

## Hypersonic Flight and Ground Testing Activities in India

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### Abstract

India has undertaken many hypersonic technology development programmes to meet the goals of future missions in space as well as missile development. While large scale ground based tests facilities are under construction, existing test facilities are being used to develop the preliminary design data needed for flight tests as well as for CFD code validation. A brief review of the hypersonic flight vehicle development programmes and the existing test facilities in the country along with some sample results from our laboratory for these programs is presented here.

### Introduction

The perceived advantages of hypersonic technology for space and missile applications have made many countries to initiate ambitious programmes in recent times. The success of these programmes critically depends on the ability to simulate the hypersonic flight conditions in the laboratory as well as on the flight tests using the rockets as launch vehicles. Hence many countries are involved in building large scale high speed test facilities and also flight testing to validate some of the vehicle and engine designs.

India has the capability to design and build launch vehicles and satellites. Our Polar Satellite Launch Vehicle (PSLV) and Geosynchronous Launch Vehicle (GSLV) are capable of launching 1500kg satellite into low earth sun-synchronous orbit and 2200 kg satellite into Geo Transfer Orbit (GTO), respectively, while GSLV-MK-II is being developed to launch 4000 kg satellite into GTO. In order to meet the domestic requirements Indian government has also proposed many hypersonic flight programmes which include the Space Capsule Recovery Experiment (SRE), Reusable Launch vehicle (RLV) [1], Scramjet Engine development and Hypersonic Technology Demonstrator Vehicle (HSTDV) [2]. The development of hypersonic technologies required to successfully complete these projects will depend on the ability to test the flight vehicle configurations both in the ground based test facilities as well as flight testing. For this purpose many large scale test facilities including hypersonic wind tunnel and shock tunnels are under construction and flight tests are planned for near future. However, currently existing moderate size high speed test facilities in the country are being used to obtain the preliminary design data for most of these programmes as well as to validate the CFD codes. The high enthalpy aerodynamics group in IISc has been actively involved in ground testing of many of the vehicle configurations. We present an overview of the hypersonic flight programmes and flight testing activities planned in India, the existing as well as under construction large scale ground testing facilities and our contribution to some of these programmes in the following sections.

### Spacecapsule Recovery Experiment (SRE)

The development of manned space vehicle requires the re-entry technology. In order to develop the re-entry technology India

launched the SRE project few year ago. This project was successfully completed recently when the 550 kg SRE module launched by PSLV-C7 vehicle was successfully recovered on

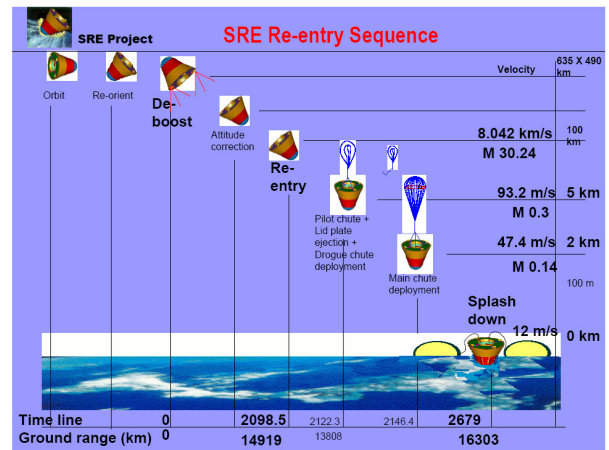


Fig. 1. Spacecapsule re-entry sequence.

Jan. 10 2007, after staying in the polar orbit for 12 days. The details of the de-orbiting manoeuvres of the SRE are shown in Fig. 1.

### Reusable Launch Vehicle (RLV)

The conventional satellite launch vehicles PSLV and GSLV are not cost effective. Hence, currently efforts are being made to develop Reusable Launch Vehicle (RLV). The proposed vehicle is a two stage to orbit configuration with a semi cryogenic winged booster and a cryogenic ballistic orbiter in which the first stage will fly back to the landing site near the launch pad like a conventional aircraft, as shown in Fig. 2.

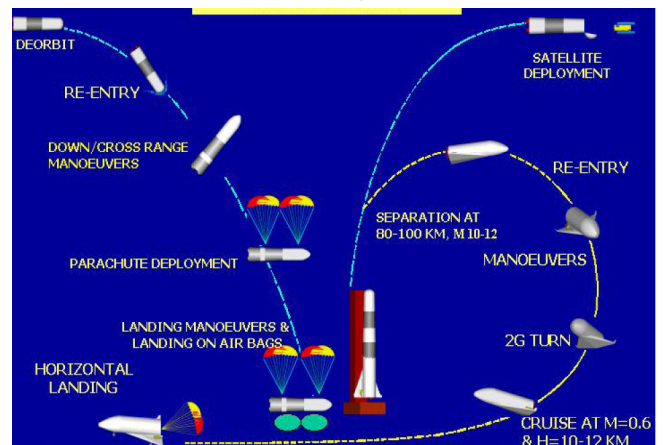


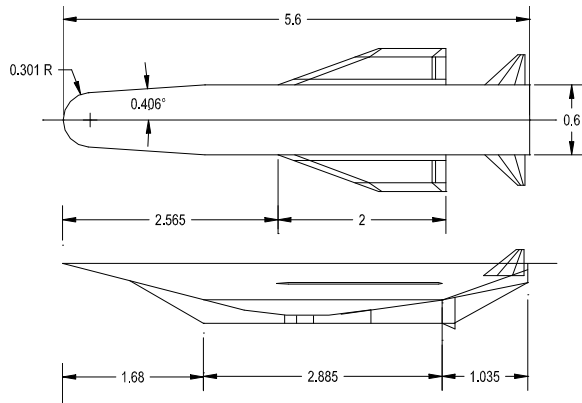
Fig.2. Fully reusable TSTO flight profile.

**Scramjet Flight Test**

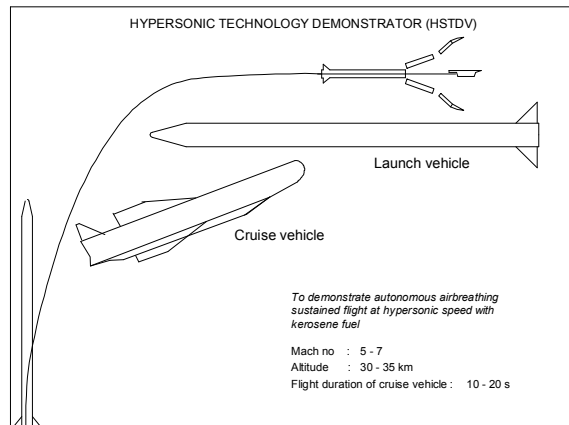
Indian Space Research Organisation has developed a hydrogen based scramjet engine. All the ground based tests have been completed using the moderate size hypersonic wind tunnel and the conventional shock tunnel available within Indian Space Research Organisation (ISRO). The flight tests using the sounding rockets will commence shortly.

**Hypersonic Technology Demonstrator Vehicle (HSTDV)**

This programme is to demonstrate a scramjet engine integrated vehicle performance in autonomous mode. In addition to proving the design and performance of the scramjet engine the HSTDV will also be able to prove the associated technologies including aerodynamic design, aero-thermal design, materials and hot structures at hypersonic flight Mach numbers. The HSTDV mission involves launching the hypersonic air-breathing vehicle called Cruise Vehicle (CV) to a Mach number of 6.5 at an altitude of 30-35 km using a rocket launch vehicle. The details of the HSTDV design and flight test are given in Fig. 3. A single scramjet engine burning kerosene fuel powers the cruise vehicle for a sustained operation of 20 second duration.



(a)



(b)

Fig. 3. Hypersonic Technology Demonstrator Vehicle configuration (a) and flight testing details (b).

**Hypersonic Ground Test Facilities**

The existing ground test facilities capable of simulating hypersonic and high enthalpy flows are mainly in the academic institutions in India. However major facilities are under

construction in various national research laboratories. A brief description of these facilities is given in the following sections.

**Indian Institute of Science (IISc)**

The department of Aerospace Engineering at IISc has been a traditional centre for hypersonics in the country. The testing facilities include a series of conventional hypersonic shock tunnels HST1 (50 mm Al shock tube and 300mmx300mm test section), HST2 (50 mm SS shock tube and 300mmx300mm test section) and HST4 (165 mm SS shock tube and 1m dia. test section) and a free piston driven hypersonic shock tunnel (FPST) HST3 (165 mm compression tube, 39/50 mm shock tube, 20 kg piston and 300mm free jet) which can be converted to a free piston driven 50mm dia. Expansion tube facility. The high speed facilities in IISc are shown in Fig. 4.



Fig. 4. Panoramic view of high enthalpy aerodynamics laboratory in IISc.

Currently efforts are being made to convert the HST4 shock tunnel to a free piston driven shock tunnel by adding a 42 m long compression tube of 600mm dia. The schematic diagram of the proposed FPST is shown in Fig. 5

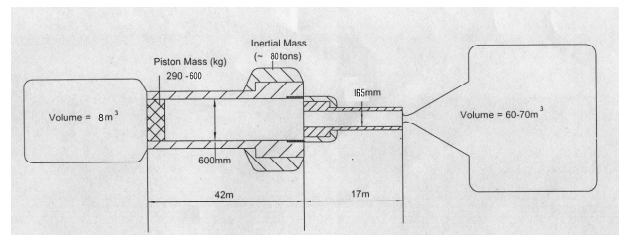
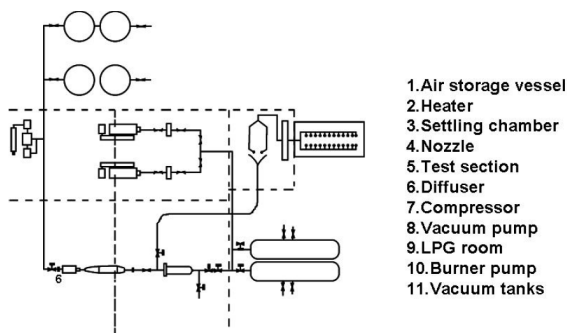
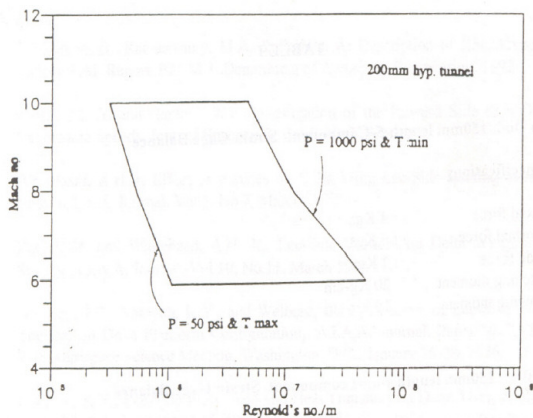


Fig.5. Schematic diagram of the proposed large scale free piston driven hypersonic shock tunnel.

The department also has a moderate size blow down type hypersonic wind tunnel, shown schematically in Fig. 6. The tunnel is capable of producing free stream Mach numbers in the range of 6-10, Reynolds numbers in the range of 1-14 millions/m and has 200 mm circular test section.



(a)



(b)

Fig.6. Schematic diagram (a) and the performance envelop of the hypersonic wind tunnel.

### Indian Institute of Technology Madras (IIT)

IIT Madras has three shock tube facilities, namely, Plunger/Pressure driven shock tube, Pressure driven shock tube, Dusty gas shock tube and Combustion driven hypersonic shock tunnel.

### Vikram Sarabai Space Centre (VSSC), Thiruvananthapuram

This laboratory under the Indian Space Research Organisation (ISRO) is involved in the development of all the rockets and launch vehicles needed for launching the Indian satellites. This centre has a moderate hypersonic wind tunnel as well as a shock tunnel. However, in order to meet the demand for ground testing of the SRE capsule, RLV and the hydrogen fuelled scramjet engine the centre is currently building a large scale hypersonic wind tunnel and also a combustion driven hypersonic shock tunnel. The specifications of these facilities are given below.

#### Hypersonic Wind Tunnel:

- Type : Intermittent pressure - vacuum blowdown
- Mach no. range : 6 to 12
- Reynolds No. : Up to 80 million/m
- Run time : 20 s
- Test section : 1.0 m diameter
- Stag. pressure : 100 bar
- Stag. Temperature : 1375 K
- Mass flow rate : 262 kg/s (max.)

#### Hypersonic Shock Tunnel:

- Velocity range : 3 to 4 km/s
- Stag. Enthalpy : 8 MJ/kg
- Run time : 1-6 ms
- Nozzle Exit Dia. : 1.0 m
- Driver pressure : 300 bar
- Type : Combustion driven (to be converted to FPST).

### Defense Research and Development Laboratory (DRDL), Hyderabad

This laboratory is involved in the development of Indian missile systems and also HSTDV. It has many aerodynamic testing facilities to meet the ground testing demands of the missile configuration. As a part of HSTDV programme the laboratory has recently commissioned a 1 m size test section hypersonic shock tunnel driven by a 180 mm dia. shock tube. This tunnel is built as a part of the large scale free piston driven hypersonic shock tunnel and the compression tube with a free piston driver will be added soon. Currently commissioning work of the tunnel is in progress.

#### Testing of Hypersonic Configurations at IISc

Since the high speed facilities in IISc cover the required test envelop of the most of the Indian hypersonic flight vehicle programmes described above, these facilities are extensively used to generate design data as well as experimental data for CFD code validation. The details of some of the tests completed recently are described in the following sections.

#### SRE

The aerodynamic testing of 1/50<sup>th</sup> scaled model of SRE was carried out in the HST2 hypersonic shock tunnel shown in Fig. 7. These tests include measurement of aerodynamic forces and heat transfer rates on the forebody and the base region at free stream Mach numbers of 8, 10 and 12 with specific stagnation enthalpy of 2.0-3.0 MJ/kg at different angles of attack.

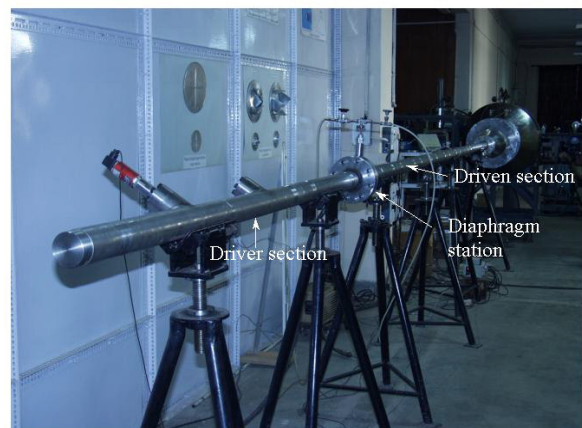
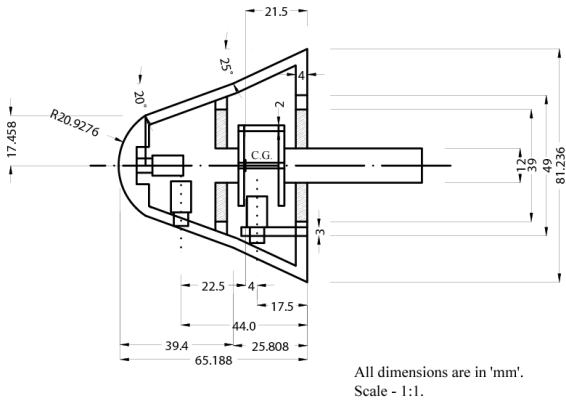
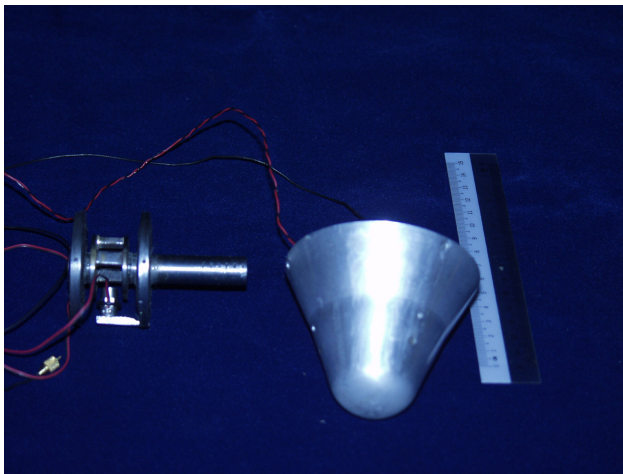


Fig. 7. Hypersonic shock tunnel HST2.

Aerodynamic forces are measured using a three component accelerometer based force balance system [3]. The schematic diagram and the photograph of the SRE test model fitted with the accelerometer balance system are shown in Fig. 8.



(a)



(b)

Fig.8. Schematic diagram (a) and photograph (b) of the SRE test model along with the force balance system.

Typical experimental data obtained for the SRE model is shown in Fig. 9.

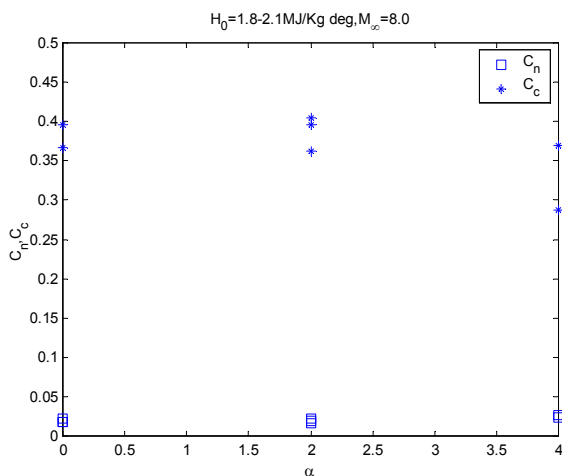
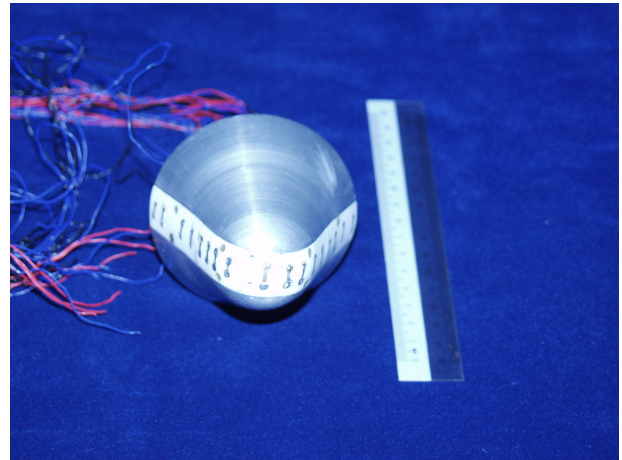
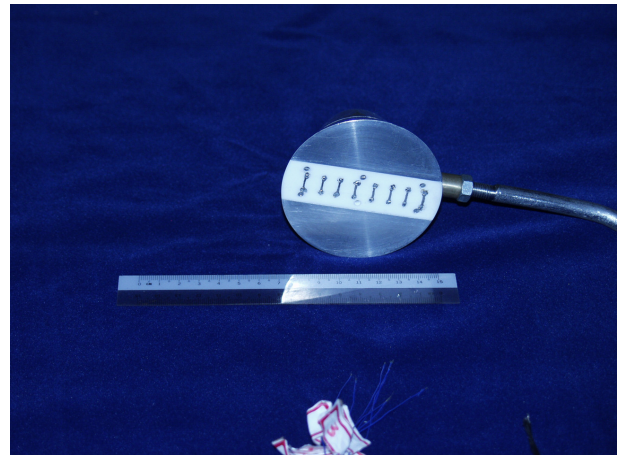


Fig.9. Typical measured aerodynamic forces for the SRE model.

The heat transfer rates for the SRE model were measured using surface mounted platinum thin film gauges on a MECOR substrate, as shown in Fig. 10. The CFD analysis



(a)



(b)

Fig.10. SRE model with platinum thin film heat transfer sensors (a) on the forebody and (b) on the base.

of the flow around the SRE model had shown that the reverse flow behind model becomes supersonic during the reentry phase and the heating rates at the model base were predicted to be as high as 10% of the stagnation point heating rate. This necessitates providing a thermal protection system at the base of the model, which adds to the complexity to the vehicle design. This issue was resolved by measuring the heating rates at the base of the model which was mounted in the test section with a side support. The measurements showed that the heating rates at the base were below 3-4% of the stagnation point heating rate. Typical heat transfer data obtained in the HST2 tunnel are shown in Fig. 11.

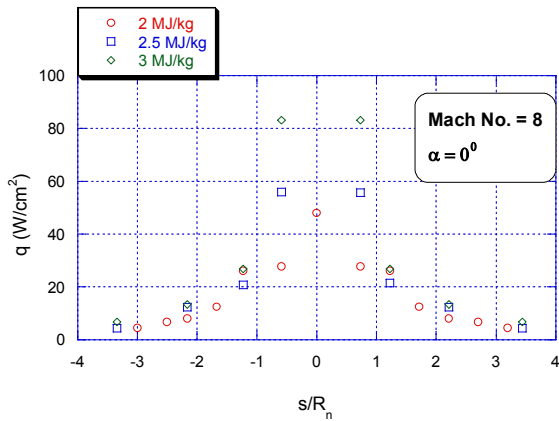
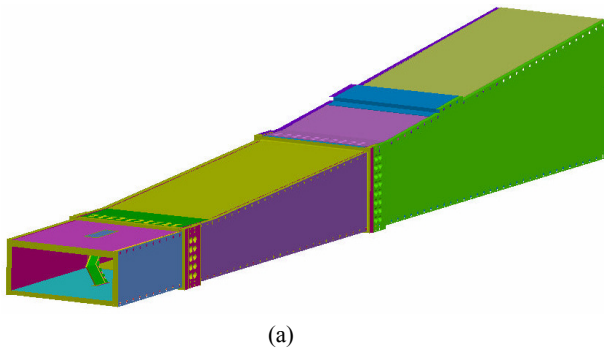


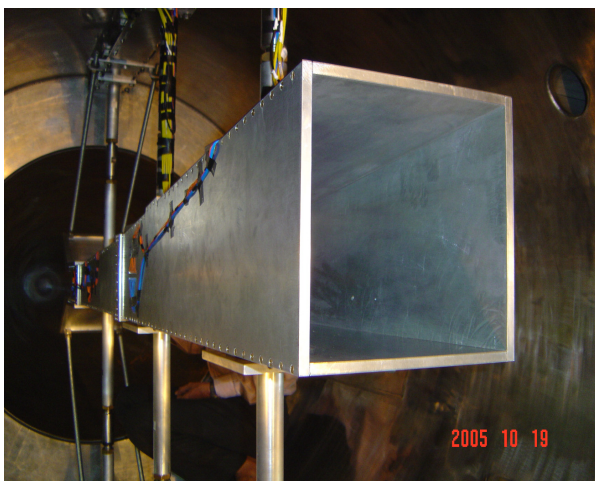
Fig. 11. Typical measured heat transfer rates for the SRE model.

### Hydrocarbon fuelled scramjet combustor

The proposed HSTDV will be powered by a scramjet engine using hydrocarbon fuel injected through a set of staggered struts. The aerodynamic characteristics of the full scale scramjet combustor designed by the DRDL with and without struts were measured in the HST4 shock tunnel. The design of 1.8 m long scramjet combustor with rectangular cross section of 100mm x 230 mm at the inlet and 250mm x 230 mm at the outlet is shown in Fig. 12 (a).



(a)



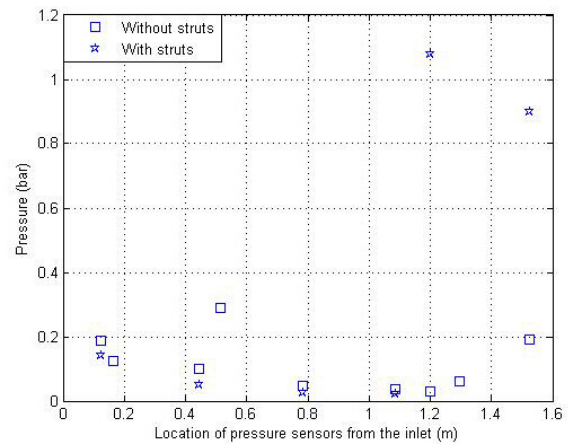
(b)

Fig. 12. The scramjet combustor (a) design and (b) mounted inside the HST4 test section.

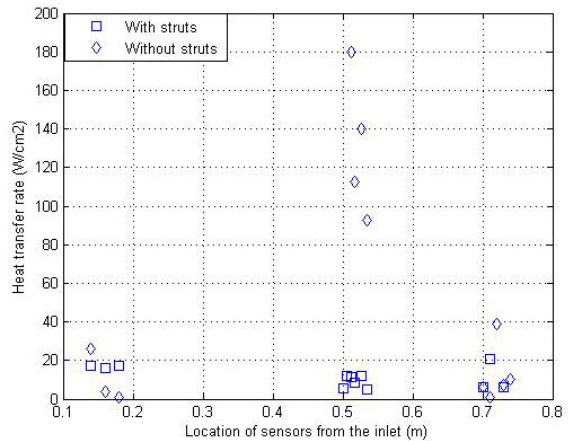
The tests carried out included measurement of static pressure and heat flux distribution along the inner surface of the combustor

and the overall drag of the model with and without fuel injecting struts. The model mounted inside the HST4 shock tunnel is shown in Fig. 12 (b).

The aerodynamic drag for the scramjet combustor was measured using the accelerometer balance system. The model was mounted on linear bearings mounted on supporting plates such that it moves freely during the flow. The accelerometer signals from the four accelerometers mounted flush with the outer surface of the freely floating model were used to calculate the aerodynamic drag force experienced by the model due to the supersonic flow through the model. The static pressure distribution along the combustor was measured using Kulite pressure transducers and the heat flux distribution was measured using the surface mounted platinum thin film gauges. Typical measured pressure and heat flux distributions are shown in Fig. 13.



(a)



(b)

Fig. 13. Typical distribution of pressure (a) and heat flux (b) along the inner surface of the scramjet combustor with and without struts.

### HSTDV

The intake studies of the scale model of HSTDV designed by DRDL were carried out in HST4 shock tunnel without control surfaces. The scale model of HSTDV with mounting details is shown in Fig. 14.

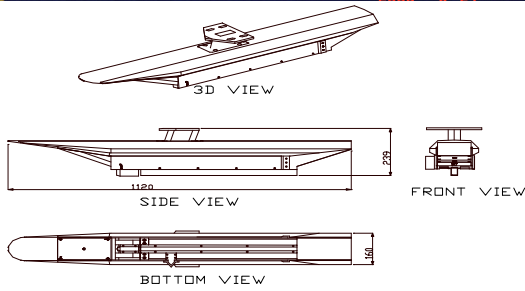
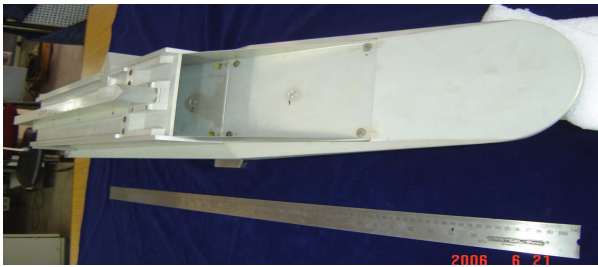


Fig. 14. Scale model of HSTDV along with the mounting details.

The intake tests included measuring the static pressure on the compression ramp and the scramjet combustor for different angles of attack. The pressure was measured using Kulite pressure transducers mounted on the model as shown in Fig. 15. Typical distribution of static pressure measured in the HST4 shock tunnel are also shown in Fig. 15.

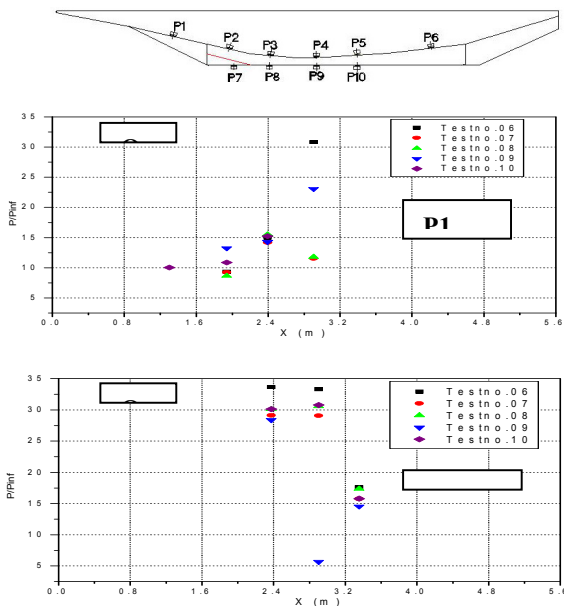


Fig. 15. Typical pressure distribution for HSTDV measured in HST4 shock tunnel.

### Conclusions

The enhanced interest in hypersonic flight and ground testing activities in India is evident from the review presented here. The

envisaged programmes are utilising the high speed tests facilities available, mostly in academic institutions, to generate preliminary design data for these missions. In addition, these facilities are used as prototypes to the large scale test facilities which are being constructed in various national laboratories involved in the future hypersonic missions. In addition to the programmes reviewed here India is also pursuing other missions like Moon Mission (Chandrayaan) to map the conditions on Moon, flight testing of hydrogen fuelled scramjet engine using sounding rockets and enhancing the flight Mach number of supersonic missile to hypersonic regime.

### Acknowledgements

Large number of technicians and scientists both from the National Laboratories and High Enthalpy Aerodynamics Laboratory of IISc were involved in the work reported here. I would like to thank all of them and also express my sincere thanks to Prof. G. Jagadeesh and Dr. S. Saravanan who are co-investigators in many of these projects.

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