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Tests of the JAPHAR dual mode ramjet engine

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Abstract

In 1997, ONERA and DLR decided to join their efforts on hypersonic air-breathing vehicles in the frame of the JAPHAR program. For this purpose, a vehicle demonstrator has been chosen as a guideline for the studies and a dual mode ramjet engine has then been designed for this vehicle. An experimental scramjet has been derived from it. A first tests campaign has been performed for simulated flight Mach number of 4.9, 5.8 and 7.5 [P. Novelli, W. Koschel, ISABE paper 99-7091, in: 14th Symp. ISABE, Florence, Italy, 1999; O. Dessornes, D. Scherrer, P. Novelli, ISABE paper 2001-1135, Bengalore, India] followed by complementary tests that consisted of weighing the test chamber. Finally, an additional test campaign was carried out in 2003 with a modified injection set-up and also with a calorimetry device that allowed to determine the combustion efficiency experimentally, which wasn't done before. In order to work as a dual mode ramjet, the combustion chamber has two injection stages. The first is mainly dedicated to supersonic combustion whereas the second allows to have a subsonic combustion with a thermal throat located near the chamber end. The main experimental results are discussed and comparisons with 3D Naviers–Stokes computation are also presented.

Résumé

En 1997, l'Onera et le DLR ont décidé de travailler en commun sur les véhicules hypersoniques aérobie, dans le cadre du programme JAPHAR. Pour ce faire, un démonstrateur en vol a été choisi comme base de travail et un stato-mixte a été conçu pour ce véhicule. En a été dérivé un statomixte destiné à des expérimentations au sol. Une première campagne d'essais a été réalisée pour des Mach de vol simulés de 4.9, 5.8 et 7.5 [P. Novelli, W. Koschel, ISABE paper 99-7091, in : 14th Symp. ISABE, Florence, Italy, 1999 ; O. Dessornes, D. Scherrer, P. Novelli, ISABE paper 2001-1135, Bengalore, India] poursuivie par des essais complémentaires qui ont permis de peser le moteur. Finalement, une campagne d'essais supplémentaire a été effectuée en 2003, avec un système d'injection modifié et avec un calorimètre qui permet de déterminer expérimentalement le rendement de combustion, ce qui n'était pas le cas auparavant. Pour assurer son fonctionnement en statomixte, la chambre de combustion comporte deux étages d'injection. Le premier est principalement dédié à la combustion supersonique alors que le second permet d'assurer la combustion subsonique, avec un col thermique situé près de la fin de chambre. Les principaux résultats expérimentaux sont présentés et des comparaisons avec des calculs Naviers–Stokes 3D sont également discutées.

Keywords: Scramjet; JAPHAR; Dual-mode ramjet; Hypersonic vehicle; Supersonic combustion; Thermal throat

Mots-clés : Superstatoréacteur ; JAPHAR ; Statomixte ; Véhicule hypersonique ; Combustion supersonique ; Col thermique

1. Introduction

The scramjet is the main considered solution for air-breathing vehicle beyond Mach 6. Nevertheless, most of the considered applications need that the airbreathing propulsion could also be used for the initial acceleration phase of the vehicle. As a result, the dual mode ramjet, which successively works in subsonic and supersonic mode, has been chosen as the central axis of the JAPHAR project, which ONERA and DLR have jointly launched in 1997 to continue the research on airbreathing hypersonic propulsion, after the Sänger and PREPHA national programs [10].

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Nomenclature

Cp	gas heat capacity	P	static pressure
Cp_{gw}	water steam heat capacity (1900 J/K/kg)	$Pdyn$	dynamic pressure
Cp_{lw}	liquid water heat capacity (4185 J/K/kg)	Pi	total pressure
D_0	inflow stream thrust	P_1	inflow static pressure
E.R	equivalence ratio	Q	heat flux density
F	pressure integral along the chamber	Q_l	heat loss
Lv	latent heat of evaporation (2.25×10^6 J/kg)	Tce	calorimeter exit temperature
M_1	inflow Mach number	Tgi	gas temperature at the inlet of the calorimeter
M_∞	flight Mach number	Ti_1	inflow total temperature
m_w	calorimeter water mass flow rate	α	chamber divergence angle
Nc	combustion efficiency	φ	equivalence ratio

The studied concept is a fixed geometry dual mode ramjet that has a staged combustion chamber that allows to obtain the different combustion regimes – subsonic with thermal throat, transonic and then supersonic – as a function of the flight Mach number.

The chamber operation has been firstly studied by 3D computations thanks to the MSD ONERA code. Then, in 2000, a test campaign was carried out in the ATD 5 test cell of ONERA for simulated Mach numbers of 4.9, 5.8 and 7.6. In 2001, complementary tests allowed us to weigh the engine for Mach 4.9 conditions and finally, in 2003, further tests were performed with a modified injection and with a calorimeter to be able to determine directly the combustion efficiency. This program is now finished.

2. Test setup

2.1. ATD 5 test cell

The tests have been performed in the ATD 5 test cell of the ONERA centre in Palaiseau.

This facility has the following capacities:

- Pi max $\leqslant$ 40 bar,
- Ti max $\leqslant$ 2400 K,
- air mass flow $\leqslant$ 8 kg/s,
- O_2 mass flow $\leqslant$ 1.4 kg/s,
- H_2 mass flow $\leqslant$ 0.3 kg/s.

For the maximum temperature, the flow rate is limited to around 4 kg/s.

The air is pre-heated thanks to a air/H_2 combustion with molar oxygen replenishment.

2.2. Test chamber geometry

In the frame of the JAPHAR project, the engine is supposed to be able to power an experimental vehicle in order to assess the propulsive balance of a dual mode ramjet. On the basis of PREPHA's previous work, this hydrogen fueled dual mode ramjet has been designed for large engines [6] and consequently, struts are used to inject the fuel (Fig. 1).

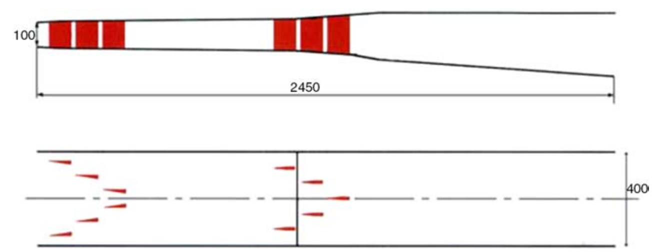

Fig. 1. Vehicle engine.

The upstream part of the chamber is slightly diverging and is essentially devoted to supersonic combustion whereas the second part which has greater divergence angles allows to work in subsonic or in transitional regime (Fig. 1). The geometry has been defined to be completely supersonic at Mach 8 when the whole hydrogen is injected in the first chamber part. The vehicle is equipped with two engines modules of 400 mm width each and 100 mm in height at the beginning of the chamber. The length is roughly 2.4 meters.

The transition between the two combustion modes, subsonic-supersonic, is controlled thanks to the injection repartition between the two injection levels. For the subsonic regime a thermal throat is used rather than a mechanical throat that should be removed for the supersonic combustion regime.

Firstly, a 0D integral analysis has been used to determine the cross section and divergence angle of the different parts of the engine. In such analysis, each vehicle flow path component (forebody, intake, combustion chamber, nozzle) is computed from integral balance laws between the entrance and the exit. Chemistry is considered in equilibrium (9 species) except in the nozzle where a frozen flow assumption is also possible. For each component, the efficiency is estimated from previous studies, in particular from PREPHA program. Then 1D and after 3D computations have been performed to assess the design of the engine.