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# Development of the Facility for Model Scramjet Testing

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**Abstract**

A hypersonic propulsion test facility has been constructed in IMCAS (Institute of Mechanics, Chinese Academy of Sciences) in order to provide a high enthalpy hypersonic flow for a model scramjet testing. The vitiated air is produced by a hydrogen/air and oxygen replenishment combustion heater with flow rate of 3.5kg/s, total pressure of 5MPa and total temperature of 2000K in maximum, and accelerated up to Mach 5.6 by a two-dimensional nozzle. Test chamber of the facility is evacuated by a one-stage central air ejector. The preliminary facility performance tests showed that the vitiated air heater could provide the high enthalpy flow as expected. A copper model scramjet without cooling is ready for testing.

**Key words:** hypersonic propulsion test facility, supersonic combustion, model scramjet



## 1. Introduction

As a strong candidate for air-breathing hypersonic propulsion system, scramjet has been investigated since 1950's[1-10]. Because of the extreme complicacy of its mechanics and technology, so far flight scramjet-powered vehicle has not been reported yet.

In order to understand the fundamental phenomena of scramjet, studies on supersonic combustion have been conducted in IMCAS since 1994. So far, many different configurations of combustor, wall and strut injections and wall cavities were investigated with hydrogen or/and kerosene fuel by using a directly connected vitiated supersonic combustion test facility. The mixing, ignition and combustion properties in the supersonic flow were studied to understand the performance of the combustor [11-15].

To extend research for this combustor component to an entire model scramjet, a hypersonic propulsion test facility (HPTF) has been constructed for the fundamental studies in IMCAS, supported by Chinese Academy of Sciences.

The present paper introduces HPTF description, the main flow performance and preliminary testing results.

## 2. Facility Description

The IMCAS HPTF is a high enthalpy free jet facility for testing a model scramjet. It consists of a high-pressure gases supply system, a vitiated heater, a supersonic nozzle, a test chamber, an ejector exhaust and a silencer tower, as shown in Fig. 1.

The gas supply system includes two air compressors, four 4m$^3$ air tanks and eighty battles divided into four rooms to provide hydrogen, oxygen, nitrogen and air. One air tank normally compressed to 15MPa is used for supply air as the main flow. Other three with 8MPa are used for the air ejector.

Fig. 2 shows the heater for increasing the total pressure and temperature of the main air flow. Premixed hydrogen and air is firstly introduced into the heater and ignited by four high-voltage sparks, forming a pilot flame. Then the main air, hydrogen and oxygen replenishment are ignited by the pilot flame and burn in the heater. Air is introduced downstream end of the heater, and goes back to

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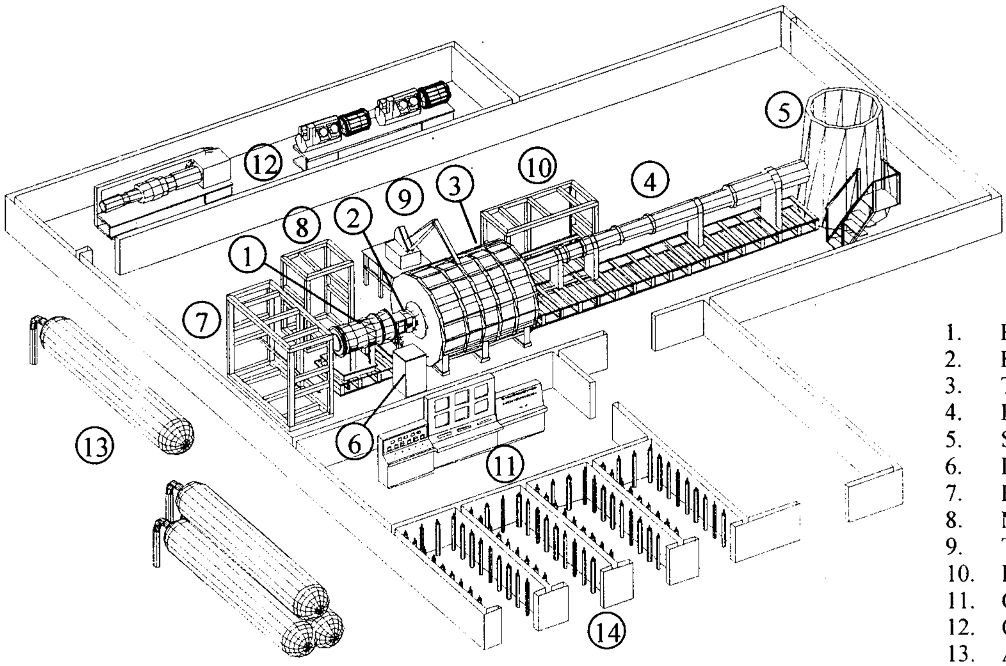
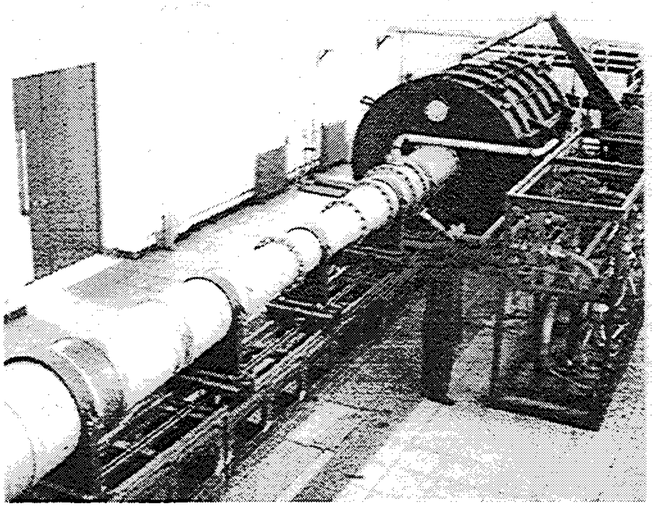
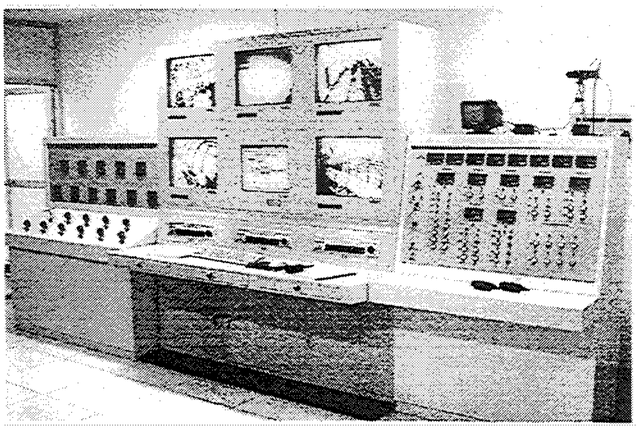



(a) Schematic of HPTF



(b) Photograph of the Facility



(c) Photograph of the Control Room

Fig. 1 Hypersonic propulsion test facility for testing model scramjets

upstream side along the wall as a coolant. The heater, 310mm in inner diameter and 600mm in length, can endure the pressure of 5MPa and temperature of 2000K respectively, and provide the gas flow rate up to 3.5 kg/s.

The supersonic nozzle, as shown in Fig. 3, was designed by means of characteristic line. It will accelerate the high enthalpy air flow up to Mach number of 5.6. The nozzle is two-dimensional with exit cross section of 300mm in width and 187mm in height. The dimension of the throat of the nozzle is consequently 3.6mm in width and 187mm in height by taking boundary layer thickness into account.

The test chamber, as shown in Fig. 4, is a cylindrical tank with 2m in diameter and 3m in length. Upper side of the tank can be opened by machine for

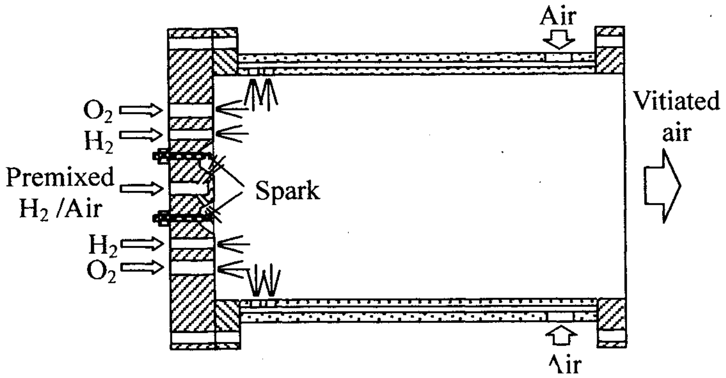


Fig. 2 Vitiated are heater

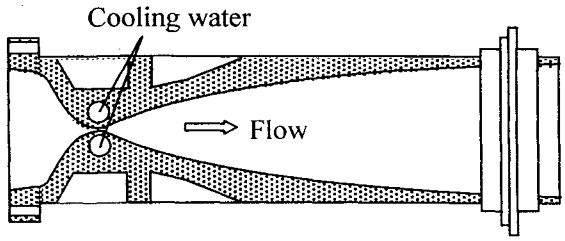


Fig. 3 Facility nozzle

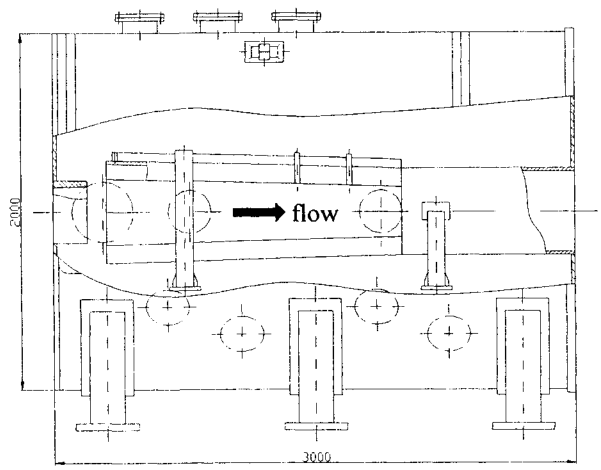


Fig. 4 Test chamber

Table 1 HPTF configurations

| | | |
|---|---|---|
| Test chamber | | $\phi$2m × L3m |
| Freejet | Mach number* | 5.6 |
| | Total temperature | 2000K |
| | Total pressure | 5MPa |
| | Static temperature | 320K |
| | Static pressure | 4kPa |
| | Flow rate | 3.5kg/s |
| Nozzle | Geometry | 2-D rectangular |
| | Exit size | 30cm × 18.7cm |
| | Length | 115cm |
| Ejector | Type | Central 1-stage |
| | Gas | Air |
| | Flow rate | 23kg/s |
| Testing duration | | <10s |

the convenience for setting test model and its maintenance. Three pairs of flow visualization windows are located 280mm, 880mm and 1980mm downstream from the chamber beginning respectively, which are designed for Schlieren photographing, laser diagnostics and other observations. A safety vent is located top of the annular wall close to the end lid of the chamber.

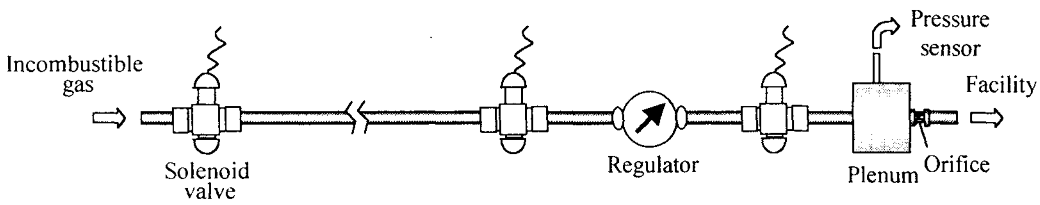
A single-stage central ejector connected to the test chamber serves as an exhaust system to evacuate the test chamber to the designed pressure and to exhaust the gas flows from the supersonic nozzle and model scramjet. The ejector operates with normal air at working pressure around 3MPa, mass flow rate of 23kg/s and nozzle exit Mach number of 4.2. By using this ejector, the pressure in the test chamber is expected to be 4kPa during a typical test run which corresponds to the flight altitude around 25km.

Finally, a vertically standing concrete duct with 200mm in thickness and 2m in inner-diameter is connected to the ejector system and serves as a silencer as well as a exhaust pipe transmitting all exhaust gases to the atmosphere.

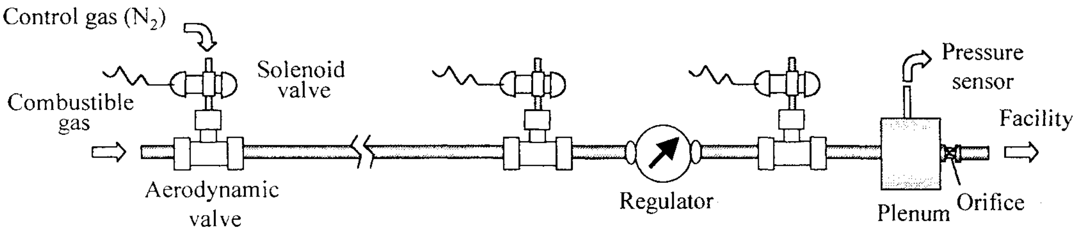
The configurations of the facility is concluded in Table 1.

### 3. Control and data acquirement systems

All 12 lines of various gases, including 6 lines supplying hydrogen, oxygen, nitrogen and air to the heater, 5 lines providing fuel such as gaseous hydrogen, gaseous hydro-carbon and liquid kerosene, and one line sending air to the ejector, are controlled both automatically and manually. About 40 electric-magnetic valves are used in these lines and operated by computer program. For safety reasons, each line is controlled by 3 valves and a regulator and works individually in a well-controlled time sequence. Fig. 5 shows the valve units used in combustible and incombustible gas supply lines. In an incombustible gas line, as shown in Fig. 5 (a), three high pressure




(a) Incombustible gas line




(b) Combustible gas line

Fig. 5 Valve units for gas supply lines

solenoid valves controlled by computer automatically and manually are used. The regulator provides desire pressure in the plenum. The flow rate of the gas can be calculated by the plenum pressure and a sonic orifice. As shown in Fig. 5 (b), each valve used in the combustible gas supply lines consists of an aerodynamic valve and a solenoid valve. The aerodynamic valve opens when the control gas passes through the solenoid valve and closes when it shut off. For safety consideration, nitrogen is used as the control gas.

38 digital pressure gauges are used to monitoring the pressure situations of the test chamber and all interested point in gas supply lines. The outputs are also recorded by a data acquisition system. 150 pressure channels are prepared for future static pressure measurements on a model scramjet. Other 40 channels are also designed for heat flux measurements.

3 pairs of observation windows located on the annual wall of the test chamber allow the laser and other optical visualizations access.

A force measurement system consisting of a 6 components force balance and its computer analysis system will also be used to measure the scramjet thrust, drag, lift and pitching forces during the test runs.

Five television monitors and three video recorders are used for monitoring and recording the facility and model scramjet behaviors.

**4. Facility operation sequence**

After setting both of regulators of each line to designed pressures and programmed valve actions, a facility run is started with the ejector operation, as shown in Fig. 6. Two seconds later, when the test chamber reaches the designed pressure, the premixed hydrogen/air is introduced and ignited by four discharging sparks. After one second, main air, hydrogen and oxygen are simultaneously injected into the heater in which a vitiated high pressure and high temperature gas mixture is generated. Then one second later, fuel (hydrogen or kerosene) is injected into the combustor of the model scramjet, once scramjet in test. After 4 seconds, all valves are shutdown except the ejector. At the same time, nitrogen gas is introduced to purge all combustible gas lines, the heater and the test chamber. Furthermore two seconds later, the nitrogen and air ejector are closed, meaning the run is terminated.

In a typical case, the run time and model scramjet test duration are 10s and 4s, respectively.

**5. Preliminary results and discussions**

Before the model scramjet test, several preliminary tests were conducted for the facility

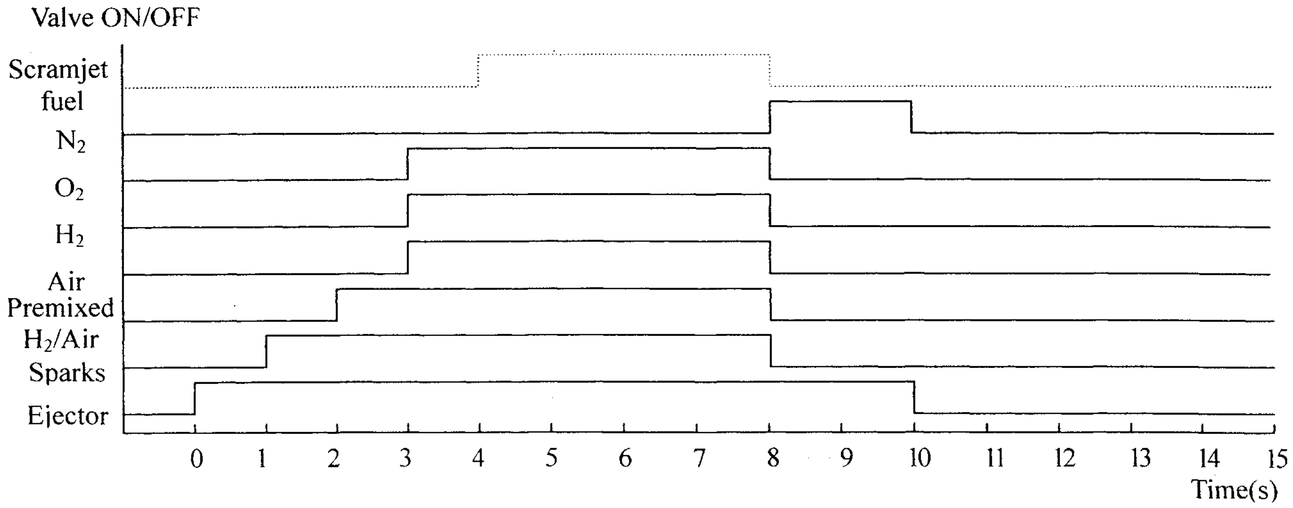



Fig. 6 A typical valve operation sequence of HPTF

performance examinations.

5.1 Vitiated air heater performance

In order to check the operability of valves used in gas supply lines and ignition characteristics, several short runs were conducted. As a typical run, Fig. 7 shows the stagnation pressures in plenum upstream each orifice in gas supply lines. Additionally, the stagnation pressure and temperature in the vitiated air heater are also shown in the same figure.

At t=0s, air and hydrogen for ignition are injected into a small mixing tank attached the heater and then injected into the heater. The mixture is ignited by the four sparks, which start to discharge at t=-1s, and forms a pilot flame. The main air, hydrogen and oxygen are injected into the heater at t=1s, showing sharp pressure increase in their plenums. Almost at the same time the stagnation pressure in the heater, Pt, gradually increases and then reaches its stable value around 30 atm at t=3.8s. The test was terminated at t=5s by shutdown of all valves and opening purge nitrogen with 2 seconds duration.

The smooth Pt curve shows that both the combustion in the heater and gas supplies are stable during the run. About four seconds are necessary to reach the desire stable pressure.

A little increase on Tt before main gases injection is due to the pilot flame. The combustion of main air and hydrogen causes the sharp increase on Tt between t=1s and t=2s. The gradually increase following it must be due to the gradually decreases of

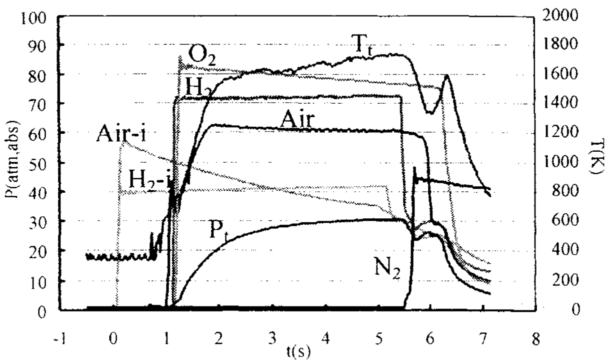



Fig. 7 Pressure and temperature distributions for a typical test run

main air and oxygen.

In this run, the designed pressure and temperature are 30 atm and 1700K, respectively. The goal is well achieved by setting plenum pressures and by using selected orifices.

5.2 Ejector performance tests

Fig. 8 shows pressure changes of the ejector plenum and the test chamber in two typical test runs. In case of shot 1, the ejector plenum pressure reaches its stable value, 1MPa, at t=1.5s and keeps that during the run. Corresponding to this pressure change, the pressure in the test chamber decreases and then keeps a stable value around 63kPa. The peak on $P_{ejector}$ is considered to be due to the instability of regulators used in ejector gas supply lines.

When the ejector plenum pressure increases to 1.2MPa represented as shot 2 in Fig.8, the pressure in the test chamber dropped to 53kPa. These two shots have similar behavior, showing that the ejector gas supply system is stable.

Interestingly, while the $P_{chamber}$ drops 10kPa as the $P_{ejector}$ raises 0.2MPa at lower region around 1MPa, the $P_{chamber}$ only drops about 5kPa for same $P_{ejector}$ change at higher region around 1.8MPa.

## 6. Conclusions and future works

As the first facility for model scramjet testing in China, HPTF has been constructed in IMCAS. The preliminary test runs showed that:

(1) The gas supply lines including computer programmed valve units, gas regulators and orifice flow meters were working well. The pressure and temperature data were acquired as designed.

(2) The vitiated air heater showed good heating performance. By selecting regulator pressures and orifice flow meters, the heater could provide the test flow at designed pressure, temperature and flow rate.

(3) The test chamber pressure drops were in good correspondence with raising ejector plenum pressure.

The followings experiments are planned in the near future:

(1) Decrease the test chamber pressure to the designed value by increasing the ejector plenum pressure up to 3MPa.

(2) A water-cooling pitot rake and a schlieren observation system will be used in certifications of flow performance from the facility nozzle.

(3) A heat sink typed model scramjet shown in Fig. 9 and Table 2 will be tested. The combustor size is as same as our directly connected facility. As the first test model, there is not any fuel injection in it. The main aims of this model are to exam the model structure endurance against the heat damage and pressure load of the test flow, to check the facility nozzle starting and to confirm the operability of control and data acquirement systems.

(4) Based on the results of the first model tests, a new model will be designed and fabricated with hydrogen fuel injection.

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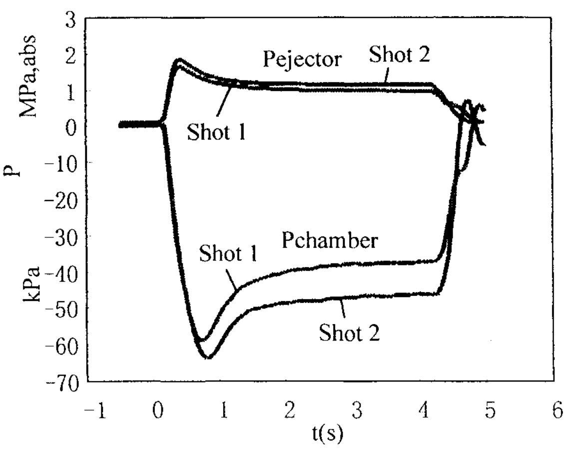


Fig. 8 Pressure distributions of ejector plenum and test chamber

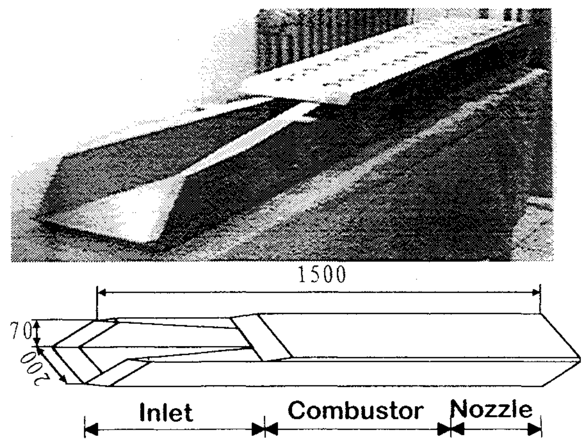


Fig. 9 Model scramjet

Table 2 Model scramjet configurations

| | | |
|---|---|---|
| INLET | Entracesize | 200X70 |
| | Sweep angle | 45° |
| | Contraction ratio | 4 |
| | Compression angle | 9° |
| CONBUSTOR | Size | 50X70 |
| | Length | 600 |
| NOZZLE | Expansion ratio | 1.7 |
| | Length | 300 |

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