DEVELOPMENT OF
CRYO- HYBRID ROCKET PROPULSION SYSTEM

PROJECT UNDER
SPECIAL ASSISTANCE PROGRAMME
(DRS-II)

FINNAL PROGRESS REPORT

SUBMITTED TO
UNIVERSITY GRANT COMISSION

DEPARTMENT OF SPACE ENGINERING & ROCKETRY
BIRLA INSTITUTE OF TECHNOLOGY
MESRA, RANCHI -83521

ANNEXURE-VII

UNIVERSITY GRANTS COMMISSION
NEW DELHI

PROGRESS REPORT FINAL REVIEW UNDER SAP (DRS-II)

Date of first approval with level at inception: 01/04/2007

Name of the University: Birla Institute of Technology
MESRA: 835215, RANCHI

Date of implementation of current phase as noted by : 01/04/2007

Name of the Department: Department of Space Engineering & Rocketry

Status(CAS/DSA/DRS-II Period of Report : From April 2007 to March 2013 with phase): DRS - II

	NR	R	Total
Amount allocated for 5 years:	31,50,000/=	1300000/=	44,50,000 + 1 P F
Amount sanctioned during the year : 2009-10		260,000/=	260,000/=
2011-12	31,50,000/=		31,50,000/=
Amount utilised up to 31/3/2015 :			24,74,529/=

Date of first sanction : 5/2/2010
(Current phase)
Total grants received since inception: 34,10,000/=

Coordinator's Name: Dr. A. K. Chatterjee
(Superannuated in Sept. 2012)

Dy. Coordinator's Name: Dr. P. C. Joshi

Address: Birla Institute of Technology, MESRA:, RANCHI

City: RANCHI
Pin: 835215
State: Jharkhand
Tel. : 0651- 2276224
Fax : 0651- 2275401

1. (a) Thrust Area(s) : Cryohybrid Rocket Propulsion System
Identified since inception: Ongoing
Modified to, if any, and when UGC approval reference no and date
Future Thrust Area proposed : Nil

(b).UGC nominees with Address,
City, Pin, State, Tel., Fax,
e- mail (as approved by the UGC) : 1. Prof. R. K. Manchanda
TRFI, Mumbai
2. Dr. Sree Kumar
Head, Space Astronomy Division
ISRO, Satellite Centre
Bangalore -

2. Major achievements (last six years depending on final term review) as the case may be:

(i) Teaching :

a. New courses introduced : None

b. Curriculum last revised & significant changes : M.E. (SER)

c. Examination reforms last made with special features:

Examination reform were made in 2006 and 2012, students are given assignments in each theory course. Emphasis has been made on self learning.

d. Teaching lab./equip./new facilities created:

Please see Annexure – I

(ii) Research

a. Research(highlight major objectives set-forth (as proposed) and achievements made with breakthrough, innovation brought in, technology transferred, international collaboration which have created resources).

Please see Annexure – II

b. If the objectives set-forth could not be achieved, the specific reasons thereof.

a) In getting major equipment specially pressure regulators and values from foreign country as these are not manufactured in India.
b) Delay in fund release from UGC
c) Resignation of faculties working on the project.
d) Non availability of suitable research fellow.

c. Utilization of findings in policy formulation, development and modification of strategies (for Social Science departments mainly)

(iii) Human Resource Training :

Persons trained (Nos.):

a. UG- PG b. Rural/Tribal c. Industrial

d. International e. From other agencies –

The static test setup for solid- gas, solid- liquid hybrid system are being utilized for imparting the training to UG and PG students in the area of rocket propulsion.

3. Infrastructure Developed : Nil

a. Name major Equipments (>3 lacs):

Sl. No.	Equipment	Cost (in Rs.)
1.	Data acquisition system CDAG- 9172, 8- Slot USB 2.0 Chassis for Compact DAG NI 9211, 4- CH + 80 MV 145/S, 24RIT TC and DIFF AI	376630.00
2.	IMPACS IS 12 INFRARED PYROMETEER, LUM ASENSE, GERMANY	381064.00

Please also see the Annexure – III

b. Central Schemes/facilities for PG, Research and Extension Activities (Please tick the one applicable to your Department :

(i) STEP : YES
(ii) IIPC
(iii) USIC / RSIC
(iv) Patent Promotion Cell : YES
(v) Guesthouse with capacity : Three, total capacity : 50 rooms

(vi) Seminar / Conference Room with capacity : One, capacity : 400; Three, Capacity 100 each
Besides Departmental Seminar Rooms

(vii) Regional/Mainframe computing facilities

Mainframe Computing Facility includes PARAM 10000 Super Computer with 8Ultra SPARC Processors and Solaris Operating System, besides several high-end servers with a variety of Operating System, besides several computers are part of the Institutional Network.

(viii) Central Library with documentation facilities

The central Library houses above 1.20 Lac volumes, including Books, Peridicals, Conference Proceedings, etc. The Library also a large stock of learning resources, such as CD- ROMs, Audio- Video Taps and Microfilms and e-learning resources. The University through INDEST consortium has access for full text to more than four thousand publications. The Institute subscribes to a large number of National and International Journals indifferent discipline. Besides, it has access to a large number of Journals through UGC's Infonet Scheme.

(ix) Continuing Education Centre : Yes
(x) Women Development Cell. : Yes

c. Networking(Please tick the right one):
(i) Library (ii) Laboratory (iii) University Department.

The Central Library, Departments and Hostel Rooms are Networked

4. Knowledge disseminated to (in the thrust area identified):

(i) Other teaching institution (Name, No. of faculty involved): Nil

(ii) Industry (Name with amount received if any) Nil

(iii) Rural/Tribal/Govt./NGOs(Provide No. with amount) Nil

(iv) International (name organisation) Nil

(v) Others Nil

(vi) Innovation/excellence brought in (Please specify in the identified thrust areas only)

5. Breakthrough (already recognized) None

6. Emerging/Hi-tech/Priority area generated None

7. Resource generation (specify amount, Rs. in lakh): Nil

Items	Amount	Items	Amount

Consultancy :

Sponsored(agency) R&D Projects:

Transfer of technology:

Product & Prototype development:

Patent utilization :

Exploitation of internal facilities

by user departments

Industrial collaboration:

Human Resource Training:

a. Neighbouring institutions: Nil
a. International students:
b. Industries :

c. Industrial :
d. National organisations:
e. Extension activities :

b. International organisations: Nil

c. Other courses Collaborative: Nil

d. Any other programmes Nil

a. Total amount of resource generated from all sources above : Nil

b. Also mention development grant received from University in other areas of the Department. Nil

8. Use of output of research, teaching in (tick and fill up the right one)

Item No.	Item No.
a. Industries	
b. Other user deptts.	Mech. Engg., Chemical & Polymer Engg.
c. National orgns.	
d. Other organisations	DRDO, ISRO

9. Other activities:

a. Items Numbers	Time duration
Seminar	
Summer Institute Conference	
Refresher Courses	**Please see the Annexure – IV**

b. Autonomous Character: Yes

a. Financial Yes

b. Administrative Yes

c. Academic Yes

d. Others Deemed University

c. Advisory Committee Meeting (No. with Dates) : Not taken place

Major Recommendations NA

1.
2.
3.

10.Faculty Involved

a. Faculty Strength: [xx]

Positions	Available	Working	Vacant Created
(Put Numbers)	In thrust Area(1)	Other Areas(2)	(1) (2) (1) (2)under SAP/ ASIST
Professor	: 2 (1)	2 (2)	
Associate Prof.	: –	1(2)	
Assistant Prof.	: 2 (1)	3(2)	
Others	:		

xx- because of frequent joining & resignation only 2or 3 faculty were available.

b. In the identified thrust area(s)*:

Faculty Name Membership Specialisation/ (INSA/BHATNAGAR/BIRLA) Specific Areas of expertise

Professor 1. 2. 3. 4. Associate Prof. 1. 2. 3. Assistant Prof. 1. 2. 3. Em./ Viz. Prof.

Please see the Annexure – V

* Provide a list of publication records in referred journals (group area wise, faculty member wise, year-wise).

Please see the Annexure – VI

c. Intake(Please put numbers) Identified thrust Other than thrust area

Ph.D. :	Flexible
PG :	24 (M.E) + 25 (M. Tech.)
Fellows :	Flexible
NET scholar :	Flexible
GATE Scholar:	Flexible
Res. Asso. :	Flexible
Proj. Asstt. :	Flexible
Others :	

11. National/Nodal Character of the Department National/Nodal/All India Centre

a. Resource Persons Invited (Nos.)- International National : National, 11

Please see Annexure – VII

b. Serving for outside user departments in (Nos. & hrs.)

i. Hands-on QR technical training : Special Course on Propulsion and Aerodynamics, for 10 Officers from DRDL, Hyderabad, Dec 04 – 17, 2008.

ii. Collaborative(international) to university/college teachers : Through Virtual Prototyping Centre

iii. Teaching to neighbouring institutions : Nil

iv. Visiting Teachers to foreign university : 01

v. Equipment facilities : Five Laboratories in the area of rocket propulsion and aerodynamics

vi. Other major infrastructure facilities : Seminar Halls

12. Most critical and essential requirements that may be required to continue the programmes if the UGC agrees to continue or extend support based on the evaluation and final review by expert committee.

Non-recurring : Recurring: Total(Rs. in lakh) :
(As per items given in the guidelines {Please add Annexure)

13.a. Whether the State Government will take up the liability of the faculties and the staff approved under SAP after cessation of the tenure of the programme i.e. five years.

The Institute will take up

b. Whether the State Government has already agreed or has taken up the liability after five years of completion of the tenure of the programme as was communicated along with the approval letter?

The Institute will take up

c. How the Department is going to maintain infrastructure and the status if UGC disagrees to continue the support further. Whether the Department /University will agree for upgradation of the status on no cost basis, if it so happens as per the recommendation of the Committee.

NO

14. Utilization Certificates may be provided as per the UGC format. The accounts of the earlier phase be completed, finalised, audited and duly authenticated by the competent authority (Registrar and Finance Officer both) (item-wise and year-wise) for all the allocations and sanctions given to the Department for ongoing/current phase are to be submitted by the Department so that UGC, if provides support again , may immediately release the funds for the phase to be approved as per the above activities.

Signature :
Programme Dy.Coordinator
Dr. P.C.Joshi
Dept Of Space Engg. & Rocketry, B.I.T. Mesra

Signature:
Registrar of the University

Registrar
Birla Institute of Technology
Mesra: Ranchi

ANNEXTURE-VI

UNIVERSITY GRANTS COMMISION

UTILIZATION CERTIFICATE

It is certified that the amount of Rs. 34,10,000.00 (Rupees Thirty Four Lacs Ten Thousand only) out of the total grant of Rs. 44,50,000.00 (Rupees forty four lacs fifty thousand only) sanctioned to Department of Space Engineering & Rocketry, Birla Institute of Technology, Mesra, Ranchi by University Grants Commission, New Delhi, vide its letter No. F.3-55/2007 (SAP-II) dated 06.09.2007 towards UGC Special Assistant Programme (SAP), at the level of DRS-II, under SAP scheme was released. Out of this, a sum of Rs. 2474529.00 (Rupees twenty four lacs seventy four thousand five hundred twenty nine only) has been utilized for the purpose for which it was sanctioned and in accordance with the terms and conditions as laid down by the Commission. An upspent balance Rs. 9,35,471.00 (Rupees nine lacs thirty five thousand four hundred seventy one only) has been surrendered to UGC through RTGS vide UTR No. UCBAH15141061423, dated May 21, 2015.

If as a result of check or audit objection some irregularities are noticed at a later stage, action will be taken to refund, adjust or regularize the objected amount.

Signature
Dy. Coordinator
Dr. P. C. Joshi, Professor
Dept. of Space Engg. & Rocketry
B.I.T. Mesra, Ranchi

Signature 21/5/15
Finance Officer with Seal
Dy. Comptroller
Birla Institute of Technology
Mesra, Ranchi (Jharkhand)

22-5-15
Signature
Registrar with Seal
Registrar
Birla Institute of Technology
Mesra, Ranchi

Signature, Charted Accountant
with Seal and Regstration No.
M No 072022

UNIERSITY GRANTS COMMISSION

University: Birla institute of Technology, Mesra: Ranchi

Sanction Letter No. & Date: F.3-55/2007 (SAP-II), dated 06.09.2007

Consolidated Statement of Expenditure incurred during 01.04.2007 to 31.03.2013 in the UGC Assistance to the Department of Space Engineering & Rocketry, Birla Institute of Technology, Mesra, at the level of DRS-II, under Special Assistant Programme (SAP-II)

Items of Expenditure	Total grant approved by the UGC	Grant released by the UGC so far	Actual Expenditure Incurred						Total Expenditure Incurred	Remarks
			2007-08	2008-09	2009-10	2010-11	2011-12	2012-13		
(1) NON-RECURRING Equipment & accessories' for high pressure oxidizer lines	7,50,000.00	7,50,000.00	48,003.00	2,50,000.00	1,56,000.00	Nil	Nil	3,62,608.00	8,16,611.00	
Data acquisition system	5,50,000.00	5,50,000.00	Nil	3,76,630.00	Nil	Nil	Nil	Nil	3,76,630.00	
Pressure transducer with digital display system	3,00,000.00	3,00,000.00	Nil	Nil	Nil	Nil	Nil	1,18,473.00	1,18,473.00	
Thrust transducer with digital display system	3,00,000.00	3,00,000.00	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
Differential pressure transducer	1,00,000.00	1,00,000.00	Nil	Nil	Nil	Nil	Nil	1,66,134.00	1,66,134.00	
Flow meters	1,00,000.00	1,00,000.00	Nil	Nil	Nil	Nil	Nil	56,613.00	56,613.00	
Ultrasonic and acoustic transducers with pre-amplifier and recording system	1,50,000.00	1,50,000.00	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
Thermocouples and temperature display unit	50,000.00	50,000.00	5,597.00	Nil	Nil	Nil	Nil	36,563.00	42,160.00	
Pressure valves pressure regulators (pneumatic as well as solenoid)	1,50,000.00	1,50,000.00	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
Infra red spectrograph for rocket plume analysis	2,00,000.00	2,00,000.00	Nil	Nil	Nil	Nil	Nil	3,81,064	3,81,064.00	
Design, fabrication and commissioning of thrust stand for 500 Kg thrust motor	2,00,000.00	2,00,000.00	Nil	Nil	85,603.00	Nil	Nil	Nil	85,603.00	
Computer/A/D/ converter cards/software	3,00,000.00	3,00,000.00	1,43,145.00	Nil	Nil	Nil	Nil	1,17,863.00	2,61,008.00	
SUB TOTAL:Rs.	**31,50,000.00**	**31,50,000.00**	**1,96,745.00**	**6,26,630.00**	**2,41,603.00**	**Nil**	**Nil**	**12,39,318.00**	**23,04,296.00**	

(2) RECURRING Contingency Working expenses, Chemicals/Glasswares Hiring charges Travels	13,00,000.00	2,60,000.00	1,05,259.00	Nil	Nil	56,875.00	Nil	8099.00	170233.00
TOTAL: Rs.	**44,50,000.00**	**34,10,000.00**	**3,02004.00**	**6,26,630.00**	**2,41,603.00**	**56,875.00**	**Nil**	**12,47,417.00**	**24,74529.00**

Certificate

1. Certified that the grant has been utilized for the purpose for which it was sanctioned and in accordance with the term & conditions attached to the grant.

2. If as result of check or audit objection, some irregularity is noticed at later stage, action will be taken to refund, adjust or regularize the objected amount.

Programme Dy. Coordinator

Finance Officer

Dy. Comptroller
Birla Institute of Technology
Mesra, Ranchi (Jharkhand)

Registrar

Registrar
Birla Institute of Technology
Mesra: Ranchi

A/C : UGC GRANT TO DEPT. OF SPACE ENGG. & ROCKETRY UNDER SAP DRS-2

List of the Equipments

Sl. No	Equipment	Party Name	Amount Rs
1	High Pressure Oxidizer line for (a) Solid –Liquid Hybrid System (b) Solid - Gas Hybrid System	 Siddharth Engineers, Pune Zentech Engineers , Kolkota	 518608 250000 7,68,608.00
2	Data Acquisition System CDAQ-9172,8-SLOT USB-2.0 , CHASSIS FOR COMPACT DAQ NI9229 ,4CH-CH ISOLATED ,24BIT, 100S/S UNIVERSAL A1 MODEL,NI9211, 4CH +80MV,14S/S 24 BIT TC AND DIFF AI	N I Software Trident Technology Pvt Ltd TECHLABS	3,76,630.00
3	Thrust chamber assembly	Revithi engineering , hyderabad	85,603.00
4	Pressure transducers	CST Sensor India Pvt Ltd, Bangalore	29,580.00
5	Strainless Steel Pipe		48,003.00
6	Thermal Sensor, Thermocouple	Thermal sensor , Nagpur, Maharastra	42,160.00
5	Differential pressure sensors	Ashcroft India Pvt Ltd, Chhatral, Gujarat	1,66,134.00
6	Digital pressure gauge	-- - do ---	88,893.00
7	software for high speed camera Midas os usa sl no 131267	Xcitex Inc, USA	61,313.00
8	Impact Model IS 12 Infrared Pyrometer	Luma Sense Technologies GmBh, Germany	3,81,064.00
9	Rockwin Flow meter TFM 1010	Rockwin FlowmeterIndia Pvt Ltd ,Ghaziabad, India	56,613.00
10	Computer ,Printer, UPS	HP India sales pvt. Ltd,Dell India Pvt Ltd, Subhash Distributer	1,99,695.00
		TOTAL	Rs. 23,04,296.00

Dy. –COORDINATOR
(Dr. P. C. JOSHI, Professor)
Deptt. Of Space Engg. & Rocketry, B.I.T. Mesra

Dy.- Controller of Account
B.I.T. Mesra ,Ranchi-835215
Jharkhand

Dy. Comptroller
Birla Institute of Technology
Mesra, Ranchi (Jharkhand)

Annexure – I

5. UP GRADATION AND INSTRUMENTATION OF HYBRID TEST SETUPS :

The following existing test setup for experimenting on hybrid propellant system have been upgraded and instrumented to meet the requirement of the scope of this programmed .

A) Solid- Gas Hybrid Rocket Test Setup :

Another oxidizer feed line in which four oxygen cylinders shall be connected to the test motor via a 12.7mm ($^1/_2$") stainless steel pipe has been laid in order to get higher mass flow rate for a longer duration. Fig.-1 shows the live diagram of this new oxygen feed live. The upgradation of the setup has been done by M/s Zentech Engineers, Kolkata. The photographs of the feed line are presented in fig.-2 . The arrangement of oxygen cylinders has been presented in fig.-3 .

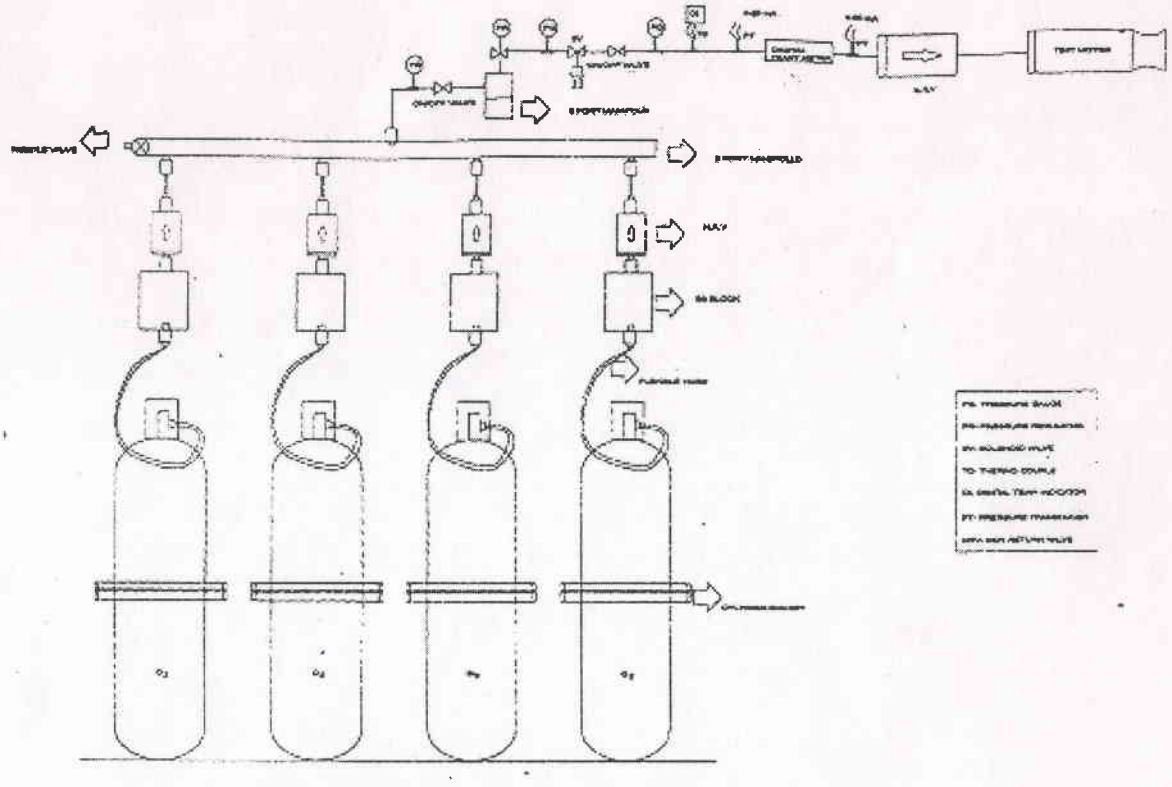
The test setup was also upgraded in term of instrument. A data acquisition system : DAG- 9172, g slot VSB 20chessis for COMPACT NI 9229 4 CH – CH i SOLATED, 24 BIT, 100 SIS universal A1 MODEL, NI 9211 – 4 CH+ 80MV, 14 SIS 24 BIT TC AND DIFFAI, was attached to the setup for accurately measuring of parameters like pressure, thrust. Velocity and Temperature. Fig.-2 also shows the photograph of the installed data acquisition system.

B) Up Gradation Of Solid- Liquid Hybrid Setup :

The solid- Liquid hybrid test cell has been also upgraded to meet the requirement for testing the rocket motor up to 250 kg thrust level. The up gradation task was assigned to M/s. Siddhatha Engineers, Pune. Fig.-4 present the live dia gramme of the proposed setup. Fig.-5 to fig.-7 shows the photograph of different section of the upgraded test facility.

C) Oxidizer N_2O Feed Line :

Apart from the above two major renovation work, a separate oxidizer feed line was also laid for feeding the N_2O into a hybrid rocket motor . it was essential of N_2O in comparison to oxygen or liquid oxidizer. The line diagramme of this setup is shown in fig.-8. Fig.-9 shows the photographs 0f the N_2O feed line .



HIGH PRESSURE OXYGEN GAS LINE FOR TEST MOTOR

FIG. -1 : HIGH PRESSURE OXYGEN GAS LINE FOR HYBRID TEST MOTOR

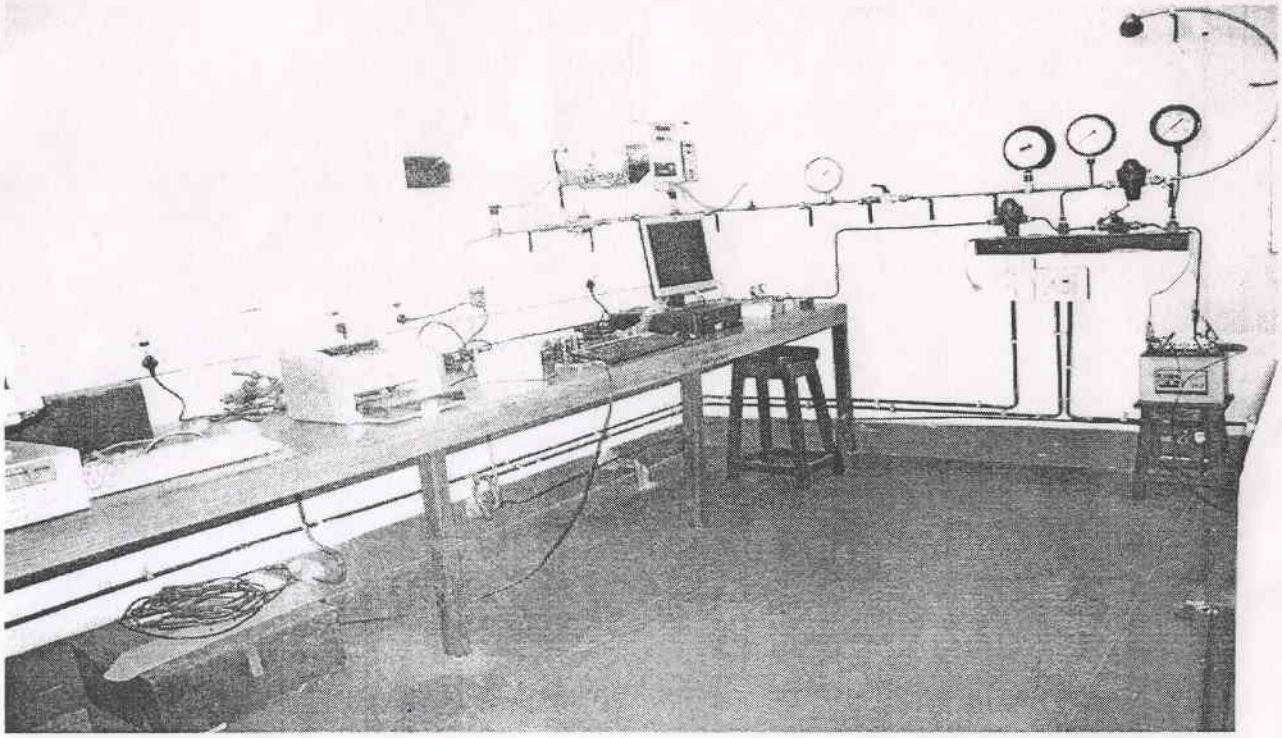


FIG. – 2 : PHOTOGRAPH OF OXIDIZER FEED LINE

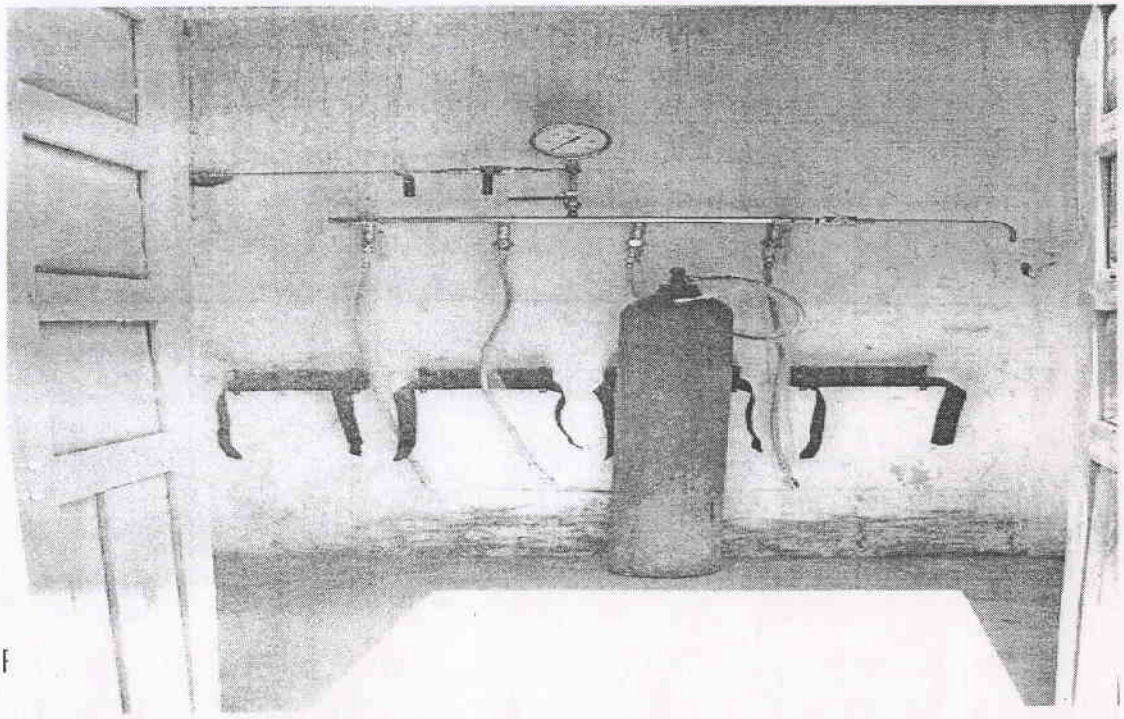


FIG. 3 : PHOTOGRAPH SHOWING UPGRADED MULTIPLE OXYGEN CYLINDER SETUP

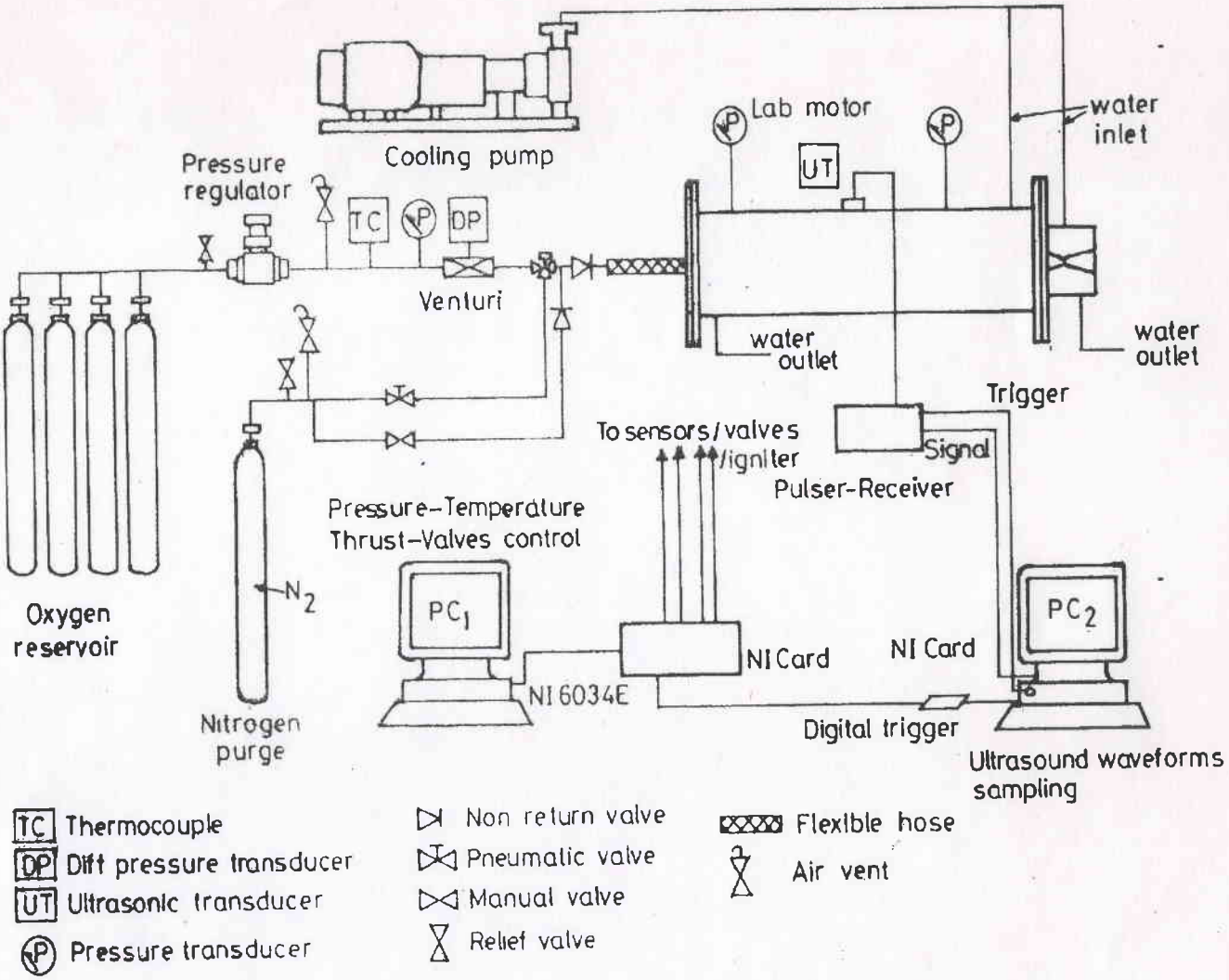
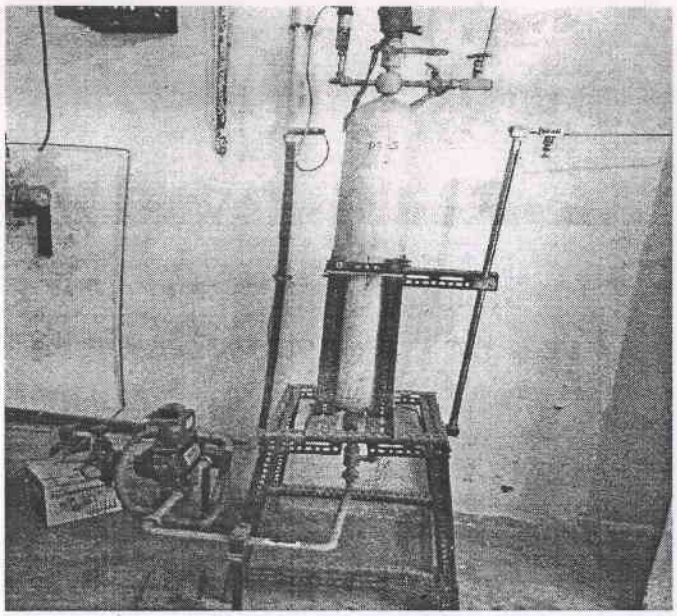
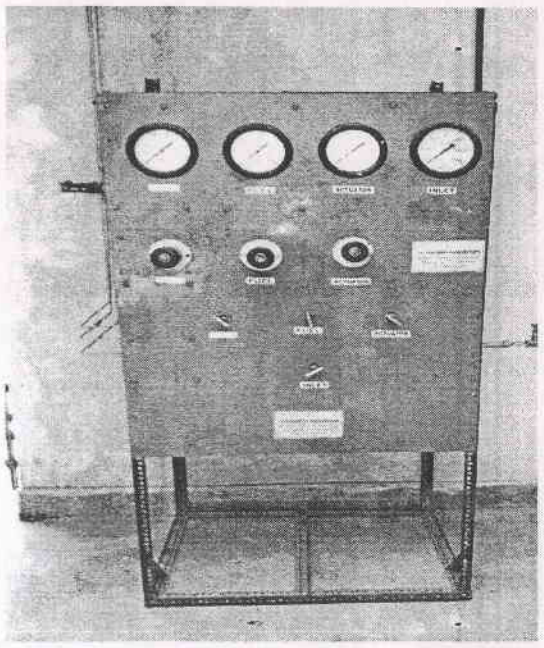


FIG. 4 : SCHEMATIC OF UPGRADED HYBRID TEST FACILITY





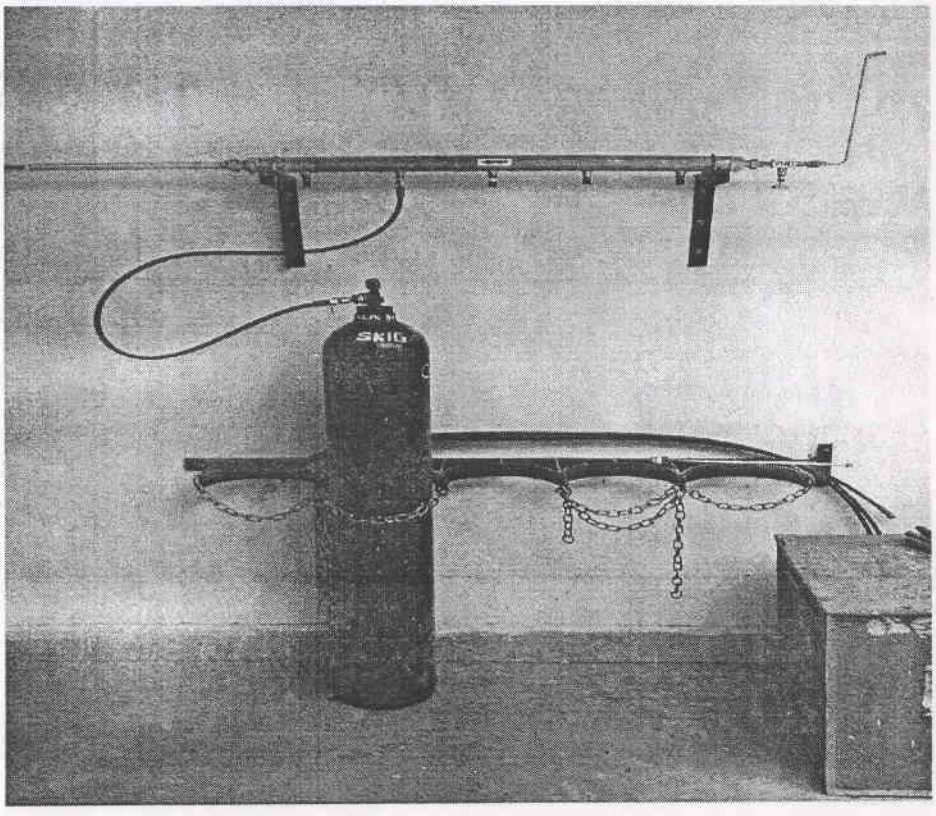


FIG. 5 : PHOTOGRAPHS OF PRESSURIZATION SYSTEM

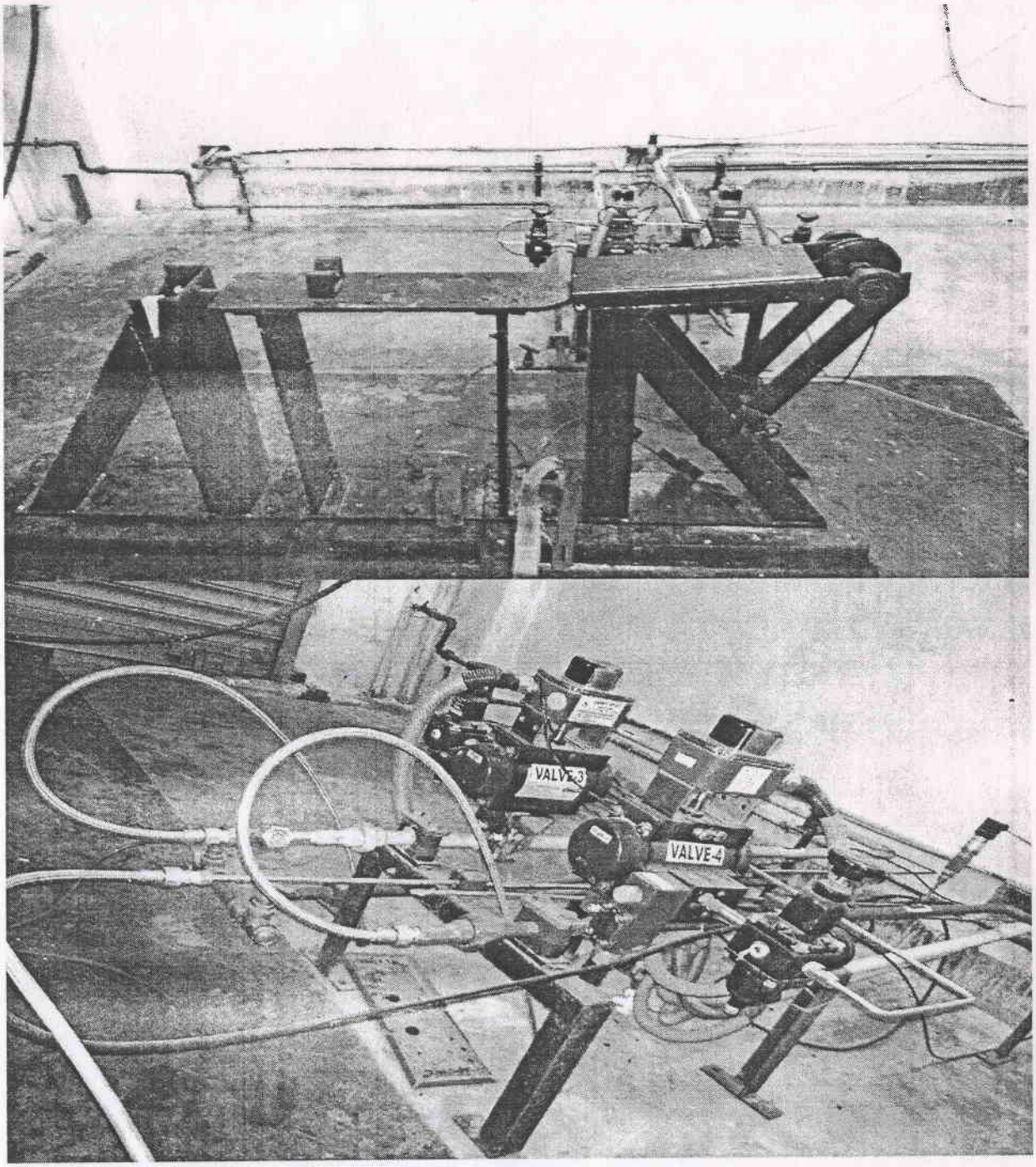
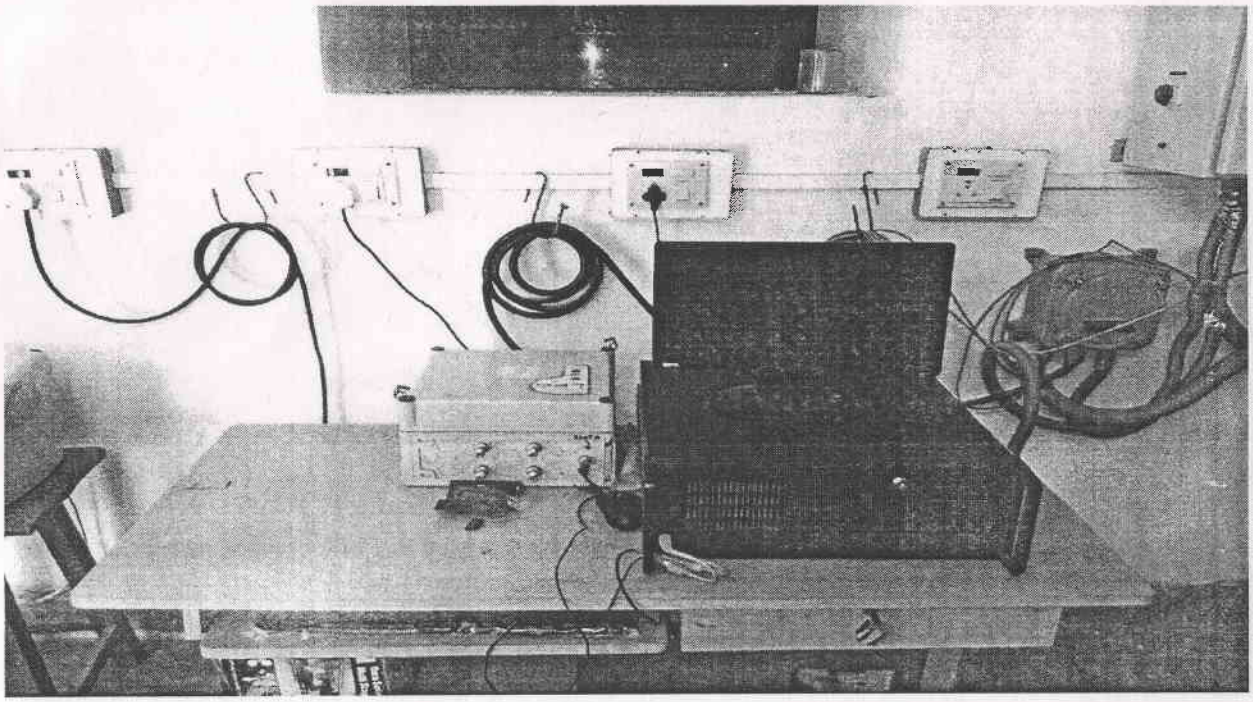


FIG. 6: PHOTOGRAPHS OF TEST FIRING CELL



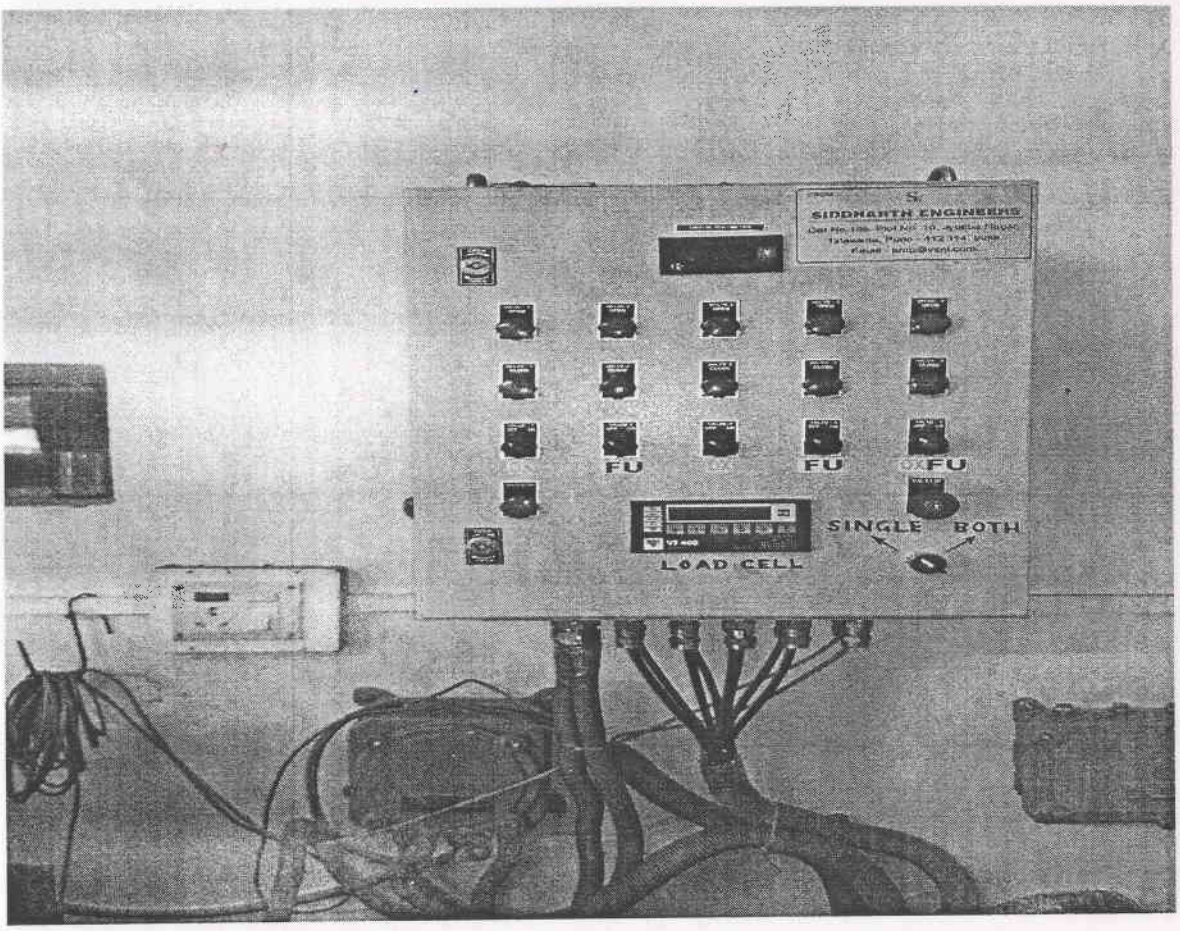


FIG. 7 : PHOTOGRAPHS OF TEST FIRING CONTROL ROOM

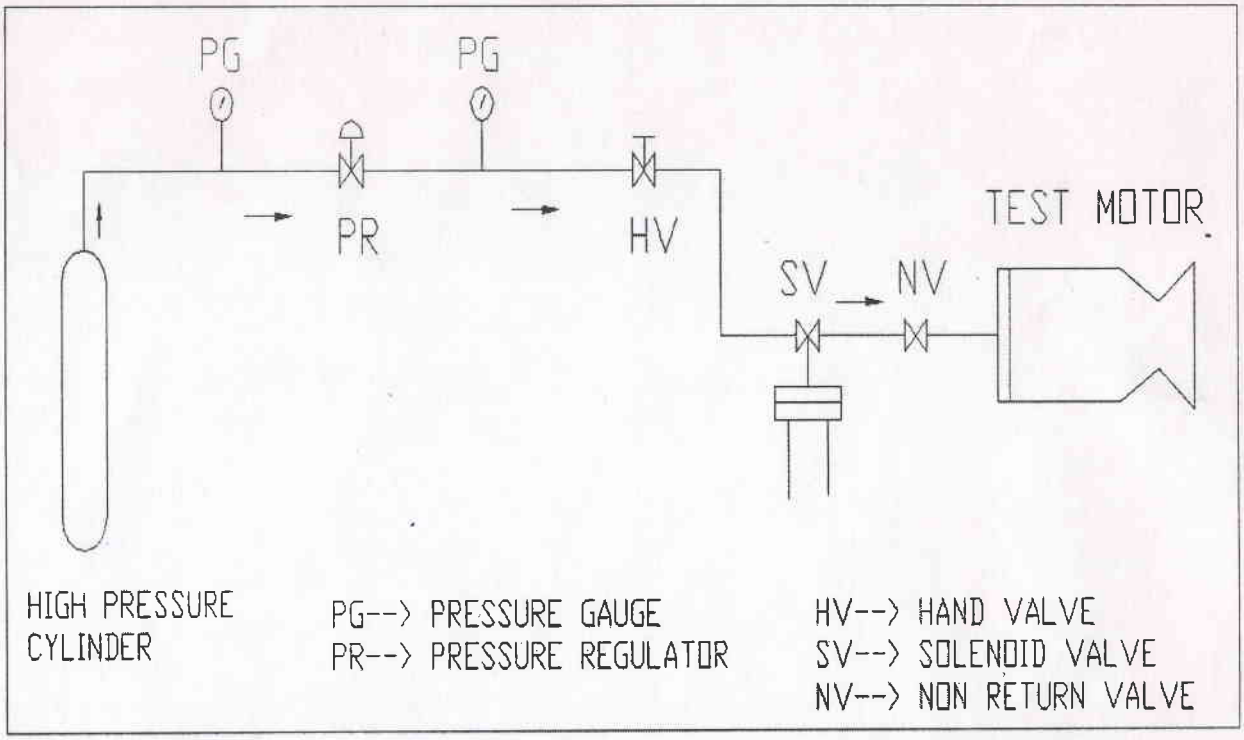
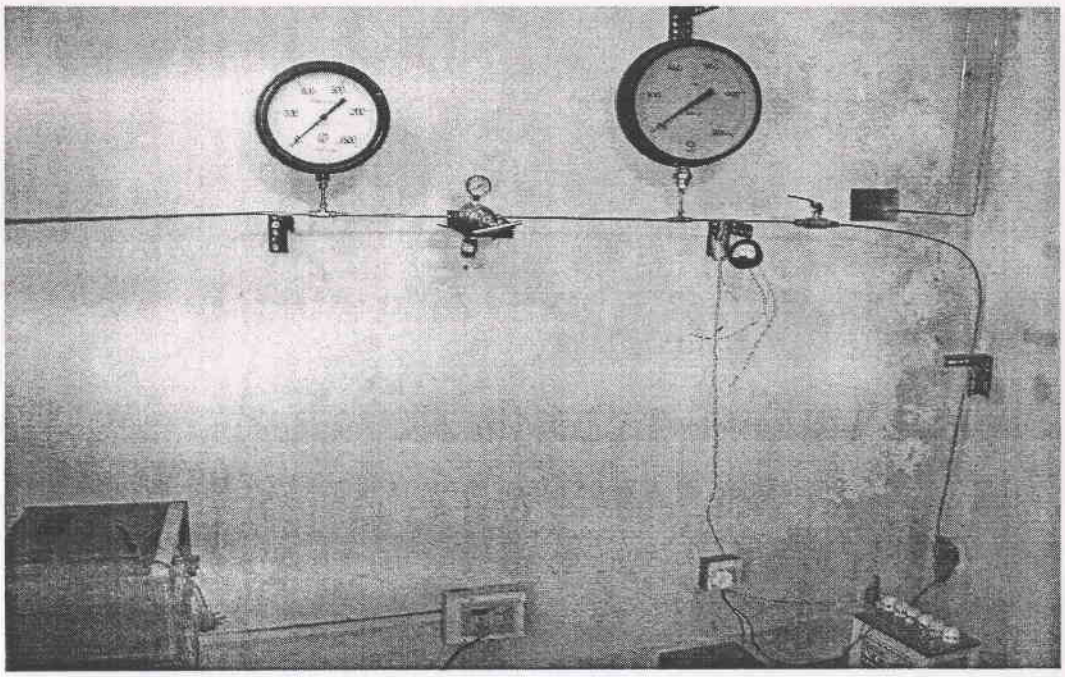
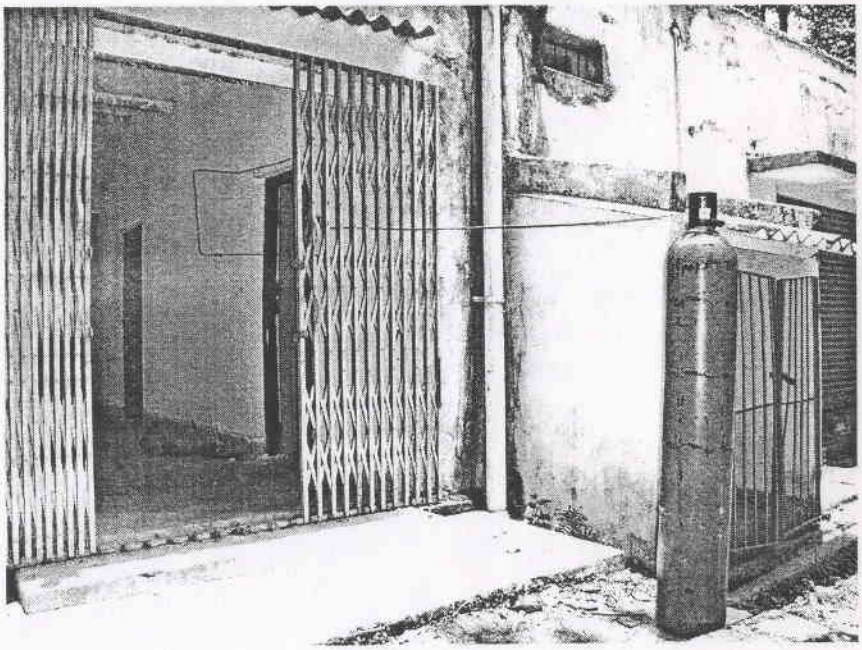


FIG. 8 : SCHEMATIC DIAGRAM OF N_2O FEED LINE



PARTIAL OXIDIZER FEED LINE



NITROUS OXIDE CYLINDER

FIG. 9 : PHOTOGRAPHS OF N_2O FEED LINE

Annexure – II

PROGRESS REPORT

The main objective, under the scope of the Project, is to develop an experimental test facility to study various aspects of development of a 250 kg thrust Cryo- Hybrid Rocket Engine which upon completion will lead to following the benefits and utility .

i. The laboratory/ sessional work on experiments related to Cryo- Hybrid Propulsion System would be conducted.

ii. A hands- on training and experience would be provided to students in handling, safety, storage and transfer of cryogenic propellants.

iii. The cryo- hybrid propellant combinations, injection and ignition systems, and motor design parameters would be selected / optimized to maximize the ballistic performance. This would provide vital experience to the researchers working on this Project.

iv. A break through in Hybrid Propulsion System in India. It has already been mentioned that it would have tremendous scope in Space- limited Upper Stage Propulsion System and Long Range Missile.

v. The facility, when fully developed, would serve as a 'model facility' for training and carrying out advanced research projects of National importance.

To achieve the objectives of the project, work was initiated in multi direction which include the fuel composition formulation, fuel grain design, hardware design and fabrication, renovation and up gradation of test firing cell and evaluation of performance of propellant system. The work was started with solid fuel – gaseous oxidizer like O_2 and N_2O with a plan to use liquid oxidizer like RFNA, N_2O, N_2O_4 and finally to liquid Oxygen . A brief summary of the work carried out is presented below.

1. FUEL GRAIN COMPOSITION:

A number of fuel grain compositions have been formulated and processed using polymeric fuel binder such as PVC plsatisol, HTPB, Shellac Sugar and Wax alone and also in combination. The primary objective behind these activities was to optimize the fuel composition in term of energetic and regression rate when used in a hybrid rocket motor.

PVC plastisol is a solid polymeric material composed of Poly Vinyl Chloride and Dibutyl Phthalate in equal proportion. It has excellent mechanical properties and loading capacity. It was used alone and also in combination of

energetic material such as Aluminum plus Ammonium Perchlorate as a hybrid fuel in conjunction with oxygen as a oxidizer. These propellant system shows excellent burning characteristics.

Hydroxy Terminated Poly Butadiene (HTPB) has wide acceptance as a high energetic fuel binder in the propellant industries. Fuel grain compositions using HTPB alone and in combination of other energetic material were formulated, processed and tested for hybrid combustion characteristics.

Shellac resin, a local produce of Chotanagpur area was also tried for use in hybrid fuel alone and in combination of HTPB and PVC plastisol considering its low cost and aboundent availability in this region. A number of compositions were developed and subjected to study of combustion properties.

One of the short coming of all the above fuel composition is low regression rate and low per unit area mass consumption rate in the hybrid combustion inspite of incorporation of other energetic materials. To over come these problems, it was decided to use Beeswax and Hydrocarbon Was as a hybrid fuel. A number of fuel composition were developed using wax alone and in combination of polymeric fuel like HTPB. HTPB was used to tailor the burning rate and toimpart mechanical strength to peep the fuel grain intact during combustion in the hybrid motor. Table – 1 present the composition of fuel grains subjected to combustion study.

TABLE- 1 COMPOSITION OF FUEL GRAIN PROCESSED

Sl No.	Fuel	Ingredient
1.	100 p	Pure wax fuel grain
2.	70 P	70% wax, 21.6% HTPB, 6.6 DOA, 1.8% TDI
3.	50 P	50% wax, 36% HTPB, 11% DOA, 3 % TDI
4.	25 P	25% wax, 54%HTPB, 16.5% DOA, 4.5%TDI
5.	95 P	95% wax and 5% AP
6.	90 P	90% wax and 5% AP
7.	45 P	45% wax, 32.4%HTPB, 99%DOA, 2.25% TDI, 0.18% glycerol &10%AP.
8.	50 S	50% Sugar and 36% HTPB, 11% DOA, 2.8% TDI and 0.2% glycerol
9.	100 PVC	50% PVC and 50% DBP

10	60 Shellac	60% Shellac, 20% PVC and 20%DBP

2. GRAIN DESIGN AND OPTIMIZATION:

The combustion within a hybrid motor is governed by the thermodynamic and flow properties within the combusting part of the fuel grain. The most accepted combustion theory for hybrid combustion is that proposed by Marxman et. All, in which the grain configuration plays a vital role in controlling the regression rate and mass consumption rate of the solid fuel.

Keeping the objective of the project, a number of moulds and mandrels were designed and fabricated for processing the fuel grains of various configurations. Few such mould and mandrel along with other accessories are shown in Fig.-10 to Fig.-13.

Stress was given to multi perforated fuel grain and star port grain to achieve the high and uniform mass consumption rate during the operation period of the hybrid motor. Fig-14 andfig.-15 shows the fuel grains of different configuration processed and subjected to combustion in a hybrid motors.

3. IGNITER COMPOSITION AND CONFIGURATION :

Conventional shellac igniters were used to initial the combustion of hybrid fuel with oxygen. These igniters were consisted of a shellac solid propellant bead around a three round coil of 5mm dia nicrome wire (34swg) for electrical heating and 5gm of some propellant in a polythene bag. The bead was placed in the bag and held in position with the help of adhesive tab. However these igniters were found unsuitable for hybrid fuel burning in the nitrous oxide (N_2O) oxidizer. Another igniters was designed and standardized to initial the combustion with N_2O oxidizer. Fig.-16 shows the photograph of one such igniter.

It consisted of a solid propellant ring of web thickness 5mm, length 20mm tight fitted in a graphite ring of OD 76mm, ID 40mm and length 30mm. The composition of this solid propellant was 30% PVC plastisol and 70% ammonium per chlorate this act as a secondary igniter. The primary igniter was fixed at the inner wall of this secondary igniter.

4. TEST MOTOR HARDWARE DESIGN & FABRICATION:

A hybrid test motor essentially consists of a combustion chamber where the solid fuel is housed and combust, an injector to feed the oxidizer into the combustion chamber and a nozzle for accelerating the combustion gasses to high exhaust velocity in order to generate the thrust from the motor.

Flanged combustion chambers of diameters 50mm, 62mm and 75mm and of various lengths up to 455mm, have been designed and fabricated for the combustion study of different types of solid fuel grain of varying size at oxidizer injection pressures upto 700 psi (48mpa). Fig.-17 & fig.-18 shows the two such combustion chamber used for combustion parameters study.

Different type of injectors have been designed, developed and fabricated to achieve more efficient combustion. These include shower head injectors, swirl injectors, impinging/non impinging injector and vertex injector. Some of them are presented in fig.19-21.

In general convergent – divergent type nozzles were used. Most of them are fabricated from graphite inserted aluminum block. Water cooled nozzle were also designed and used in fuel test firing where high combustion temperature of the exhaust gases expected for long firing duration. Fig.-22 & fig.-23 shows the water cooled nozzle used in few test firing.

4. REGRESSION RATE MEASUREMENT

The regression rate of the solid fuel burning in a stream of oxidizer is one of the basic parameter which not only decides the overall motor dimension but also geometry of the feed grain used therein. The regression rate of a solid fuel depends on many parameters both propellant specific parameters such as chemical reactivity of fuel and oxidizer and flow specific parameters which are mostly controlled by oxidizer injectors pressure, oxidizer injector quality and grain configuration. Therefore whenever a fuel was formulated, it is necessary to subjected it to regression rate measurement in a hybrid static test motors using the oxidizer selected for propellant system a number of fuel composition are formulated during last five years keeping in view the objectives of this programme and combustion unit oxygen and nitrous oxide gaseous oxidizer in a hybrid test motor. Apart from fuel composition, the effect of other parameters like injector type, oxidizer injection pressure / mass flow rate, and grain surface configuration

on the regression rate was also examined. Fig.-24 show typical firing carried out using hybrid test set up.

Table 2 present the average regression rate and average mass consumption rate of 50P hybrid fuel with O_2 and N_2O at oxidizer.Table -3 present the effect of solid oxidizer ammonium perchlorate loading in wax fuel with oxygen at oxygen injection pressure 28.12ksc. Table -4 present the effect of injector configuration on the combustion of PVC Plastisol and wax with oxygen at oxygen injection pressure 28.12 Ksc. Table 5 shows the regression rate, mass consumption rate of shellac and PVC plastisol fuel dependent on injector configuration at fixed oxidizer injection pressures. These data clearly shows that the fuel regression rate or mass consumption rate is a highly venerable parameter. It depends apart from the propellant properties to other parameters like injector quality, grain configuration and oxidizer injector velocity.

The regression rate of hybrid fuel within a rocket motor is highly position and time dependent parameter. Fig.-25 shows the variation of regression rate along the lengh of the fuel grain composed of 49.5% paraffin wax, 35.64%HTPB,10.89%DOA,2.78%TDI 0.19%GLYCEROLE AND 1.0% Carbon Black. Fig.-26 shows the combusting port geometry before and after test firing of a star shaped fuel grain. Such unevenness in the regression rate was observed almost in all the test firing irrespective of fuel composition and oxidizer mass flow however the magnitude is variable. This variation may expose certain portion of combustion chamber to hot combustion gases before scheduled firing duration and may result in damage of the rocket motor. Similarly the regression rate is time dependent which result in detrimental to performance with time. These problem to some extend can be resolved by proper selection of fuel composition, grain design and oxidizer feed system.

5. CONCLUSION –

During the last five years a good amount of work has been carried out in the diversified area of the hybrid propulsion system in spite of many hurdles such as sufficient trained research staff and late release of grant. Most of the work was done in the area of propellant selection, fuel regression rate study , its enhancement to meet the requirement and to understand the combustion mechanism within the hybrid rocket motor. A good number of postgraduate student were trained in this area. They did their postgraduate thesis work in the area of hybrid propulsion. This

will have a great impact on demand of human resource in future in this area of advance propulsion system.

Table -2 Average Regression Rate and Mass Consumption Rate of 50P fuel with O_2 and N_2O

Oxidizer specification oxidizer	In. Press. ksc	Fuel specification Fuel Dimension	Average regression rate mm/sec	Average Consumption Rate gm/sec
O_2	24.61	50P, L=110mm port dimension - 30mm	0.325	4.05
O_2	35.15	-do-	0.330	4.806
N_2O	28.12	-do-	0.165	4.296
N_2O	35.15	-do-	0.217	4.425

Table -3 Effect of AP loading on the regression rate of Wax in Nitrous Oxide

Sl. No.	N_2O In. Pressure Ksc	Fuel Specification, L=120mm D= 28 mm r in mm/sec, m in gm/sec					
		Wax 100% r avg	m avg	5% AP 95 %wax r avg	m avg	10%AP 90%WAX r avg	m avg
1.	21.09	0.482	**3.56**	.825	9.3	.881	12.68
2.	35.15	0.802	5.77	1.1183	15.93	1.267	16.51

Table -4 Effect of injector type on combustion of PVC plastisol and wax with oxygen (Oxygen Injector Pressure – 28/2 ksc)

Injector Type	Fuel Specification	r avg cm/sec	m avg gm/sec	Flame Nature
Single swirl $A=28.3mm^2$	Plastisol L= 220mm D= 30mm	0.071	24.05	Yellowish except at Nozzle end.
Single swirl $A=62mm^2$	-do-	0.052	15.46	-do-
Double swirl $A= 90mm^2$	-do-	0.083	26.33	-do-
Single swirl A=28.3	Paraffin wax L = 220mm D = 30mm	0.25	67.14	Bright Blue flame
Single $A=62\ mm^2$	-do-	0.275	90.98	-do-
Double swirl A= 90.3	-do-	0.221	65.95	Yellowish Flame

Table - 5 Regression rate, Fuel Mass combustion, IP and Injector Type for Shellac and PVC plastisol fuel at 3.447 M.P

Sl. No.	Injector & Injector Pressure	Fuel specification		PVC Plastisol L=12 ID-1.5cm	
		Shellac =12cm, ID-1.5cm M gm/sec	r mm/sec	M gm/sec	r mm/sec
1.	Convergent type 500psc	13.60	1.298	9.76	1.202
2.	Convergent Divergent 500psc	14.624	1.508	11.78	1.379
3.	Divergent Type	10.32	1.055	8.29	1.102

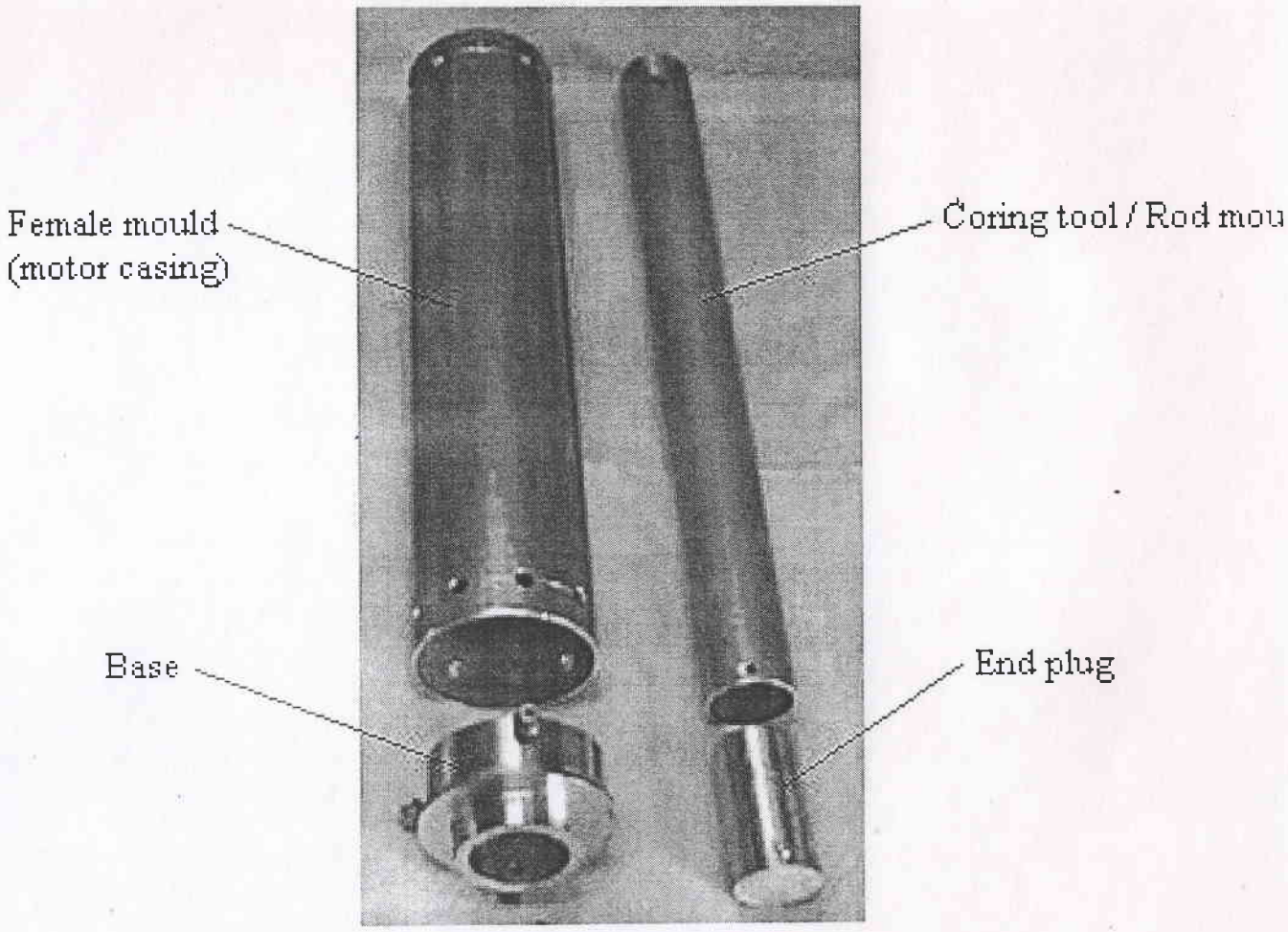


FIG. - 10: A TYPICAL MOULD AND MANDREL FOR CYLINDRICAL FUEL GRAIN

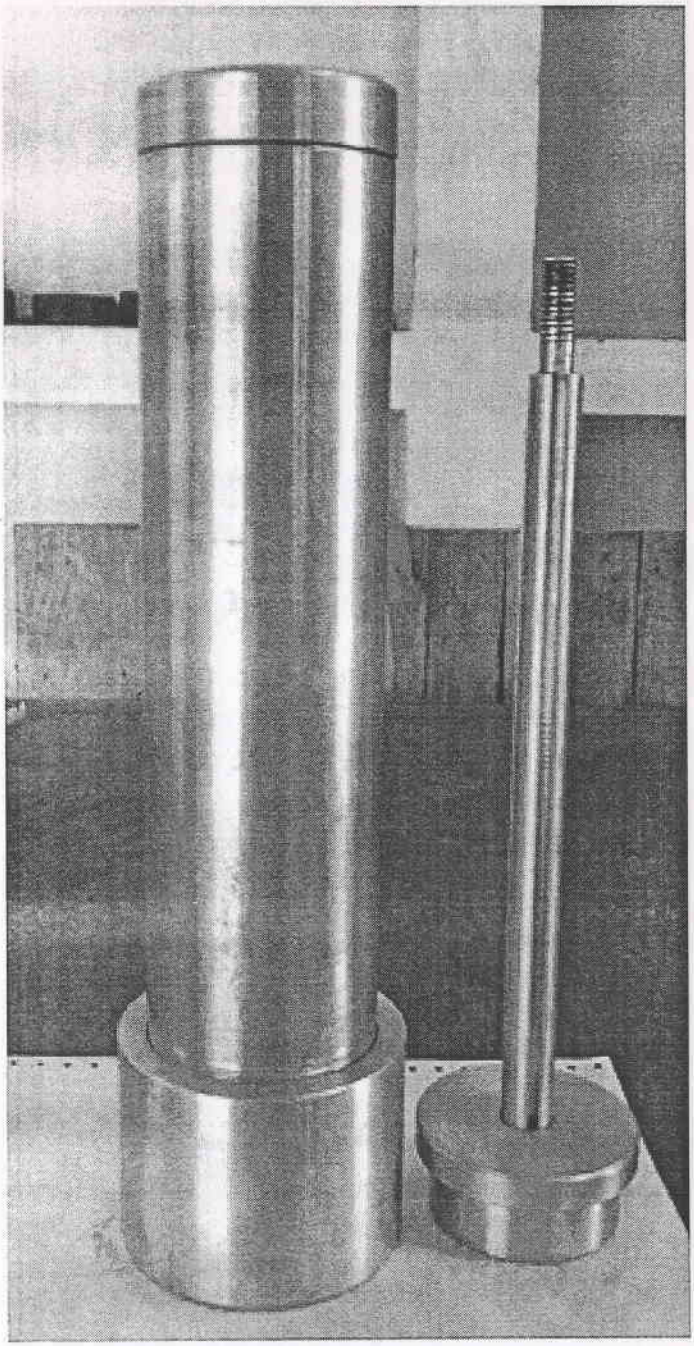


FIG. – 11 MOULD AND MANDREL SYSTEM FOR STAR SHAPED FUEL GRAIN

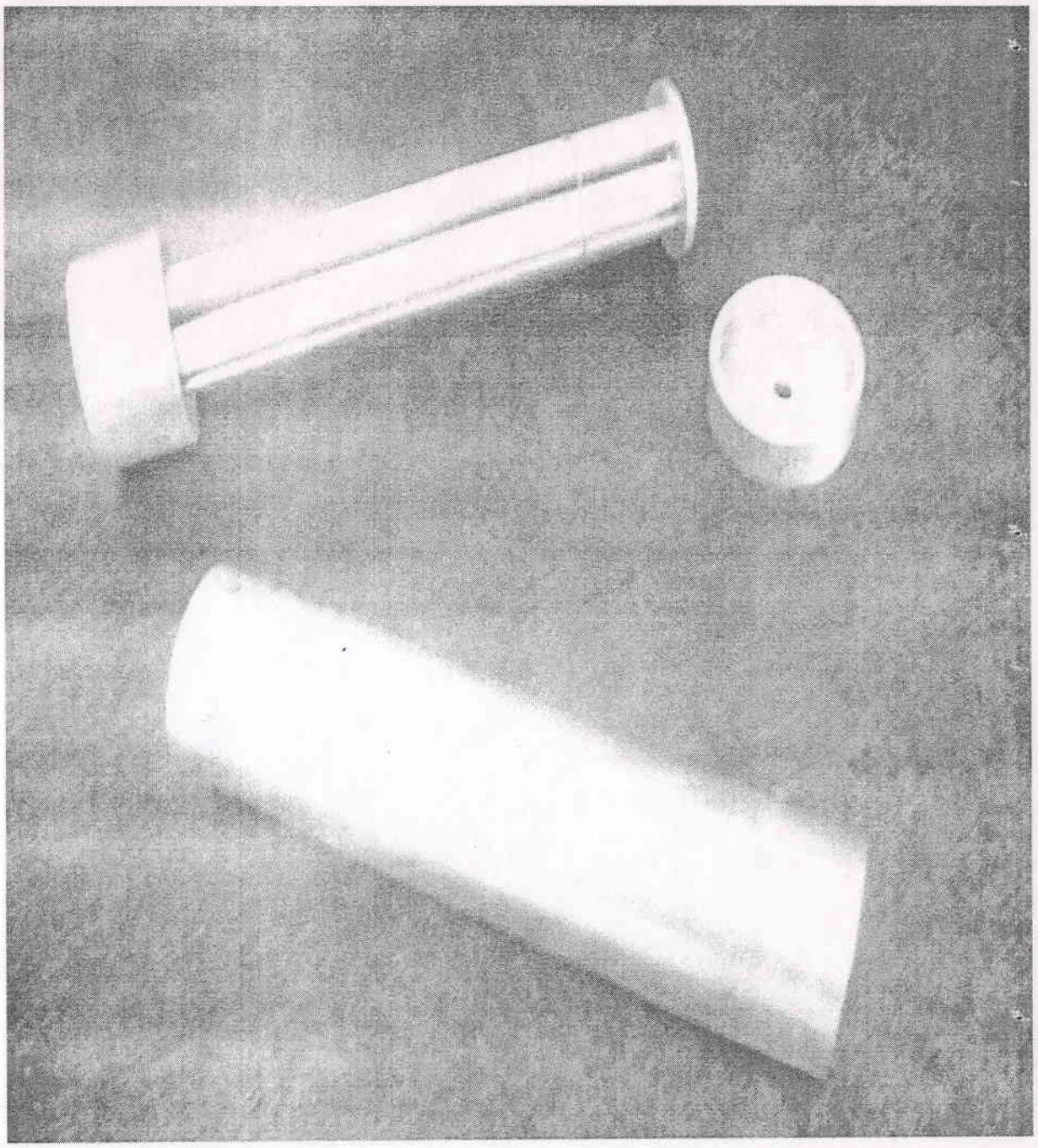


FIG. 12 : PHOTOGRAPH SHOWING MOULD AND MANDREL FOR MULTI- PERFORATED GRAIN

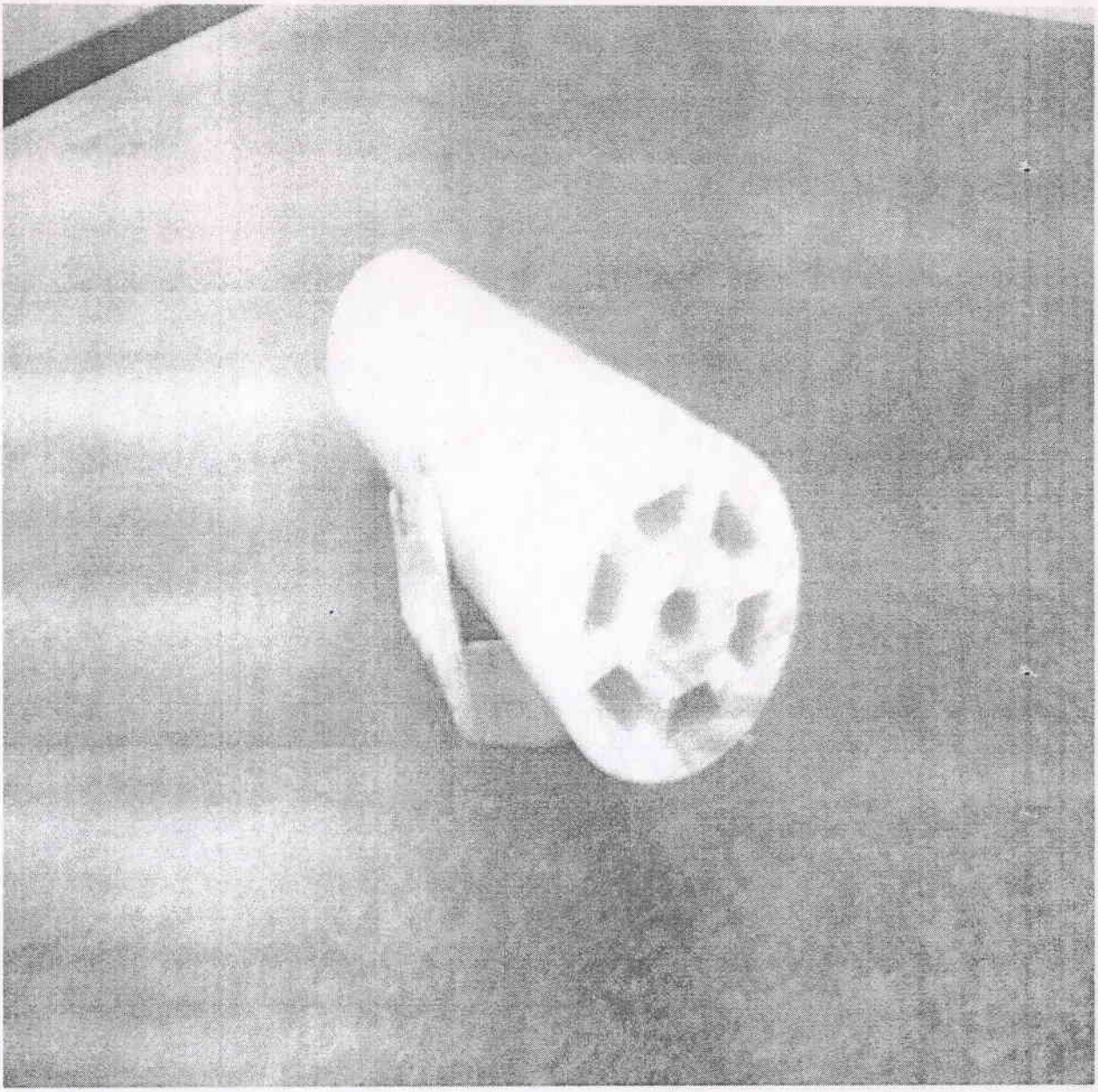


FIG.13 : PHOTOGRAPH SHOWING MULTI- PERFORATED FUEL GRAIN

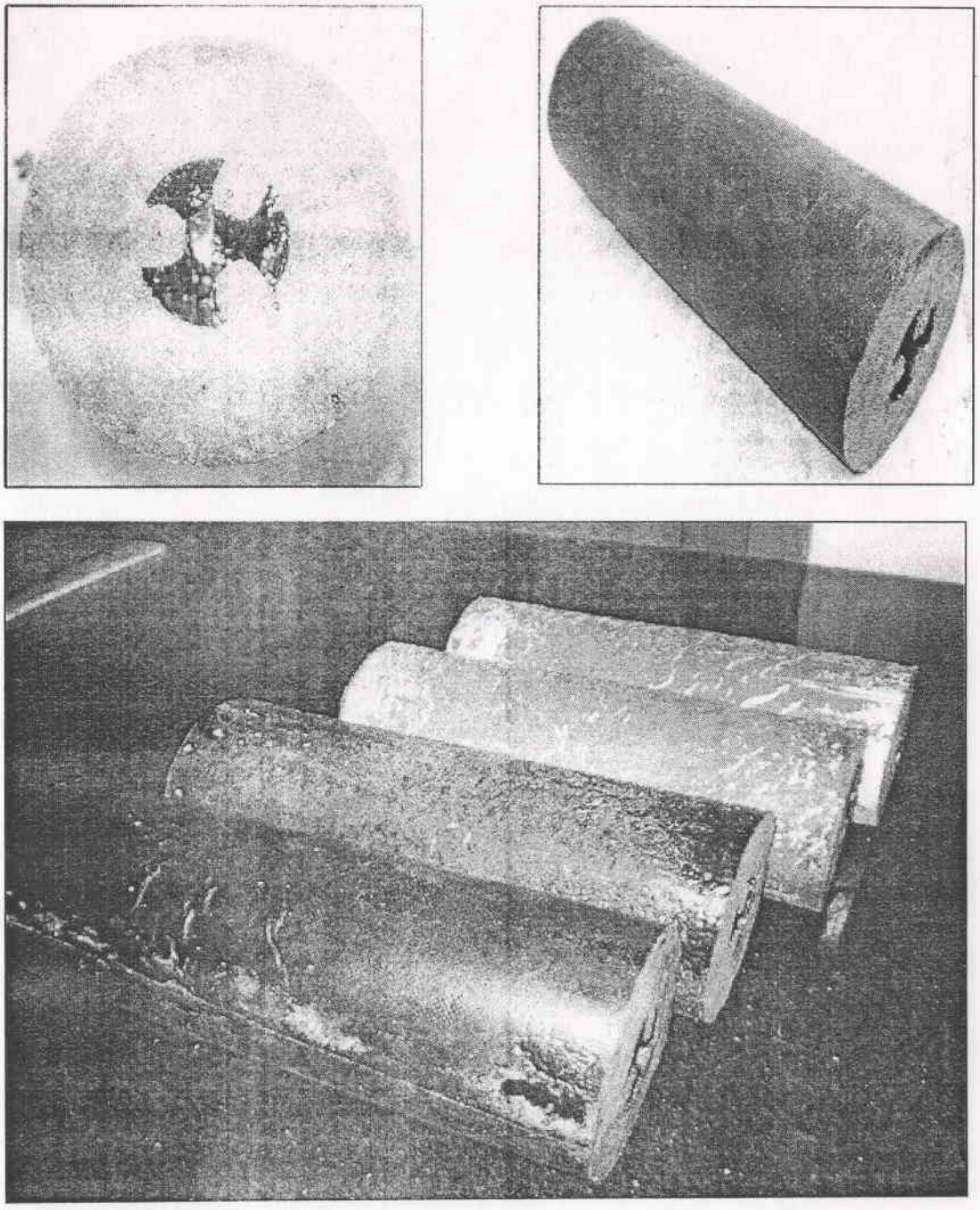
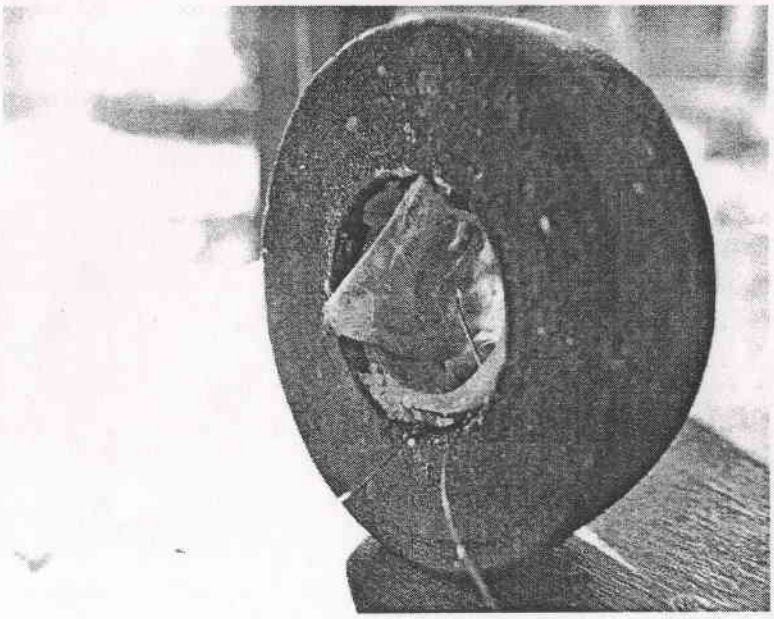


FIG.14 : PHOTOGRAPH SHOWING STAR SHAPED FUEL GRAIN



IGNITER

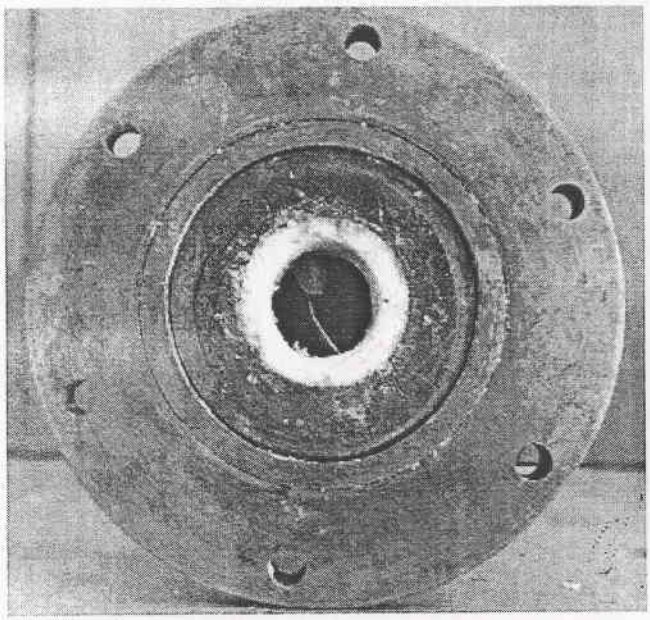
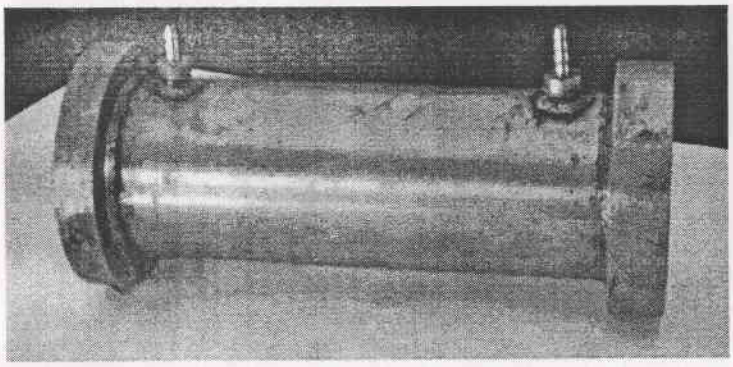
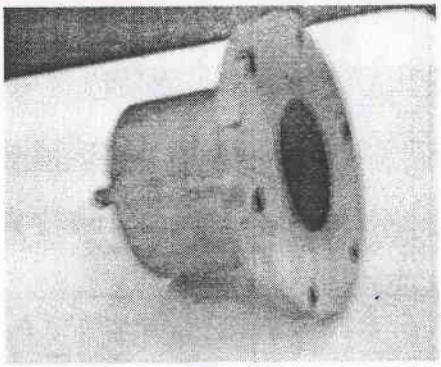


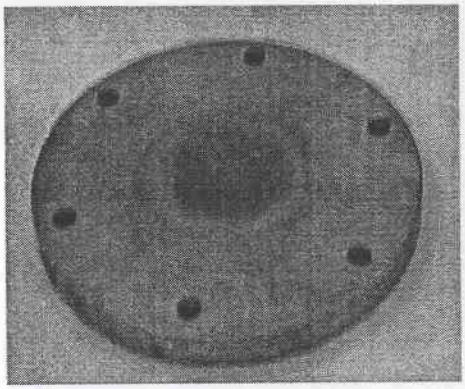
FIG. – 15 : IGNITER SYSTEM FOR FUEL BURNING WITH N_2O OXIDIZER



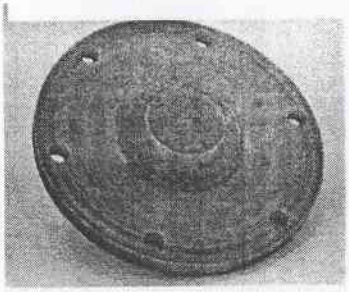
COMBUSTION CHAMBER



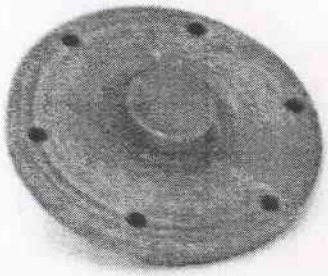
Oxidiser Chamber



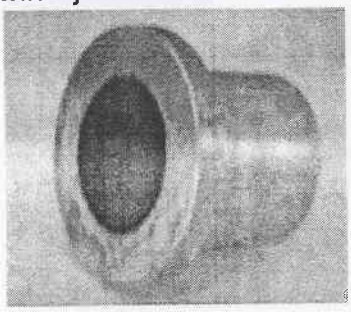
Shower Head Injector



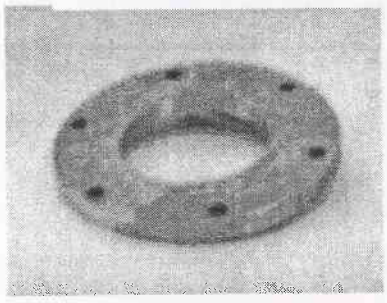
Swirl Injector SWA



Swirl Injector SWB

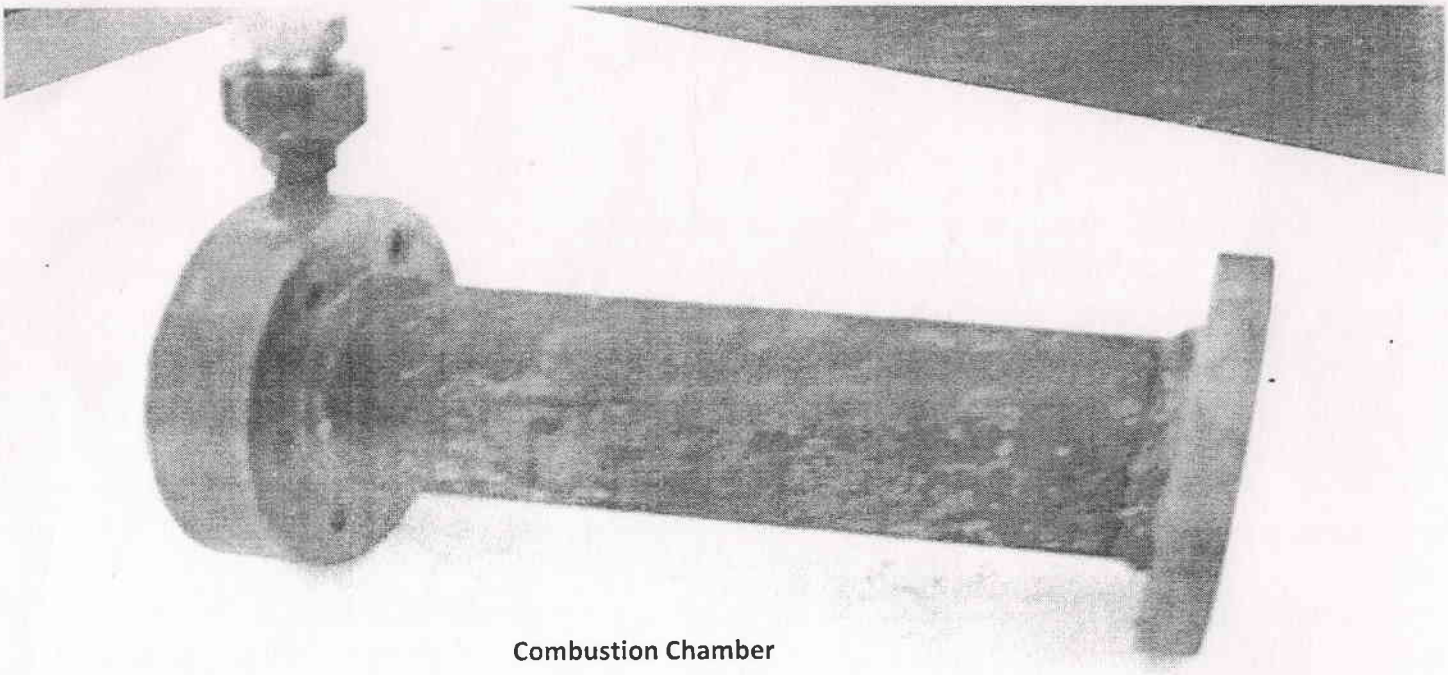


C-D Nozzle

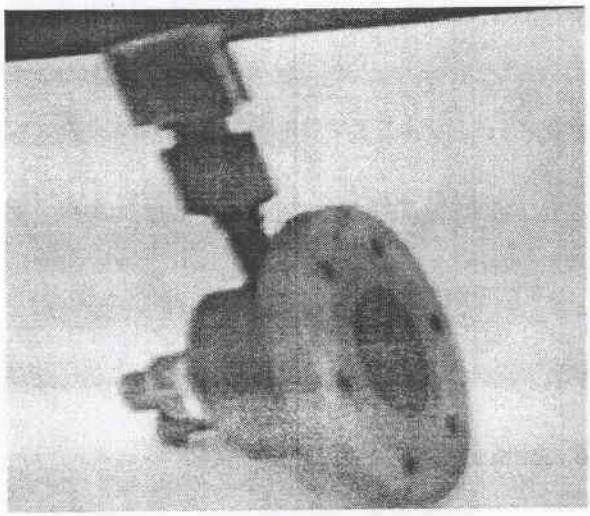


Nozzle Retainer Plate

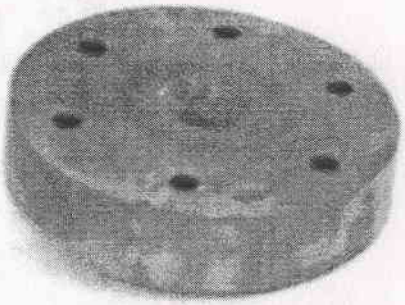
FIG. 16 : COOLED TEST MOTOR



Combustion Chamber



Oxidiser Chamber



Injector

FIG. 17 : UNCOOLED TEST MOTOR

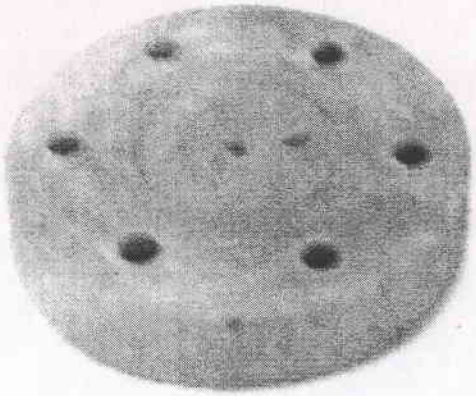


Fig.- 18A : Photograph showing Shower Head Injector

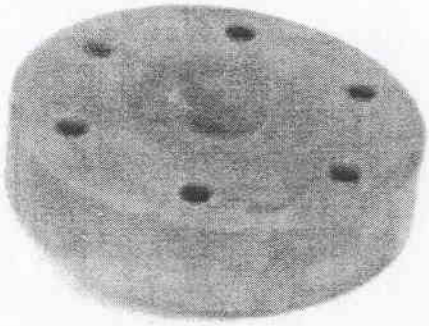


Fig.- 18B : Photograph showing Shower Head Injector

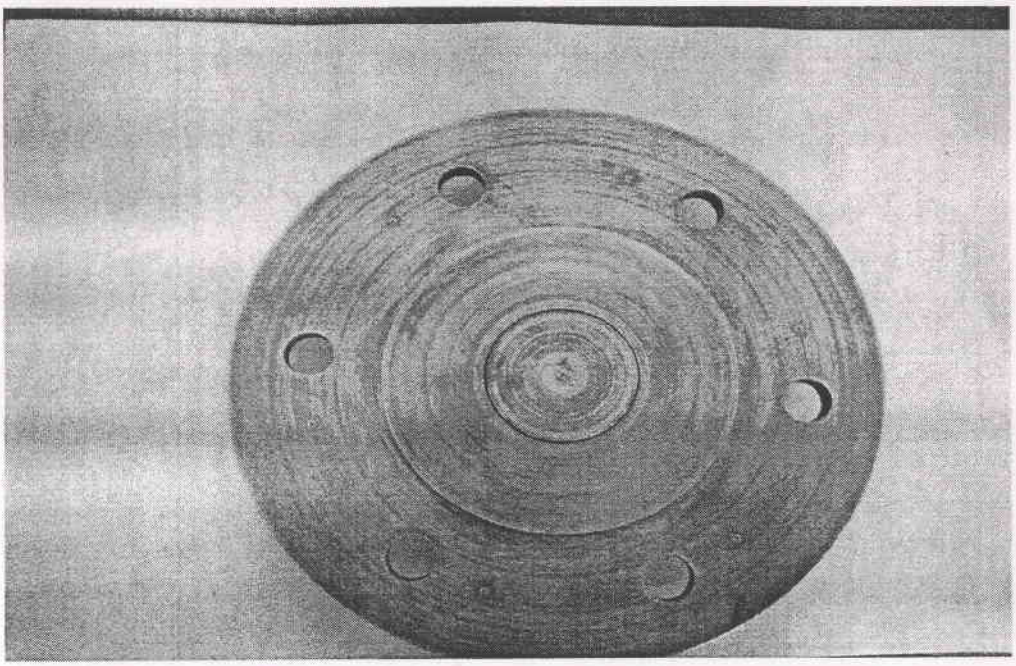


Fig.- 19A OXYGEN OUTLET SIDE OF SWIRL INJECTOR

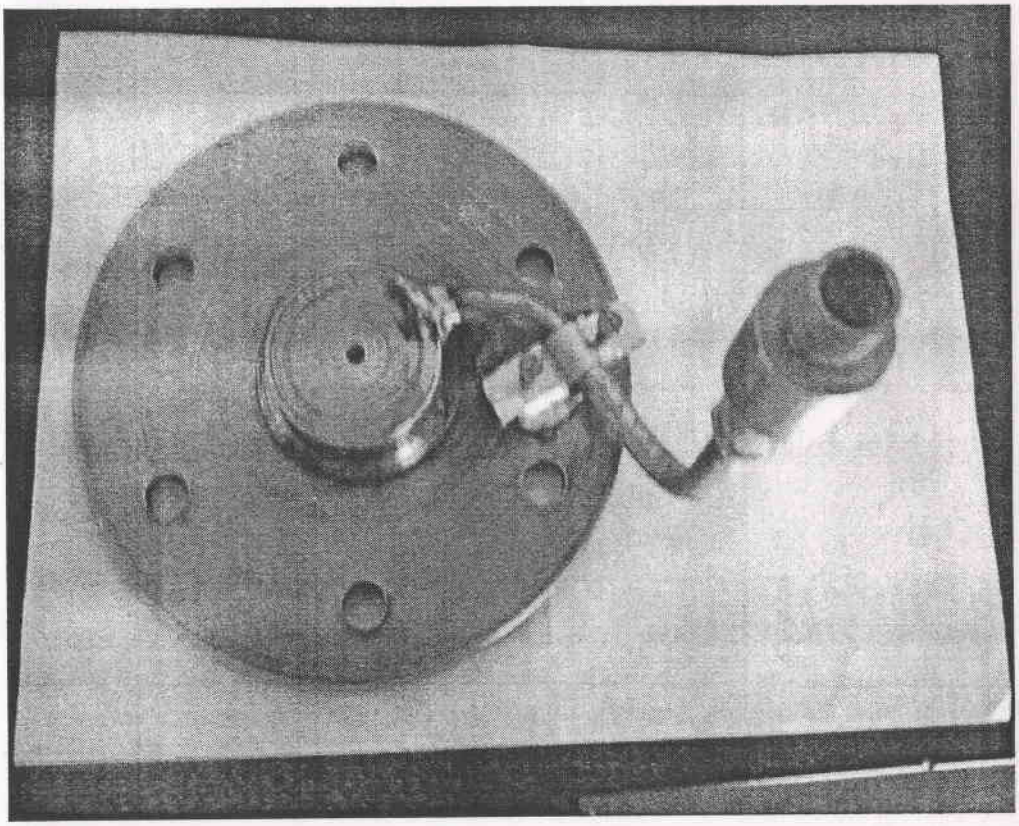


Fig.- 19B. OXYGEN INLET SIDE OF SWIRL INJECTOR

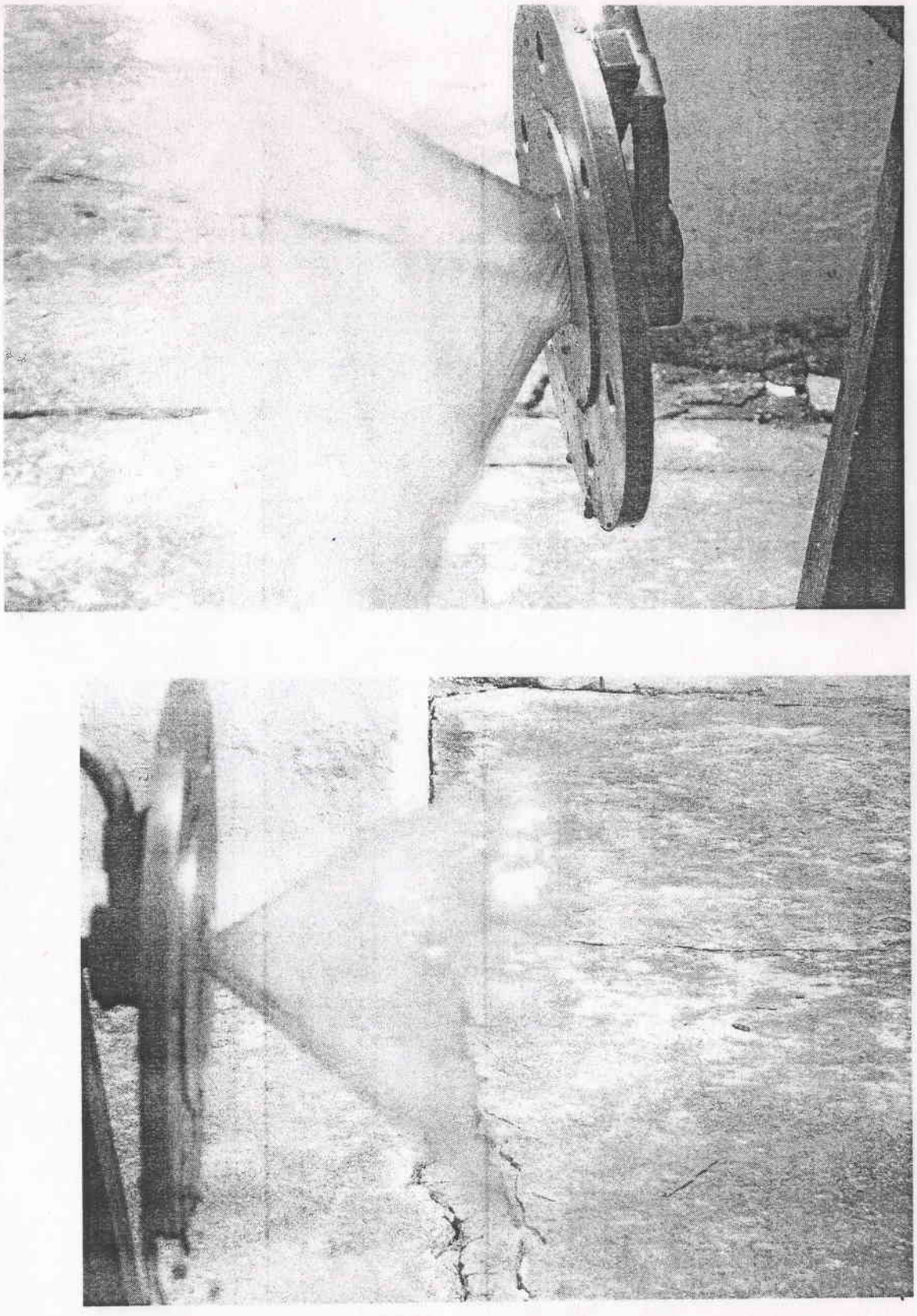


Fig. – 20 A&B WATER TESTING OF SWIRL INJECTORS

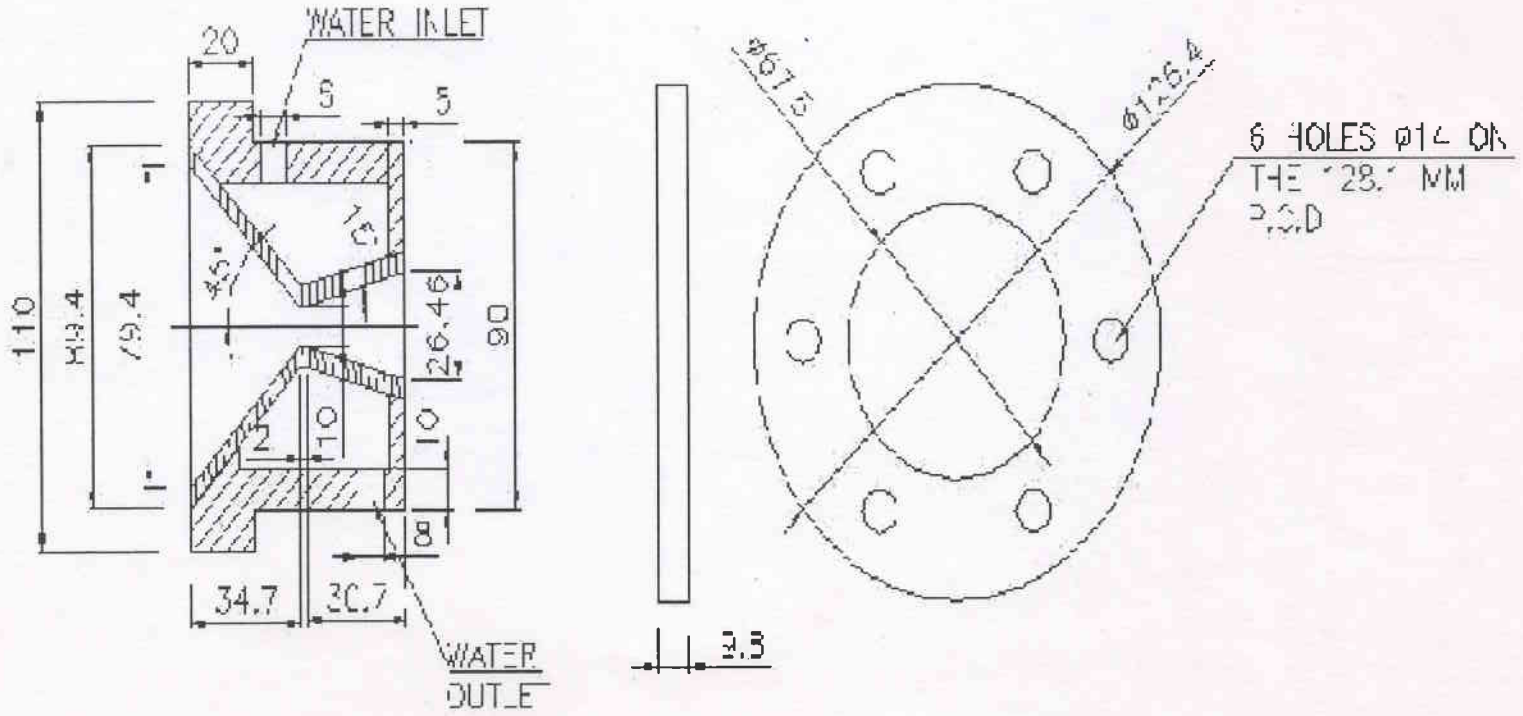


Fig. 21 : SCHEMATIC DIAGRAM OF NOZZLE AND NOZZLE RETAINER RING

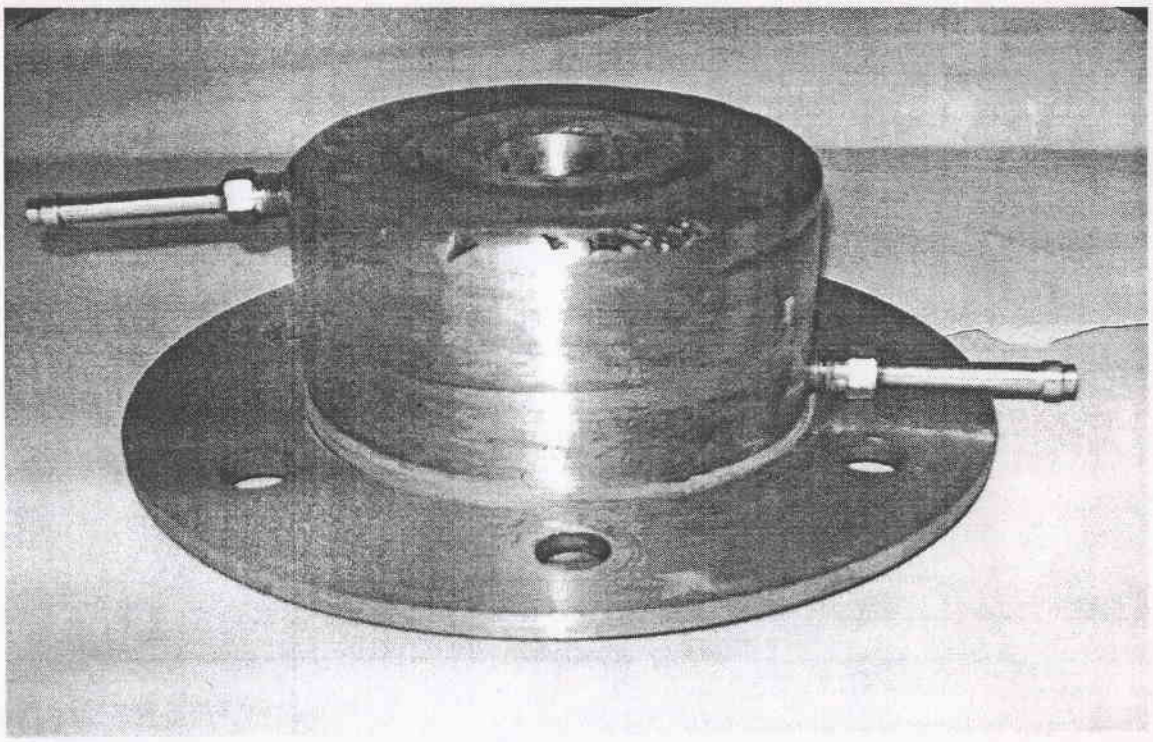
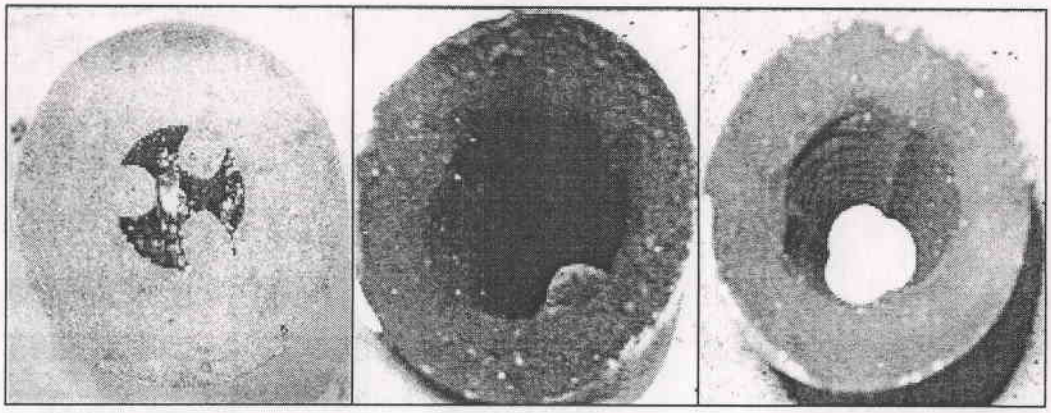
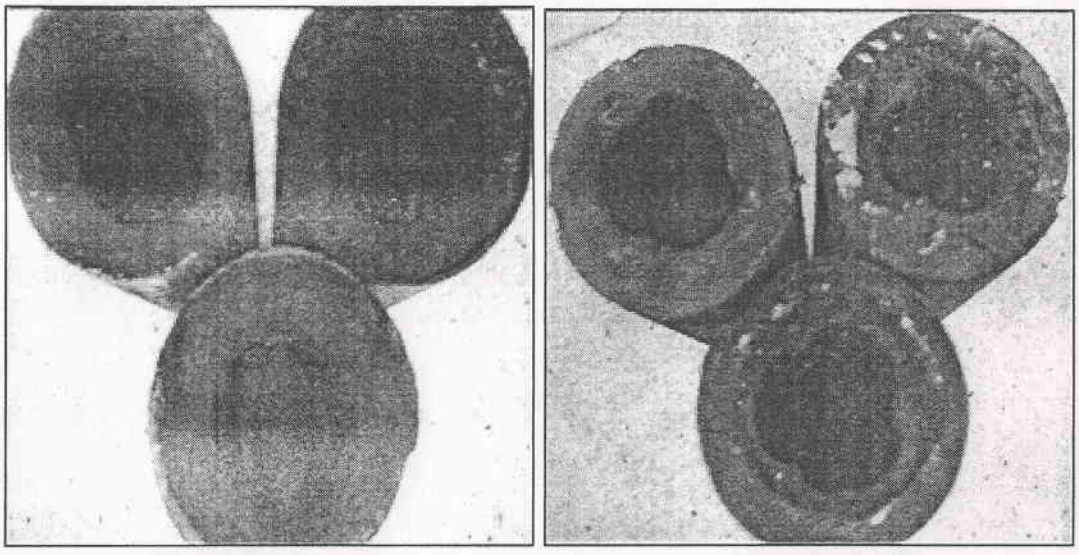


FIG. - 22 : NOZZLE ASSEMBLY



Before Firing | Head End | Nozzle End



Head End | Nozzle End

Fig. 23 : HEAD END AND NOZZLE GRAIN PORT SHAPES BEFORE AND AFTER FIRING

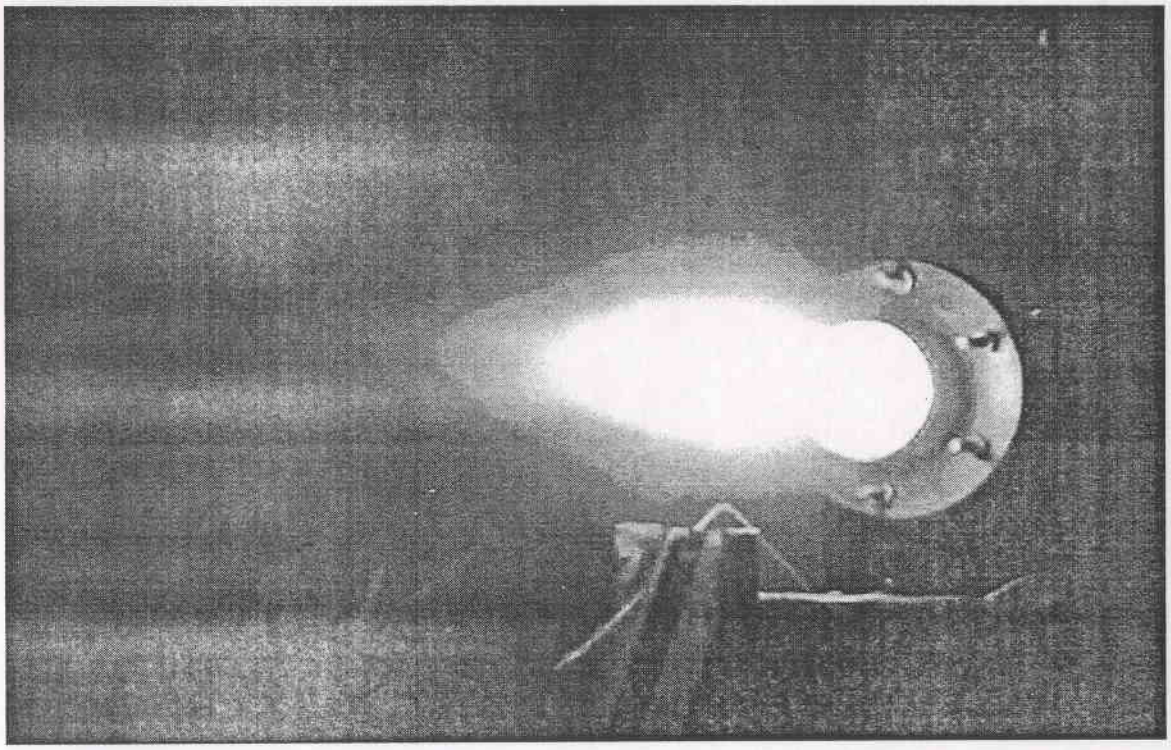


FIG. 24(A) : EXHAUST PLUME OF 50%HTPB-50%WAX WITH OXYGEN AT INJECTION PRESSURE 24.61 KSC

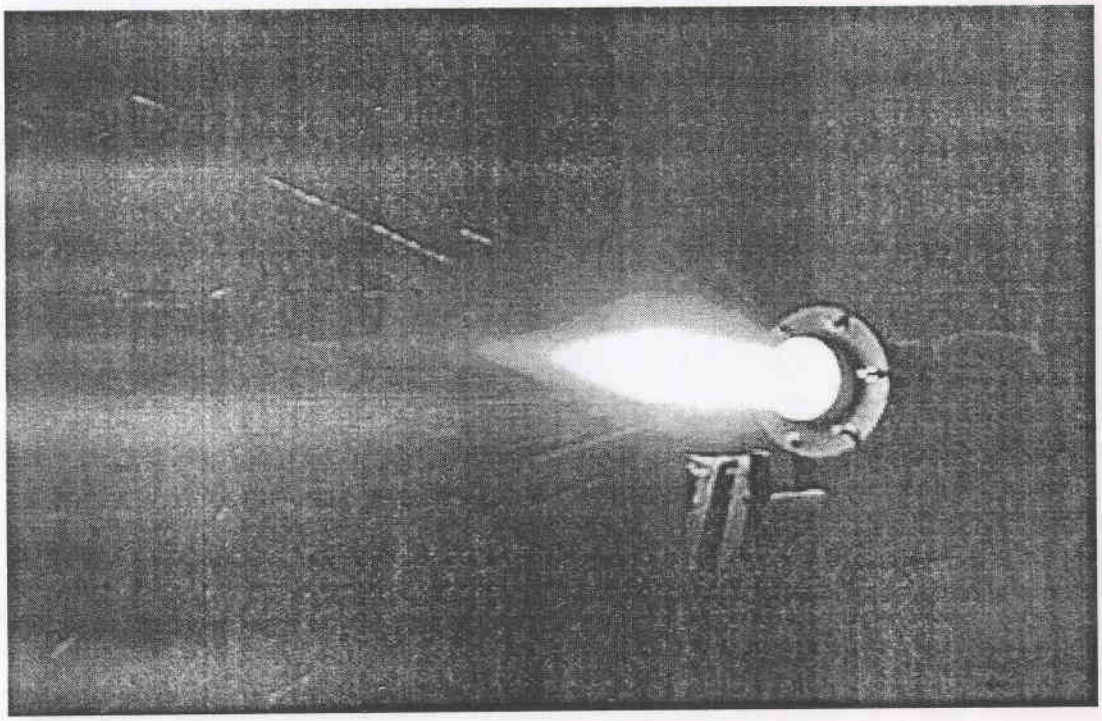


FIG. 24(B): EXHAUST PLUME OF 49.5%HTPB-49.5% PARAFFIN WAX- 1% CARBON BLACK WITH OXYGEN AT INJECTION PRESSURE 24.61 KSC

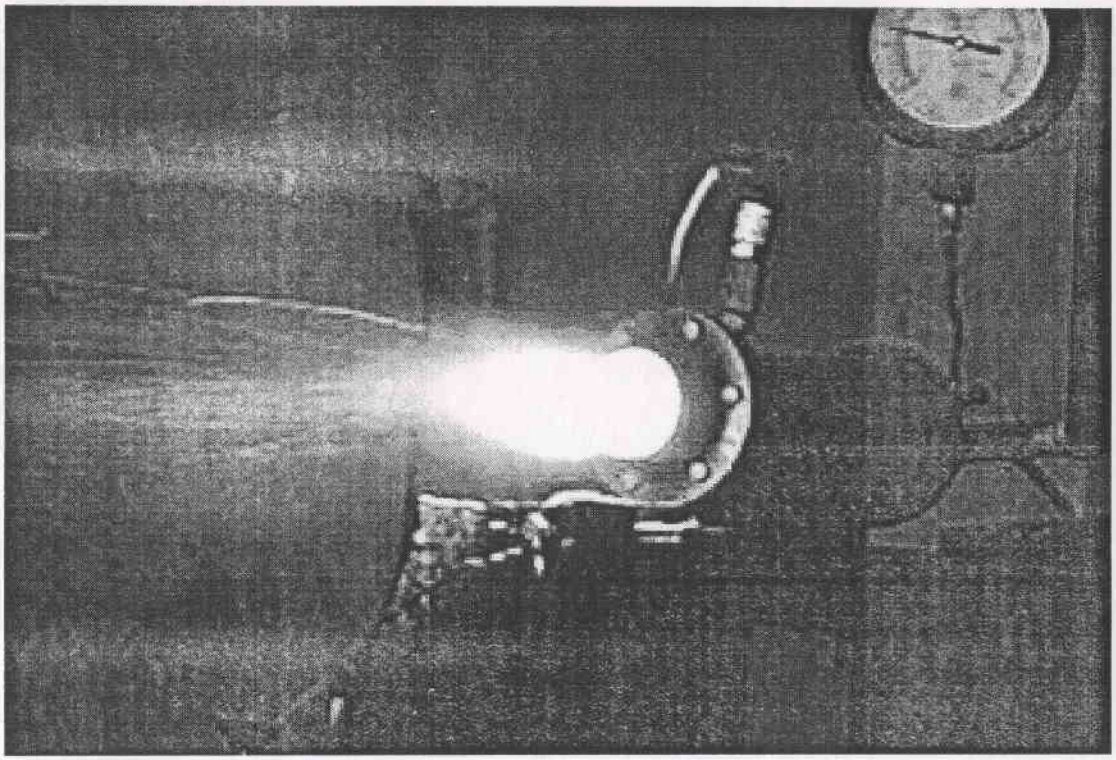


FIG. 24(C): Exhaust Plume of 49.5%HTPB-49.5% Paraffin Wax- 1% carbon black with nitrous oxide at injection pressure 28.12 ksc

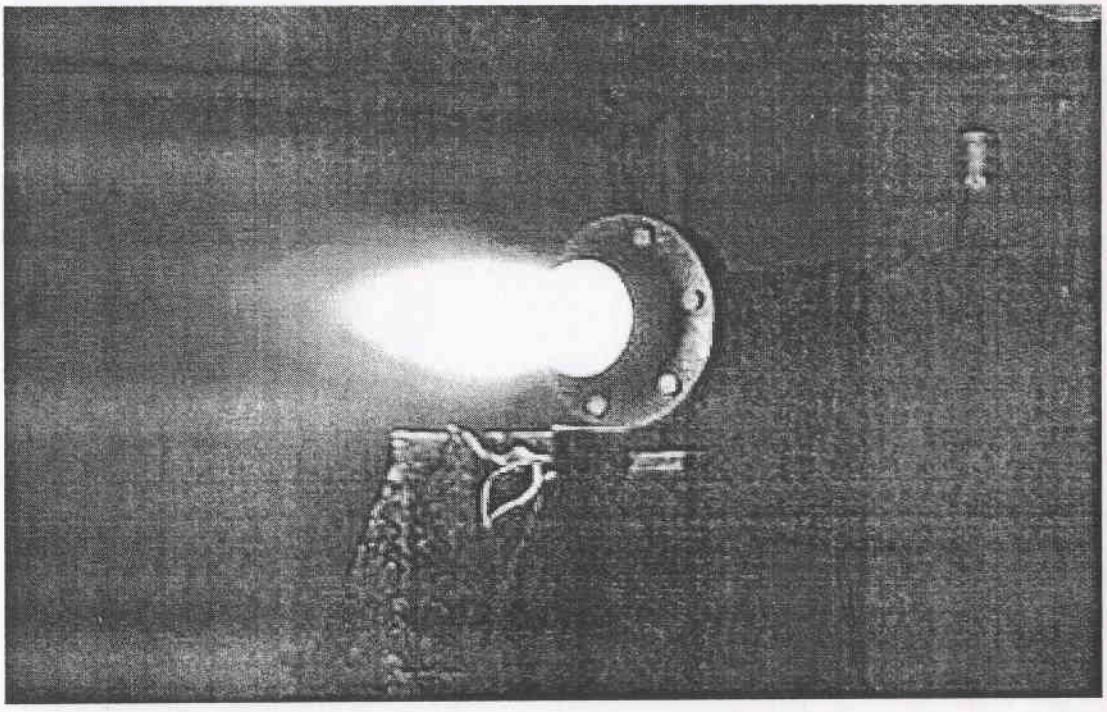


FIG. 24(D): Exhaust Plume of 49.5%HTPB-49.5% Paraffin Wax- 1% carbon black with nitrous oxide at injection pressure 35.15 ksc

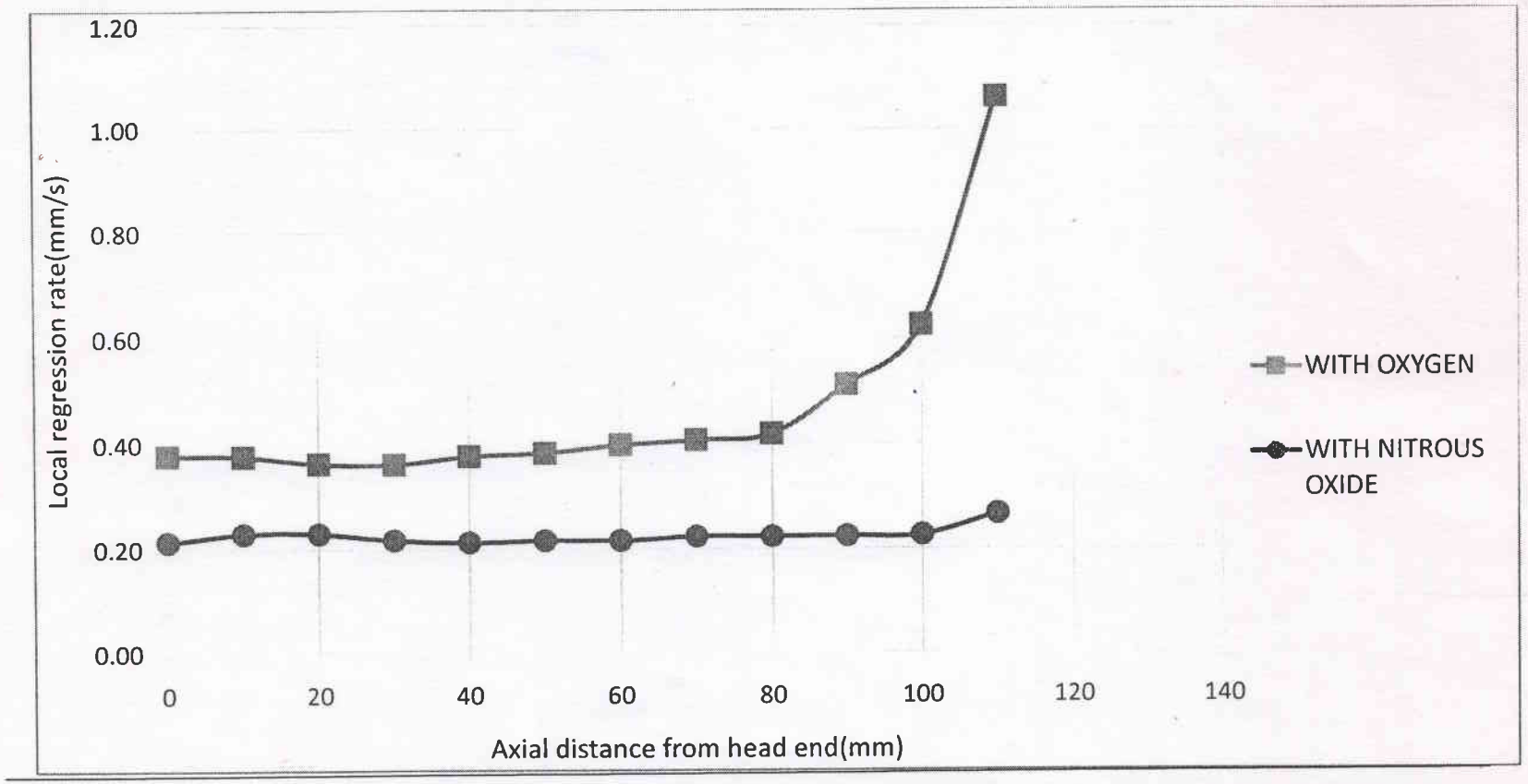


Fig. 25 : LOCAL REGRESSION RATE OF COMPOSITION-II AT 35.15KSC INJECTION PRESSURE

ANNEXURE – III

List of equipments received under UGC SAP (DRS – II)

Sl. No.	Equipment
1.	Pressure Transducers
2.	Thermal sensor
3.	Differential Pressure sensor
4.	Digital Pressure Gauge
5.	Xcitexione Software for high speed camera
6.	Flow meters
7.	Thrust Chamber Assembly
8.	Computer/ Printer/ UPS
9.	Pressure Regulator
10.	Thrust Transducer
11.	C C Camera
12.	ON- Off Valve Indicator Panel
13.	Manifold for Nitrogen Cylinders
14.	Cable ($1.5mm^2$, 3 Core, 1.5 mm^2 , 2 core)
15.	Load cell indicator
16.	Oriface Type Digital Flow Meter with Flow Indicator And Totalizer
17.	Temperature Indicator Panel

ANNEXURE – IV

NATIONAL/ INTERNATIONAL SEMINARS CONFERENCES ORGANISED (2007-13)

1. National Seminar on Recent Advances in Energy Systems & Combustion Processes, Feb 14 – 16, 2007

   Convenor : Dr. A. K. Chatterjee
   Organising Secretary : Dr. P. C. Joshi

2. 34th National Conference on Fluid Mechanics and Fluid Power, Dec 10 – 12, 2007

   Convenor : Dr. A. K. Chatterjee
   Organising Secretary : Dr. J. K. Prasad

3. Twenty Second national Convention of Aerospace Engineers & National Seminar on Present Status and Technological Challenges of Indian Aerospace Programme, Nov 27 – 29, 2008

   Convenor : Dr. A. K. Chatterjee
   Organising Secretary : Dr. J. K. Prasad

4. Special Course on Propulsion and Aerodynamics, for 10 Officers of DRDL, Hyderabad, Dec 04 – 17, 2008.

5. 25th National Convention of Aerospace Engineers "Indian Aerospace Programmes : Technological Challenges beyond 2020". Nov. 04 -05, 2011

   Convenor : Dr. A. K. Chatterjee
   Organising Secretary : Dr. J. K. Prasad

ANNEXURE – V

Details of Faculty members

Name & Designation	Qualification	Specialisation	Remarks
Dr. A. K. Chatterjee Professor & Head	M. Sc. Engg., Ph. D.	Rocket Propulsion, Cryogenic Engg.	Superannuated in Sept. 2012
Dr. P. C. Joshi Professor	M. Sc., Ph. D.	Combustion, Rocket Propulsion	
Dr. M. Varma Professor	M. Sc., Ph. D.	Propellant Technology	
Dr. J. K. Prasad Professor	M. Tech. Ph. D.	Aerodynamics	
Dr. P. K. Das Lecturer	M. Tech, Ph. D.	Composite Materials, Propulsion (Left the Institute in July 2008)	
Dr. Sudip Das Asso. Professor	M. E., Ph. D.	Aerodynamics	
Mr. S. K. Ghosh Lecturer	M. Tech	Cryogenics (Feb. 2007 – March 2008)	
Ms. Nivedita Gupta Lecturer	M. Tech	Fuels & Combustion (Feb. 2007 – Aug 2007)	
Mr. Priyank Kumar Asst. Professor	M. E.	Aerodynamics	
Dr. Sumana Ghosh Asstt. Professor	M. Tech, Ph. D.	Rocket Propulsion, Cryogenic Engg. June 2012 – Nov. 2012	
Dr. Srinibas Karmakar Asstt. Professor	M. Tech, Ph. D.	Combustion, Rocket Propulsion (Sept. 2012 – June 2013)	

ANNEXURE – VI

PUBLICATION (2007- 13):

FOREIGN JOURNAL

Sl. No.	Author	Title	Journal	Date / Year
1	Chandan Guria Mohan Varma S. K. Gupta S. P. Mehrotra	Optimal Synthesis of an Industrial Fluorspar Beneficiation Plant using a Jumping Gene Adaptation of Genetic Algorithm	Int. J. of Mineral & Metallurgical Processing, 26, 2009, 174-190	2009
2	H. P. Tiwari P. K Banerjee R. Sharma P. C Joshi	Coal as Generator in arbonizations Process : A Comparison between Top charged and Stamp- charged Coke- making Processes",.	Journal of Fuels	2009
3	Mohan Varma Roland Pein	Optimization of Processing condition for Gel Propellant Production	International Journal of Energetic Materials and Chemical Propulsion, Vol. 8, (6) 2009, pp. 501- 513	2009
4	S. Das J. K. Prsad.	Starting Characteristics of a Rectangular Supersonic Air-Intake with Cowl Deflection	The Aeronautical Journal, Royal aeronautical Society, UK, 114 (2010) 177-189	2010
5	S. R. Nagaraja J. K. Prsad and G. Jagadeesh	Theoretical- experimental study of shock wave- assisted metal forming process using a diaphargmless shock tube	Journal of Aerospace Engineering	2011
6	S. R. Nagaraja J. K. Prsad and G. Jagadeesh	Theoretical- experimental study of shock wave- assisted metal forming process using a diaphargmless shock tube,	Journal of Aerospace Engineering, 12 (226) 2012, 1534-1543 (Proceedings of the Institution of Mechanical Engineers)	2012
7	S. R. Nagaraja S. G. Rakesh J. K. Prsad P. K. Barhai G. Jagadeesh	Investigations on micro- blast wave assisted metal foil forming for biomedical applications International	Journal of Mechanical Sciences, 1 (61) 2012 1-7	2012

National / Indian Journal

Sl. No.	Author	Title	Journal	Year
1	P. Omprakash Arnab Roy S. Das J. K. Prasad	Investigation of Incompressible Flow past a Two-Dimensional Wedge	Journal of Aerospace Sciences and Technologies, Vol. 59, No. 4, Nov 2007, pp. 229- 245.	2007
2	Das, S. Prasad, J. K	Cowl Deflection Angle in a Supersonic Air- Intake"	Defence Science Journal, Vol. 59, No. 2, pp. 99- 105, Mar 2009.	2009
3	S. Das J. K. Prasad.	Flow Field Investigation of a Rectangular Supersonic Air-Intake with Cowl Bending	Journal of Aerospace Sciences and Technologies, Vol. 61, No. 2, pp. 312 – 324, May 2009	2009
4	S. Das J. K. Prasad	Unstart Suppression and Performance Analysis of Supersonic Air- Intake Adopting Bleed and Cowl Bending	Journal of Institution of Engineers (India), 91, 2010 27-35.	2010
5	S. Das P. Kumar M. K. Ralh R. K. M. Rao J. K.Prasad	Drag reduction of a hemispherical body adopting spike at supersonic speed	Journal of Aerospace Sciences and Technologies, Vol. 65, No. 4, Nov 2013, pp. 313-325.	2013

Seminar/ Conference/ Workshop

Sl. No.	Author	Title	Conference / Seminar	Date / Year
1	Nivedita Gupta P. C. Joshi	Combustion Studies of Bio-diesel Droplets	National Seminar on Recent Advances in Energy Systems & Combustion Processes, B.I.T., Mesra, Feb 14- 16, 2007, pp. 155- 165.	2007
2	H. P. Tiwari P. K. Banerjee R. Sharma P. C. Joshi	A Combustion Evaluation of Taryield from Top charged and Stamp charged Coke making Processes	National Seminar on Recent Advances in Energy Systems & Combustion Processes, B.I.T., Mesra, Feb 14- 16, 2007, pp. 95- 100.	2007
3	Mohan Varma C. R. Chodankar	Design and Validation of a Premixed Swirl Burner for LPG - Air System	National Seminar on Recent Advances in Energy Systems & Combustion Processes, B.I.T., Mesra, Feb 14- 16, 2007, pp. 252- 263.	2007
4	Mohan Varma Ronald Pein	Optimization of Processing Conditions for Gel Propellant Production",	7th International Symposium on Special Topics in Chemical Propulsion, Kyoto, Japan, 2007.	2007
5	S. Das J. K. Prasad	Flow Field Simulations around a Reentry Capsule at Hypersonic and Supersonic Speeds	7th ACFD Conference, Bangalore Nov 26- 30, 2007.	2007
6	Mohan Varma Joshi Vivek C	Rheological Investigation on Gelled UDMH Fuel	High Energy Materials Conference & Exhibit, Tagore Engineering College, Chennai, Dec 13- 15, 2007	2007
7	B. Nath, S. Das J. K. Prasad	Investigation of Flow Field over Blunted Delta Wing	Symposium on Applied Aerodynamics and Design of Aerospace Vehicle (SAROD-2007), Thiruvanathapuram; Nov 22- 23, 2007.	2007
8	P. Kumar, A. Roy, S. Das and J. K. Prasad,	Experimental Investigation of Flow Field around Blunt Fins at Supersonic Speed	34th National Conference on Fluid Mechanics and Fluid Power, , BIT Mesra, Ranchi, Dec 10- 12, 2007	2007
9	S. Das and J. K. Prasad	Starting Characteristics of a Mixed Compression Supersonic Air-Intake	34th National Conference on Fluid Mechanics and Fluid Power, BIT Mesra, Ranchi, Dec 10- 12, 2007	2007
10	Mohd. Yousuf Ali, S. Das and J. K. Prasad,	Flow Field Studies on a Rectangular Air-Intake at Supersonic Speed	34th National Conference on Fluid Mechanics and Fluid Power, BIT Mesra, Ranchi, Dec 10- 12, 2007	2007
11	Sateesh Kr R. A. Roy, S. Das and J. K. Prasad	Ground effects on the Flow Field over a Typical Reusable Launch Vehicle	22nd National Conference of Aerospace Engineers", IIT Kanpur, Nov 16 - 17, 2007	2007
12	Sibani Das and P. K. Dash	Computational Simulation of Combustion Instability in SRM by Vortex Shedding Method	34th National Conference on Fluid Mechanics and Fluid Power, Dec 10- 12, 2007, BIT Mesra, Ranchi, pp. 182- 194.	2007
13	S. Das and J. K. Prasad	Characteristics of a Supersonic Air-Intake with Bleed	International Conference on Aerospace Science and Technology, Bangalore June 26- 28, 2008.	2008
14	S. Das and J. K. Prasad	Flow Field a Re-Entry Capsule at Supersonic Speeds	International Conference on Aerospace Science and Technology, Bangalore	2008

			June 26- 28 2008.	
15	S. Das and J. K. Prasad	Alleviation of Unstart of a Supersonic Intake Adopting Cowl Deflection and Bleed	12th Asian Congress of Fluid Mechanics, Daejeon, Korea, Aug 18-21, 2008	2008
16	S. Das and J. K. Prasad	Computation of Flow Field Re-Entry Capsule at Supersonic Speeds	12th Asian Congress of Fluid Mechanics, Daejeon, Korea, Aug 18-21, 2008	2008
17	J. K. Prasad S. Das	Investigation of Flow Field around Blunt Protrusions at Supersonic Speed	12th Asian Congress of Fluid Mechanics, Daejeon, Korea, Aug 18-21, 2008	2008
18	J. K. Prasad and S. Das	Effect of Mach Number on the Performance of a Mixed Compression Speed	Twenty Second National Convention of Aerospace Engineers & National Seminar on Present Status and Technological Challenges of Indian Aerospace Programme, B.I.T., Mesra, Ranchi, Nov 27- 29, 2008.	2008
19	S. Das J. K. Prasad D. N. Thakur S. Paneerselvan	Flow field on a Forebody of Hypersonic Research Vehicle at Supersonic Speed	Twenty Second National Convention of Aerospace Engineers & National Seminar on Present Status and Technological Challenges of Indian Aerospace Programme, B.I.T., Mesra, Ranchi, Nov 27- 29, 2008.	2008
20	S. Bogadi, S. Das, P. Kumar and J. K Prasad	Investigation of flow field around a Reentry Capsule at Supersonic Speed	Twenty Second National Convention of Aerospace Engineers & National Seminar on Present Status and Technological Challenges of Indian Aerospace Programme, B.I.T., Mesra, Ranchi, Nov 27- 29, 2008.	2008
21	P. Kumar, S. Das and J. K Prasad	Flow Field around Blunt Fin of different Thickness at Supersonic Speed	Twenty Second National Convention of Aerospace Engineers & National Seminar on Present Status and Technological Challenges of Indian Aerospace Programme, B.I.T., Mesra, Ranchi, Nov 27- 29, 2008.	2008
22	S. R. Nagaraja G. Jagadesh and J. K. Prasad	Experimental Investigation of Shock Wave Loaded Metal Plates"	Twenty Second National Convention of Aerospace Engineers & National Seminar on Present Status and Technological Challenges of Indian Aerospace Programme, B.I.T., Mesra, Ranchi, Nov 27- 29, 2008.	2008
23	R. Asokan P. K. Dash V. Arumugam A. J. Stanely	Application of AET on Damage Characterization of Single Lap Bonded Composite	Twenty Second National Convention of Aerospace Engineers & National Seminar on Present Status and Technological Challenges of Indian Aerospace Programme, B.I.T., Mesra, Ranchi, Nov 27- 29, 2008.	2008
24	B. V. S. Jyoti and M. Varma	Ignition of Combustion Studies of Gel Propellant	Proceedings of Twenty Second National Convention of Aerospace Engineers & National Seminar on Present Status and	2008

			Technological Challenges of Indian Aerospace Programme, B.I.T., Mesra, Ranchi, Nov 27- 29, 2008	
25	S. Das and J. K. Prasad	Effect of Incidence on Internal Shock Characteristics of a Mixed Compression Supersonic Air-Intake"	35th National Conference on Fluid Mechanics and Fluid Power, PES Institute of Technology, Bangalore, Dec 11- 13, 2008.	2008
26	A. K. Singh P. Kumar S. Das and J. K. Prasad	Flow Field Around Two Dimensional Multiple Cylinders at Subsonic Speed	Proceedings of 35th National Conference on Fluid Mechanics and Fluid Power, PES Institute of Technology, Bangalore, Dec 11- 13, 2008.	2008
27	P. Kumar S. Das and J. K Prasad	Effect of Reynolds Number over a Blunted Delta wing at Subsonic Speed	35th National Conference on Fluid Mechanics and Fluid Power, PES Institute of Technology, Bangalore, Dec 11- 13, 2008	2008
28	B. Nath S. Das and J. K Prasad	Flow Field Study on a 65deg. Blunted Delta Wing	CP-6, National Conference on Wind Tunnel Testing (NCWT-20), Bangalore, Mar 12- 14, 2009.	2009
29	S. Das and J. K Prasad	Effect of Cowl Bending and Bleed on the starting characteristics of a Supersonic Air Intake .	CP-7, National Conference on Wind Tunnel Testing (NCWT- 20), Bangalore, Mar 12- 14, 2009.	2009
30	S. R. Nagaraja S. G. Rakesh G. Jagadeesh P. K. Barhai J. K. Prasad	Studies on formation of metal foils for bio medical application of shock waves	27th International Symposium on Shock Waves, Russia, July 2009.	2009
31	Lovely Mallick, Mohan Varma	Laser Induced Ignition of Virgin, Metalized and Catalyzed HTPB-AP Composite Solid Propellants	7th International High Energy Materials Conference and Exhibits, Pune, Dec. 08 – 10, 2009	2009
32	J. Sreenivasulu S. K. Epuri P. Kumar S. Das J. K. Prasad	Experimental and Computational Studies over a Blunt Double Delta wing	Symposium on Applied Aerodynamics and Design of Aerospace Vehicle (SAROD 2009), Bangalore, December 10 – 12, 2009	2009
33	S. Das J. K. Prasad	Unsteadiness in Supersonic Air-Intake at Supercritical Condition	Symposium on Applied Aerodynamics and Design of Aerospace Vehicle (SAROD 2009), Bangalore, December 10 – 12, 2009	2009
34	J. Sreenivasulu S. Das P. Kumar J. K. Prasad	, Investigation of Flow Field Over a Blunt Double Delta Wing,	36th National Conference on Fluid Mechanics and Fluid Power, College of Engineering, Pune, Dec 17–19, 2009	2009
35	M. Ramakrishna, P. Kumar S. Das J. K. Prasad	Computational and Experimental Studies on Slender Body at Large Angles of Attack	36th National Conference on Fluid Mechanics and Fluid Power, College of Engineering, Pune, Dec 17–19, 2009	2009
36	S. Das	Studies on Soft Unstart of	36th National Conference on Fluid	2009

	J. K. Prasad	Supersonic Air- Intake	Mechanics and Fluid Power, College of Engineering, Pune, Dec 17–19, 2009	
37	M. Ramakrishna P. Kumar S. Das J. K. Prasad	Investigation of flowfield on slender body at high angles of attack	Symposium on Applied Aerodynamics and Design of Aerospace Vehicle (SAROD 2009), Bangalore, Dec. 10 – 12, 2009	2009
38	S. K. Epuri P. Kumar S. Das J. K. Prasad	Flow Field over a Reusable Launch Vehicle at Subsonic Speed	37th National & 4th International Conference on Fluid Mechanics and Fluid Power, FMFP 2010, IIT Madras, Chennai, December 16-18, 2010.	2010
39	S. Das J. K. Prasad	Behaviour of Flow Unsteadiness in a Supersonic Air-Intake with Throttles	37th National & 4th International Conference on Fluid Mechanics and Fluid Power, FMFP2010, IIT Madras, Chennai, December 16-18, 2010.	2010
40	R. Madhav Sen P. Kumar S. Das J. K. Prasad	Effect of angle of attack on slender body at subsonic speed	37th National & 4th International Conference on Fluid Mechanics and Fluid Power, FMFP2010, IIT Madras, Chennai December 16-18, 2010.	2010
41	Revanth Reddy L. Mallick and A. K. Chatterjee	The Effect of TiO_2 on Burning Rate and Thermal Decomposition on Composite Solid Propellant	National Seminar & Conference on Recent Trends in the Role of catalyst in Industry, Laxmi Narain College of Technology, Indore, Aug 18 – 20, 2011.	2011
42	Revanth Reddy L. Mallick and A. K. Chatterjee	Mechanistics, Rheological and & Atomization Studies of RFNA Gel	National Seminar & Conference on Recent Trends in the Role of catalyst in Industry, Laxmi Narain College of Technology, Indore, Aug 18 – 20, 2011.	2011
43	Pratim Kumar Dr. P.C. Joshi	Combustion studies of solid propellants at subatmospheric pressure"	National multi-conference on contemporary global trends in technology and management, Aug. 18-20, 2011, Lakshmi Narain College of Technology.	2011
44	A. Manash L. Mallick and A. K. Chatterjee	Thermal decomposition and burning rate study of AP- HTPB based composite solid propellants	25th National Convention of Aerospace Engineers (NCAE 2011), BIT Mesra, Ranchi Nov 4 – 5, 2011.	2011
45	A. M. Nagarajeswaran L. Mallick and A. K. Chatterjee	The Effect of Catalyst on Burning Rate and Thermal Decomposition of Solid Propellants	25th National Convention of Aerospace Engineers (NCAE 2011), BIT Mesra, Ranchi Nov 4 – 5, 2011.	2011
46	R. Reddy L. Mallick and A. K. Chatterjee	Mechanistic, Rheological and Atomization Studies of Kerosene Gel	25th National Convention of Aerospace Engineers (NCAE 2011), BIT Mesra, Ranchi, Nov 4 – 5, 2011.	2011
47	D. Shashikala and P. C. Joshi	Combustion Studies of HTPB-Shellac Fuel in the Gaseous Oxidizer	25th National Convention of Aerospace Engineers (NCAE 2011), BIT Mesra, Ranchi, Nov 4 – 5, 2011	2011
48	M. K. Ralh, R. Krishna Mohan Rao, S. Das, P. Kumar and J. K. Prasad	Effect of Spike Shapes on Drag of Hemispherical Body at Supersonic and Hypersonic Speed	25th National Convention of Aerospace Engineers (NCAE 2011), BIT Mesra, Ranchi, Nov 4 – 5, 2011.	2011
49	Rohit R. P. Kumar	Flow Field in the Interference Region of Multi Body at	25th National Convention of Aerospace Engineers (NCAE 2011), BIT Mesra,	2011

	S. Das and J. K. Prasad	Supersonic Speed	Ranchi, Nov 4 – 5, 2011.	
50	P. S. Vignesh R. S. Das P. Kumar and J. K. Prasad	Flow Field Investigation on Cylindrical Protrusion of Different Heights with Vortex Generator at Supersonic Speed"	25th National Convention of Aerospace Engineers (NCAE 2011), BIT Mesra, Ranchi, Nov 4 – 5, 2011	2011
51	S. Karthikeyan P. Kumar, S. Das and J. K. Prasad	Effect of Fuselage on Reusable Launch Vehicle at Subsonic Speed	25th National Convention of Aerospace Engineers (NCAE 2011), BIT Mesra, Ranchi, Nov 4 – 5, 2011.	2011
52	V. Jagadish Babu, P. Kumar S. Das and J. K. Prasad	Effect of Notched Cowl Field Inside a Supersonic Air- Intake	Fifth Symposium of Applied Aerodynamics and Design of Aerospace Vehicle (SAROD – 2011), Eagleton Resorts, Bangalore, Nov 16-18, 2011.	2011
53	N. Kannamanimuthu S. Das, P. Kumar and J. K. Prasad	Flow Field around a Blunt Body with Spike at Supersonic Speed	Fifth Symposium of Applied Aerodynamics and Design of Aerospace Vehicle (SAROD – 2011), Eagleton Resorts, Bangalore, Nov 16-18, 2011.	2011
54	P. Kumar Ch. Srikanth S. Das and J. K. Prasad	Effect of Trips on Side Force on Slender Body at Large Angles of Attack	Fifth Symposium of Applied Aerodynamics and Design of Aerospace Vehicle (SAROD – 2011), Eagleton Resorts, Bangalore. Nov 16-18, 2011.	2011
55	P. S. Vignesh Ram S. Das, P. Kumar and J. K. Prasad	Influence of Vortex Generator on Flow Field Around Cylindrical Protrusion at Supersonic Speed	38th National Conference on Fluid Mechanics & Fluid Power, NIT, Bhopal, Dec 15-17, 2011.	2011
56	M. Venkatesan N. Kannamanimuthu S. Das, P. Kumar and J. K. Prasad	Flow Field Investigation over a Hemispherical Blunt Body with Different Spikes at Supersonic Speed	38th National Conference on Fluid Mechanics & Fluid Power, NIT, Bhopal, Dec 15-17, 2011.	2011
57	M. S. Chenji P. Kumar S. Das and J. K. Prasad	Effect of Control Deflection on the Aerodynamics of Reusable Launch Vehicle at Subsonic Speed	National Conference on Space Transportation Systems ; Opportunities and Challenges, VSCC, (ISRO) Thiruvanathapuram, Dec 16-18, 2011.	2011
58	N. Wang, J. Hanberry S. Karmakar S. Acharya and K. M. Dooley	BoronComposite Nanoparticles for Enhancement of Biofuel Combustion 2012	AIChE Meeting Aug. 2012	2012
59	S. K. Karthick S. Das P. Kumar and J. K. Prasad	Aerodynamics and performance of a projectile in ground proximity at supersonic	ISTAM, Pune, Dec. 2012	2012
60	David N P. Kumar S. Das and J. K. Prasad	Investigation of Unsteady Flow across Double Delta Wing at Subsonic Speed	26th National Convention of Aerospace Engineers, AP State Centre, Hyderabad, Nov. 23-25, 2012.	2012
61	V. Jagadish Babu P. Kumar S. Das and J. K. Prasad	Studies of Supersonic Air-Intake with Notched Cowl	26th National Convention of Aerospace Engineers, AP State Centre, Hyderabad, Nov. 23-25, 2012.	2012

62	S. K. Karthick S. Das P. Kumar and J. K. Prasad	Effect of ground proximity on the trajectory of a bullet at supersonic speed	26th National Convention of Aerospace Engineers, AP State Centre, Hyderabad, Nov. 23-25, 2012.	2012
63	Senthil Kumar S. Das P. Kumar and J. K. Prasad	Investigation of flow field around a typical reentry capsule at Supersonic Speed	26th National Convention of Aerospace Engineers, AP State Centre, Hyderabad, Nov. 23-25, 2012.	2012
64	N. K. Gahlot P. Kumar S. Das and J. K. Prasad	Flow Field Studies of a Supersonic Air-Intake with Vortex Generators	39th Conference on Fluid Mechanics and Fluid Power, SVNIT, Surat, Gujarat, Dec. 2012.	2012
65	S. Puja S. Das P. Kumar and J. K. Prasad	Effect of bluntness on the reduction of drag using a spike at supersonic speed	39th Conference on Fluid Mechanics and Fluid Power, SVNIT, Surat, Gujarat, Dec. 2012	2012
66	S. J. Sivabharaty P. Kumar S. Das and J. K. Prasad	Effect of Apex flap deflection on double delta wing at subsonic speed	39th Conference on Fluid Mechanics and Fluid Power, SVNIT, Surat, Gujarat, Dec. 2012.	2012
67	Pratim Kumar	Application of mathematical tools for predicting the burning rate of solid propellant: a review	National Conference on Recent Trends in Mathematics and Their Applications, Vinobha Bhave University, Hazaribagh Dec 21-22, 2012	2012
68	G. K. Prashant D. B. Lata P. Leela, and P. C. Joshi	Experimental study on various parameters of a single droplet Ethanol, Methanol and its mixtures"	International Proceedings, 9th Asia pacific Conference on Combustion, South Korea May 2013	2013
69	J. Sinha S. Das P. Kumar J. K.Prasad	Studies on an Axisymmetric supersonic Cavity with Front Wall Inclinations	Int. proceeding of 15th Annual CFD Symposium, 2013, IISc Bangalore	2013
70	P. Kumar and J. K. Prasad	Investigation of side force on slender body with trip at a large angle of attack at subsonic speed	3rd National Conference on Wind Tunnel Testing, VSSC, Trivandrum, August 2013	2013
71	Deepan J S. Das P. Kumar and J. K. Prasad	Flow field around cylindrical protrusion with vortex generators at supersonic speed	3rd National Conference on Wind Tunnel Testing, VSSC, Trivandrum, August 23-23, 2013	2013
72	D. Sahoo S. Das P. Kumar and J. K. Prasad	Steady and unsteady flow over spiked blunt body at supersonic speed"	14th Asian Congress of Fluid Mechanics (14 ACFM), Hanoi, Vietnam, October 15-19, 2013	2013
73	P. Kumar and J. K. Prasad	Effect of reynolds number on flowfield over a slender body at high angles of attack at subsonic speed	27th National convention of Aerospace Engineers, Institution Engineers, Dehradun, November 2013	2013
74	J. Yuvaprakash P. Kumar	Investigation of flow field on double delta wing with sharp	27th National convention of Aerospace Engineers, Institution Engineers,	2013

	S. Das and J. K. Prasad	leading edge at subsonic speed	Dehradun, November 2013.	
75	P. Kumar and J. K. Prasad	Effect of height of trip on the side force over a slender body at subsonic speed	6th International Conference Symposium on Applied Aerodynamics and Design of Aerospace Vehicles, Hyderabad, November 2013	2013
76	D. Sahoo S. Das P. Kumar and J. K. Prasad	Effect of Spike Length on Steady and Unsteady Flow Over a Spiked Blunt Body at Supersonic Speed	6th International Conference Symposium on Applied Aerodynamics and Design of Aerospace Vehicles, Hyderabad, November 2013	2013
77	M. Kiran Kumar and P. C. Joshi	Combustion study of AP mixed paraffin wax hybrid fuel with gaseous nitrous oxide N_2O	6th International Conference Symposium on Applied Aerodynamics and Design of Aerospace Vehicles, Hyderabad, November 2013.	2013
78	P. Kumar and J. K. Prasad	Effect of location of circular trip on slender body flowfield at high angles of attack at subsonic speed	40th National Conference on Fluid Mechanics and Fluid Power, NIT Hamirpur, December 2013	2013
79	G. Chopra S. Das P. Kumar and J. K. Prasad	Investigation of Flowfield inside a Supersonic Air-Intake with 3-D Bump	40th National Conference on Fluid Mechanics and Fluid Power, NIT Hamirpur, December 2013	2013
80	Prem D. S. Das P. Kumar and J. K. Prasad	Flow field over a reentry capsule with ventilation at supersonic speed	40th National Conference on Fluid Mechanics and Fluid Power, NIT Hamirpur, December 2013	2013

M.E. THESIS ON HYBRID (2007-13)

Shelly Biswas	Combustion Studies on Shellac based Hybrid Fuel	Dr. P. C. Joshi	2007
Anil Kumar Yadav	Effects of Swirling GOX Injection in Hybrid Rocket Regression Rate Behavior	Dr. A. K. Chatterjee	2007
Equbal Hassan	Combustion studies of HTPB and HTPB- Shellac Hybrid Fuel	Dr. P. C. Joshi	2009
Tribikram Chattaraj	Combustion Studies of HTPB- Shellac fuel grain in gaseous oxygen injected through a swirl injector	Dr. P. C. Joshi	2010
Doma Shashikala	Effect of AP and Al on the combustion of HTPB Shellac Hybrid Fuel in Gaseous Oxidiser	Dr. P. C. Joshi	2011
Siva Ramakrishna P.	Combustion instabilities in hybrid rocket motor	Dr. P. C. Joshi	2011
C. Nandha Kumar	Development and analysis of multi perforated solid fuel grains using oxidizer for the hybrid rocket technology	Dr. A. K. Chatterjee	2011
Sandeep Patnala	Hybrid Rocket Combustion of paraffin fuel and N_2O oxidizer	Dr. P. C. Joshi	2011
Ravi Shankar	Combustion Studies of HTPB- Wax Hybrid Fuel with Nitrous Oxide and Oxygen Oxidizer	Dr. A. K. Chatterjee	2012
Jiju R. Justus	Combustion Steady of Beeswax and Gaseous Oxygen in a Hybrid Rocket System	Dr. P. C. Joshi	2012

Sonal Singh	Experimental Investigation on Regression Rate of Paraffin Wax- Nitrous Oxide Hybrid System	Dr. P. C. Joshi	2012
Prateek Chaturvedi	Combustion Studies of Vortex Hybrid Rocket Engine	Dr. A. K. Chatterjee	2012
Prakhar Jindal	Regression Rate Studies of Hybrid Rocket Using Vortex Injectors	Dr. A. K. Chatterjee	2013
Parthiban S.	Conventional Hybrid Fuel Regression Rate Augmentation Studies Using a Catalyst	Dr. A. K. Chatterjee	2013
Bharathi Raja R.	Experimental Investigation on Regression Rate of Paraffin Wax- HTPB Fuel with Gaseous Nitrous Oxide Hybrid System	Dr. P. C. Joshi	2013
Magesh V	Regression Rate Studies with Incorporation of Metal Mesh in Hybrid Fuel Grain	Dr. A. K. Chatterjee	2013
Anandha Kumara Swamy M.	Regression Rate Studies of Hybrid Fuel Using Helical Port Configuration	Dr. A. K. Chatterjee	2013
M Kiran Kumar	Combustion Studies of AP Mixed Paraffin Wax Hybrid Fuel with Gaseous Nitrous Oxide	Dr. P. C. Joshi	2013
Hema Bushan K.	Regression Rate Studies of Multi perforated Fuel grains in a Hybrid Propulsion System	Dr. A. K. Chatterjee	2013
Sri Nithya Mahottamananda	Combustion Study of HTPB- Sugar Hybrid Fuel with Gaseous Oxygen	Dr. P. C. Joshi	2013
N. S. Sahana	Experimental investigation on Hybrid combustion of paraffin Wax- HTPB Fuels with Gaseous Oxygen and Nitrous Oxide	Dr. P. C. Joshi	2014
S. Elaya Kumar	Combustion study of HTPB-Paraffin wax-AP Fuels in Gaseous Oxygen and Nitrous Oxide	Dr. P. C. Joshi	2014
Jhumki Nandy	Development of Paraffin based fuels for hybrid rocket motor	Dr. P. C. Joshi	2014
M Priyadharshini	Regression rate studies of paraffin wax-gaseous nitrous oxide hybrid propellant using swirl injector	Dr. P. C. Joshi	2014

ANNEXURE – VII

Resource person invited (2007-13)

Name of the Expert	Expert Organisation	Expert From Academic/ Industry	Topic of Lecture	Date of Visit (MM/DD/YY)
V. Kanagarajan Ex. Deputy Director	NAL, Bangalore	Industry	Measurement Techniques in Fluid Mechanics	Oct. 01 -6, 2007
Dr. Kunal Ghosh	IIT, Kanpur	Academic	Power Control and Strom Devices for Wind Turbine	July 23, 2010
Padmashri R. M. Vasagam Chairman NDRF, IE(I)	NDRF, IE(I)	Industry	Future Space Programme of India	Sept. 27, 2010
Dr. G. Jagadeesh	IISc., Bangalore	Academic	Enchanting Shock Waves: Experience at IISc	Feb. 22, 2011
Dr. Channa Raju Asstt. Director	NAL, Bangalore	Industry	Pressure Measurement using Pressure Sensitive Paint Technique	Feb. 25, 2011
Er. R. Krishna Mohan Rao, Scientist 'F'	DRDL, Hyderabad	Industry	Aerodynamics of Missiles	Apr.-02, 2011
Er. Yogesh Bhumkar SRF	IIT, Kanpur	Academic	Computation of flow field using parallel computation technique	Aug. 04, 2011
Dr. S. Mittal Professor	IIT, Kanpur	Academic	Application of High Performance Computation for Fluid Flow	Nov. 23, 2011
Dr. R. K. Gupta Project Director, AGNI	DRDO, Hyderabad	Industry	Design of Indian Missiles and Systems	Jan. 23, 2013
Dr. K. P. J. Reddy Professor	IISc., Bangalore	Academic	Activities of IISc Bangaore in the field of Aerospace Engineering	Feb. 25, 2013
Dr. K. P. Sinhamahapatra Professor & Head Dept. of Aerospace Engg.	IIT, Kharagpur	Academic	Large Eddy Simulation of Flow over a Cavity	Mar. 9, 2013