# Application of Heat and Force Fields to Sonic-Boom Minimization

David S. Miller* and Harry W. Carlson†
*NASA Langley Research Center, Hampton, Va.*

**There is much interest and some controversy concerning the possibility of sonic-boom suppression through airstream alteration by application of force or heat fields. The present paper presents a discussion of the relationship of these more exotic schemes to conventional approaches involving shaping of the aircraft itself, describes the required flowfield alteration for the more promising heat field method and provides a first estimate of power requirements. The results of the study indicate that finite rise-time signatures which offer substantial sonic-boom alleviation are theoretically obtainable but that severe, if not unsurmountable, problems of implementation are presented.**

## Nomenclature

$A_E$ = effective cross-sectional area due to a combination of airplane lift, airplane volume, and the altered airstream
$A_0$ = initial phantom-body cross-sectional area
$A_s$ = cross-sectional area of airstream
$h$ = airplane flight altitude or perpendicular distance from model to measuring probe
$l$ = airplane or model reference length
$l_p$ = phantom-body length
$M$ = Mach number
$P$ = power summation, $\int_0^x \left(\frac{dP}{dx}\right) dx$ with circulation $\int_0^x \left|\frac{dP}{dx}\right| dx$ without
$dP/dx$ = power distribution
$\Delta p$ = incremental pressure because of the flowfield of airplane or model
$\Delta t_r$ = rise time of sonic-boom pressure signature
$T_0$ = stagnation temperature
$x$ = distance measured along longitudinal axis from airplane nose, model nose, or initial change in phantom-body area (i.e., phantom-body nose)
$\beta$ = $(M^2 - 1)^{1/2}$

## Introduction

THE sonic boom continues to present one of the most severe problems confronting the development of an efficient supersonic transport system. It is estimated that current plans to prohibit supersonic flight over populated areas will limit worldwide supersonic transport sales to less than half the potential market. Thus, a solution to the sonic-boom problem would have a profound influence not only on the current supersonic transport program, but also on the entire structure of the air-transport system. Although intensive research efforts of the past decade have led to a general understanding of the sonic-boom phenomena and the development of reliable prediction and minimization techniques, no means has been found to reduce the sonic boom to a level which unquestionably would be acceptable for routine overland operation of supersonic transports.

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* Aerospace Technologist, Supersonic Analysis Section, Large Supersonic Tunnels Branch, High-Speed Aircraft Division.
† Head, Supersonic Analysis Section, Large Supersonic Tunnels Branch, High-Speed Aircraft Division. Member AIAA.

Recently, there has been much interest and some controversy concerning the utilization of heat or force fields to alter the airflow in the vicinity of the airplane in a manner which might provide substantial improvements in sonic-boom characteristics. The electroaerodynamic concept advanced by Cahn,[1] which on re-examination[2] appears to be unfeasible for any practical degree of boom alleviation, at least has served to stimulate imaginative consideration of unexplored approaches. In this paper, basic concepts for application of these more exotic schemes to sonic-boom minimization are formulated, are related to the well-established body of information concerning sonic-boom generation and propagation, and are compared with more conventional minimization techniques. For the more promising heat-field concept, preliminary estimates of variations in flowfield properties and power requirements for a representative supersonic transport are presented.

## Conventional Minimization Techniques

Numerous studies have attacked the problem of defining configuration requirements for sonic-boom minimization under various constraints. An illustration of conventional minimization techniques, which employ shaping of the aircraft to result in a favorable volume and lift development and a more acceptable pressure signature, is given in Fig. 1. For currently operational supersonic aircraft, a classical $N$ wave, as shown at the left of the figure, has been found to exist for most flight conditions. For these aircraft, shaping for sonic-boom minimization[3–5] could affect a moderate reduction in bow-shock overpressure and signature impulse (perhaps about 15%) but the basic $N$-wave signature shape would remain.

For somewhat longer and more slender configurations, representative of supersonic transport designs, a near-field signature may be expected to extend from the aircraft to the ground for some portions of the flight plan. Because the signature shape depends on the airplane shape, further reductions in overpressure, as illustrated by the plateau signature, could be achieved through airplane design modifications.[6–9] Although the plateau signature achieves sonic-boom benefits, the shocks and the attendant sonic-boom noise still exist.

Upon relaxation of all realistic restraints on airplane length and with a very carefully controlled effective area development, the shocks themselves could theoretically be eliminated[10,11] as depicted by the finite-rise-time signature shown at the right of Fig. 1. However, theoretical calculations indicate that in order to implement this minimization tech-

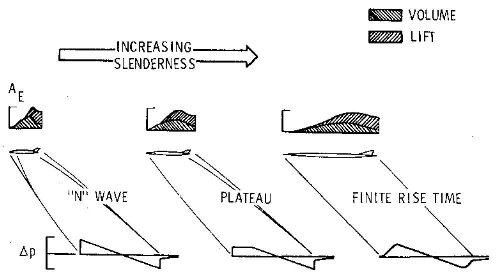


**Fig. 1 Airplane design for sonic-boom minimization.**

nique it would be necessary to increase the lengths of supersonic transports now under development by a factor of 3 or more with no attendant increase in airplane weight. Thus, at the present time a finite-rise-time signature appears to be a desirable but unobtainable goal. Alternate methods for the achievement of finite-rise-time signatures through employment of heat or force fields will be the subject of further discussion in this paper; however, at this point, it seems appropriate to present evidence of the applicability of present sonic-boom prediction methods and of airplane shaping techniques for sonic-boom reduction.

Current sonic-boom prediction and minimization techniques are based on the solution for the supersonic flow about bodies of revolution developed by Whitham[12] and on the theoretical work of Hayes,[13] which relates airplane geometry and lifting effects to equivalent bodies of revolution. With the proper equivalent body used to represent the airplane, present techniques, utilizing high-speed digital computers,[14] permit the definition not only of the far-field pressure pattern where an $N$ wave has formed, but also of the complex near-field pressure pattern where the signature characteristics depend on the detailed airplane shape. Studies in which theoretically determined pressure signatures are compared with experimental data from wind-tunnel and flight-test programs indicate that present techniques provide reasonably accurate estimates of the sonic-boom characteristics for a wide variety of airplanes and operating conditions.[15–18]

A sample of wind-tunnel test data which serves to substantiate the applicability of Hayes-Whitham techniques to both the prediction and minimization problem is given in Fig. 2. Signature measurements were made at a variety of flowfield positions and test conditions for the 4-in.-long supersonic transport models shown in the figure. These particular signatures were obtained five body lengths below the model at a Mach number of 1.4 and a lift coefficient of 0.1. Effective area developments used in the derivation of the theoretical signatures are shown in the inset sketches. Although the signature for the basic model is quite complex, there is seen to be excellent agreement with the theoretical prediction. The signature shown at the right was obtained for a model with a fuselage modification designed to produce a plateau signature. The desired result was not quite attained but a good approach has been made, and the extreme sensitivity of the signature shape to small changes in model

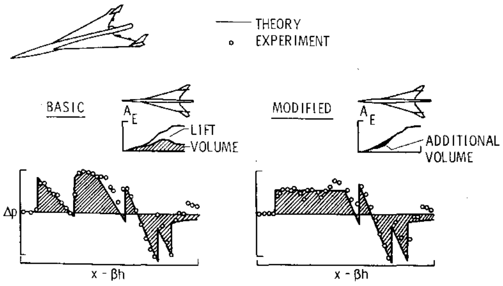


**Fig. 2 Wind-tunnel verification of prediction and minimization techniques, $M$ = 1.4, $h/l$ = 5.**

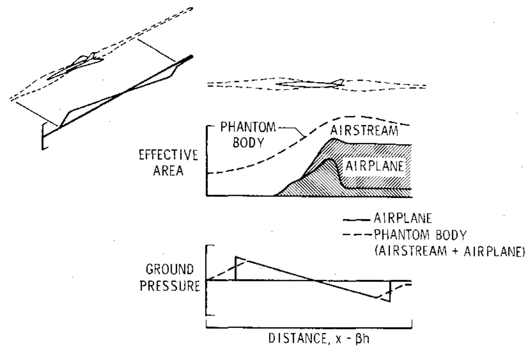


**Fig. 3 Phantom-body concept.**

shape is clearly shown. The same theory applied to an airplane of 400,000 lb flying at 40,000 ft and $M$ = 1.4 indicates a maximum positive overpressure of 2.2 psf for the design at the left and a value of 1.3 psf for the modified design. Theoretical estimates for the basic configuration at $M$ = 2.7 and $h$ = 60,000 ft indicate the existence of a fully developed $N$ wave which precludes effective application of this minimization concept for cruise conditions.

## Phantom-Body Concept

Minimization techniques discussed thus far have required changes in the physical shape of the airplane; however, it may be possible to alter the airflow about the airplane by the employment of heat or force fields in such a way as to create desired pressure signature characteristics without drastic changes in the airplane dimensions.[11,19] A phantom-body or airstream-alteration concept for achievement of the highly desirable finite-rise-time signature is shown in Fig. 3. Depicted in the figure is an effective area development of an airplane which would produce an $N$ wave and the effective area development of a phantom body, resulting from the combination of an altered airstream and the airplane, which would generate a signature without shocks on the airplane flight track. The heat or force field must be distributed very carefully and must extend well ahead and well behind the airplane to insure a sufficiently long and properly shaped phantom body. In fact, without careful planning the flow-field alterations could easily aggravate rather than improve the situation. A massive heat addition localized at the airplane nose, for example, would create an intense bow shock and an obvious degradation of sonic boom characteristics. Even with a properly constructed axial distribution, the airplane effective area assumes a different shape and magnitude at ground positions away from the flight track, and thus, shock elimination over the whole of the ground exposure area requires carefully controlled azimuthal as well as longitudinal distribution of the airstream alteration.

Alternate applications of the phantom-body concept which would be equivalent within the assumptions of area-rule considerations on which present theory rests are illustrated in Fig. 4. The altered airstream whose boundary streamlines are depicted by dashed lines need not envelop the airplane as shown at the left, but may be displaced below the airplane as shown at the center, provided the displacements occur along Mach cutting planes. The airstream alteration

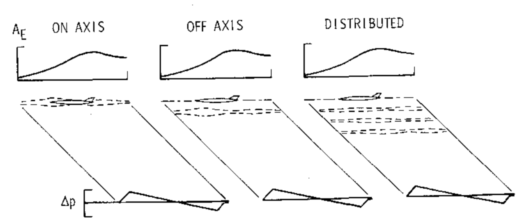


**Fig. 4 Equivalent application of concept.**

could also take place over a wider area as shown at the right, the criterion being that area rule dictated effective area development of the airstreams and airplane combine to create the specified shape for each of the azimuth angles. For simplicity, the following analysis is restricted to the azimuth angle corresponding to the flight track and treats the on-axis case as shown at the left; however, it can be seen that analysis of the other systems would not be different in principle. The analysis is also restricted to the heat-field method which appears to offer more hope for practical implementation. A treatment of both the heat and force-field methods has been given in NASA TN D-5582.

## Analysis

The theoretical method employed to analyze the altered airstream flow properties and to estimate the heat distribution and power requirements is based on the assumption that the airstream which is to be shaped around the airplane can be treated as steady, one dimensional, inviscid channel flow of a perfect gas.

For a given airplane and given flight condition, the phantom-body area development which will completely envelop the airplane and produce a desired sonic-boom signature can be determined. The forepart of the area development will have a growth of area that varies as the $\frac{5}{2}$ power of the distance (an isentropic spike). The Whitham theory for a uniform atmosphere can be employed to define the required length and diameter relationship to prevent bow shock formation for a specified Mach number and altitude. Prevention of a tail shock is accomplished by a design process for the remainder of the phantom-body area development which involves trial and error application of a computing program solution of the Whitham equations.[14] Account of the favorable "freezing" effect of a real atmosphere through employment of the atmospheric propagation program of Hayes[21] requires further iteration to define phantom-body shape characteristics for a specified rise time.

The airstream channel is defined as the difference between the phantom-body cross-sectional area and the effective cross-sectional area of the airplane. The boundary conditions of longitudinal pressure distribution along the channel are established by calculating the surface pressure on the phantom body using small-disturbances theory[20] and by assuming that the pressure is constant across the channel. The governing differential equations written in terms of influence coefficients[22] are then solved by iteration for successive increments along the channel. A thorough description of the governing equations and solution techniques employed is given in Ref. 19.

The applicability of the present simplified analysis in treating practical problems of phantom-body concept implementation can be assessed by examining the assumptions and simplifications employed in its development. One basic assumption is that flow variations within a single heated airstream channel are sufficient to provide the distribution of local compressions and expansions necessary for the desired airstream alterations. It is recognized that the application of this concept to an actual airplane configuration would require a detailed three-dimensional description of the required heat field and would thereby necessitate the employment of not one but a multitude of streamtubes. This more complex approach would provide information concerning the radial and azimuthal variations of the heat field in addition to the longitudinal variations obtained from the present method; however, neglecting the radial and azimuthal variation greatly reduces the complexity of the analysis procedure and is not expected to significantly alter the results of this preliminary study.

Another basic assumption is that all of the distributed heat energy is confined within the boundaries of the airstream and is completely effective in creating the desired airstream alterations. A more realistic approach would consider heat transfer across the airstream boundaries which would in turn influence the entire flowfield in a different manner than does the heating with no heat transfer. The relationships between the heating rates and airstream variations for this case cannot be easily established and are beyond the scope of this preliminary analysis. Under the assumption of no heat transfer, the manner in which the local heating influences the flow is well defined.

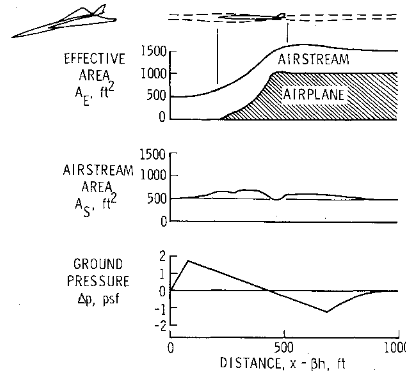


**Fig. 5 Concept application for a supersonic transport, $M$ = 2.7, $h$ = 60,000 ft.**

It is also recognized that for strong shocks formed immediately at the airplane surfaces, the airstream expansions might not be fully effective in providing a cancellation; however, a typically pointed airplane nose or a subsonic-leading-edge wing need not form strong shocks and cancellation should be possible. Other complicating factors are the effects that variations in the airstream flow properties will have in altering the aerodynamic performance and flowfield characteristics of the airplane and the effects that airplane produced disturbances will have on the airstream; this interaction between the airstream and the airplane is neglected for results presented in this paper.

Subject to the previously discussed assumptions and simplifications, the present method of analysis is believed to be sufficient to indicate the nature of the altered airstream flow properties and to make preliminary estimates of the required heat distribution and minimum power requirements.

## Concept Application

The problems encountered in employing the phantom-body concept to minimize the sonic boom can best be explored by applying the concept to an actual airplane configuration. A typical proposed supersonic transport having a length of 300 ft and a cruise Mach number of 2.7 at an altitude of 60,000 ft is the base-line configuration for the following discussion. The cruise weight of the airplane is assumed to be 575,000 lb and no account is taken of weight increases due to onboard equipment required to generate the phantom body.

Illustrations of the results of the study as reported herein are restricted to the heat-field application which at present appears to be of greater practical interest. In Ref. 19, attention is given to both the heat- and the force-field methods.

As shown in Fig. 5, the creation of a finite rise time signature ($\Delta t_r$ = 0.03 sec) required airstream modification extending over 200 ft ahead of and over 400 ft behind the 300-ft-long airplane. An initial airstream channel area of 500 ft$^2$ was selected for reasons which will be discussed later. It is seen that because a typical airplane configuration with irregularities in effective area development was chosen, the smooth effective area required for the phantom body can be created only with a modified airstream channel which also displays irregularities.

Local variations in the airstream channel area cause local variations in flow properties as illustrated in Fig. 6. Extreme variations in Mach number and temperature could,

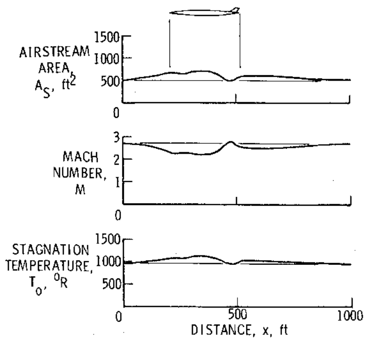


**Fig. 6 Airstream flow properties.**

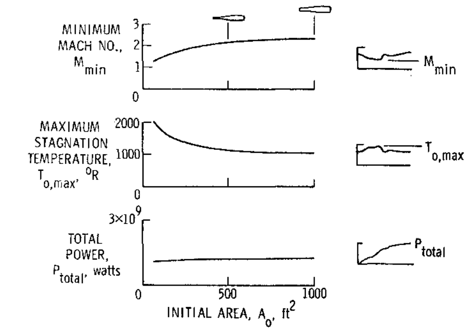


**Fig. 8 Phantom-body initial area considerations.**

of course, result in a degradation of aircraft aerodynamic performance and would intensify already severe heating problems. A very large initial channel area would minimize these problems but would make the task of insuring the proper distribution of heat that much more difficult.

The power requirements shown in Fig. 7 demonstrate the severity of the problems to be encountered in attempts at practical implementation of the phantom-body concept. Irregularities and extreme gradients in the local power distribution indicate that great care would be required in the selection and arrangement of heating devices. An even more difficult problem is posed by the necessity of power removal or refrigeration dictated by the presence of the negative values of local power. As will be explored in somewhat greater detail later, the power removal requirement could be avoided by reshaping of the airplane, but this in itself would be a rather drastic measure. From the power summation plot, it is seen that in the forepart of the airstream, ahead of the airplane nose, it is necessary to add power to the airstream amounting to more than the propulsive power output supplied by engines producing an estimated 75,000 lb of thrust for the assumed flight conditions. Additional requirements for heating and refrigeration along the remainder of the phantom-body length would, if supplied by separate devices, bring the total power requirement to about $12 \times 10^8$ w or more than four times the propulsive power. Even if a reasonably efficient system for recycling heat energy could be devised to result in relatively low net power consumption, the equipment would be sized by the lower curve, a power requirement of more than $4 \times 10^8$ w.

It should be recognized that in the unlikely event of the development of efficient means of processing the airstream to drastically reduce cross-sectional area, the ideas of E. L. Resler, Jr.[23] would be worthy of further consideration. His approach may be considered as an extreme application of the phantom-body concept in which a constant area body would be created by stream tube reduction only. If this could be accomplished, no disturbance of any kind would be felt outside the phantom-body boundaries.

An important factor in analyzing the phantom-body concept is the selection of the phantom-body capture area $A_0$. Variations in the flow properties and the total power requirements with changes of $A_0$ are shown in Fig. 8. As expected,

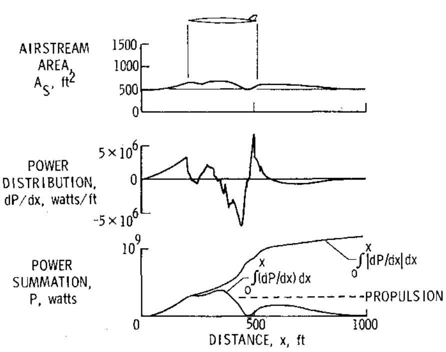


**Fig. 7 Airstream power requirements.**

the flow properties are very sensitive for small values of $A_0$; therefore, to avoid large changes in the flow properties which in turn alter the airplane performance characteristics, a large initial area is desired. The total power is fairly insensitive to changes in $A_0$ throughout the range considered; thus, an area of 500 ft$^2$ appears to be a reasonable selection. Larger values which do not significantly reduce flow property variations would create even greater problems of heat-field distribution.

The phantom-body length is the primary factor upon which the sonic-boom signature characteristics as well as the power requirements depend. Figure 9 shows how the rise time $\Delta t_r$ increases and the maximum ground overpressure $\Delta p_{max}$ decreases as the phantom-body area development is stretched out. In selecting a reasonable body length, no values less than 900 ft were considered because lengths less than that produce no finite rise time. Allowance has been made for the somewhat reduced lengths which result from an exacting treatment of real atmosphere effects afforded by use of the Hayes computer program. As expected, the power requirements increase with increasing length. The desired rise time is the primary factor for defining the necessary phantom-body length and the total power requirements. A rise time of 30 msec and a corresponding body length of 975 ft was chosen for the example to provide a near minimum power requirement while offering significant noise benefits[24] and a margin against possible adverse effects of atmospheric distortion.

The results of the studies reported in NASA TN D-5582 indicate that power requirements become less for lower Mach numbers, but not to such an extent that the scheme appears to be more practical. For higher Mach numbers, which are more attractive from an economic standpoint, the power requirements are greater. For a given Mach number, power requirements are not significantly less at altitudes above or below those normally selected for cruise economy.

## Thermal Fin Concept

This discussion would not be complete without mention of recent studies of ingenious methods for concept implementation conducted by S. B. Batdorf and R. J. Swigart of Aerospace Corporation.[25,26] Among the ideas explored were the use of a powered tethered drone whose fuel for propulsion and heating would be supplied through the tether, the use of a continuous in-line train of explosive pellets ignited upon launch from the airplane, and the use of what has been termed a thermal fin.

The more practical of these ideas appears to be the thermal fin which will be described with the aid of Fig. 10. The unique features of the thermal fin scheme are the direct burning of fuel to produce the heat field and the introduction of the heat below the airplane itself. S. B. Batdorf points out that with direct burning of the jet fuel the power requirements for bow-shock alleviation are not necessarily prohibitative; and that off-axis heating in accordance with area-rule concepts previously discussed would be more attractive for prac-

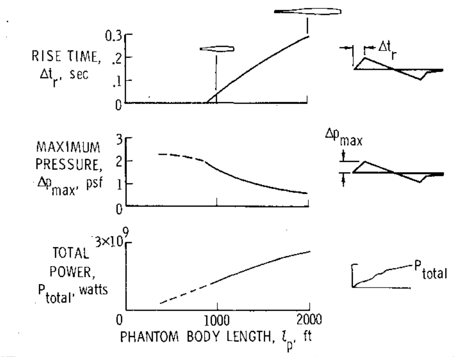


**Fig. 9 Phantom-body length considerations.**

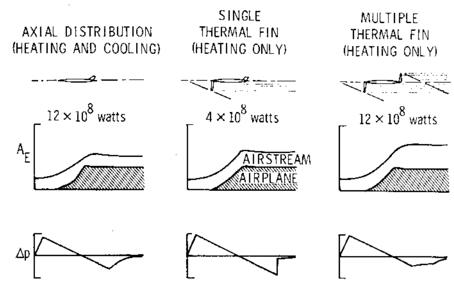


**Fig. 10 Thermal fin implementation.**

tical implementation, especially from the standpoint of the aircraft thermal environment and safety.

The conceptual single thermal fin arrangement illustrated at the center of the figure is compared with the previously discussed axial distribution of heating and cooling shown at the left. The retractable fin which is required to extend about 80 ft below the aircraft nose would, of course, incur problems of aerodynamic performance, stability and control, structural dynamics, and weight that have not been fully explored. Because the thermal fin method as presently conceived employs heating only, the airplane must be reshaped and the phantom-body nose lengthened by about 27 ft to provide an airstream which requires no heat removal. With direct burning during the supersonic portion of the flight for the example chosen, it is estimated that the power requirement of about $4 \times 10^8$ w can be met with about a 20% increase in onboard fuel. It will be noted that while a single fin with heat addition only could theoretically eliminate the bow shock, the tail shock would remain unless the aft portion of the phantom body were reshaped in some manner.

A preliminary study of the additional heating requirements of a second thermal fin for tail-shock elimination has been carried out. The solution was not iterated to the point where all shocks are removed, but those that remain are small and the over-all power requirement is believed to be a reasonable estimate. From this study, it is concluded that total elimination of shocks by employment of thermal fins would require about 60% additional onboard fuel with no account being taken of weight and performance penalties of the system. There is however, the possibility that some of the propulsive thrust could be supplied by the thermal fins, thus reducing the propulsion system requirements. It should be pointed out that the second thermal fin is only one approach for elimination of the tail shock and that other, not so obvious, extensions of the phantom-body concept should be explored.

## Conclusion

A study has been made of the potential benefits to be gained, the problems encountered, and the power required in the application of heat-field concepts to the sonic-boom alleviation problem. The results indicate that, subject to the simplifying assumptions made in the study, finite rise-time signatures which would practically eliminate the shock-wave noise are theoretically obtainable but require the creation of a carefully controlled heat field extending far ahead of and behind the airplane itself. A complicating factor is the not insignificant variation of the flow properties within the phantom body which may alter the airplane aerodynamic performance. There is also some doubt that, in the practical application of these schemes, airplane-produced shocks could be completely cancelled and thereby prevented from penetrating the phantom body and propagating to the ground.

To assess some of the problems to be encountered in attempts at practical implementation of the concept, an illustrative example for a representative supersonic transport configuration at a cruise Mach number of 2.7 has been treated. Under the simplifying assumptions of the study and for idealized conditions with weightless power generation equipment and no energy dissipation, a power expenditure considerably greater than the propulsive power output supplied by the engines to sustain steady level flight was found to be necessary to create the heat field ahead of and surrounding the airplane. It was also discovered that not only must some means be found to deliver continuously large quantities of power to the air in the proper way, but that unless extensive airplane redesign is undertaken means must also be provided to extract power from the air in a prescribed manner.

The thermal fin implementation of the phantom-body concept proposed by Aerospace Corp. can be extended to prevent formation of both the bow and tail shock without the necessity of power extraction or circulation; however, reshaping of the airplane as well as the thermal fin heat addition is required to achieve the desired result. For a typical SST at cruise conditions, it is estimated that with direct burning of fuel the bow shock could theoretically be eliminated with 20% additional onboard fuel but that elimination of all shocks would require about 60% additional fuel.

In spite of all the problems and limitations of the phantom-body concept for sonic-boom alleviation (those discussed herein, and others not treated) it is believed that further study is warranted. There is no other approach yet suggested for elimination of sonic-boom shocks that is not directly contradictory to the accumulated knowledge of sonic-boom phenomena or that does not require airplane lengths far beyond any present contemplations.

## References


[1] Cahn, M. S. and Andrew, G. M., "Electroaerodynamics in Supersonic Flow," AIAA Paper 68-24, New York, 1968.

[2] Cheng, S. and Goldburg, A., "An Analysis of the Possibility of Reduction of Sonic Boom by Electro-Aerodynamic Devices," AIAA Paper 69-38, New York, 1969.

[3] Jones, L. B., "Lower Bounds for Sonic Bangs," *Journal of the Royal Aeronautical Society,* Vol. 65, No. 606, June 1969, pp. 433–436.

[4] Carlson, H. W., "The Lower Bound of Attainable Sonic-Boom Overpressure and Design Methods of Approaching This Limit," TN D-1494, 1962, NASA.

[5] Ryhming, I. L. and Yoler, Y. A., "Supersonic Boom of Wing-Body Configurations," *Journal of the Aerospace Sciences,* Vol. 28, No. 4, 1961, pp. 313–320.

[6] McLean, F. E. and Shrout, B. L., "Design Methods for Minimization of Sonic-Boom Pressure-Field Disturbances," *Proceedings of the Acoustical Society of America,* St. Louis, Mo., Nov. 3, 1965, pp. S19–S25.

[7] George, A. R., "Reduction of Sonic Boom by Azimuthal Redistribution of Overpressure," AIAA Paper 68-159, New York, 1968.

[8] Ferri, A. and Ismail, A., *Report on Sonic Boom Studies,* NASA SP-180, 1968.

[9] Seebass, R., "Sonic Boom Theory," *Journal of Aircraft,* Vol. 6, No. 3, May-June 1969, pp. 177–184.

[10] McLean, F. E., Carlson, H. W., and Hunton, L. W., "Sonic Boom Characteristics of Proposed Supersonic and Hypersonic Airplanes," TN D-3587, 1966, NASA.

[11] McLean, F. E., *Configuration Design for Specified Pressure Characteristics*, NASA SP-180, 1968.

[12] Whitham, G. B., "The Flow Pattern of a Supersonic Projectile," *Communication of Pure Applied Mathematics*, Vol. 5, 1952, pp. 301–348.

[13] Hayes, W. D., "Linearized Supersonic Flow," Rept. AL-222, 1947, North American Aviation.

[14] Middleton, W. D. and Carlson, H. W., "A Numerical Method for Calculating Near-Field Sonic-Boom Pressure Signatures," TN D-3082, 1965, NASA.

[15] Carlson, H. W., "Correlation of Sonic-Boom Theory With Wind Tunnel and Flight Measurements," TR R-213, 1964, NASA.

[16] Carlson, H. W., *Experimental and Analytic Research on Sonic Boom Generation at NASA*, NASA SP-147, 1967.

[17] Hunton, L. W., *Current Research in Sonic Boom*, NASA SP-180, 1968.

[18] Garrick, I. E. and Maglieri, D. J., "A Summary of Results on Sonic Boom Pressure-Signature Variations Associated With Atmospheric Conditions," TN D-4588, 1968, NASA.

[19] Miller, D. S. and Carlson, H. W., "A Study of the Application of Heat or Force Fields to the Sonic Boom Minimization Problem," TN D-5582, 1969, NASA.

[20] Brown, C. E., "Internal and External Aerodynamics of Ducted Bodies at Supersonic Speeds," WR L-728, 1946, NACA (formerly NACA CB L6B26).

[21] Hayes, W. D., Haefeli, R. C., and Kulsrud, H. E., "Sonic Boom Propagation in a Stratified Atmosphere, With Computer Program," CR-1299, 1969, NASA.

[22] Shapiro, A. H., *The Dynamics and Thermodynamics of Compressible Fluid Flow*, Vol. I, Ronald Press, 1953, pp. 226–232.

[23] Resler, E. L., Jr., "Lifting Aerodynamic Configurations With No Sonic Boom," *AFOSRUTIAS Symposium on Aerodynamic Noise*, University of Toronto, Institute for Aerospace Sciences, Toronto, Canada, May 1968.

[24] Kryter, K. D., "Laboratory Tests of Physiological Reactions To Sonic Booms," *Journal of the Acoustical Society of America*, Vol. 39, No. 5, Pt. 2, May 1966, pp. 565–572.

[25] Batdorf, S. B., "On a New Approach to the Alleviation of the Sonic Boom," Rept. ATR-70 (S9990)-1, Sept. 1969, Aerospace Corp.

[26] Swigart, R. and Lubard, S., "Sonic Boom Studies," Rept. ATR-69 (S8125)-1, May 1969, Aerospace Corp.

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# Biotechnology Problems Relative to the Space Shuttle Vehicle

Richard Carpenter*
*NASA Flight Research Center, Edwards, Calif.*

**This paper idscusses some of the problems associated with a shirtsleeve, side-by-side crew station as presently proposed for the shuttle vehicle. Experience in the areas of visibility and mission safety from flight programs such as the X-15 are cited as examples that lead to considering design criteria affecting the crew station configuration in the shuttle vehicle. Adequate outside visibility envelopes must be provided for the approach and landing task, and window size must be minimized to prevent breakage as a consequence of high-temperature structural distortion. X-15 experience also indicates the necessity for a pressure backup system when vehicles are repeatedly exposed to the extremes of re-entry conditions.**

## Introduction

THE shuttle mission presents some unique features which should be investigated to allow engineering tradeoffs on factors affecting the crew station. The space shuttle concepts to date are seriously considering only a side-by-side, shirtsleeve environment for the pilot/copilot crew station. This arrangement has been interpreted from the NASA Statement of Work for Phase B Shuttlecraft Design which specifies a reusable airliner type of vehicle operated by two crewmen in a shirtsleeve environment with high-performance aircraft visibility.

The NASA Flight Research Center, although not directly involved, has followed closely the evolution of the space shuttle and is supporting the program in several technological development areas. In the biotechnology area, investigations of pilot visibility requirements and crew thermal and pressure protection systems are being conducted. It is anticipated that the results of these investigations will contribute to the development of the shuttle. Other contributions of equal or possibly greater importance may be realized as a result of the Flight Research Center's experience with research aircraft. This unique experience, although not acquired in space, is directly pertinent to the shuttle vehicle, because the vehicle will operate as an aircraft once it has entered the atmosphere. The assumption that the shuttle will be manually landed in a conventional manner requires an estimate of the mission-related importance of this task and the concomitant visibility requirements. Our X-15 experience provides information concerning the relative importance of these landing tasks and illustrates some of the practical problems associated with providing the pilot with the direct vision essential for the approach and landing tasks.

The reusable shuttle concept poses some other problems unique to the space community but familiar to aircraft designers and operators. Cockpit pressurization problems encountered in the X-15 airplane are but one example of the kinds of failures to be expected when a vehicle is reused,[1] particularly after being repeatedly exposed to the environmental extremes of space and re-entry.

This paper briefly discusses the Flight Research Center's experience related to biotechnology problems of the space shuttle vehicle and suggests guidelines to satisfy the factors considered.

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* Chief Engineer, Biotechnology.