AD-A181 257 UNSTEADY FLOW IN SUPERSONIC INLET DIFFUSERS(U) MICHIGAN 1/1
UNIV ANN ARBOR COLL OF ENGINEERING T C ADAMSON ET AL.
DEC 86 AFOSR-TR-87-0673 AFOSR-84-0327

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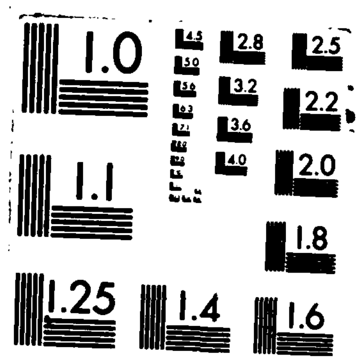

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~~ANNUAL~~ FINAL TECHNICAL REPORT

TO

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

UNSTEADY FLOW IN SUPERSONIC INLET DIFFUSERS

DEPARTMENT OF AEROSPACE ENGINEERING

The University of Michigan
Ann Arbor, Michigan, 48109

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Contract AFOSR-84-0327

15 August 1985 to 14 August 1986

Principal Investigators

T. C. Adamson, Jr. and A. F. Messiter
Department of Aerospace Engineering
The University of Michigan

December 1986

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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: APPROVED FOR PUBLIC RELEASE DISTRIBUTION IS UNLIMITED
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S): AFOSR-TR- 87-0673
6a. NAME OF PERFORMING ORGANIZATION: UNIV OF MICHIGAN; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION: AFOSR/NA
6c. ADDRESS (City, State and ZIP Code): COLLEGE OF ENGINEERING, UNIV OF MICHIGAN, ANN ARBOR, MI 48109	7b. ADDRESS (City, State and ZIP Code): BUILDING 410, BOLLING AFB, DC 20332-6448
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: AFOSR/NA; 8b. OFFICE SYMBOL (If applicable): NA	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: AFOSR-84-0327
8c. ADDRESS (City, State and ZIP Code): BUILDING 410, BOLLING AFB, DC 20332-6448	10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
61102F	2307	A4	

11. TITLE (Include Security Classification): (U) UNSTEADY FLOW IN SUPERSONIC INLET DIFFUSERS

12. PERSONAL AUTHOR(S): T C ADAMSON, A F MESSITER

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
FINAL	FROM ______ TO ______	DEC 1986	8

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	INLET FLOWS, UNSTEADY INLET FLOWS, DIFFUSERS

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A symmetric supersonic inlet diffuser with flow at supercritical conditions has been analyzed, using both analytical and numerical methods. An equation describing the unsteady motion of the shock passage caused by vibrations in back pressure and/or variations in wall shape has been derived for inviscid flow. Results have been compared with those found using numerical methods both for inviscid and viscous flows fields.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL: HENRY E HELIN, CAPTAIN, USAF	22b. TELEPHONE NUMBER (Include Area Code): 202-767-4935; 22c. OFFICE SYMBOL: AFOSR/NA

1. Summary

A symmetric supersonic inlet diffuser with flow at supercritical conditions has been analyzed, using both analytical and numerical methods of attack. As part of the results, an equation describing the unsteady motion of the passage shock caused by variations in back pressure and/or variations in wall shape has been derived for inviscid flow. Results have been compared with those found using numerical methods both for inviscid and viscous flow fields. In the latter case, the instantaneous displacement thickness found numerically, including the case where the flow is separated, is used to give the proper effective wall shape for the inviscid core flow in the desired equation. In both cases, the agreement in phase is excellent and in amplitude is good. In addition numerical examples have been calculated showing the effects of various parameters on the instantaneous shock wave position when pressure oscillations are impressed upon the flow; these examples illustrate how variations in any given parameter, holding others fixed, may lead to the shocks being disgorged (engine unstart). Finally, a mechanism for self-sustained oscillations of the shock wave has been proposed and illustrated by example. Numerical examples show the effects of the various parameters upon the magnitude and frequency of the self-sustained oscillations; again, conditions under which the shock wave is disgorged are illustrated. The results are being presented as a paper at the AIAA Aerospace Sciences Meeting in Reno, January 1987, and as a PhD thesis; a journal article will be submitted.

2. Research Objectives

The essential objective of this analysis is an understanding of the important physical mechanisms in unsteady supersonic inlet flow with particular emphasis first on self induced oscillations caused by interaction between the passage shock wave and the separated boundary layer and second on the phenomenon of inlet buzz. The specific objectives associated with this work and the order in which they are being considered is as follows:

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Dist Special
A-1

Prof. T. C. Adamson, Jr.
Prof. A. F. Messiter
Dr. M.-S. Liou
Mr. R. T. Biedron

6. Interactions

a) Papers presented at meetings, conferences, seminars, etc.

1) Liou, M.-S., Hankey, W.L., and Mace, J.L., "Numerical Simulaltions of a Supercritical Inlet Flow" AIAA Paper No. 85-1214, presented at AIAA/SAE/ASME/ASEE 21st Joint Propulsion Conference, July 1985, Monterey, California

2) Liou, M.-S., "Computational Study of Supersonic Inlet Flows," presented at AIAA/ASEM 4th Joint Fluid Mechanics, Plasma Dynamics and Lasers Conference, May 1986.

3) Liou, M.-S., "A Generalized Formulation of High Resolution Schemes," presented at First World Congress in Computational Mechanics at The University of Texas-Austin, September 22-26, 1986.

4) Biedron, R. and Adamson, T.C., Jr., "Unsteady Flow in a Supercritical Supersonic Inlet Diffuser," accepted for presentation at AIAA 25th Aerospace Sciences Meeting, January 12-15, 1987.

b) Consultative and Advisory Functions

None

7. New Discoveries, Inventions, or Patent Disclosures.

None

8. Additional Statements

None

In the case of self-sustained oscillations, the critical feature in the mechanism proposed for the explanation of this phenomenon is the fact that the flow downstream of the shock wave must be separated at some point, and that when there is shock induced separation, the distribution of displacement thickness downstream of the shock wave is a function of the relative (to the shock) Mach number of the flow entering the shock wave. Hence, the core flow area downstream of the shock wave is a function of time through its dependence on the relative Mach number. This variation in core flow area, in turn, drives the shock wave; hence this interaction can cause self-sustained oscillations. The important parameters in the problem are the initial position of the shock wave, the shock wave Mach number at which separation occurs, the velocity at which the separated region blows back downstream in those cases where the relative Mach number at the shock is low enough that the flow no longer separates, and, to a considerably lesser extent, the magnitude and frequency of the disturbance which starts the self-sustained oscillations.

The investigation is proceeding and will be completed very soon. A paper covering this work will be presented at the AIAA Aerospace Sciences Meeting in Reno, in January 1987, and a paper will be submitted to a journal. In addition a detailed account of the work will be presented in Mr. Robert Biedron's PhD dissertation.

Very little has been done on extending the work to cover the phenomenon of inlet buzz. Due to complications in setting up the program to handle self-sustained oscillations and the move of Dr. M.-S. Liou to NASA Lewis Research Center, additional work on extending the general ideas of solution to cover the case of buzz have been relegated to discussions of the problem formulation and the diffuser shape to be considered for the numerical work. When the main work on the supercritical inlet diffuser has been completed, then an attempt will be made to consider the problem of buzz.

4. Cumulative Chronological List of Written Publications

None

5. Professional Personnel Associated with Research Effort:

viscous flows. In order to use the derived equation, it is necessary to know the effective wall shape for the inviscid core flow. When comparing with the viscous flow solutions, instantaneous displacement thickness distributions found from the numerical computations were added to the phsyical wall shape to give the effective wall shape. In both cases agreement between the results found using the derived equation and those found from completely numerical solutions were good insofar as amplitude of the motion of the shock wave is concerned, and excellent insofar as the phase is concerned.

Since the derived equation does give good results, it is now possible to use it to investigate many problems of unsteady flows in diffusers. It is a first order nonlinear ordinary differential equation which must be solved numerically; typical run times are roughly one to three minutes of CPU time on an IBM 3090-400.

Two fundamental problems are being investigated by means of example computations for systematic variations of parameters. In the first, the diffuser flow is subjected to forced oscillations at the exit plane. In the second, self-sustained oscillations, started by impressed pressure oscillations which are then stopped, are being considered. In both cases, a base line set of values for the important parameters has been set, and then variation of one parameter from its base line value, holding all others constant, is carried out. In this way, the relative importance of each mechanism on the overall motion of the shock wave can be ascertained.

In the case of impressed pressure oscillations, the important parameters are the initial position of the shock wave, and the amplitude and frequency of the impressed oscillation; the effects of different diffuser shapes has not been accounted for systematically, although this may be done later. The results show how each of these parameters can cause the shock wave to be disgorged, as well as, in some cases, how the shock wave can move upstream of the minimum area in its oscillations and still not be disgorged.

been completed, was a numerical solution for unsteady viscous flow in a supersonic inlet, and the comparison of these results with experimental data.

3. Status of the Research

As mentioned in the previous technical report (November 1985), numerical analyses for several cases have been carried out by Dr. M.-S. Liou, using the computing facilities at Wright Patterson AFB. Both inviscid and viscous flows were considered, as were two different diffuser shapes. Unfortunately, due to a policy decision made at WPAFB and which was not communicated to this outside user in time, all storage files were destroyed. Fortunately, enough of these files had been transferred to The University of Michigan that the thesis work of Mr. Biedron could be completed. However, Dr. Liou had planned to use the remaining data in a paper, summarizing his work under this grant; this paper cannot be written now, unless all the calculations are repeated.

The solutions for the flow in a supercritical inlet diffuser have been completed. The most important part of this work has been the derivation of the equation for the instantaneous position of the shock wave when the flow is being affected by impressed pressure oscillations at the exit and variations in wall shape downstream of the shock wave. Solutions were found for two different limit processes, corresponding to two different physical problems; in the first, because of the choice made for the ratio of the time characteristic of the impressed or self excited oscillations to the residence time, the signals from the exit of the diffuser reach the shock wave "instantaneously". In the second problem, signals travel more slowly and a lag time is introduced. Although it is easy to differentiate between solutions asymptotically, this becomes more difficult when a physical problem with a given set of parameters is confronted. Hence, a combined solution was derived, which goes to the correct solution in either limit. This provides a solution with a considerable range of validity when the important parameters are considered.

Numerical example calculations of the instantaneous shock wave position have been carried out and compared with those found using numerical methods for both inviscid and

1. Using equations derived from asymptotic analysis, with instantaneous displacement thickness in unseparated and separated flow found from numerical computations, predictions of the shock wave position in unsteady flows caused by variations in diffuser exit pressure are to be made and compared with those found from numerical computations. Self-sustained oscillations are sought; i.e., cases of interest are those for which oscillation of the shock wave position, once it has begun, will continue even after the diffuser exit pressure has been returned to its original constant value, due to the interaction between the separated boundary layer and the core flow caused by the motion of the shock wave. The differential equation governing the position of the shock wave is analyzed in an attempt to ascertain those conditions under which self sustained oscillations occur, or at least to identify the essential mechanisms causing this phenomenon.

2. The ideas and methods used in (1) are to be extended and applied to the phenomenon of inlet buzz . Thus, both analytical and numerical (Navier Stokes) solutions are to be sought. The numerical solution will be used to obtain typical variations with time of both the separating streamline which intersections the diffuser lip and the vortex sheet extending downstream from the triple point associationed with the external shock wave. These instantaneous shapes will be used in the differential equation describing the position of the external shock wave system in an effort to identify the important mechanisms in buzz phenomena. This study is to begin upon completion of the first objective.

3. It should be noted that some support for this project was given also in the form of a mini-grant through the Southestern Center for Electrical Engineering Education, Inc. A specific objective of this support, which has

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