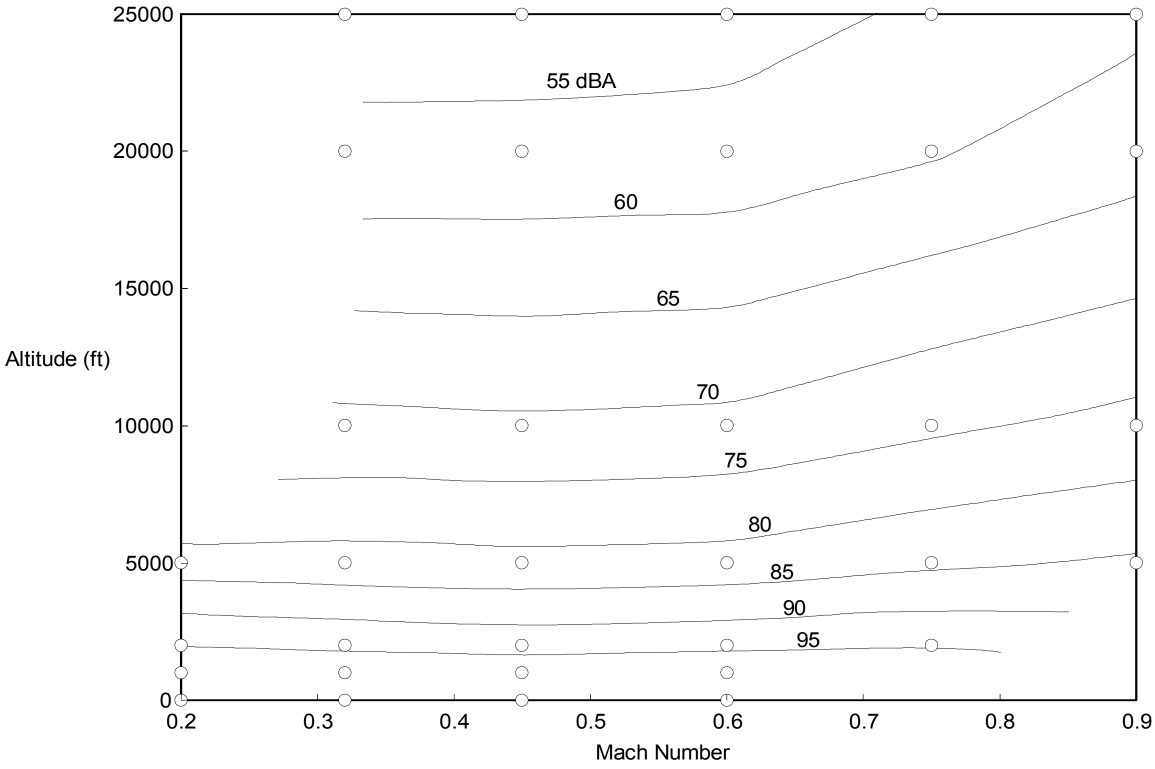

Figure 6: Peak Flyover L_A Levels: Ejector Deployed, Full Power, SGLJET Noise Model, Mean Absorption

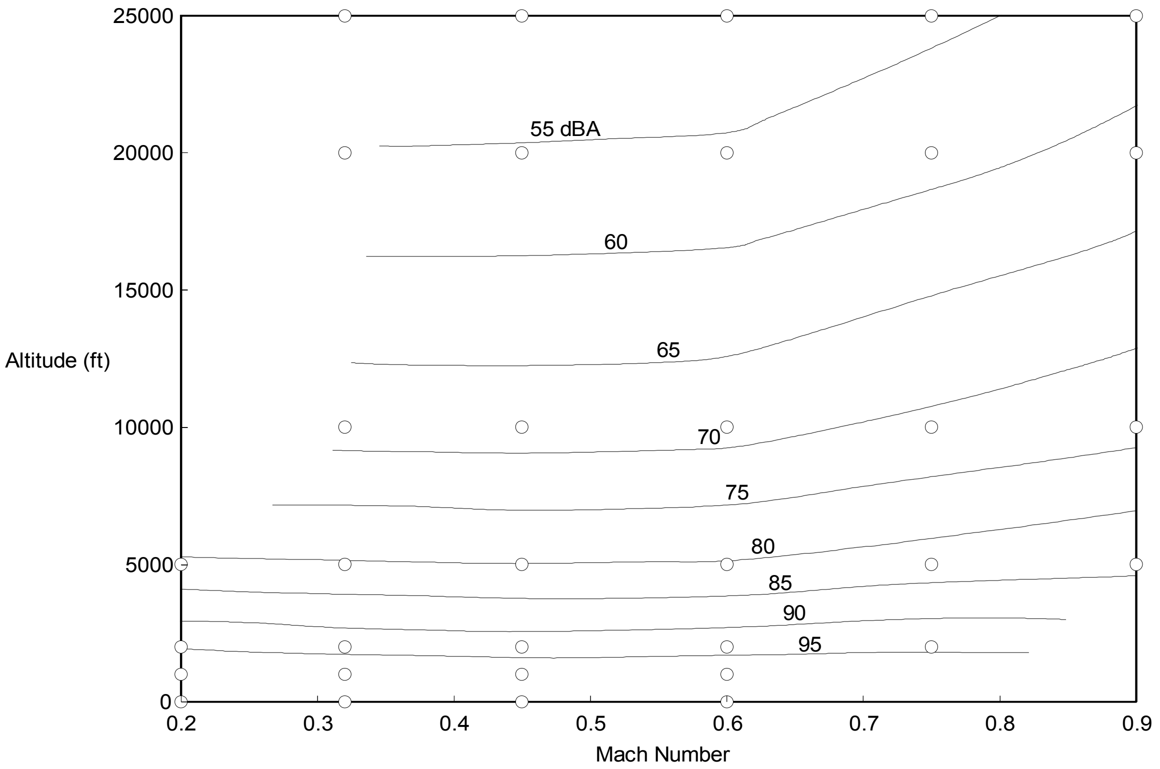

Figure 7: Peak Flyover L_A Levels: Ejector Deployed, Full Power, SGLJET Noise Model, Maximum Absorption

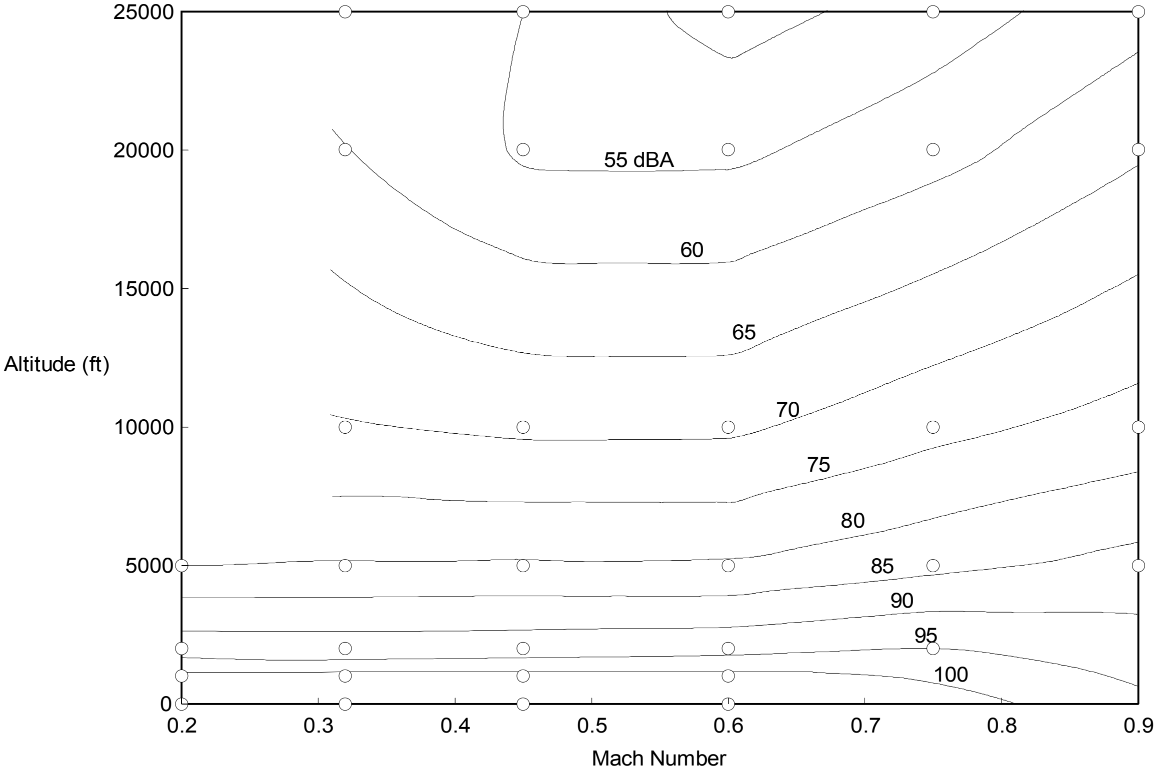

Figure 8: Peak Flyover L_A Levels: Ejector Deployed, Full Power, JN8 Noise Model

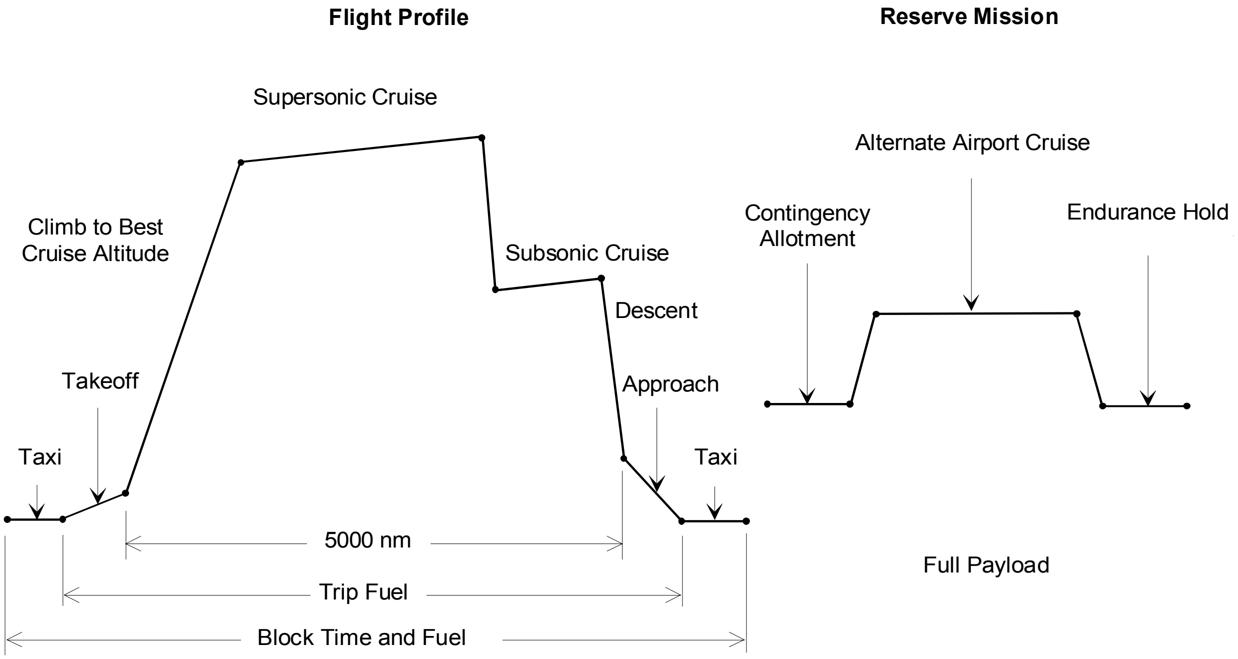

Figure 9: Technology Concept Aircraft HSCT Design Mission

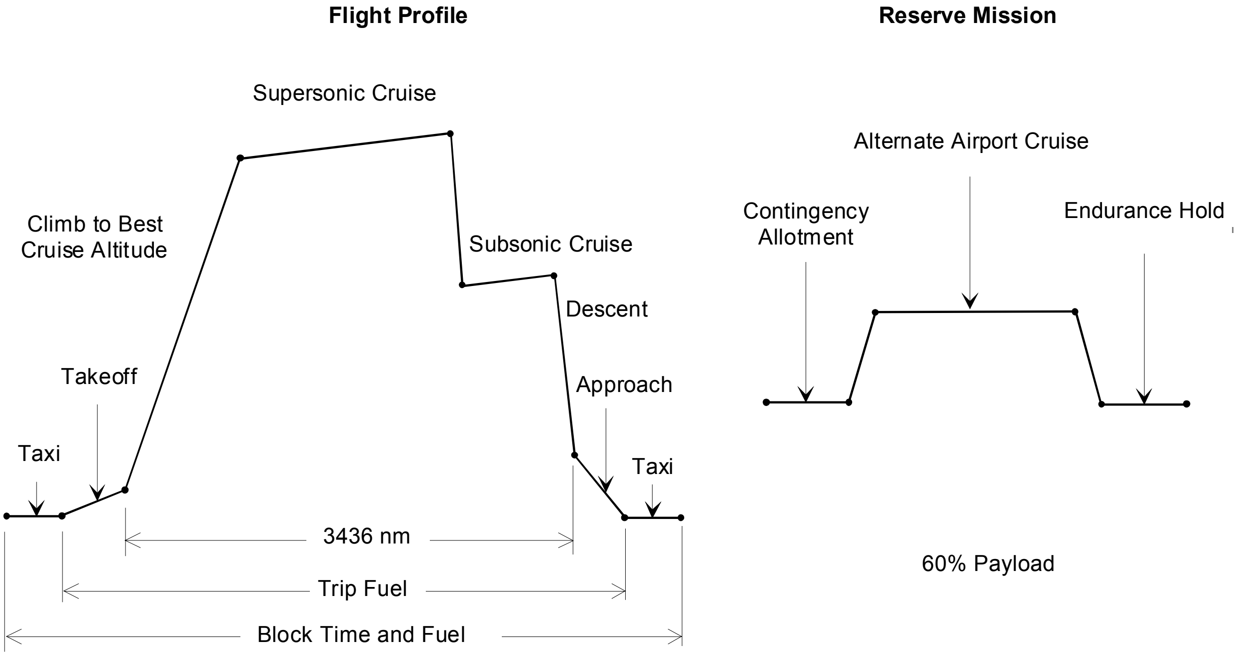

Figure 10: Technology Concept Aircraft HSCT Economic Mission

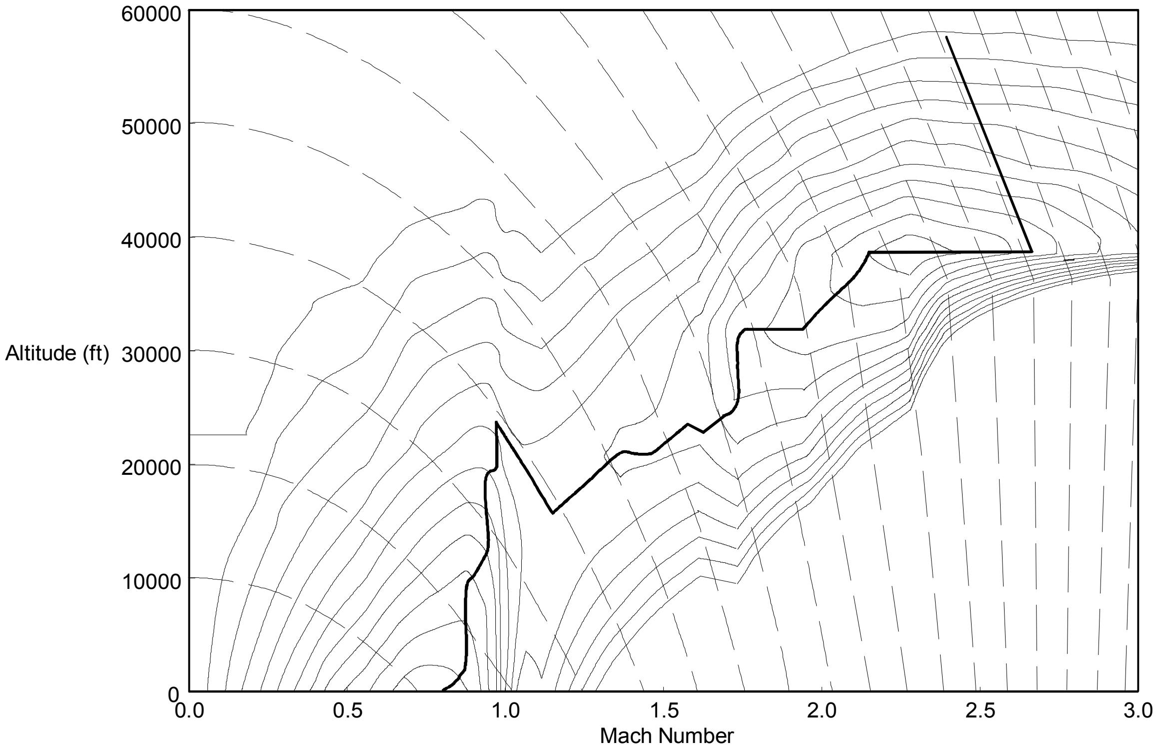

Figure 11: Ideal Time Trajectory

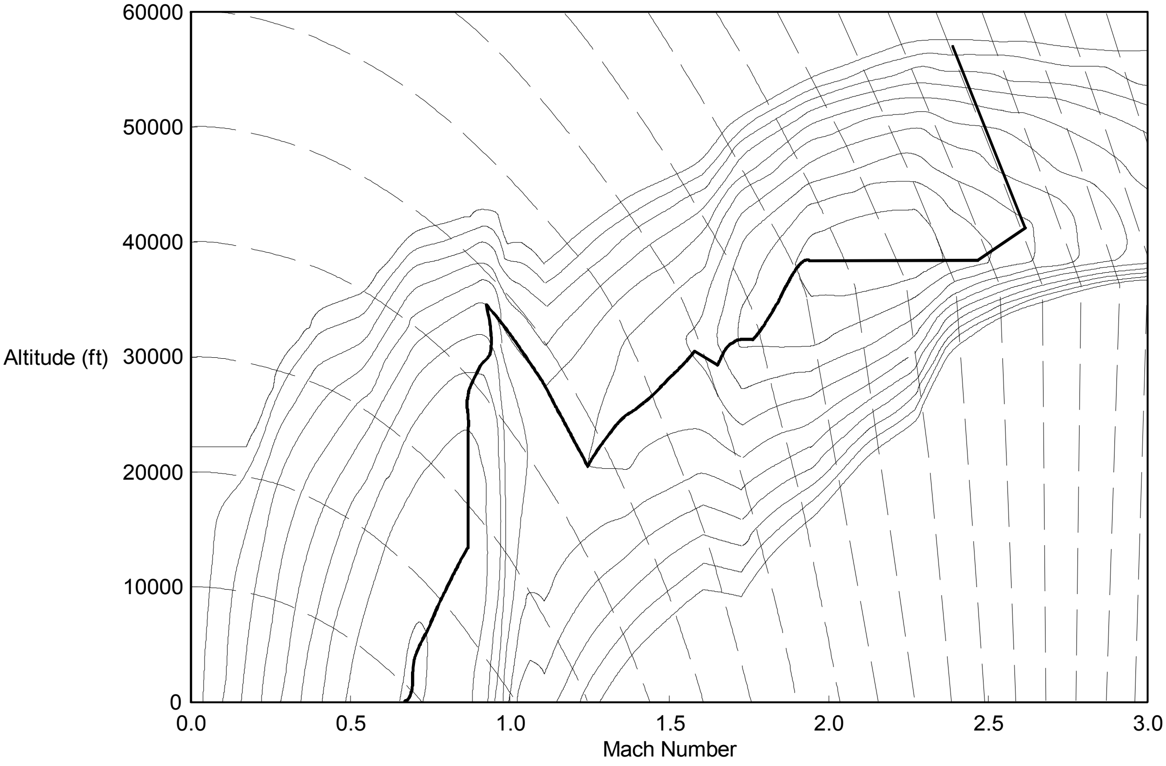

Figure 12: Ideal Fuel Trajectory

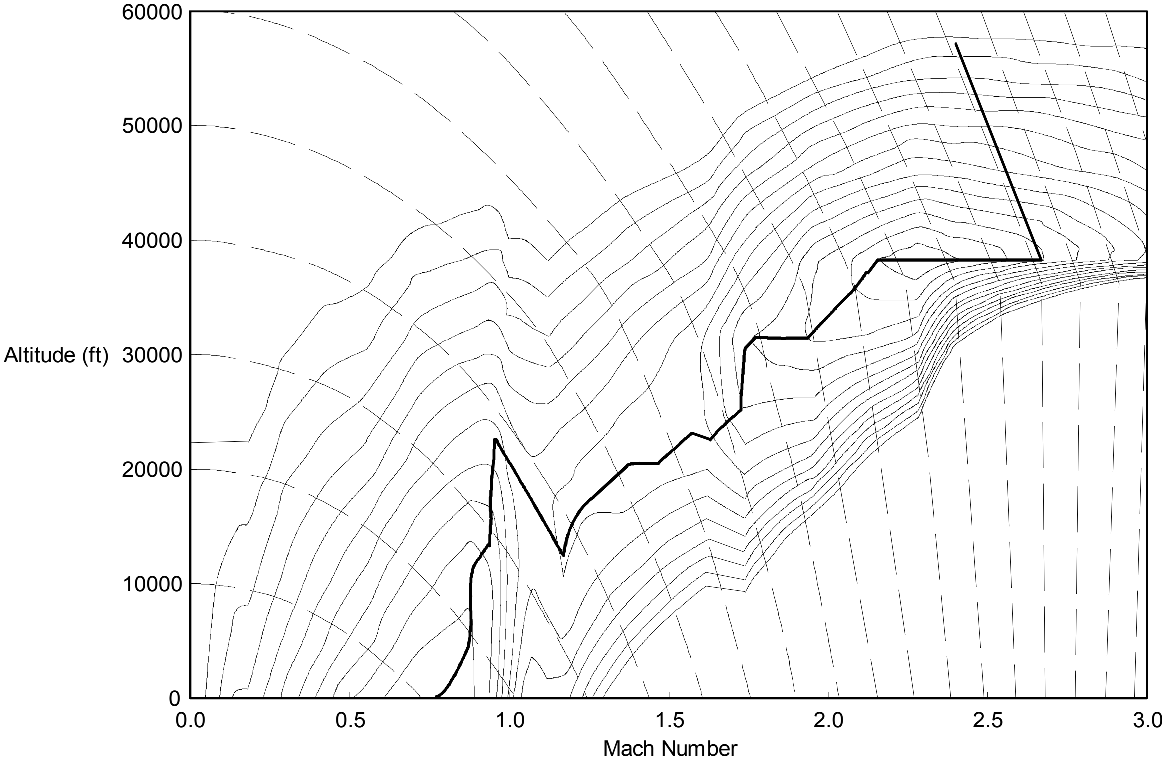

Figure 13: Ideal Noise Trajectory

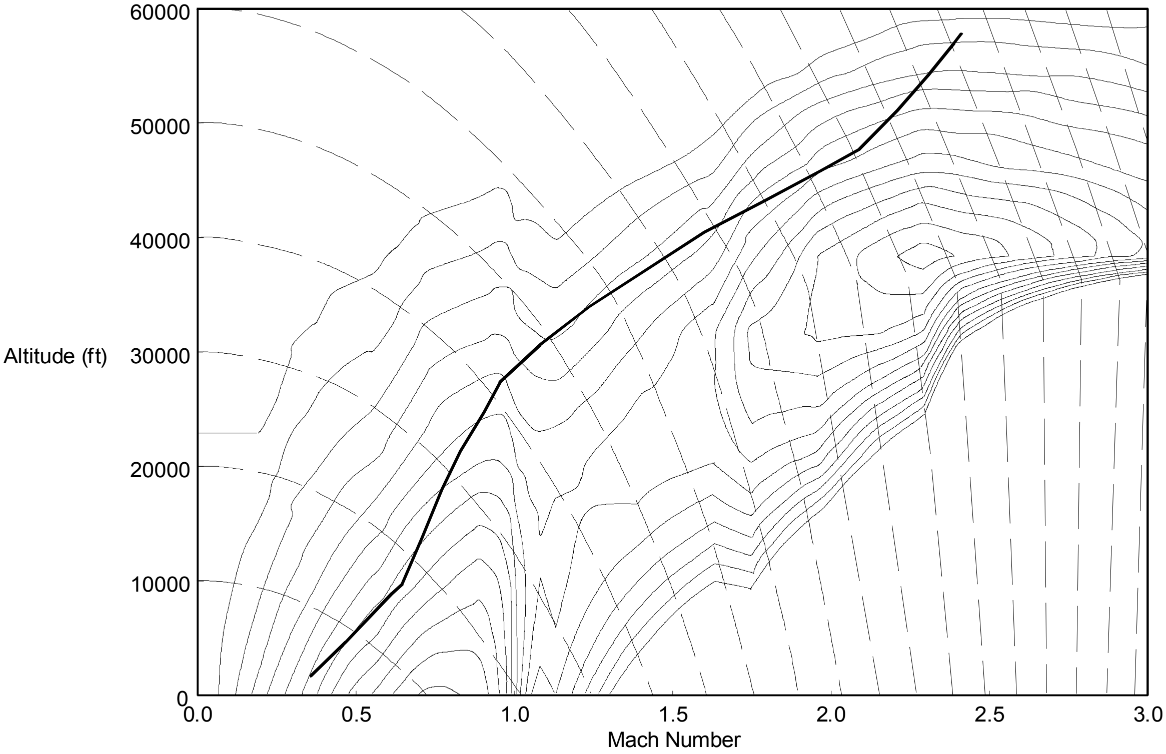

Figure 14: Baseline Trajectory

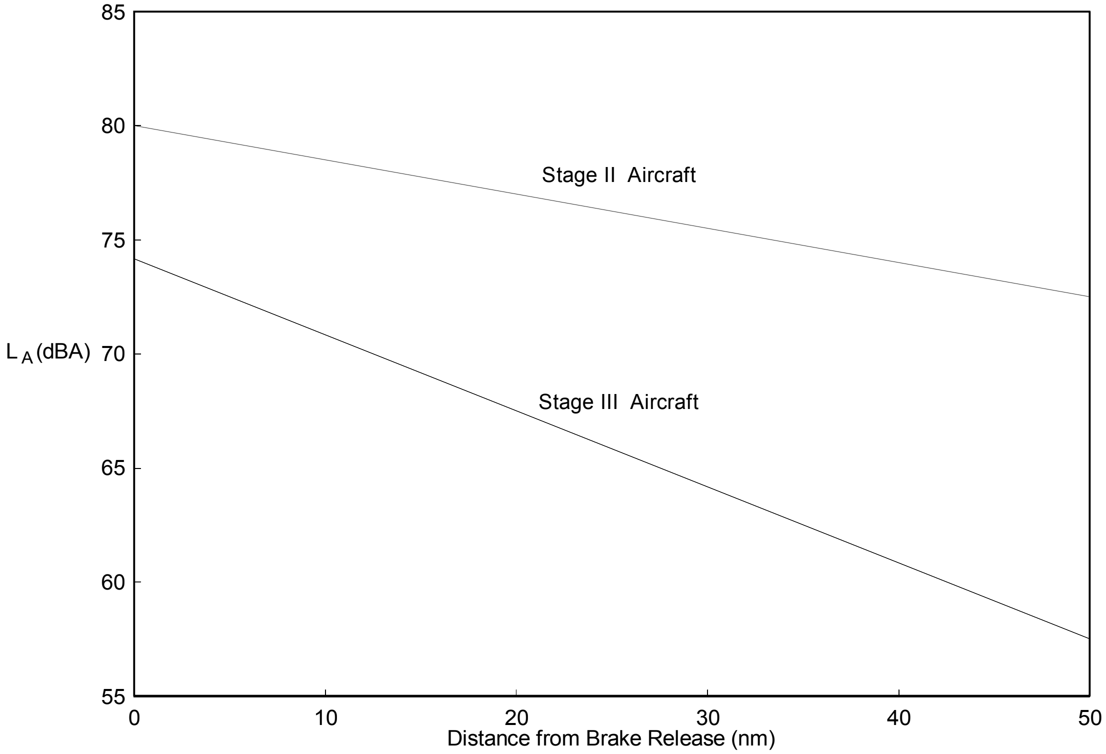

Figure 15: Peak Flyover L_A Levels, Typical Subsonic Commercial Aircraft

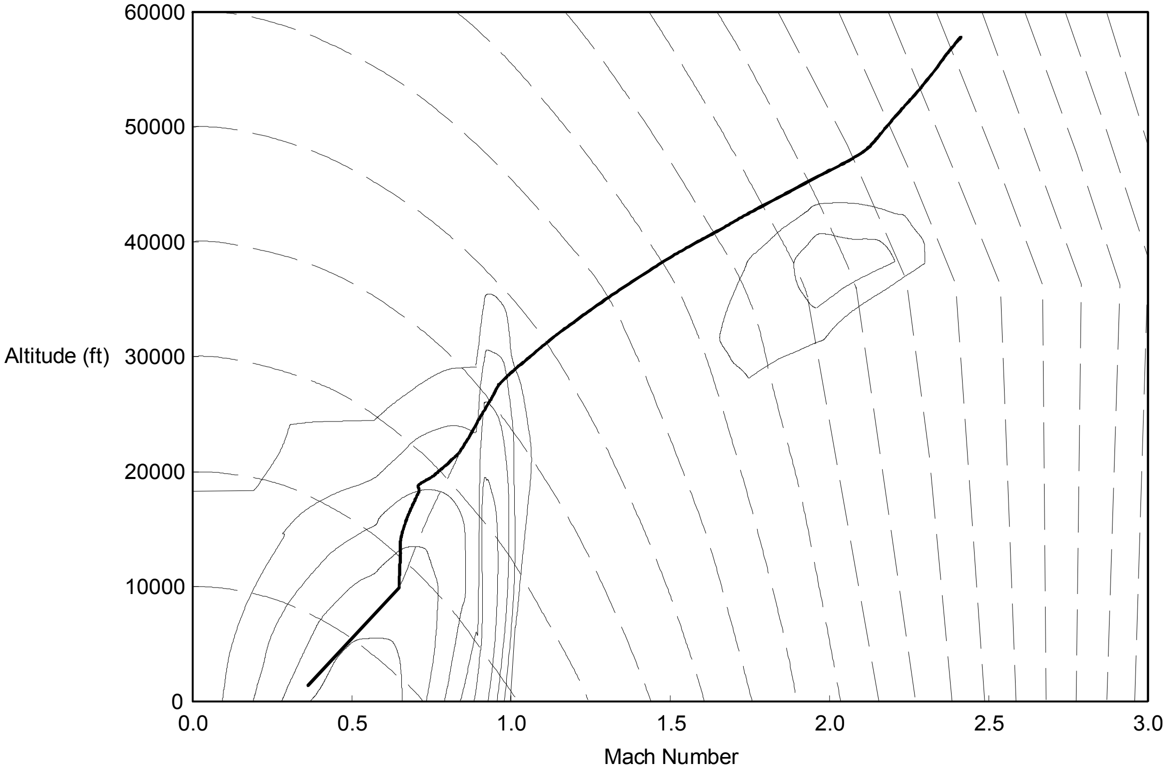

Figure 16: Lofted Trajectory with Stage III Subsonic Aircraft Plus 7 dBA Noise Constraint

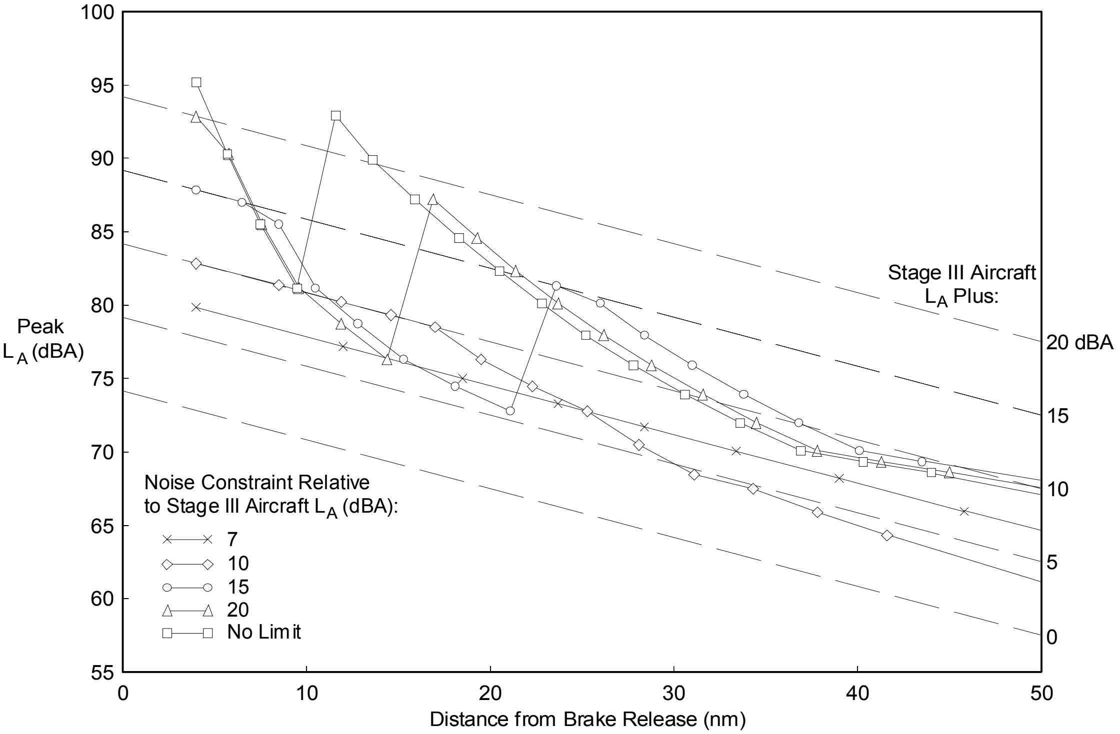

Figure 17: L_A Levels: Noise Constraint Relative to Stage III Subsonic Aircraft; Lofted Trajectories

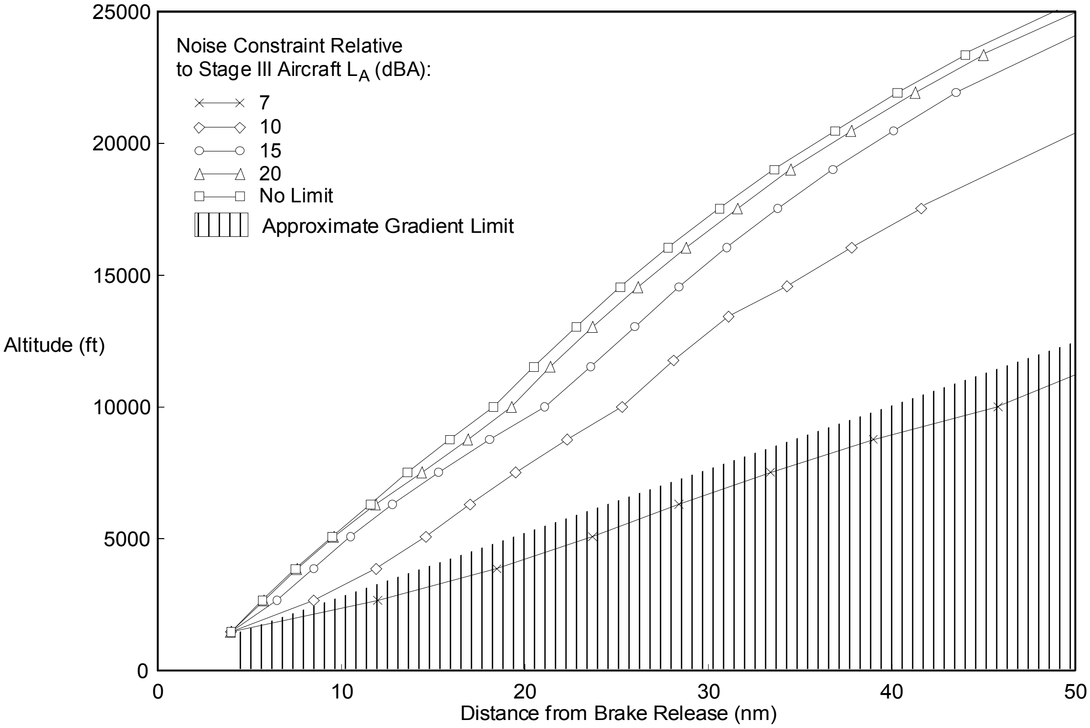

Figure 18: Altitude Gain: Noise Constraint Relative to Stage III Subsonic Aircraft; Lofted Trajectories

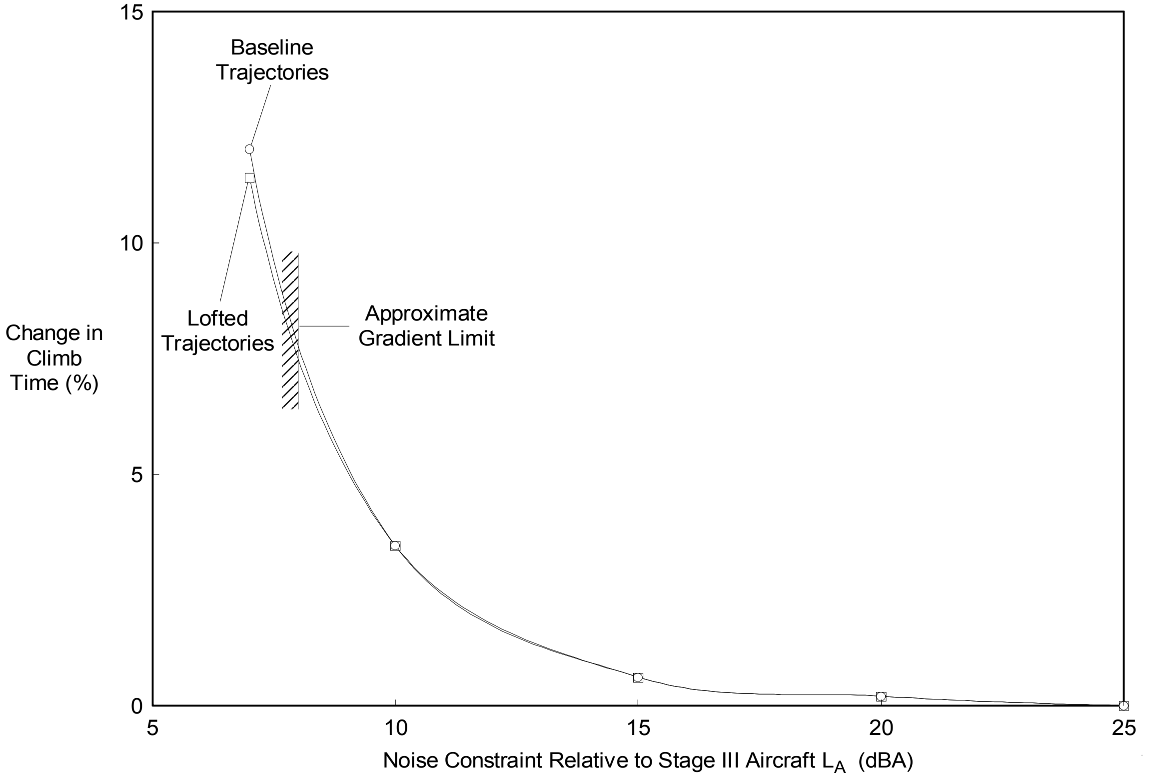

Figure 19: Influence of Noise Constraint Relative to Stage III Aircraft on Design Mission Climb Time

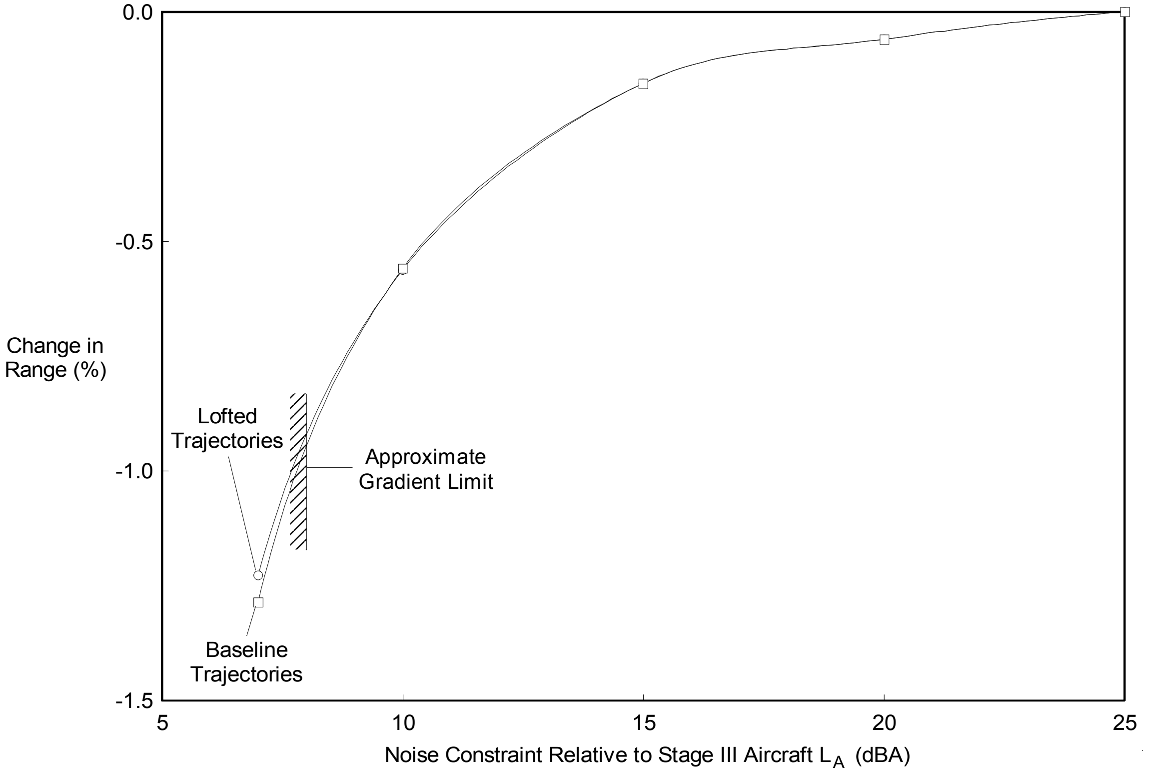

Figure 20: Influence of Noise Constraint Relative to Stage III Subsonic Aircraft on Design Mission Range

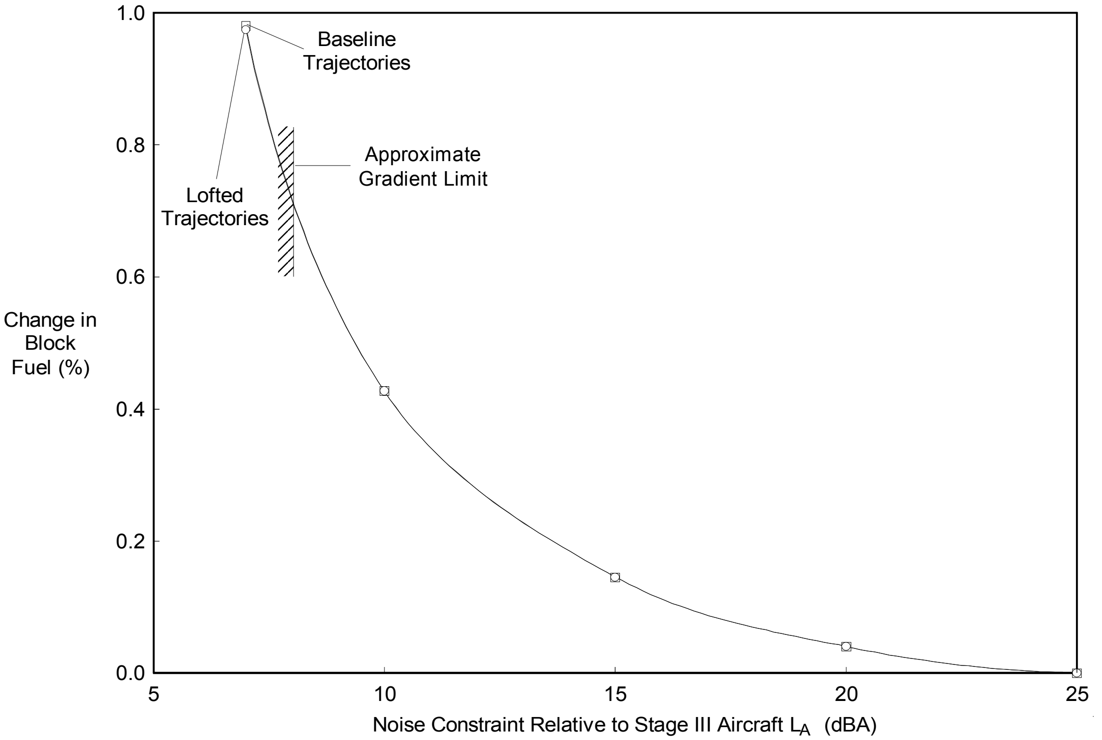

Figure 21: Influence of Noise Constraint Relative to Stage III Aircraft on Economic Mission Block Fuel

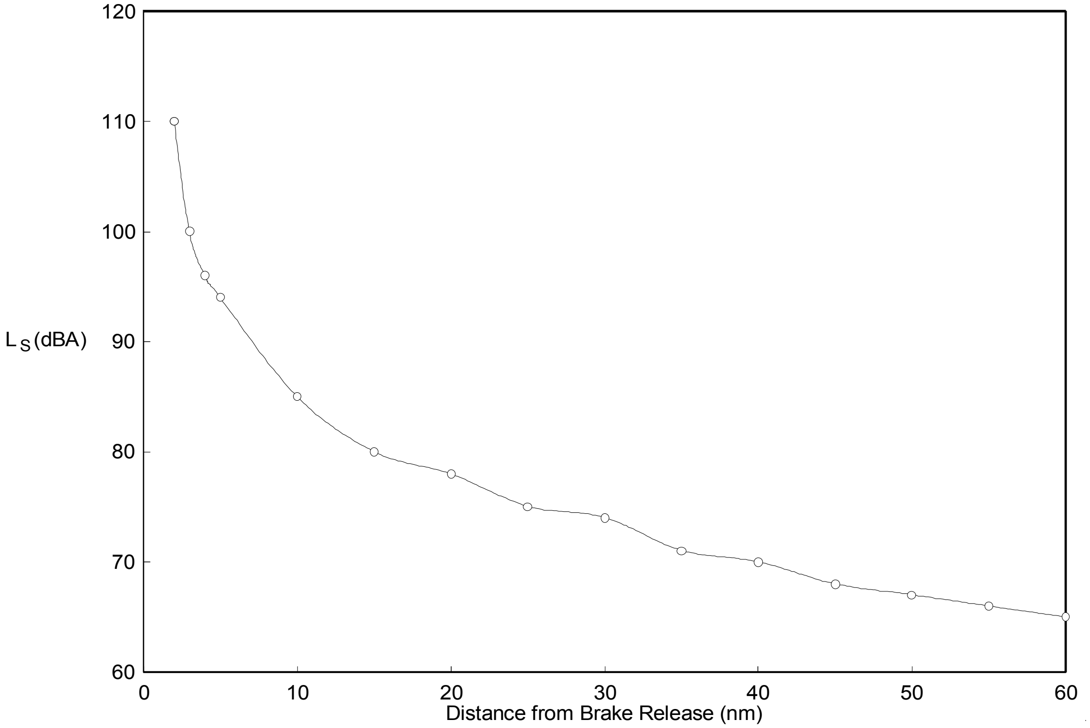

Figure 22: Typical B747-400/PW4056 Flyover L_S Levels

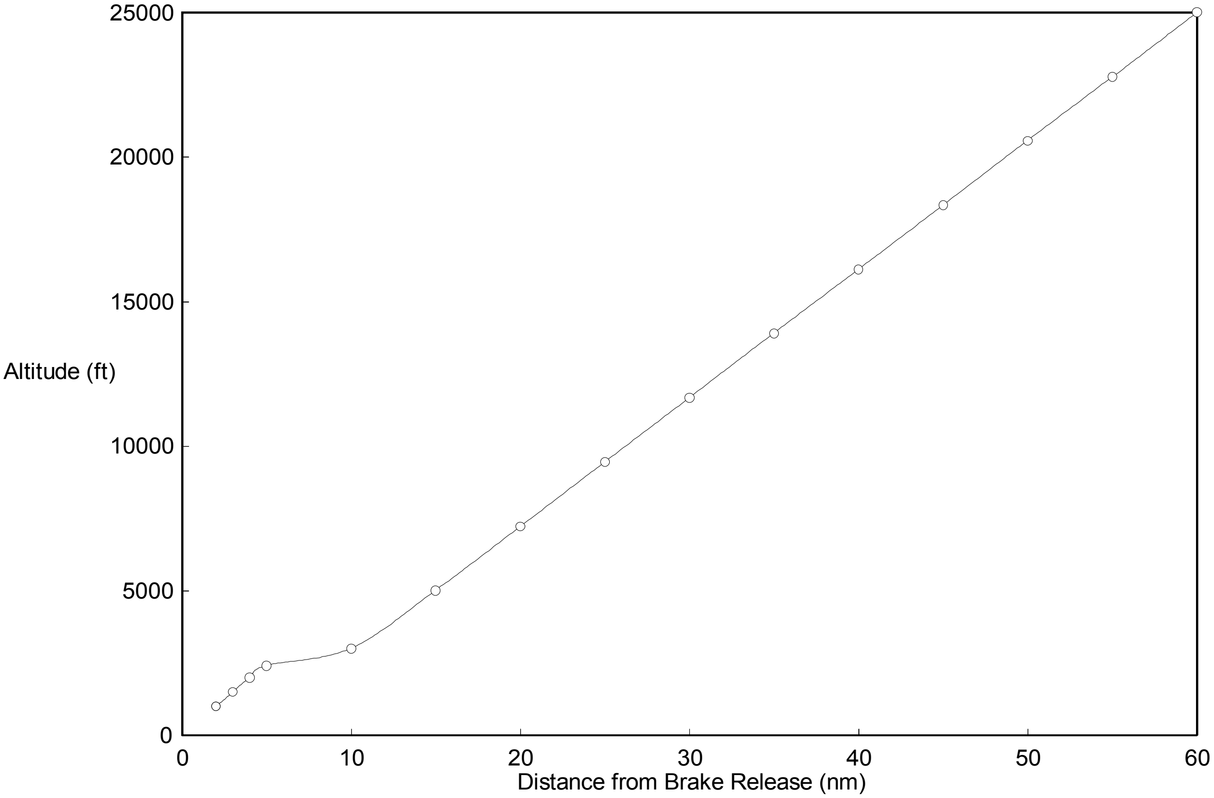

Figure 23: Typical B747-400/PW4056 Trajectory

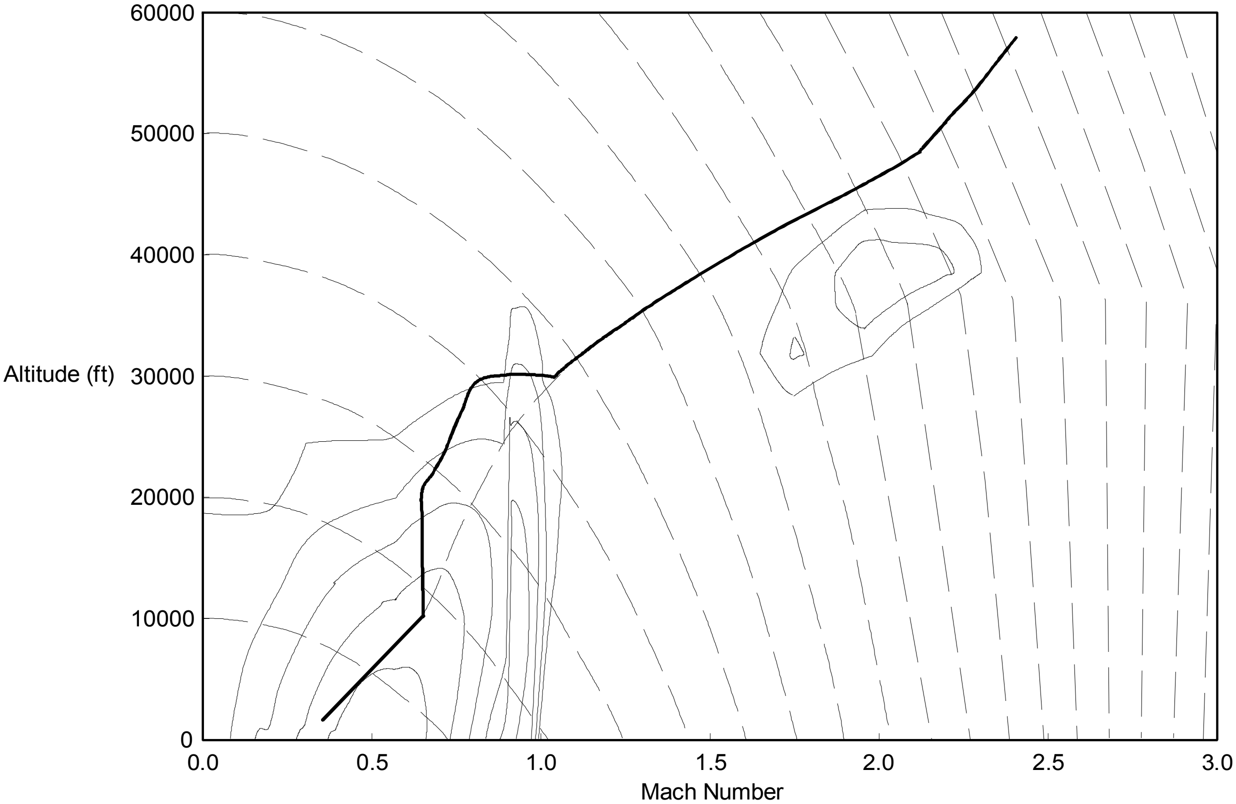

Figure 24: Lofted Trajectory with 747-400 L_S Plus 5 dBA Noise Constraint

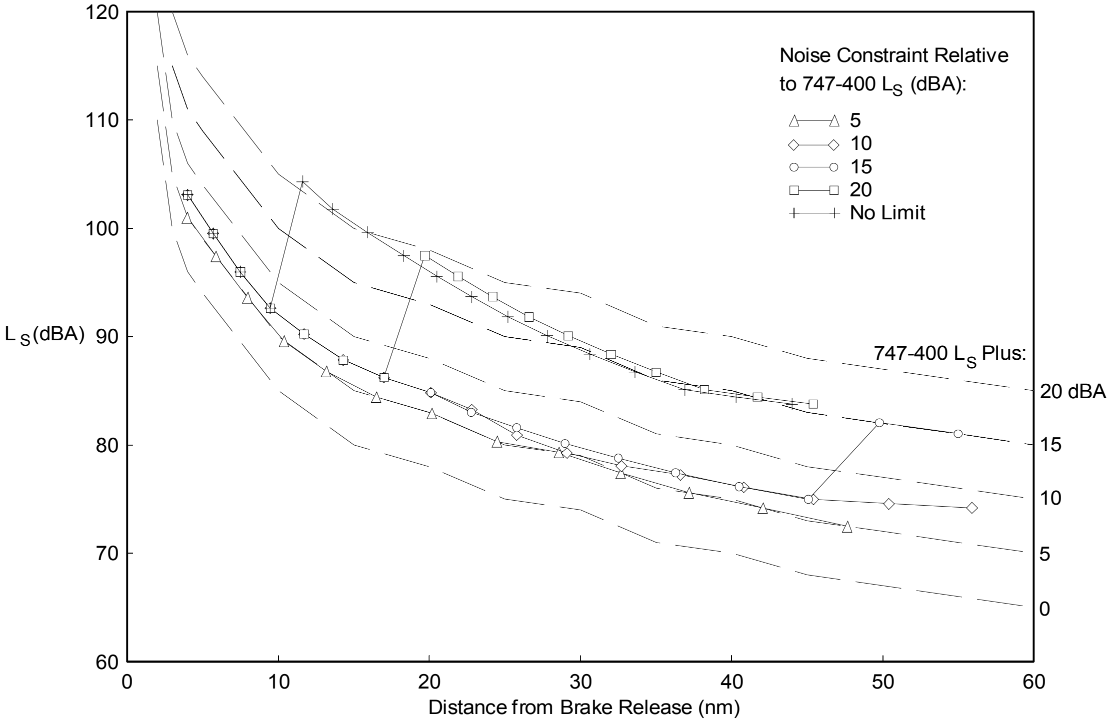

Figure 25: L_S Levels: Noise Constraint Relative to 747-400; Lofted Trajectories

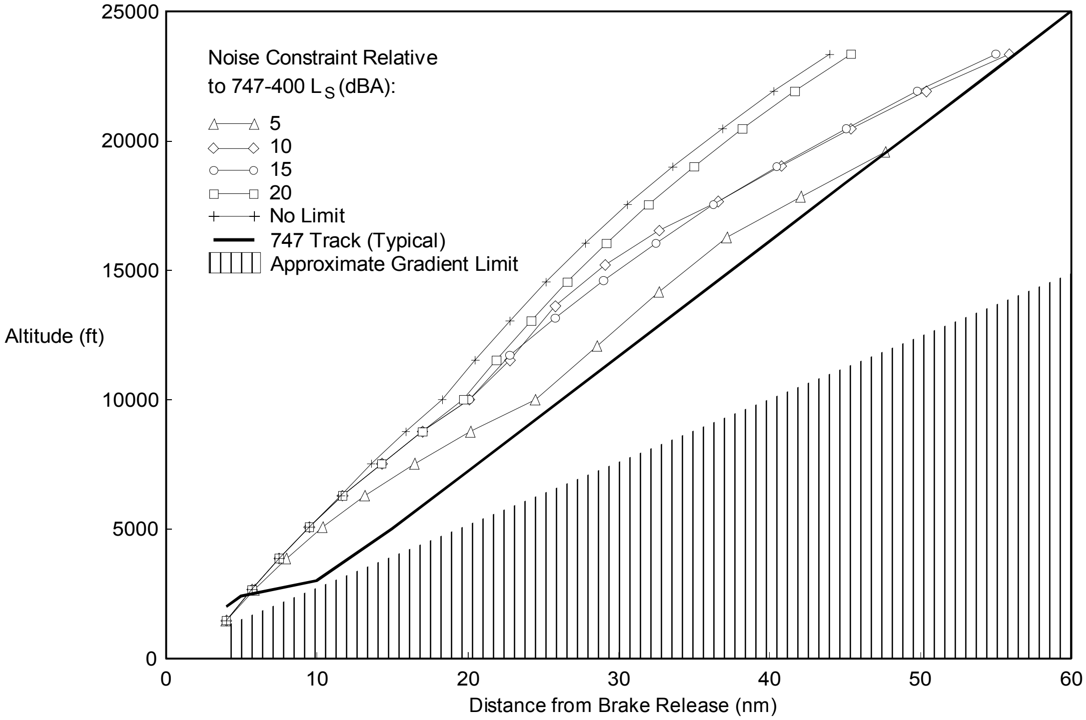

Figure 26: Altitude Gain: Noise Constraint Relative to 747-400; Lofted Trajectories

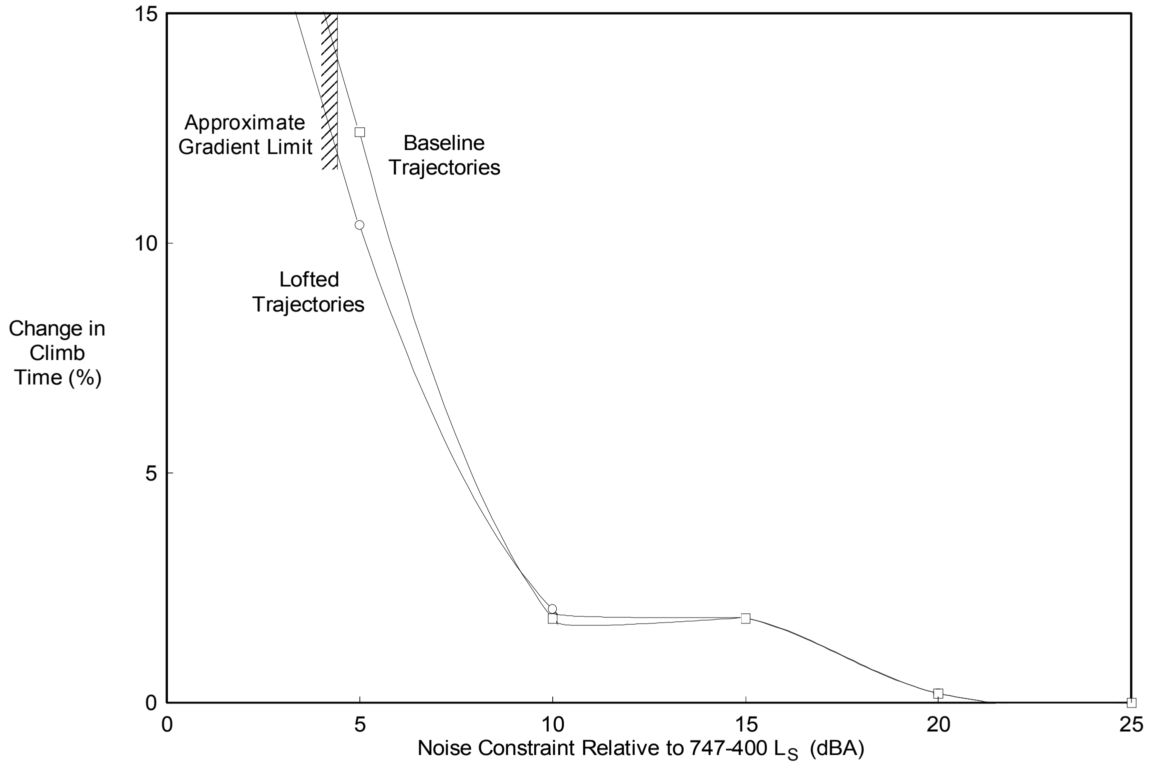

Figure 27: Influence of Noise Constraint Relative to 747-400 on Design Mission Climb Time

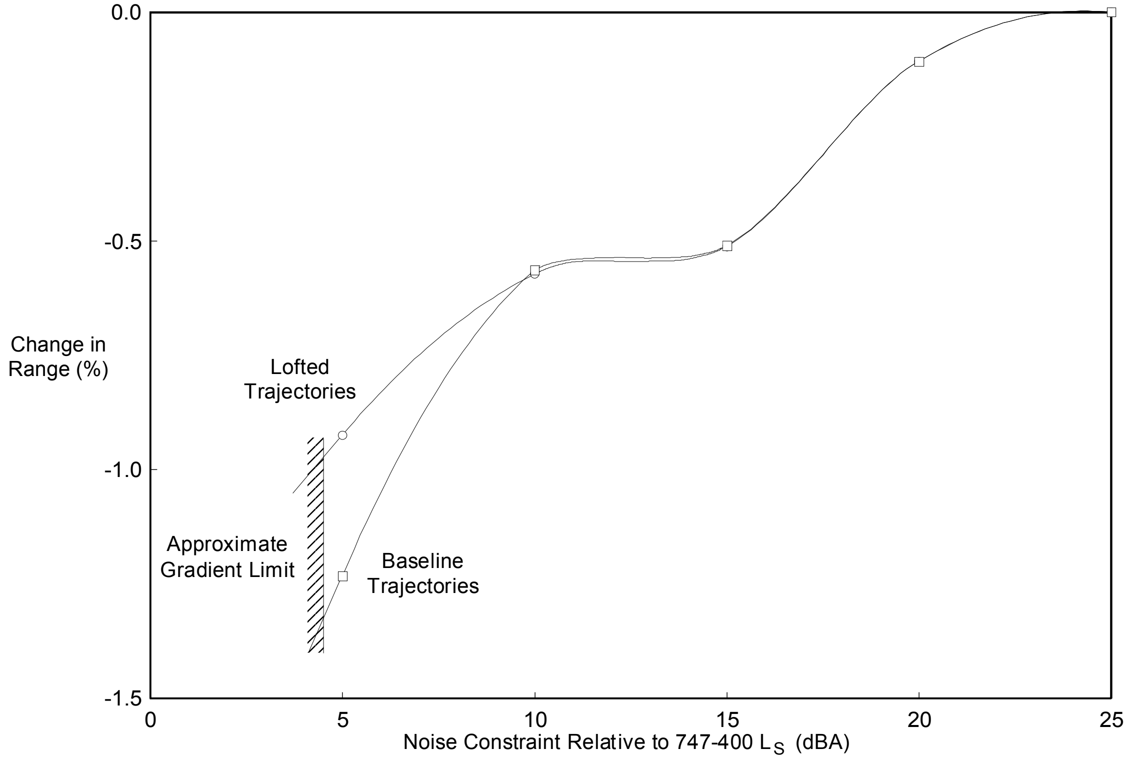

Figure 28: Influence of Noise Constraint Relative to 747-400 on Design Mission Range

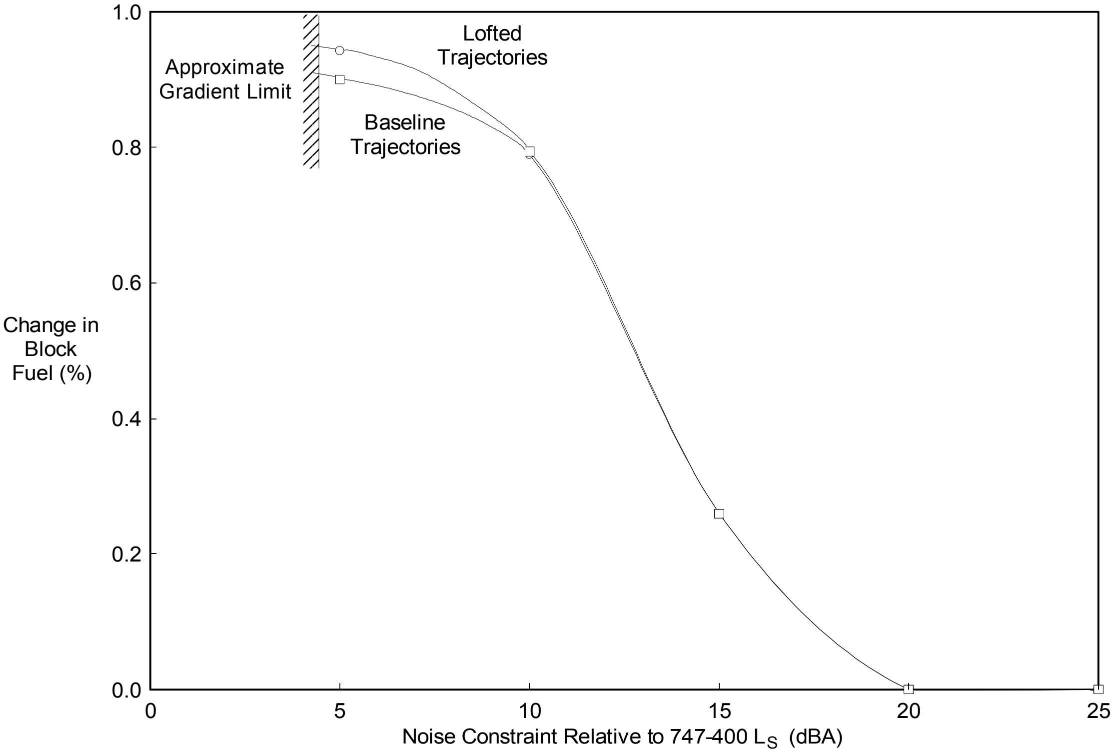

Figure 29: Influence of Noise Constraint Relative to 747-400 on Economic Mission Block Fuel

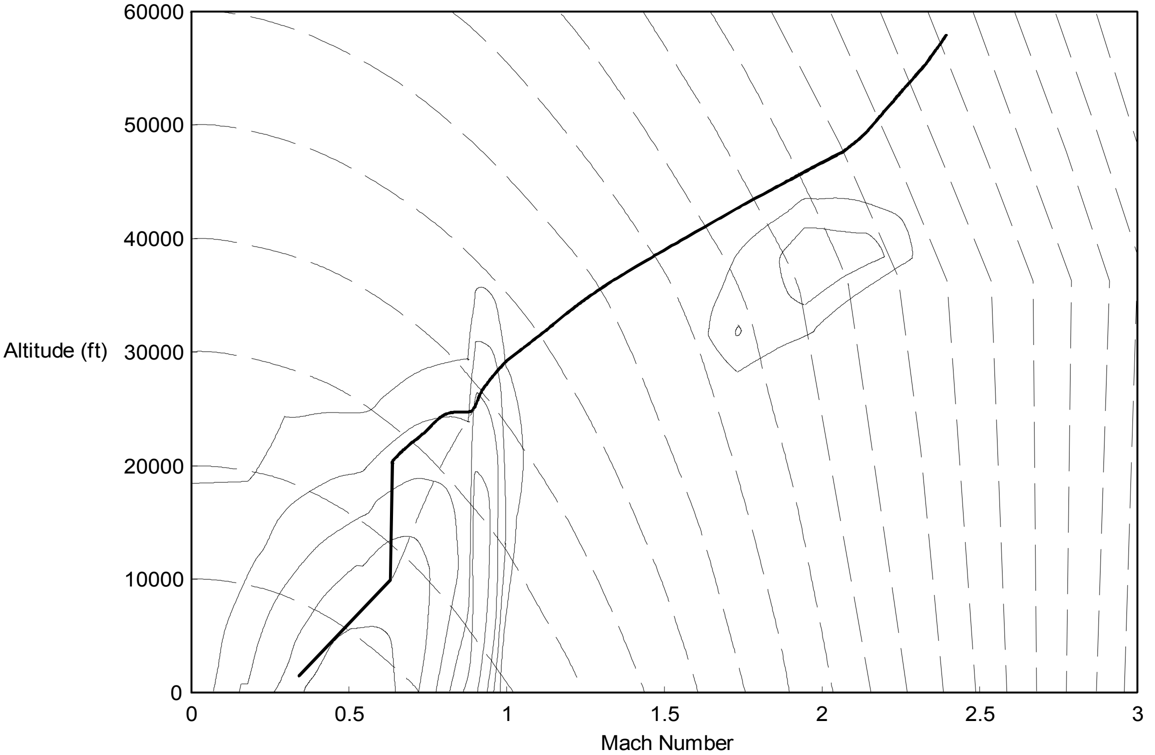

Figure 30: Lofted Trajectory with Maximum Allowed dh_e/dt = 2500 ft/min

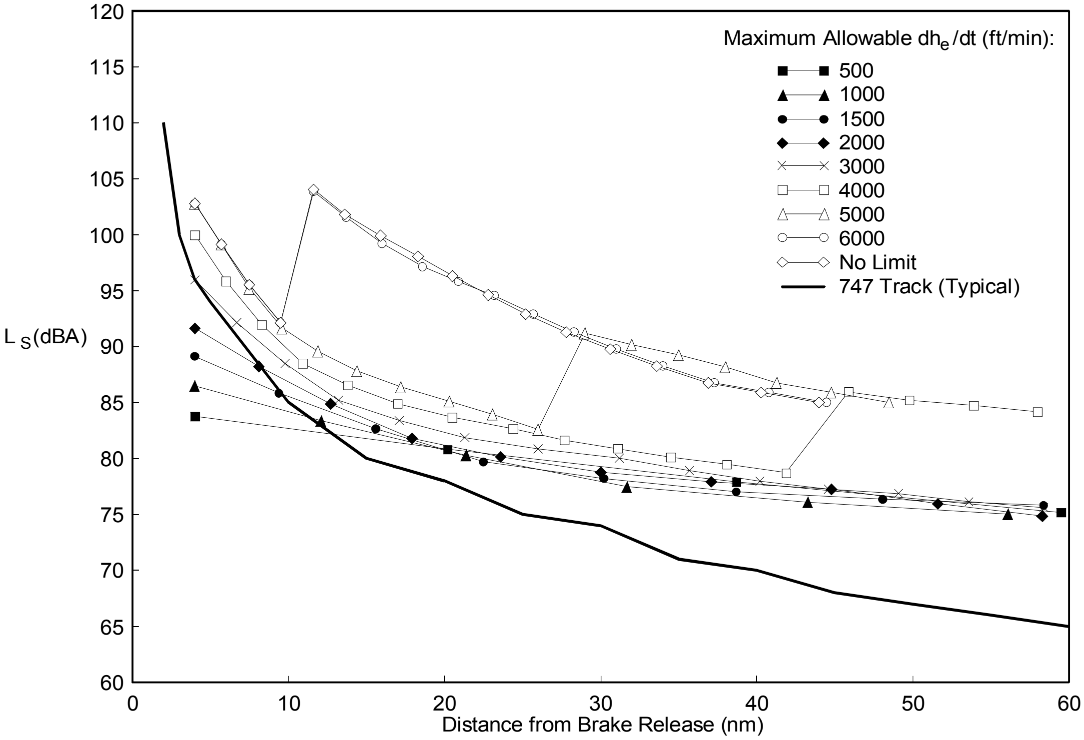

Figure 31: L_S Levels: Limited dh_e/dt, Lofted Trajectories, Minimum Absorption

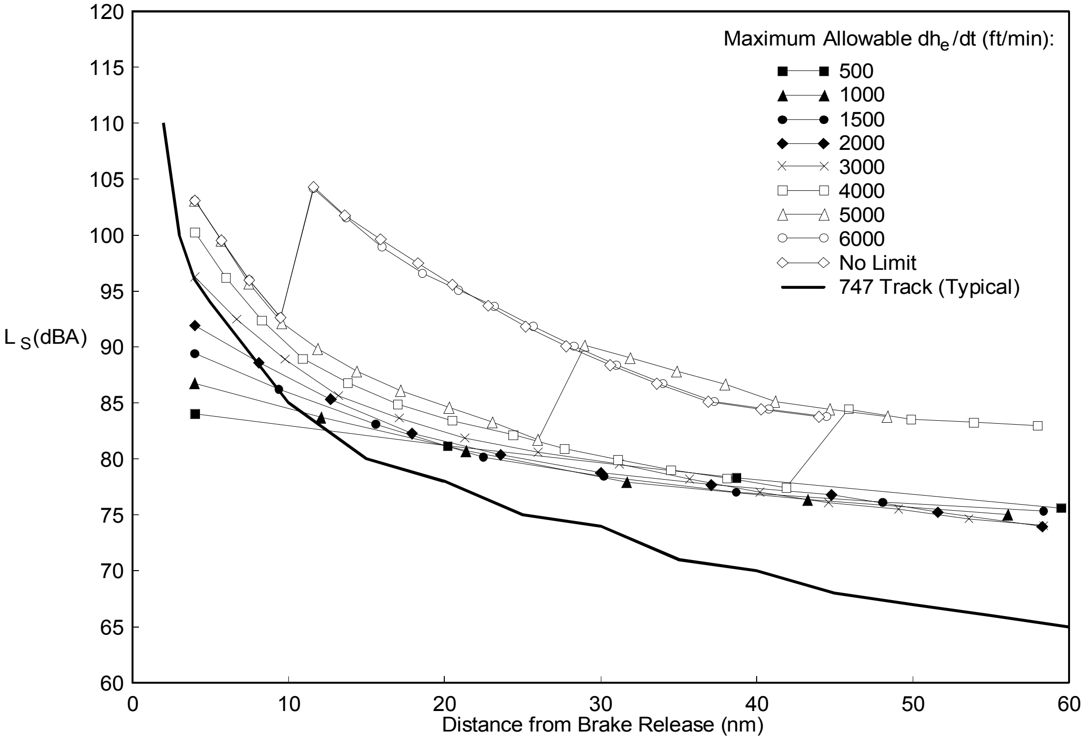

Figure 32: L_S Levels: Limited dh_e/dt, Lofted Trajectories, Mean Absorption

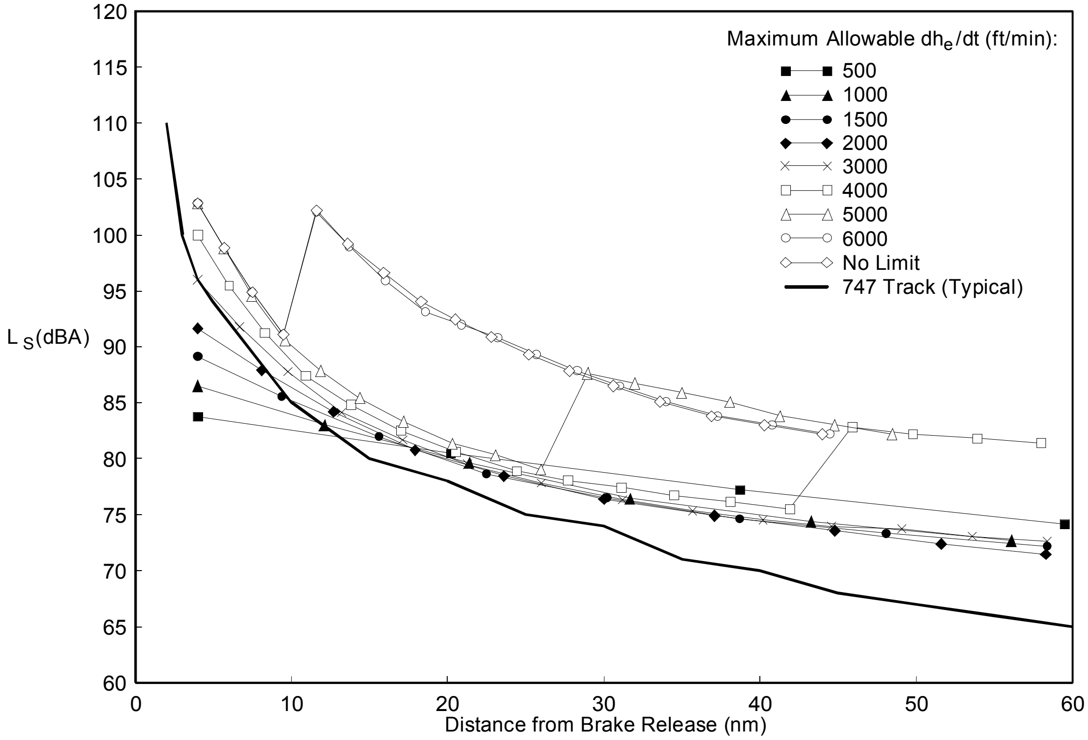

Figure 33: L_S Levels: Limited dh_e/dt, Lofted Trajectories, Maximum Absorption

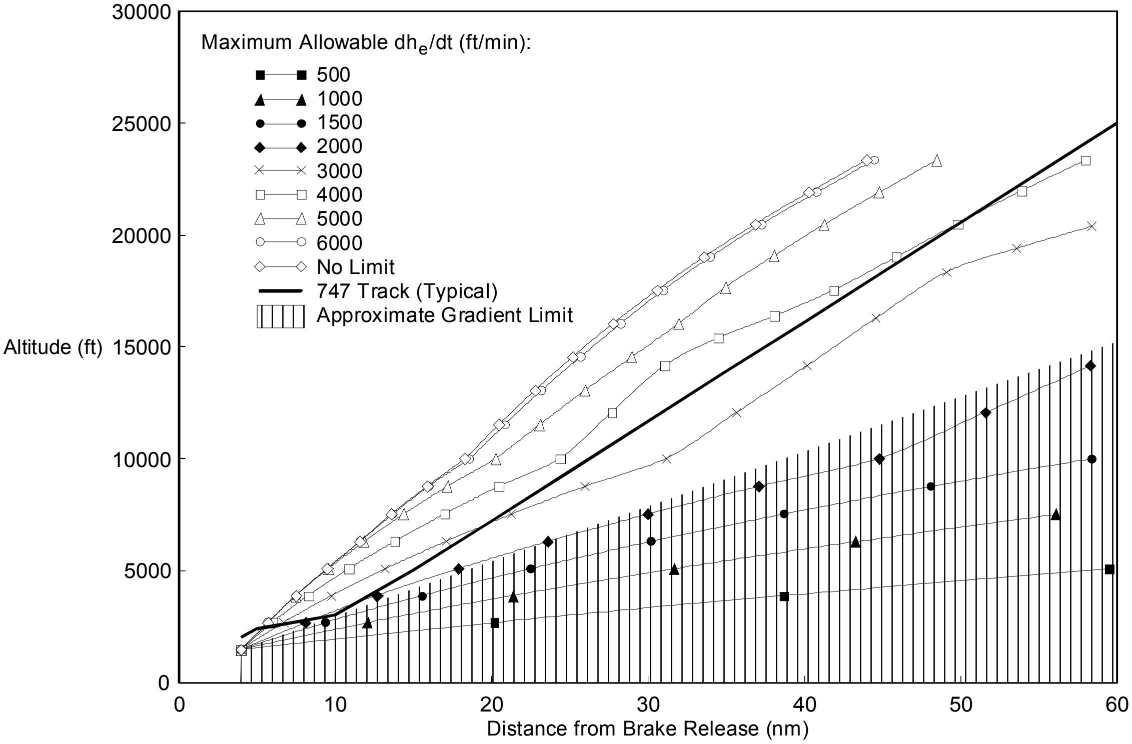

Figure 34: Altitude Gain: Limited dh_e/dt, Lofted Trajectories

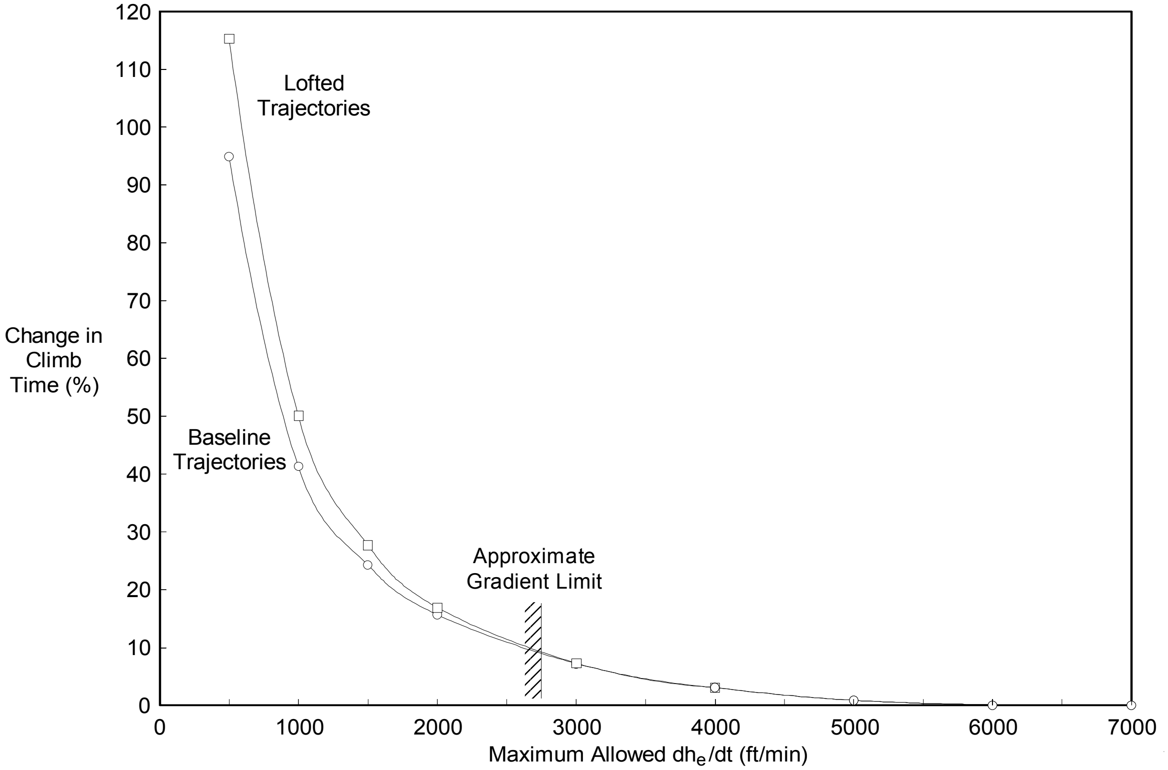

Figure 35: Influence of Maximum Allowed dh_e/dt on Design Mission Climb Time

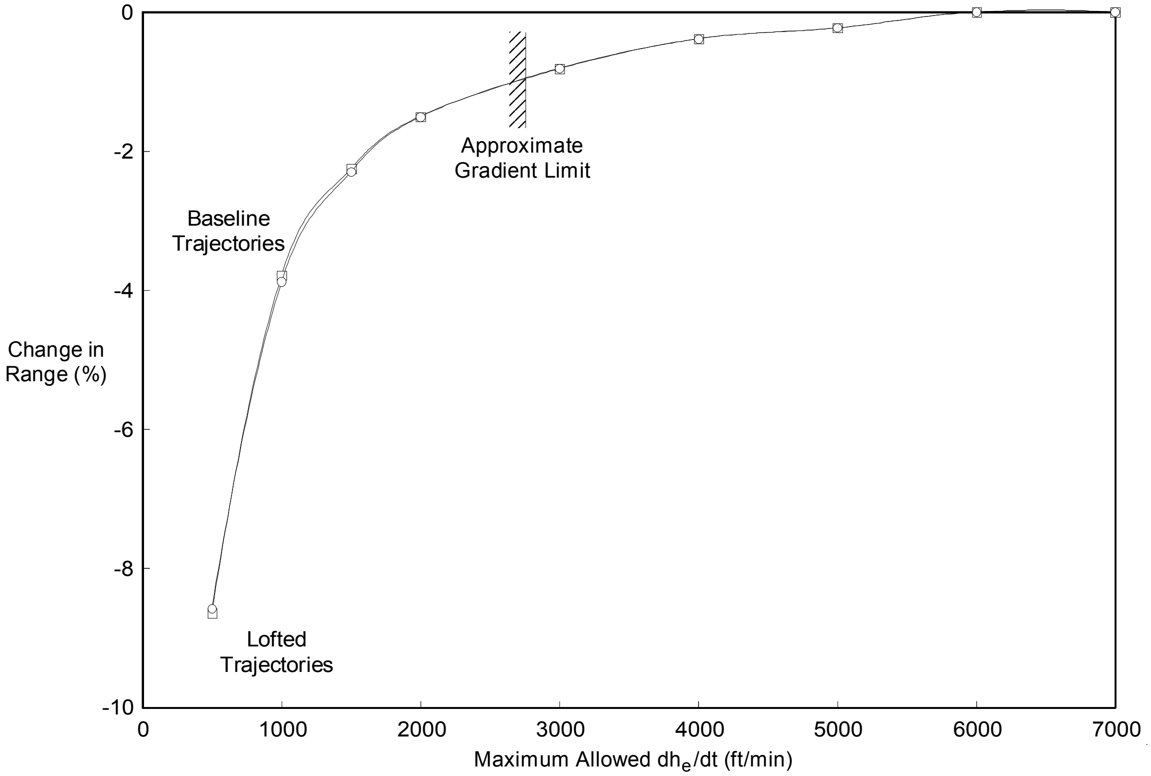

Figure 36: Influence of Maximum Allowed dh_e/dt on Design Mission Range

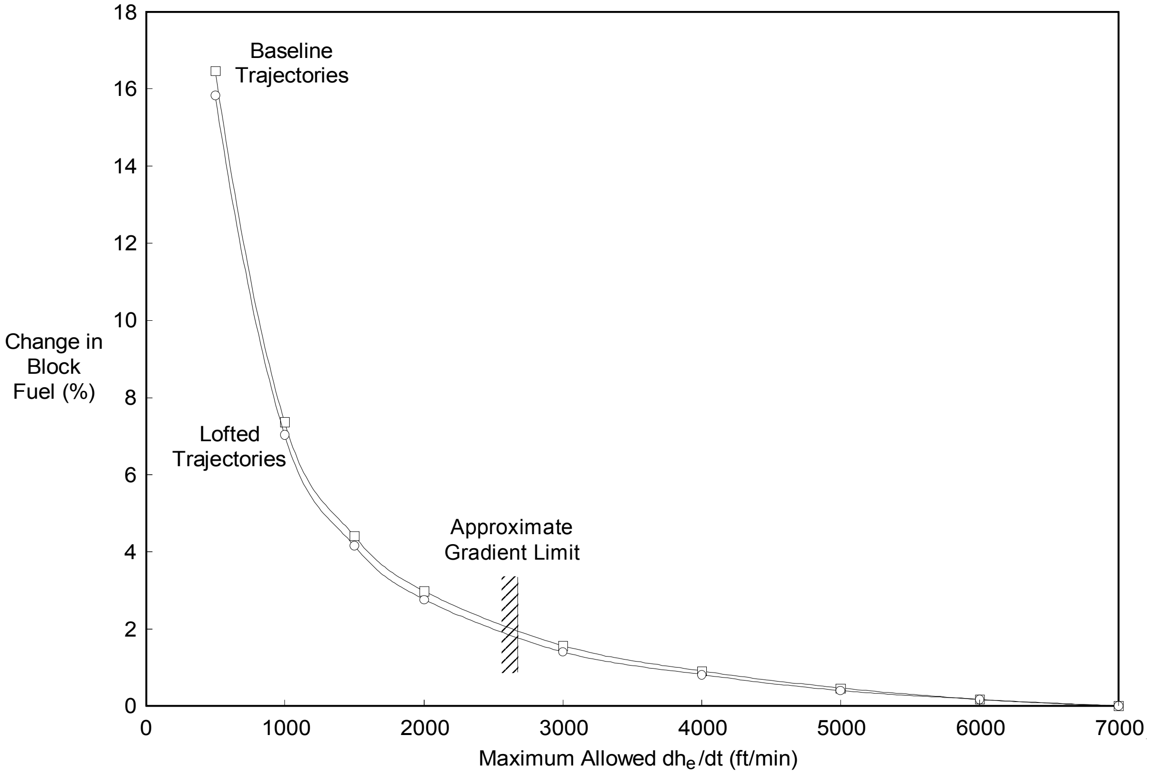

Figure 37: Influence of Maximum Allowed dh_e/dt on Economic Mission Block Fuel

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6. AUTHOR(S) Jeffrey J. Berton	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration John H. Glenn Research Center at Lewis Field Cleveland, Ohio 44135–3191	**8. PERFORMING ORGANIZATION REPORT NUMBER** E–14214
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11. SUPPLEMENTARY NOTES

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13. ABSTRACT ***(Maximum 200 words)***

By entraining large quantities of ambient air into advanced ejector nozzles, the jet noise of the proposed High Speed Civil Transport (HSCT) is expected to be reduced to levels acceptable for airport-vicinity noise certification. Away from the airport, however, this entrained air is shut off and the engines are powered up from their cutback levels to provide better thrust for the climb to cruise altitude. Unsuppressed jet noise levels propagating to the ground far from the airport are expected to be high. Complicating this problem is the HSCT's relative noise level with respect to the subsonic commercial fleet of 2010, which is expected to be much quieter than it is today after the retirement of older, louder, domestic stage II aircraft by the year 2000. In this study, the classic energy state approximation theory is extended to calculate trajectories that minimize the climb to cruise noise of the HSCT. The optimizer dynamically chooses the optimal altitude-velocity trajectory, the engine power setting, and whether the ejector should be stowed or deployed with respect to practical aircraft climb constraints and noise limits.

14. SUBJECT TERMS Jet aircraft noise; Noise reduction; Noise prediction (aircraft); Trajectory optimization	**15. NUMBER OF PAGES** 63
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