

Delft University of Technology
Department of Aerospace Engineering
Delft

Prins Maurits Laboratory
Organization for Applied
Scientific Research TNO
Rijswijk

Report LR -482
Report PML 1986 - C5

SOLID FUEL COMBUSTION CHAMBER

PROGRESS REPORT VIII

Seventh phase, July-December 1985

H. Wittenberg
P.A.O.G. Korting
C.W.M. van der Geld
J.B. Vos
T. Wijchers
R. van de Berg
J.H. van Dijk

Delft/Rijswijk, The Netherlands

January 1986

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1. INTRODUCTION

The seventh phase (July-December 1985) of the Solid Fuel Combustion Chamber Project (SFCC), DLR 14.0120/PBE 90743.140 is described.

The primary aim of the project is to gain a thorough understanding of the flow and combustion processes in solid fuel grains, which will be achieved by a combination of experimental and theoretical research. The project has been extensively described elsewhere [1] and the scope of the project has remained the same since this publication. SFCC's have a potential for aerospace propulsion (ramjets), energy conversion systems, hot gas generation, 'clean' combustion of waste and possible others.

This project is sponsored by the Technology Foundation (Stichting voor de Technische Wetenschappen STW) and the Project Office for Energy Research (Project-beheer Energie Onderzoek). In addition, money and manpower is made available by a special funding from DUT (Beleidsruimte) while manpower and computer facilities are provided by DAEDUT and PMLTNO. Also PMLTNO provides the project with funding.

At the end of this report the planned activities for the next half year period (January-June 1986) are outlined.

2. FINANCIAL SUPPORT

A proposal for continuation of the present research project has been submitted to STW (SFCC Publication no. 28). A final decision by the Board of STW is expected to be made by the end of February 1986.

In order not to hamper the continuation of this project STW already decided to continue the appointment of Dr. Wijchers (spectroscopist) until June 1986 and to release the remaining funding.

3. FINANCES

During the period July-December 1985 the following expenditures have been paid by STW:

Small equipment, various components for the teststand, gases and fuel	f 50.529,84
Monochromator	f 67.305,00
Foreign travel expenses	f 5.814,34

In addition, the following payments have been made by PMLTNO but have not yet been submitted to STW for refunding:

Grid (spectroscopy)	f 8.760,--
Various components, fuels, and gases	~ f 20.000,--
Foreign travel expenses	f 1.769,--

By DAEDUT the following expenses for the project have been made on the account of a special funding (Beleidsruimte):

Fuels	f 9.222,--
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4. PROJECT MANAGEMENT

Dr. C.W.M. van der Geld started his activities of DUT by July 15th. He is staff member of DUT and is primarily involved in the physical aspects of combustion, including experimental techniques.

Ing. J.P.M. Versmissen has left the project group by September 1st, while his successor Ing. R.P. van de Berg started his work by August 15th. He is employed by PML, but timely charged to STW.

For maintenance of the test installation, a successor for mr. H. van der Heiden has been found. Mr. J. van der Brandt will start his activities by February 1986. He will be employed by PML for 7,5 months but charged to the Department of Labour and Social Affairs.

As funding for a computerprogrammer expires at DUT by the end of December 1985, ir. J. van Dijk has left the project team. An attempt is made to find new financial support for this position. DAEDUT has expressed its willingness to make the necessary funding available. A final decision is expected to be taken by the end of January 1986.

5. LIST OF PERSONS INVOLVED IN THE SFCC PROJECT DURING THE PERIOD
JULY-DECEMBER 1985

In addition to staff members, assigned to the project by DAEDUT, PMLTNO and STW the following persons have contributed directly to the project:

F.H. van der Laan	Student assistant DAEDUT, Data reduction of experiments
G. Klein-Lebbink	Student DAEDUT, Data reduction of experiments
G.H. Ronner	Apprentice HTS Haarlem; 1-12-1985 until 1-3-1986, Data reduction of experiments
W.J. Nijhuis	Apprentice HTS Haarlem; 1-12-1985 until 1-3-1986, Programming support of theoretical study of vortex shedding
P. Elands	Student DAEDUT, Fourth years' task on the use of visi- ble radiation measurement equipment. Thesis work: implementation of a dif- fusion flame model in Coppef. Starting date: 3-10-1985
J.P. de Wilde	Student DAEDUT, Pyrolysis in connection with the solid fuel combustion chamber. Co-coaching by dr. J. de Leeuw (Depart- ment of Organic Chemistry) Starting date: early November 1985
G. Vermij	Student DAEDUT, Laser doppler velocimeter for solid fuel combustion chamber research (feasibility study). Co-coaching by ir.Th. van der Meer (Department of Applied Physics) Starting date: mid November 1985
R. Veraar	Apprentice HTS Haarlem; August 15, 1985 until December 1, 1985, Implementation of chemical kinetics program (database)
W. Boelen	Apprentice HTS Haarlem, August 11, 1985 until December 1, 1985, Experiments with SFCC
P. van Marrewijk	Apprentice HTS Haarlem, December 1, 1985 until March 1, 1986, Experiments with vitiator and SFCC

P. Merckx

Apprentice HTS Eindhoven, September 1,
1985 until March 1, 1986,
Design and construction of multiple
probe sensing system for URR

T. Israeli

Student Technion (Haifa, Israel),
August 1, 1985 - September 15, 1985
Sound velocity measurements in plexi-
glass and PE

6. THEORETICAL DEVELOPMENTS

6.1. Supercomputers

As mentioned in the previous progress report [1] COPPEF was slightly modified in order to obtain a larger vectorization-efficiency on supercomputers. Test-runs for a turbulent flow through a sudden expansion using a 50 x 25 grid with 400 iterations were carried out on the Cray-1. These testruns showed that 29% of the execution time was spent in the routines used to solve the temperature from the enthalpy by means of a Newton-Rhapson procedure, and 31.5% of the execution time was spent in the routine used to solve the algebraic difference equations by means of the Thomas-algorithm.

Early July, a modified version of the routines used to calculate the temperature from the enthalpy was implemented on the Cray. Calculations carried out showed that, for the above described testproblem, only 7% of the execution time was spent in these new routines. The vectorizing of the Thomas-algorithm was studied by Drs. A.R. Burgers of ENR, and by the end of October, a modified version of the Thomas-algorithm which could be fully vectorized became available. In this new version, the coupling between the variables in flow direction was broken and it was expected that more iterations should be necessary to obtain the same results as with the old Thomas-algorithm. This was confirmed by the testruns carried out with the modified Thomas algorithm. The number of extra iterations was equal to 9 (2%), but because this modified algorithm was fully vectorizable, the execution time spent in this routine decreased to 14.2%. The results of the testruns are summarized in Table 6.1.

An attempt was made to implement COPPEF on the Cyber-205 of SARA. Only in scalar mode, results could be obtained. In vector mode the Cyber-205 produced physically unreliable results and the program stopped at the first iteration step. Several routines have to be modified to obtain results. This is studied by ir. R. Llurba of the Computing Centre of DUT.

Computer	CPU-time	Acceleration
Amdahl 470	1292.24	1.00
IBM-3083	552.32	2.34
Cray-1 scalar	143.52	9.00
Cray-1 vector (June 1985)	77.29	16.72
Cray-1 vector modified Newrap	61.86	20.89
Cray-1 vector modified Thomas	44.59	28.98
Cyber-205 scalar	~ 240	5.38
Cyber-205 vector	-	-

Table 6.1: Computertime required to solve a turbulent flow through a sudden expansion, 50 x 25 grid.

6.2. Modelling heat and mass transfer at solid boundaries

In an SFCC the solid fuel pyrolyzes due to a heat flux from the main flow to the wall. This pyrolyzing fuel causes a mass flux from the wall to the main flow. In this period attention has been given to extending COPPEF in order to account for mass transfer at the solid wall. The wall-function method of Chieng and Launder has been extended, and the wall-shear stress is now calculated from

$$\tau_w = \rho C_\mu^{1/4} k_v^{1/2} \left[\frac{x U}{\ln(E C_\mu^{1/4} k_v^{1/2} Y/\nu)} - \frac{V_w}{4x} \ln(E C_\mu^{1/4} k_v^{1/2} Y/\nu) \right]$$

The Von Karman constant E is in this case a function of the injection rate and the local boundary layer structure, and is found by solving an additional equation. Calculations showed that good results could be obtained for blowing velocities upto 0.05 m/s. For higher blowing velocities it was not possible to calculate the Von Karman constant E . It is believed that for blowing velocities greater than 0.05 m/s, the extended wall-function method of Chieng and Launder cannot be applied anymore. It must be remarked that in fact it is not allowed to use wall-functions in flows with blowing, but for small blowing velocities, the error will be small. For flows with considerable blowing one has to adopt the low-Reynolds version of the k - ϵ turbulence closure model, in which both the equation for k and ϵ are integrated to the wall. This low-Reynolds version of the k - ϵ model was implemented in COPPEF by the end of November. Calculations carried out for a turbulent pipe flow showed a good resemblance between experimental results obtained from the literature, and the calculated results. Presently the model is being tested by calculating a turbulent flow through a sudden expansion.

Several calculations were carried out for a laminar flow through a sudden expansion with blowing at the down wall. Figure 6.1, 6.2 and 6.3 show the velocity profiles as calculated by COPPEF. Figure 6.1 shows the calculated results for a zero blowing velocity, while the Figures 6.2 and 6.3 show the results for a blowing velocity of 0.1 m/s. As can be seen from these figures the re-attachment point has been moved in the upstream direction in the blowing velocity case. Furthermore, the secondary eddy which is visible in the non blowing case has been blown up by setting V_w to 0.1 m/s. COPPEF has been extended to account for heat transfer processes at the wall of the channel, and this model is presently being tested. The first calculations showed a fair agreement between calculated and experimental results.

RATIO BETWEEN X AND Y LENGTH SCALES = 0.25
SCALE FACTOR BETWEEN VELOCITY AND LENGTH = 0.18

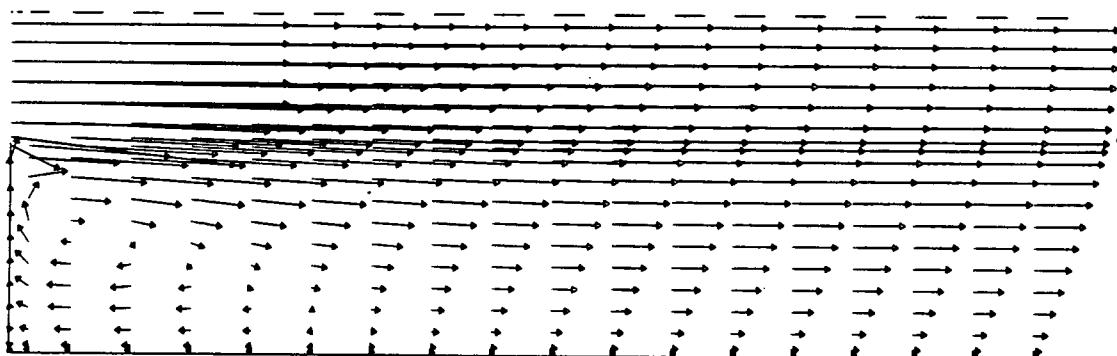


Figure 6.1: Calculated velocity profile for a laminar flow through a sudden expansion, zero blowing velocity.

RATIO BETWEEN X AND Y LENGTH SCALES =0.25
SCALE FACTOR BETWEEN VELOCITY AND LENGTH=0.19

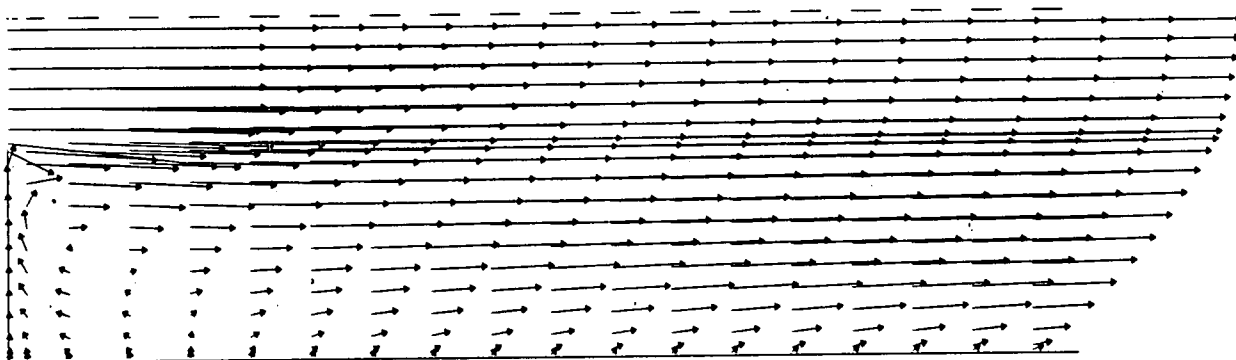


Figure 6.2: Calculated velocity profile for a laminar flow through a sudden expansion, blowing velocity = 0.1 m/s.

DETAILPLOT OF RECIRCULATION ZONE
NUMBER OF STEPS IN X-DIRECTION : 40
NUMBER OF STEPS IN Y-DIRECTION : 40

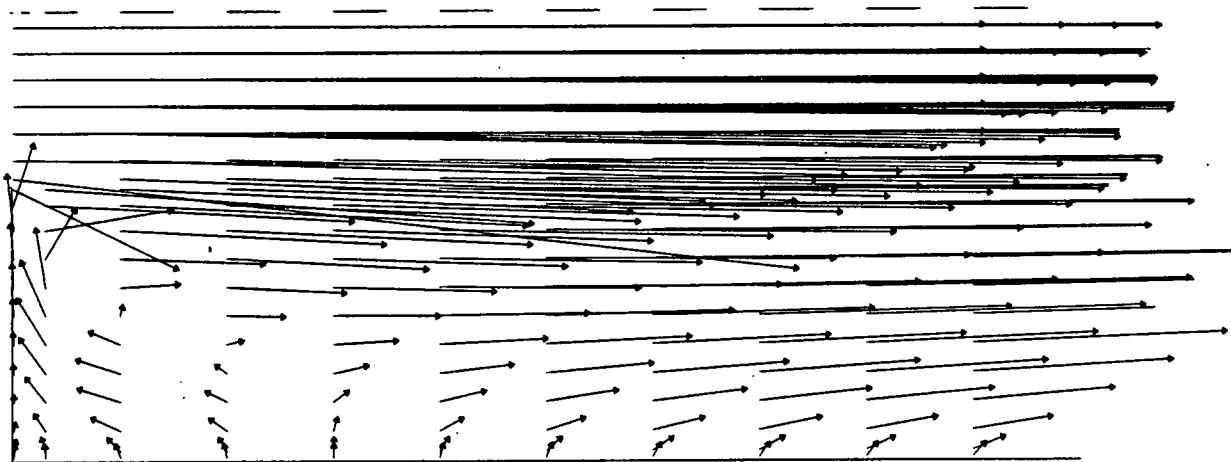
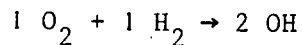


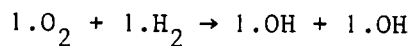
Figure 6.3: Detail plot of recirculation zone of laminar flow through a sudden expansion with blowing.

6.3. Combustion Modelling

In this period the KINETICS computer program, developed to integrate the chemical production/destruction term in the equations for the mass-fractions has been extended by incorporating the possibility for combustion under constant pressure. Calculations for an H₂-air flame showed an excellent agreement between the calculated results and the results reported in the literature. The KINETICS-computerprogram could be accelerated by assuming all stoichiometric coefficients in a reaction equal to 1. This implies that the reaction



has to be written as



A large reaction kinetic databank has been developed in which 291 reactions with their Arrhenius constants are stored.

7. EXPERIMENTS

7.1. Experimental program

Over 50 combustion experiments of Polymethylmethacrylate (PMMA) with cold air were performed and analyzed.

The general combustion behaviour was studied by means of high speed cinematography, while in particular the oscillatory character of the turbulent flow was also investigated by radiation measurements.

The dependance of the regression rate on the following parameters has been investigated:

- air mass fluid
- chamber pressure
- initial step height.

In addition, the measured characteristic velocity has been compared with the predicted value, to determine the combustion efficiency.

Chordal beam averaged temperatures were measured by means of a spectroscopic technique. Local and instantaneous values were obtained.

Some typical results are shown in the figs. 7.1 through 7.6. The results will be presented at the 28th Israel Conference on Aeronautics and Astronautics in Tel-Aviv (19 and 20 February 1986). A paper is submitted (ref. 2).

7.2. Vitiator experiments

During this phase a modified version of the vitiator became available with a better ignition and mixing system. An experimental program has been carried out to establish the radial temperature distribution and the general performance. The results are promising and will be reported in the next phase.

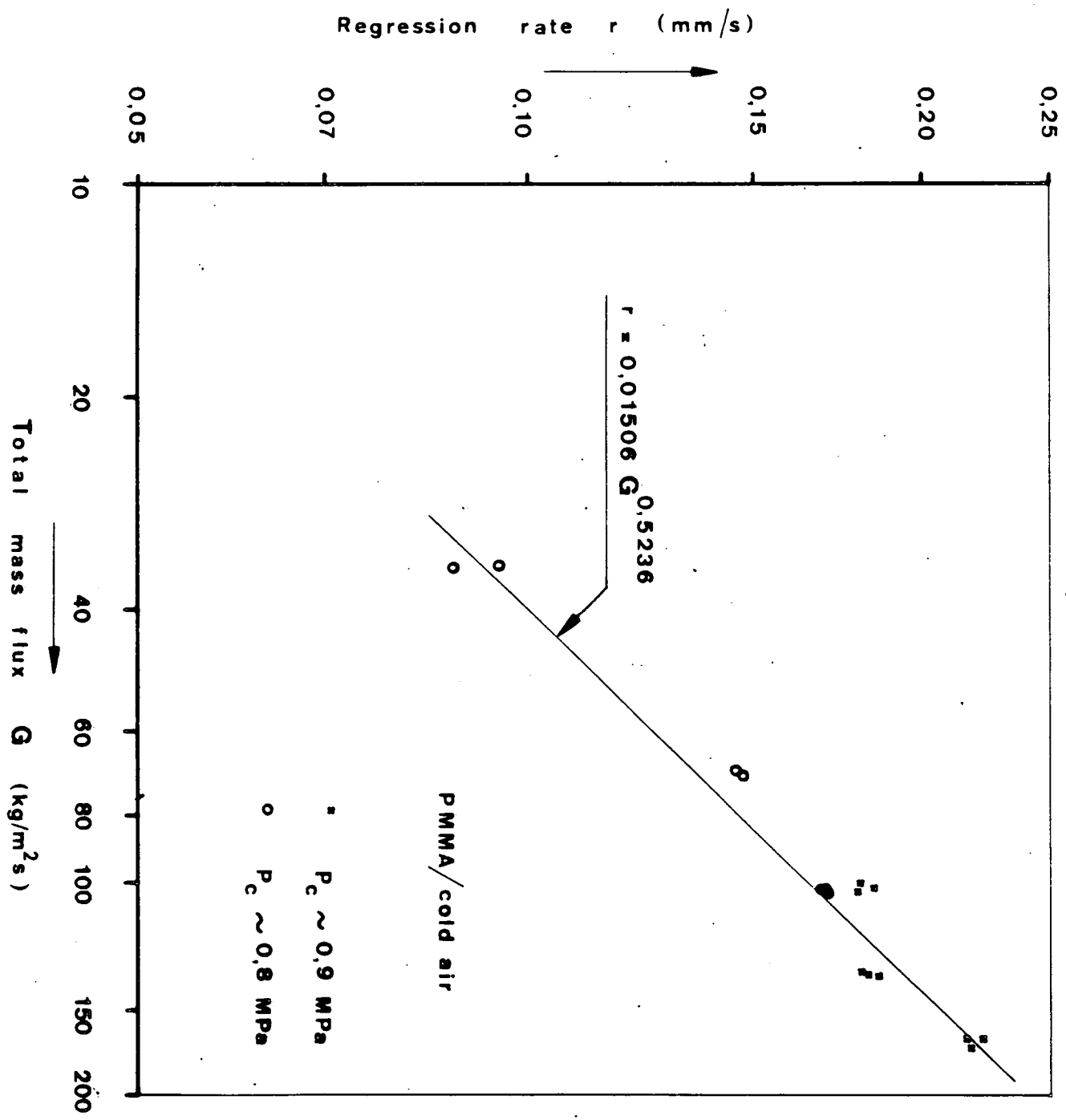


Figure 7.1: The regression rate dependence on the total mass flux for combustion of PMMA with cold air.

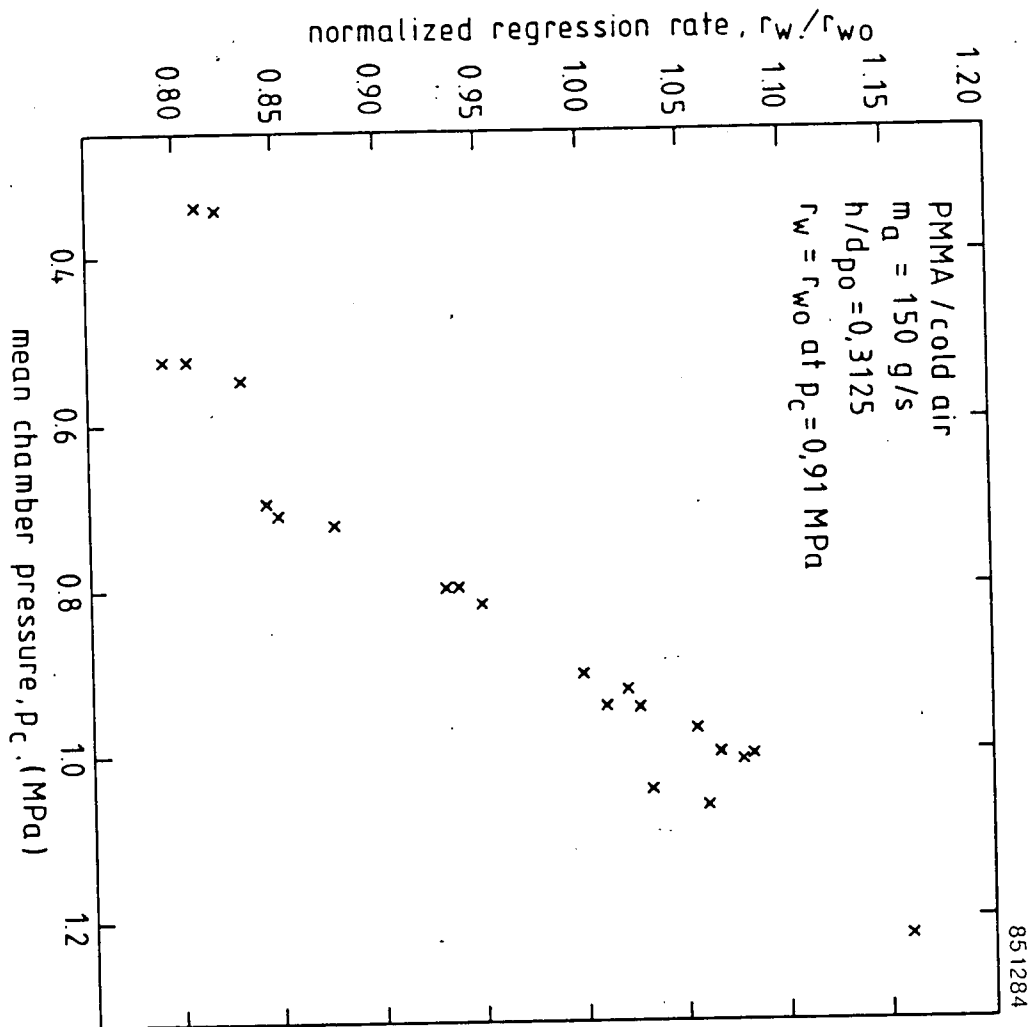


Figure 7.2: Dependency of normalized regression rate on chamber pressure during combustion of PMMA with cold air. Note the low pressure sensitivity at pressures below 0.6 MPa.

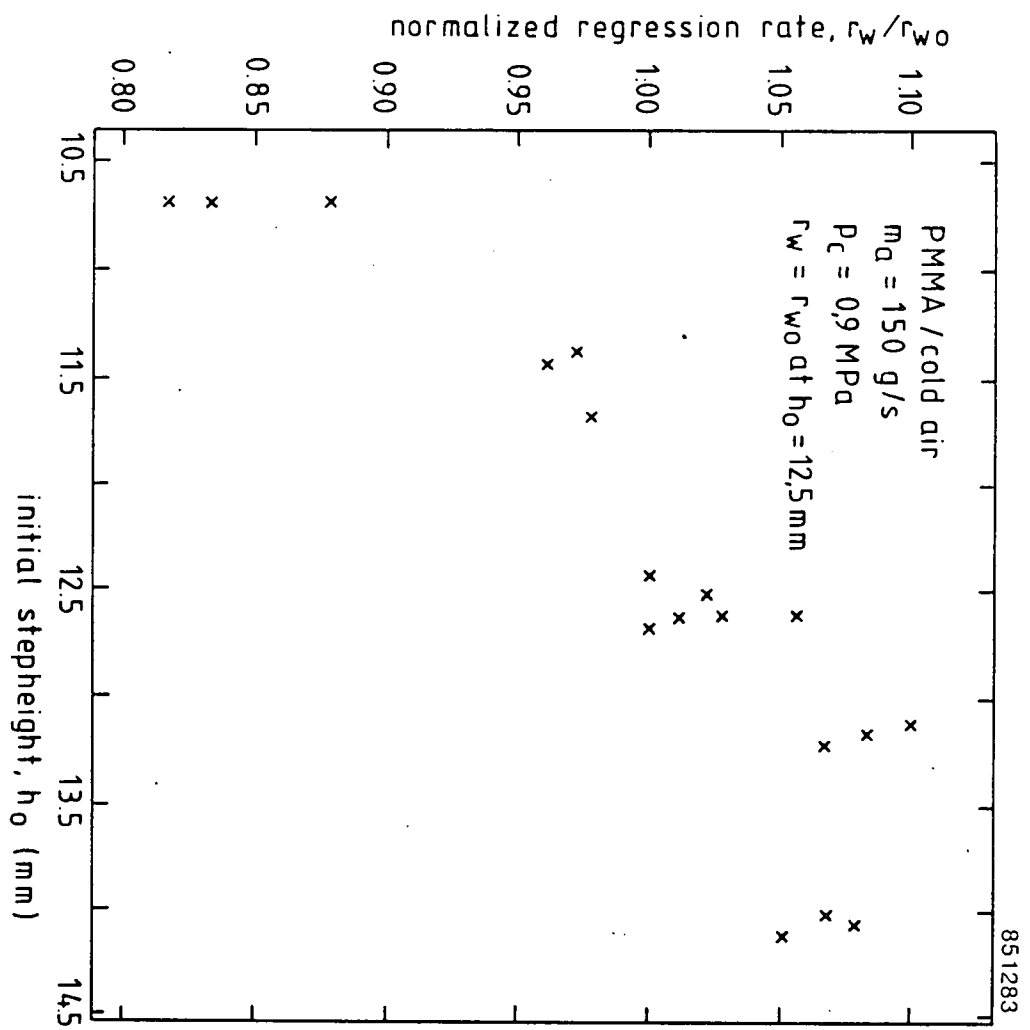


Figure 7.3: Dependency of normalized regression rate on the initial stepheight during combustion of PMMA with cold air.

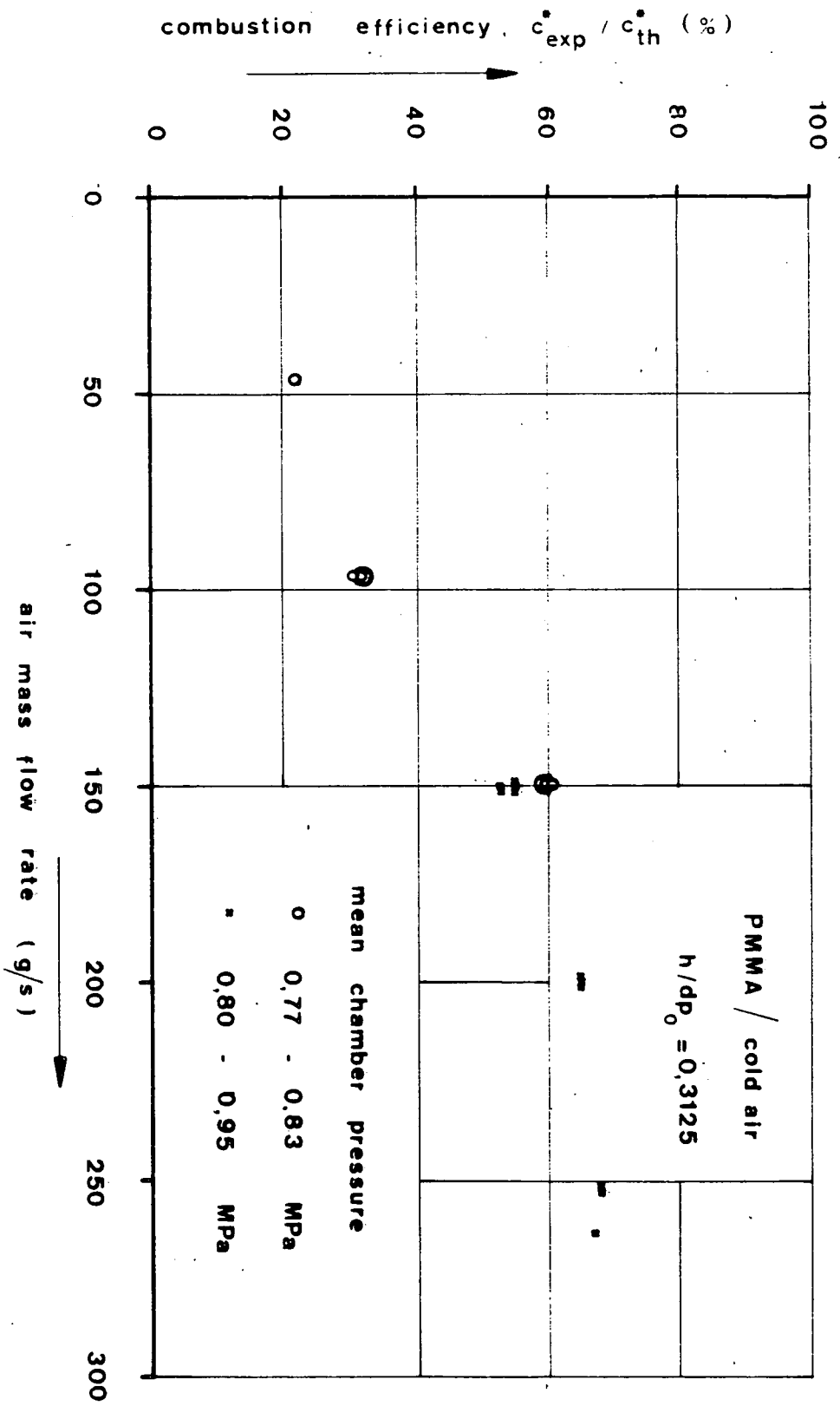


Figure 7.4: Dependency of combustion efficiency on mean chamber pressure during combustion of PMMA with cold air.

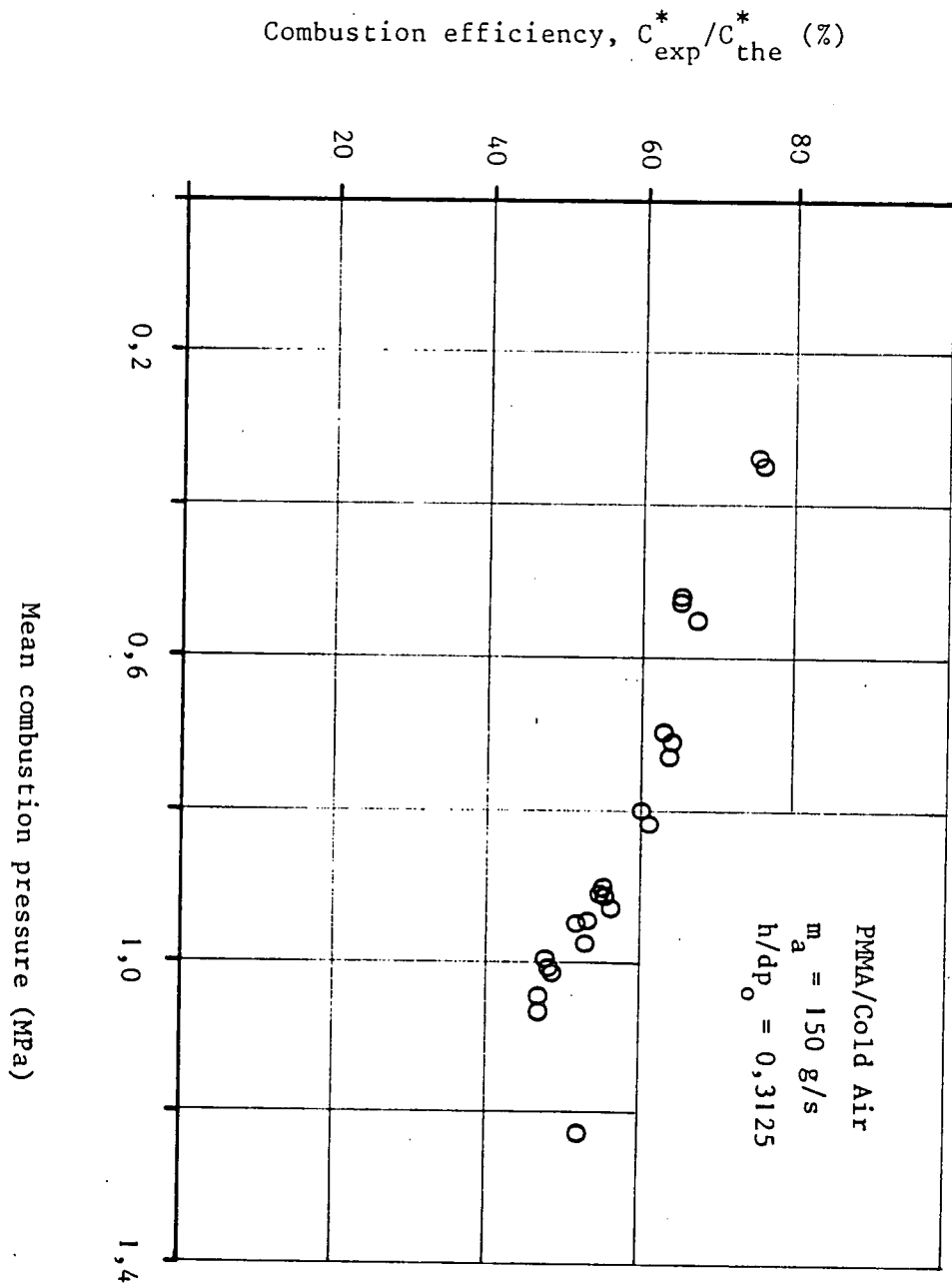


Figure 7.5: Dependency of combustion efficiency on air mass flow rate during combustion of PMMA with cold air.

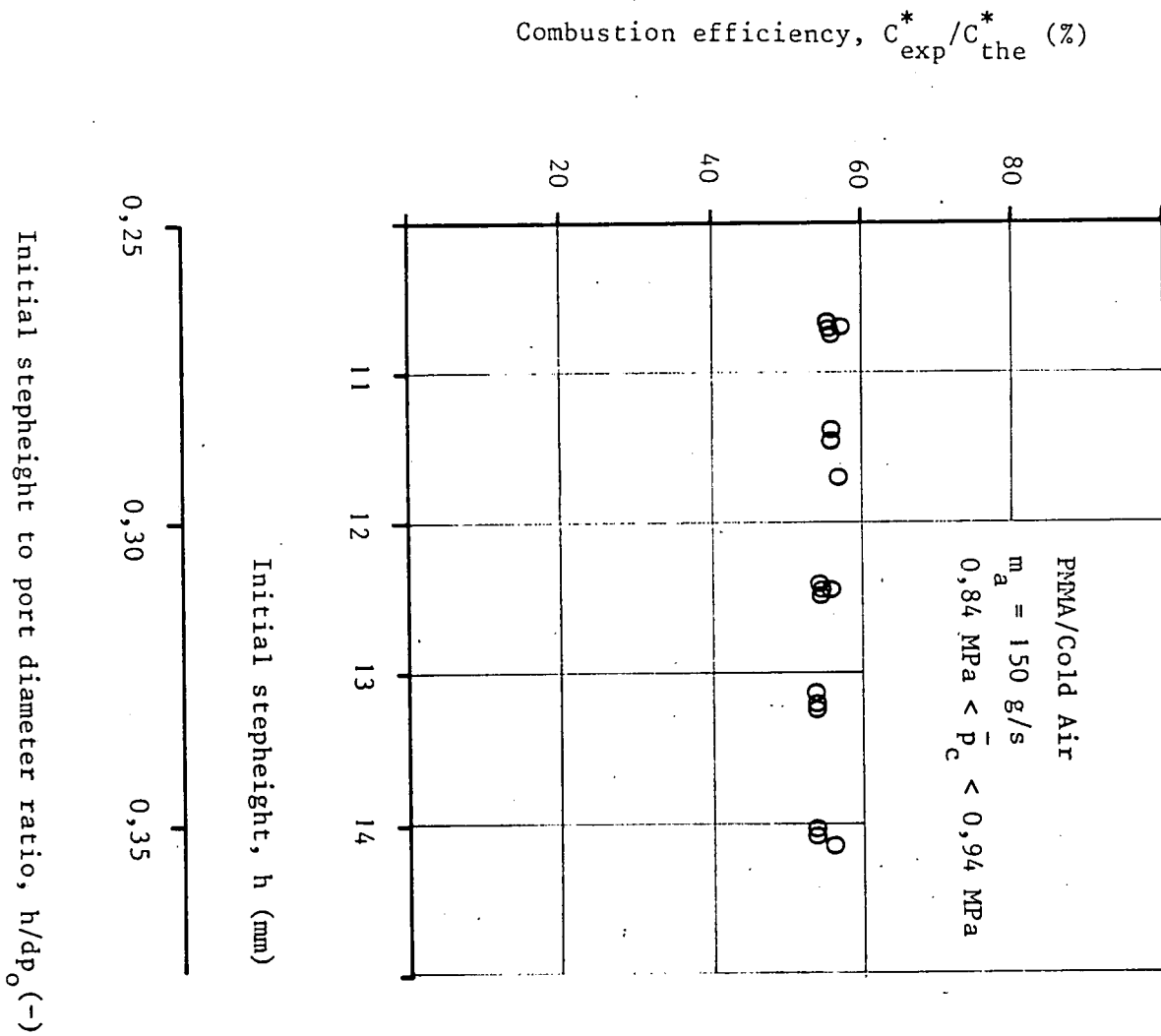


Figure 7.6: Dependency of combustion efficiency on initial step height during combustion of PMMA with cold air.

8. STATUS OF THE EXPERIMENTAL FACILITY

During this phase, the following components had the attention of the project group.

- a) Air-SCMC
Calibrations were performed. The device is now fully operational.
- b) Vitiator
The ignition system and the inner tube have been modified. The vitiator is now fully operational.
- c) Expansion part
As to prevent leakage, the connection part between the three-way valve and the SFCC has been modified.
- d) Thrust Stand
A design has been made for the calibrating system of the thrust stand. It is anticipated that the system will become operational in the next period.
- e) Air supply line
The supply line is equipped with a heating coil to ensure a proper operation at high mass flows.

9. SPECTROSCOPY

The work that has been done during this phase can be divided in the following items:

1. Pyrometric calibration of a photometer
2. Temperature determinations of SFCC flames
3. Extension of equipment
4. Laser Doppler Velocity measurements..

9.1. Pyrometric calibration of a photometer

Since the need was felt to measure flame temperatures in a simpler way, a photometer has been calibrated pyrometrically. The photometer consists of a detector in a photocamera at a location where normally the film used to be. The detector, a 1 cm^2 light sensitive PIN diode behind a special filter, had a practically uniform spectral sensitivity between 450 nm and 900 nm while it was insensitive outside this region. Extensive calibrations of the several camera diafragn diameters to derive geometry factors have been performed as well as calibrations of the amplified detector signals against measured radiative power. The latter calibrations were carried out with help of a calibrated tungsten ribbon lamp. As a result, a calibration factor has been determined. With this factor, radiances in the wavelength region between 450 nm and 900 nm and hence temperatures of objects can be calculated easily, if the absorption coefficients in the mentioned wavelength region of those objects are known.

Details of this pyrometric calibration can be found in ref. [3].

9.2. Temperature determinations of SFCC flames

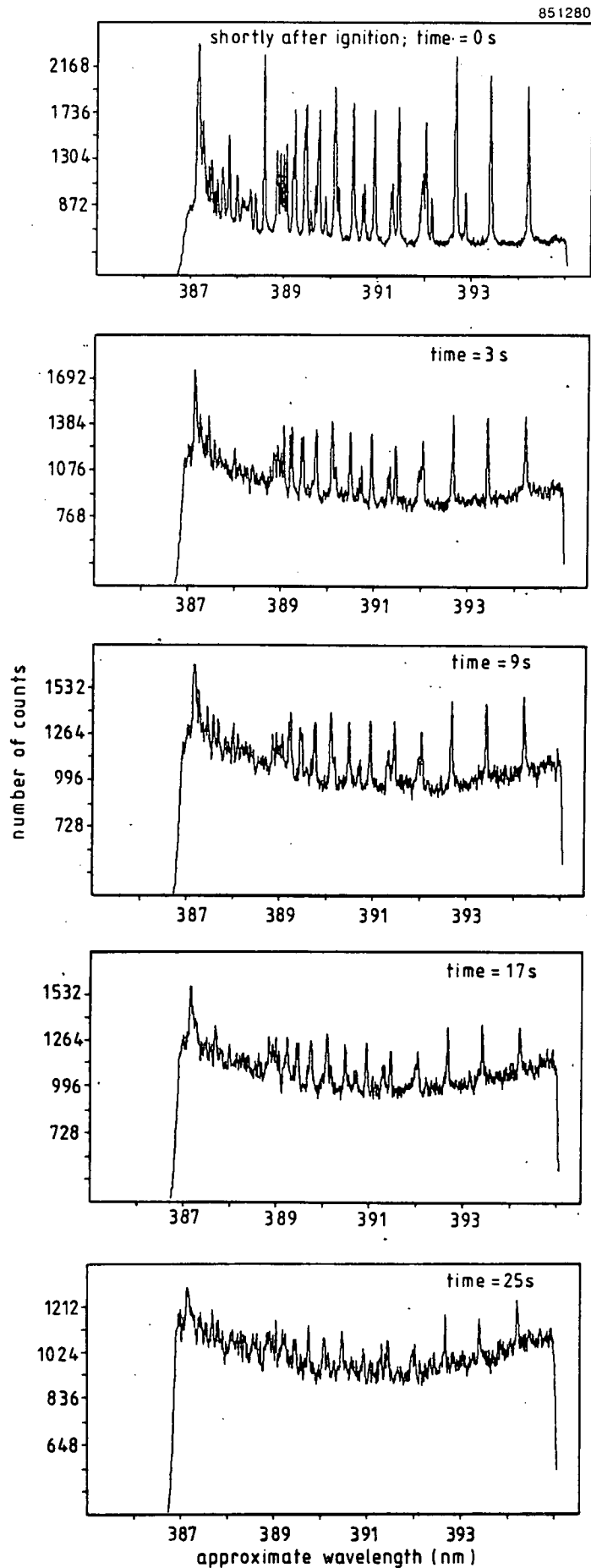
In October and November SFCC test runs were carried out with perspex and fuel. During each test run, 32 spectra of the flame were recorded successively at intervals of about 1 s. The exposure time for each spectrum was 1 s, while data transfer of each spectrum required 0,033 s. Spectra of radially emitted light at distances of 75 mm, 110 mm, and 225 mm from the entrance of the fuel grain were recorded, while in some cases spectra of ascially emitted light was registered.

Flames at pressures higher than about 0,6 MPa has no detectable CH rotational lines and mostly appear to have temperatures in the range 1500 K - 1800 K. Since reliable temperature determinations from relative rotational line intensities were possible only for flames with pressures lower than 0,4 MPa, temperatures were derived from the soot radiation spectra.

In Fig. 9.1 spectra of a flame at a mean pressure of 0,53 MPa, taken at 6, 12, 18, 24 and 30 s after ignition, are shown. Note the decrease of the intensity of the rotational lines with a measured increase of pressure and a determined decrease in soot temperature.

Application of the pyrometrically calibrated photometer, discussed above, revealed strong fluctuations in radiation intensity with a main frequency of about 73 Hz. The ratio of the maximum to the minimum intensity is about 10. During 30 s of turning, the mean radiation intensity of the flame grew by a factor of 1,5 to 2.

Figure 9.1: Time history of spectral emission during combustion. Air flow rate 149 g/s; 0.35 MPa, 22,5 mm from inlet; spectra not corrected for background, nor for non-uniform sensor sensibility.



9.3. Extension of equipment

- a) Determination of the (qualitative) chemical composition of the SFCC flame is one of the goals of the spectroscopic investigations. This determination requires a broad spectral bandwidth which is obtained with the new 600 l/mm grating (Jobin Yvon). The bandwidth now is 336 Å at 3910 Å instead of 84 Å obtained with the 2400 l/mm grating used until now.
- b) For tests of future spectroscopic methods and for validation experiments of theoretical flame models, a Méker Burner was purchased. To use this burner, an H₂, O₂, N₂ gas supply system and a chimney have been ordered. The latter has already been installed. The burner is equipped with a pneumatic nebuliser for adding chemical components to the flame. The flame is laminar, while the temperature can be kept very constant and is well reproducible.
- c) The spectrograph now can be used as a scanning monochromator for detailed study of (rotational) spectra, since a photomultiplier (EMI 9558 QB) and a phase sensitive (lock in) amplifier (PAR 128 A) have been purchased. With Peltier elements, the internal housing of the photo-multiplier can be cooled down to at least -20 °C. At this temperature, the influence of dark current on all measurements is practically zero.

9.4. Laser Doppler Velocity measurements

Apart from the temperature, the measurement of gas velocity as a function of location is interesting for one validation of the theoretical flow pattern model.

A student of the DUT started a feasibility study on the application of Laser Doppler Velocity (L.D.V.) measurements at the SFCC flame. It has been planned to construct a low-cost, forward scattering L.D.V. set up in order to obtain experience with this type of instrumentation from test measurements first at the Méker burner and later on at the SFCC..

10. UTILIZATION

In this period a Data Exchange Agreement on solid fuel ramjet propulsion between the government of the United States of America and the Netherlands has been established.

Two poster presentations have been prepared. One was presented at the space exhibition which was organized by the Society of Aerospace Students Leonardo da Vinci at DUT in September 1985. All Dutch industries and organizations in the field of aero-space technology participated in this exhibition.

The other poster session has been prepared for the DUT "Industry Meeting Day" (Bedrijvendag), that will be held in April 1986.

11. USERS COMMITTEE

The Users Committee was convened for its seventh meeting on Friday, December 13, 1985 at TNO-PML. The following persons were present:

SFCC project group: H. Wittenberg
P.A.O.G. Korting
J.B. Vos
J.H. van Dijk
T. Wijchers
C.W.M. van der Geld
R. van de Berg
TNO-PML : H.J. Reitsma
TNO-PML : H.J. Pasma
TNO : Cdr. b.d. R.H. Kerkhoven
STW : F.C.H.D. van den Beemt
FDO : G. Troost
ESTEC : H. Schöyer
KEMA : F. Hermans
DAEDUT : J.A. Stekete
THE : C.W.J. van Koppen

The following themes were presented:

Status and planning of the project (see Section 13 and 14)	H. Wittenberg
PMMA-experiments	C.W.M. van der Geld
Spectroscopic Measurements	T. Wijchers
Progress on Flow and Combustion Modelling	J.B. Vos

During this meeting, the project proposal for a second phase has been discussed.

12. CONTACTS

For this period the following contacts can be listed:

Institute:	Persons:	Subject:
DFVLR Lampoldshausen	G. Schulte	Joint Research Program on Solid Fuel Combustion
IMI Summerfield	G. Owen	Testing of Ducted Rocket Rocket Motors
Naval Research Laboratory, America	J.D. Baum	Theoretical Modelling SFCC
DUT, Department of Chemistry	J. de Leeuw	Thesis and Ph.D-work on pyrolysis of PMMA and PE in connection with SFCC
DAEDUT	P. Deken	The carrying out of Laser- doppler experiments with a hollow perspex cylinder
DUT, Department of Physics	P. v.d. Meer	Feasible study and build- ing laser-doppler equip- ment for SFCC application
Ministry of Defence	E. van Hoek	Status SFCC project
KSLA Shell	G. Ooms	Theoretical study of vor- tex shedding
DUT computing centre	R. Llurba	Subroutines of Coppef
ENR	A.R. Burgers	Vectorisation of the Thomas-algorithm
DUT, Department of Chemistry	G.R. Kornblum	Spectroscopy
Laboratory of ex- perimental physics RUU (Utrecht)	H.A. Dijkerman	Purchase of spectroscopic equipment
NOS	H. Blankensteijn	Presentation of SFCC re- search in the TV-program 'Horizon'

13. STATUS OF THE PLANNING PERIOD JULY-DECEMBER 1985

<u>PLANNING:</u>	<u>STATUS:</u>
1. Calibration air-SCMC	Ready
2. Calibration report air- SCMC and CH ₄ -SCMC	Included in larger report about gas-supply system. In preparation.
3. Extension software for control gassupply system to allow for temp. control vitiator	Ready
4. Sound velocity versus temp. measurements of PE and PS	Initial experiments performed by Israelian student
5. Testing vitiator with temp. and mass flow control	Ready
6. Experiments with large SFCC in combination with spectroscopic and ultrasonic regression rate equipment	60 experiments performed and analyzed (PMMA/cold air)
7. Manufacture of ultrasonic equipment for more than one probe	Nearly finished
8. Software for data reduction	Ready for first analysis
9. Temp. measurements using radiation equipment	Possible
10. Theoretical work	
- implementation of heat and mass transport	Ready, but has to be tested
- implementation of chemical kinetics program into flow model program	Ready, but has to be tested Databank for reaction rate constants ready
- extension of computer program	Continuous effort. Low Reynolds version of k-ε model has been implemented

14. PLANNED PROGRAM FOR THE PERIOD JANUARY-JUNE 1986

Subject	Jan	Feb	March	April	May	June
1. Experiments with SFCC in combination with spectroscopic, ultrasonic regression rate and radiation equipment	-----					
2. Testing of ultrasonic equipment for more than one probe	-----					
3. Implementation of spectroscopic techniques for colorimetry for soot temperature measurements	-----					
4. Study of accurate and local species/temperature determination by fluorescence techniques				-----		
5. Study of laser doppler velocity measurements in an SFCC	-----					
6. Extension of software for data analysis	-----					
7. Small modifications of experimental system		-----				
8. Theoretical work Study of fuel pyrolysis in connection with SFCC combustion	-----					
9. Theoretical work Study of instationary combustion behaviour in an SFCC	-----					
10. Theoretical work (Coppef)						
- Testing of heat transport model	-----					
- Further testing of Low Reynolds version of the k-ε model	-----					
- Testing of combustion model implemented		-----				
- Implementation of diffusion flame model	-----					

Subject

Jan

Feb

March

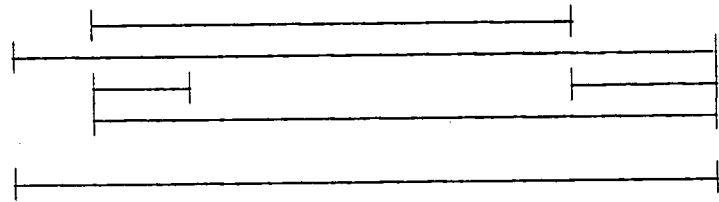
April

May

June

11. Other activities

- hiring of personnel
- reporting
- presentations
- commercializing spin-offs
- contacts



15. SFCC PUBLICATIONS

1. J.B. Vos and J.H. van Dijk, The Development of a Computational Model for a 2 Dimensional Turbulent Flow. Part II: Description of the Computer Code and Computational Results for various Pipe Flows.
SFCC nr. 27
LR 469
PML 1985-C22
2. Project proposal Investigation of a Solid Fuel Combustion Chamber (second phase).
SFCC nr. 28
LR 470
PML 1985-C46
3. D. Bakkeren and P.A.O.G. Korting, Combustion behaviour of the vitiator - Experimental results of a first test series.
SFCC nr. 29
LR 473
PML 1985-C57
4. R.G. Veraar, Het opstellen van een reaktiekinetische databank, en het uitbreiden van de thermodynamische databank van NASA SP-273, November 1985.
SFCC nr. 32
LR M-546
PML 1985-C85

In addition a paper has been presented at the 23th National Heat Transfer Conference in Denver entitled: "Determination of the regression rate in solid fuel ramjets by means of the Ultrasonic Pulse Echo Method".

At the IAF congres at Stockholm, October 1985 a paper has been presented entitled "Advanced hybrid rocket motor experiments".

In the journal PT/Procestechniek 40 (1985), nr. 9, an article has appeared about SCMC.

A presentation has been prepared for the 28th Israel National Conference on Aeronautics and Astronautics in February 1986.

16. REFERENCES

- (1) H. Wittenberg, et.al,
Solid Fuel Combustion Chamber Progress Report VII; Sixth Phase, January-
June 1985; Report LR-472/PML 1985-C47, DAEDUT/PMLTNO, Delft/Rijswijk,
July 1985.
- (2) P. Korting, C. van der Geld, Y. Timnat, J. Vos and T. Wijchers,
Investigation of a Solid Fuel Combustion Chamber. Paper to be presented
at the 28th Israel Annual Conference on Aviation and Astronautics, Haifa/
Tel Aviv, 19 and 20 February 1986.
- (3) P. Elands and T. Wijchers,
Visible Radiation Measurement for Temperature Determination, SFCC publica-
tion 31, Report LR-479/PML 1985-C74, DAEDUT/PMLTNO, Delft/Rijswijk, Novem-
ber 1985. In print.

17. ACRONYMS

COPPEF	Computer Program for Calculation 2D Parabolic and Elliptic Flow
DAEDUT	Department of Aerospace Engineering Delft University of Technology
ENR	Energie Centrum Nederland Rekencentrum
ESA	European Space Agency
ESTEC	European Science and Technology Center
PEO	Stichting Projektbeheerbureau Energie-Onderzoek
PMLTNO	Prins Maurits Laboratory TNO
SCMC	Sonic Control and Measuring Choke
SFCC	Solid Fuel Combustion Chamber
STW	Stichting voor de Technische Wetenschappen
ZWO	Nederlandse Organisatie voor Zuiver Wetenschappelijk Onderzoek

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