DEVELOPMENT OF
CRYOGENIC PROPULSION SYSTEM

PROJECT UNDER

SPECIAL ASSISTANCE PROGRAMME
(DRS)

PROGRESS REPORT FOR FINAL REVIEW

SUBMITTED TO
UNIVERSITY GRANTS COMMISSION

DEPARTMENT OF SPACE ENGINEERING AND ROCKETRY

BIRLA INSTITUTE OF TECHNOLOGY

MESRA : RANCHI

ज्ञान-विज्ञानं विमुक्तये

UNIVERSITY GRANTS COMMISSION
NEW DELHI

PROGRESS REPORT FOR FINAL REVIEW UNDER SAP (DRS)

Date of first approval with level at inception: 1.4.2002

Name of the University: Birla Institute of Technology, Mesra, Ranchi

Date of implementation of current phase as noted by: (Phase I): 01. 04. 2002

Name of the Department: Department of Space Engineering & Rocketry

Status (DRS Period of Report: From 1.4.2002 to 31.3.2007 with phase I):

	NR	R	Total
Amount allocated for 5 years:	37, 00,000/-	12, 00,000/-	49, 00,000/-
Amount sanctioned during the year (2001-02):	37, 00,000/-	1, 90,000/-	38, 90,000/-
Amount utilized upto 31.03.2007:			33, 52,440.44
Date of first sanction: 21.03.2002 (Current phase)			
Total grants received since inception:			38, 90,000/-

Coordinator's Name: Dr. A. K. Chatterjee
Dy. Coordinator's Name: Dr. T. K. Nandi*
*Left the Institute in August 2004

Address: Birla Institute of Technology, Mesra Ranchi
City: Ranchi
State: Jharkhand
Pin: 835215
Tel.: 0651-2276224
Fax: 0651-2275401

1. (a) Thrust Area(s): Cryogenic Propulsion System

Identified since inception	Ongoing	Modified to, and any when UGC approval reference no and date
Cryogenic Propulsion System	-same-	N. A

Future Thrust Area proposed: CRYO-HYBRID ROCKET PROPULSION

1. (b) UGC nominees with Address,
City, Pin, State, Tel., Fax,
E- mail (as approval by the UGC) : Prof. S. K. Sullery
Department of Aerospace Engg.
Indian Institute of Technology
KANPUR – 208 016 (U.P.)

Prof. B. N. Sreedhar
Department of Aerospace Engg.
Indian Institute of Technology
KHARAGPUR – 721302 (W.B.)

2. Major achievements (last five years) as the case may be:

(i) **Teaching:**

a. New courses introduced: M.Tech. (Fuels & Combustion) in July 2002

b. Curriculum last revised & significant changes: 2000 for M.E. and
2002 New curriculum for M.Tech.

c. Examination reforms last made with special features:

Examination reforms were made in 2006. Students are given Assignments in each theory course. Quiz (Progressive evaluation) and End Semester marks are accordingly modified. Emphasis has also been made on self learning.

d. New facility/ Lab created

A Cryogenic Laboratory has been developed in order to conduct static test of a small cryogenic rocket engine. In this laboratory, one liquid nitrogen plant with capacity of 10 litres per day has been installed. Liquid nitrogen is used for cooling the gaseous hydrogen for subsequent use in the firing of rocket engine. In this laboratory, students get practical experience and training in conducting static test of a small cryogenic rocket engine and also a hand-on experience on handling of cryogenics.

Please also see **Annexure-I**

(ii) **Research**

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

The basic design approach of the engine, including the thrust chamber, the nozzle, the injector, and cooling system has been completed. Liquid nitrogen plant commissioning is in the last phase. Major equipments have been procured and are under commissioning. The flow lines (LOX and gases) are being laid for final commissioning.

Please also see **Annexure-II**

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

- Construction of a new laboratory building
- In getting major equipments from foreign country
- The cryogenic specialist left the Institute in August 2004, and it took over two years to appoint a new person.

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

(iii) **Human Resource Training** :

Personal trained (Nos.): Not yet imparted
a. UG-PG- b. Rural/Tribal- c. Industrial-
d. International- e. From other agencies-

Final set up to conduct static test of a small cryogenic rocket engine is under progress. Training of personnel will start after commissioning of Test Facility.

3. Infrastructure developed:

A new Cryogenic Laboratory building (19.5m x 5.5m) has been designed and constructed. There are five rooms in the building for ease of operation. In the Control Room, operations of control and recording would be done during the static tests. Second room is used for housing the Liquid Nitrogen Plant, where required quantity of liquid nitrogen will be produced. Third room is being used for assembly work. Fourth room is the Flow Control Room, housing the different valves and actuators to control the flow of liquid nitrogen, liquid oxygen and gaseous hydrogen. The Static Tests will be conducted in the Static Test Bay.

Please also see **Annexure III**

a. Name major Equipments (> 3 lacs):

Sl. No.	Equipments	Amount	Company
1	Liquid Nitrogen Plant- LNP 10	1350529.00	Cryo Mech Inc, New York
2	Pressurizable liquid storage tank	573089.00	Cryo fab Inc, New Jersey
3	Solenoid Valves	435573.44	El-O Matic (I)

Please also see **Annexure - IV**

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) Guest house 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 8 Ultra SPARC Processors and Solaris Operating System, besides several high-end servers with a variety of Operating Systems. Over 500 stand-alone computers are part of the Institutional Network.

(viii) Central Library with documentation facilities –

The Central Library houses about 1.20 lac volumes, including Books, Periodicals, Conference Proceedings, etc. The Library also has a large stock of learning resources, such as CD- ROMs, Audio-Video Tapes and Microfilms. The University through INDEST consortium has access for full text to more than for thousand publications. The Institute subscribes to a large number of National and International Journals in different disciplines. 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 Development

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 organization): None

(v) Others: None

(vi) Innovation/excellence brought in (Please specify in the identified thrust areas only)
None

Will be taken up shortly, soon after the Hybrid Propulsion System becomes operational

5. Breakthrough (already recognized): ------------- None

6. Emerging/Hi-tech/Priority areas generated:
Cryogenic Propulsion (yet to be commissioned)

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:

Industrial collaboration: by user departments:

Human resource Training:

a. Neighboring institutions: Nil

a. International students:
b. Industries:
c. Industrial:
d. National Organisations:
e. Extension activities:

b. International organizations: Nil

c. Any other Collaborative: Nil

d. Other Courses programmes: No

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:	Nil
(√)b. Other user Deptts:	Applied Physics, Polymer
c. National Orgns:	Nil
d. Other Organisations:	Nil

---

9. Other activities:

a. Items numbers Time duration

Seminar
Summer Institute Conference
Refresher Courses

Please also see **Annexure -V**

* 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 Not applicable

1.

2.

3.

---

10. <u>Faculty involved</u>

a. Shri S. K. Ghosh
Faculty Strength: positions

Available : Working/ Vacant /Created
(Put Numbers) In Thrust Areas (1) Other Areas (2) under SAP/ASIST

Professor:	1 (1)	3 (2)
Reader:		
Lecturer:	1 (1)	4 (2)
Others:		

b. <u>In the identified thrust area(s)</u> :

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

Please see **Annexure-VI**

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

Please see **Annexure VII**

c. Intake (Please put numbers) Identified Thrust areas / 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. Assitt. :	Flexible

Same

Others :

---

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

a. Resource Persons Invited (Nos.) – National , 08

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

i. Hands-on OR technical training to university/college teachers During STTP: 24
ii. Collaborative (international) : Through Virtual Prototyping Centre
iii. Teaching to neghbouring institutions : Nil
iv. Visiting Teachers to Foreign university : 01
v. Equipment facilities : Five Laboratories
vi. Other major infrastructure facilities : Seminar Hall

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: Submitted as **Phase II**

Items	Non-recurring:	recurring:	Total (Rs. in Lakh)
Items : Equipments	83.50	-	83.50
Consumables/ Contingency Travel etc.	-	26.08	26.08
			109.58

13. a. Whether the state Government will take up the liability of the faculties and the staff in the areas identified after cessation of the tenure of the programme say in five or three years as the case may be) 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 progamme as was communicated along with the approval latter? 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 up gradation 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, finalized, audited and duly authenticated by the competent authority (Registrar and Finance other both) (item-wise and year-wise) for all the allocation and sanction 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 Coordinator

Signature:

Registrar of the University

Additional Registrar
Birla Institute of Technology
Mesra, Ranchi

BIRLA INSTITUTE OF TECHNOLOGY
A Deemed University u/s 3 of UGC Act , 1956
MESRA - 835 215 (RANCHI) INDIA

Phone : 0651-2275444/2275896, 2276002/2276006 FAX : 0651-2275401/2275868 Website: www.bitmesra.ac.in

UTILISATION CERTIFICATE

		Amount in Rs.
GRANT RECEIVED		**38,90,000.00**
As per letter No.F3-21/2002 (SAP –II) dated 21/03/2002 (37,00,000.00 + 190,000.00)		
EXPENDITURE AGAINST GRANT RECEIVED		
Equipment	33,52,440.44	
Fellowship	91960.98	
Contingency	97873.01	
Traveling	96584.08	**36,38,858.51**
Balance :		**2,51,141.49**

Certified that the amount of Rs.38,90,000/-(Rupees Thirty-Eight Lacs Ninety Thousand only) was released by the University Grant Commission, New Delhi vide their letter no. F3-21/2002 (SAP –II) dated 21/03/2002 to Birla Institute of Technology, Mesra, Ranchi for the project title"**Special Asistance Programme (DRS) in the Department of Space Engeneering & Rocketry**".

Out of this grant, a sum of Rs. 36,38,858.51 (Thirty Six Lacs Thirty Eight Thousand Eight Hundred Fifty Eight and Paise Fifty one Only) has been utilized for the purpose it has been sanctioned.

(G.S.Sharma)
Chief Accountant
G. S. Sharma
Chief Accountant
B.I.T. Mesra Ranchi

Additional Registrar
Birla Institute of Technology
Mesra, Ranchi

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

List of the Equipment :

Sl. No.	Equipment	Party Name		Amount Rs.
1 (I)	a) Liquid Oxygen pressurizable storage tank 110 Lts	M/s Cryofab Inc USA Laboratory		
	b) LN2 Pressurizable storage tank 110 Lts			
	c) LN2 Dewar Flask with top flange 34.5 Lts			
	d) LN2 storage Dewar (Open Neck) 25 Lts.			
	e) Transporation Trolley			
	f) Vaccum Insulated flexible transfer tube , Model CFCL-5M-0.5			
	g) Vaccum Insulated flexible transfer tube , Model : CFCL -2M-0.5		573,089.00	
(II)	a) Liquid Nitrogen Generator (LNP -10)	M/s Cnyomech Inc,New York		
	b) Dehumidifier Assembly			
	c) Electrical Protection System for LNP		1,259,696.00	
	Customs and Clearing		101,822.00	1,934,607.00
2	a) Solenoid valve	M/s Elomatic India (P) Ltd ,		
	b) Control Valve System Assembly			
	c) Electro -pneumatic Actuator for LO2			
	d) Electro -pneumatic Actuator for LN2			
	e) FRL Unit		422,373.44	
	Stabilizer	M/s Tirupati Enterprises ,	4,400.00	
	Stabilizer	M/s Tirupati Enterprises ,	8,800.00	435,573.44
3	Connector PTH 0-6 A	M/s Sensotec Inc, USA		
	Conductor Cable 043			
	Load Cell Nodel			
	Pressure fransducer Nodel TTE AP -112			
	Differential prezz transducer		297,462.00	297,462.00
4	Pressuizable Tank & Element Holder	M/s Revati Engg		171,600.00
5	PCL -208 (DAC) - 5 Nos PCL -226 (DAC) - 2 Nos	M/s MICRO System Foundation Calcutta		113,953.00
6	Conductor Ribbon Cable	M/s NI System		105,872.00
7	Reciprocating Air Compressor	M/s Elgi, India		95,300.00

Con... Page 2

8	a) Copper Cable Armelred 1 5 sq mm 4 core b) Gas moisture Control unit c) Gas Detector Head d) Siren for Gas Detector	M/s Substronics (India) Pvt. Ltd.	95,579.00
9	Computer & Accesseries		44,120.00
10	Digital Camera.		21,918.00
11	Technical Software on Cryogenic Engineering & its application	M/s Impetus Unlimited	15,000.00
12	Insulated industrial Armoured cable Alm	M/s Havell's	13,468.00
13	Moisture Separator Cum Oil Serubbler	M/s J.J. Associates,	5,908.00
14	Internal TV Tuner Card		2,080.00
		Total Rs.	3,352,440.44

G. S. Sharma
Chief Accountant
B.I.T. Mesra

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

List of the Equipment :

Sl. No.	Equipment		Amount Rs.
1	Customs and Clearing		101,822.00
2	Pressure Transdecr	34,241.00	
	Pressure Transdecr	236,221.00	297,462.00
3	M/s Elomatic India (P) Ltd , Electronic Item	422,373.44	
	M/s Tirupati Enterprises , Stabilizer	4,400.00	
	M/s Tirupati Enterprises , Stabilizer	8,800.00	435,573.44
4	M/s Cryofab Inc. USA Laboratory Equipment	573,089.00	
	M/s CryoMech. Inc. USA , LNP 10 Liqid Nitrogen Generator	1,259,696.00	1,832,785.00
5	M/s MICRO System Foundation , Calcutta , High Performance		113,953.00
6	M/s Substronics (India) Pvt. Ltd. Electronic Devices		95,579.00
7	M/s J.J. Associates, Moisture Separator Cum Oil Serubbler		5,908.00
8	Computer & Accesseries		44,120.00
9	Digital Camera (Sony Cybershot Model DSC)		21,918.00
10	Internal TV Tuner Card		2,080.00
11	Prof EVS Namboodiry		15,000.00
12	Conductor Ribbon Cable		105,872.00
13	Presserriable Tank & Element Holder M/s Revati Engg.		171,600.00
14	Havell's Make Xlpe Insulated Indutrial Armoured Cable Alm		13,468.00
15	Reciprocating Air Compressor		95,300.00
		Total Rs.	3,352,440.44

G. S. Sharma
Chief Accountant
B.I.T. Mesra Ranchi

Annexure – I

Brief Description of the Work

Cryogenic rocket engines use liquid hydrogen (LH_2) as fuel and liquid oxygen (LOX) as oxidiser. In real rocket engines, LH_2 before injecting to the combustion chamber, is circulated around the exhaust nozzle and the combustion chamber (for cooling the engine) and on the process the LH_2 vapourises to gaseous form. Eventually the combustion chamber is fed with gaseous hydrogen and liquid oxygen. The temperature of hydrogen is normally maintained within 90 to 110 K for efficient and stable combustion. With this goal, a small water cooled cryogenic rocket engine has designed to develop a low thrust of about 50 kg or so.

In order to fire the rocket engines in a simulation mode, the proposed test set up is based on the gaseous hydrogen and liquid oxygen as propellants. The gaseous hydrogen (GH_2), before injecting to the engine, is to be cooled by liquid nitrogen (LN_2) to reduce the temperature closer to the normal operating range (90-110K). Since LH_2 is not used for the static test set up, the exhaust nozzle and the combustion chamber is to be cooled by water by using a suitable pump. Inert gas pressurisation mechanism is used to feed liquid oxygen from the storage tanks to the engine while high pressure hydrogen gas is to be fed by using a regulator. LOX and LN_2 are available locally.

Figure 1 shows the schematic of the proposed set up. The nomenclature given in Table 1 describes the use of different valves and other components. There are three major fluid lines in the system; GH_2 line, LOX line and LN_2 line. A regulator on the hydrogen line controls the flow rate of hydrogen and monitoring the pressure inside the LOX storage tank controls the flow rate of LOX. Therefore before switching on to the computer automated control, hydrogen regulator and the nitrogen regulator are to be kept open manually depending upon the pressure requirements in their respective downstream.

The supply of nitrogen gas is required for (i) purging GH_2 line and LOX line (ii) pressurisation of LN_2 and LOX tanks and (iii) for operating the pneumatic valves to handle the fluid flow systems. The supply of oxygen gas is required for pressurisation of LOX tank.

Annexure – II

Objectives

The superiority of cryogenic propellants was well established even at the beginning of the space activities, and infact the very first rocket[1] in the world, fired by Dr. Robert H. Goddard, used liquid oxygen as oxidizer. Though the liquefaction of gases, e.g. oxygen, hydrogen, etc. were being carried out at the beginning of the twentieth century[3,4], it took nearly fifty years to develop a rocket engine using liquid oxygen and liquid hydrogen as propellants, and a sound beginning was made during Atlas-2 Ballistic Missile Programme[1,5] of USA in 1953. This delay was partly because of the non-availability of efficient liquefaction plant for production of liquid hydrogen and also due to the problem associated with the use of extremely low temperature of the liquid hydrogen. Earlier to this, liquid oxygen was being used in combination with hydrocarbon fuels such as RP fuels, gasoline, kerosene, etc. Technology wise, we have now reached to near perfection in the area of cryogenic propulsion through a number of major space vehicle programmes, including Space Shuttle of USA, Ariane of France, Energia of Russia and GSLV of India. These vehicles are used for interplanetary mission and making a manned transportation system for near-earth space station, or for launching of satellite.

In this background, it was felt appropriate to develop a cryogenic propulsion system to train the engineers and scientists at academic levels and to have hand on experience on handling of cryogenic liquids and a cryogenic propulsion systems.

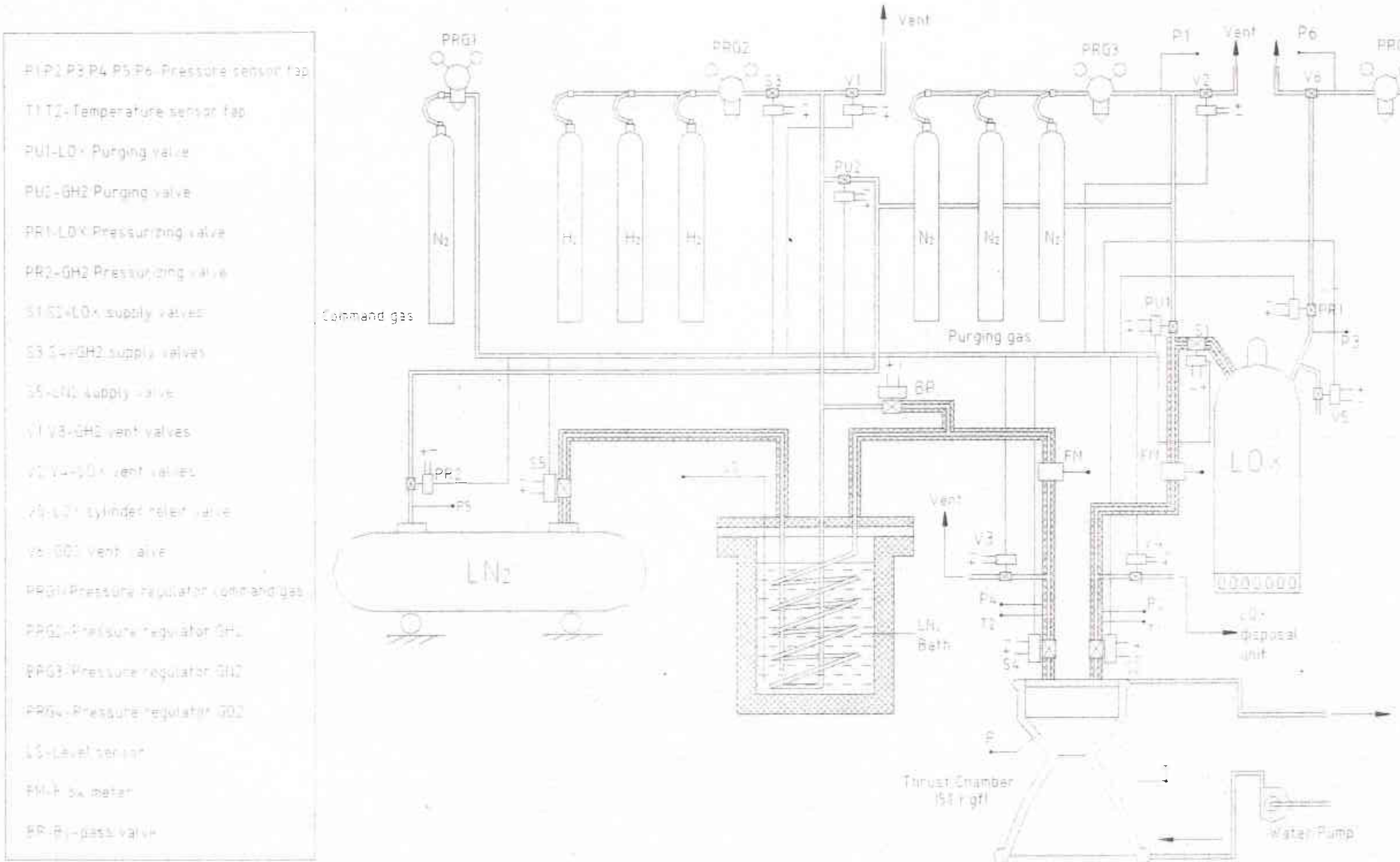
Under the scope of the project

(1) Practical experience to undertake static test of a small cryogenic rocket engine

(2) Understanding and development of computer controlled rocket engine static test system and associated software.

(3) Introduction of cryogenic practice specially handling of liquid (oxygen propellant) and liquid nitrogen (for cooling of gaseous hydrogen propellant). Liquid nitrogen is to be used for cooling the gaseous hydrogen for simulating the firing of rocket engine in a more realistic manner.

(4) Realisation of safety aspects for handling potentially dangerous gas like hydrogen specially because of presence of liquid oxygen nearby.



SCHEMATIC OF A CRYOGENIC PROPULSION TEST STAND

Cryogenic Propulsion System

A small rocket engine using liquid oxygen as oxidiser and gaseous hydrogen as fuel is developed in the Department. In practical rocket engines, liquid hydrogen (LH_2) is circulated around the thrust chamber for the purpose of cooling the engine, before injecting to the combustion chamber and in the process LH_2 vaporises. It is the gaseous hydrogen that is fed into the combustion chamber along with liquid oxygen for taking part in the combustion process. The temperature of the hydrogen is normally maintained 90 to 110 K for efficient and stable combustion. In this background, the gaseous hydrogen (GH_2) would be cooled by nitrogen to this temperature range in the present design.

Design of Thrust Chamber

A typical rocket thrust chamber assembly consists of the following principal parts: injector, combustion chamber and nozzle, besides a feed system and an appropriate ignition system in the case of non-spontaneously ignitable propellants. The combustion chamber and the nozzle are commonly designed as an integral part of the thrust chamber. For lightweight and ease of manufacture, the thrust chamber will typically [7,8] have a shape as depicted in Fig. 2.

Design calculation of the thrust chamber is carried out for the required thrust level, and the other basic parameters are partly decided by engineering judgement and partly by the literature-reported data. The data considered for the present design are summarised in Table 1 (Annexure I). In addition to these assumed data, the shape of the thrust chamber that has been adopted for the present design is shown in Fig.1 along with geometrical parameters.

Design of Injector

There are numerous requirements to qualify a given injector for operational use. The most important objectives for injector design are: a) combustion stability b) performance c) hydraulic quality d) structural integrity e) Combustion chamber heat protection, and such other parameters. The complete theory relating injector design parameters to rocket performance and combustion phenomenon is yet to be devised. In view of the above, the approach to the design and development of the injector of liquid propellant rocket engine has been largely empirical.

In the present design, a co-axial type injector has been selected, because it provides higher combustion performance and is not susceptible to high frequency instability. Also, the pressure drop across the injector is less in comparison to other type of injectors. This injector employs two concentric tubes for the two propellants, which are injected co-axially.

The total mass flow rate of the propellant is found to be 166 g/s. Considering the better combustion stability a mixture ratio (MR) of 4 is chosen. For six elements, the annular area in each element should be 7.07 mm^2. Thus the annular gap is to be decided from the outer diameter of the LOX injection tube. The schematic of the co-axial type injector assembly is presented in Fig.3 and details of injector element and element holder are shown in Fig. 4 and Fig. 5 respectively. Table 2 (Annexure I) summarizes the geometrical parameters of the thrust chamber and the injector elements.

Design of Pressurisable LOX Tank

The LOX tank is to be used to store Liquid oxygen and would be pressurized by Gaseous oxygen. Design calculation of the LOX tank with a volume 20-25 litres has been carried out for a requirement of internal pressure of approximately 30 bar.

Since, the size, capacity and pressurization requirements do not match with the standard LOX tanks available in the market, the tank has been designed and fabricated. Standard techniques that are recommended for designing a pressure vessel are adopted in the present design. The internal pressure in the shell gives rise to stresses in the shell thickness, on in the circumferential direction and, the other in the longitudinal direction. In addition to the internal pressure, the other load that has to be considered is the weight of the vessel with its contents. This dead weight will produce longitudinal or axial stress, compressive in nature. Since the magnitude of the circumferential/ hoop stress is significantly greater than that of the longitudinal /axial stress, hoop stress is taken as the basis of design. The details of LOX tank with its support is shown in Fig. 6.

In order to provide thermal insulation to the liquid oxygen, the stainless steel LOX tank is to be housed inside an outer metallic cover. The gap between the LOX tank and the outer cover will be filled with foam, powder, or glass wool insulation.

There should also be a provision to dry up the insulation by pumping the insulation through a compressor or a rotary pump.

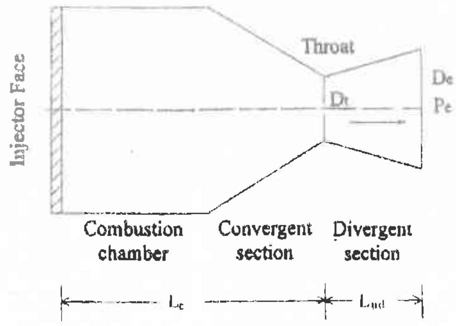


Fig. 2: A typical Thrust chamber

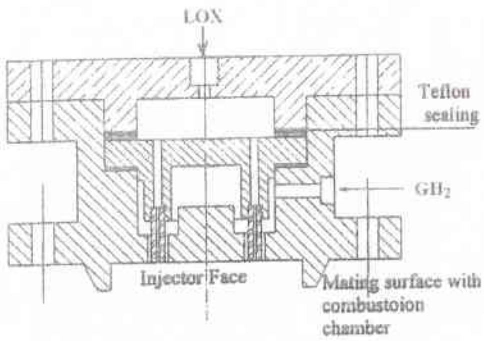


Fig. 3: Design of co-axial type injector assembly

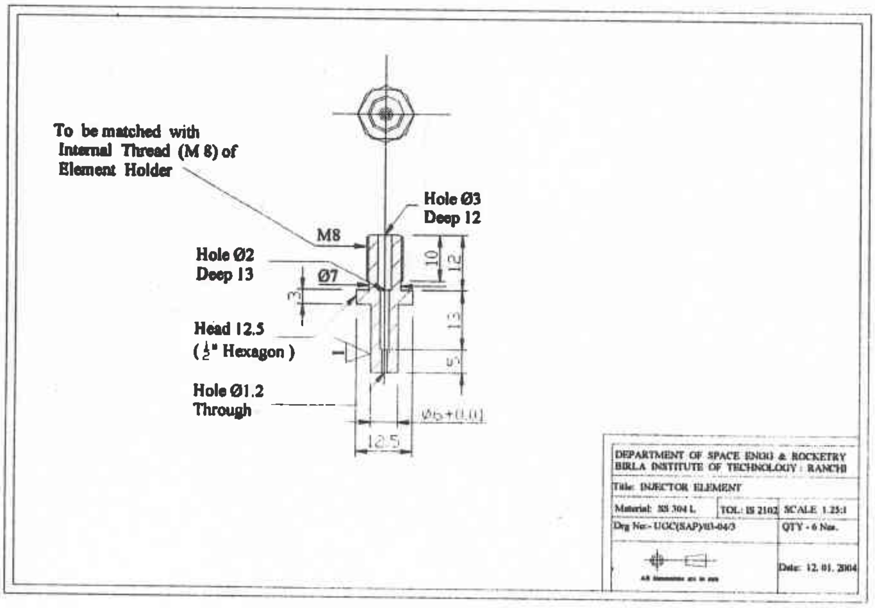


Fig. 4 Design of Injector element

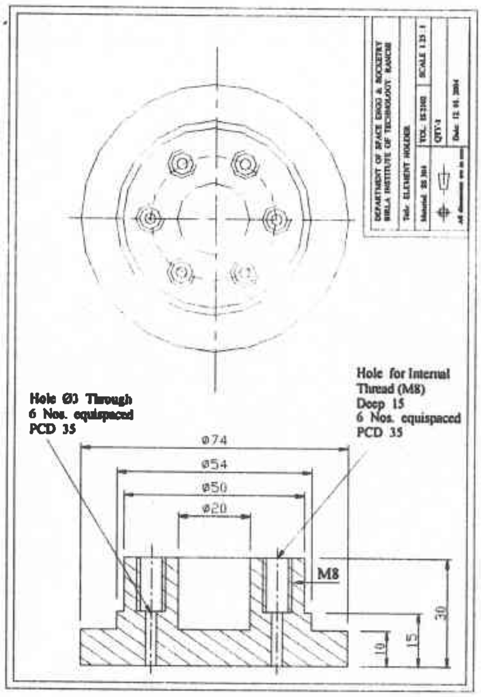


Fig. 5 Design of Element holder

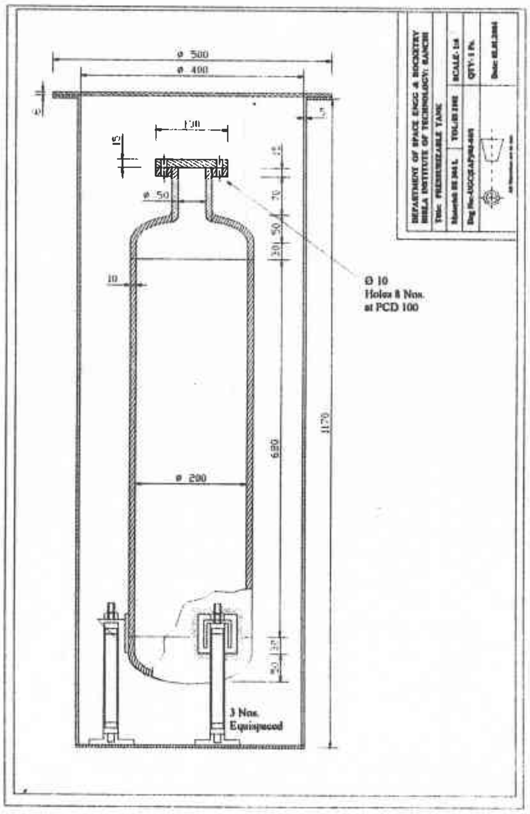


Fig. 6 Design of LOX tank

Table 1: Design data for thrust chamber

Thrust level (F)	=	50 kgf
Chamber pressure (P_c)	=	10 bar
Mixture ratio (O/F, by wt)	=	4
Exit pressure (P_e)	=	1 bar
Characteristic length (L*)	=	72 cm
Velocity in the combustion chamber (υ_c)	=	100 m/s
Combustion chamber temperature (T_c)	=	2980 K
Mean molecular weight (M)	=	10.08
Specific heat ratio (γ)	=	1.30

Table 2: Geometrical parameters of thrust chamber and injectors

Comb. Chamber dia. (D_c)	=	71.0 mm
Nozzle throat dia. (D_t)	=	22.0 mm
Nozzle exit dia. (D_e)	=	32.0 mm
Comb. Cham. Length (L_c	=	53.0 mm
Length of the convergent portion of the nozzle	=	42.5 mm
Length of the divergent portion of the nozzle	=	18.7 mm
Flow passage area of each oxidiser element	=	1.13 mm^2
Annular flow passage area for fuel injection	=	7.07 mm^2
Number of injectors	=	6

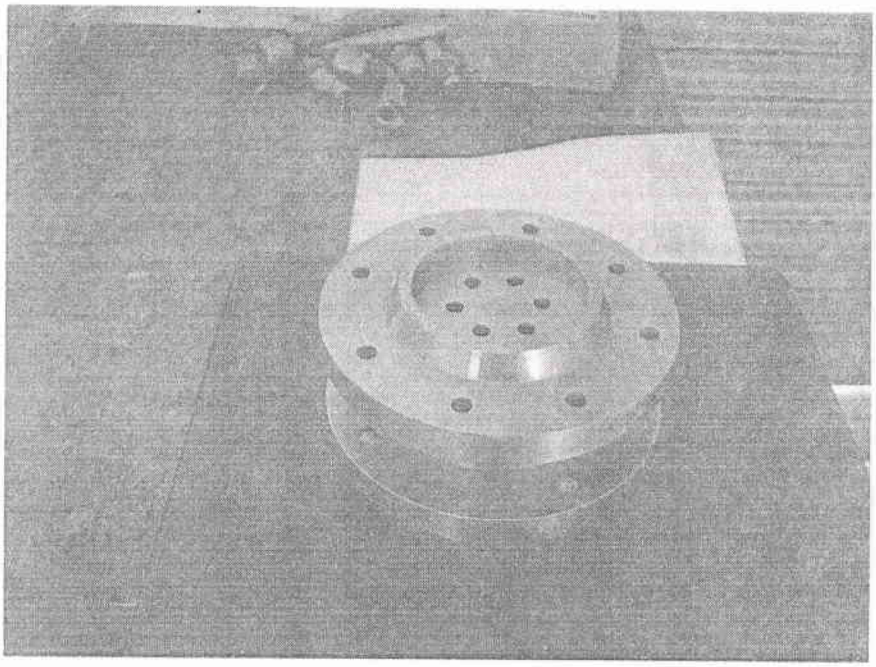


Figure 8: Fabricated Thrust Chamber

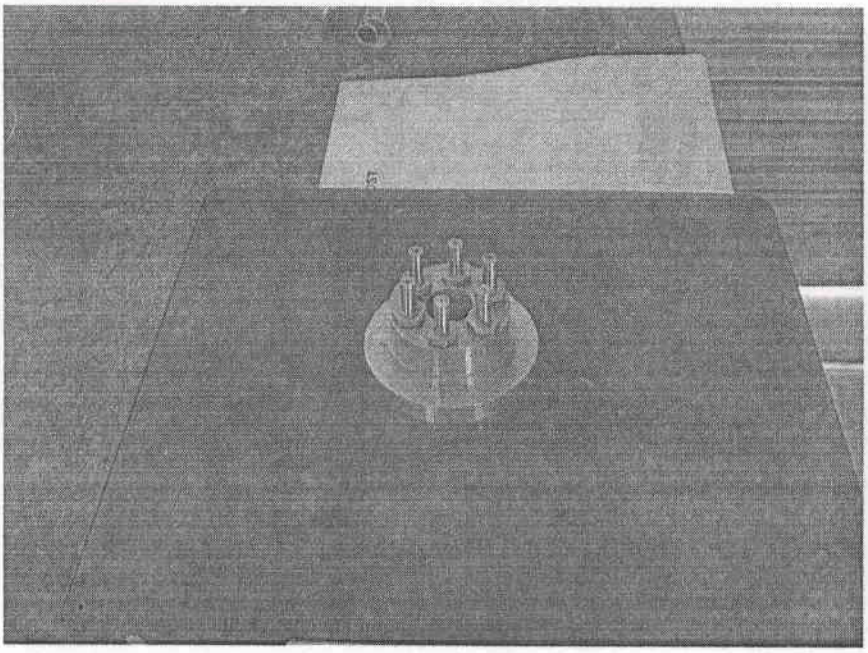


Figure 9: Fabricated Injectors

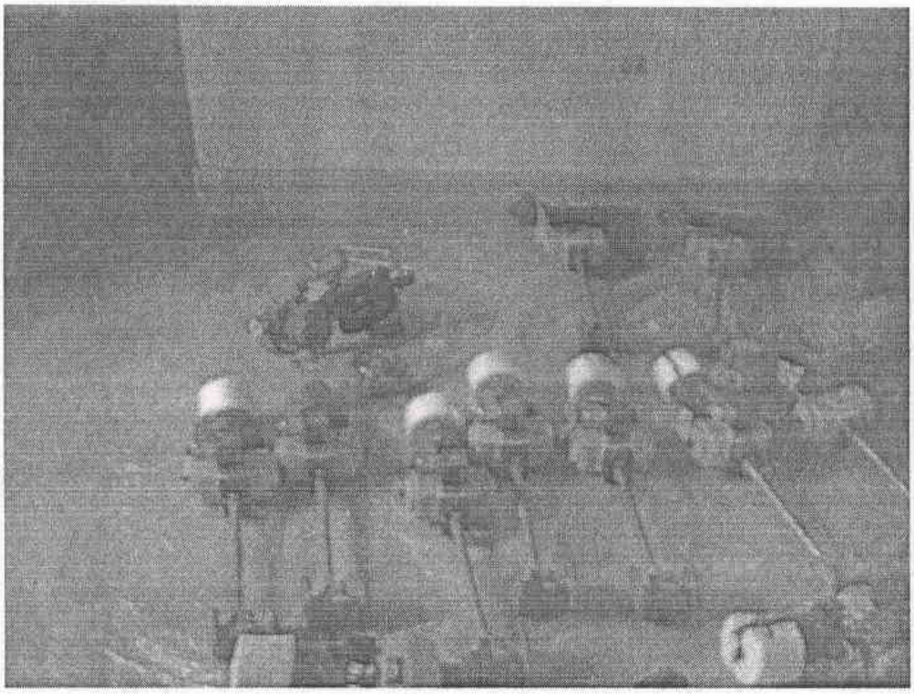


Figure 10: Procured Solenoid Valves

Testing of the Engine

In order to test the engine, a static test stand is under development in the Department. A schematic of the test set-up is shown in Fig.1. Gaseous hydrogen before injecting into the engine, is to be cooled by liquid nitrogen to reduce the temperature closer to the usual operating range[9] of 90 to 110 K. Gas pressure feed mechanism would be used to transfer liquid oxygen from storage tank to the engine. Gaseous oxygen (not shown in Fig.3) will be used to pressurize the LOX tank. All the feed lines and other pipelines are to be purged by nitrogen gas drawn from gas cylinder through a regulator. Flow control for purging, propellant feeding and venting are to be done by pneumatic valves that operate with the supply of nitrogen gas at a moderate pressure. The supply of the nitrogen gas to the pneumatic valves is to be done by solenoid valves that will be operated remotely through computer commands.

Computer Controlled Sequence of Operation

The commencement of test is carried out by initial inspection of all components. This is done to ensure no leakage and to maintain the safety aspects. One every thing is found correct, the three manual pressure regulators PRG1, PRG2, & PRG3 is opened upto the required pressure level. All the solenoid valves assumed to be normally closed.

Step 1: SYSTEM CHECKING

To be defined later.

Step 2: PURGING

a) Purging of LOX line.

i. Open valve PU1
ii. Open valve S2
iii. Close valve S2
iv. Close valve PU1

b) Purging of H_2 line.

i. Open of valve PU2
ii. Open of valve S4
iii. Close valve S4
iv. Close valve PU2

Step 3: PRESSURIZATION

i. Adjust tank pressure through valve V2
ii. Open valve PR1
iii. Open valve PR2

Step 4: CHILLING DOWN AND FILLING OPERATION

a) LOX

i. Open valve S1
ii. Open valve V4 and wait and for the specific time for complete chill down
iii. Close valve V4
iv. Read T1

b) GH_2

i. Open valve S5
ii. Open valve S3
iii. Open valve V3 and wait for the given time for complete chill down
iv. Close valve V3
v. Read T2

Step 5: FIRING

i. In case of over pressurization in LOX tank open valve V5
ii. Open of valve S2 and S4 simultaneously
iii. Firing signal

Step6: SHUT DOWN

i. Close valve S2 and S4 simultaneously
ii. Close valve PR1
iii. Close valve S1
iv. Open valve V4 (Connected to LOX disposal unit)
v. Close valveS3
vi. Open valve V3 (GH_2 vent)
vii. Close valve PR2
viii. Close valve S5

Step 7: PURGING

a) Purging of LOX line

i. Open valve PU1

ii. Close valve V4 (Connected to LOX disposal unit)

iii. Open valve S2

iv. Close valve PU1

v. Close valve S2

b) Purging of H2 line

i. Open valve PU2

ii. Close valve V3 (GH_2 vent)

iii. Open of valve S4

iv. Close valve PU2

v. Close valve S4

At this stage pressure regulator PRG1, PRG2, PRG3 are to be closed manually.

Conclusions

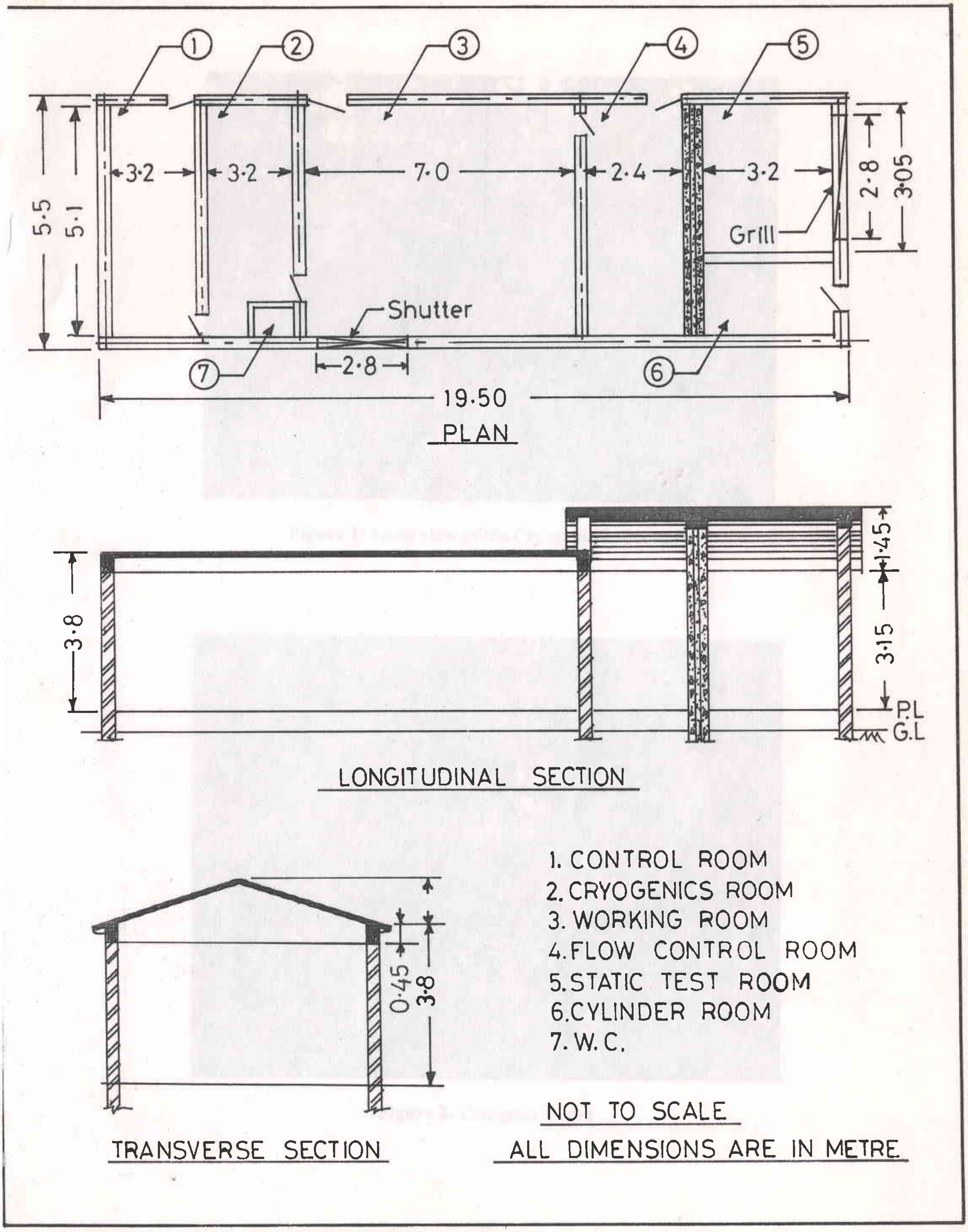
- An attempt has been made to develop a small cryogenic rocket engine with a nominal thrust of 50-kgf using liquid oxygen and gaseous hydrogen as its propellants. The basic design approach of the engine, including the thrust chamber, the nozzle, the injector, and the cooling system is presented. A schematic of the proposed set-up for static test of the engine has been presented and discussed to an extent.
- Most of the major equipments have been procured and are under commission
- The liquid nitrogen plant is in commissioning process

For successful completion of the project the experts from Cryogenic Engineering Centre from IIT Kharagpur are regularly invited and various activities of the project are discussed.

Annexure III

Distribution of Equipments:

Gas Cylinder Room:	1.	H_2 gas cylinder (3 Nos.) and H_2 regulator
	2.	N_2 gas cylinder(4 Nos.) and N_2 regulator
	3.	O_2 gas cylinder (1 No.) and O_2 regulator
	4.	H_2 gas detector head
	5.	B/W camera
Static Test Room	1.	Engine
	2.	Water cooling system
	3.	Electro-Pneumatic actuator (4 Nos.; S2, S4, V3, V4)
	4.	Colour camera
	5.	2 way audio box
Flow Control Room:	1.	LN_2 bath (open neck, 1 No.)
	2.	Pressurizable LOX tank (1 No.)
	3.	LN_2 tank (1 No.)
	4.	H_2 detector head
	5.	B/W camera
	6.	Electro-Pneumatic actuator (5 Nos. S1, S3, V1, V5, V6)
Cryogenics Room:	1.	LOX tank
	2.	LN_2 Dwar (35 litrs) with trolley
	3.	LN_2 plant i. Air compressor ii. Helium compressor iii. LN_2 generator
Control Room:	1.	Computer, Pentium IV (4 Nos)
	2.	UPS (4 Nos.)
	3.	Laser printer (1 No.)
	4.	4 Ch switcher (1 No.)
	5.	Audio-Video capture card fitted in one computer
	6.	PCI Data Acquisition Card fitted in one Computer
	7.	PCI Relay card fitted in one computer



CRYOGENICS PROPULSION LABORATORY

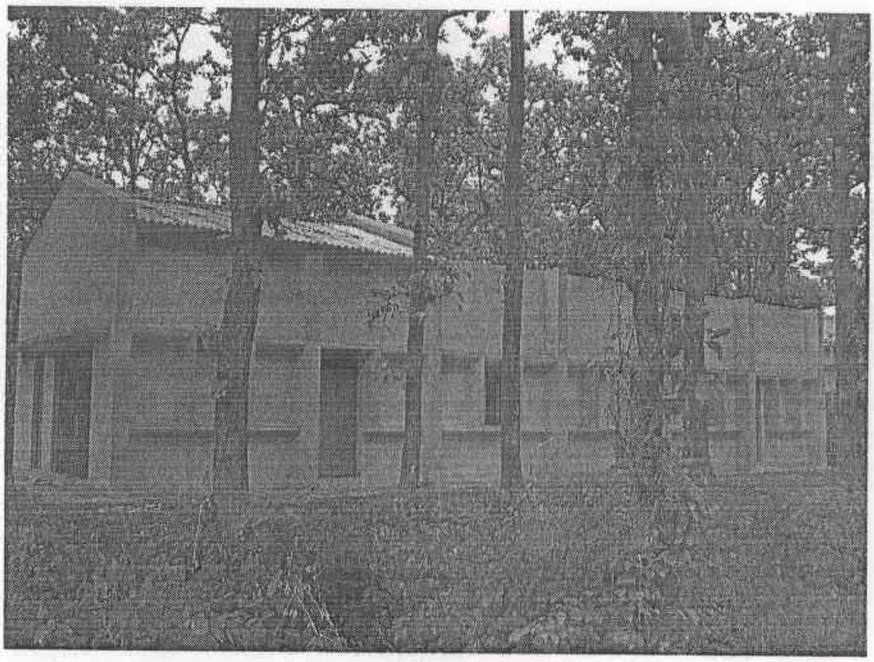


Figure 1: Front view of the Cryogenic Laboratory

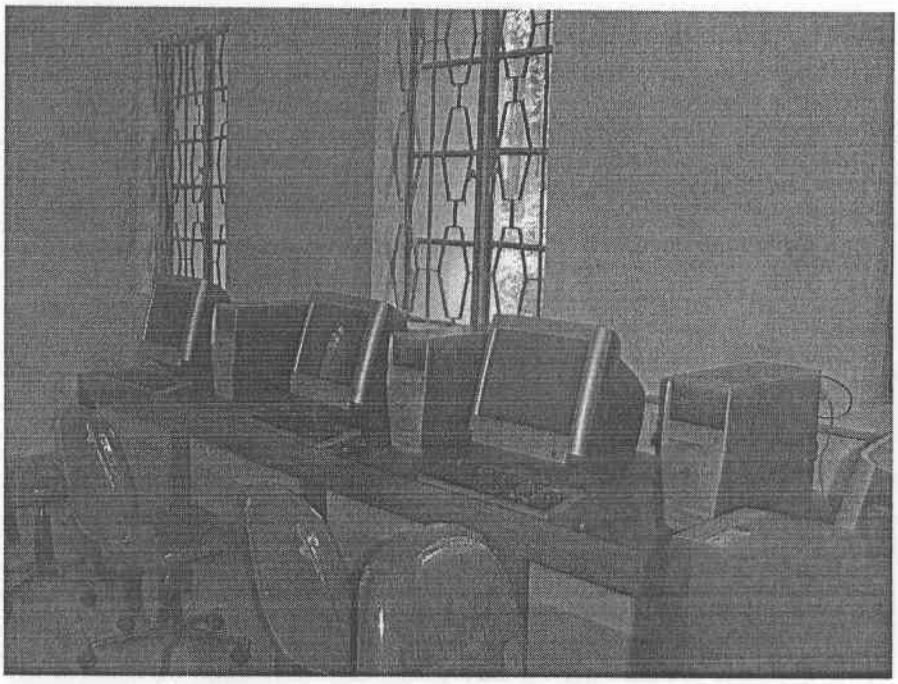


Figure 2: Computer Room

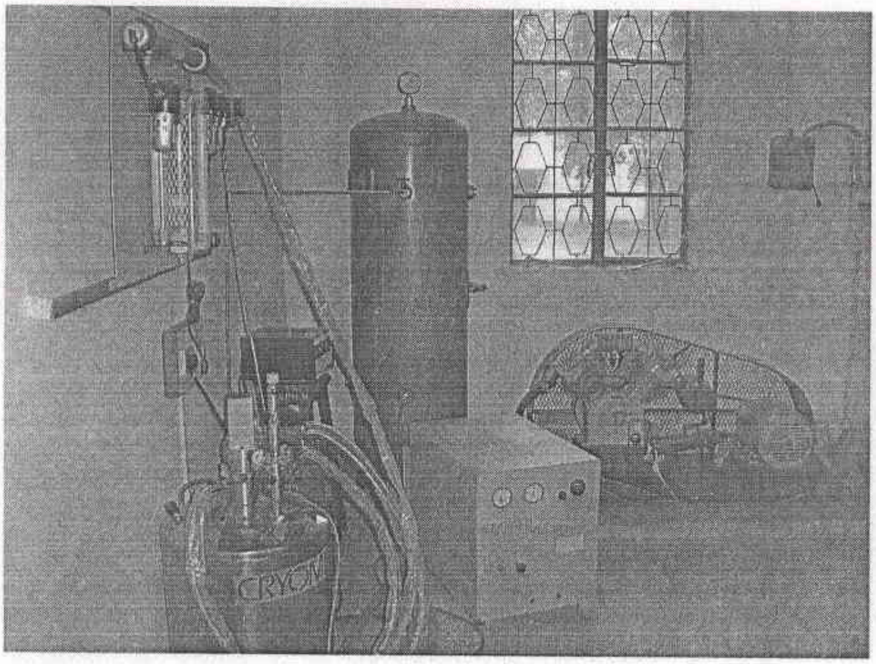


Figure 3: Cryogenic Room with LNP-10

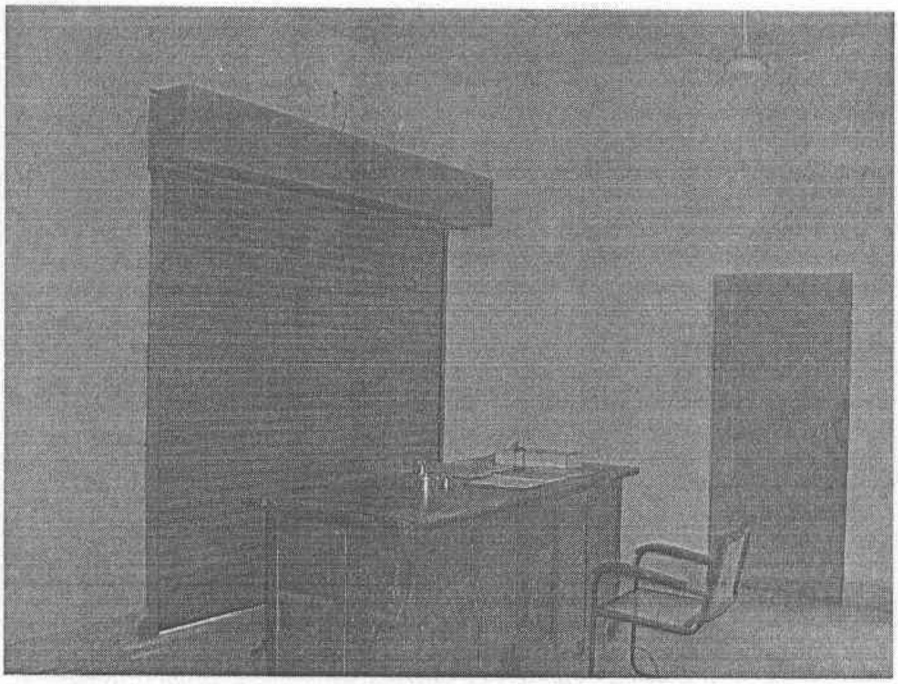


Figure 4: Assembly Room with work table

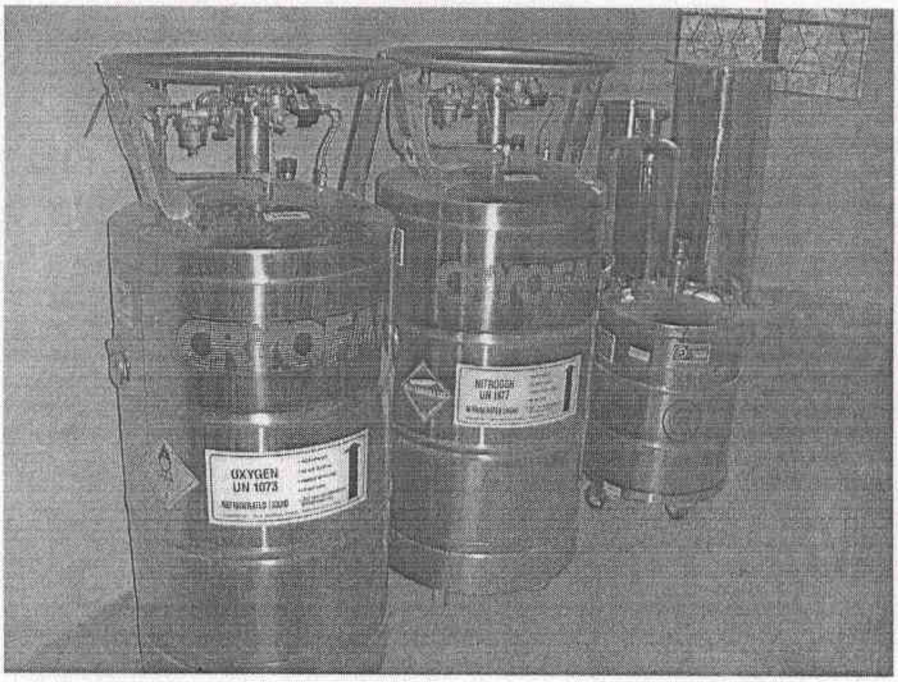


Figure 5: Flow Control Room with Liquid Storage Tank

Annexure – IV

List of Equipments received under UGC (SAP) Project

Sl. No.	List of Equipments
1.	Liquid Oxygen Pressurisable Tank 110 Lts.
2.	LN2 Pressurisable Storage Tank 110 Lts.
3.	LN2 Dewar Flask with top flange 34.5 Lts
4.	LN2 storage Dewar (Open Neck) 25 Lts
5.	Transportation Trolley
6.	Vacuum Insulated flexible transfer tube, Model CFCL-5M-0.5
7.	Vacuum Insulated flexible transfer tube, Model CFCL-2M-0.5
8.	Liquid Nitrogen Generator (LPN-10)
9.	Dehumidifier Assembly
10.	Electrical Protection System for LNP
11.	Reciprocating Air Compressor
12.	Solenoid valve
13.	Control Valve System Assembly
14.	Electro-pneumatic Actuator for LO2
15.	Electro-pneumatic Actuator for LN2
16.	FRL Unit
17.	Stabilizer
18.	Connector PTH 0-6 A
19.	Pressurisable Tank & Element Holder
20.	PCL -208 (DAC), PCL -208 (DAC)
21.	Conductor Ribbon Cable
22.	Copper Cable Armelred 1.5 sqr mm 4 core
23.	Gas moisture Control Unit
24.	Gas Detector Head
25.	Siren for Gas Detector
26.	Computer
27.	Digital Camera Model VCC-3912P
28.	Technical Software on Cryogenic Engineering & its application
29.	Insulated Industrial Armoured cable Alm
30.	Moisture Separator Cum Oil Serubbler

ANNEXURE – V

Details of Seminars, Conferences etc. Organized

	Number organized	05
	National 04	International 01
Conference	17th National Convention of Aerospace Engineers, Nov. 03-05, 2003	
Seminar	National Seminar on Recent Advances in Energy Systems and Combustion Processes, Feb. 14-16, 2007	
Workshop	National Workshop on Emerging Trends in Aerospace Engineering & Rocketry, April 18-20, 2005	1st International HEMSI Workshop on Advances in Solid Propellant Technology, Nov.12-13, 2002
Summer Institutes	Advances in Aerospace Engineering and Rocket Propulsion, June 28 – July10, 2004	
Refresher Courses		

Annexure – VI

Details of Faculty Members

Name of the Teacher	Designation	Qualification	Specialization
Dr. A. K. Chatterjee	Professor & Head	M. Sc. (Engg), Ph. D.	Rocket Propulsion, Cryogenic Engineering
Dr. P. C. Joshi	Professor	M. Sc., Ph. D.	Combustion, Rocket Propulsion
Dr. Mohan Varma *	Professor	M. Sc., Ph. D.	Propellant Technology
Dr. J. K. Prasad	Professor	M. Tech., Ph. D.	Aerodynamics
Dr. P. K. Dash	Lecturer	M.E., Ph. D.	Composite Materials, Propulsion
Shri Sudip Das	Lecturer	M. E.	Aerodynamics
Shri C. R. Chodankar	Lecturer	M. Tech.	Combustion
Shri S. K. Ghosh	Lecturer	M. Tech.	Cryogenics
Ms. Nivedita Gupta	Lecturer	M. Tech.	Combustion

* Dr. Mohan Varma is a recipient of

Dalmia - HEMSI Award -2003

Technology Day Award - 2004

Annexure – VII

Publications During Last Five Years

BOOKS

1. Dr. Mohan Varma and Dr. A. K. Chatterjee:
   Advances in Solid Propellant Technology (Ed.), 2002
2. Dr. J. K. Prasad and Dr. A. K. Chatterjee:
   Indian Aerospace Vehicles: Technological Challenges (Ed.), 2003
3. Dr. A. K. Chatterjee and Dr. T. K. Nandi:
   Advances in Aerospace Engineering and Rocket Propulsion (Ed.), 2004
4. Dr. P. C. Joshi and Dr. A. K. Chatterjee:
   Recent Advances in Energy Systems & Combustion Processes (Ed.), 2007

FOREIGN JOURNALS

1. R.C. Mehta and J. K. Prasad, "Numerical analysis of Flow fields of Axisymmetric Supersonic Free Jets", International Jr. of Computational Fluid Dynamics, Vol.12, Apr 2003, pp 115-120
2. A. Roy, and G. Bandyopadhyay, "Numerical Computation of Flow past a Rectangular Cylinder placed at Different Ground Clearance from a Fixed Wall", Jr. of Aerospace Science & Technologies, Vol. 55, May 2003, pp. 112-117.
3. Chandan Guria, Mohan Varma, Surya P. Mehrotra and Santosh K. Gupta, Simultaneous Optimization of the Performance of Flotation Circuits and their Simplification using the Jumping Gene Adaptation of Genetic Algorithm, Int. J. of Mineral Processing, Vol.77, 2005, pp. 165-185.
4. Chandan Guria, Mohan Varma, Surya P. Mehrotra and Santosh K. Gupta, Multi Objective Optimal Synthesis and Design of Froth Flotation Circuits for Mineral Processing, using the Jumping Gene Adaptation of Genetic Algorithm, Ind. Eng. Chem. Res. Vol. 44, 2005, pp. 2621-2633.
5. A. Roy, and G. Bandyopadhyay, " A Finite Volume Method for Viscous Incompressible Flows Using a Consistent Flux Reconstruction Scheme", International J. of Numerical Methods in Fluids, published online on Feb10, 2006.
6. A. Roy and G. Bandyopadhyay, "Numerical Calculation of Separated Flow Past a Circular Cylinder Using Panel Technique", Journal of Wind Engineering and Industrial Aerodynamics, Volume 94, No.3, Mar 2006, pp. 131-149.

7. Chandan Guria, Mohan Varma, Surya P. Mehrotra and Santosh K. Gupta, Simultaneous Optimization of the Performance of Flotation Circuits and theirSimplification using the Jumping Gene Adaptation of Genetic Algorithm – II: More Complex Problems, Int. J. of Mineral Processing, Vol. 79, 2006, pp. 149-166.
8. Chandan Guria, Mohan Varma, Santosh K. Gupta, and Surya P. Mehrotra, Optimal Synthesis of an Industrial Beneficiation Plant using a Jumping Gene Adaptation of Genetic Algorithm – II: More Complex Problems, Int. J. of Mineral Processing, 2007 (in press).

INDIAN JOURNALS

1. A. K Chatterjee and S. Som, "Influence of Oxidiser Incorporation in PVC Plastisol Hybrid Fuel", Journal of The Institution of Engineers (I), Aerospace Div, Vol. 48, 2003, pp. 41- 46.
2. Mohan Varma, M. Pandey and B. L Gupta, "Pressure Dependence of Thermal Decomposition of Ammonium Nitrate Oxidiser", Journal of Indian Chemical Society, Vol. 80, No. 5, 2003, pp. 574.
3. A. Roy and G. Bandyopadhyay, "Numerical Investigation of Confined Flow Past a Square Cylinder Placed in a Channel", Journal of Institution of Engineers (India), Aerospace Division, Vol. 85, Nov 2004, pp. 60-63.
4. P. K. Dash and A. K. Chatterjee, "Effect of Environment on Fracture Toughness of Woven Carbon / Epoxy Composite", Journal of the Institution of Engineers (I), Aerospace Division, Vol. 35, May 2004, pp. 16-21.
5. H. P. Tiwari, P. K. Banerjee, R. Sharma and P. C. Joshi, " Coal Ash Generation in Carbonisation Process : A Comparison between Top Charged and Stamp Charged Coke making Processes." Fuel, (communicated).

CONFERENCE / SEMINAR / WORKSHOP

1. Mohan Varma, A. K. Chatterjee, M. Pandey, " Ecofriendly Propellants and their Combustion Characteristics", Proc. of the 1st International HEMSI Workshop on Advances in Solid Propellant Technology, Birla Institute Technology, Ranchi, Nov. 12- 13, 2002, pp. 144 – 179
2. N. K. Singh, D. Mishra, T. K. Nandi & A. K. Chatterjee, Manufacturing of Herringbone Grooved Journal Bearing by Chemical Milling, International Conference on Manufacturing, Bangladesh University of Engineering & Technology, Dhaka, Bangladesh, Aug 9-11, 2002, pp. 534 – 542.

3. D. Mishra, W.S.Mahadev, T.K.Nandi & A. K. Chatterjee, Development of a LOX/GH_2 Propulsion System, Nineteenth National symposium on Cryogenics(NNSC-2002), Jadavpur University, Kolkata, Mar 24-26,2003.

4. A. K. Chatterjee and T. K. Nandi , " Cryogenic Propulsion in Space Missions", Proc. Of National Seminar & Conference on Cryogenics and Its Frontier Applications, B. E. College , Howrah, Mar 25-27 , 2004, pp. 29-35.

5. A. K. Chatterjee, V. Kumar, S. Das and J. K. Prasad , "Upstream Influence of a Protrusion on a Cone –Cylinder Body in Supersonic Stream" , Proc. of Seventeenth National Convention of Aerospace Engineers & National Seminar on Aerospace Vehicles: Technological Challenges, B.I.T., Mesra, Ranchi, Nov. 3-5, 2003, pp. 59-71

6. Basant Kumar, Sudip Das and J. K. Prasad, " Flow Field around Ogive Cylinder at Large Angles of Attack" , Proc. of Seventeenth National Convention of Aerospace Engineers & National Seminar on Indian Aerospace Vehicles: Technological Challenges, B.I.T., Mesra, Ranchi, Nov. 3-5 2003, pp. 52-58.

7. Basant Kumar, Sudip Das and J. K. Prasad "Experimental Investigation of Flowfield around Slender Body at High Angles of Attack" , Proc. National Conf. on Fluid Mech.and Fluid Power , National Institute of Technology, Suratkal, Dec. 2003, pp. 471-478.

8. M. K. Rahl, Sudip Das and J. K. Prasad " Interaction of Flow Field around Blunt Protrusions at Supersonic Speed", Proc.of Seventeenth National Convention of Aerospace Engineers & National Seminar on Indian Aerospace Vehicles: Technological Challenges, B.I.T., Mesra, Ranchi, Nov. 3-5 2003, pp. 44-51.

9. S. Debdas, T. K. Nandi and A. K. Chatterjee, Development of Herringbone Grooved Journal Bearing for Cryogenic Applications", Proc. of Seventeenth National Convention of Aerospace Engineers & National Seminar on Indian Aerospace Vehicles: Technological Challenges, B.I.T., Mesra, Ranchi, Nov. 3-5 2003, pp. 536-544.

10. A. Roy and G. Bandyopadhyay, " Computation of Flow Past a Three Dimensional Square Cylinder using a Finite Volume Navier Stokes Solver" , Proc. of Seventeenth National Convention of Aerospace Engineers & National Seminar on Aerospace Vehicles: Technological Challenges, B.I.T., Mesra, Ranchi, Nov. 3-5, 2003, pp. 241-247.

11. P. K. Dash and A. K. Chatterjee , "An Investigation of In-plane Shear Properties of Bidirectional Woven Carbon Epoxy Composites under Adverse Environment" ,

Proc. of Seventeenth National Convention of Aerospace Engineers & National Seminar on Indian Aerospace Vehicles: Technological Challenges, B.I.T., Mesra, Ranchi, Nov. 3-5 2003, pp. 383-394.

12. A. K. Srivastava and P. K. Dash "Effect of Corrosive Environment on Elasto-Buckling Strength of FGRC Plate" , Proc. of Seventeenth National Convention of Aerospace Engineers & National Seminar on Aerospace Vehicles: Technological Challenges, B.I.T., Mesra, Ranchi, Nov. 3-5 2003, pp. 359-407.

13. Basant Kumar, Sudip Das and J. K. Prasad, "Experimental Investigation of Flow Field Around Slender Body at High Angle of Attack", 30th National Conference on Fluid Mechanics and Fluid Power, National Institute of Technology, Suratkal, Dec 2003, pp. 479-486.

14. Das, S. and Prasad, J. K. "Experimental Investigation of Flow around Three Dimensional Bluff Bodies in Tandem" , 30th National Conf. on Fluid Mech. and Fluid Power , National Institute of Technology, Suratkal, Dec. 2003, pp. 471-478.

15. Ralh, M.K., Das, S., Roy, A. and Prasad, J. K., "Flow Field around Blunt Protrusions Mounted on A Flat Surface", Proceedings of 18th National Convention of Aerospace Engineers, I.I.T. Kharagpur, Dec.2004, pp. 6-11.

16. Tarun Kumar, Sudip Das, Arnab Roy and J. K. Prasad, "Effect Of Nose Shape on Slender Body at Large Angles of Attack at Subsonic Speed", Proceedings of 18th National Convention of Aerospace Engineers, I.I.T. Kharagpur, Dec.2004., pp. 58-65.

17. Tarun Kumar, Sudip Das, A. Roy and J. K. Prasad, "Flow Field around Slender Body Having Different Fineness Ratios at High Angles of Attack", Proceedings of 31st National Conference on Fluid Mechanics and Fluid Power, Dec 16-18, 2004, Kolkata, pp. 622-632.

18. S. Challa, A. Roy, Sudip Das and J. K. Prasad, "Effect of Height on Flow Field around Protrusions at Supersonic Speed", Proceedings of 31st National Conference on Fluid Mechanics and Fluid Power, Dec 16-18 , 2004, Kolkata, pp. 679-686.

19. A. Roy and G. Bandyopadhyay, "A Numerical Investigation of Unsteady Two Dimensional Flow around a Square Cylinder at Incidence", Proceedings of the 7th CFD Symposium, Aug 11-12, 2004, Bangalore, CP10.

20. A. Roy and G. Bandyopadhyay, " Numerical Investigation of Confined Flow Past a Square Cylinder Placed in a Channel", All India Seminar on Aircrafts and Transatmospheric Vehicles: Missions, Challenges and Perspectives, Institution of Engineers, May 29, 2004, Kolkata.

21. Mohan Varma and M. Pandey, "Thermal Degradation of HTPB, AN, their Virgin and Catalyzed Propellants under Slow Decomposition Conditions", 5th International High Energy Materials Conference & Exhibit, Hyderabad, Nov 23-25 , 2005.

22. N. S Vikramaditya., Sudip Das , Arnab Roy and J. K. Prasad., " Study of Flow Field around a Pair of Protrusions at Different Gaps at Supersonic Speed", 19th National Conference on Aerospace Engineers and National Seminar on Indian Aerospace Engineering Perspective - 2020, Jaipur , Nov 19-20, 2005.

23. P. Omprakash, Arnab Roy, Sudip Das and J. K. Prasad, "Computation of Incompressible Flow around Circular Cylinder", 19th National Conference on Aerospace Engineers and National Seminar on Indian Aerospace Engineering Perspective - 2020, Jaipur, Nov 19-20, 2005.

24. J. K Prasad, "Behaviour of Flow Field around Sharp Fins at Different Angles at Supersonic Speed", 19th National Conference on Aerospace Engineers and National Seminar on Indian Aerospace Engineering Perspective - 2020, Jaipur, Nov 19-20, 2005.

25. P. Omprakash, Arnab Roy, Sudip Das and J. K. Prasad, "Investigation of Incompressible Flow Field around a Two Dimensional Wedge", 32nd National Conference on Fluid Mechanics & Fluid Power, Osmanabad, Dec 15-17, 2005.

26. N. S. Vikramaditya, Sudip Das, Arnab Roy and J. K. Prasad, "Flow Field around Protrusions of Different Height and Leading Edge and Rear Face Angles at Supersonic Speed", 32nd National Conference on Fluid Mechanics & Fluid Power, Osmanabad , Dec 15-17, 2005.

27. P. Gupta, Arnab Roy, Sudip Das and J. K Prasad, "Flow field around Sharp Fins of Different Heights at Supersonic Speed", 32nd National Conference on Fluid Mechanics & Fluid Power, Osmanabad , Dec 15-17, 2005.

28. P. Omprakash, Arnab Roy, Sudip Das and J. K. Prasad, "Effect of Wedge Angle on Incompressible Flow past a Two Dimensional Wedge", 50th Congress of Indian Society of Theoretical & Applied Mechanics - An International Meet, Kharagpur, Dec 14-17, 2005.

29. N. S. Vikramaditya, Sudip Das, Arnab Roy and J. K. Prasad, "Effect of Width and Height Flow Field around Protrusion at Supersonic Speed", 50th Congress of Indian Society of Theoretical & Applied Mechanics – An International Meet, Kharagpur, Dec 14-17, 2005.

30. P. Gupta, Arnab Roy, Sudip Das and J. K Prasad, "Effect of Gap on the Flow Field around Sharp Fins at Supersonic Speed", 50th Congress of Indian Society of Theoretical & Applied Mechanics - An International Meet, Kharagpur, Dec 14-17, 2005.

31. A. Roy and G. Bandyopadhyay, "Numerical Simulation of Unconfined Turbulent Flow past Square Cylinder", Proceedings of Math Seminar-05, I.S.M., Dhanbad, Feb 25, 2005.

32. Y. G. Bhumker, A. Roy, S. Das and J. K. Prasad " Investigation of Two - dimensional Incompressible Flow Past a Pair of Circular Cylinders " 20th National Convention of Aerospace Engineers and National Seminar on India Aerospace : Present Scenario and Future Trends, The Institution of Engineer (India), Kerala State Centre, Thiruvananthapuram, Oct 29 – 30, 2006.

33. M. Prasath, S. Das, A. Roy and J. K. Prasad " Effect of Angle of Attack on a Rectangular Supersonic Air Intake ", 20th National Convention of Aerospace Engineers and National Seminar on Indian Aerospace : Present Scenario and Future Trends, The Institution of Engineers (India), Kerala State Centre, Thiruvananthapuram, Oct 29 – 30, 2006.

34. N. Karthik, S. Das, A. Roy and J. K. Prasad " Flow field around protrusion of Different Cross- sections at Supersonic Speed ", National Seminar on Indian Aerospace : Present Scenario and Future Trends, The Institution of Engineers (India), Kerala State Centre, Thiruvananthapuram, Oct 29 – 30, 2006.

35. M. Prasath, S. Das, A. Roy and J. K. Prasad " Behavior of Flow Field of an Isolated Rectangular An Intake at Supersonic Speed " 33rd National and 3rd International Conference on Fluid Mechanics & Fluid Power, IIT Bombay, Dec 7-9, 2006.

36. N. Karthik , S. Das, A. Roy and J. K. Prasad " Flow around Circular Cylinder on Flat Surface at Supersonic Speed " 33rd National and 3rd International Conference on Fluid Mechanics & Fluid Power, IIT Bombay, Dec 7-9, 2006.

37. G. Bhumker, A. Roy, S. Das, and J. K. Prasad " Incompressible Flow Field around Two demensred Circular Cylinders in Pair " 33rd National and 3rd International Conference on Fluid Mechanics & Fluid Power, IIT Bombay, Dec. 7-9, 2006.

38. P. Kumar, S. Das, A. Roy and J. K. Prasad " Computation of flow field around blunt times at Supersonic Speed ", 51st Congress of ISTAM (An International Meet), A. U. College of Engineering, Visakhapatnam. Dec 18 – 21, 2006.

39. S. Das, A. Roy and J. K. Prasad " Numerical simulation of combined External / Internal Compression supersonic air intake ", 51st Congress of ISTAM (An International Meet), A. U. College of Engineering, Visakhapatnaam, Dec 18 – 21, 2006.

40. Nivedita Gupta and P. C. Joshi, "Combustion Studies of Bio- diesel Droplets" Proceedings of National Seminar on Recent Advances in Energy Systems & Combustion Processes, B.I.T., Mesra, Feb 14-16, 2007, pp. 155-165.

41. H. P. Tiwari, P. K. Banerjee, R. Sharma and P. C. Joshi, "A Combustion Evaluation of Taryield from Top charged and Stamp charged Coke making Processes " Proceedings of National Seminar on Recent Advances in Energy Systems & Combustion Processes, B.I.T., Mesra, Feb 14-16, 2007, pp. 95-100.

42. Mohan Varma and Chetan R. Chodankar, "Design and Validation of a Premixed Swirl Burner for LPG - Air System", Proceedings of National Seminar on Recent Advances in Energy Systems & Combustion Processes, B.I.T., Mesra, Feb 14-16, 2007, pp. 252-263.

43. Mohan Varma and Roland Pein, "Optimization of Processing Conditions for Gel Propellant Production", 7th International Symposium on Special Topics in Chemical Propulsion, Kyoto, Japan, 2007 (Accepted).