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Sonic Boom Configuration Minimization

by

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The pressure pulse on the ground accompanying supersonic overflights is popularly known as a "sonic boom." It differs significantly from the pressure pulse accompanying subsonic overflights in that it typically contains two shocks (front and rear). These shocks are audible, and, due to their impulsive nature and rapid onset, can often times be startling and annoying. To a first approximation, the annoyance caused by these shocks constitutes the current sonic boom "problem" for supersonic commercial transports.

Theoretically, it is not necessary to have shocks reach the ground for supersonic overflight. Techniques that carefully control the growth of aircraft volume and lift can be employed to eliminate the shocks. The primary drawback to these techniques is the fact that they typically require long, slender bodies outside the range of feasible structures for todays technology. The audible sonic boom, then, is a fallout of current technology, and not a necessity of supersonic flight.

Technology will eventually advance to the point where shockless booms are feasible for commercial supersonic aircraft, opening up large portions of the commercial air transport market that are currently landlocked to supersonic aircraft, and creating a significant business opportunity for those who are poised to exploit the new technology. For this reason it is important to continue sonic boom minimization research, even in the face of considerable skepticism.

THE SONIC BOOM "BIG PICTURE"

- AUDIBLE SONIC BOOM IS A FALLOUT OF CURRENT TECHNOLOGY - NOT A NECESSITY OF SUPERSONIC FLIGHT
- TECHNOLOGY WILL EVENTUALLY ENABLE SHOCKLESS BOOMS
- INCORPORATION OF LOW-BOOM TECHNOLOGY INTO 2ND GENERATION SST:
    - DESIRABLE....YES
    - FEASIBLE.......???
- LOW-BOOM TECHNOLOGY EVENTUALLY = $$$

The current low-boom technology is focussed on shaping the pressure pulse so as to minimize those aspects that most contribute to the loudness of the boom, primarily the shock strengths. Pioneering work by Seebass and George in the early 1970's[1] showed that a body of revolution could be defined to generate a specified sonic boom shape that minimized the shock strength, maximum overpressure, or the impulse of the waveform. This body of revolution can then be approximated with wing/body configurations by matching the equivalent area distribution with the proper control of aircraft volume and lift. This process has been formalized into a computer program by Darden called SEEB.[2]

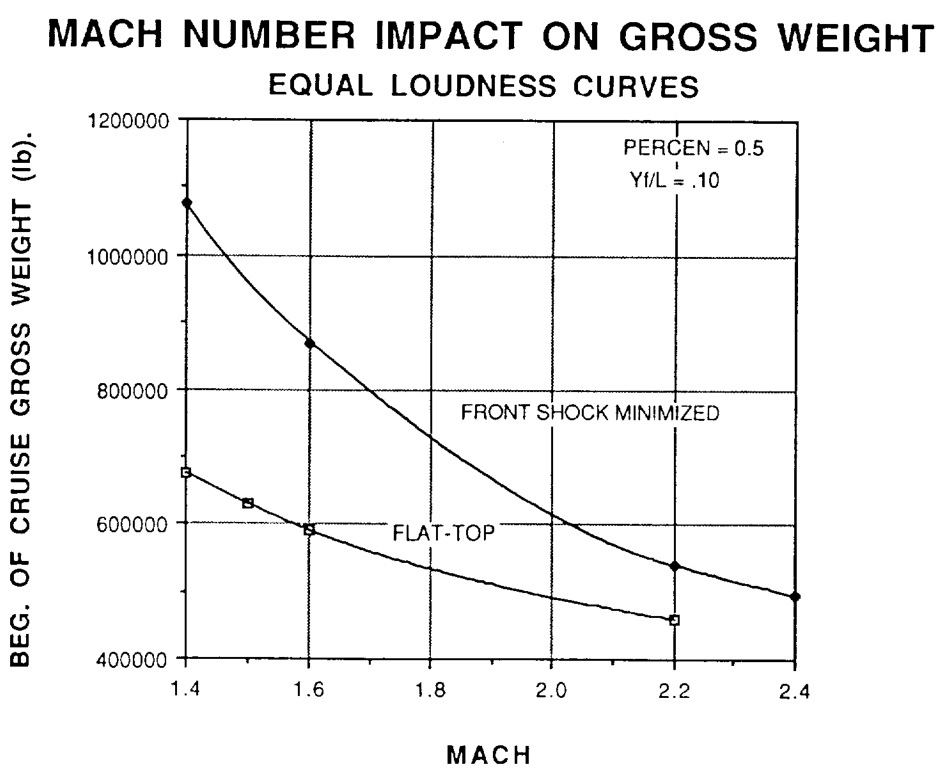
The SEEB code is the most widely used tool for sonic boom minimization today. It has proven to be a powerful tool for designing low-boom configurations and has led to the design of several sonic boom wind tunnel models. Some of the limitations of the SEEB code include a restriction to two basic waveform types (front shock and overpressure minimized), and a lack of adequate treatment of off-track waveforms (SEEB only addresses the undertrack waveform).

CURRENT LOW-BOOM TECHNOLOGY

WAVEFORM SHAPING

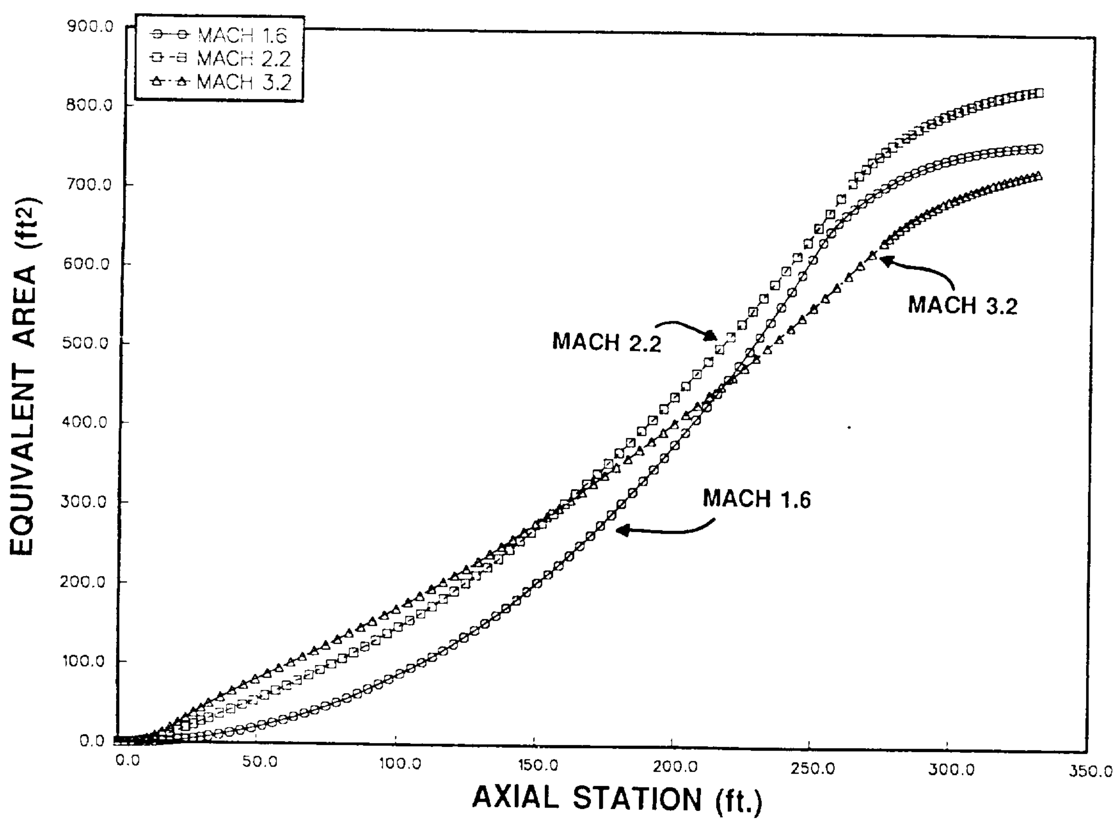
- CURRENT ACTIVITY CENTERS ON AREA DISTRIBUTIONS FROM SEEB COMPUTER CODE (SEEBASS/GEORGE SCHEME)
    - GOOD STARTING POINT (IT WORKS)
    - LIMITED IN PARAMETER SPACE
    - LIMITED TO UNDERTRACK WAVEFORM

The choice of Mach number for a low-boom aircraft is crucial to the success of the resultant design. The physics of waveform shaping require vastly different combinations of shapes and weights to achieve similar loudness levels on the ground. The figure below shows the theoretical beginning of cruise weight allowable for low-boom configurations vs. design Mach number for the two classes of waveforms to achieve equal loudness levels. Two things are immediately evident; higher Mach numbers severely limit the weight of low-boom aircraft, and the flat-top (overpressure minimized) waveform is much more restrictive than the front shock minimized waveform, particularly at lower Mach numbers.



The choice of Mach number strongly impacts the shape of the low-boom aircraft as well as the weight. Shown below are equivalent areas of equal loudness for three Mach numbers; 1.6, 2.2, and 3.2. Whereas the previous figure showed a clear advantage to designing for lower Mach numbers, in this figure it can be seen that the equivalent area distribution required at Mach 1.6 is much more slender than that required at Mach 2.2 or 3.2. This can cause problems in several areas including structures, payload capability, and balance. This figure, coupled with the previous one, illustrates some of the trade-offs involved in choosing a design Mach number for low-boom aircraft. The best low-boom design is one that represents the optimum compromise between all of the various parameters.

EQUAL LOUDNESS EQUIVALENT AREAS



Based on some of the data shown previously, Douglas Aircraft conducted low-boom configuration studies under the 1990 NASA contract with a mixed Mach number configuration flying at Mach 1.6 overland and Mach 3.2 overwater. Mach 1.6 was chosen overland based on sonic boom criteria (primarily weight considerations) for a front shock minimized waveform, and Mach 3.2 was chosen overwater to maintain the maximum level of productivity possible. The initial cruise weight and altitude were set at 669,000 lb. and 42,000 ft. respectively. Internal SEEB parameters include a nose bluntness ratio of 0.1, secondary pressure rise ratio of 0.7, and front/rear shock ratio of 1.0.

The sonic boom goal for 1990 is to achieve a Stevens' MkVII perceived loudness[3] level of 90 PLdB undertrack at the beginning of cruise. The MkVII loudness metric is appropriate for high-energy, impulsive sounds and has been proven accurate for estimating and tracking human subjective response to sonic booms, including shaped booms.[4]

DAC 1990 CRAD DESIGN

- MACH 1.6 OVERLAND / MACH 3.2 OVERWATER (30 % OVERLAND MISSION)
- 669,000 lb. BEGINNING OF CRUISE WEIGHT
- 42,000 ft. BEGINNING OF CRUISE ALTITUDE
- SEEB PARAMETERS:
  - NOSE BLUNTNESS (Yf/L) = 0.1
  - SECONDARY PRESSURE RISE = 0.7
  - FRONT/REAR SHOCK RATIO = 1.0
- SONIC BOOM DESIGN GOAL - STEVENS MkVII LOUDNESS < 90 PLdB

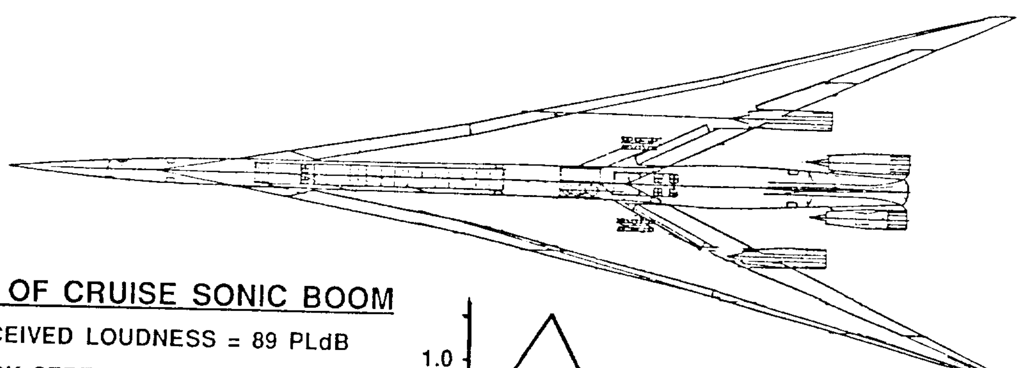
By the end of the contract work period a low-boom configuration was defined to meet the desired sonic boom goals. The configuration, shown below, is 355 ft. long, and carries 286 passengers mixed class. The beginning of cruise, undertrack sonic boom (also shown) has a perceived loudness of 89 PLdB, 1 dB under the design goal. The desired front shock minimized shape was achieved in the front portion of the waveform with a 0.6 psf. front shock. Some weak shocks persisted in the middle of the waveform. These shocks slightly increase the loudness of the boom.

Salient characteristics of the low-boom aircraft, named the SB14, include a high sweep wing to generate the desired lift distribution, two aft mounted engines to smooth the volume distribution, and wing tips extending beyond the aft fuselage to smooth the transition back to free stream flow. It is also worthy to note that the SB14 has no horizontal tail.

SONIC BOOM STATUS

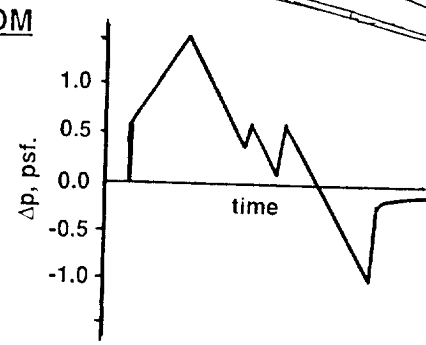
SEPT. 1990

MACH 3.2 OVERWATER/ MACH 1.6 OVERLAND
286 PASSENGERS
355 FT. LENGTH

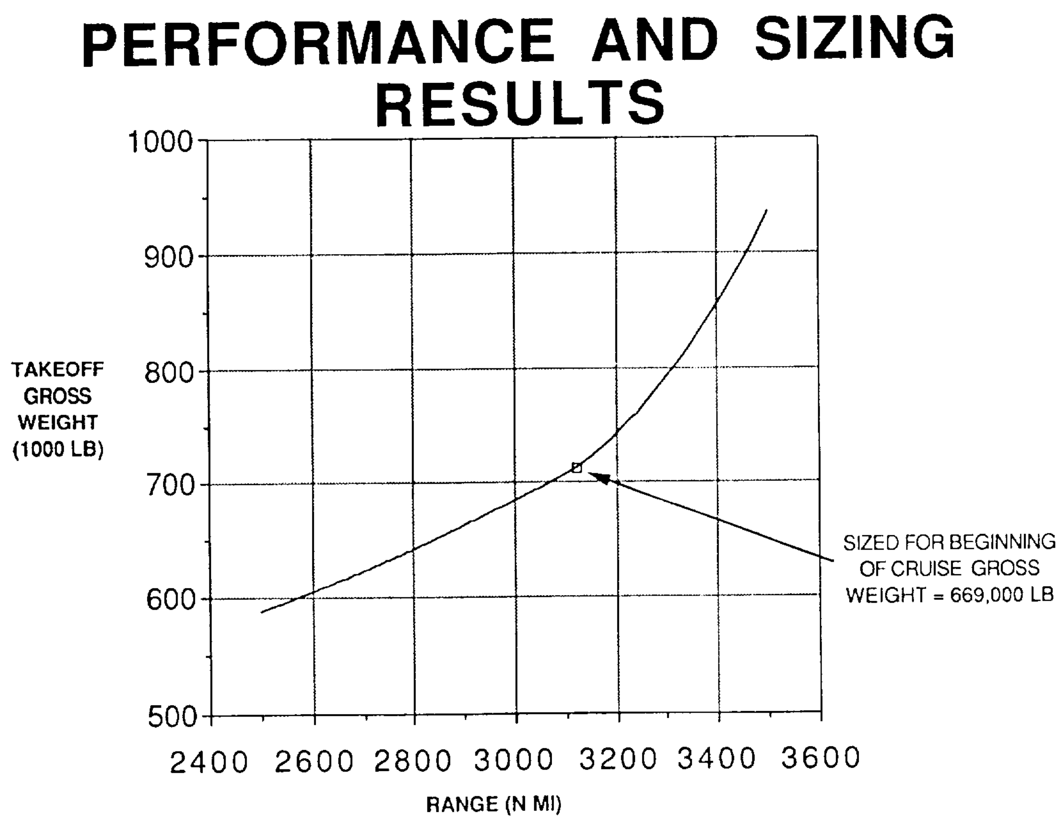


BEG. OF CRUISE SONIC BOOM

- PERCEIVED LOUDNESS = 89 PLdB
- SHOCK STRENGTH = 0.6 psf.
- MAX. OVERPRESSURE = 1.5 psf.

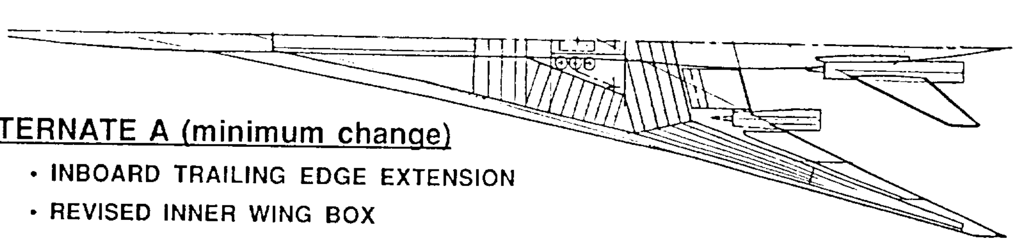


The overall performance of the SB14 suffers from poor low-speed aerodynamic characteristics. poor wing structural qualities , and balance (high speed trim) problems. The figure below shows that the mission range is 3150 n.mi. for a beginning of cruise weight of 669,000 lb., roughly half of the 6500 n.mi. baseline design goal. Unlike most aircraft, the SB14 cannot be sized up to increase the range because the sonic boom design point must be strictly adhered to.



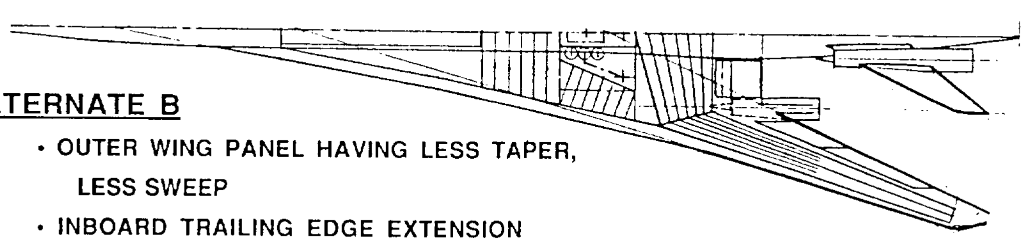
Several configuration modifications have been identified for the SB14 to improve its overall performance. These modifications focus on bringing down the weight of the wing and improving the low speed aerodynamics and high speed trim characteristics. Two of the potential modifications are shown below. Alternate A represents a minimum planform change approach where the inner wing box is modified and the inboard trailing edge is extended in conjunction with mounting the two aft engines on a vee-tail. Alternate B represents a more drastic modification where the outer wing panel is unswept, the outboard wing chord is increased, and a large chord inboard wing box is incorporated along with the modifications of Alternate A. It is believed that these modifications can bring the performance of the low-boom aircraft back up to par with the baseline standard.

POTENTIAL CONFIGURATION MODS



ALTERNATE A (minimum change)

- INBOARD TRAILING EDGE EXTENSION
- REVISED INNER WING BOX
- INBOARD AFT ENGINES ELEVATED ON AFT VEE TAIL

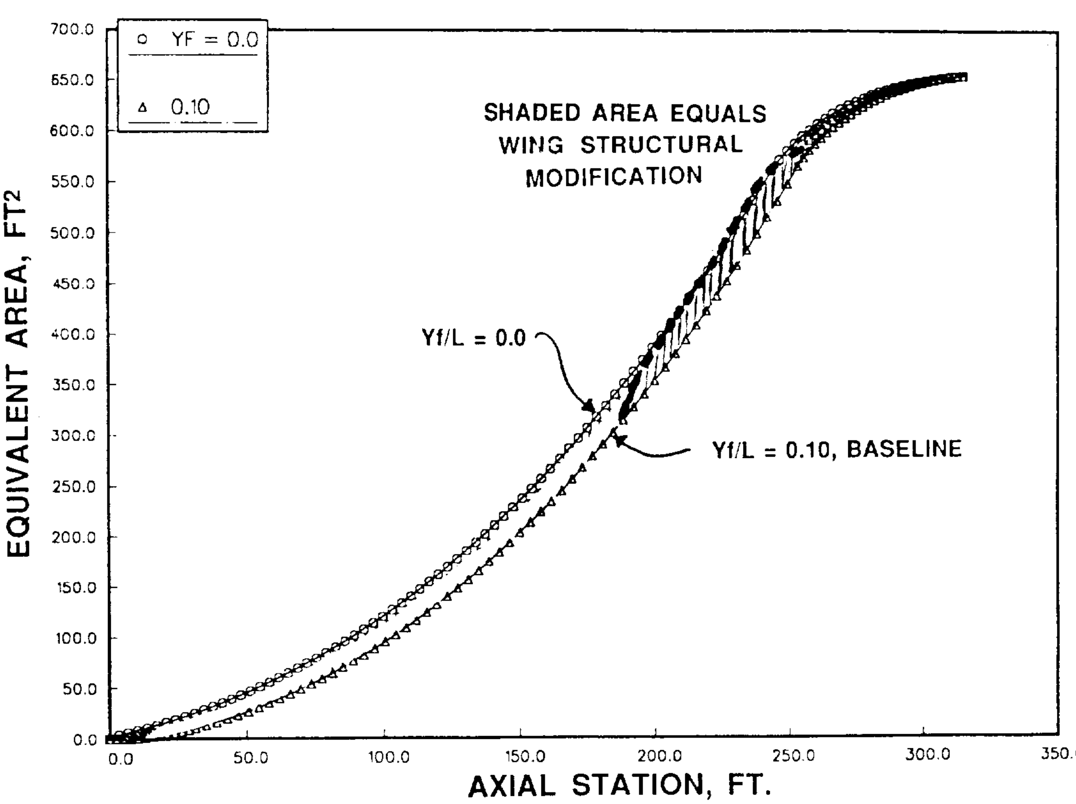


ALTERNATE B

- OUTER WING PANEL HAVING LESS TAPER, LESS SWEEP
- INBOARD TRAILING EDGE EXTENSION
- LARGE CHORD INBOARD WING BOX
- INBOARD AFT ENGINES ELEVATED ON AFT VEE TAIL

The configuration modifications shown in the previous figure can be incorporated with little to no impact on the sonic boom if they are implemented carefully. In the figure below two equivalent area distributions are shown. Both represent ground waveforms less than or equal to the 90 PLdB goal. One of the area distributions was generated for a nose bluntness factor of 0.10 corresponding to the 1990 design point. The other area distribution was generated with a nose bluntness factor of 0.0. The shaded area between the two curves represents the estimated area increase from the modifications shown previously for Alternate A. By increasing the nose bluntness (decreasing the factor) it is possible to incorporate the desired configuration modifications with little to no sonic boom penalty.

EQUIVALENT AREA MATCHING

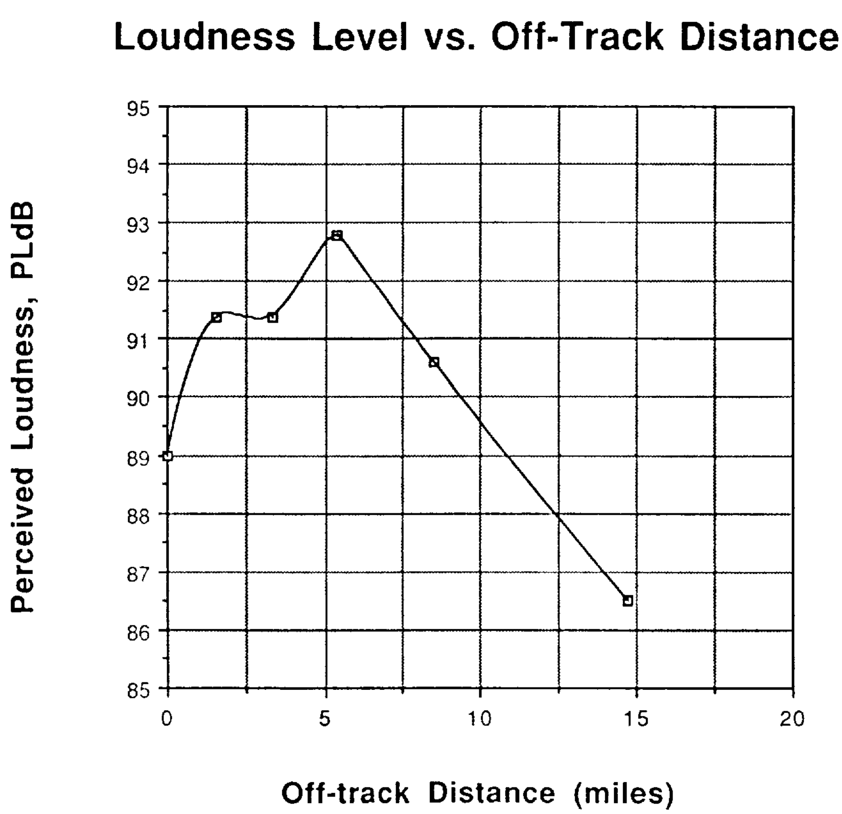


The previous figure showed that it is possible to incorporate the desired modifications to the SB14 wing by increasing the nose bluntness of the configuration. The corresponding increase in wave drag from such an increase is shown in the table below. By changing the nose bluntness parameter (Yf) from 0.10 to 0.0 the wave drag is increased by 13.7% which in turn decreases the L/D_{max} from 8.576 to 8.446 (1.52%). This represents a minimal aerodynamic impact and is not significant compared to the potential weight savings that can be achieved through implementing the planform changes mentioned previously. These studies indicate that the performance of the SB14 can be brought up to the baseline standard with minimal changes to the sonic boom levels and the aerodynamic drag.

IMPACT OF NOSE BLUNTNESS ON AERODYNAMIC CHARACTERISTICS

Yf	Cdwave	Δ Cdwve (%)	Cdmin(tot)	L/Dmax	ΔL/Dmax (%)
0.10	.001373	0.0	.00707	8.576	0.0
0.05	.001430	4.2	.00712	8.555	-0.24
0.00	.001561	13.7	.00723	8.446	-1.52

It was mentioned earlier that the SEEB code is limited to undertrack waveforms. This is not usually considered to be a serious limitation because for most aircraft the sonic boom levels decrease off-track, primarily because of the increased attenuation realized over greater propagation distances. The plot shown below of loudness level vs. off-track distance at the beginning of cruise indicates that this is not the case for the SB14. The off-track boom reaches a peak level of 92.7 PLdB before attenuating out to the cutoff value of 86.5 PLdB on the edge of the carpet. This atypical increase in off-track levels is the result of a lack of attention to off-track area growth during the initial design stage for the SB14. Currently no methodology exists for minimizing off-track booms, though it is clearly prescribed by results such as these.



SUMMARY

- CURRENT EFFORTS LIMITED TO SEEB CODE, EXTENSIONS OF PARAMETER SPACE MAY BE USEFUL
- SEEB F-FUNCTION AND DESIGN PARAMETERS EXERT CONSIDERABLE INFLUENCE ON AIRCRAFT GEOMETRY
- 1990 STUDY AIRCRAFT MEETS LOW BOOM CRITERIA UNDERTRACK BUT HAS UNACCEPTABLE PERFORMANCE
- PLANFORM AND STRUCTURAL MODS APPEAR FEASIBLE TO ENHANCE PERFORMANCE
- OFF-TRACK LEVELS MUST BE MONITORED AND CONTROLLED

FINAL THOUGHT

QUESTION IS NOT <u>IF</u> LOW-BOOM AIRCRAFT CAN BE DESIGNED,

BUT RATHER <u>WHEN</u> IT WILL BE DESIGNED,

AND <u>WHEN</u> WILL THE TECHNOLOGY BE AVAILABLE.

TRUE FINAL THOUGHT (I PROMISE)

" IF YOU THINK ABOUT ANYTHING LONG ENOUGH
SOMETHING IS BOUND TO POP INSIDE YOUR HEAD
BESIDES A COLD"

- VIN SCULLY

REFERENCES

1. George, A.R., and Seebass, R., "Sonic Boom Minimization Including Both Front and Rear Shocks", AIAA Journal, 9 (10), 2091-2093, October 1971.

2. Darden, C.M., "Sonic Boom Minimization With Nose Bluntness Relaxation", NASA TP 1348, 1979.

3. Stevens, S.S., "Perceived Level of Noise by Mark VII and Decibels (E)," JASA, 51 (2) (Part 2), pp. 575-601, 1972.

4. Niedzwiecki, A., and Ribner, H.S., "Subjective Loudness of Sonic Boom: N-Wave and Minimized ('Low Boom') Signatures," UTIAS TN-215, 1977.