Acta Astronautica 69 (2011) 975–986

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

Aerodynamic analysis of a Mars exploration manned capsule

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ARTICLE INFO

Article history:
Received 18 February 2011
Received in revised form
16 June 2011
Accepted 17 June 2011
Available online 25 August 2011

Keywords:
Atmospheric planetary entry
Non-equilibrium hypersonic flow
Capsule-type vehicle aerodynamics
Planetary exploration

ABSTRACT

The paper deals with the aerodynamic analysis of a manned braking system entering the Mars atmosphere, with the aim to support planetary entry system design studies. The capsule configuration is an axisymmetric blunt body close to the Apollo capsule. Several fully three-dimensional Computational Fluid Dynamics analyses have been performed to assess the flowfield environment around the vehicle to address the aerodynamic performance of the entry capsule within mission exploration to Mars. To this end, a wide range of flow conditions including reacting and non-reacting flow, different angles of attack, and Mach numbers have been investigated and compared. Moreover, non-equilibrium effects on the flowfield around the capsule have been also investigated. Results show that real-gas effects, for all the angles of attach considered, increase both the aerodynamic drag and pitching moment, whereas the lift is only slighted affected. Finally, comparison of the results highlights that experimental and CFD aerodynamic findings available for the Apollo capsule in air adequately represent the static coefficients of the capsule in the Mars atmosphere.

1. Introduction

The paper deals with the aerodynamic analysis of a Manned braking system (MBS) entering the Mars atmosphere, with the aim to support planetary entry system design studies.

The human exploration of Mars will be a complex undertaking. It is an enterprise that will confirm the potential for humans to leave our home planet and make our way outward into the cosmos. Although just a small step on a cosmic scale, it will be a significant one for humans, because it will require leaving Earth with very limited return capability. The commitment to launch is a commitment to several years away from Earth, and there is a very narrow window within which return is possible. This is the most radical difference between Mars exploration and previous lunar explorations [1].

The paper reports on some aerodynamic analysis of an Apollo shaped vehicle performed for flight conditions compatible for a manned mission entering the Mars atmosphere. With this in mind, those results may be used to provide numerical data for understanding the requirements for human exploration of Mars. To this, end aerodynamic analysis has been made at several levels. Indeed, vehicle aerodynamic assessment has been extensively addressed through engineering-based design approach as hypersonic panel methods. Then, a number of Computational Fluid Dynamics (CFD) simulations of the hypersonic flowfield past the entry capsule have been performed and results provided in the paper.

Several are the reasons that suggest to get ready Mars manned exploration. Mars is the most accessible planet beyond the Earth–Moon system where sustained human presence is believed to be possible. The technical objectives of Mars exploration should be to understand what would be required to sustain a permanent human

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doi:10.1016/j.actaastro.2011.06.020

presence beyond Earth. Moreover, the scientific objectives of Mars exploration should be to understand the planet and its history, and therefore to better understand Earth. The human exploration of Mars currently lies at the ragged edge of achievability. The necessary technical capabilities are either just available or on the horizon. Commitment to the program will both effectively exploit previous investments and contribute to advances in technology. Finally, the goals of Mars exploration are grand; they will motivate our youth, benefit technical education goals, and excite the people and nations of the world.

The crew will travel to and from Mars on relatively fast transits (4–6 months) and with long periods of time (18–20 months: days nominal) on the surface, rather than alternative approaches which require longer in space and reduced time on the surface [1]. Fig. 1 illustrates a typical trajectory designed to the worst-case mission opportunity (2007–2009) of the next two decades; the transit legs are less than 180 days both directions. For easier Mars mission opportunities (for example, 2016–2018), the transit legs are on the order of 130 days. Shorter transit time reduces the time spent by crew in zero g to the length of typical of duty for the International Space Station [1].

In the paper, however, neither mission architecture needed to reach Mars from Earth or neighbor Earth space, nor surface exploration have been addressed. Only capsule aerodynamic in Mars atmosphere has been focused in this work as key technology needed to get the real manned descent through the Mars atmosphere.

To this end, fully three-dimensional CFD analyses, both Euler and Navier–Stokes, have been performed in order to address the aerodynamic performance of an Apollo-like capsule for mission exploration to Mars, considering an entry approach scenario to red planet compliant with the spacecraft released from circular orbit [2,3]. Today the need for research activities on Mars entry are ever more apparent, and among the available technologies; capsule option is still the safest and cheapest way to get the exploration vehicle on Mars [4,5].

This paper presents an aerodynamic analysis of a capsule vehicle entering the Mars atmosphere, aimed to support future Mars manned exploration mission studies. The capsule configuration is an axisymmetric blunt body shown in Fig. 2.

The Martian atmosphere has been considered as a mixture of 95.7% carbon dioxide, 1.6% argon, and 2.7% nitrogen. The flow has been modeled as a reacting gas mixture of 9 species (Ar, CO_2, N_2, O_2, CO, NO, N, O, and C). The Fluent code together with user defined functions, developed in order to simulate mixtures of gas in thermochemical non-equilibrium, has been used for these computations with a non-equilibrium chemical model suitable for Martian atmosphere. Several numerical computations have been performed in order to obtain pressure distributions and other several flowfield features both over and around the entry vehicle for the aerodynamic system design analyses scopes. For this purpose, a wide range of flow conditions including reacting and non-reacting flow, different angles of attack, and Mach number have been investigated and compared. Moreover, 3-D numerical simulations have been carried out to investigate the effects of chemical non-equilibrium on the vehicle aerodynamics. For code validation purpose, the available numerical and experimental data of Mars Pathfinder probe at the entry peak heating

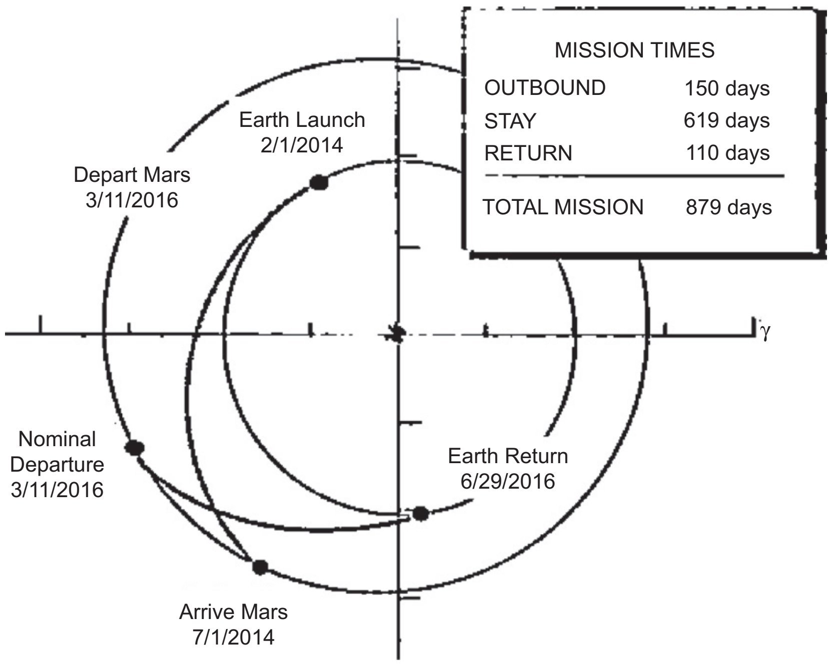

Fig. 1. Typical fast-transit interplanetary trajectory [1].