

NASA Ares I Crew Launch Vehicle Upper Stage Avionics and Software Overview

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Abstract

Building on the heritage of the Saturn and Space Shuttle Programs for the Design, Development, Test, and Evaluation (DDT&E) of avionics and software for NASA's Ares I Crew Launch Vehicle (CLV), the Ares I Upper Stage Element is a vital part of the Constellation Program's transportation system. The Upper Stage Element's Avionics Subsystem is actively proceeding toward its objective of delivering a flight-certified Upper Stage Avionics System for the Ares I CLV.

I. Introduction

NASA is leading the design of the Avionics System for the Ares I Crew Launch Vehicle (CLV) Upper Stage and The Boeing Company was recently selected as the Avionics production contractor. The term "Avionics" refers to the on-board electronics that guide and control the launch vehicle and is often referred to as "the brain of the vehicle."

Assigning NASA the responsibility for design lead was done with forethought and builds on the legacy of the Saturn development model, where NASA designed the Avionics and International Business Machines (IBM) Corporation (Federal Systems Division) was responsible for production. This approach provided flexibility to compete the Avionics hardware and the Upper Stage structural core hardware separately, which resulted in reducing cost. Further, by NASA owning the design, proprietary solutions entering into the design can be controlled, further maximizing competition and lowering cost. The NASA Design Team (NDT) can establish an architectural philosophy and system design that provides for a low-risk development through (1) seeking available component solutions, (2) design for obsolescence, (3) design for production, and (4) an architecture that economically accommodates change. Lastly, the approach allows NASA to consider future Constellation vehicles and spacecraft and leverage opportunities.

This approach allows NASA to assure that considerations for production and long-term sustaining engineering are incorporated into the design. This early design influence is then realized through the next 40 years of reduced cost. The approach also benefits NASA by educating the NDT and positions the Agency as a smart buyer for such upcoming Constellation vehicles as the Ares V Cargo Launch Vehicle (CaLV) and Lunar Lander.

II. Upper Stage Avionics Subsystem Function

The Upper Stage Avionics Subsystem performs three basic functions: Guidance, Navigation, and Control (GN&C); command and data handling; and pre-flight checkout.

The GN&C function is implemented through an inertial navigation system, rate gyroscopes, flight control software, Thrust Vector Control (TVC) systems on the engine nozzles, and the reaction and roll control systems (ReCS and RoCS). The GN&C function is real-time closed loop controlled. Vehicle alignment is performed on the launch platform, and, shortly prior to launch, GN&C parameters are

adjusted. As the vehicle rises at liftoff, the inertial navigation system and the rate gyros sense and measure position and acceleration, and send the data to the flight computer. Speed and relative position, from the vehicle's ascent, are calculated within the flight software from this information. The flight software then calculates the difference of the former position and the current position, and control commands are generated. The control commands are sent to the engine and First Stage thrust vector control systems, as well as the ReCS and RoCS.

The command and data handling function is implemented through the flight computer, command and telemetry computer, data busses, and data acquisition and control units. Commands to the launch vehicle come from many sources. From the time the vehicle is activated on the launch pad, to the end of the launch vehicle's mission, commands are being accepted and processed and data is being collected and processed. The launch vehicle data and the commands serve as the vehicle management system source for operations. On-board operational logic is coded in the flight software, which implements the vehicle systems control, management, and monitoring function. The flight software performs vehicle health monitoring and management through fault detection, diagnostics, and response algorithms. The flight software also implements abort recommendations to the Crew Exploration Vehicle (Orion), Mission, and Ground operations for execution. On-board flight software also interacts with ground control, mission control, and crew (astronauts) operations to encompass the total launch system's operations function. The Instrumentation and Program Command List (IP&CL) document is used to define the full complement of commands and data for the launch vehicle.

The pre-flight checkout function provides all required launch vehicle control, management, and monitoring prior to liftoff. Pre-launch functions include valve and sensor checkout, vehicle GN&C alignment, propellant loading and monitoring, engine purges and conditioning, and providing data to operations in support of launch commit criteria.

These basic subsystem functions are expressed through requirements and specifications contained in the Upper Stage Avionics and Software Subsystem Specification. The Avionics System Architecture is considered the first level of the systems design and implements the Avionics and Software Subsystem Specification's requirements.

III. Upper Stage Avionics Subsystem Architecture

The Upper Stage Avionics Architecture is based on a few fundamental tenets and focuses on reducing schedule risk and ownership costs. These tenets are: safety, simplicity, and reliability; move away from proprietary solutions and instead use a mature standard and open system and concepts; a design that economically accommodates change; and, as a goal, a growth path to future Constellation segments. The Avionics Architecture and the component specifications meet all requirements contained in the Avionics and Software Subsystem Specification.

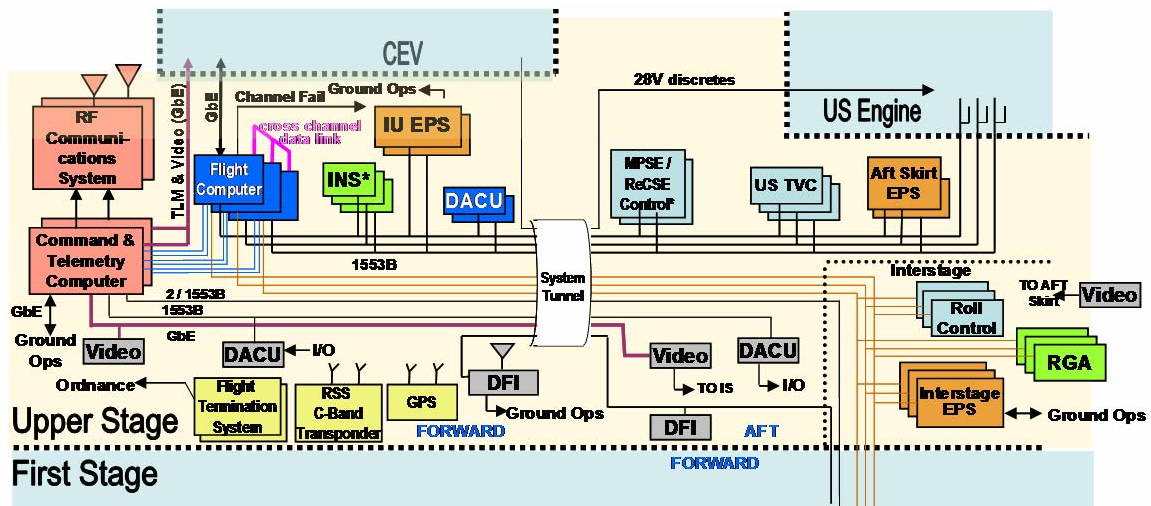


Figure 1. Upper Stage Avionics Architecture (Notional).

Trade studies were performed at the outset of the Ares I Project to select the most appropriate avionics architectural design. A fault tolerant voting architecture was selected. Functional, fault tolerant, and reliability analyses were all performed using historical, parametric, and some vendor-provided data as a base to assure the architecture design met requirements. The Avionics Architecture is configured with the following major components: Flight Computers, Command and Telemetry Computers, Application Flight Software, Inertial Guidance System, Data Acquisition and Control Units, Electrical Power Distribution Units, Batteries, Radio Frequency Communications Subsystem, TVC System, Cable harnesses, Global Positioning System (GPS), and numerous smaller components, such as instrumentation and video system.

Upper Stage Avionics Subsystem Key Features

Key features of the Ares I Upper Stage Avionics are: a fault tolerant architecture structured to economically accommodate such changes as obsolescence, requirements, and design changes; a GPS that is planned to support an independent range tracking source with a long-term objective of elimination of Ground Station resources; a design that is influenced for lower cost production and assembly; an Electrical Power System that has a reduced mass through a distributed design and uses Lithium Ion battery chemistry; and flight software designed with modern software engineering practices. The flight software also uses data tables within its design to accommodate operational changes.

Upper Stage Avionics Subsystem Locations

The Ares I Upper Stage Avionics is located in four areas of the Upper Stage. The Instrument Unit (IU) is a structural ring at the top of the Upper Stage that forms the separation plane between the Ares I Upper Stage and the Orion Spacecraft. The Aft Skirt is located below the Liquid Oxygen (LO2) tank. The Interstage is attached to the Aft Skirt and separates with the First Stage to form the separation plane between the First Stage and Upper Stage. The Thrust Cone is located at the bottom of the LO2 tank's dome directly above the J-2X Engine. Figure 2 depicts the four locations.

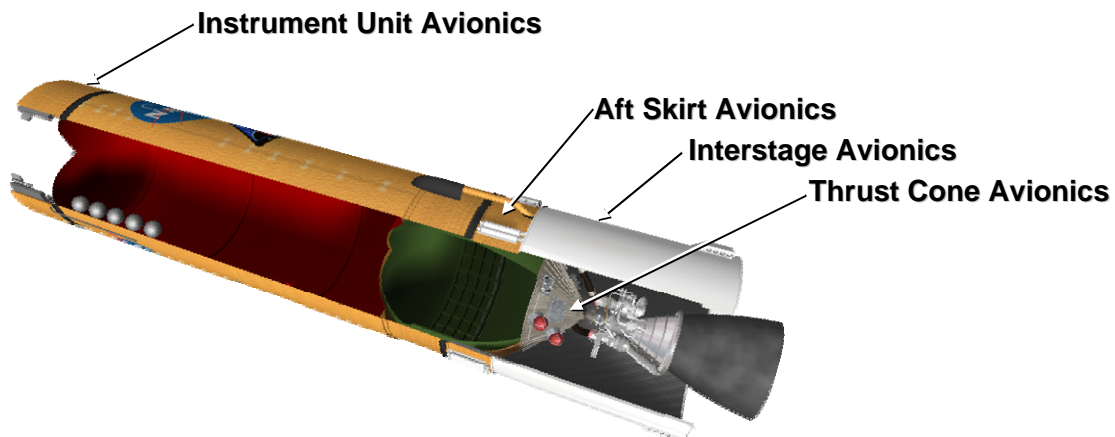


Figure 2. Upper Stage Avionics Locations.

The Upper Stage Avionics is often referred to as the “Instrument Unit Avionics,” and although a majority of the Avionics components will reside in the IU, other areas of the Upper Stage core structure will also contain Avionics components. Because this terminology has confused the Aerospace community, the NASA team takes every opportunity to explain the rationale for continuing to use “Instrument Unit Avionics.” The Saturn I, Saturn IB, and Saturn V vehicles each had a stage called “Instrument Unit.” Each of these IU stages housed the critical avionics for the respective vehicles. Dr. Walter Haeussermann, who led the Saturn IU’s initial development, said it was important enough to be considered a “non-propulsive” stage. The Saturn family IU stages were often referred to as the “Brains” of the vehicles. This notion will

also apply to the new Ares I vehicle. It was decided that the Ares Avionics would keep the traditional name of “Instrument Unit (IU)” as the primary descriptor for the Upper Stage Avionics. Using the “IU” name follows suit with the Ares Vehicle naming conventions, as well as the Saturn vehicle family naming heritage of playing off of the “I” and “V” designators from the Saturn I and Saturn V vehicles (i.e., Areas I and Ares V). The use of this name also pays tribute to those space pioneers who went before us and recognizes the evolutionary approach we build upon.

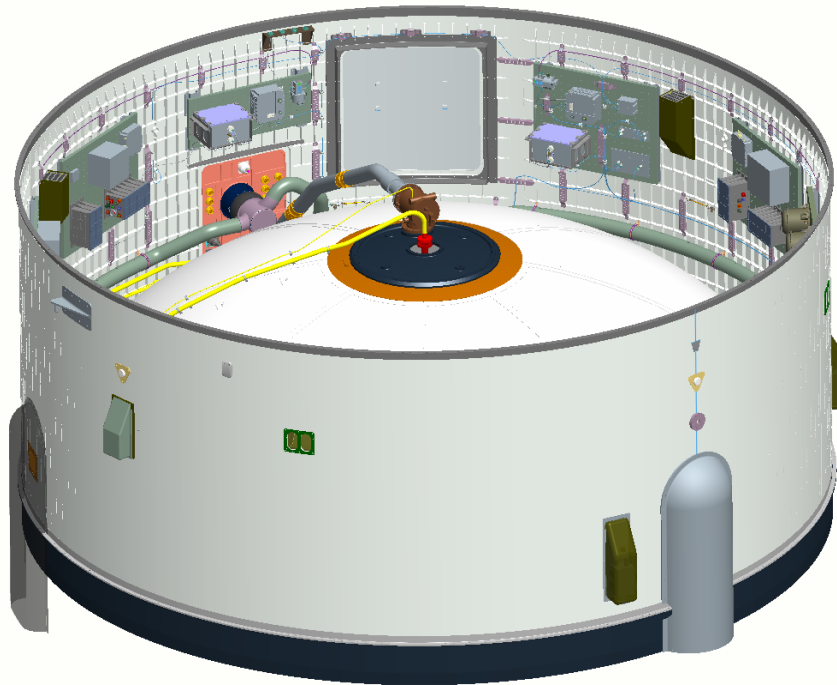


Figure 3. Instrument Unit Depiction (Notional).

Historical literature discusses the benefits of the Saturn IU Stage packaging and the placement on top of the Saturn stack as weight reduction, as well as improved structural and flight characteristics from previous configurations. Although it is difficult to reconstruct the specific 1960s-era rationale for the packaging of the Avionics in the IU and placement on top of the stack of the Saturn vehicle, reasons for a similar placement on the new Ares Launch Vehicle can be deduced. First, the IU, as its own major assembly, supports an independent assembly and checkout, thereby assisting in a more parallel vehicle production. Secondly, cable weights, being significant weight components, are reduced by close and confined proximity of the Avionics boxes. Thirdly, placement of the IU at the top of the vehicle stack provides for “Vehicle Management” functions to exist in only one location; therefore, as stages are jettisoned, “Vehicle Management” capability remains seamlessly at the top. Fourth, separating the Launch Vehicle Avionics from the Orion Avionics provides the capability to autonomously put a complete payload into orbit, crewed or uncrewed, and allows for early uncrewed test flights that do not depend on an integrated Orion Spacecraft. Fifth, the Ares Launch Vehicle can be assembled, checked, and delivered as an integrated launch system.

Upper Stage Avionics Subsystem Interfaces

Upper Stage Interfaces are grouped into three categories: External to Ares Launch Vehicle (Constellation Level 2), Ares Launch Vehicle Element (Level 3), and Element Internal (Level 4). The Level 2 interfaces are the Ground System, Mission System, Communications and Tracking Network (CTN) Systems, and the Orion Spacecraft. The First Stage and the J-2X Engine are the Level 3 interfaces for

Upper Stage. The Upper Stage Avionics System has numerous internal interfaces. Command and Data bus interfaces and electrical power interfaces have been, as a goal, kept to mature standards.

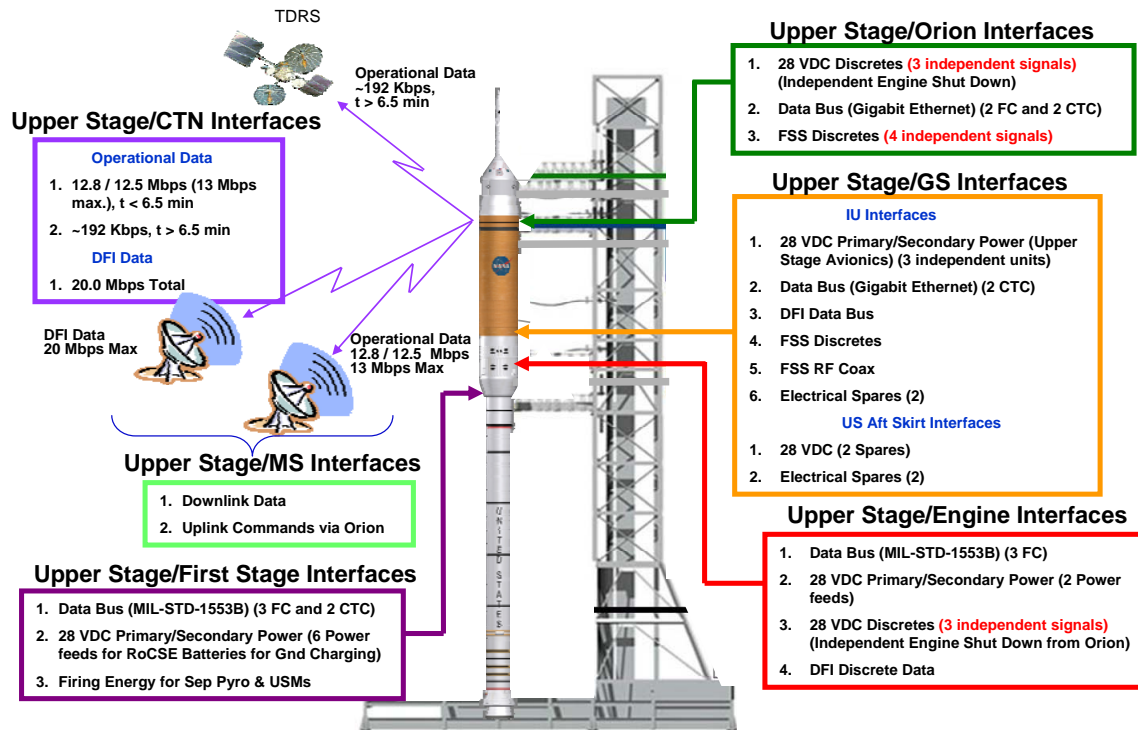


Figure 4. Upper Stage Avionics External Interfaces (Notional).

Upper Stage Avionics Subsystem Design with Production Influence

Influencing the design early to assure production considerations has the largest potential for life cycle cost reduction. The term “Producibility” has been around since the 1950s, although there is still no accepted definition for the term. Therefore, when the Upper Stage Avionics Contract was being competed, the Statement of Work (SOW) used the following three glossary terms for Industry bidders to interpret:

(1) Production – As used within the scope of this SOW, a phase of the project in which operational flight units are manufactured and tested.

(2) Producibility Analyses - Evaluation of design concepts and engineering drawings for manufacturability, including methods of manufacture, processes, equipment capability, tooling requirements, ability to meet tolerances, and cost effectiveness.

(3) Producibility Engineering – Leveraging industry’s design, manufacturing, and logistics/supportability expertise during the design phase of the Upper Stage development process to ensure the Upper Stage design is optimized to reduce overall life cycle cost and maximize operability.

After the Award of the Upper Stage Avionics contract, the NDT and Boeing jointly established the following interpretation:

“Producibility is: a planned set of engineering analyses (and activities) intended to influence the requirements, specifications, design, and processes of the Upper Stage avionics and software system, with the primary driver being reduction of life cycle cost during the production phase. The more standard terms that encompass the forethought for “producibility” are manufacturability, operability, testability, sustainability, and maintainability. Production phase considerations for the avionics and software system are at two levels: Box (and Software Subsystem) level and the integrated IU level. In addition to the flight vehicle avionics and software system, considerations should include ground facilities infrastructure, ground processes, and tools for assembly, checkout, and logistics.

III. Upper Stage and Avionics Subsystem Reviews

In 2007, the Ares I Upper Stage Element successfully completed its Systems Requirements Review (SRR) and Systems Definition Review (SDR). The Element is currently conducting its Preliminary Design Review (PDR). While the Avionics Subsystem did not conduct an independent SRR or SDR, it did follow suit with the other Upper Stage Subsystems and engaged in the larger Upper Stage review. The Flight Software team did, however, conduct its own Software Requirements Review, not coincident with the Upper Stage SRR. Avionics and all other Upper Stage Subsystems did conduct independent PDRs prior to the Upper Stage PDR.

IV. Conclusion

The NASA Design Team (NDT) has planned a development approach that implements within the larger Constellation framework. The NDT has maintained that approach and wavered only in small adjustments. The approach has not been without challenge, and re-planning is the nature of development work. There have been no insurmountable technical or programmatic issues to-date.

The strategic decision by the NASA Administrator to have a NASA-owned and led design has already resulted in cost savings through competition, and provides the mechanisms to further reduce cost through early design influence for production. This strategy leverages opportunities for NASA's workforce and future Constellation developments.

Competition, technical architecture, and design philosophy all contribute to the Avionics team objectives: 1) Successfully deliver a certified US Avionics System to the Project, and 2) Maintain lower life cycle cost.

NASA and Boeing personnel work in a "One Team" environment approach that is working well. NASA and the Boeing Company are making conscience investments in personnel by utilizing young talent. Team members are immersed in and learning from challenging work. Opportunities to lead are available for members wanting to fulfill professional and personal growth. This experience will allow personnel to maximize their career opportunities in the future. For Constellation's upcoming work, this investment is a win-win situation.