

Standard

Human Spaceflight: Spacecraft Architecture and Systems Engineering Ontology

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Standard

Human Spaceflight: Spacecraft Architecture and Systems Engineering Ontology

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Abstract

This is the first level of a three-level standard defining a human spaceflight (HSF) spacecraft ontology from architectural and system engineering viewpoints. It provides guidance for systems and architecture design emphasizing human-system integration (HSI) requirements and constraints. While adopting a holistic approach, this complex domain is stratified using a three-dimensional roadmap (lifecycle, function, location) that guides the user to a high-level, fundamental, and context-specific design requirement based on the HSF program, mission and spacecraft goals.

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Foreword

This ANSI/AIAA S-153 standard was prepared by the Space Architecture Committee on Standards, the Systems Engineering Technical Committee, and the Space Architecture Technical Committee of the American Institute of Aeronautics and Astronautics. This standard is focused exclusively on Human Spaceflight (HSF) Spacecraft Ontology from Space Architecture and System Engineering perspectives.

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Introduction

This standard is proposed to define a currently nonexistent standard on ontology of HSF spacecraft and their architectures within the Commercial Space Transportation domain. This includes subsystems and human safety requirements. It organizes the complex interdisciplinary environment of the human space flight systems. This standard interconnects existing system engineering, system design, operation and process standards relevant to Human Spaceflight (HSF).

This standard will support execution of more cost-effective Human Spaceflight vehicle design and mission planning from the perspective of vehicle complexity, national and international scope and vehicle application. It does so by introducing a common language and navigation structure within the HSF standardization environment.

1 Scope

This is the first level standard of a three level standard set defining a human spaceflight (HSF) spacecraft ontology from architectural and system engineering viewpoints. It provides guidance for systems and architecture design emphasizing human-system integration (HSI) requirements and constraints. While adopting a holistic approach, this complex domain is stratified using a three-dimensional roadmap (Figure 5) that guides the user to a high-level, fundamental and context-specific design requirement based on the HSF program, mission and spacecraft goals.

Examples:

- The International Space Station is a spacecraft in Low Earth Orbit (LEO).
- NASA's Space Transportation System (STS) is an example of another HSF program yielding a specific type of reusable spacecraft, the Space Shuttle, enabling transport between the ground and LEO.

A human spaceflight mission involves a variety of activities from concept development to manufacturing and operations to full mission realization. The architecture of a mission consists of various elements such as the mission concept; ground segment; command, control and communications; orbit and trajectory design; launch system; payload; and spacecraft systems. While this standard is focused on the spacecraft element, other elements will need to be considered.

This first level standard describes a Human Spaceflight ontology that captures the spacecraft architecture via three high-level areas: development activities or processes related to the spacecraft lifecycle (e.g., concept and engineering design activities, simulations, testing, etc.), a specific application or function of the spacecraft (e.g., space transportation, tourism, exploration, resource mining, construction, etc.) and destination or operating environment of the spacecraft (e.g., suborbital, orbital, cis-lunar, lunar surface, etc.). It provides organizational guidance for effective spacecraft architecture development. The first and second levels focus on the more specific design requirements definition, while the third level identifies specific values for the engineering of subsystems and the HSI process.

The three levels composing this three level standard set are organized in the following manner:

1st level – Ontology of HSF spacecraft domain. This serves to structure the HSF domain by defining categories of spacecraft, fundamental environmental requirements within a specific phase of the spacecraft lifecycle, and their relationship, and provides a guide to a systematic design requirements definition (see Figure 6).

2nd level – Spacecraft types and their properties related to HSI. This includes human-imposed vehicle requirements, and environmental constraints of vehicles vis-à-vis mission and duration, e.g., suborbital point A to point A vehicle (returning to the departure spaceport), long duration habitat.

3rd level – Human requirements and subsystems properties related to HSI (e.g., atmosphere requirements, radiation shielding).

The 2nd level standard develops spacecraft types drawn from the 1st level document (S-153-2021). It describes the specific requirements for each category of spacecraft and its components related to the spacecraft operational environment in form of typical scenarios and typical requirements on the vehicle. The 2nd level standard also references existing standards by third parties. The scope of the 2nd level standard includes:

- Spacecraft function
- Duration of spaceflight
- Details of the operational environment, destination
- Spacecraft occupancy, etc.

The 3rd level further develops the 2nd level by focusing on the technical details of individual components or parameters of the spacecraft and its operator, and other occupants. It describes specific tasks and their allocation in nominal, off-nominal and emergency scenarios for all occupants and other artificial agents. All necessary subsystems are defined in a higher level of detail according to 2nd level requirements and HSI considerations, such as physical and cognitive ergonomics, social interaction and medical requirements. Examples include:

- Spacecraft autonomy (self-sufficiency)
- Spacecraft automation (levels of control)
- Radiation detection and protection
- Atmosphere requirements, generation and recycling
- Human body consumables and waste (refer to existing ISO 16157-2018 “Space systems — Human-life activity support systems and equipment integration in space flight — Techno-medical requirements for space vehicle human habitation environments”)
- G-load (acceleration) dependent restraint principles and requirements

2 Justification and Applicability

There is no standardized ontology of human spaceflight spacecrafts developed either by NASA or other space agencies. The Commercial Space Transportation (CST) branch of the Federal Aviation Administration (FAA) has initiated the formation of Recommendations and Best Practices documents in 2014. Recent CST development and progress required its update in which multiple industrial, governmental and academic stakeholders were involved. The document focuses on human spaceflight safety but not on HSF system ontology or system of systems architecture. CST initiates realistic commercial design, development, and operations of space vessels by corporations such as: Blue Origin, Space-X, Virgin Galactic, Sierra Nevada Corporation, Northrop Grumman, Boeing and Lockheed Martin. NASA's most recent National Space Exploration Campaign Report of September 2018 lays down five points that foster HSF with highest priority on commercial operation in LEO, support and leadership of lunar surface operations, cis-lunar activities, return of U.S. astronauts to the lunar surface and demonstration of HSF capabilities on the Moon for Mars applications, but no common standardized or internationally accepted spacecraft ontology is in place to support such a complex endeavor.

This standard is proposed to define a currently nonexistent standard on ontology of HSF spacecraft and their architectures within the CST. This includes subsystems and human safety requirements. It organizes the complex interdisciplinary environment of the human space flight systems. This standard interconnects existing system engineering, system design, operation and process standards relevant to HSF.

This standard will support execution of more cost-effective HSF vehicle design and mission planning from the perspective of vehicle complexity, national and international scope and application. It does so by introducing a common language and navigation structure within the HSF standardization environment.

This standard is applicable for lifecycle planning and execution of HSF systems (vessel, subsystem, mission planning or ground supporting system planning), and for the stakeholders involved, such as designers, engineers, system architects, managers, researchers, educators, enterprises, international organizations or national agencies.

This standard is developed by integrating and connecting existing relevant standards across disciplines and hence provides an essential guidance in human spaceflight spacecraft classification and standardization.

This project provides a human livability/suitability perspective above basic systems engineering for HSF, and gives structure to future astronautical architecture language and, therefore, standards. Together with the systems engineering level of parallel HSF work in other groups, this project will complete system and operational support needs for sustainable HSF.

3 Vocabulary

Acronyms and Abbreviated Terms

AIAA	American Institute of Aeronautics and Astronautics
AD Element	Architecture Description Element
ANSI	American National Standard Institute
CoS	Committee on Standards
DISA JTA	Defense Information Systems Agency Joint Technical Architecture
EIA	Electronic Industries Alliance
EMU	Extravehicular Mobility Unit (EVA spacesuit)
EVA	Extravehicular Activity
FAA	Federal Aviation Administration
HSF	Human Spaceflight
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Standardization Organization
IVA	Intravehicular Activity
INT	International
LEO	Low Earth Orbit
MMU	Manned Maneuvering Unit
PHM	Prognostics and Health Management
SACoS	AIAA Space Architecture Committee on Standards
SAFER	Simplified Aid For EVA Rescue
SATC	Space Architecture Technical Committee
SDO	Standards Developing Organization
SETC	Systems Engineering Technical Committee
SFP	Spaceflight Participant
STS	Space Transportation System