

Special Project

Recommended Design Practices for Conceptual Nuclear Fusion Space Propulsion Systems

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Special Project Report

Recommended Design Practices for Conceptual Nuclear Fusion Space Propulsion Systems

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Abstract

This document provides recommended design practices for conceptual engineering studies of nuclear fusion space propulsion systems. Discussion and recommendations are included on key topics including design reference missions, degree of technological extrapolation and concomitant risk, thoroughness in calculating mass properties (nominal mass properties, weight-growth contingency and propellant margins, and specific impulse), and thoroughness in calculating power generation and usage (power-flow, power contingencies, specific power).

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Foreword

To facilitate the improvement and standardization of conceptual designs of nuclear fusion space propulsion systems, Technical Interchange Meetings (TIM) took place in late 1999 and early 2000. The TIMs were broadly represented by the members of the National Aeronautics and Space Administration (NASA), the Department of Energy (DOE) laboratories, academia, and industry professionals active in the field. The TIMs were led by NASA's Glenn Research Center (GRC). At their conclusion, it was suggested and all agreed that the results of the TIMs should be offered to the appropriate AIAA Technical Committee (TC) to review and codify the recommended design practices into an appropriate AIAA technical standard. The AIAA Nuclear and Future Flight Propulsion Technical Committee (NFFPTC) was identified as the most appropriate TC for this task. The NFFPTC's Chairman was approached and agreed to bring the TIMs product to the TC for their consideration. The NFFPTC subsequently formed an ad hoc working group for the expressed purpose of authoring an AIAA standards document to guide the development of higher quality conceptual designs for nuclear fusion space propulsion vehicles. Most of the recommendations stem from the work of the TIMs, with the balance contributed by the AIAA NFFPTC Fusion Design Working Group.

The following participants in the Nuclear Fusion Propulsion Technical Interchange Meetings deserve special mention:

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The working group was created in 2002 and completed work in 2003.

The AIAA Standards Executive Council (Mr. Phil Cheney, Chairman) accepted the document for publication in October 2004.

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1 Introduction

1.1 Scope

This document provides recommended design practices for conceptual engineering studies of nuclear fusion space propulsion systems. Discussion and recommendations are included on key topics including design reference missions, degree of technological extrapolation and concomitant risk, thoroughness in calculating mass properties (nominal mass properties, weight-growth contingency, propellant margins, and specific impulse), and thoroughness in calculating power generation and usage (power-flow, power contingencies, specific power). This report represents a general consensus of the nuclear fusion space propulsion system conceptual design community. It is intended for technically experienced senior engineers who may not be fully cognizant of all primary aspects of nuclear fusion space propulsion system design, and who desire a useful guide in the development of credible concepts.

1.2 Purpose

This document establishes a standardized set of design practices to be employed in conceptual engineering design studies of nuclear fusion space propulsion systems. A concerted effort was made to establish design practices that were balanced between being too detailed and all encompassing (thus an unwarranted burden to implement) and being too general and incomplete (thus not meaningfully improve fundamental aspects of a design). It is intended for technically experienced senior engineers who may not be fully cognizant of all primary aspects of nuclear fusion space propulsion system design, and who desire a useful guide in the development of credible concepts. The recommendations made in this document are intended to facilitate equitable comparisons between system concepts and to improve their overall technical quality.

1.3 Developments Focusing Attention on Nuclear Fusion Propulsion

NASA modified its long-range agency goals in the mid 1990's to include expanding human presence throughout the solar system. In 1998, after a 20 year hiatus, NASA re-established modest funding for very advanced space propulsion research, particularly nuclear fusion. Many conceptual vehicle designs emerged to guide technological research and development in this area. But comparing performance capabilities and assessing scientific/engineering credibility was difficult due to widely varying study assumptions.^{1, 2} It soon became apparent that the figures of merit associated with these goals were not sufficiently established, inhibiting clarity in linking funding for experiments to credible vehicle conceptual designs. While the advent of human exploration of the solar system remains a long-term NASA goal, funding for advanced propulsion concepts wax and wane, though usually at extremely modest levels. It is therefore imperative that the meager funds be spent on well defined concepts, with realistic system and performance parameters, that offer the best chances for success in the opinion of the NASA and DOE communities. In 2003, funding for very advanced space propulsion research, including nuclear fusion, was terminated. The future of this technical area remains unclear.

2 Quantifying Figures of Merit

A top-down, requirements-driven design process had been proposed to quantify the ranges of mission-level figures of merit (FoM)^{1, 2, 3, 4}. The most demanding requirements usually came from piloted, outer solar system missions expected within the 21st century. These generally had mission distances of 10's of AU, required adequate payload mass fractions (5% to 15%), multi-month trip times, and initial mass in low Earth orbit (IMLEO) of no more than a few 1,000's t^{1, 2}. Although several advanced propulsion concepts could, in theory, provide this caliber of performance, it is the judgment of many that some type of direct nuclear fusion space propulsion was the leading technology that could reasonably be expected to offer this capability. Further, a consensus (though not unanimous) agreement was arrived at among the TIM participants that mission-level FoM rather than engine / reactor-specific FoM, should be the primary focus of the designer's attention. It was emphasized during the TIM, and is repeated here for clarity, that a