08:43:13 OCA PAD INITIATION - PROJECT HEADER INFORMATION 09/11/11

Active

Project #: E-16-666 Cost share #: E-16-326 Rev #: 0
Center # : R6390-0A0 Center shr #: F6390-0A0 OCA file #:
Work type : RES
Contract#: DE-FG05-87ER75366 Mod #: Document : GRANT
Prime #: Contract entity: GTRC

Subprojects ? : N
Main project #:

Project unit: ICS Unit code: 02.010.142
Project director(s):
ZINN B T AE

Sponsor/division names: US DEPT OF ENERGY / DOE OAK RIDGE - TN
Sponsor/division codes: 141 / 017

Award period: 870915 to 900914 (performance) 901214 (reports)

Sponsor amount	New this change	Total to date
Contract value	93,224	93,224
Funded	93,224	93,224
Cost sharing amount		23,306

Does subcontracting plan apply ?: N

Title: INTENSIFIED DIGITAL IMAGING SYSTEM FOR PULSATING COMBUSTORS

PROJECT ADMINISTRATION DATA

OCA contact: Brian J. Lindberg 894-4820

Sponsor technical contact	Sponsor issuing office
DONNA J PROKOP	MARLENA CLARK
(202)586-8910	(615)576-7599
U.S. DEPARTMENT OF ENERGY	U.S. DEPARTMENT OF ENERGY
DIV. OF UNIV. & INDUSTRY PROGR	PROCUREMENT AND CONTRACTS DIVI
WASHINGTON, DC 29585	P.O. BOX 3, OAK RIDGE, TN 3783

Security class (U,C,S,TS): U ONR resident rep. is ACO (Y/N): N
Defense priority rating: N/A N/A supplemental sheet
Equipment title vests with Sponsor GIT X

Administrative comments -
THIS IS AN EQUIPMENT GRANT. ALL SPONSOR FUNDS ARE FOR EQUIPMENT PURCHASES.

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 03/12/91

Project No. E-16-666

Center No. R6390-0A0

Project Director ZINN B T

School/Lab AERO ENGR

Sponsor US DEPT OF ENERGY/DOE OAK RIDGE - TN

Contract/Grant No. DE-FG05-87ER75366

Contract Entity GTRC

Prime Contract No.

Title INTENSIFIED DIGITAL IMAGING SYSTEM FOR PULSATING COMBUSTORS

Effective Completion Date 900914 (Performance) 901214 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	N	
Final Report of Inventions and/or Subcontracts	N	
Government Property Inventory & Related Certificate	Y	900315
Classified Material Certificate	N	
Release and Assignment	N	
Other	N	

CommentsLETTER-OF-CREDIT NO.89-00-3039, NO INVOICE REQUIRED.

Subproject Under Main Project No.

Continues Project No.

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
Reports Coordinator (OCA)	N
GTRC	N
Project File	Y
Other	N
	N

E-16-666

Georgia Tech

Office of Grants and Contracts Accounting

Georgia Institute of Technology
Lyman Hall/Emerson Building
Atlanta, Georgia 30332-0259
404•894•4624; 2629
Fax: 404•894•5519

October 27, 1989

Ms. Melissa Y. Johnson, Contract Specialist
U. S. Department of Energy-Oak Ridge Operations
Procurement and Contracts Division
Contracts Management Branch
P. O. Box 2001
Oak Ridge, TN 37831-8758

REFERENCE: Grant E DE-FG05-87ER75366

Dear Ms. Johnson,

Enclosed in triplicate is the Financial Status Report (SF-269) for Grant No. DE-FG05-87ER75366, covering the period September 15, 1987 through September 14, 1989.

If you have questions or require additional information, please contact Geraldine Reese of this office at (404) 894-2629.

Sincerely,

David V. Welch
Director

DVW/GMR/djt

Enclosure

cc: Dr. D. P. Giddens, Aerospace Eng 0150
Dr. B. T. Zinn, Aerospace Eng 0150
Ms. Mary Wolfe, OCA/CSD 0420
File E-16-666/R6390-0A0

FINANCIAL STATUS REPORT
(Short Form)
(Follow instructions on the back)

1. Federal Agency and Organizational Element to Which Report is Submitted	2. Federal Grant or Other Identifying Number Assigned By Federal Agency	OMB Approval No.	Page	of
U. S. Department of Energy	DE-FG05-87ER75366	0348-0039	1	1 pages

3. Recipient Organization (Name and complete address, including ZIP code)
Georgia Tech Research Corporation
P. O. Box 100117
Atlanta, GA 30384

4. Employer Identification Number	5. Recipient Account Number or Identifying Number	6. Final Report	7. Basis
58-0603146	E-16-666/R6390-0A0	☐ Yes ☒ No	☒ Cash ☐ Accrual

8. Funding/Grant Period *(See Instructions)* From: (Month, Day, Year)	To: (Month, Day, Year)	9. Period Covered by this Report From: (Month, Day, Year)	To: (Month, Day, Year)
September 15, 1987	September 14, 1990	September 15, 1987	September 14, 1989

10. Transactions:	I Previously Reported	II This Period	III Cumulative
a. Total outlays	-0-	$112,668.77	$112,668.77
b. Recipient share of outlays	-0-	19,444.77	19,444.77
c. Federal share of outlays	-0-	93,224.00	93,224.00
d. Total unliquidated obligations			-0-
e. Recipient share of unliquidated obligations			-0-
f. Federal share of unliquidated obligations			-0-
g. Total Federal share *(Sum of lines c and f)*			93,224.00
h. Total Federal funds authorized for this funding period			93,224.00
i. Unobligated balance of Federal funds *(Line h minus line g)*			$ -0-

11. Indirect Expense

a. Type of Rate *(Place "X" in appropriate box)* ☐ Provisional ☐ Predetermined ☐ Final ☒ Fixed

b. Rate	c. Base	d. Total Amount	e. Federal Share
See Below	MTDC	N/A	N/A

12. *Remarks: Attach any explanations deemed necessary or information required by Federal sponsoring agency in compliance with governing legislation.*

If you have questions pertaining to this report please contact: Geraldine Reese (404) 894-2629

GEORGIA TECH FISCAL YEAR ENDS JUNE 30

13. Certification: **I certify to the best of my knowledge and belief that this report is correct and complete and that all outlays and unliquidated obligations are for the purposes set forth in the award documents.**

Typed or Printed Name and Title	Telephone (Area code, number and extension)
David V. Welch, Director Office of Grants and Contracts Accounting	(404) 894-2629
Signature of Authorized Certifying Official	Date Report Submitted

Previous Editions not Usable

Standard Form 269A (REV 4-88)
Prescribed by OMB Circulars A-102 and A-110

FY'88 @ 60.0%
FY'89 @ 60.0%
FY'90 @ 62.5%

E-16-666

ANNUAL REPORT

INTENSIFIED DIGITAL IMAGING SYSTEM FOR PULSATING COMBUSTORS

DOE Grant Number: DE-FG05-87ER75366

Principal Investigators: B.T. Zinn and J.I. Jagoda
School of Aerospace Engineering
Georgia Institute of Technology

Period Covered: 9/15/87 - 9/14/88

Shortly after this project was initiated by DOE, the scientific imaging market was reinvestigated by the principal investigators. This was necessary, since the digital imaging market is currently in a state of rapid expansion and new products become available every month. This search revealed that the imaging system most suitable for our needs is an intensified digital imaging system now being marketed by CSPI (formerly Microtex) of Bellerica, MA. The CSPI system is somewhat more expensive than that originally proposed. However, additional funds made available by Georgia Tech enabled us to initiate the purchase of the CSPI imaging system along with its software.

The CSPI imaging system consists of two cameras, one intensified and one non-intensified, a data acquisition and reduction computer and extensive data acquisition and reduction software. The cameras contain Reticon arrays consisting of 128x128 16 bit pixles which are capable of capturing 200 full frames per second (proportionally more for partial frames). The intensifier has a gain of 5000 and is gateable down to 100 nano-seconds. Its phosphor is fast quenching to assure that the intensifier does not adversely affect the maximum framing rate.

Data are acquired via a MicroVAX II workstation. The computer is fitted with 4Mb rapid access memory capable of storing up to 256 full frames at 12 bit resolution. Also included is 17 Mb of regular memory. Up to 20,000 images at 16 bit can be stored on a 760 Mb hard disc. The workstation is programmed via a VT 320 terminal and the images are displayed on a 19" color monitor with 1280 x1024 pixel resolution swept at 100 MHz. Also included are a digitizing tablet and a laser printer. In addition, a Data Translation 16 channel, 250 kHz A/D board and its input system are added to the computer. This permits the acquisition of single channel data, such as combustor pressures, along with each image. The incorporation of this A/D board into the imaging system represents a new development for CSPI.

All software required for data acquisition and storage is included. The data analysis software includes frame addition, subtraction, edge enhancement and filtering. FFT capabilities for full frame images are also provided. All the above software is "off the shelf" In addition CSPI has committed itself to develop software capable of carrying out single pixel FFTs, auto- and cross-correlations and the determination of power spectra as well as of phase angles between the signals originating from specified pixles. CSPI is also fully integrating the Data Translation A/D board, its software and its library into the imagenet operating system which runs the MicroVAX II.

Because of the extensive new ground which is to be broken by the vendor in the area of hardware integration and software development, the system has not yet been delivered to Georgia Tech. Delivery, installation and initial check-out are now planned for mid-November 1988. However, the vendor has supplied all existing manuals for the system and a Graduate Research Assistant, funded by Georgia Tech, has been assigned to bringing the imaging system on line. This graduate student has started to familiarize herself with the system's operation.

E 16-666

FINAL REPORT

INTENSIFIED DIGITAL IMAGING SYSTEM FOR PULSATING COMBUSTION

DoE Grant Number: DE-FG05-87ER75366

Principal Investigators: B.T. Zinn and J.I. Jagoda
School of Aerospace Engineering
Georgia Institute of Technology

Period Covered: 9/15/87 - 9/14/90

Introduction

Early during the contract the scientific digital imaging market was reinvestigated. This became necessary because significant advances in available technology occured since the proposal was first written. Furthermore, additional funds were made available by the Georgia Institute of Technology which enabled us to significantly upgrade the system. The system finally decided on is an intensified digital imaging system, developed by Microtex and now marketed by CSPI of Bellerica, MA. It has become an integral part of the Pulse Combustion Engineering Laboratory currently being set up at the School of Aerospace Engineering at Georgia Tech.

System Description

The CSPI imaging system consists of two cameras, one intensified and the other non-intensified, a frame grabber, a data acquisition and reduction computer and extensive data acquisition and reduction software. The cameras contain Reticon arrays consisting of 128 x 128 16 bit pixels. The intensifier has a gain of 500 and is gateable down to 100 nanoseconds. Its phosphor is fast quenching to assure that the intensifier does not adversely affect the maximum framing rate.

The outputs of the Reticon arrays are read by an Omnicomp frame grabber which is capable of capturing 200 full frames per second, proportionally more for partial frames. The data are then stored in a MicroVax II workstation fitted with 4 Mb rapid access memory (RAM). This allows up to 256 full frames with 12 bit resolution to be stored in memory before data acquisition has to be interrupted to download the data. In addition, 17 Mb of regular memory are available. Up to 20,000 images with 16 bit resolution can be stored on the 760 Mb hard disc. The workstation is programmed via a VT 320 terminal and the images are displayed on a 19" color monitor with 1280 x 1024 pixel resolution swept at 100 MHz. Also included are a digitizing tablet, a back up tape drive and a laser printer.

A Data Translation 16 channel, 250 kHz A/D converter board and its input system were acquired from the manufacturer as an add on. This permits us to acquire and store analog, scalar data, such as pressures or temperatures, simultaneously with individual images. The incorporation of this A/D board and associated software was a new development for CSPI.

All software required for data acquisition and storage was included with the system. In addition, data analysis software was supplied by the manufacturer which includes frame addition, subtraction, averaging, edge enhancement and filtering. FFT capabilities for full frame images were also provided. The manufacturer also included capabilities to average and sort frames and "stack" them behind each other. Individual or groups of pixels can then be selected and their variation with time traced. These traces can then be used to carry out FFTs and auto correlations which lead to the determination of power spectra of the signals at the selected locations. Similarly, cross correlations between two pixel locations or one pixel location and one of the scalar signals can be obtained. These can then be used to determine the phase angle between these signals, if they are periodic. This, in turn, permits one to visualize, for example, the flame spread through a pulse flow under investigation or to determine the phase angle between local heat release and pressure oscillations. The latter can be shown to be a measure of the strength of the driving of the pressure pulsations by the heat release fluctuations. Finally, the display software supplied with the system permits the display of individual frames and series of frames using either gray scales or false colors, linearly or logarithmically normalized. Successive frames can also be displayed, one after another, resulting in a moving picture representation of time varying images. In addition, three dimensional plots of pixel location and intensity can be generated.

The software supplied by the vendor has been refined by the staff and students at Georgia Tech. For example, additional software has been written which permits the display of the data in the form of phase angle contour plots.

Applications

After delivery of the system an M.S. level student was assigned to set it up and to carry out an extensive check out of all the supplied hardware and software. The system generally met the manufacturers specifications although initial problems with the frame grabber module persisted for a number of months. These have since been solved. The student also wrote an instruction manual as part of her Special Problem. This manual is primarily designed for first time users and, therefore, is more concise than the manufacturer's instructions. It also contains many practical hints and tips learnt from experience but not provided by the manufacturer. The system has now become a central focus of our pulse combustion research capabilities. The results of two application of the system to our ongoing research are briefly outlined below.

Helmholtz Pulse Combustor

The performance of a natural gas fired, valved, Helmholtz type, pulse combustor is being investigated in this program sponsored by the Gas Research Institute. This pulse combustor, which is based upon an AGA design, is shown schematically in Fig. 1. It consists of cylindrical mixing and combustion chambers, a tailpipe, a cylindrical decoupling chamber and a short vent pipe. Natural gas and air enter the combustor at right angle to each other through separate flapper valves attached to the curved side wall of the mixing chamber. During start up, the reactants are allowed to mix and are ignited using a spark plug. As the natural gas burns (a process which has been shown to take place primarily in the mixing chamber) the pressure in the combustor rises. This closes the flapper valves which prevents further reactants from entering the mixing chamber. This pressure rise also pushes the combustion products out through the tail pipe. The momentum of the expelled exhaust gases causes the pressure in the mixing chamber to drop which reopens the flapper valves. New reactants now enter the combustor where they mix and are ignited by burning pockets of gas left over from the previous cycle. The cycle now repeats itself. Thus, pulse combustion operation can be maintained indefinitely without the use of the spark plug.

The gap in the fuel flapper valve is fixed while that in the air valve can be adjusted using a micrometer, see Fig. 2. The overall equivalence ratio in the pulse combustor is, therefore, varied by adjusting the air flapper valve setting which changes the air flow rate.

Local radical radiation and, therefore, heat release rates in the combustor were measured by imaging CC radiation through a flat quartz window at the upstream end of the mixing chamber. Images obtained at the same instants during consecutive cycles indicate that while the overall features of the flame shape are very similar at given instants during the cycle, the precise path over which the flame has spread varies somewhat from cycle to cycle. Figure 3 shows four frames which indicate the locations of the ignition and flame spread during one cycle in the pulse combustor. Each "frame" actually represents the average of 128 separate images obtained at the same phase during different cycles. The mechanism of flame spread is best illustrated by comparing the instantaneous flow fields (as obtained from high speed Schlieren records) with the heat release distributions in Fig. 3. Early in the cycle (Fig. 3a), as the fuel jet enters the mixing chamber, it begins to react weakly with the air left over from the previous cycle. Main ignition of the new fuel occurs at the time and location where the fuel jet impinges upon the opposite wall, as shown in Fig. 3b. At that instant the new air jet has just reached the center of the mixing chamber. Shortly thereafter, the upper part of the leading mushroom vortex of the air jet entrains the reacting fuel which intensifies the combustion process and spreads it throughout the upper part of the mixing chamber (Fig. 3c). Only after a pair of counter-rotating vortices have established themselves does the flame spread throughout the entire mixing chamber, as shown in Fig. 3d.

In order to quantify the flame spread in the mixing chamber, the phase angle between the local radiation fluctuations and the pressure oscillations were calculated and displayed using the phase angle contour plot mentioned above. This distribution of the phase angles then gives an indication of the instantaneous shape of the flame and of its spread through the combustor. Figure 4 shows a contour plot obtained using this technique. The numbers indicate the phase by which the local heat release leads the pressure. The flame, thus, spreads from the upper left hand side of the mixing chamber, opposite the fuel port, towards the lower left hand side and, finally, towards the right hand side of the mixing chamber into the region between the fuel and air ports. These results have allowed us to gain invaluable insight into the timing and spatial distribution of the reactant injection, mixing and heat release.

Rijke Pulse Combustor.

The concept of the Rijke tube has been known as a laboratory curiosity for some 200 years. However, recently researchers at Georgia Tech have been able to develop pilot scale models of Rijke type pulse combustors capable of burning heavy fuel oils or unpulverized coal with extraordinarily high combustion efficiencies and with a minimum amount of excess air. This work was sponsored by D.o.E. Current work in progress under the same sponsorship, is investigating the mechanisms responsible for the operation of this type of pulse combustor.

A standard Rijke tube consists of a vertical tube of constant cross sectional area, open at both ends. If heat is supplied by a flame or by resistive heating at one quarter of the tube length from the bottom end of the tube, a standing wave, similar to that in an organ pipe, is set up in the tube.

In the practical device being investigated at Georgia Tech the combustor tube is maintained horizontally. Two large decouplers are fitted to the ends of the tube, see Fig. 5. Compressed air is forced into one decoupler and excess air and combustion products are vented from the other. Fuel and additional air are injected into the combustor tube at a location one quarter of the length of the tube from the inlet decoupler. Details of this injection system are shown in Fig. 6. Fuel and air are premixed in a small mixing chamber and the resulting mixture is injected through an injection duct tangentially into the combustor tube. Combustion begins in the injection duct and extends all the way into the combustion tube. Quartz windows which permit optical access are, therefore, fitted into the walls of the injection duct and of the combustion tube immediately downstream of the injector. Propane has been used in early investigations in order to avoid the added complication of two phase flow and combustion posed by the use of liquid fuel sprays.

Preliminary visualization of the the CC radiation intensity and, therefore, of the reaction rate distribution in the injection duct and combustion tube at five instants during the cycle are shown in Fig. 7. A jet of the fuel air mixture with a large leading edge vortex enters the injection duct from the mixing chamber early in the cycle. Combustion of the mixture for this cycle is initiated in the vortex causing the pressure in the combustor to begin to rise. The spatial distribution and intensity of the combustion process then increase until the flame has spread throughout the entire injection duct near maximum pressure. The reaction rate then reduces and the flame begins to spread downstream into the combustor tube. This is accompanied by a decrease in acoustic pressure which continues as the combustion intensity decreases. Eventually, ignition of new reactants occurs in the leading edge vortex of the fuel air jet and the cycle repeats itself.

The reaction rate intensity distributions in Fig. 7 are shown as three dimensional plots of radiation intensity versus pixel locations in Fig. 8. The time variation of the complex flow field is currently being visualized using high speed Schlieren photography in order to obtain a better understanding of the interaction between the fluid mechanics and the flame spread in the pulse combustor.

Conclusions

An intensified digital imaging system with its associated software has been acquired, set up and thoroughly tested. Additional software has been developed which permits the system to be utilized to its fullest potential. The equipment has been used to visualize the the locations of cycle to cycle reignition and the flame spread through the combustion chambers of Helmholtz and Rijke type pulse combustors. The system will find additional uses once a planar laser induced fluorescence set up becomes operational. This equipment is being purchased with funds made available by the Gas Research Institute and by Georgia Tech. In conclusion, it can be stated that this intensified digital imaging system has significantly extended the diagnostic capabilities of the combustion laboratory at the School of Aerospace Engineering at Georgia Tech.

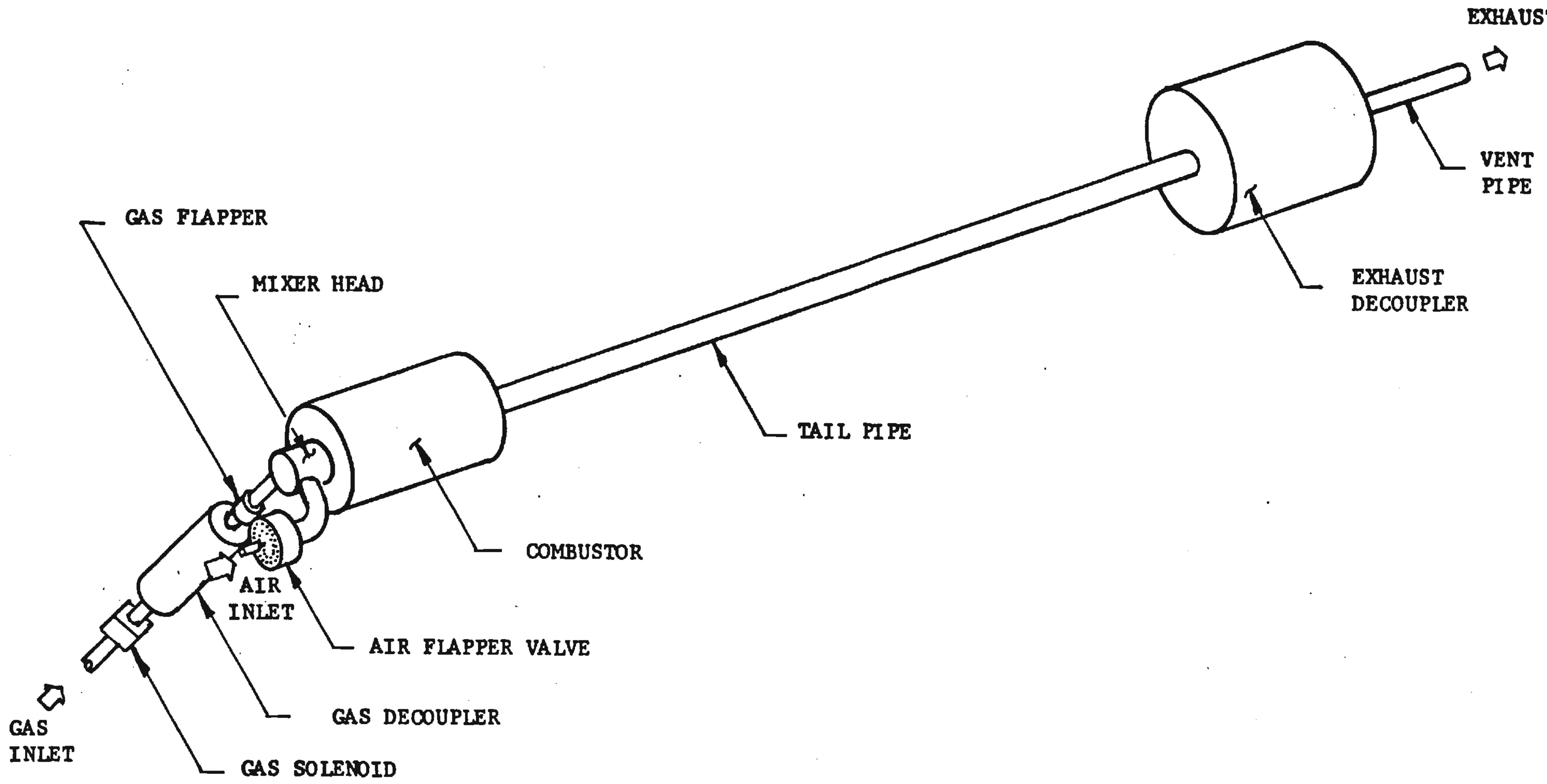

Fig. 1 Schematic of the Helmholtz Type Pulse Combustor

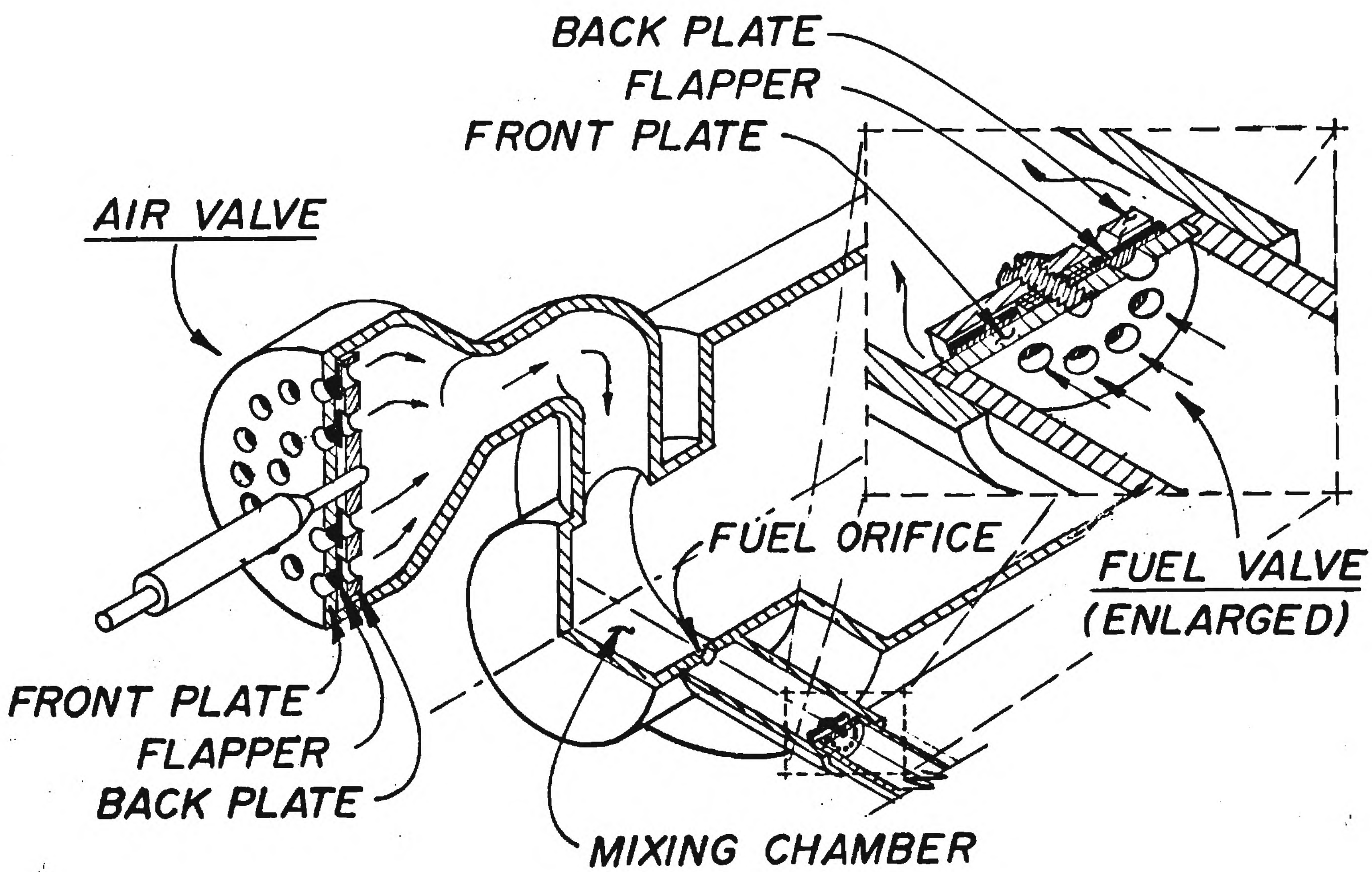

Fig. 2 Schematic of the Mixing Chamber Showing the Fuel and Air Flapper Valves

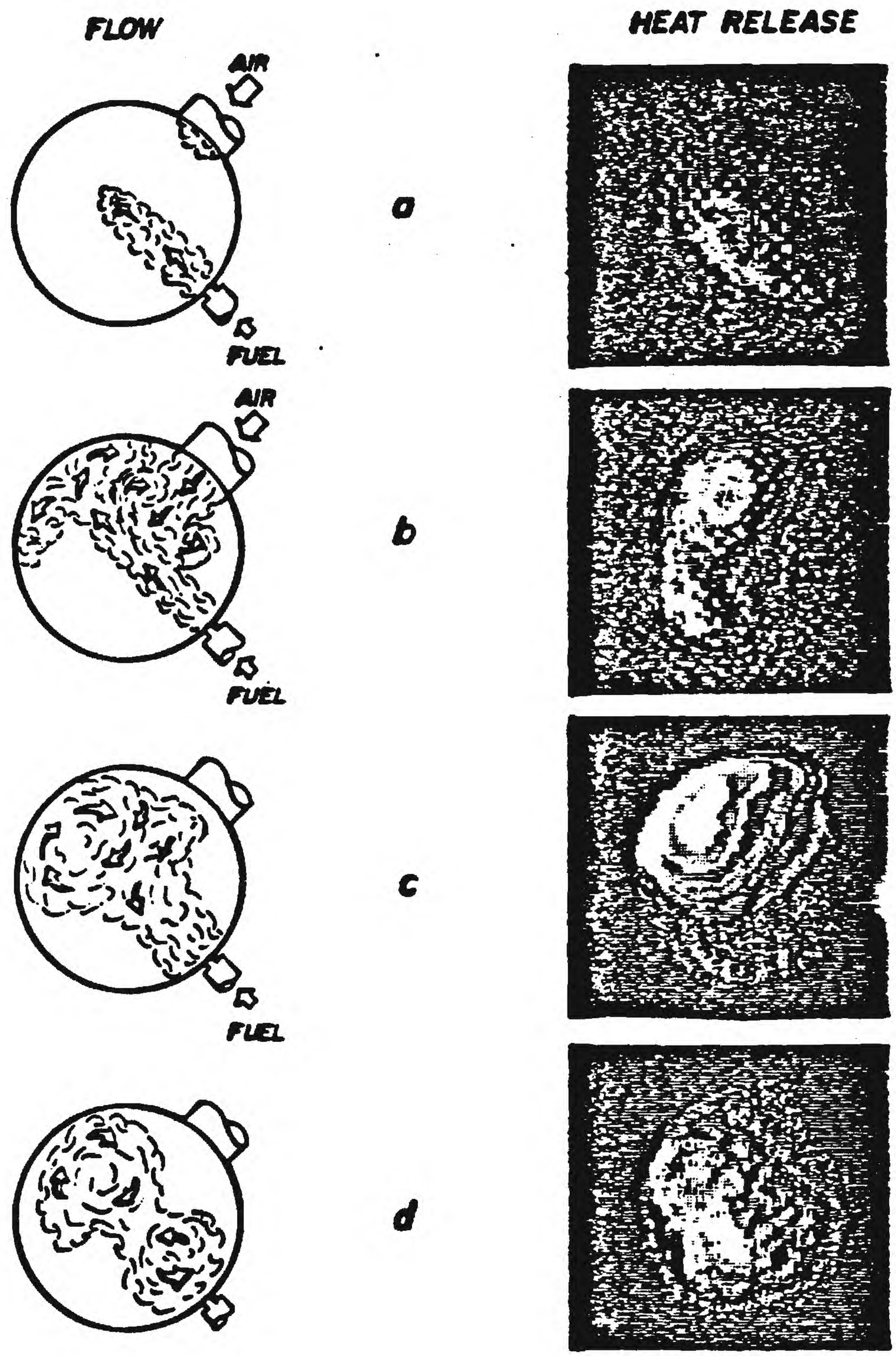

Fig. 3 Comparison of the Flow Field and the Heat Release Distribution as Seen along the Combustor Axis at Four Instants during the Cycle.

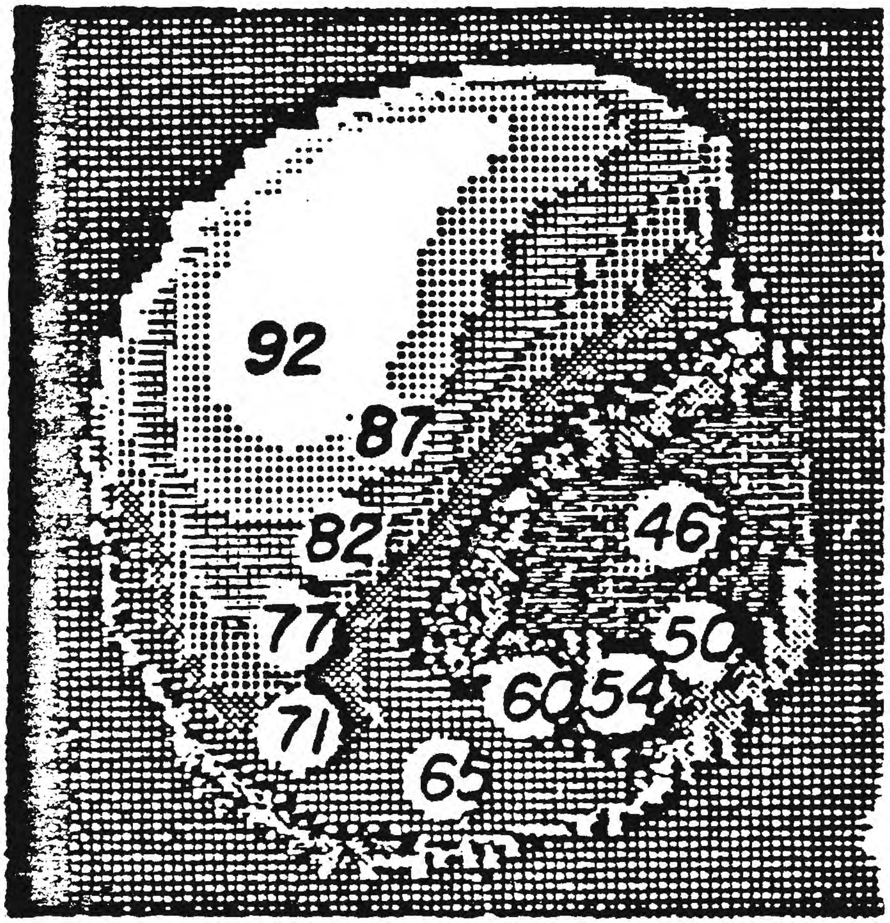

Fig. 4 Contour Plot of Phase Angle by which the Heat Release Oscillations Lead the Pressure Oscillations.

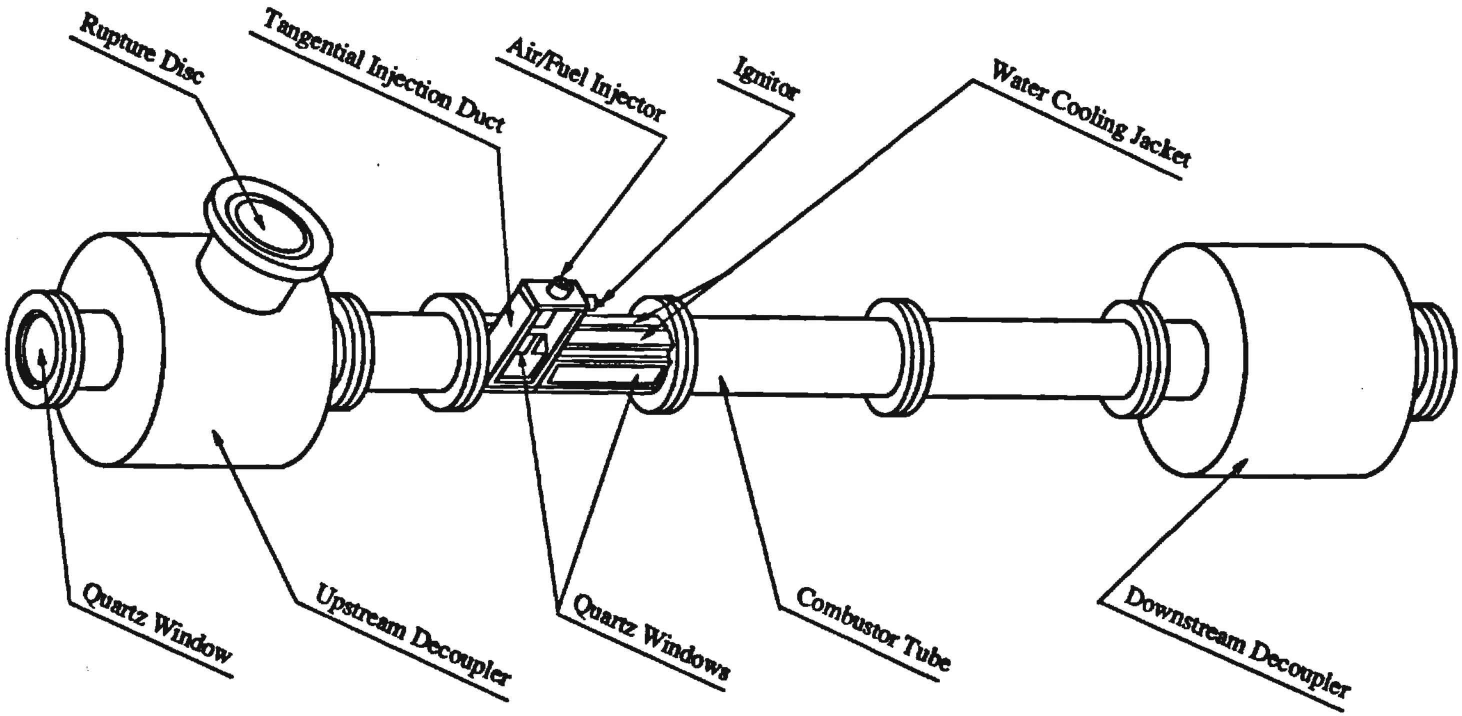

Fig. 5 Schematic of the Rijke Type Pulse Combustor.

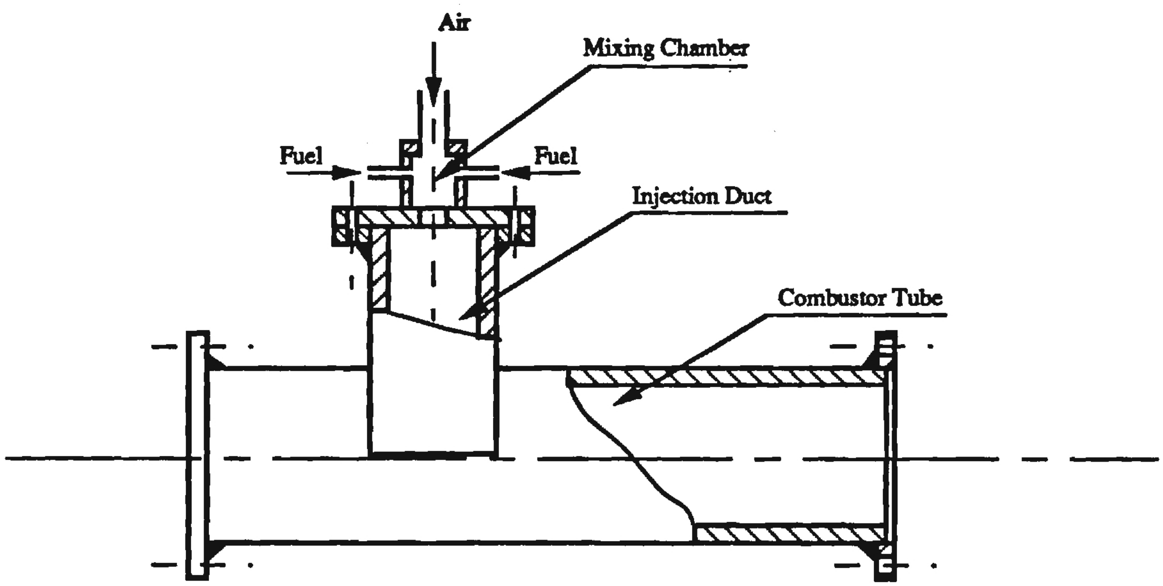

Fig. 6 Schematic of the Fuel Air Injection System for the Rijke Type Pulse Combustor.

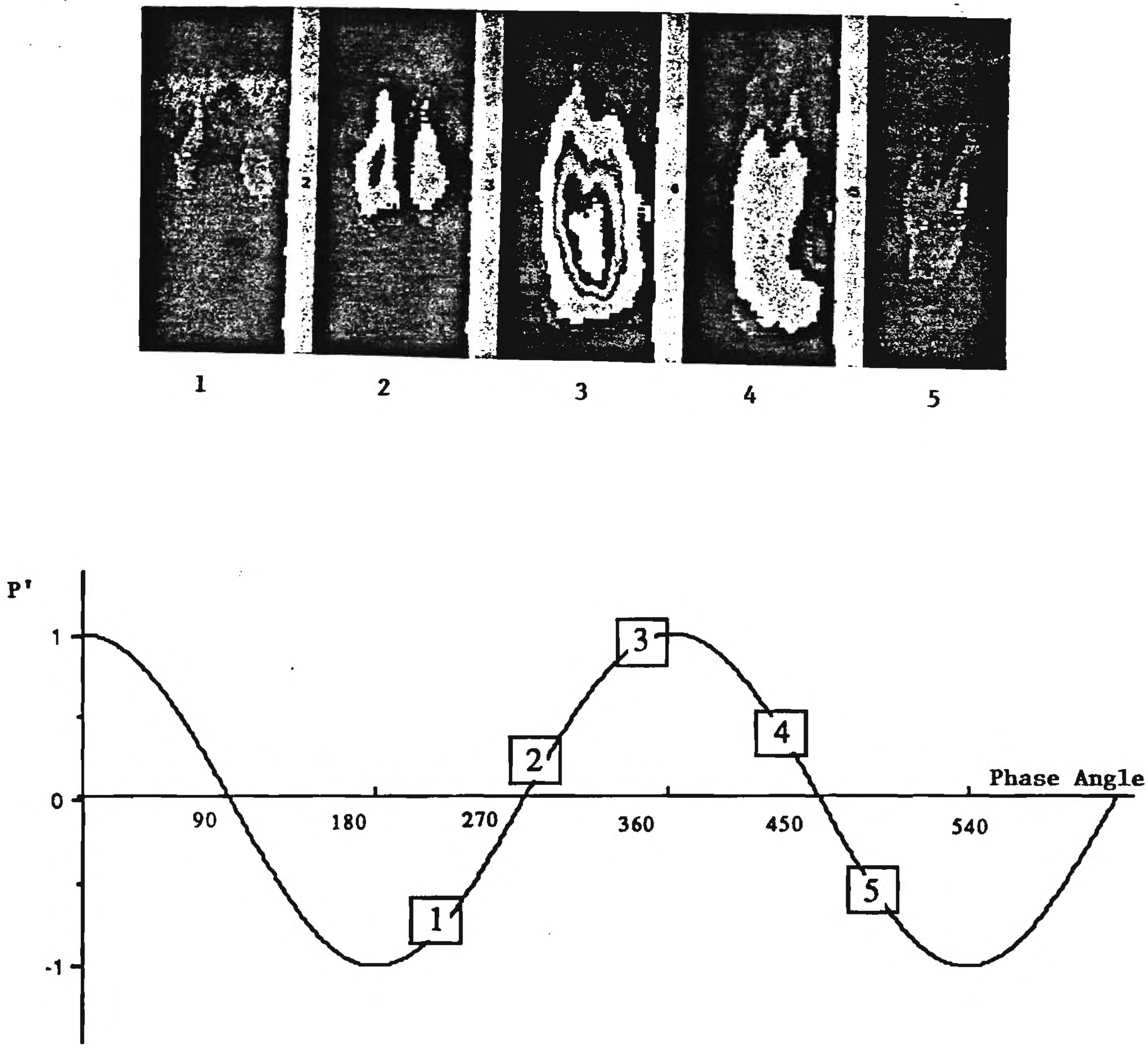

Fig. 7 Radical Radiation Intensity Distributions in the Injector Duct of the Ryjke Type Pulse Combustor at the Five Instances during the Pressure Cycle.

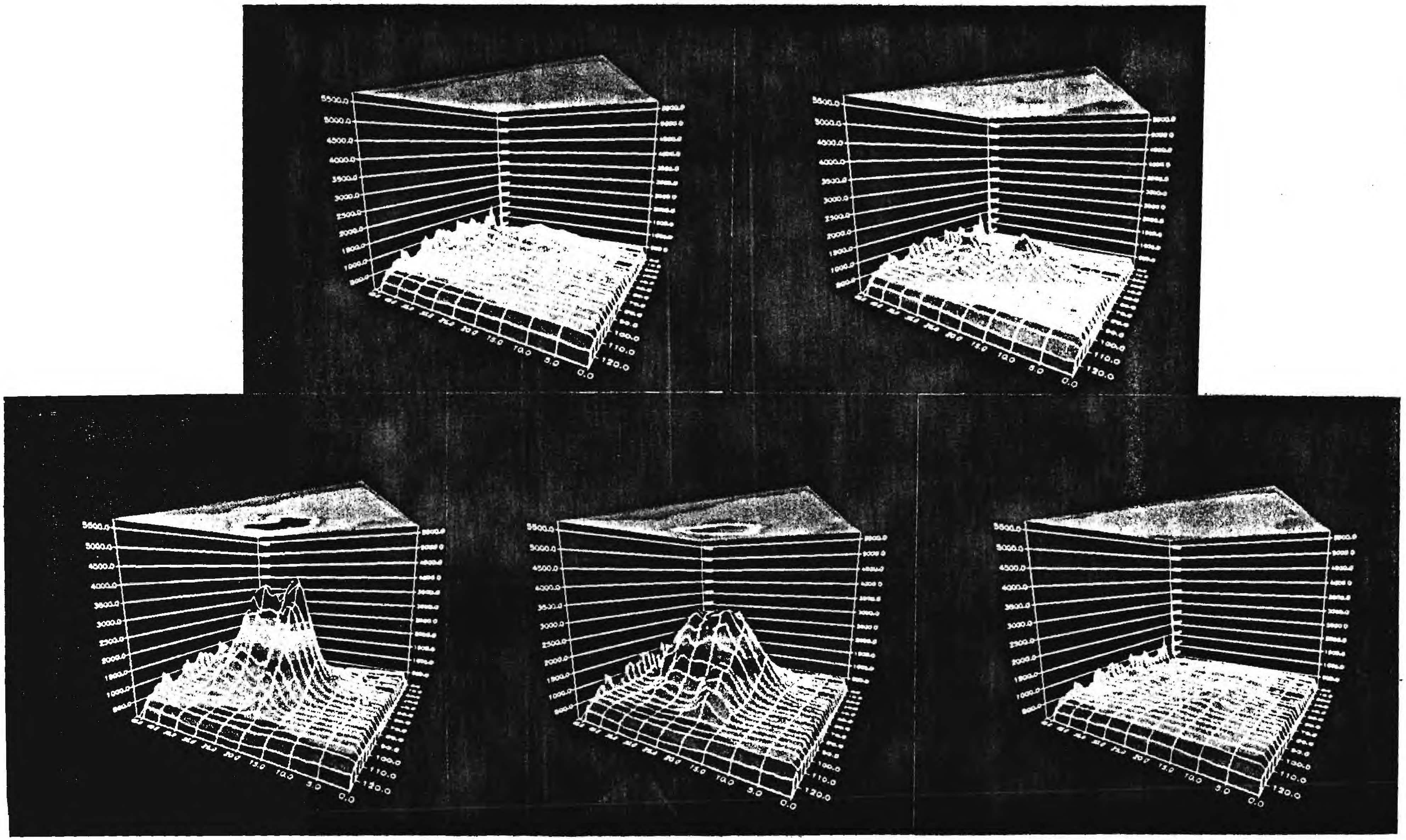

Fig. 8 Three Dimensional Representation of the Radical Radiation Intensity
Distributions Shown in Fig. 6.