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SOME EFFECTS OF MACH NUMBER AND GEOMETRY ON SONIC BOOM

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SOME EFFECTS OF MACH NUMBER AND GEOMETRY ON SONIC BOOM[1]

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SUMMARY

A study has been conducted to determine the effects of Mach number and geometry on the level of sonic boom overpressure and on the applicability of the Whitham theory to the calculation of sonic boom. This study consisted of wind-tunnel tests and a theoretical analysis of the sonic boom characteristics of a 7.5° half-angle cone-cylinder and a model of the X-15 airplane over a Mach number range from 2 to 5.5 to compare experiment with theory. The geometric effect was examined in tests of three hypersonic transport configurations over the same Mach number range. This study shows the Whitham theory gives good predictions of sonic boom overpressure up to a Mach number of about 3, but deviates rapidly from experiment above a Mach number of 3. It also shows that configuration geometry can have a considerable influence on the level of sonic boom overpressure at low hypersonic Mach numbers.

INTRODUCTION

Experience gained in the development of the supersonic transport has shown that an important area of hypersonic transport research is the sonic boom. The problem at hypersonic Mach numbers may be somewhat different from the supersonic counterpart because of the different configuration geometry characteristic of cryogenic fueled hypersonic aircraft. This report will present some answers to two questions raised by the sonic boom problem at hypersonic Mach numbers: (1) Will the good correlation between experiment and the Whitham theory at moderate supersonic Mach numbers persist at hypersonic Mach numbers? (2) How will changing the geometry of hypersonic configurations change the level of sonic boom? The validity of the Whitham theory at hypersonic speeds will be considered by comparing experiment and theory for a body of revolution and a complete airplane configuration. The effect of geometry will be examined by presenting data for three different hypersonic transport aircraft.

NOMENCLATURE

C_L lift coefficient

h altitude

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[1]Presented at NASA Conference on Hypersonic Aircraft Technology, Ames Research Center, May 16-18, 1967.

l body length

M Mach number

P reference pressure

ΔP sonic boom overpressure

α angle of attack

η shock angle minus Mach angle

MODELS AND APPARATUS

The models in this study were a 7.5° half-angle cone-cylinder, a model of the X-15 airplane, and three hypersonic transport models - a blended-wing-body, a delta-wing-body, and an all-body configuration. The three hypersonic transport configurations and the cone-cylinder were manufactured from mild steel and the X-15 model was cast from beryllium copper. The three transport models and the cone-cylinder were 4 inches long, and the X-15 model was 4.8 inches long.

The tests were conducted at Mach numbers of 2 and 3 in the Ames 9- by 7-Foot and 8- by 7-Foot Wind Tunnels, respectively, and at Mach numbers of 4 and 5.5 in the 21-Inch Hypersonic Wind Tunnel of the Jet Propulsion Laboratory.

All models were mounted on a two-component internal strain-gage balance which was manufactured integral with the sting support. The static probe used to measure the pressures in the model shock system was manufactured from stainless steel in two sections. The front section was a 10-inch long, 1/2° half-angle cone; the aft section, also 10 inches long, was a 1-1/4° half-angle cone.

The pressure transducers used in the study were of the capacitance type and had a maximum load capability of 10 mm of mercury.

TEST TECHNIQUE

The comparison between experiment and theory was made for an altitude of 100 body lengths (an altitude for which the Whitham theory is known to predict sonic boom characteristics accurately at moderate supersonic Mach numbers). Since it was not practical to obtain wind-tunnel data at an altitude of 100 body lengths, an experimental technique developed at Ames for deriving sonic boom characteristics from near field data for any greater altitude was used.

An expeditious way to describe the experimental technique is to compare it with the standard theoretical procedure. This comparison is presented in figure 1. The theoretical procedure shown at the left requires a detailed calculation of the cross-sectional area distribution, lift distribution, and interference lift distribution before the F-function and the desired pressure signature can be calculated. One of the main difficulties with the theoretical procedure is the inability of existing theories to define the lift distribution accurately. (For a complete description of this procedure, see ref. 2.) The only requirement for applying the experimental procedure shown at the right is that a near field pressure signature be measured in a wind tunnel (or other suitable experimental facility). Once this has been done, an experimental F-function and then the pressure signature at any higher altitude can be calculated.

An evaluation of the validity of the experimental procedure used for deriving sonic boom characteristics from measurements of near field pressure signatures is presented in figure 2. The XB-70 at $M = 1.8$ and the X-15 at $M = 5.5$ were used as test cases. The two pressure signatures shown at the top of the figure were measured in a wind tunnel at a ratio of altitude to body length (h/l) of 1. The experimental F-functions calculated from these near field pressure signatures were used to calculate pressure signatures (hereafter called derived pressure signatures) for altitude-length ratios of 4.5 and 290 for the XB-70 and for an altitude-length ratio of 1770 for the X-15. These derived pressure signatures are compared with experimental data obtained at the same altitude-length ratios. As can be seen, the derived pressure signatures and the experimental data agree well, except for the location and strength of the rear shock for the X-15 at $h/l = 1770$. An analysis of schlieren photographs has indicated that this discrepancy is due to interference with the trailing shock on the X-15 wind-tunnel model caused by a shock emanating from the model support system. This problem is particularly severe at high Mach numbers and, to obtain reliable data for the trailing shock, would require a longer sting than that employed in this test. This experimental procedure has been used to derive the experimental sonic boom characteristics shown for all configurations in the remainder of this report.

RESULTS AND DISCUSSION

The first question to be considered here concerns the validity of the modified linear theory of Whitham at hypersonic speeds. A comparison of experiment with the Whitham theory for a 7.5° half-angle cone-cylinder at $h/l = 100$ is shown in figure 3. The correlation between experiment and theory is good at Mach numbers of 2 and 3 while the Whitham theory is seen to underpredict the strength of the bow shock at Mach numbers of 4 and 5.5. This trend is not surprising since the assumptions used in the development of the Whitham theory place a definite Mach number limitation on the theory (see ref. 3). This underprediction of the bow shock strength at low hypersonic Mach numbers has been noted before (ref. 4) on a 7.5° half-angle cone at $M = 5.14$.

Figure 4 shows a comparison of experiment with theory for the X-15 at the lift coefficients indicated. Again, it is evident that the correlation between experiment and theory is fairly good at the low Mach numbers but not as good as for the slender, nonlifting configuration shown in figure 3. At Mach numbers of 4 and 5.5 the theory again underpredicts the strength of the bow shock. In the calculation of sonic boom, the theoretical overpressure signatures for the X-15 were based on experimental pressure distributions (see refs. 5-7). Hence, the lack of correlation between experiment and theory cannot be blamed on inaccurate loading distributions.

Another measure of the accuracy of a sonic boom theory is the degree of correlation between experimental and theoretical shock angle. This comparison is made in figure 5 by plotting shock angle minus free-stream Mach angle for a 7.5° half-angle cone. Two theories (the Whitham theory and the cone tables) are presented along with an experimental value at $M = 5.5$. It can be seen that the cone tables quite accurately predict the shock angle at $M = 5.5$. If the cone tables are accepted as a good estimate of shock angle throughout the Mach number range shown in this figure, it can be seen that the Whitham theory predicts the shock angle well to about $M = 3$ and then deviates rapidly from experiment above $M = 3$. It is interesting that the bow shock angle predicted by the Whitham method is greater than the experimental shock angle at high Mach numbers while the opposite is true for the pressure jump at the bow shock (see figs. 3 and 4). This anomaly has not yet been explained.

The second question to be considered here is the effect of geometry on the level of sonic boom. This question has been examined in tests of the three hypersonic transport configurations shown in figure 6 at Mach numbers of 2, 3, 4, and 5.5. The three configurations chosen were a blended wing body, a delta wing body, and an all body. All models, complete with empennage and simulated engine inlets, were 4 inches long. These models were not designed to minimize sonic boom, but were chosen as being typical of current thinking on hypersonic transports; hence, the level of sonic boom overpressure presented may be somewhat higher than could be achieved if the configuration geometry were reshaped. The results of this study are presented in figure 7, which is a plot of maximum overpressure divided by the reference pressure versus Mach number for the three hypersonic configurations flying at a constant altitude of 50,000 feet and a constant weight of 600,000 pounds. All aircraft had the same volume. As shown by the silhouettes of the configurations in figure 7, however, the lengths for constant volume were different for each aircraft. The results of this study indicate that for the Mach number range shown, the level of sonic boom generated by the blended wing body is about the same as that generated by the delta wing body, both being less than that for the all-body configuration. It should be pointed out that the assumption of constant weight may have penalized the all-body configuration since preliminary mission analysis studies indicate that the weight of the all body may be less than the weight of the other two configurations for the same mission. This would result in a somewhat lower sonic boom overpressure.

Now that the relative levels of sonic boom overpressure have been established for the three hypersonic transport configurations, it is of interest to see what level of sonic boom (in pounds per square foot) would be generated by the blended wing body flying a typical mission profile. In the plot at the left in figure 8, the solid curve defines the basic mission profile. The mission begins at $M = 2$ since tests were not conducted at Mach numbers below 2. The overpressures that would be generated on the ground by the blended wing body flying the basic mission are shown by the solid curve at the right in the figure. (The values for $M = 6$ were obtained by extrapolating the $M = 5.5$ values.) As can be seen, overpressures would be rather large between $M = 2$ and 3 but would drop rapidly to about 1 psf at the end of cruise. The 1 psf value is lower than that anticipated for the supersonic transport because of the higher cruise altitude for the hypersonic transport. If engines were available that would permit alteration of the climb leg of the mission profile to that shown by the dashed curve at the left, the level of sonic boom overpressure could be reduced during climb to the level shown by the dashed curve at the right.

CONCLUSIONS

The following conclusions can be drawn from this study:

1. The modified linear theory of Whitham predicts sonic boom characteristics fairly well for slender configurations up to a Mach number of about 3 but deviates rapidly from experiment above Mach 3.

2. The sonic boom overpressure generated by the delta-wing configuration is approximately the same as that generated by the blended-wing-body configuration, both being considerably below the overpressure level of the all-body configuration for the conditions and Mach number range of this study.

3. The use of near field data to derive sonic boom characteristics at any larger altitude appears to have application up to low hypersonic Mach numbers.

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National Aeronautics and Space Administration
Moffett Field, Calif., 94035, May 16, 1967
720-01-00-02-00-21

REFERENCES

1. Carlson, H. W.: Influence of Airplane Configuration on Sonic-Boom Characteristics. J. Aircraft, vol. 1, no. 2, 1964, pp. 82-86.

2. Whitham, G. B.: The Flow Pattern of a Supersonic Projectile. Communications on Pure and Applied Mathematics, vol. V, 1952, pp. 301-348.

3. Callaghan, J. G.: A Feasibility Investigation Concerning the Simulation of Sonic Boom by Ballistic Models. Rep. 52970A, Douglas Aircraft Co., 1966.

4. Keener, Earl R.; and Pembo, Chris: Aerodynamic Forces on Components of the X-15 Airplane. NASA TM X-712, 1962.

5. Pyle, Jon S.: Comparison of Flight Pressure Measurements With Wind-Tunnel Data and Theory for the Forward Fuselage of the X-15 Airplane at Mach Numbers From 0.8 to 6.0. NASA TN D-2241, 1964.

6. Pyle, Jon S.: Flight-Measured Wing Surface Pressures and Loads for the X-15 Airplane at Mach Numbers From 1.2 to 6.0. NASA TN D-2602, 1965.

DESCRIPTION OF THEORETICAL AND EXPERIMENTAL PROCEDURE

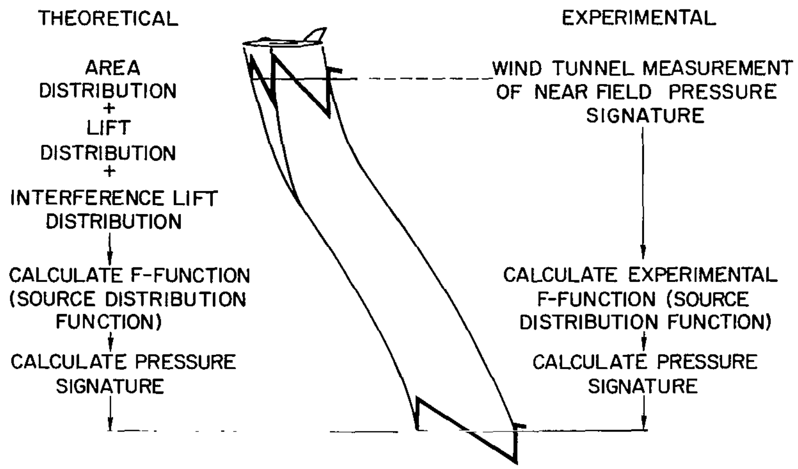

Figure 1

EVALUATION OF EXPERIMENTAL PROCEDURE

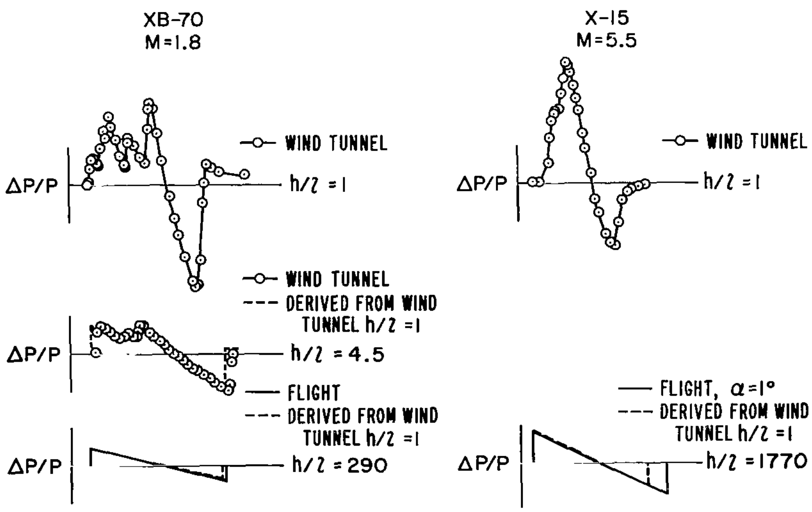

Figure 2

COMPARISON OF EXPERIMENT WITH THEORY
7.5° HALF ANGLE CONE CYLINDER
h/l = 100

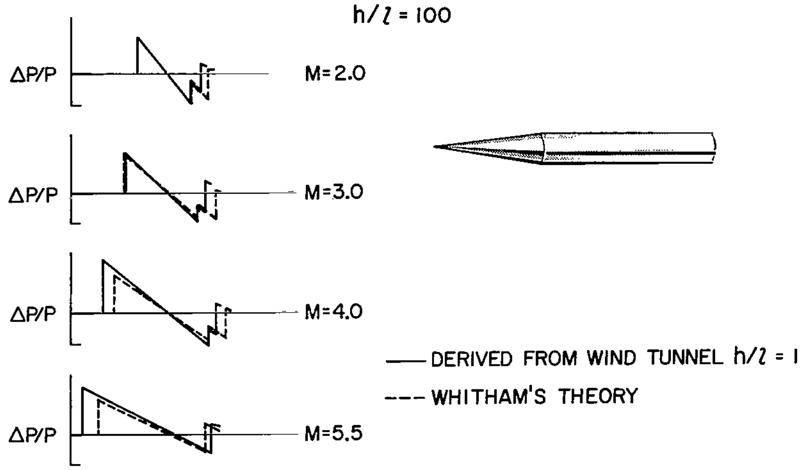

Figure 3

COMPARISON OF EXPERIMENT WITH THEORY
X-15
h/l=100

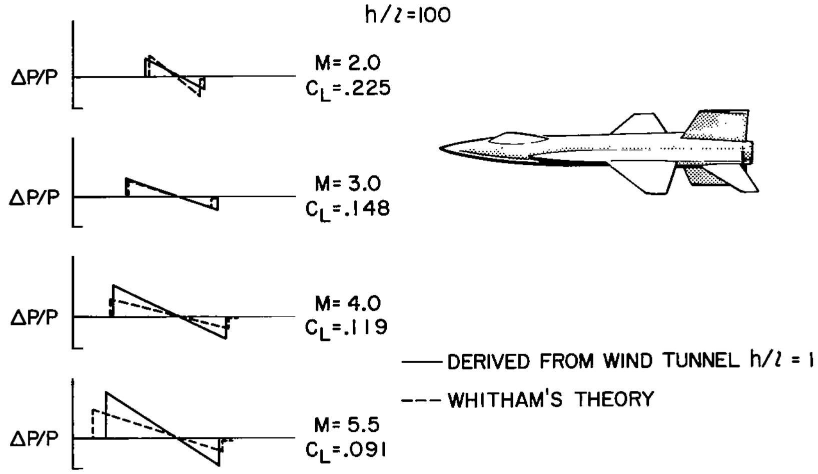

Figure 4

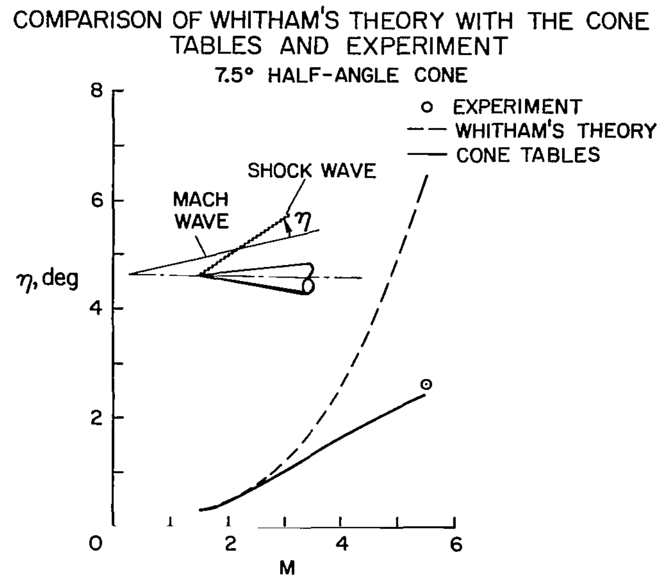

Figure 5

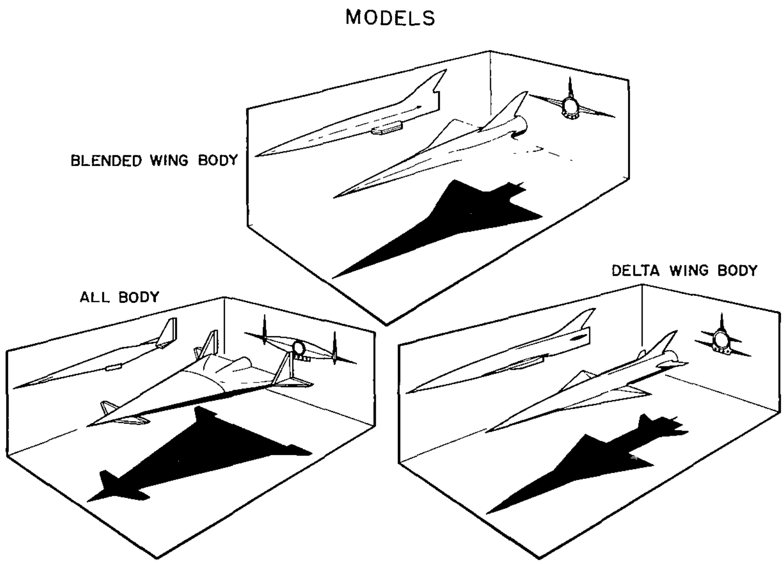

Figure 6

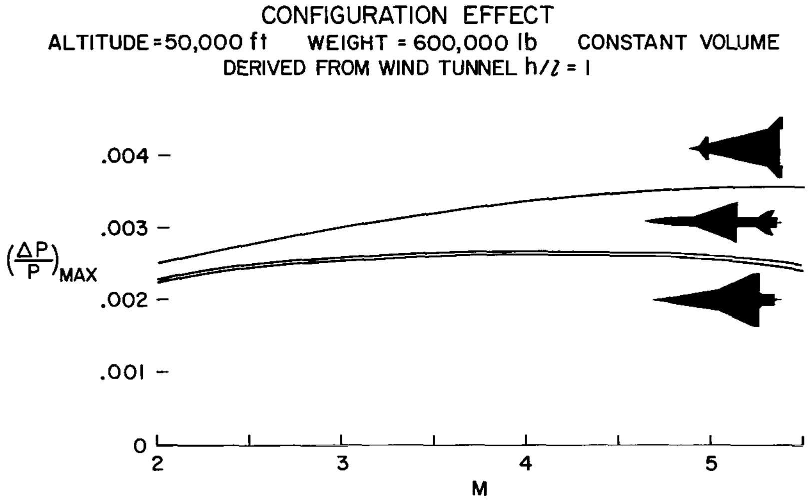

Figure 7

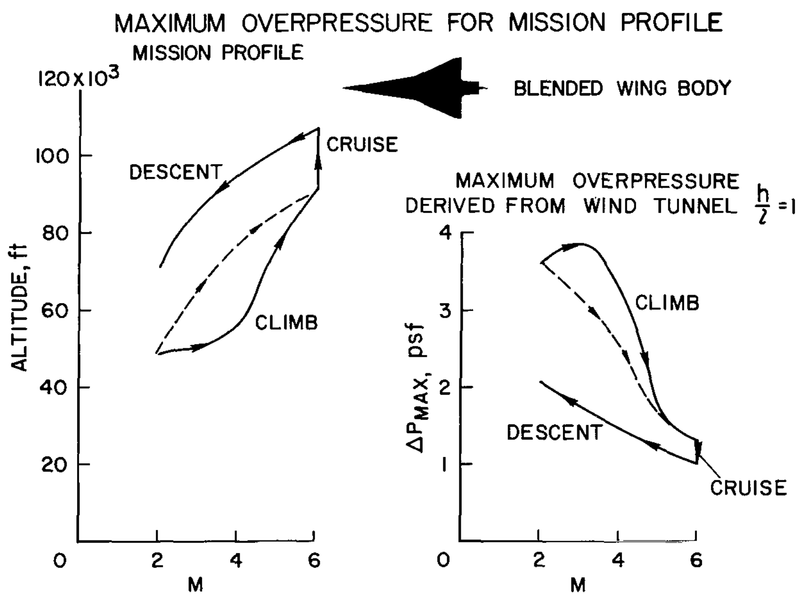

Figure 8

NASA-Langley, 1967 —— 1 A-2669

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