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THERMOACOUSTIC ENVIRONMENTS TO SIMULATE REENTRY CONDITIONS *

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ABSTRACT

Aerothermal environments as encountered during the reentry of spaceplanes or during the cruise of hypersonic aircrafts represent complex loading conditions for the external structures of those vehicles. In order to shield against the aerodynamic heating a special Thermal Protection System (TPS) is required which is designed as a light weight structure to reduce the weight penalty.TPS is therefore vulnerable to vibroacoustic fatigue caused by the pressure fluctuations of the environment (1), (2).

Because of the complex interactions between the loading forces and the resulting structural response which make an analytical treatment difficult and in order to provide means for fatigue testing IABG has designed and built a thermoacoustic facility which recently became operational. The facility is capable to produce surface temperatures up to 1.300 °C at sound pressure levels up to 160 dB. This paper describes the design of the facility, some operational test work it also deals with problems associated with the facility instrumentation.

INTRODUCTION

Thermoacoustic environments are composed of vibroacoustic and thermal loadings of varying severity. Depending on the mission of the vehicle the nature of these environments may be different. A general survey is as follows

MISSION PHASE	ORIGIN	SEVERITY
LIFT-OFF LAUNCHER	PROPULSION SYSTEM	
	Radiated Noise	severe
	Radiated Heat	moderate
TRANSONIC LAUNCHER	AERODYNAMIC EFFECTS	
	Separated Flows	severe
	Aerodynamic Heating	moderate
CRUISE OF HYPERSONIC VEHICLES	AERODYNAMIC EFFECTS	
	Boundary Layer Noise	remarkable
	Aerodynamic Heating	severe
REENTRY OF SPACE-PLANES	AERODYNAMIC EFFECTS	
	Boundary L./Separated Fl.	remarkable
	Aerodynamic Heating	severe

The objective was to simulate these environments with respect to their acoustic and thermal components. The approach taken consisted in the use of an excisting Progressive Wave Tube (PWT) to generate the acoustic loading with the addition of a specific heating system.

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FACILITY DESIGN

The selection of an appropriate heating system is a crucial point because of the required compatibility with the acoustic environment. A comparison between the often used quartz lamps and a flame system is given below

	QUARTZ LAMPS	FLAME SYSTEM
CONTROL	GOOD	MODERATE
SURFACE TEMP:	max. 560 °C	> 1.300 °C
FATIGUE LIFE	POOR	NO PROBLEMS
OPERATION	EXPENSIVE	CHEAP

Mainly because of the higher surface temperatures and the simpler overall design it was decided to go for the flame system.

Fig. 1 shows an array of nine burners mounted into the PWT. Each burner is clamped on a ball pivot to allow individual adjustment. The burners are driven with Methan (CH_4) and Oxygen (O_2) whereby each burner has its separate control valves. Flame sensors on top of each row control correct burning, in case of irregularities the relevant valves will shut down the gas supply. Spark plugs for each row allow ignition so that the flame unit can be fully remote controlled.

This flame unit can be built into a reverberation chamber (Fig. 2) or installed into the PWT; the relevant data of the resulting facilities are as follows:

	REVERBER. CHAMBER	PROGR. WAVE TUBE
SIZE/TEST SECT.	206 m^3	0,8 x 1,2 m^2
OASPL at R.T.	max. 155 dB	max. 160 dB
FREQUENCY R.	100 Hz - 10 kHz	50 Hz - 10 kHz
HEAT FLUX	max. 100 W/cm^2	max. 100 W/cm^2
SURFACE TEMP:	max. 1.300 °C	max. 1.300 °C

OASPL Overall Sound Pressure Level
RT Room Temperature

No modifications were necessary when installing the flame system into the reverberation chamber. Due to the extensive air flow from the noise generators the temperature increase inside the reverberation chamber is very moderate. As the flame unit is placed in the middle of the chamber the walls are not effected by the heat.

The PWT, however, had to be substantially modified. Burning a flame system with a heat flux of 100 W/cm^2 inside a PWT is only possible if the basic structure is shielded against this heat input.

Fig. 9 shows the cross section of the thermoacoustic PWT. By insertion of an inner tunnel made of stainless steel the basic structure is protected against the heat. The duct which is formed by these two elements is subdivided into various channels. An air distribution system feeds these channels with predetermined massflows to provide the necessary cooling. The area around the test section which naturally has the highest temperatures is intensively cooled by the highest mass flow whereas the rear side with much lower temperatures obtains only reduced cooling air. The total cooling air is delivered by the same compressor which also feeds the noise generators.

The flame heating system is mounted into a window of the PWT so that the flames impinge directly on the test article which is just opposite. Each burner can be adjusted individually so that the total test section of 0,8 x 1,2 m^2 is uniformally heated.

Mounting of the test specimen into the thermoacoustic PWT needs a dedicated design. The specimen shall be supported as for its intended use and care should be taken to allow for thermal expansion. If necessary the mounting frame can be additionally cooled with water.

OPERATIONAL TESTS

In order to illustrate the operation of the facilities two different tests which have been recently performed are described.

ARIANE 5 Tank Insulation

The European launcher ARIANE 5 presently in the final development stage is depicted in Fig. 3. The tank marked with an arrow contains Helium and is covered with flexible insulation material to protect it against the heat radiated by the engine of the cryogenic main stage. The insulation is equally exposed to the high noise levels at lift-off and to turbulent flows at transonic speeds. In order to verify that the surface of the tank structure will not be subjected to temperatures above 80 °C as well as to qualify the insulation with respect to the turbulent pressure field a thermoacoustic test was performed.

One half of the tank structure partially covered with a sample of the insulation material and the rest covered with ordinary fire resistant carpets was placed inside the reverberation chamber opposite the flame heating system (Fig. 4). Four control microphones were positioned around this test set-up, their locations being well outside the hot zone. In addition a probe microphone was installed for direct measure of the dynamic pressures on the surface of the insulation material inside the hot zone.

The readings of these microphones are presented in Fig. 5. The upper part contains the spectra as measured under RT. There are certain differences in the frequencies up to 315 Hz and beyond 400 Hz, however, the OASPL-value is the same for the probe microphone and the average out of the four control microphones.

Looking at the lower part it is obvious that the spectra obtained during the flame heating process differ substantially. Whereas the shape of the averaged control microphone spectrum is not very much affected, the probe microphone indicates substantially lower noise levels. Due to the lower density of the hot gas medium the sound pressure levels are considerably reduced leading to an OASPL-value which is 6 dB lower compared with RT.

The temperature curves as monitored by thermocouples are displayed in Fig. 6. The requirement was to achieve 660 °C on the surface of the insulation material over a period of four minutes. The upper part shows that this requirement was reasonable good fulfilled. The lower part gives the temperature rise of the tank shell (below the insulation). In this case the temperature did not exceed 80 °C as specified.

TPS for Advanced Launcher

In the framework of a study sponsored by ESTEC (3) a multiwall TPS-panel was developed by DASA which was used as a candidate for a thermoacoustic test. The TPS-panel is considered to be taken from a reference vehicle (Fig. 7), the arrow indicating the reference location.

Critical loadings occur during separation of the two stages with 700 °C surface temperature and sound pressure levels up to 165 dB and during reentry of the upper stage with 1.000 °C surface temperature and an OASPL = 140 dB. With the objective to simulate these environments the multiwall panel was installed into the thermoacoustic PWT according to Fig. 8.

Fig. 10 shows the facility with the burners alighted, the test window, however, is still open. In the next step the PWT will be closed and the airflow started. Temperature rise on the panel surface will be observed until the specified values are reached. Finally the noise generators are activated over a predetermined time duration.

FACILITY INSTRUMENTATION

The instrumentation of the facility as shown in Fig.9 is required to monitor the environmental loading conditions as well as the response of the test specimen. However, there are some limitations of current instrumentation which needs to take special provisions.

In order to control the characteristics of the exciting pressure field acting on the surface of the test specimen microphones should be placed in the vicinity of the test article. Apart from very exotic devices no transducers are known which are capable to work in a temperature environment beyond 1.000 °C.

With condensor microphones commonly used the temperature environment is limited to about 60 °C. The approach therefore is to design a probe capable to withstand the high temperatures at the hot end which leeds the dynamic pressures to the sensing capsule where the temperatures are reduced to a level which allows the application of the usual microphone equipment. Such a probe needs extensive calibration testing to take care of the transfer functions. This is a field where current investigations are under way.

Apart from the probe microphones reference microphones are located upstream of the hot section to control the noise output of the generators. Taking into account the change of density of the medium and also the change in speed of sound a first order estimate is possible between the readings of the reference microphones and the characteristics of the dynamic pressures inside the hot zone.

Temperature measurements are presently taken by thermocouples which are directly applied to the exposed surface of the test article. This method is still more reliable and accurate compared with radiation measurements because the latter are heavily disturbed by the open flames. Development tests are directed towards the isolation of the specimen radiated IR-part against the flame radiation.

As far as the dynamic response of the test article is concerned a laser vibrometer can deliver complete mode patterns even under the extrem conditions of flame heating. Direct strain measurements, however, are not feasable in such a hostile environment.

For the purpose of overall control a TV-camera is employed which checks not only the correct flame burning but also provides information about possible desintegration of the test article during noise exposure.

References

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2. Bayerdörfer, G., "Development of a Thermoacoustic Test Facility", ESA-Conference „Spacecraft Structures and Mechanical Testing", October 1988

3. *Study on Thermal Protection for Advanced Launchers,* ESA/ESTEC-Presentation prepared by DASA, ALENIA, ARCS and IABG, February 1994

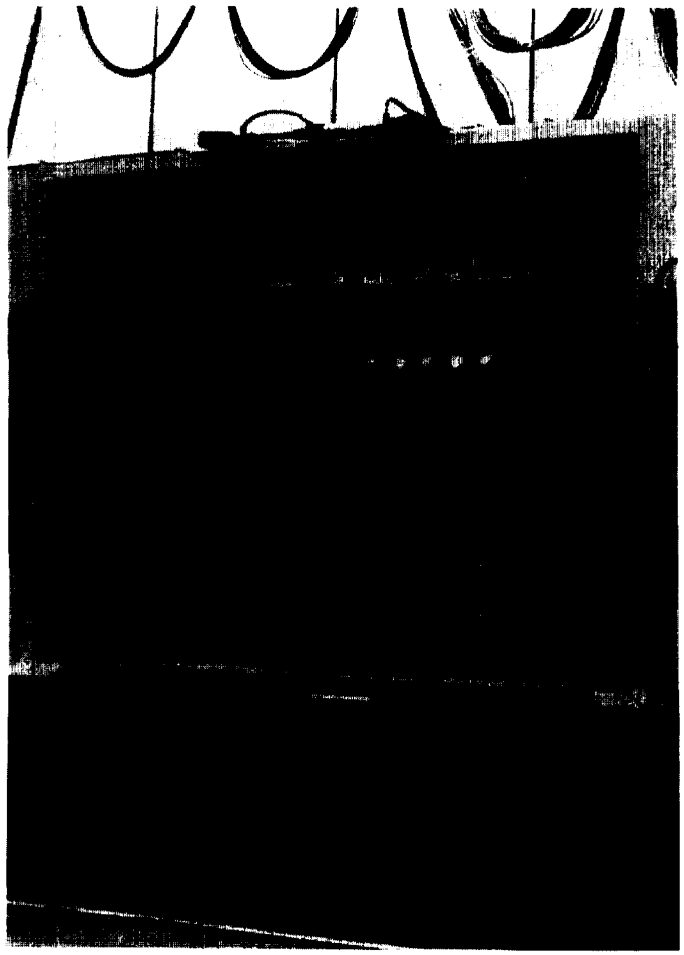

Fig. 1: Burners mounted in PWT

Fig. 2: Burners mounted in Reverberation Chamber

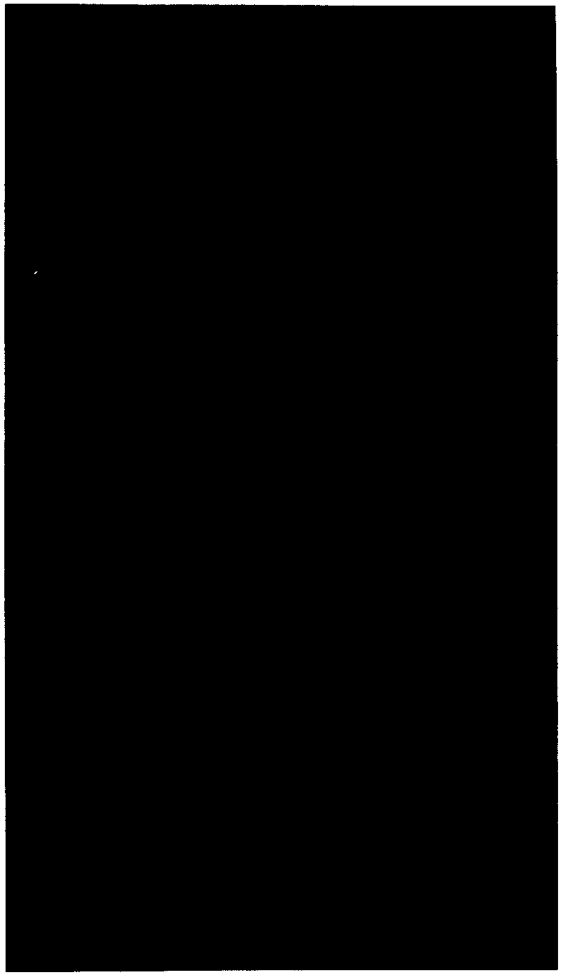

Fig. 3: ARIANE 5-Launcher

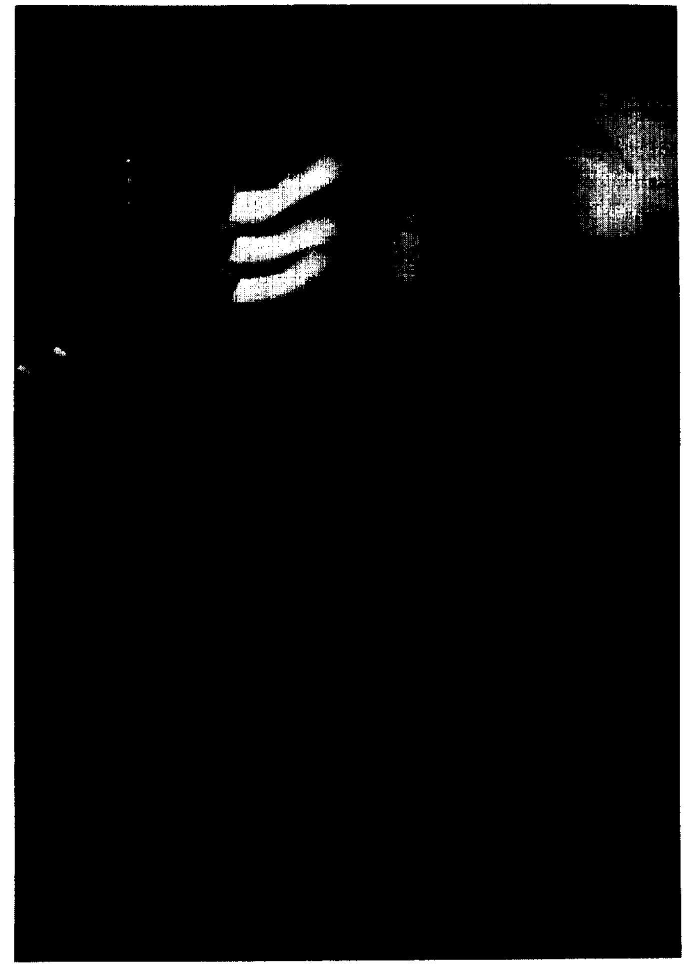

Fig. 4: Thermoacoustic Test
inside Reverberation Chamber

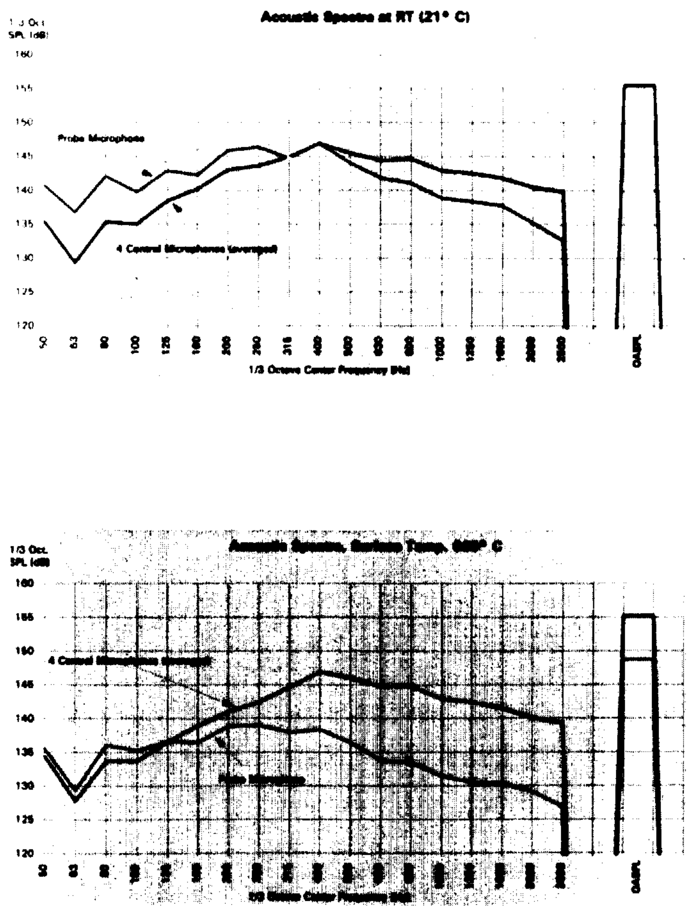

Fig. 5: Acoustic Spectra

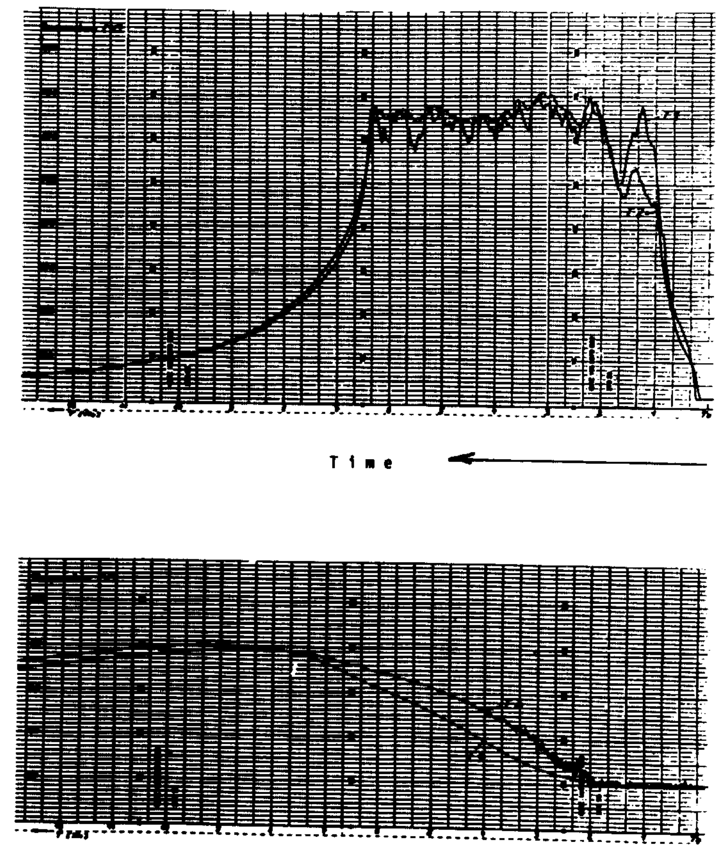

Fig. 6: Temperature Curves

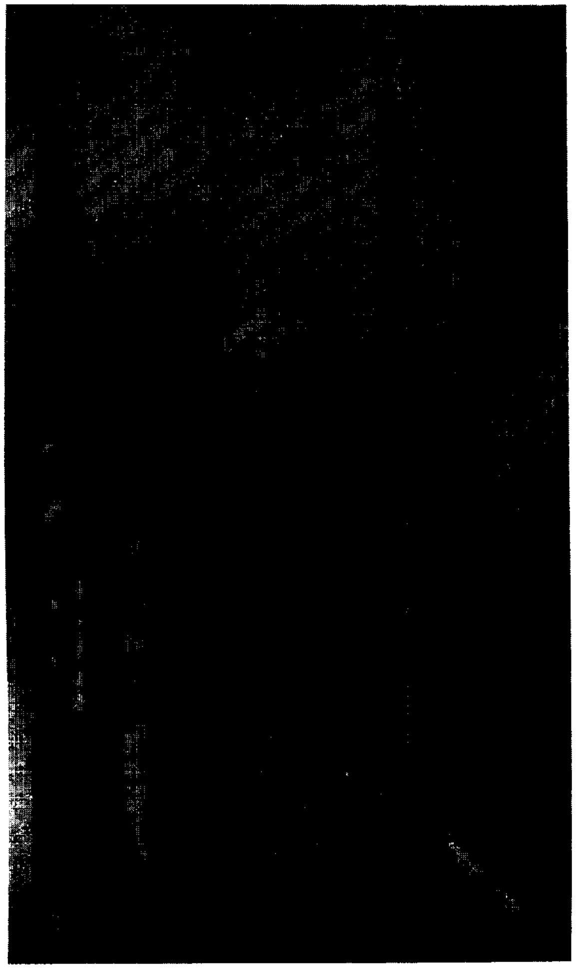

Fig. 7: Reference Vehicle

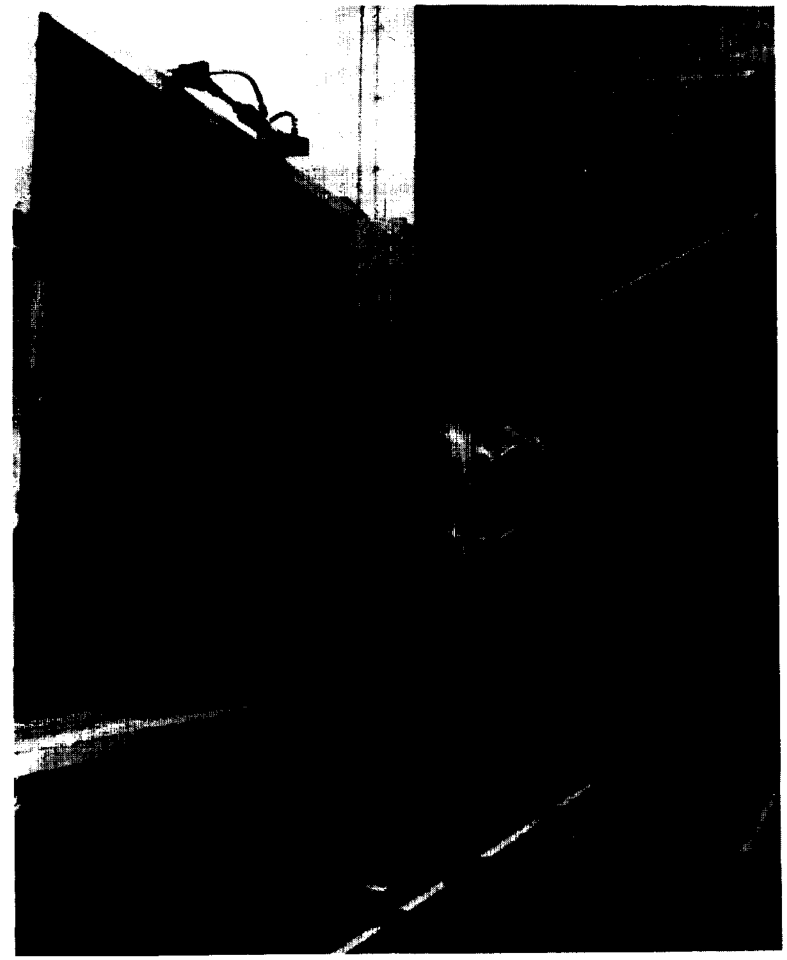

Fig. 8: TPS-Panel built into PWT

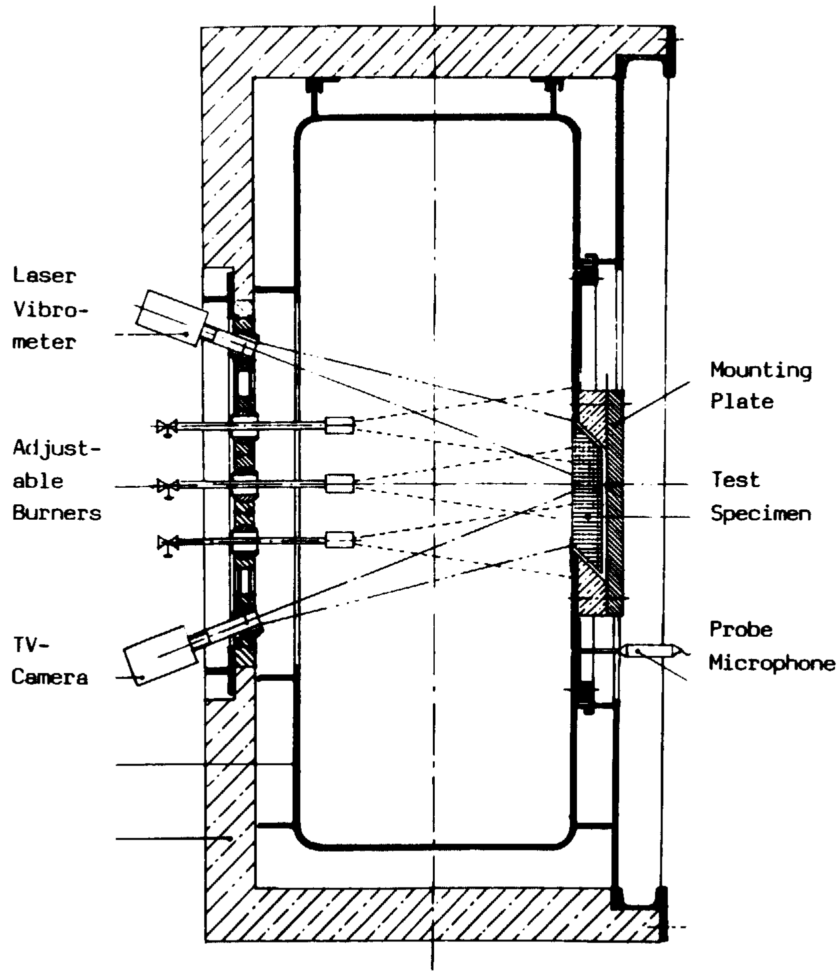

Fig. 9: Thermoacoustic PWT, Instrumentation

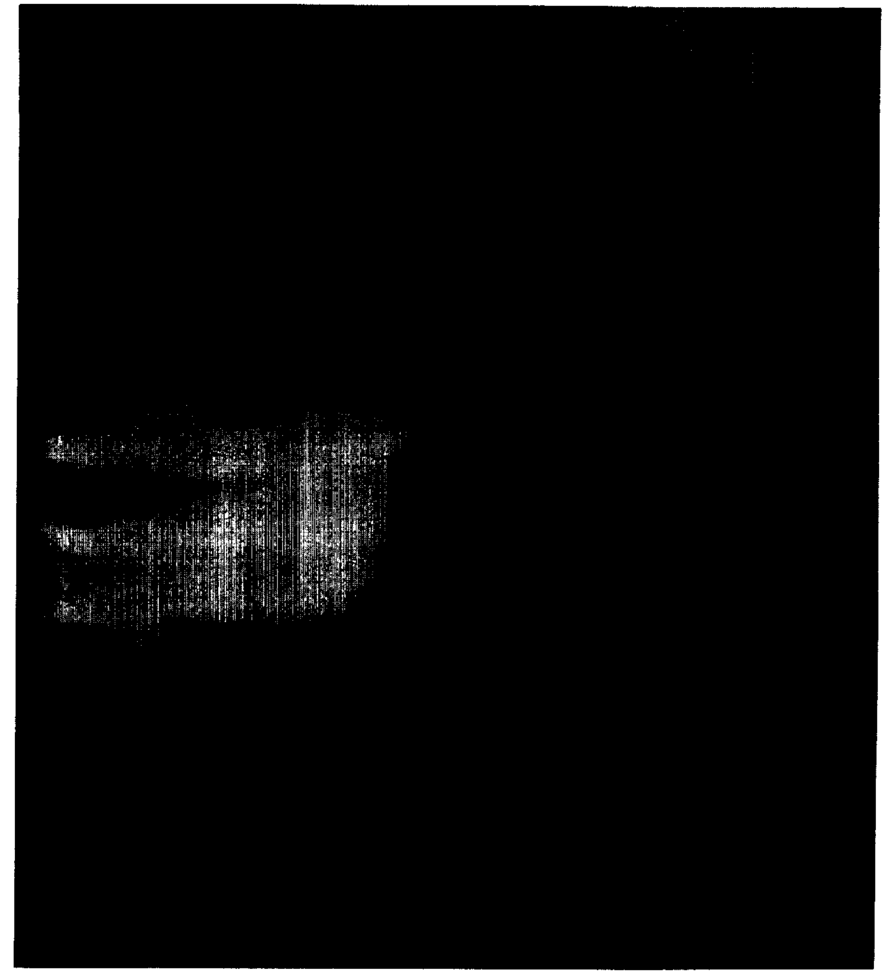

Fig. 10: Burners alighted in PWT