ATLAS V Changing it into an RLV for Better Performance

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ABSTRACT:

This journal delves into the intricacies of the Atlas V launch vehicle, focusing on four key aspects: propulsion, structure, avionics, and materials. It offers a comprehensive exploration of the Atlas V's propulsion systems, including the RD-180 and RL-10 engines, as well as the new solid rocket booster. The journal examines the structural components that make up this launch vehicle, highlighting their design and functionality. It delves into the avionics systems that play a critical role in guiding and controlling the Atlas V. Additionally, the journal explores the materials utilized in its construction and their impact on the vehicle's performance. Together, these components contribute to Atlas V's aerodynamics Abstract for Atlas V incorporating changes in materials and structure:

The utilization of corrugated steel sheets in the construction of the Atlas V rocket's structure serves a pivotal role in weight reduction, promoting its potential for reusable launches. While retaining durability and safeguarding against insect attacks and algae growth, this innovative application leverages the lightweight nature of the corrugated structure to enhance the rocket's efficiency.

Furthermore, the integration of titanium-nickel alloys in place of traditional materials like aluminum and carbon fiber titanium demonstrates a strategic shift towards enhancing strength, corrosion resistance, and weight balance within the rocket's components. This substitution capitalizes on the unique properties of these alloys, aligning with the aerospace industry's ongoing pursuit of improved materials for spacecraft construction.

This underscores the profound impact of these material alterations on the Atlas V's performance, particularly in elevating structural integrity, reducing weight, and advancing reusability—a paradigm shift that augments the rocket's capabilities in space exploration endeavors.

Keywords: Titanium Nickel Alloys, Atlas V, Honeycomb structure

Introduction:

The Atlas V, a cutting-edge launch vehicle created by Lockheed Martin, stands at the forefront of space exploration technology. Its versatility and adaptability make it suitable for a wide range of missions. This journal aims to dissect the Atlas V by examining its integral components and providing insights into its operational mechanisms.

1. Propulsion Systems:

The Atlas V family employs three distinct propulsion systems, each with its purpose. The RD-180 engine powers the first stage, while the RL-10 engine drives the Centaur stage. Furthermore, a novel strap-on solid rocket booster (SRB) contributes to the rocket's lift-off capabilities. The RD-180 and RL-10 engines come with a proven track record and full qualification for all Atlas V missions. The SRB is currently undergoing qualification testing.

2. Vehicle Design:

The design of the Atlas V rocket represents a pinnacle of engineering and innovation, ensuring its reliability and flexibility for a wide range of mission requirements. The Atlas V vehicle boasts a modular and versatile architecture, with multiple configurations tailored to meet specific payload needs. Its design principles are rooted in simplicity, performance, and adaptability.

3. Structural Elements:

The Atlas V's structure is a result of meticulous engineering. It emphasizes robustness, flexibility, and reliability. This section elucidates the design and functionality of the structural components, which form the backbone of the launch vehicle.

4. Avionics:

The avionics systems embedded in the Atlas V play a pivotal role in the rocket's guidance, navigation, and control. This part of the journal explores how these systems ensure precision and safety during flight.

5. Materials and Construction:

Materials used in the construction of the Atlas V are carefully selected to meet the highest standards of performance and durability. This section examines the impact of these materials on the vehicle's overall capabilities and longevity.

6. Aerodynamics:

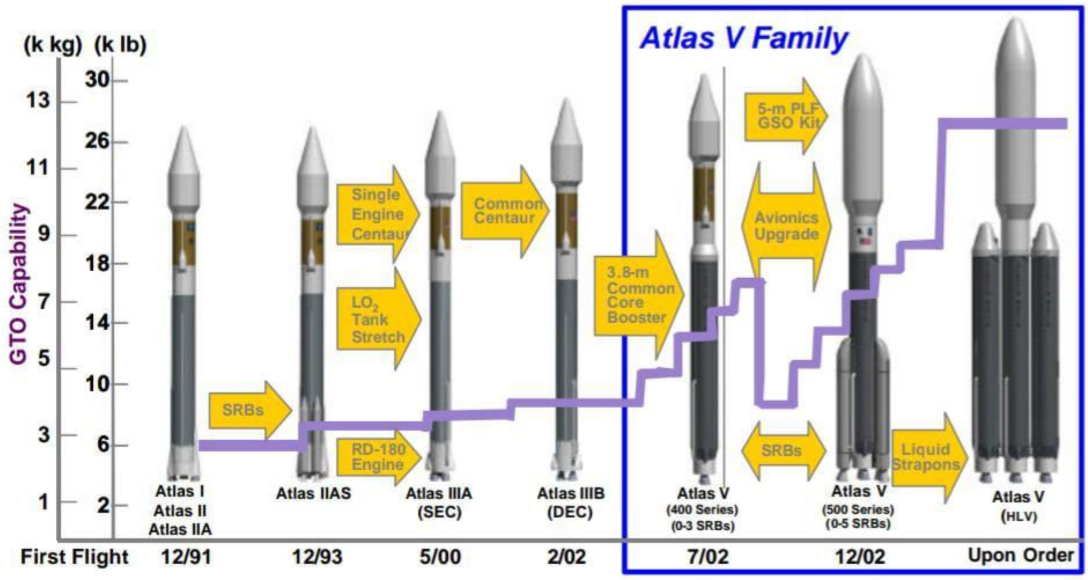
Aerodynamics is a fundamental aspect of any rocket's design. Here, we discuss how the Atlas V's aerodynamic features contribute to its efficiency and effectiveness in reaching space.

PROPULSION SYSTEM

"The Atlas V family relies upon the Russian RD-180 engine as its cornerstone, a derivative of the successful RD-170 engine crafted by NPO Energomash. RD AMROSS, a joint venture of NPO Energomash and United Technologies Pratt & Whitney, is responsible for manufacturing the RD-180 engine for Lockheed Martin, having delivered 13 flight-ready engines, two of which have seen actual flight. Distinguished as the world's sole throttleable, expendable rocket engine in production, the RD-180 has obtained certification for Atlas V vehicle flight, accumulating over 29,000 seconds of test time across 45 engines, including more than 360 seconds of actual flight time. Lockheed Martin's rigorous testing has underscored the engine's robustness, subjecting it to firings spanning a broad range of parameters. Each test engine undergoes seven full-duration hot fires before teardown and refurbishment, ensuring its capability to withstand anticipated flight environments and anomalies. Notably, the engine has displayed minimal wear on subsystems during inspections of the 20 development engines, affirming its resilience and design validation. It has successfully passed all qualification tests for the Atlas V family, including the HLV configuration, and has demonstrated the capacity for prolonged, low-throttle runs.

The utilization of the RD-180, with its substantial thrust levels of 3,830 kN at sea level (4,150 kN in a vacuum), has simplified Atlas III and V system designs by eliminating stages and propulsion systems compared to previous Atlas configurations. Notably, its continuous throttling capability optimizes launch vehicle trajectories for specific missions, offering unparalleled flexibility in tailoring flight environments. This flexibility opens new horizons for mission design, catering to end-users unique needs, thus enhancing Atlas V's appeal to the satellite community.

Additionally, the Pratt & Whitney RL-10 engine, a minor derivative of the long-standing Atlas engine, plays a crucial role in Atlas V. The RL-10 engine is employed on the Centaur upper stage, with either one or two engines used depending on mission requirements. Most missions to geostationary transfer orbit (GTO) or beyond utilize the single-engine version, while only performance-critical low Earth orbit (LEO) missions resort to the dual-engine configuration. Operating with LH2 and LO2 propellants, the RL-10-A4-2 provides 198.4 kN of vacuum thrust at a specific impulse of 450.5 seconds. The RL-10-A4-2's key difference from its predecessor, the RL-10-A4-1, used on Atlas II and III, is the incorporation of redundancy in the ignition system, enhancing ignition event reliability. The turbo-machinery, nozzle, and combustion chamber remain unchanged, and the RL-10-A4-2 has successfully passed qualification tests for Atlas V.



Furthermore, the Atlas V will introduce a new solid rocket booster (SRB) developed by Gencorp Aerojet. Designed for use with both the 400 series (up to 3 boosters) and the 500 series (up to 5 boosters), the Atlas V SRB offers unprecedented flexibility to end-users. Each SRB is identical with a fixed 3° nozzle cant angle and ground ignition. The SRB measures 19.5 meters in length, 1.55 meters in diameter, and has a gross weight of 46,500 kg. Its system design prioritizes simplicity and robustness, notably devoid of segment joints and an active thrust vector control system. Qualification testing for the Atlas V SRB is nearing completion, with structural qualification testing nearly finished and ballistic qualification testing already underway. While challenges have arisen, with one firing not meeting all objectives, further firings are planned to conclude the qualification process by the end of the year."

VEHICLE DESIGN

Atlas Booster

The Atlas booster is powered by a single RD-180 engine fueled by Liquid Oxygen (LO2) and RP-1 (Rocket Propellant-1). It can accommodate up to three strap-on SRBs for the Atlas V 400 series and up to five for the Atlas V 500 series. The light Atlas Booster configuration (without SRB capability) is used for the Atlas V HLV.

The Atlas booster structure is 3.8 meters (12.5 feet) in diameter and 33 meters (109 feet) long. It consists of aluminum grid tanks and is constructed from only eight simple subassemblies, which is a significant simplification compared to previous Atlas IIAS designs. Avionics components are housed in a pod structure along the side of the fuel tank.

The LO2 and RP tanks have specific structures: the LO2 tank consists of forward and aft barrel sections joined by a splice ring, while the RP tank has a single barrel. Propellant feedlines are used to deliver LO2 and RP from the tanks to the RD-180 engine.

The Pressurization System ensures in-flight pressurization of the LO2 and RP tanks and provides ground pressurization capabilities during transportation, storage, prelaunch, and launch countdown operations. It consists of Composite Overwrapped Pressure Vessels (COPVs), Flow Control Assemblies (FCAs), and pressure transducers.

Aft Transition Structure and Heat Shield

The RD-180 engine is connected to the Atlas booster through the Aft Transition Structure (ATS). The ATS provides the load path for the engine's thrust loads and houses helium bottles used to pressurize the propellant tanks. The heat shield offers thermal protection and environmental closure for the engine compartment. It's constructed using aluminum ring frames, fittings, and skins for the ATS, while the heat shield itself is a composite structure with graphite-epoxy face sheets over an aluminum honeycomb and aluminum ring frames.

RD-180 Engine

The RD-180 engine is a two-chamber design that is fed by a common turbopump assembly. This engine is a self-contained unit with an integral start system, hydraulics for control-valve actuation and thrust-vector gimbaling, pneumatics for valve actuation, and a thrust frame for load distribution. The engine operates using a LO2 oxidizer and RP-1 fuel, providing continuous throttle capability between 47% and 100% of nominal thrust. This feature allows for precise control over the launch vehicle (LV) and spacecraft (SC) environments.

The RD-180 is a derivative of the four-chamber RD-170/171 engines used on Russia's Energia boosters and was first test-fired in July 1997. It is flight-proven with a substantial flight history for Atlas V 400 and 500 series LV configurations.

Solid Rocket Booster

The Solid Rocket Boosters (SRBs) are a key component of the Atlas V launch system. Each SRB is 1.5 meters in diameter, 20.4 meters long, and weighs around 46,000 kg. They are ground-lit and have a fixed nozzle canted at 3 degrees. The SRBs have a monolithic design with no segment joints, using a proven design that incorporates elements from U.S. government systems. These SRBs are manufactured by Aerojet and are shipped in a ready-to-fly configuration to the launch site for installation on the LV.

Atlas V Interstage Adapters

The various interstage adapters provide structural attachment and transition between different components in the Atlas V system, including connecting the Atlas booster to the Centaur upper stage and payload fairing.

Meter Diameter Payload Fairing Boattail Assembly

The 5-meter Payload Fairing (PLF) boattail assembly serves as a transition structure between the Centaur interstage adapter and the 5-meter diameter PLF modules. It is a composite structure composed of graphite-epoxy face sheets over an aluminum honeycomb core.

Centaur Forward Load Reactor

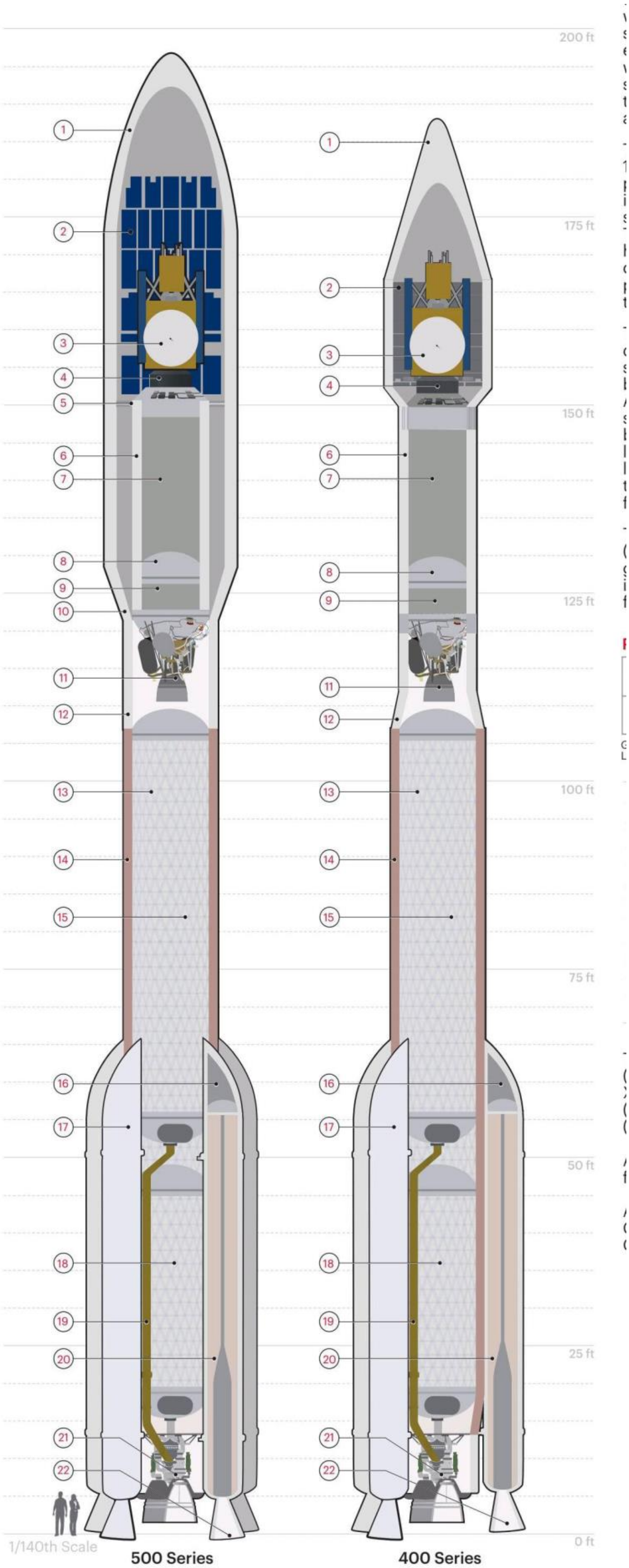
The Centaur Forward Load Reactor (CFLR) is attached to the Centaur forward adapter and plays a crucial role in load sharing between the Centaur structure and the 5-meter PLF. This component is also responsible for accommodating work access platforms inside the PLF. It is used in the Atlas V 500 series and HLV configurations.

Common Centaur Major Characteristics

The common Centaur used in the Atlas V 400 and 500 series configurations is a stretched version of the flight-proven Centaur used on Atlas III. This Centaur offers a 1.7-meter stretch in tank length compared to the Atlas IIAS Centaur, providing added performance. It uses the RL10A-4-2 engine, and the nozzle extension is in the fixed position before flight.

Major components of ATLAS V

1. Payload Fairing
2. Acoustic Panels
3. Spacecraft
4. Payload Adapter
5. Centaur Forward Load Adapter (5m Only)
6. Centaur
7. Centaur Fuel (LH2) Tank
8. Common Bulkhead
9. Centaur Oxidizer (LO2) Tank
10. Boattail (5m Only)
11. Centaur Engine (RL10)
12. Interstage Adapter
13. Booster Oxidizer (LO2) Tank
14. Common Core Booster
15. Isogrid Structure
16. Nose Cone
17. Solid Rocket Booster
18. Booster Fuel (RP-1) Tank
19. Booster Oxidizer (LO2) Feedline
20. Solid Rocket Propellant
21. Booster Engine (RD-180)
22. Solid Rocket Booster Nozzle


200 ft
175 ft
150 ft
125 ft
100 ft
75 ft
50 ft
25 ft
0 ft
1/140th Scale
500 Series
400 Series

STRUCTURES

1. Introduction

The Centaur structural system comprises three primary components, namely the propellant tank, Centaur forward adapter, and propellant tank insulation. These elements are essential for ensuring the structural integrity, support for onboard systems, and thermal control of the Centaur vehicle.

2. Propellant Tank

The propellant tank serves as the primary structural component of the Centaur vehicle, supporting all airborne systems and components. It features a double-wall, vacuum-insulated intermediate bulkhead that separates the propellants, constructed from thin-wall fully monocoque corrosion-resistant steel. Tank stability is maintained through internal pressurization. In the case of DEC configurations, engines are directly mounted to the propellant tank aft bulkhead, whereas the SEC incorporates an engine support beam with redesigned thrust vector control actuator supports.

3. Centaur Forward Adapter

The Centaur Forward Adapter (CFA) combines the functions of the stub adapter and equipment module from previous Atlas configurations into a single, more producible structure. It provides mounting for avionics components, electrical harnesses, and the forward umbilical panel. The CFA's load-carrying capacity has been enhanced to accommodate the loads required by various payload configurations. Structural improvements and the use of aluminum-lithium stringers provide cost and mass-efficient enhancements without necessitating the requalification of avionics hardware.

4. Propellant Tank Insulation

Centaur propellant tank insulation plays a critical role in minimizing ice formation and boil-off of Liquid Oxygen (LO2) and Liquid Hydrogen (LH2) during ground storage and atmospheric ascent. This insulation consists of foam insulation bonded to the exterior surface of the LH2 and LO2 tanks.

5. Conclusion

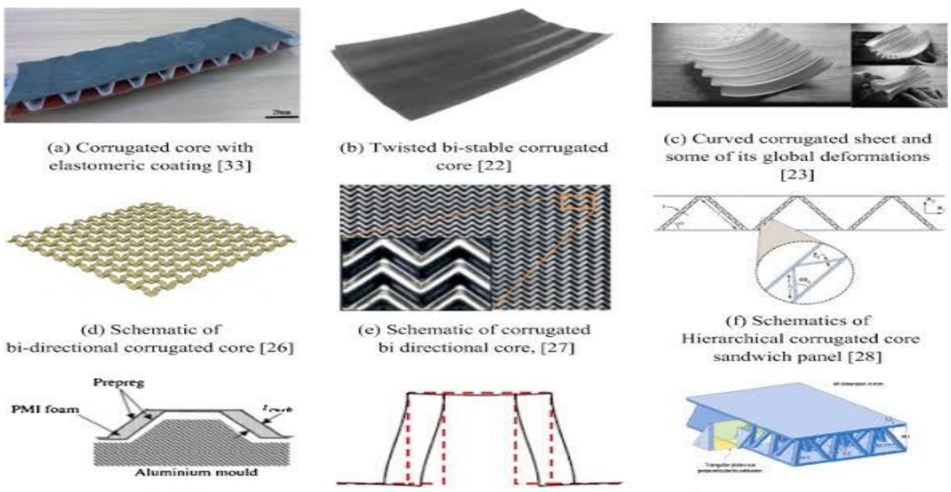
The structural elements of the Centaur vehicle, as described in this article, are vital for its functionality and performance. The propellant tank, Centaur forward adapter, and propellant tank insulation contribute to the vehicle's structural integrity, load-carrying capabilities, and thermal control, ensuring the successful execution of its missions.

CORRO STRUCTURE:

Corrugated roof sheets are a Lightweight material and due to this property, it has been a wide choice for many roofs. This is one of the many corrugated steel sheet benefits that anyone considers when using for their structure, However, some homeowners are afraid of choosing corrugated sheets as their roofing material due to the possible noise it may have during the rainy season. Compared to the noise you get inside a building which is covered with corrugated steel is much similar to the noise of a roof covered with asphalt or any other metal. Homeowners can easily use insulation materials to prevent such noise when they use corrugated metal sheets as their roof covering.

When you choose your roofing material you cannot forget the durability. Durability is one of the properties that you should check when you build your structure. While metal roofing can stand over different weather conditions, corrugated steel roofs are also safe from insect attacks. Due to the chemicals used in steel sheets during its production stage, termites and other similar insects cannot attack your roof. Corrugated steel sheets are also safe from algae growing

The Atlas V's first stage is the common core booster. This main booster is 107 feet (32.5 meters) long, with a diameter of 12.5 feet (3.8 meters). With the payload on board, the launch vehicle is 188 feet (57.3 meters). Fully fuelled, with the spacecraft on top, it weighs about 730,000 pounds (333,000 kilograms). For reducing the weight of Atlas 5 we use a honeycomb structure because the wall skin thickness is 4 inch to 5 inches approximately so we use a Corro sheet structure to reduce the weight of Atlas 5 rocket to a reusable launch vehicle.



(a) Corrugated core with elastomeric coating [33]
(b) Twisted bi-stable corrugated core [22]
(c) Curved corrugated sheet and some of its global deformations [23]
(d) Schematic of bi-directional corrugated core [26]
(e) Schematic of corrugated bi directional core. [27]
(f) Schematics of Hierarchical corrugated core sandwich panel [28]
(g) PMI foam filled hierarchical corrugated sheet Kazemahvazi et al. [21]
(h) Double wall corrugated concept Previtali et al. [30]
(i) Schematics of extruded pyramidal lattice truss sandwich structure. [32]

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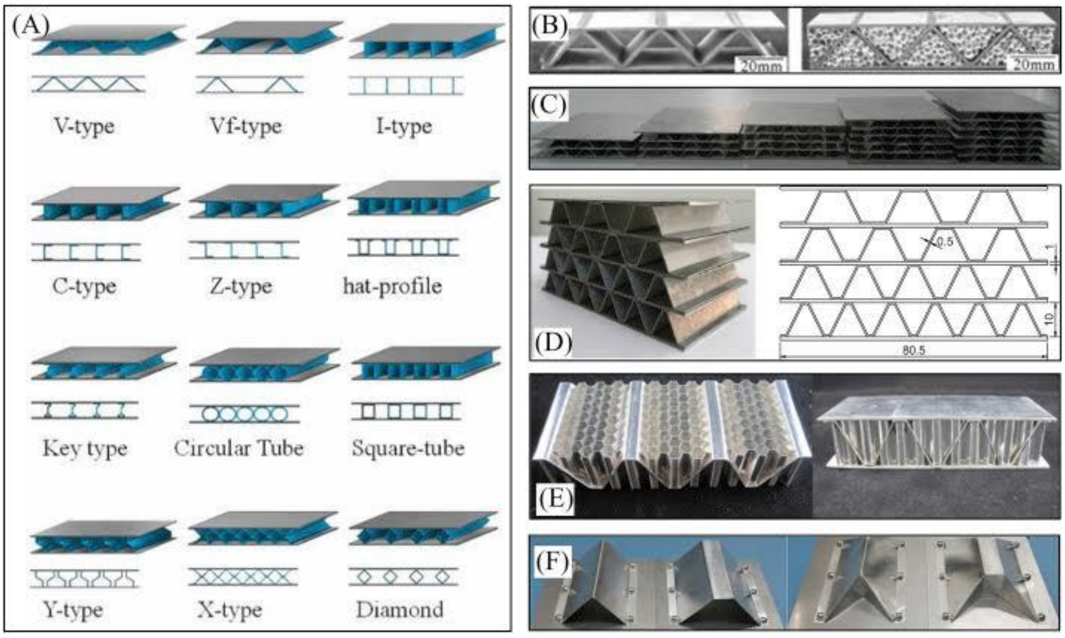

TITANIUM AND NICKEL ALLOY:

Titanium alloy won the title of “space metal”. It has the advantages of lightweight, high strength, and high-temperature resistance. It is especially suitable for manufacturing aircraft and various spacecraft. At present, about three-quarters of the titanium and titanium alloys produced in the world are used in the aerospace industry. Many parts originally made of aluminum alloy have been replaced with titanium alloy

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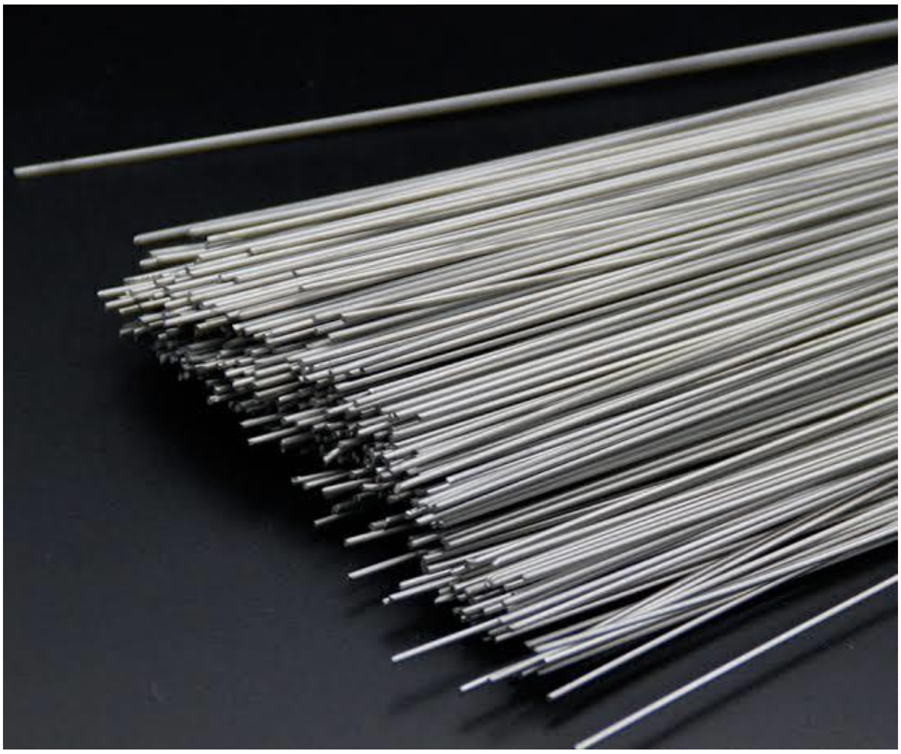
In Atlas 5 there is an aluminum, carbon fiber titanium as used as a material for this material we changed the titanium nickel alloy because titanium is Known for its strength and resistance to corrosion, titanium is heavier than aluminum but lighter than steel. It's commonly used in aerospace applications. Titanium Nickel Alloys, these alloys can offer a balance between the properties of titanium and nickel. They may be used in specific components to achieve desired characteristics so they can be changed in Atlas 5 rocket for reusable launch vehicle



Aviation application of titanium alloy :

Titanium alloy is mainly used in aircraft and engine manufacturing materials, such as forged titanium fans, compressor discs and blades, hoods, exhaust devices, and other parts, as well as structural frame parts such as girder spacer frames of aircraft. Spacecraft mainly use the high specific strength, corrosion resistance, and low-temperature resistance of titanium alloy to manufacture various pressure vessels, fuel tanks, fasteners, instrument straps, frames, and rocket shells. Titanium alloy plate weldments are also used in artificial earth satellites, lunar modules, manned spacecraft, and space shuttles.

Advanced Avionics Systems in the Atlas V Launch Vehicle

Advanced avionics systems are utilized in the Atlas V launch vehicle, focusing on both the booster and Centaur avionics. It describes enhancements in redundancy and technology, as well as the essential roles these systems play in vehicle control, monitoring, and telemetry.

1. Booster Avionics

In the Atlas booster, the design incorporates redundant main batteries for added reliability. The Fault-Tolerant Inertial Navigation Unit (FTINU) now routes inputs to the Booster Rate Sensor Controller Unit (BRCU) and subsequently to the Inertial Navigation Unit (INU) via the 1553 data bus. Similar to the Centaur, the Pyrotechnic Controllers (PYCs) have been replaced by Orbital Rocket Controller Assemblies (ORCAs) for pyrotechnic events, establishing redundancy with two ORCAs and two dedicated pyrotechnic batteries. Notably, the Atlas Flight Termination System (FTS) has been replaced by the Automatic Destruct System (ADS), a system that autonomously commands destruction in case of inadvertent stage separation, while preserving the existing Centaur capability.

2. Centaur Avionics

Centaur avionics components, including the Inertial Navigation Unit (INU), Control Rate Sensor Unit (CRCU), Electrical Control Unit (ECU), Master Data Unit (MDU), and Remote Data Unit (RDU), remained consistent with the Atlas III for the first 13 Atlas V vehicles. The significant change involves the replacement of PYCs with ORCAs for pyrotechnic events, once again ensuring redundancy with two ORCAs and two dedicated pyrotechnic batteries. Furthermore, the Main Vehicle Battery (MVB) has been upgraded to enhance its capacity.

3. Advanced Redundancy and Technology

A prominent example of added redundancy is the introduction of the new FTINU developed by Honeywell for service on Atlas V since mid-2005. It supersedes the existing Internal Navigation Unit (INU) and provides enhanced mission accuracy and redundancy. It incorporates a fully fault-tolerant pentad of ring laser gyros and a dual-channel processor system, arranged in an active/hot-spare architecture. Additionally, the FTINU houses and executes the flight software, responsible for guiding and controlling the vehicle throughout the mission.

SYSTEMS USED FOR COMMUNICATION AND FLIGHT COMPUTER SOFTWARE

The specific details of the communication and flight computer software systems used in the Atlas V spacecraft may have evolved since then.

1. Communication Systems:

i. **Telemetry and Command Systems:** The Atlas V spacecraft employs telemetry and command systems to facilitate communication between the spacecraft and ground control. Telemetry involves the transmission of real-time data from the spacecraft to Earth, including information about its health, status, and mission parameters. Command systems allow ground control to send instructions and commands to the spacecraft.

ii. **Tracking and Data Relay Satellites (TDRS):** The Atlas V may use NASA's TDRS system, which is a constellation of geostationary satellites designed to provide continuous communication coverage between Earth and spacecraft in orbit. This system ensures that there is a constant and reliable communication link between the Atlas V spacecraft and ground control, even when the spacecraft is not within the line of sight of ground stations.

iii. **Frequency Bands:** Communication with the Atlas V spacecraft typically occurs in different frequency bands, including S-band and Ku-band. These bands are used for telemetry, tracking, and commanding, with specific frequencies allocated for uplink and downlink communication.

iv. **Antenna Systems:** The spacecraft is equipped with high-gain antennas for communication. These antennas may be steerable to maintain a stable communication link as the spacecraft moves through different phases of its mission.

2. Flight Computer Software:

i. **Guidance, Navigation, and Control (GNC) Software:** For the navigation and control of the Atlas V spacecraft, GNC software is essential. It has algorithms for orbital maneuvers, attitude control, and trajectory planning. During various mission phases, these algorithms guarantee that the spacecraft stays on course and maintains the proper orientation.

ii. **Onboard Computer Systems:** The Atlas V spacecraft's onboard computers analyze data from a variety of sensors and make decisions in real-time to maneuver the vehicle. Sophisticated software is programmed into these computers to perform various tasks like orbital adjustments, payload deployment, and engine burns.

iii. **Redundancy and Fault Tolerance:** Redundancy and fault tolerance are built into flight computer software. The spacecraft can carry out its mission even in the event of hardware or software failures thanks to redundant systems and failover procedures.

iv. **Mission-specific Software Modules:** The flight computer software may contain modules for orbit insertion, payload deployment, and other mission-critical operations, depending on the mission profile. These modules are tailored to the particular needs of the launch payload for every mission.

ADVANCEMENT IN FLIGHT SOFTWARE AND AVIONICS SYSTEM

Launch vehicle Flight Safety

The Automatic Destruct Unit (ADU-208) of L3Harris' Flight Termination System was created to offer a way to automatically end powered elements in the event of an unintentional separation or launch vehicle breakup.

Ignition and staging Control:

The ISC is NASA standard initiator compliant and interfaces to a standard one-ohm initiator. The device can interface with extraordinarily long cable lengths and meet low voltage initiator current and energy requirements. By using capacitive discharge firing circuitry, the ISC reduces the complexity of the avionics architecture by doing away with the requirement for a separate pyrotechnic battery. Specifically designed for the highly dependable human-rated NASA space launch system vehicle, the ICS is dual-fault tolerant. Because of its distinctive modular design, the ISC can be easily replaced in a line and its firing circuit quantity can be adjusted to meet specific mission requirements. Additionally, a variety of spacecraft pyrotechnic-actuated deployment and separation applications can be implemented with the ISC. If Atlas V system uses this Control system we will be more advantageous.

Communications spacecraft UHF transceiver

The C/TT-505 UHF Command/Telemetry Transceiver is made to be able to communicate with a wide range of space systems that need to be able to send and receive commands. A full-duplex wireless RF command, telemetry, and data link between two spacecraft is provided by the transceiver.

By using an error-detection and retransmission service, the C/TT-505 offers error-free communication through the integration of the OIC Proximity-1 protocol. Furthermore, the Proximity-1 protocol offers an automatic link-establishment function that lets the primary transceiver configure the secondary transceiver without the secondary spacecraft having to get involved.

Launch Phoenix flight computer in the vehicle

Phoenix is a ruggedized flight computer that is scalable and modular.

Phoenix from L3Harris is a ruggedized flight computer that can be used in a variety of launch vehicle and spacecraft applications. Launch vehicle guidance, navigation, and control (GNC), launch vehicle engine control, satellite attitude control, mission data network control (solid-state compressive recorder), instrumentation & display controller, software-defined radio controller, vehicle health & status monitoring, command & data handling computer, and payload control computer are just a few of the applications for L3Harris' Phoenix, a modular and scalable ruggedized flight computer.

Launch vehicle telemetry unit:

The Master/Remote Telemetry Unit (MRTU) from L3Harris is a replaceable, fully programmable data acquisition line unit. For use in extreme environment launch vehicle boosters and upper-stage applications, this unit offers a range of sensor input signal conditioning and sensor excitations. The vehicle's multiple MRTUs combine to form a telemetry system that can support up to seven units in total: one master, three first-tier remotes, and three second-tier remotes. With fifteen distinct types of sensor and telemetry inputs, each defined by its parameters such as voltage range, sampling rate, and analog filtering, the MRTU has over 500 telemetry and sensor inputs per unit.

CONCLUSION

The journal thoroughly scrutinizes the intricacies of the Atlas V launch vehicle, centering on its propulsion, structure, avionics, and materials. By focusing on the RD-180 and RL-10 engines, alongside the incorporation of a new solid rocket booster, it provides a comprehensive view of the propulsion system's evolution. Additionally, it delves into the structural composition, highlighting the use of corrugated steel sheets for weight reduction and durability, thereby enhancing the potential for reusable launches. Furthermore, the integration of titanium-nickel alloys in place of traditional materials emphasizes a strategic shift toward strength, corrosion resistance, and weight balance, aligning with the aerospace industry's pursuit of improved spacecraft materials. These material advancements notably impact the Atlas V's performance, elevating structural integrity, reducing weight, and promoting reusability—a significant paradigm shift that enhances its capabilities in space exploration endeavors.

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