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Design of a Non-Diaphragm Driver for the UFABC Hypersonic Wind Tunnel

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Abstract **— Laboratory study of hypersonic vehicles and air-breathing engines such as "waveriders" and scramjets demands experimental facilities capable of simulating fligths at Mach numbers in excess of 5 with high stagnation temperatures. This paper shows the design and operational principle of a non-diaphragm driver for a hypersonic impulse wind tunnel at Universidade Federal do ABC (UFABC). Such a diaphragmless driver operates without the necessity of using the conventional diaphragm. Experimental advantages of using the non-diaphragm driver are much cleaner flowfields, no erratic runs, good reproducibility and costliness setup of the facility within minutes.**

Keywords **— Hypervelocity, Wind tunnel, Design**

I. Introduction

Hypersonic wind tunnels are ground-based experimental facilities capable of simultaneously duplicating scale, enthalpy level, pressure and stream flow around bodies at hypervelocities. Simple shock tunnels are impulse test facility which heats and pressurizes a stagnant gas prior to supply it to a Laval nozzle, where the gas is rapidly expanded into a test chamber as shown in Fig. 1. The benefits to this technique are that flight velocity up to Mach 20 can be simulated. Impulse hypersonic test facilities are limited to milliseconds of run time because of the timing of the moving shock and the length of the reservoir. Usually, they are very large and are well suited for aerothermodynamics studies associated with hypersonic speeds [1].

Currently, the 0.6-m Diameter Hypersonic High Enthalpy Real Gas Pulsed Reflected Shock Tunnel (T3) is the only national asset capable of simulating the high enthalpy that would be experienced by vehicles during hypersonic flight.

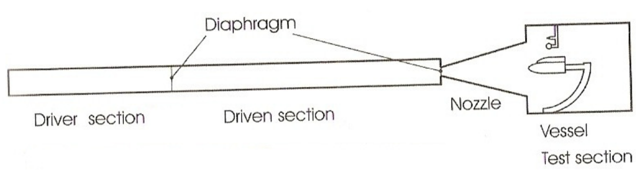

Fig. 1. Scheme of a conventional shock tunnel for hypervelocity research (adapted from [1]).

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Fig. 2 shows the T3 which is installed at the Laboratory of Aerothermo-dynamics and Hypersonics of the Institute for Advanced Studies (IEAv) and under the Brazilian Air Force administration The T3 can generate free-stream Mach numbers ranging from 6 to 25 and stagnation pressures and temperatures of 200 atm and 5500 K, respectively with run times within 2 and 10 milliseconds making supersonic combustion and hypersonic flight experiments possible [2].

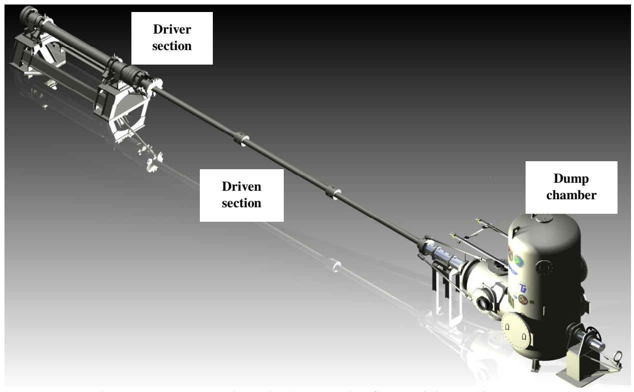

Fig. 2. Hypersonic wind tunnel of Brazilian Air Force (picture courtesy IEAv).

A new type of hypersonic facility is being designed by the Universidade Federal do ABC (UFABC) in cooperation with the high-speed experimentalists from IEAv for experimentation on "waveriders" and scramjet engines. A non-diaphragm driver technique is being suggested in order to replace the necessity of utilizing any diaphragm to operate the simple shock tunnel. The benefits of using such an advanced shock tunnel driver are cleaner flowfields without fragments of ruptured diaphragm, more controllable operation without erratic run and much easier and quicker setups. Fig. 3 shows the capability (in terms of flight velocity and run time) of various types and existing hypersonic test facilities for simulating hypersonic flow in comparison with the T3 and the envisaged UFABC hypersonic wind tunnel.

Next, the details on the design of the non-diaphragm driver of the UFABC hypersonic wind tunnel are given followed by its principle of operation. The paper is summarized in Conclusions.

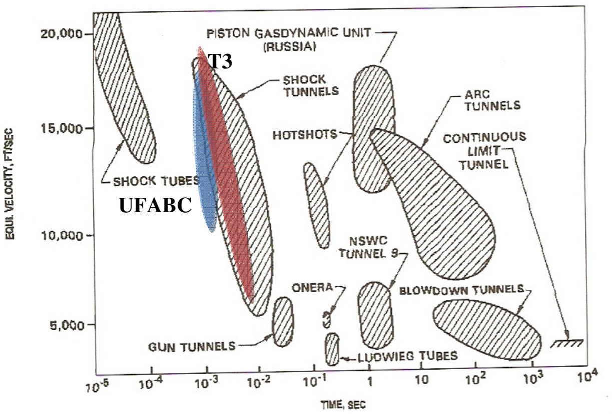

Fig. 3. Comparative capability of envisaged UFABC wind tunnel, T3 and existing facilities (Adapted from [1]).

II. DIAPHRAGMLESS DRIVER SECTION DESIGN

The UFABC hypersonic wind tunnel will be driven by a diaphragmless section as shown in Fig. 4. Its design will be a variation of the double-piston actuated driver [3-4].

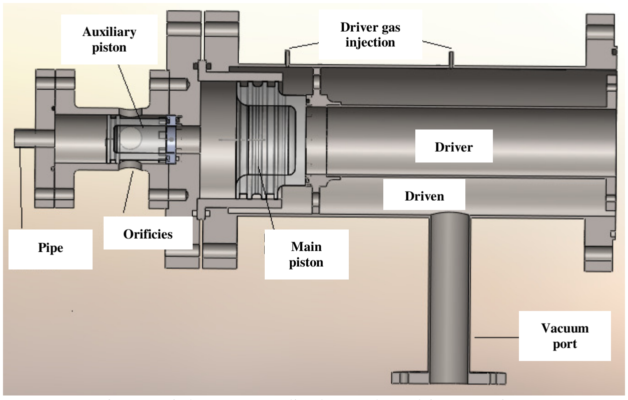

Fig. 4. High-pressure diaphragmless driver section.

Gas feed lines

The driver section is fitted with gas feed lines through which driver and auxiliary gases can be introduced into the driver section at pressures of above 5 MP. They can be either rigid or flexible stainless steel pipes. Exhaust pipe and high-conductance orifices constitute the exhaust ports of the driver section. Through both the auxiliary gas the driver section is purged to atmosphere during operation. Also, a vacuum port is available depending on the experiment needs. The number of pipes and orifices and their conductance impacts directly on the sliding process of the pistons, thereby, the sliding time (analogous to the opening time of a usual diaphragm).

Solenoid valves

The sliding process of both pistons is initiated by solenoid valves. The exhaust pipe (see Fig. 4) attached to the rear flange of the driver section are connected to solenoid valve. The solenoid should be able to deal with pressure differences of 5 MPa. The opening time of the solenoid is vital to the quick movement of the pistons.

Auxiliary piston

Fig. 5 shows the configuration of the auxiliary sliding piston used to actuate the main piston. The auxiliary piston is actuated by the solenoid valve. The auxiliary piston is hollow and elaborately shaped. There is a piston O-ring employed on its lateral surface and a low-conductance hole perforated thought the center line of its base. The actual auxiliary piston configuration aims to save its total mass while reduces the contact area, thereby, the friction during its movement. The auxiliary piston should be made of lightweight plastic materials with good impact resistance. The auxiliary piston can slides back and forward into a piston cylinder when actuated due to a clearance in between both. The squeeze of the piston O-ring in its groove should be such that prevents gas leakage from the auxiliary chamber to the atmosphere while ensures that the friction force due to the compression of the piston O-ring will not retard the piston motion seriously.

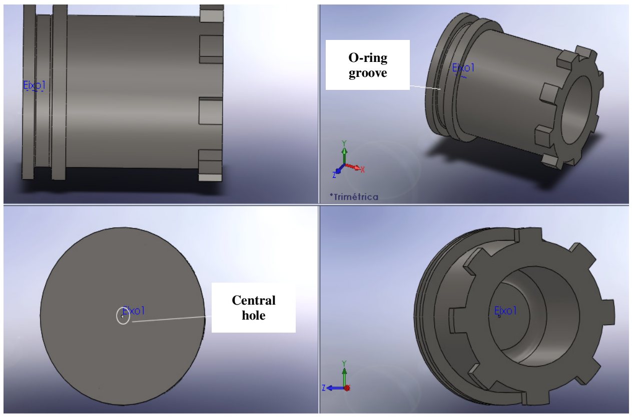

Fig. 5. Auxiliary sliding piston.

Interchangeable O-ring grooves

There is an O-ring opposite to the face of the auxiliary piston (see Fig. 4) whose function is to seal actuating gas from atmospheric environment. This O-ring cannot strips from its groove during the inrush of actuating gas otherwise reliable operation would not be possible. In order to overcome such a failure and ensure reliable operation of the auxiliary piston, grooved flanges with different groove dimensions and geometry were designed with the intention of capturing the O-ring as shown in Fig. 6.

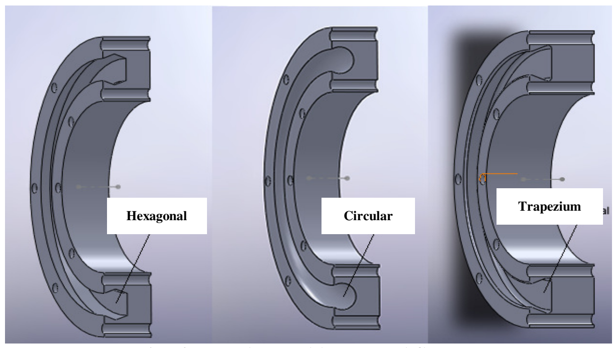

Fig. 6. Interchangeable grooved flanges.

Also there is an O-ring opposite to the face of the main piston (see Fig. 4) whose function is to seal driver gas from driven one. This O-ring must not be stripped by the inrush of driver gas during the piston sliding process, otherwise reliable operation would not be achieved. Likewise, interchangeable grooved flanges were designed with the intention of keeping the O-ring in place.

Main piston

Fig. 7 shows the main piston used to separate the high-pressure region from the low-pressure one. The main piston is hollow and elaborately shaped. There are two O-rings on its lateral surface. The actual main piston configuration aims to save its total mass, lower its contact area, i.e., friction and prevent somehow from fractures and cracks during the its rapid movement. The main piston should be made of lightweight plastic materials with good impact resistance. The main piston can slides back and forward when actuated into a hollow piston cylinder due to a clearance in between both. The squeeze of both piston O-rings in their groove should be such that prevents gas leakage from the auxiliary chamber to the driver-gas chamber and vice versa as well as ensures that the friction force due to the elastic deformation of the piston O-rings would not dramatically decelerate the piston during the sliding process.

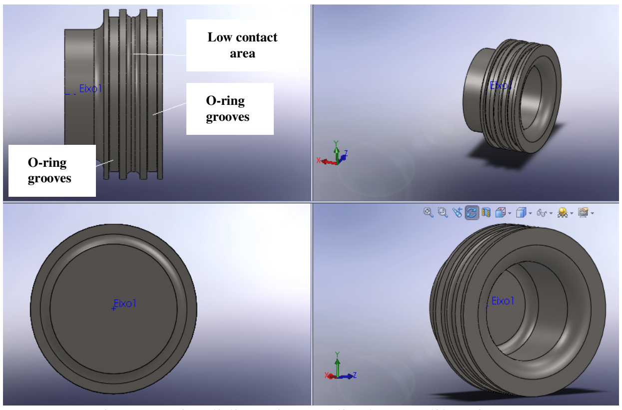

Fig. 7. Main sliding piston (diaphragm-like piston).

III. Diaphragmless Driver Section Operations

The double piston-actuated driver (see Fig. 4) does not employ any diaphragm as the simple shock tunnel does in order to operate. Fig. 8 illustrates how the non-diaphragm driver section operates. The role of generating running shocks by means of the diaphragmless driver technique is explained as follows: **A**. An actuating gas at pressures around 4 MPa is supplied through a gas feed line to the auxiliary chamber. As the inside of the actuating chamber is filled, the pistons slide forward. The auxiliary piston shuts the passage between the auxiliary chamber and the atmosphere environment while the main piston shuts a passage between the driver chamber and the driven Driver gas is introduced into the driver chamber (through a gas feed line) with a pressure slightly lower than the pressure in the auxiliary chamber one. Such a pressure is equivalent to P_4 in shock tube theory. The driver gas is then sealed in its chamber with the main piston; **B**. By rapidly purging the actuating gas from the rear of the auxiliary piston via the solenoid valve, the auxiliary piston is quickly actuated backward due to a pressure imbalance across its base. This allows the rest of the actuating gas to escape massively through various high-conductance orifices on the piston tube open to the ambient air; **C**. Now, due to a pressure imbalance across the base of the main piston, such a piston backs rapidly driven by P_4, opening the passage for the driver gas which discharges into the driven section (low-pressure section), thereby generating compression waves that travels downstream into the driven section.

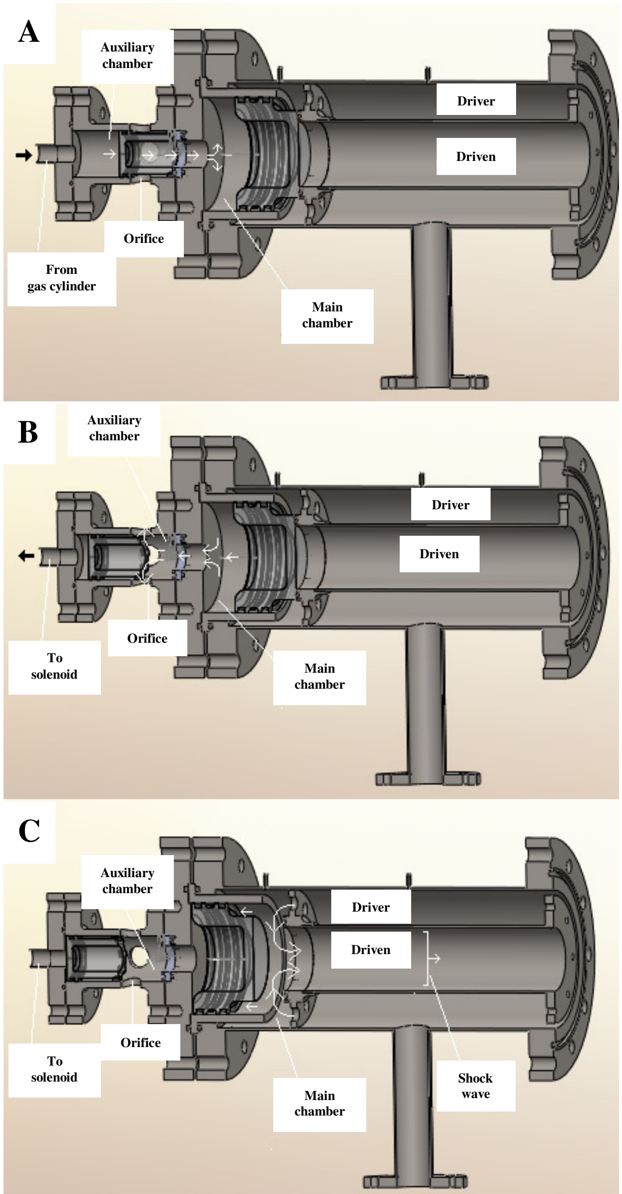

Fig. 8. Schematic drawing of shock generation for the driver section.

References [3-4] show that the preparation of the hypersonic wind tunnel driving by a non-diaphragm driver of this type takes only 15 minutes or so without using much effort. Also, erratic runs and fragments of ruptured diaphragm into the downstream flow are not expected simply because there is no diaphragm to be bursted. However, the main disadvantage of diaphragmless driver is that its "opening time" is approximately of the order of 10 times higher than that of the conventional diaphragm (of the order of 0,1 ms) meaning that the strength of the running shock wave will be lower, thereby, limiting the maximum Laval nozzle speed of the air flow into the test section of the wind tunnel.

IV. Conclusions

A novel wind tunnel for experimentation on aerothermodynamics and hypersonics is being designed by the Universidade Federal do ABC in partnership with the Institute of Advanced Studies of the Brazilian Air Force. The UFABC hypersonic shock tunnel will employ a non-diaphragm driver technique whose main advantages over the simple shock tunnel are fragment-free flowfield, no erratic runs, good reproducibility and costliness and quick preparation of the facility. The design of the double-piston actuated driver section was preliminarily shown and its principle of operation elucidated. Future tasks for completion of the design of the UFABC hypersonic wind tunnel will include simulations on internal flows, design of a driven section (low-pressure section), supersonic nozzles, test sections and dump chambers. While there remains much work to do, the prospects of developing the first Brazilian diaphragmless wind tunnel for hypersonic research appear good.

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