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Survey of high-enthalpy shock facilities in the perspective of radiation and chemical kinetics investigations

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A R T I C L E I N F O

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A B S T R A C T

This contribution is a survey of the capabilities of the main facilities, shock-tubes, shock-tunnels, expansion tubes and hot-shots that allow the experimental investigation of chemical kinetics and radiation of hypersonic flows encountered during atmospheric entry. At first, the capabilities of the main facilities available in Australia, Asia, Europe, and United States, have been surveyed using the available literature, and the specific use of each facility identified. The second step of the study consists in an analysis of each type of shock facility to identify their advantages and drawbacks. The main objective of this analysis is to support a trade-off for the selection of the type of facility to be developed in order to give Europe a ground test with the capabilities to support future exploration and sample return missions. The last point of the study has been to identify the experimental datasets related to the targeted application, and to select the most attractive for the validation of the future facility.

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1. Introduction

The European Space Agency (ESA) is actually preparing exploration missions to Jupiter (JUICE) [1], Mars [2], sample return missions to Mars [3] and to a Near Earth Object [4]. Most of these missions (all except JUICE) involve atmospheric entries of capsules (exploration probes and return capsules). Among these different missions, sample-return ones involve the superorbital Earth reentry of the return capsule. Such entries are characterized by high heat-fluxes and the return capsule has to endure severe entry conditions, as highlighted in Fig. 1, in which the radiative and convective heat-fluxes evolution predicted during the Stardust mission preparation [5] are plotted. Such high levels of heat-fluxes have characterized all sample return missions performed so far, like Stardust, Genesis and Hayabusa.

As a consequence, for ensuring the success of such missions, thorough efforts are required to simulate properly the flow environment during entry using CFD codes and ground facilities. The proper duplication on ground of the entry conditions is necessary but currently the available facilities do not provide all elements needed to guarantee the mission success [10]. This is the reason why ESA is actually preparing a flight demonstrator [6] with for objectives to validate some of the technologies that will be used for a sample return mission. The main interest of such flight test is to gathered information on the radiative environment to which the capsule is submitted during re-entry. So far, the only dataset obtained for similar conditions dates back to the sixties when the Fire 2 flight experience was conducted [7].

For sample return missions and most of the exploration missions, issues like chemical kinetics at high enthalpy, and plasma radiation have to be handled. Their experimental study requires dedicated facilities since high energy levels are required to simulate these phenomena. This is possible only for short durations, and as a consequence, facilities that can fit such requirements are shock-tubes, shock-tunnels, expansion tubes, and hot-shots [8]. So far, since the final stop of the shock-tube TCM2 [9], Europe has no more such experimental capabilities and this need has been identified [10,11]. As a consequence, ESA has fostered the development of a new facility dedicated to such fundamental studies [12].

To support development of this future facility, a survey of existing facilities dedicated to experimental investigations of radiation and chemical kinetics has been undertaken. Previous efforts have been previously carried out to review the capabilities of European facilities for Earth orbital entry simulations and planetary and sample return missions. IABG [13] performed a review on facilities dedicated to TPS qualification but this review was essentially focused on mechanical testing and did not account for all aerothermodynamic aspects particularly if super-orbital entries are considered. ONERA [14] dedicated an extensive effort on aerothermodynamics testing in Europe and Russia, which is a very complete review but mostly focused on Earth suborbital reentry. Bugel et al. [10,11] have performed a review for sample return missions and Mars entry capabilities in Europe, Australia and CIS, with additional elements on testing related to dynamic stability. However, this review is a general effort on aerothermodynamics and TPS testing, and additional efforts are needed focusing on chemical kinetics and radiation. While the previous survey was limited to Europe, ISC and Australia, here the analysis has been extended to other facilities located in China, India, Japan, and USA. Three hypersonic shock-tunnels (denoted T1, T2 and T3) are operating in Brazil at the IEAv near São Paulo [15]. These facilities are utilized for investigating scramjet [16] and aerothermodynamics related to Earth orbital entry [17,18] but are not used for radiation and chemical kinetics investigation, as a consequence they have not been detailed in this paper.

The current effort has for objective to complete this review for supporting the development of the ESTHER [12] facility and to select the most suitable option between shock-tunnel, shock-tube, expansion tube and hot-shot facilities. Here, the objective is not to

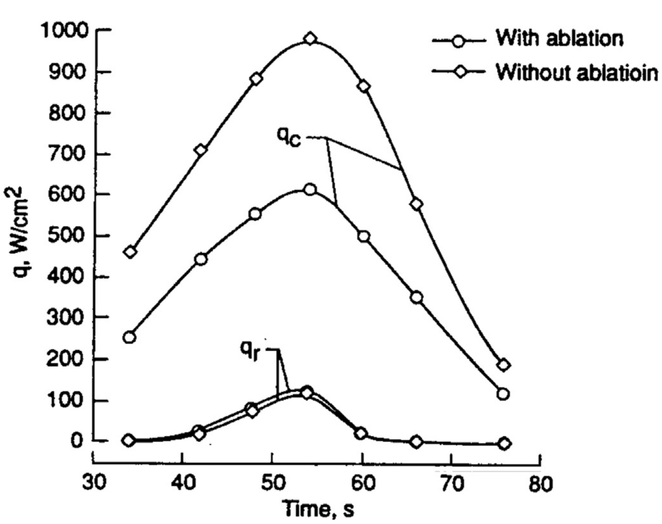

Fig. 1. Radiative and convective heat-fluxes predicted during Stardust re-entry [5].

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