14:26:59 OCA PAD AMENDMENT - PROJECT HEADER INFORMATION 06/13/88

Active

Project #: E-16-636 Cost share #: E-16-319 Rev #: 8
Center # : R5742-1A0 Center shr #: F5742-1A0 OCA file #:
Work type : RES
Contract#: N00014-84-K-0293 Mod #: P00007 Document : CONT
Prime #: Contract entity: GTRC

Subprojects ? : N
Main project #:

Project unit: AE Unit code: 02.010.110
Project director(s):
STRAHLE W C AE

Sponsor/division names: NAVY / OFC OF NAVAL RESEARCH
Sponsor/division codes: 103 / 025

Award period: 840401 to 880930 (performance) 881130 (reports)

Sponsor amount	New this change	Total to date
Contract value	0.00	435,865.00
Funded	40,450.00	435,865.00
Cost sharing amount		23,210.00

Does subcontracting plan apply ?: N

Title: ACOUSTIC RESPONSE OF TURBULENT RECIRCULATORY FLOWS

PROJECT ADMINISTRATION DATA

OCA contact: E. Faith Gleason 894-4820

Sponsor technical contact

RICHARD S. MILLER
(202)696-4405
MECHANICS DIVISION, CODE: 1132P
800 NORTH QUINCY STREET
ARLINGTON, VA 22217-5000

Sponsor issuing office

CAROL BENNER, CODE: 1513A:CMB
(202)696-4508
OFFICE OF NAVAL RESEARCH
800 NORTH QUINCY STREET
ARLINGTON, VA 22217-5000

Security class (U,C,S,TS) : U
Defense priority rating : NA
Equipment title vests with: Sponsor
PRIOR APPROVAL REQUIRED, OR MUST BE INCLUDED IN APPROVED PROPOSAL BUDGET.

ONR resident rep. is ACO (Y/N): Y
GOVT. supplemental sheet
GIT X

Administrative comments -
P00007 ADDS THE FINAL INCREMENT OF $40450 TO FULLY FUND THIS CONTRACT.

JUN 1988
RECEIVED
OCA

12/88

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Date 2/22/89

roject No. E-16-636 Center No. R5742-1A0

roject Director W.C. Strahle School/Lab AE

ponsor NAVY

ontract/Grant No. N00014-84-K-0293 GTRC XX GIT ___

rime Contract No. ___

itle Acoustic Response of Turbulent Recirculatory Flows

ffective Completion Date 9/30/88 (Performance) 11/30/88 (Reports)

loseout Actions Required:

- ___ None
- ___ Final Invoice or Copy of Last Invoice - Already Submitted
- X Final Report of Inventions and/or Subcontracts - Patent Questionnaire sent to P/I
- X Government Property Inventory & Related Certificate
- ___ Classified Material Certificate
- ___ Release and Assignment - Already submitted
- ___ Other ___

ncludes Subproject No(s). ___

ubproject Under Main Project No. ___

ontinues Project No. ___ Continued by Project No. ___

istribution:

- X Project Director
- X Administrative Network
- X Accounting
- X Procurement/GTRI Supply Services
- X Research Property Management
- ___ Research Security Services
- X Reports Coordinator (OCA)
- X GTRC
- X Project File
- X Contract Support Division (OCA)(2)
- ___ Other ___

E-16-636

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

SCHOOL OF
AEROSPACE ENGINEERING

404-894-3000

DANIEL GUGGENHEIM SCHOOL
OF AERONAUTICS

September 25, 1984

Dr. M. K. Ellingsworth
Mechanics Divison - Code 432
Office of Naval Research
800 North Quincy St.
Arlington, VA 22217

Dear Dr. Ellingsworth:

This letter constitutes the "End-of-the-Fiscal-Year" report for our ONR Contract entitled "Acoustic Response of Turbulent Reacting Recirculating Flows". The contract number is N00014-84-K-0293/NR 684-004. The principal investigators are W. C. Strahle and S. G. Lekoudis.

Significant Technical Results

The combined experimental-theoretical program has made progress in both facility development and analysis. The solid-fueled ramjet simulator facility is under modification to accept acoustic excitation. The modification is complete for the cold flow situation with favorable results. That is, the acoustic exciter, which was a high risk element, works well.

The acoustics of the geometry corresponding to the experimental setup has been analysed using parallel duct theory. Choosing the mean flow as provided by a Navier Stokes solver the duct mode shapes were calculated at frequencies up to 500 Hz (the highest to be experimentally achieved). These calculations are the first known to have been made in the instability field and show that the plane wave modes in this duct are, in fact, dominantly plane. This allows, then, a wall pressure measurement to be a valid indicator of the pressure across the duct.

Efforts were initiated on a finite difference program for solving the linearized Euler equations. The program is currently being debugged.

Technological Significance

The ability to predict the acoustic behavior of turbulent reacting recirculatory flows is essential to make progress in the understanding of ramjet instability. The current program is aimed at gaining this predictability.

Presentations, ONR Technical Reports, Publications

None as yet.

Other Research Tasks

AFOSR Heterogeneous Diffusion Flame Stabilization	$193,000/yr.
ARO Stagnating Turbulent Reacting Flows	$ 50,000/yr.
Lockheed Three Dimensional Turbulent Boundary Layer Separation from Smooth Surfaces	$ 25,000/yr.
ARO Task III - Center of Excellence for Rotary Wing Aircraft Technology - Computation of Blade Tip Loading	$ 60,000/yr.

Participants

Prof. Warren C. Strahle, Co-Principal Investigator
Prof. Spyridon G. Ledoudis, Co-Principal Investigator
Mr. Ronald E. Walterick, Research Engineer
Dr. Narayanan Komerath, Research Engineer
Mr. Ravindra Goonetilleke, Graduate Research Assistant

Sincerely,

Warren C. Strahle
Co-Principal Investigator

WCS/jj

cc: S. G. Lekoudis

F-10-000

GEORGIA INSTITUTE OF TECHNOLOGY

ATLANTA, GEORGIA 30332

SCHOOL OF
AEROSPACE ENGINEERING

404-894-3000

DANIEL GUGGENHEIM SCHOOL
OF AERONAUTICS

September 27, 1985

Dr. R.E. Whitehead
Head, Mechanics Division
Office of Naval Research
Arlington, Virginia 22217-5000

Subject: End of Fiscal Year Letter Report
N00014-84K-0293 NO 684-004

Dear Dr. Whitehead:

I. Contract Information

a. Title: Acoustic Response of Recirculatory Turbulent Reacting Flows
b. ONR Contract No.: N00014-84K-0293
c. ONR Work Unit No.: NO 684-004
d. Co-Principal Investigators: Warren C. Strahle and Spyridon G. Lekoudis
e. ONR Scientific Officer: M. Keith Ellingsworth
f. Period Covered: 1 October 1984 to 30 September 1985

II. Research Description

a. Description of Research

The work involves wind tunnel experiments and theoretical analysis on the problem of an unsteady turbulent reacting recirculatory flow, as encountered in ramjets. The facility is subsonic wind tunnel with a backward facing step and provision for blowing of a foreign gas or combustible from the bottom wall, simulating a solid fueled ramjet. The technical issues are the predictability of the flowfield under acoustic excitation and determination of mechanisms of amplification of acoustic waves. The practical problem addressed is one of combustion instability in ramjets.

Wind tunnel instrumentation includes LDV, hot film and dynamic pressure sensors for phase averaged velocity and pressure measurements. Analysis techniques have included duct mode analysis, spatial marching techniques using finite differences and wave envelope techniques for the acoustic field. The mean flow is being treated by a numerical code developed on another program. Particular attention is being paid to acoustic excitation of the shear layer shed from the backward facing step and the possible role that this shear layer may play in ramjet instability.

b. Significant Results in the Last Year

In cold flow, with and without sidewall blowing, measurements have been made of 1) the acoustic impedance of the forward end of the wind tunnel, 2) phase averaged acoustic pressure waveforms in the region of interest, 3)phase averaged velocity profiles across the windstream at selected positions, and 4) space separated cross correlations of velocity fluctuations. The latter measurements have yielded the important scientific result that there is no apparent significant response of the shear layer to acoustic excitation at any frequency. While there are some large scale structures evident in the shear layer they are insensitive to acoustic manipulation.

Analytically, success has been achieved in duct mode analysis which has shown the important result of nearly plane wave mode shapes in the frequency range of interest. However spatial marching techniques have suffered from numerical instability when attempting to calculate the complete acoustic field.Thus the numerical problem that existed in treating the Helmholtz equation with such techniques persists in the case of the steady Euler equations. Accordingly, a new technique, wave envelope analysis, is currently being tried.

c. Plans for Next Year's Research

Combustion capability should become available in December, 1985, at which time the above experiments will be repeated, but with LDV replacing the hot films for velocity and cross correlation measurements. The wave envelope analysis will be completed for the cold flow case and the results compared with the measurements already completed. If there is good agreement between the two, the analysis will be extended to the combustion case. If the agreement is not satisfactory, reanalysis will be required to specifically separate the hydrodynamic and acoustic motions.

d. Presentations

"Acoustic Response of Turbulent Reacting Recirculating Flows," ONR/NAVAIR Contractors' Meeting on Combustion Instabilities in Compact Ramjet Engines, October 23-25, 1984.

e. Technical Reports

None

f. Publications

Goonetilleke, R.S., Lekoudis, S.G. and Strahle, W.C. (Submitted to AIAA J.) "Nonisentropic propagation of sound in uniform ducts."

Goonetilleke, R.S., Davis, J.A., Komerath, N.M., Walterick, R.E., Lekoudis, S.G., and Strahle, W.C. (Submitted for 24th AIAA Aerospace Sciences Meeting) "Acoustic behavior of an SFRJ simulator."

g. Honors and Awards

AIAA Pendray Aerospace Literature Award to Dr. Warren C. Strahle, January, 1984

h. Participants

R.S. Goonetilleke, Graduate Research Assistant, Master of Science awarded 1984

J.A. Davis, Graduate Research Assistant, Master of Science awarded 1985

R.E. Walterick, Research Engineer

N.M. Komerath, Research Engineer

J.R. Richardson, Post-doctoral Fellow

W.C. Strahle and S.G. Lekoudis, Co-Principal Investigators

i. Other Sponsored Research

W.C. Strahle, "Heterogeneous diffusion flame stabilization", AFOSR, $100,000/yr.

W.C. Strahle, "Stagnating reacting turbulent flows", ARO, $50,000/yr.

S.G. Lekoudis, "Computation of blade tip flows", ARO, $50,000/yr.

Sincerely,

Warren C. Strahle
Co-Principal Investigator

Spyridon G. Lekoudis
Co-Principal Investigator

E-16-602

GEORGIA INSTITUTE OF TECHNOLOGY

ATLANTA, GEORGIA 30332

SCHOOL OF
AEROSPACE ENGINEERING

404-894-3000

DANIEL GUGGENHEIM SCHOOL
OF AERONAUTICS

September 30, 1986

Dr. Richard S. Miller
Power Program Office
Dept. of the Navy
Office of Naval Research
Ballston Tower # 1
800 North Quincy St.
Arlington, VA 22217

Subject: End of Fiscal Year Letter Report
N00014-84-K-0293

Dear Dr. Miller:

I. Contract Information
Title: Acoustic Response of Recirculatory Turbulent Reacting Flows
ONR Contract No: N00014-84-K-0293
Work Unit No: N32K-004
Principal Investigators: Warren C. Strahle and Spyridon G. Lekoudis
ONR Scientific Officer: Dr. Richard S. Miller
Period Covered: 1 October 1985 to 30 September, 1986

II. Research Description
a) Description of Research

The work involves wind tunnel experiments and theoretical analysis on the problem of an unsteady turbulent reacting recirculatory flow, as encountered in ramjets. The facility is a subsonic wind tunnel with a backward facing step and provision for blowing of a foreign gas or fuel from the bottom wall, simulating a solid fueled ramjet. The technical issues are the predictability of the flowfield under acoustic excitation and determination of mechanisms of amplification of acoustic waves. The practical problem is one of combustion instability in ramjets.

Wind tunnel instrumentation includes LDV, hot film and dynamic pressure sensors for phase averaged and turbulent velocity and pressure measurements. Analysis techniques currently being used are quasi one dimensional acoustics with imbedded quadrupole sources and direct numerical simulation with Navier Stokes equations.

b) Significant results in the last year

In cold flow it has been found possible to synchronize the shear layer at distinct frequencies and to force a notable vorticity-acoustic interaction. There is a complex interplay between the locked-in shear layer and the acoustic field that depends intimately upon the wave mode structure of the apparatus. The shear layer can either produce resonant or antiresonant phenomena depending upon the mode structure.

Using direct numerical simulation it has not yet been found possible to synchronize the shear layer numerically in the current experimental configuration. However, it has been found possible to find a true vorticity-acoustic instability in a related configuration. This leads to the scientific conclusion that boundary conditions are crucial to the interaction. Currently, the numerical simulation of the experimental apparatus is being investigated insofar as boundary condition sensitivity is concerned.

c) Plans for Next Year's Research

Combustion capability will become available in October, 1986. Many of the cold flow experiments will be repeated in hot flow and additional acoustic interactions will undoubtedly be discovered. Direct numerical simulation will be extended to the reacting case.

d) Participants

J. A. Davis	Ph.D. Graduate Research Assistant
R. E. Walterick	Research Engineer
J. R. Richardson	Post Doctoral Fellow
N. L. Sankar	Associate Professor replacing S. G. Lekoudis
W. C. Strahle	Principal Investigator

Sincerelv.

Warren C. Strahle
Regents' Professor

WCS/jj

cc: Dr. N. L. Sankar
Attachments

List of Publications/Reports/Presentations

1. Papers Published in Refereed Journals:

   Goonetilleke, R. S., Lekoudis, S. G. and Strahle, W. C., "Nonisentropic propagation of sound in uniform ducts using Euler equations," AIAA J., 24, 1088-1094 (1986).

2. Technical Reports:

   Davis, J. A., Komerath, N. M., Walterick, R. E., Strahle, W. C., and Lekoudis, S. G., "Acoustic behavior of an SFRJ simulator," AIAA Paper No. 86-0003 (1986).

3. Presentations:

   a) Invited

   b) Contributed

   "Acoustic behavior of an SFRJ simulator," 24th AIAA Aerospace Sciences Meeting, January, 1986.

4. Books (and sections thereof)

LIST OF AWARDS

None

PUBLICATIONS/PATENST/PRESENTATIONS/HONORS REPORT
(Number Only)

Papers Submitted to Refereed Journals (and not yet published): 1

Papers Published in Referenced Journals: 1

Books (and sections thereof) Submitted for Publication: 0

Books (and sections thereof) Published: 0

Patents Filed: 0

Patents Granted: 0

Invited Presentations at Topical or Scientific/Technical Society Conferences: 0

Contributed Presentations at Topical or Scientific/Technical Society Conferences: 1

Honors/Awards/Prizes: 0

E-16-002

GEORGIA INSTITUTE OF TECHNOLOGY

ATLANTA, GEORGIA 30332

SCHOOL OF AEROSPACE ENGINEERING

404-894-3000

DANIEL GUGGENHEIM SCHOOL OF AERONAUTICS

September 28, 1987

Dr. R. E. Whitehead
Director, Mechanics Division
Department of the Navy
Office of Naval Research
Arlington, VA 22217-5000

Subject: End of Fiscal Year Letter Report
N00014-84-K-0293; Work Unit 432K-004
Period 1 October 1986 to 30 September 1987
Reference: 5000, Ser 1132/273, 7 August 1987

Dear Dr. Whitehead:

a) Description of scientific goals.

The primary purpose of the combined experimental and computational program is to determine feedback mechanisms between acoustic waves on the one hand, and vorticity generation, combustion and flow boundaries on the other hand. This work is performed in a ramjet-type configuration as the genesis of the scientific goals resides in ramjet instability mechanisms.

b) Significant results of the last year.

The interaction between acoustic and vorticity generation has been found to be one-sided, both analytically and experimentally. While it is possible to generate shear layer vortical synchronization downstream of a flame holder configuration by acoustic means, the back reaction of the vorticity on the acoustics is negligible. An exception occurs if the organized vorticity impacts or passes through a strong flow constriction, such as a choked nozzle. This refutes a long standing theory that vorticity waves passing through a nozzle produce no acoustic return. Nevertheless, the feedback is weak.

More importantly, in the case of a reacting flow (the above results were given for a cold flow) there is strong interaction between combustion in the vortices and the acoustic field. What is occurring here is that without combustion the vorticity synchronization appears as a weak quadrupole interaction, but with combustion these quadrupoles become organized monopole sources. The fundamental scientific issue that is being elucidated here is that it is not synchronized vorticity *per se* that is important but that combustion is necessary for acoustic feedback.

Active control of the combustion region shape and length has been found under acoustic excitation. The significance of the results is being investigated.

c) Plans for next year's research.

Combustion tests will be continued to fully map the acoustic-combustion feedback with respect to frequency and tunnel location. The results will be used to compare with theory to close the theoretical-experimental gap. Direct numerical simulation has been initiated for the reacting case to elucidate the acoustic-combustion interaction.

d) Participants

J. A. Davis	Graduate Research Assistant
R. E. Walterick	Research Engineer
L. N. Sankar	Co-Principal Investigator
W. C. Strahle	Co-Principal Investigator

Sincerely,

Warren C. Strahle
Regents' Professor

WCS/jj

cc: Dr. L. N. Sankar

Attachments

List of Publications/Reports/Presentations

1. Papers Published in Refereed Journals

   (None this year)

2. Technical Reports

   a) Strahle, W. C., Davis, J. A. and Sankar L. N., "Acoustic response of turbulent reacting recirculating flows," CPIA Proceedings of 23rd JANNAF Combustion Meeting, October, 1986.

   b) Strahle, W. C. and Davis, J. A., "Acoustic-vortical interaction in a complex turbulent flow," AIAA Paper No. 88-0595 (1988).

   c) Tang, W. and Sankar, L. N., "Numerical simulation of vorticity-acoustics interactions within dump combustors," AIAA Paper No. 88-0597 (1988).

3. Presentations

   Strahle, W. C. and Sankar, L. N., "Acoustic response of turbulent reacting recirculatory flows," 23rd JANNAF Combustion Meeting, October, 1986.

4. Books

   (None)

List of Awards

Warren C. Strahle	Georgia Tech	AIAA Fellow	AIAA

Publications/Patents/Presentations/Honors Report

Papers submitted to refereed journals (and not yet published): 0

Papers published in refereed journals: 0

Books submitted for publication: 0

Books published: 0

Patents filed: 0

Patents granted: 0

Invited presentations at topical or scientific technical society conferences: 0

Contributed presentations: 1

Honors/Awards/Prizes: 1

Other Sponsored Research

Sponsor	Title	Amount	Period
ARO	Stagnating Turbulent Reacting Flows	$56,867	10/1/86-9/30/87
AFOSR	Heterogeneous Diffusion Flame Stabilization	$196,577	10/1/86-9/30/87

E-16-636

Final Technical Report

November, 1988

ACOUSTIC RESPONSE OF TURBULENT RECIRCULATORY FLOWS

from
School of Aerospace Engineering
Georgia Institute of Technology
Atlanta, GA 30332

Sponsor:
Office of Naval Research
Power Program Office

Contract: N00014-84-K-0293

Warren C. Strahle
Principal Investigator

WORK PERFORMED

The following tasks were performed:

1. An existing two dimensional, backward facing step windtunnel was modified for acoustic excitation for both cold and combustion flows.

2. Duct mode analysis was performed for this recirculatory flow.

3. Cold flow experiments were performed by hot wire anemometry and acoustic measurements for unforced and forced acoustic motions.

4. Laser sheet light visualization and schlieren visualization was performed in hot and cold flows.

5. Acoustic feedback experiments were performed in hot and cold flows.

6. Acoustic feedback analysis was performed for cold and hot flows.

7. Direct numerical simulations were conducted, primarily on cold flow but with some calculations on hot flows.

A summary paper was prepared for the 25th JANNAF Combustion Meeting and is attached to this report. It contains the summary of technical findings for this 4 1/2 year program.

PUBLICATIONS AND REPORTS

Davis, James A., "Acoustic-vortical-combustion interaction in a solid fueled ramjet simulator," Ph.D. Dissertation, Georgia Institute of Technology, March, 1989.

Strahle, W. C., Sankar, L. N., Davis, J. A. and Walterick, R. E., "Acoustic response of turbulent reacting recirculatory flows," to be published by CPIA as 25th JANNAF Combustion Meeting Proceedings. Also attached to this document.

Davis, J. A. and Strahle, W. C., "Acoustic vortical interaction in a complex turbulent flow," submitted to Journal of Sound and Vibration, 1988.

Tang, W., Sankar, L. N. and Strahle, W. C., "Numerical simulation of vorticity-acoustics interaction within dump combustors," AIAA Paper No. 88-0597, 1988.

Davis, J. A. and Strahle, W. C., "Acoustic-vortical interaction in a complex turbulent flow," AIAA Paper No. 88-0595, 1988.

Davis, J. A., Komerath, N. M., Walterick, R. E., Lekoudis, S. G. and Strahle, W. C., "Acoustic behavior of a SFRJ simulator," AIAA Paper No. 86-0003, 1986.

Goonetilleke, R. S., Lekoudis, S. G. and Strahle, W. C., "Nonisentropic propagation of sound in uniform ducts using Euler equations," AIAA Journal, 24, pp. 1088-1094, 1986.

ACOUSTIC RESPONSE OF TURBULENT REACTING RECIRCULATORY FLOWS (u)*

W. C. Strahle, L. N. Sankar, J. A. Davis and R. E. Walterick
School of Aerospace Engineering
Georgia Institue of Technology
Atlanta, Georgia 30332

ABSTRACT

(u) A summary is given of the results obtained in a 4 1/2 year program in ramjet instability at Georgia Tech. Topics covered are facility development and characterization, cold flow experiments in the two dimensional backward facing step configuration under acoustic excitation, combustion experiments under acoustic excitation and cold and hot flow numerical calculation of the two dimensional, unsteady, compressible Navier Stokes equations. Conclusions are drawn which are practical from a ramjet combustor design standpoint.

INTRODUCTION

(u) As part of an ONR Ramjet Instability Accelerated Research Initiative, a Georgia Tech program was conducted using a modified ramjet combustor facility and various analytical/computational techniques. The fundamental purposes were to investigate vortical-acoustics, vortical-combustion and combustion-acoustics interactions. Dominant issues were feedback between vortical and combustion processes with the imposed acoustic field. General principles were sought which could aid an engine designer in avoidance of the instability problem.

FACILITY

(u) Depicted in Fig. 1 is the experimental facility used in the program. The wind tunnel was a two dimensional suction type tunnel with the inlet flow dumping into a combustion chamber behind a backward facing step. Combustibles and inerts were injected from the tunnel floor behind the step. The step height, H, was 3.5cm, the tunnel height behind the step was 10.5cm high, and the tunnel aspect ratio was 12 to 1 based on step height. The injection plenum was compartmentalized to allow various axial distributions of injectants.

(u) A rectangular spanwise rotor, capable of introducing a 0-500 Hz disturbance of the tunnel flow, was located downstream of the combustion chamber. The upper limit frequency was chosen so that only plane wave motion would be dominant (longitudinal waves). This was designed as an open loop acoustic facility whereby only forced oscillations were induced. Measurements of acoustic pressure, velocity and OH radiation (under combustion conditions) were carried out. Hydrogen (diluted with N_2) was usually used as the fuel under combustion conditions although methane was occasionally used.

(u) Being an open loop acoustic system and a rather complex configuration it was necessary to know the general tunnel mode structure under oscillatory conditions. This structure is shown in Fig. 2 where measured velocity and pressure at a plane upstream of the step are used in conjunction with a plane wave model to deduce the unusually rich set of modes as a function of open loop driving frequency. The objective was to observe any feedback from acoustic-velocity, acoustic-combustion or vorticity-combustion interactions under the forced conditions.

COLD FLOW ACOUSTIC-VORTICITY INTERACTION

(u) By a variety of cross correlation techniques and spectral analysis it was found that a) in this configuration under a non-forced situation very little organized structure was shed from the backward facing step, but b) under forced conditions the vorticies would synchronize into ordered structures at select frequencies. These frequencies were at about 230, 330 and 440 Hz, with the most organized behavior near 230 Hz. Shown in Fig. 3 is a "cartoon" taken from a photograph made by two-dimensional laser-sheet lighting, clearly showing organized structure at 230 Hz. This frequency does not correspond to an acoustic resonant frequency, but does correspond to the frequency calculated as the most unstable frequency of the shear layer.

(u) Subsequent tests endeavored to see if these organized vortices fed back and altered the applied acoustic field. The lower curve of Fig. 4 shows that no such alteration was affected. The vortices

* This work was performed under Contract No: N00014-84-K-0293
at a Georgia Tech ramjet windtunnel facility.

were in one case removed by removing the backward step in favor of a slowly divergent diffuser, and no acoustic field alteration took place. Even though organized, the vortices are acoustic quadrupoles, which are weak acoustic sources. This conclusion was supported by direct measurement of the quadrupole strength and its insertion into an aeroacoustics theory. This conclusion is not to say that the organized structures are unimportant. Interaction with downstream boundaries and/or combustion is necessary, however, for important effects to occur. In the current apparatus there were no important downstream interactions; in a real ramjet there would be.

COMBUSTION-ACOUSTIC INTERACTION

(u) With the addition of combustion there is a strong alteration of the acoustic field, as compared with the no-combustion case. This was expected, but current work is still in progress to allow full physical conclusions to be drawn. Figure 5 shows the magnitude and phase angle of the fluctuating component of pressure, p', for two cases. The first case is with no burning in the test section (0-35 cm on the figure) and the second case is for burning hydrogen in the test section. These figures demonstrate that combustion in the test section modifies the acoustic mode shape. This is in contrast to the shear layer/no shear layer comparison where no modification was noted. These results should be considered preliminary for two reasons. First, the pressure measurements were made along the top of the test section and it is not yet clear if both acoustic and hydrodynamic (i.e., non-acoustic) fluctuations were recorded. Second, it is currently being checked whether or not plane wave structure to the acoustic field is being violated with combustion. This is highly possible because of the vertical stratification of the temperature field.

(u) Other experiments currently being carried out are the OH radiation measurements and their relation to the pressure fluctuation measurement. The purpose here is to see whether or not, under shear layer synchronization, the combustion process is driving or damping acoustic oscillations.

NUMERICAL CALCULATIONS - COLD FLOW

(u) Numerical solution of the 2-D unsteady, compressible Navier-Stokes equations have been obtained for the flow field within a dump combustor. The shear layer coming off the step was excited at selected frequencies by changing the over-all length of the combustor/inlet combination, or by closing part of the downstream boundary forming a cavity of known acoustic characteristics. In all cases studied the shear layer locks on to the preferred acoustic frequency of the configuration, and undergoes periodic flapping and vortex shedding, as shown in Fig. 6 for a combustor configuration with an open downstream boundary. Fourier spectra of the pressure field at selected X-locations on the shear layer are plotted in Fig. 7. While the predominant peak in these spectra was always associated with the acoustics of the configuration, secondary peaks traceable to the natural frequency of the shear layer were also found. Thus the calculations seem to indicate that the acoustics controls the vorticity field, while the vorticity field has a small but discernible influence on the acoustics.

NUMERICAL CALCULATIONS - HOT FLOW

(u) Some studies of the effect of chemical reaction on the behavior of the shear layer within the combustor were also carried out. For cold flows with species injection, and for low energy release chemical reactions the shear layer behavior was quite similar to the no-species/no-reaction case. When the energy release due to the chemical reaction was increased, it was found that the high pressure rise within the combustor was able to cause a momentary separation of the shear layer upstream of the step as shown in Fig. 8.

CONCLUSIONS AND TECHNOLOGY TRANSFER

1. (u) In ramjet configurations where vortex formation is essential for flameholding action, it is imperative that organized structures' natural frequencies become detuned from the chamber acoustics. This conclusion is supported by both experiment and computation. This may be accomplished by design, since the effects are largely calculable, or by designing for broad band vortical structures (as others have suggested).

2. (u) The presence of combustion does not strongly alter the frequencies of vortical resonance, but strongly influences the ability to feedback to the acoustic field. While this conclusion is experimentally supportable, computations are currently in progress to add further support. Where combustion takes place mainly in the vortex field (not necessarily always the case), the vortices become powerful acoustic monopoles. In such cases the vortex combustion time (vortex size and possibly chemistry) must be detuned from the acoustic resonance times of the combustion chamber-ramjet system.

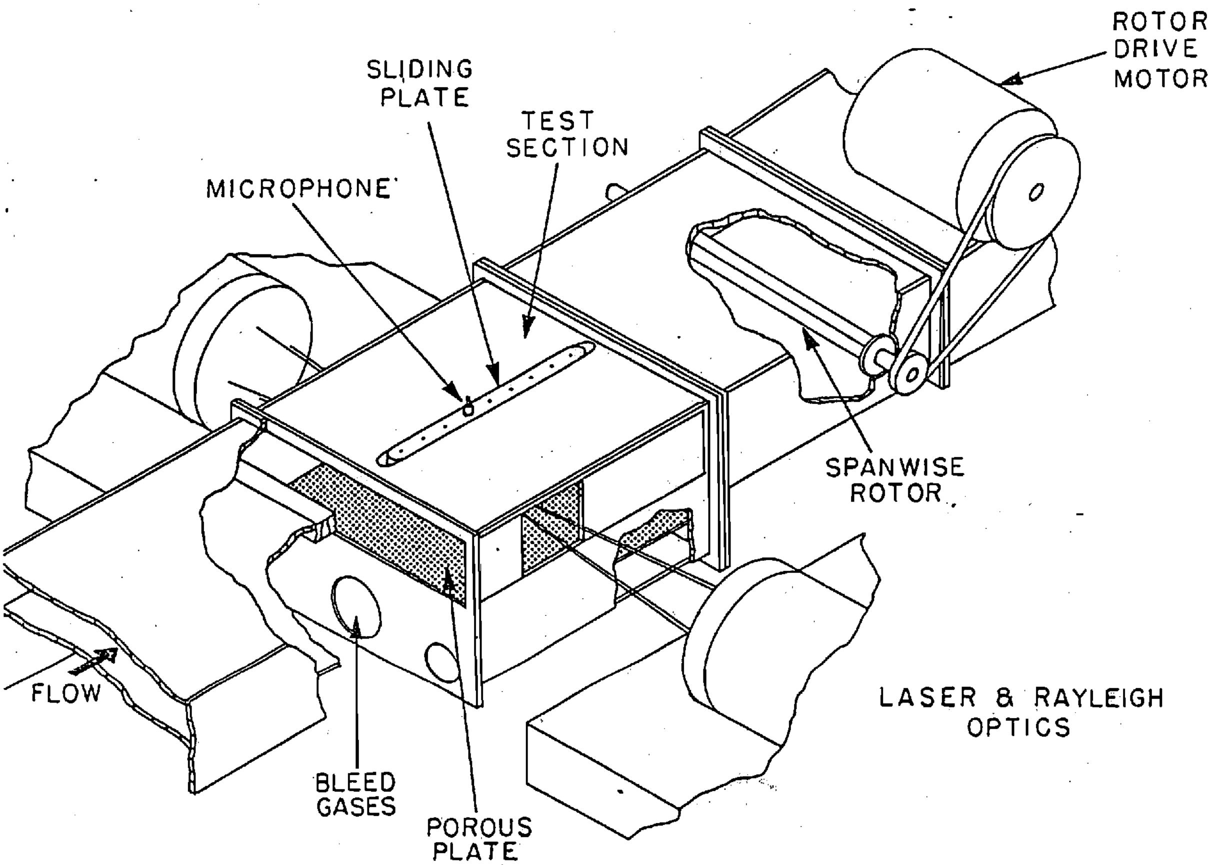

Figure 1. Facility Schematic

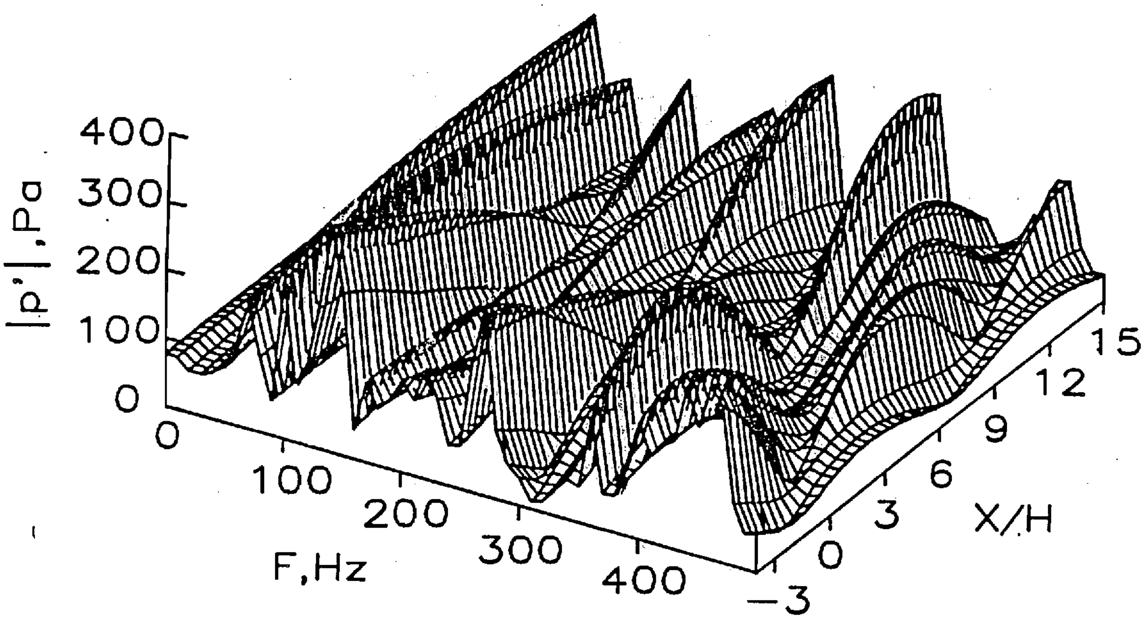

Figure 2. Tunnel Acoustic Modes as a Function of the Driving Frequency

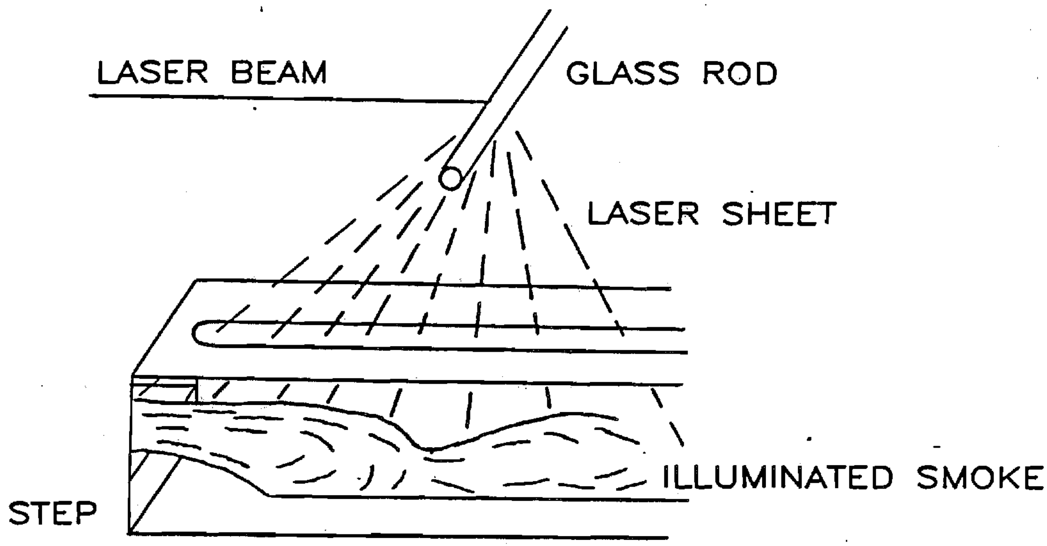

Figure 3. Schematic View of Organized Vortex Structures Produced by the Applied Acoustic Field

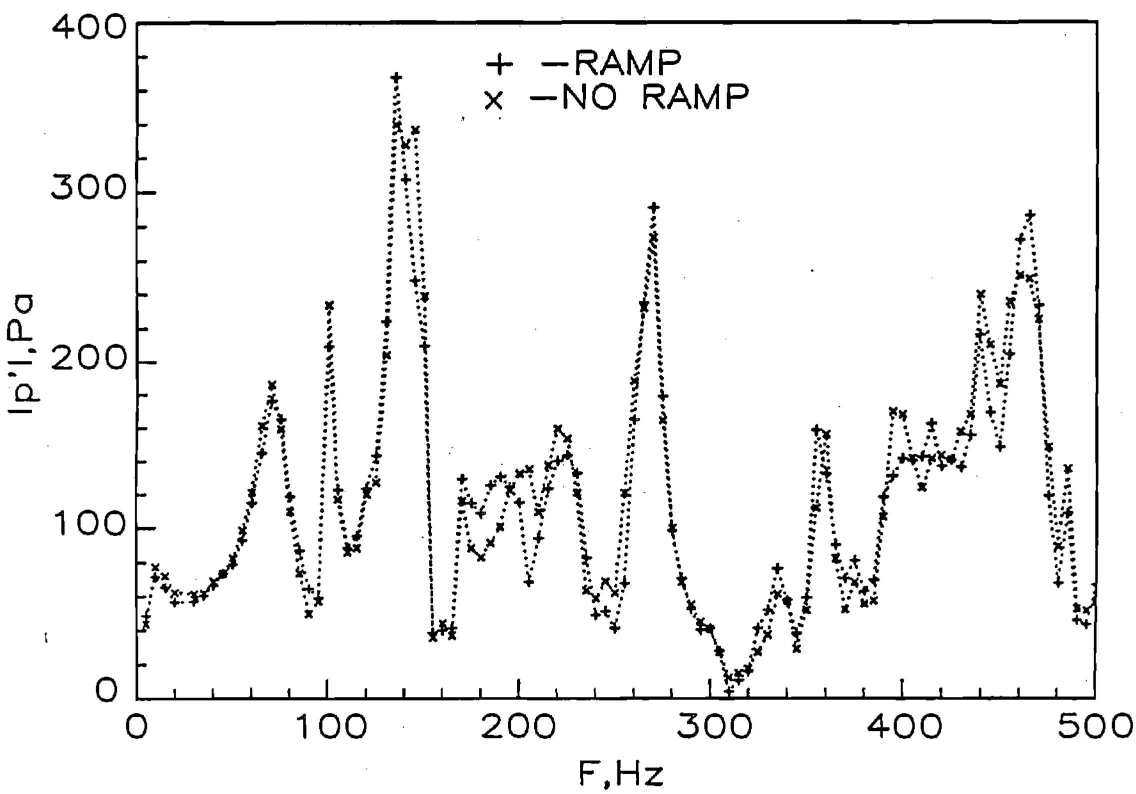

Figure 4. Variation of Pressure with Driving Frequency with and without Vortex Shedding

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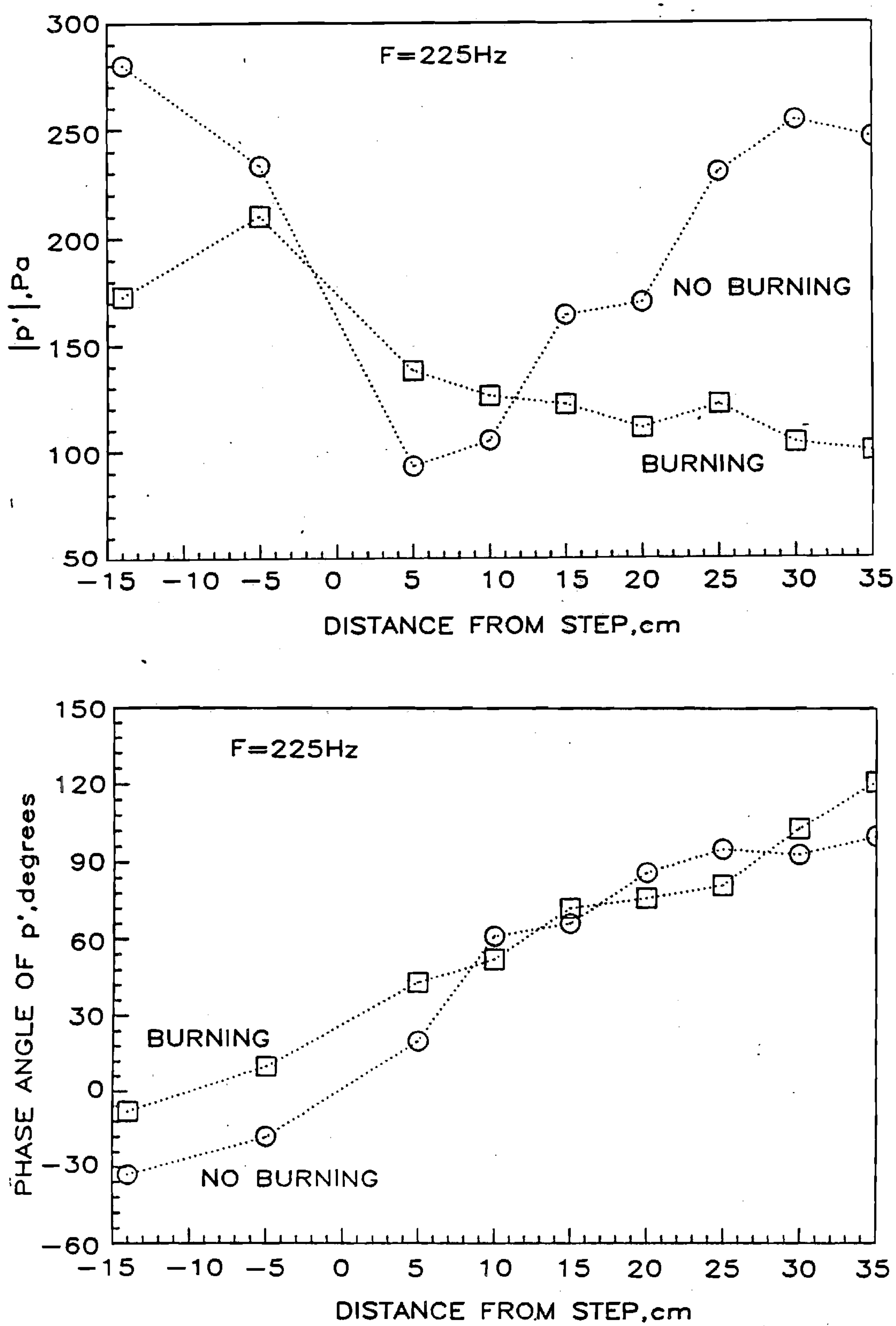

Figure 5. Effect of Combustion on the Pressure Field within the Tunnel

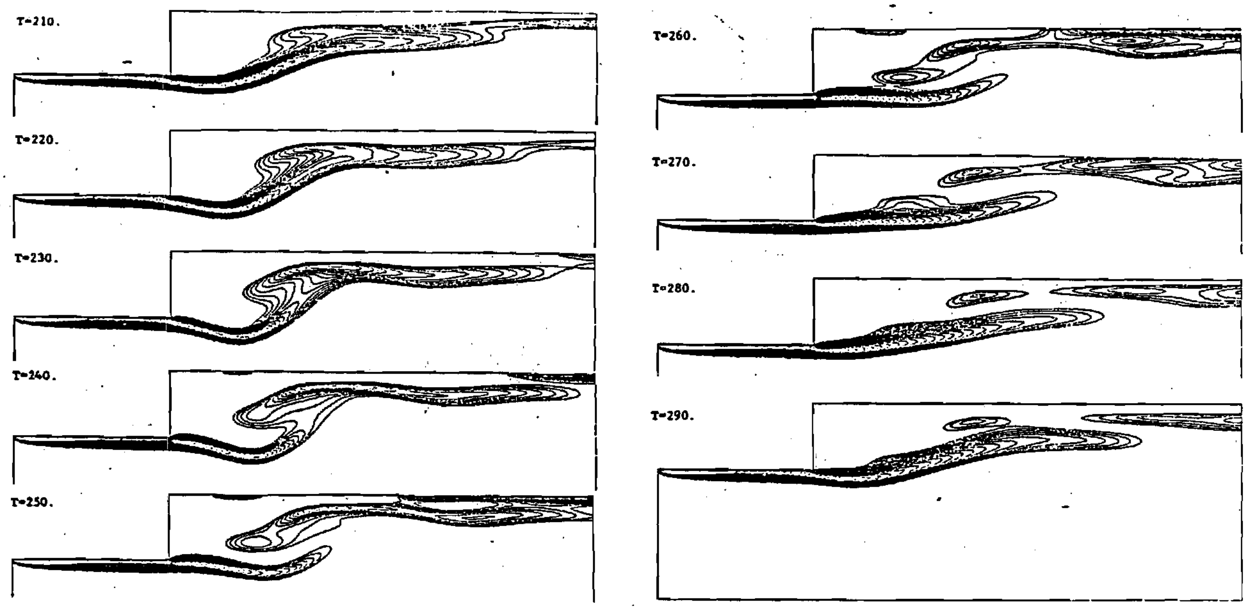

Figure 6. Computed Vorticity Contours at Selected Time Levels (Cold Flow)

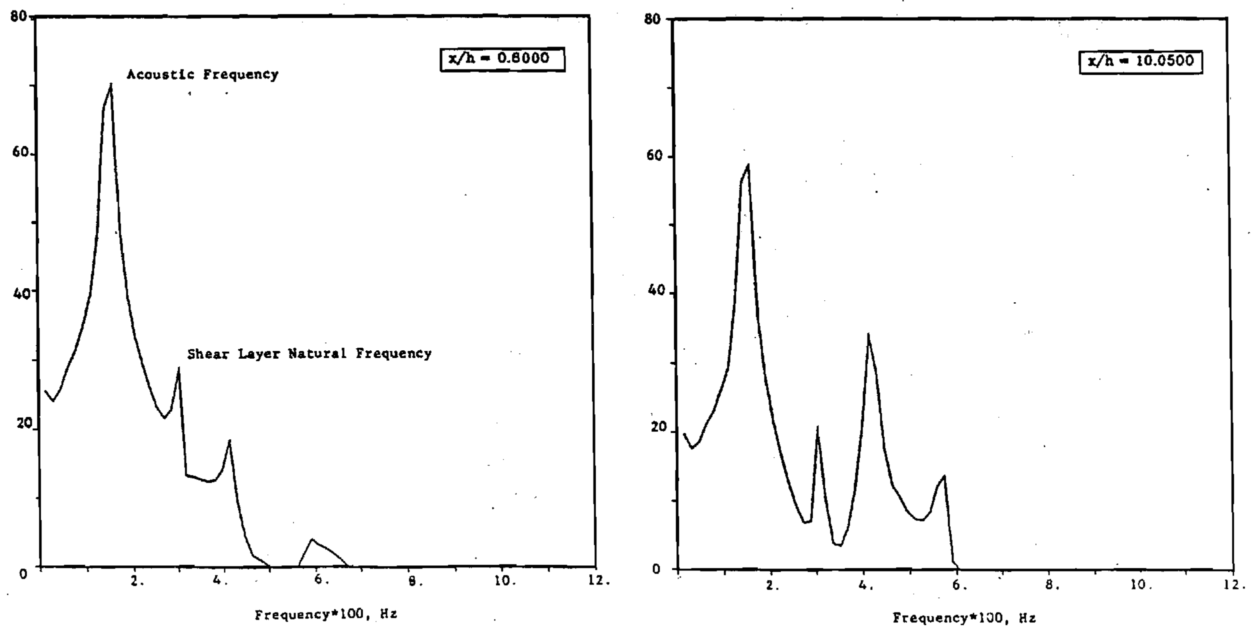

Figure 7. Fourier Transform of the Computed Pressure Field at Selected Locations within the Shear layer

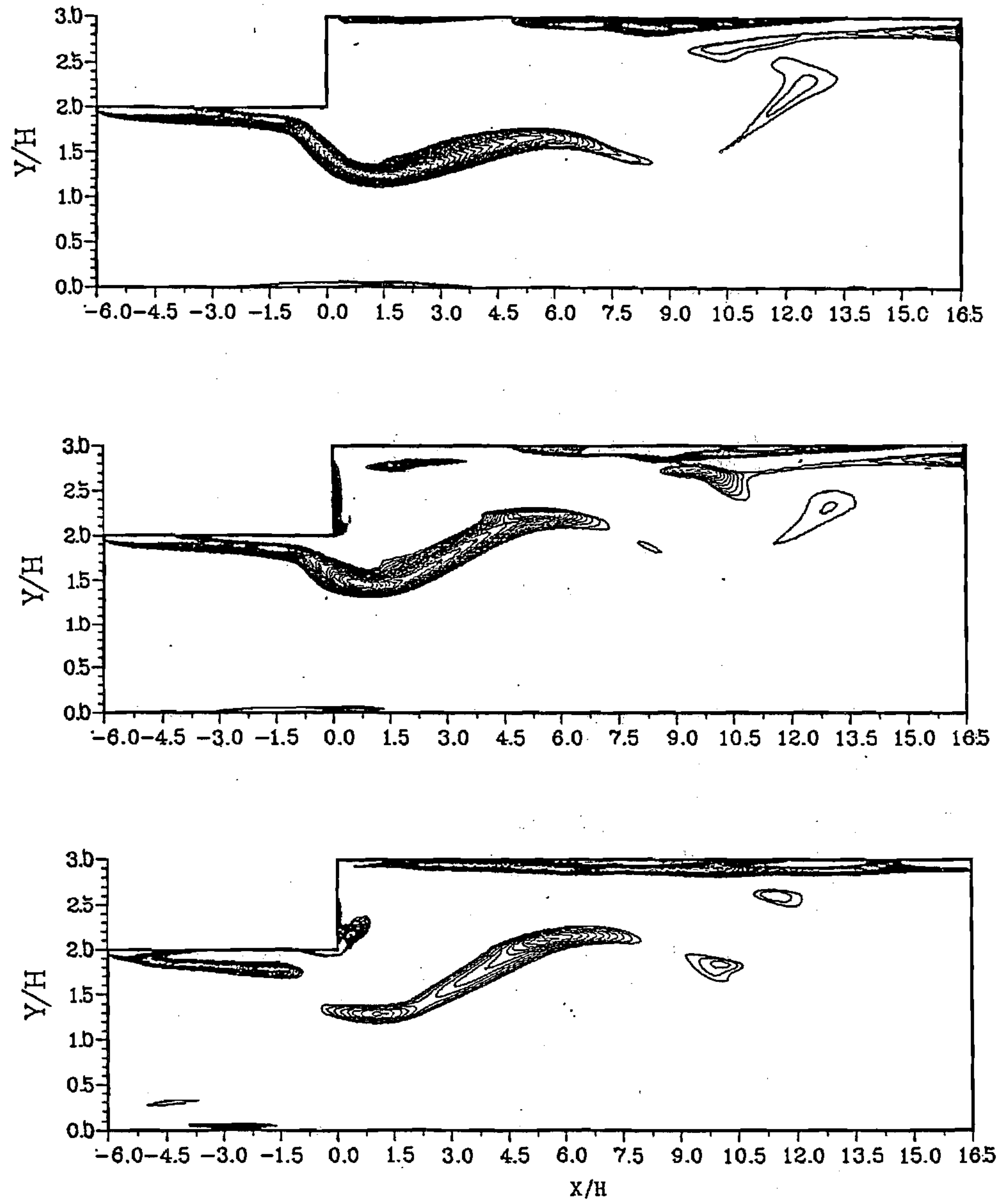

Figure 8. Computed Vorticity Contours at Selected Time Levels (Reacting Flow)