ATS- 16144

FFA

FLYGTEKNISKA FÖRSÖKSANSTALTEN
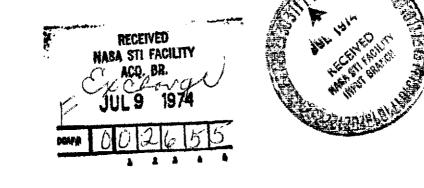
THE AERONAUTICAL RESEARCH INSTITUTE OF SWEDEN

FINAL TECHNICAL REPORT

on NASA GRANT No. NGR 52-120-001

RESEARCH ON THE SONIC-BOOM PROBLEM

by

Georg Drougge

PRICES SUBJECT TO CHANGE

Stockholm 1973

THE AERONAUTICAL RESEARCH INSTITUTE
OF SWEDEN

Aerodynamics Department

F I N A L   T E C H N I C A L   R E P O R T

on NASA GRANT No. NGR 52-120-001

RESEARCH ON THE SONIC-BOOM PROBLEM

by

Georg Drougge

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 pre-
sented.

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 in-
vestigation, 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 care-
ful 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) Ex-
perimental 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 ex-
perimental 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 re-ported 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 pre-sented 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 calcul-ated 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 care-fully. The details of the investigation, including a descrip-tion of the test layout, the model, the probe, the data sampling technique, the accuracy in the measurement readings, etc., to-gether with the experimental results were presented as a com-prehensive 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 pro-
duced 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 re-
lating 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 re-
sults 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.

REFERENCES

List of Progress Reports, Semi-Annual Reports, Interim Final Reports, Final Reports and other published reports or papers concerning this Grant:

1. Landahl, M.T., Ryhming, I.L. and Hilding, L.: Nonlinear Effects on Sonic Boom Intensity. Second Conference on Sonic Boom Research, NASA SP-180, 1968, pp. 117-124.

2. Landahl, M.T. and Drougge, G.: Nonlinear Effects on Sonic Boom Intensity. Semi-annual report for the time period February 15 - August 15, 1968.

3. Landahl, M.T. and Drougge, G.: Nonlinear Effects on Sonic Boom Intensity. Interim final report and progress report for the period August 15, 1968 - February 15, 1969.

4. Landahl, M.T., Drougge, G. and Ryhming, I.: Nonlinear Effects on Sonic Boom Intensity. Progress report for the period September 1969 - April 1970.

5. Landahl, M.T., Ryhming, I., Sörensén, H. and Drougge, G.: A New Method for Determining Sonic Boom Strength from Near-Field Measurements. NASA Third Conference on Sonic Boom Research, NASA SP-255, October 1970, pp. 285-295.

6. Landahl, M.T., Ryhming, I. and Löfgren, P.: Nonlinear Effects on Sonic Boom Intensity. NASA Third Conference on Sonic Boom Research, NASA SP-255, October 1970, pp. 3-15.

7. Drougge, G.: Nonlinear Effects on Sonic Boom Intensity. Informal Status report for the period February 15, 1971 - February 15, 1972.

8. Landahl, M. and Löfgren, P.: Final report on NASA GRANT No NGR 52-120-001: Research on the sonic boom problem. Part 1: Second order solutions for the flow field around slender bodies in supersonic flow for sonic boom analysis. 1973.

9. Ferri, A., Wang, H-C. and Sörensén, H.: Experimental verification of low sonic boom configuration. NASA Contractor Report 2070, June 1972.

10. Landahl, M., Sörensén, H. and Hilding, L.: Final report on NASA Grant No. NGR 52-120-001: Research on the sonic boom problem. Part 2: Flow field measurement in wind tunnel and calculation of second order F-function, 1972.