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From Gasdynamic Models to High Speed Design: A Learning Process

H. Sobieczky
DLR German Aerospace Center

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FROM GASDYNAMIC MODELS TO HIGH SPEED DESIGN OPTIMIZATION: A LEARNING PROCESS

Invited lecture:
A Contribution in memory of working with Richard Seebass

Helmut Sobieczky [x]
DLR German Aerospace Center
D-37073 Göttingen, Bunsenstr. 10
Germany

e-mail: helmut.sobieczky@dlr.de/

Abstract

This paper reviews theoretical roots, illustrates educational examples and extends some ideas which have been useful for the development of computational tools for the design and optimization of aerospace vehicle component design, like airfoils, wings, integrated lifting bodies and turbomachinery components. The material presented in this contribution has, in part, been discussed, developed and refined with great help stemming from a long lasting friendship and cooperation with Richard Seebass who passed away in Nov. 2000.

Introduction

25 years ago the author was invited by Richard Seebass to spend a sabbatical year to lecture [1] at the University of Arizona, coming from Göttingen, Germany. This time was the beginning of a fruitful cooperation in theoretical aerospace design engineering, which led to a number of publications and some concepts for practical aircraft wing and turbomachinery blade design. With an illustration of some highlights of our work together the reader might follow how theoretical modelling of the time before powerful computing gradually led us to provide tools and design concepts which helped to control the difficulties in the transonic flow regime, with extending of some ideas to supersonic aerodynamics.

* Sr. Research Scientist, Associate Fellow AIAA

Hodograph Models

Pre-CFD time, 40 years ago, forced researchers in aerodynamics to use analytical modelling for rudimentary quantitative prediction of aerodynamic performance of lifting wings in high speed flow. Skilled use of mathematics and hydrodynamic analogy suggested solution of a linear P.D.E. to learn about treating a mixed type (subsonic/supersonic) boundary value problem, which focuses on the sonic locus as the basic "axis" of coupling the different parts of the problem. With this approach in the late period of pre-CFD research, ground was laid for a practical use of hodograph transformation, later being the foundation of inverse CFD techniques.

Learning to see the basic problem of transonic flow as a linear one in a rheoelectric tank of shallow conducting fluid resulted in simulations of this classical experimental set-up of old-time physics by numerical Poisson solvers, this way allowing to design airfoils in an inverse way in the hodograph plane [2].

Fictitious Gas

Approach of numerical routines to solve non-linear P.D.E's suggested the development of techniques corresponding to the linear but transformed hodograph problem: The "method of fictitious gas" [3] became a tool for every CFD analyst to easily turn his code into a design tool for shock-free airfoils, wings [4] and turbomachinery blades. Later, extensions from Potential to Euler methods led to an interesting interpretation of "gasdynamic flow control" which may even support some future methods to influence flows locally by energy control.

Adaptive Airfoils and Wings

The theoretical concept and the resulting computational tools for designing transonic wings suggested a focus on controlled shape modifications along the surface wetted by supersonic flow: Transonic adaptive geometry was born in a time when practical realization was far from technically possible [5]. Today we see various R&D projects aimed toward skilled techniques to optimize aerodynamic performance in a widened area of design conditions using adaptive geometry, the most promising of these suggest shape modifications predicted by our transonic knowledge base:

Recent results for high performance airfoils in transonic steady and unsteady (helicopter rotor) flow are obtained by systematic shape modifications which calibrate mechanical devices to control flow quality.

New Waverider Shapes

Extension of the principle to treat mixed type problems successfully starting from the sonic locus, to supersonic flows puts the bow wave into a similarly outstanding role as the sonic surface plays for transonics: Here we have an inverse problem to find the body surface if the shock created by it is given. Again the experience with previous theoretical studies prevented us to resign from developing computational solution methods when facing this mathematically ill-posed problem.

Two concepts were developed in our collaboration continued at the University of Colorado:

One led to the solution of an inverse extension of the Euler equations to 3D flow with a given arbitrary shock wave [6] , the other one exploits the properties of axisymmetric flow to arrive at a flexible extension of using conical flow for designing waveriders [7].

Recent results allow for generalizations of the waverider concept applied to supersonic and hypersonic forebodies and inlets.

Oblique Flying Wing

Renewed interest in supersonic transport as well as in very large transport airplanes calls for innovative ideas to bring such projects to reality. R. Seebass advocated strongly for the concept of an oblique all-wing (OFW) configuration flying in the lower supersonic regime and at the same time being a large capacity transport airplane. German Alexander-v.-Humboldt Foundation awarded the cooperation of the author with R. Seebass in this topic and related fields of interest with a Max-Planck Award: Our design methods were applied to an innovative and promising concept for future aircraft.

Novel design ideas have been compiled [8] resulting in the conclusion that indeed the OFW should be the most promising candidate for an economically successful supersonic transport aircraft. At the same time there is a need to develop systematic design methods for such aircraft. We have experienced that learning from the basic gasdynamic knowledge base gives a valuable support to go novel, unusual routes when innovative concepts should be supported by computational models [9].

Conclusion

All previous experience of 25 years taught us how to develop some computational tools based on a proper modelling of the observed aerodynamic phenomena. Resulting computer codes are then still far from routine industrial design tools but an implementation in commercial CAD software is a logical and consequent conclusion of our previous work. Such efforts have been and are under way at different research places. Discussing various concepts for novel aircraft, like the OFW, the Corporate Supersonic Transport and the Blended Wing Body have been stimulating examples in the cooperation with R. Seebass.

His legacy is his constant encouragement to carry through novel and seemingly playful ideas in creative engineering: There will be success at unexpected occasions.

References

See also the URL http://www.as.go.dlr.de/~helmut/ for a collection of illustrations and related literature to be downloaded.

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