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RESEARCH ON THE SONIC-BOOM PROBLEM

by

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SUMMARY

The results from research on the sonic-boom problem carried out at the Aeronautical Research Institute of Sweden under NASA Grant No. NGR 52-120-001 are summarized in this Final Technical Report. The results have been obtained during the four-year period 1968-1972 and they have all been published earlier in the references given. From these references a very condensed version of the aim of the research and its results is now presented.

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RESEARCH ON THE SONIC BOOM PROBLEM

INTRODUCTION: GRANTS AND PROPOSALS

During the period February 15, 1968, to February 15, 1972, research on the sonic boom problem has been carried out at the Aeronautical Research Institute of Sweden (FFA) under the NASA Grant No. NGR 52-120-001 and three supplements to the same Grant.

In the proposal for the first year, which was considered as an introductory and exclusively theoretical phase of the investigation, it was suggested to explore when non-linear effects on the sonic boom strength could become important.

During the second year it was proposed to devote the principal efforts to the following two main areas: (1) Continued careful examination of non-linear effects on the sonic boom strength, in particular as to effects of surface geometry on the near field both at low and at high supersonic Mach numbers. (2) Experimental investigation for verification of the more important conclusions reached from the theoretical analysis. The proposed experimental program should consist of a very careful mapping of the supersonic flow field on cylindrical surfaces of a few body lengths from suitable, selected models. The experimental program - being fairly ambitious - was anticipated to require more than one year to complete.

During the third year the theoretical work was to be directed towards producing accurate approximative methods valid both for bodies of revolution and for general three-dimensional bodies with lift. Also should be performed continued development of correction formulas for use with experimental determination of the Whitham F-function applicable to moderate to high aspect ratio configurations at high M. Special consideration should be given to the fact that the "far" field will creep closer to the body at high M.

The experimental program should aim at fulfilling the earlier proposed test program which was anticipated to require also the third period for its completion. The experimental technique was to measure flow velocity and inclination angles by means of a special flow field probe giving very high accuracy.

For the fourth and last year work was proposed in the following theoretical and experimental main areas: Completion of the theoretical examination of non-linear effects in near and far flow fields as well as on sonic boom shock strength. The experimental part should be directed towards a verification of the theory and an airplane-like model to be proposed by Professor A. Ferri, New York University, should be tested.

RESULTS

Some early results from the introductory study on non-linear effects on sonic boom intensity were reported at the NASA Conference on Sonic Boom Research in Washington, D.C., in May, 1968 (Ref. 1). In this paper it was shown that first-order acoustic theory is capable of describing the supersonic flow at large distances from a three-dimensional body with a relative error of ϵ^4, where ϵ is the thickness ratio of the equivalent body of revolution. Thus, for slender configurations the first-order theory will be quite accurate and higher-order effects will be confined primarily to the near field, where they will contribute to the Whitham F-function with terms that are of order ϵ^2 relative to linearized theory. Second-order theory was used to demonstrate that these terms may become quite important, particularly at high Mach numbers.

In a semi-annual report (Ref. 2) the same results were summarized and some further progress was reported. The latter concerned the calculation of the Whitham curve for the region behind the body. It was found that the second-order effect on the shock-wave strength and pressure signature towards the rear is small but not negligible even for very small thickness ratios.

For the remaining part of the first year the results were reported in a combined interim final report and progress report (Ref. 3). In this more extensive report it was described what non-linear effects beside the first-order ones accounted for in Whitham's theory are important. Use had been made of the previously developed second-order theory for large distances as well as of Van Dyke's second-order theory for axisymmetric flow to outline a uniformly valid second-order solution. The possibility to determine the F-function in wind-tunnel test was studied closely and a practical way to correct the measured F-function for second-order non-linear effects was worked out. All this proved later to be of great importance for the future research.

The first part of the next progress report (Ref. 4) gives some new results from the theoretical analysis. The earlier outlined uniformly valid second-order solution for a body of revolution was now worked out in full detail and a full account was presented as a self-contained and comprehensive summary in an Appendix to the report. A study of the Mach-lines and bi-characteristics in three-dimensional flow was also pursued. The direction derivatives of the bicharacteristics were calculated in a general three-dimensional flow field and the result was also presented in a self-contained style in another Appendix.

In the second part of the same progress report results from the initial wind-tunnel investigation were given. A simple body of revolution was used and the near flow field was measured carefully. The details of the investigation, including a description of the test layout, the model, the probe, the data sampling technique, the accuracy in the measurement readings, etc., together with the experimental results were presented as a comprehensive summary in a third Appendix.

Important conclusions could be drawn from the experiments. It was found possible to measure the crucial streamline inclination very accurately in the near field. From these measurements the F-function could be calculated to second order. The measurements were performed for two different radial distances. A critical test of the theory and the measurements was thus obtained since the two F-curves produced should coincide, which they also did when calculated to second order. If the F-curves were calculated according to the first-order Whitham theory, the two curves differed.

This new method for determining the F-function based on accurate wind-tunnel measurements was later presented (Ref. 5) in more detail at the NASA Third Conference on Sonic Boom Research in Washington, D.C., in October, 1970. At the same conference the corresponding progress on the theoretical side was also reported (Ref. 6). In this paper it was concluded that by application of a coordinate perturbation to the second-order solution for axisymmetric flow in the manner of Lin and Oswatitsch one could cast the results for the velocity components in very simple forms. This amounts to an extension of Whitham's principle to second order, which is only slightly more complicated than the first-order one.

During the remaining part of the work under the Grant the effects (Ref. 7) were directed towards a continuation and completion of the different parts of the theoretical study and towards an evaluation of the wind-tunnel measurements which were carried out on the airplane-like model designed by Professor A. Ferri, New York University.

The results from the theoretical investigation were written up as Part 1 of a Final report (Ref. 8). In this report a second-order theory for supersonic flow past slender bodies was presented. Through the introduction of characteristic coordinates as independent variables and the expansion procedure proposed by Lin and Oswatitsch, a uniformly valid solution was obtained for the whole flow field in the axisymmetric case. For distances far from the body the theory is an extension of Whitham's first-order solution and for the domain close to the body it is a modification of Van Dyke's second-order solution in the axisymmetric case. From the theory useful formulas relating flow deflections to the Whitham F-function were derived, which permitted determination of the sonic-boom strength from wind-tunnel measurements fairly close to the body.

The first evaluation of the measurements on the Ferri model was made by A. Ferri and his group at the New York University, to whom the experimental results early were made available. This evaluation was reported in Ref. 9. The experimental results agreed reasonably well with the analysis for this low sonic-boom configuration.

In Part 2 of the Final report (Ref. 10) the results of the experimental investigation carried out under this research grant are summarized. The models used consist of a parabolic spindle tested at M = 3 and a wing-body configuration, the Ferri model, tested at M = 2.7. For this last model an independent evaluation was made, which agreed fairly well with the results from the Ferri group (Ref. 9).

The theory (see Final report, Part 1, Ref. 8) indicated that shock position and strength at an arbitrary distance can be calculated by means of near-field measurements. The results show that this method is an appropriate one for simple bodies and for bodies with complicated geometries as well.

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