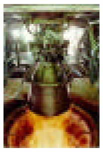

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The Centaur Upper Stage Vehicle

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The Centaur Upper Stage Vehicle

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Abstract

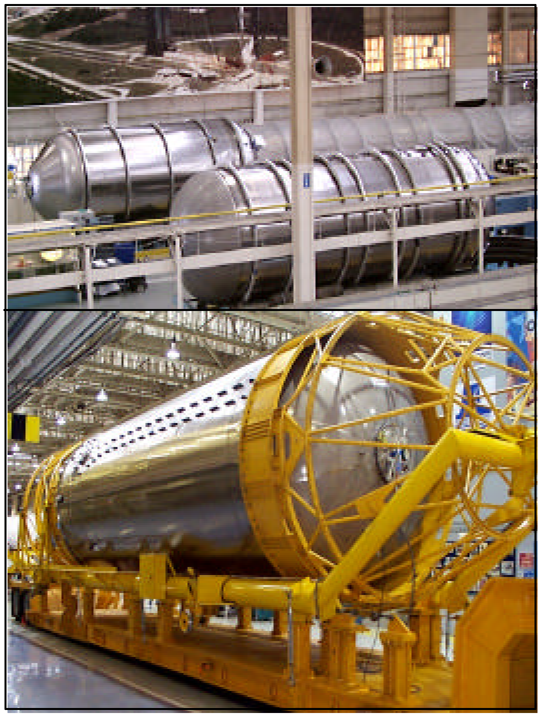
The high-energy Centaur upper stage has evolved to become a very reliable and versatile vehicle. The Centaur program began in 1958, with its first successful flight in 1963. Centaur was flown on Atlas for NASA in the 1960's. The design of the vehicle evolved in the 70's into the D-1A (Atlas) and D-1T (Titan) with improved avionics. The D-1T configuration was built to fly long planetary missions on the Titan IIIE (TC-1 through TC-7). Titan Centaur evolved following the Challenger accident. The wide body Centaur being developed for shuttle began modification to fly on the Titan IV booster (TC-8 through TC-23) in 1985, incorporating features to reliably perform long-coast, 3-burn missions. The Titan Centaur program will conclude after the flights of the last two Titan Centaur missions in 2003. The Atlas program has successfully launched 62 consecutive Atlas Centaur missions. The latest Centaur upgrade was in support of the Atlas V family of launch vehicles. The Common Centaur builds on the Single Engine Centaur (SEC) program that flew successfully on an Atlas IIIA in May 2000. It stretches the propellant tanks 66 inches from the SEC version to carry more propellant, yielding increased performance, and also incorporated long-coast, 3-burn mission capability. The maiden flight of the Atlas V included a Common Centaur to successfully deploy a commercial satellite on August 21 2002. Using 30+ years and over 160 previous flights of lessons learned, additional enhancements were made to major vehicle systems to improve reliability, operability, performance, and flexibility of this latest Centaur. The Common Centaur offers an improved high-energy upper stage at exceptional value to end-users.

Centaur History

The Centaur program began in 1958 with its first successful flight in 1963. Centaur was flown on Atlas for NASA in the 60s, then modified with improved avionics into the D-1A (Atlas) and D-1T (Titan) configurations during the 70s. The D-1T configuration was built to fly longer park orbit coasts for inter-planetary missions on the Titan IIIE (TC-1 through 7). In the 80s, a wide body Centaur was developed to be integrated into the Shuttle, however, the program was canceled following the Challenger accident in 1986. In 1985, work had already begun to modify the larger Shuttle/Centaur design to fly on the Titan IV. A fleet of 16 Titan/Centaur vehicles has been produced for the U. S. Air Force, with one of these vehicles launching the NASA Cassini Interplanetary mission to Saturn. The Titan IV Centaur missions flown are the same long coast, 3 burn mission capability that is designed into the Atlas V. To date, 14 of these Titan/Centaurs have been launched with the two remaining flights scheduled through 2003. There have been over 160 Centaurs launched between Titan and Atlas boosters. As of September 2002, there have been 62 consecutive Atlas Centaur vehicles successfully launched.

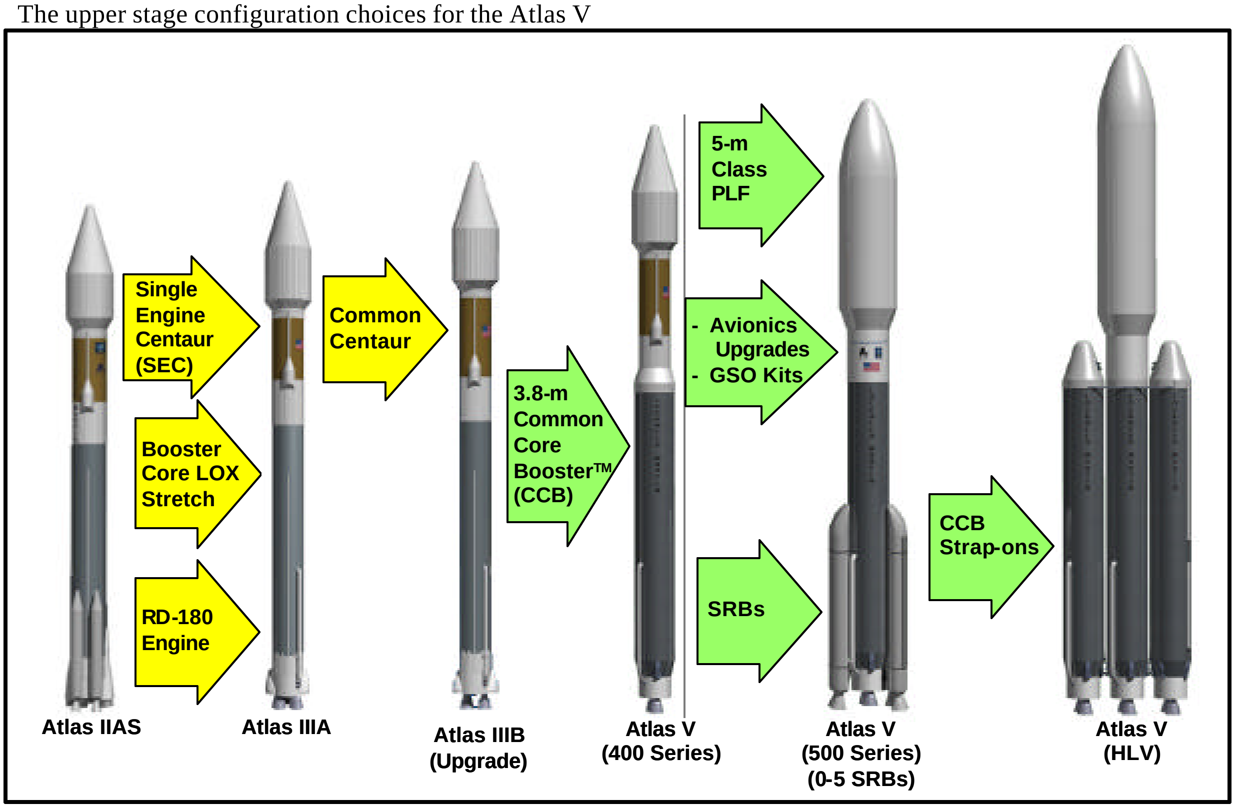
The Atlas IIIB and V Family - The Atlas IIIB and V family of launch vehicles provides a wide selection of performance capabilities to our customers to accommodate a variety of needs. The Atlas IIIB program is an evolutionary step from the Atlas IIIA program, providing additional performance with relatively low risk. The Atlas booster is the same, but the Centaur II upper stage has been replaced with the Common Centaur in either a single engine or a dual engine configuration. Both versions receive the benefit of the Common Centaur improvements to reliability and operability. In addition, the dual engine option can be selected for additional performance. All Atlas IIIB launch vehicles use the flight-proven Atlas 14-ft diameter payload fairing in either large or extended versions.

Titan Centaur launch vehicle in the tower with Cassini mission (NASA photo)



Upper: A Common Centaur tank is shown in San Diego below a Centaur II tank. Lower: A Common Centaur tank leaves San Diego bound for final assembly in Denver.

The upper stage configuration choices for the Atlas V are essentially the same as for the Atlas IIIB. All Atlas V launch vehicles use the newly developed Common Core Booster®, which uses a structurally stable 12 ½-ft diameter tank and the Atlas III flight-proven RD-180 engine. The Atlas V-400 series uses the Common Centaur in either the single or dual engine version, and incorporates the 4-m (14-ft) diameter payload fairing mounted atop the Centaur, similar to all previous Atlas/Centaur versions. Up to three solid rocket boosters (SRB) can be attached to the booster for additional performance. The Atlas V-500 series is the same as the 400, with the exception of using a large 5-m diameter payload fairing, which encapsulates both the Common Centaur and the spacecraft similar to Titan Centaur. Up to five SRBs can be attached to the 500 series booster for additional performance. The third variant is the Atlas V Heavy Lift Vehicle, which uses three Common Core Boosters strapped together for additional thrust for heavy payloads. A longer 5-m payload fairing encapsulates the Common Centaur and the spacecraft, similar to the 500 series. This variant was brought to the critical design review level of maturity in September of 2002, and will be implemented upon customer request.



The Atlas launch vehicle evolution. The Common Centaur is the upper stage for all Atlas IIIB and Atlas V configurations.

The first Atlas IIIB was successfully launched in February 2002 from Launch Pad 36B at Cape Canaveral Air Force Station (CCAFS), where modifications to accommodate the additional length of the Common Centaur were incorporated. This is the same pad where commercial Atlas/Centaur launch vehicles are now launched. The Atlas V family of vehicles will also be launched from CCAFS, but on a new launch pad on Complex 41. The first Atlas V-400 vehicle was successfully launched in August 2002. The booster and Common Centaur for the first Atlas V performed flawlessly on this maiden voyage.

Titan IV Centaur Vehicle Description - The Centaur consists of a 576 cubic foot aft liquid oxygen tank that shares a common intermediate bulkhead with the 1890 cubic foot forward liquid hydrogen fuel tank. To reduce overall length for the Shuttle cargo bay, the T/C LH2 tank diameter was increased to 14 ft. compared to the 10 ft. diameter Atlas/Centaur tank. A conical transition section joins the LH2 tank with the 10 ft. diameter LO2 tank, which attaches to the Titan Forward Skirt Extension (FSE). This transition ring maintains the successful 10 ft diameter common bulkhead, which reduced development cost and risk. Using a PLF as long as 86 ft with the Centaur upper stage accommodates the same payload volume as the original Shuttle/Centaur.

Titan Centaur Tank in production in San Diego

The stainless steel thin-walled propellant tanks are pressure stabilized, and give Centaur an excellent energy to weight ratio. The vehicle depends on additional pressure to provide the required strength to react to bending and vibration loads on ascent and throughout the mission. The last Titan Centaur tank incorporates the improved aft bulkhead design used on the Atlas Centaur with welded gimbal mounts and pressure assisted seals. The tanks are manufactured in San Diego in the same facility as the Common Centaur tanks.

Using this lightweight design requires a fluids system that is capable of maintaining the required pressure levels for all phases of flight as well as on the ground. The fluid and propulsion systems consist of a helium supply system, a pressurization system, a vent system, a hydraulic system, two main engines, a reaction control system, and a computer control system. The long TIV missions require radiation shields on the LO2 and LH2 tank. In addition, the LH2 tank uses foam purged on the ground with helium.

Helium Supply and Pressurization System - Helium is the main pressurant used for tank pressurization. Typically, four 26-inch diameter high-pressure helium bottles mounted on the aft bulkhead are used for storage. They are made of a graphite/epoxy composite overwrap enveloping a stainless steel or aluminum liner. These bottles are charged to 4000 psia prior to liftoff. Helium in-flight purges are used for the sense lines, LO2 vent valve and the LO2 bubbler line.

The bottles are manifold together and are linked to two pressurization valve modules, one for each propellant tank. Each valve module contains four individual valves, which provide single failure tolerance both to open or close. Helium is used for tank pressurization prior to engine burns. A hydrogen autogenous system bleeds gaseous hydrogen off the engines and is used for LH2 pressurization during the engine burns. A valve module identical to those used for helium pressurization provides control. The T-IIIE Centaur used boost pumps for engine inlet requirements, which reduced the helium load to one smaller bottle at 3300 psia, but at the expense of a more complicated feed system. Testing at NASA Plumbrook in the 1970's on a full-scale Centaur stage in an altitude chamber verified pressurization and engine start without boost pumps. Those tests served as the basis for the change. The Atlas

Centaur first flew the pressurized feed system on AC-62 in June 1984.

Titan Centaur erection on Titan vehicle at the launch pad

Vent System - The LO2 vent system consists of a self-regulating vent valve with a solenoid-locking feature that is mounted on the sidewall of the tank. The LH2 tank vent system consists of two (primary and secondary) self-regulating vent valves with a solenoid-locking feature. The valves are locked to allow pressurization. The secondary valve with an orifice is used during the controlled vent-down on ascent by cycling the solenoid. The primary valve has no orifice and is used later on ascent and throughout the mission. The T-III E Centaur used a secondary valve that was set slightly higher than the primary valve and remained unlocked for ascent. The higher lift-off pressure of the T-IV requires both valves to be locked. The LO2 valve remains locked until SRMU separation at T+175 seconds, venting the tank to the self-regulating range.

CCVAPS - The Computer Controlled Vent and Pressurization System (CCVAPS) is the flight software that controls the pressurization and vent systems to maintain the required tank pressures throughout the mission. A redundant system of three pressure transducers is used to measure ullage pressure in each tank. The output of these transducers is provided to the flight computer system (FCS) contained in the Inertial Navigation Unit (INU), which commands pressurization, and vent valves as needed. Tank pressure must be maintained at minimum required levels to prevent the tanks from buckling. The intermediate bulkhead creates an additional requirement. LO2 tank pressure must always be greater than LH2 tank pressure to prevent the bulkhead from reversing. Since the engines require a given Net Positive Suction Pressure (NPSP) or delta-Pressure above liquid vapor pressure, the tanks are pressurized to a given delta-pressure above liquid vapor pressure during the engine burns.

Launch of TIVB 38 with TC-19 in January 2002

Propulsion System - The Titan Centaur propulsion system uses two RL10A-3-3A Pratt & Whitney engines, shown in Figure 8. Each engine produces 16,500 lbf of thrust, a 444.4 sec nominal Isp at 5.0:1 MR and an area ratio of 61:1. This series of engines has been used successfully since 1963 on the Saturn and Atlas/Centaur vehicles. The last Centaur will use the RL10A-4-1A engine that is similar to the Atlas Centaur III. The RL10 uses an expander cycle, where all of the LH2 is burned in the combustion chamber, except for a small amount used for autogenous pressurization and pump bearing cooling/gear box pressurization. The turbine working fluid is the supercritical hydrogen heated in the regeneratively cooled thrust chamber. Engine control for prestart,

start and shutdown is provided by solenoid valves which control the flow of vehicle helium to pressure actuated valves. Engine gimbaling on Titan Centaur is provided by pitch and yaw actuators powered by a hydraulic power unit mounted on the RL10 LO2 pump shaft.

The engine pumps are chilled with ground system gaseous helium prior to launch to reduce prestart time on the first main engine start (MES-1). Prior to each main engine start, the engines is chilled with vehicle propellants. LH2 chills the fuel pump and is exhausted though the two cooldown valves. The LO2 flows through the by-pass valve and cooldown passages in the oxidizer flow control valve (OFCV), then through the injector and thrust chamber. At MES, the start solenoid opens, providing pressure to open the main fuel shutoff valve (MFSOV), partially closes the ISCDV and the PDCDV, and close the OFCV bypass (reducing LO2 flow to the chamber). LH2 enters the thrust chamber cooling tubes, where it vaporizes and passes through the turbine, powering the LH2 and LO2 pumps. As the engine accelerates, increasing system pressures which closes the ISCDV and open the inlet poppet of the OFCV. The latter allows full LO2 flow to the chamber further increasing temperature and energy to the GH2 and "bootstrapping" the system to full thrust in about 2-3 seconds.

Thrust overshoots are reduced with a delay in the reference pressure of the thrust control valve (TCV), which opens the GH2 turbine bypass early and prevents high chamber pressures. The ignition system uses a spark plug embedded in the center of the injector. During ignition, oxygen is supplied to the region of the spark plug from the injector manifold through a GOX igniter shuttle valve. Fuel is supplied from flow paths in the injector and flows to the igniter region. The fuel and oxygen local to the spark provide the initial ignition to light the chamber at the low pressure, cold conditions of space. The GOX valve closes after start from increasing system pressures to prevent high temperatures around the igniter spark plug. The spark plug is cooled by GH2 during steady state. The RL10A-4-1A will eliminate the need for this GOX valve and improved reliability and performance.

During steady state, the vehicle Propellant Utilization (PU) system provides commands to the OFCV to modulate mixture ratio. The chamber pressure is held nearly constant when the mixture ratio is increased or decreased by the TCV. The LO2 pump accessory drive pad supplies power to the vehicle hydraulic power unit pump which provides 1100 psia to vehicle thrust vector control servo actuators. The solenoid valves are closed at shutdown, closing both inlet valves and the MFSOV. The cooldown valves are opened, bleeding off system pressure.

Electrical recirculation motors are turned on in the hydraulic system before launch. These motors remain on during ascent, are cycled during the coasts to keep the hydraulic fluid warm, and are turned off during each burn.

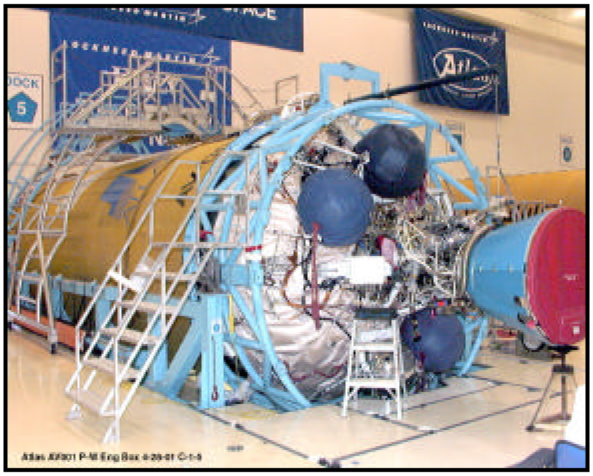
All burns use this same sequence except for the prestart duration, which varies with predicted pump temperatures, and the burn duration dictated by mission trajectory requirements. The prestart times are pre-programmed while the burn durations are determined by the Inertial Navigation Unit (INU).

Reaction Control System - A hydrazine reaction control system (RCS) performs vehicle control, thermal roll maneuvers and propellant settling. The RCS uses two bladder tanks with a total of 340 lb and a pressure regulated feed system supplying twelve, 6 lbf thrusters in two 2-thruster modules and two 4-thruster modules. A redundant pyrovalve isolates the thruster loop from the bottles. Redundant pyrovalves also isolate the pressure side of the bottles from the helium system pressure. This system was first introduced when the boost pumps were eliminated in 1984. The pumps were run with a hydrogen peroxide monopropellant system that also provided the RCS. Two bottles with 242 lb capability were used. There were several problems in flight with this old system on Atlas Centaur. The new hydrazine system has been trouble-free on both Atlas and Titan Centaurs.

The Common Centaur Philosophy

The Common Centaur is an enhancement of the existing Centaur II upper stage, which is used by the Atlas II and IIIA family of launch vehicles. The Centaur II will gradually be phased out of production as those launch vehicle families fly out. It will be completely replaced by the Common Centaur, also referred to as the Centaur III. In addition to the significant performance benefits, this shift to the Common Centaur greatly reduces the requirements at two manufacturing facilities, which currently accommodate two different length Centaurs.

The San Diego Operations facility manufactures the Common Centaur tank structure and configures it for shipment to the Final Assembly Building (FAB) in Denver, where assembly is completed. The Centaur is then shipped to the CCAFS, where it is mated with the Atlas booster and prepared for launch.



The first Common Centaur (AVC-001) in final assembly in the clean room in Denver.

The Common Centaur tank is configured for either a single or dual engine at the San Diego tank assembly building before it is shipped to Denver. If a late change in the launch manifest requires a change to a different number of engines, that change can be performed at the FAB in Denver. The design of the engine support structure, first implemented on the Atlas IIIA program, allows this type of late change to the vehicle.

Several other tasks that were previously performed in the FAB have moved to San Diego. This shift in task location allows better throughput in the Denver facility by preferring many common tasks to San Diego to take advantage of available manufacturing capacity. The installation of the entire Reaction Control System (RCS) is an example of a primary task that has been moved to decrease the amount of time in Denver. The tooling, planning, and engineering required to support this installation are now in use in San Diego.

When the Common Centaur tank has been received from San Diego properly equipped with the single or dual engine support structure, it goes through the final assembly process in Denver. The vehicle configuration is determined, normal vehicle assembly occurs, and the appropriate kits for the engine(s), pneumatics system, and propellant feed systems are added. For missions that require three burns and 5+ hour transfer orbit coasts, an Extended Mission Kit is also added. This kit includes an additional helium bottle, radiation shielding, a liquid hydrogen (LH_2) tank anti-slosh baffle, and larger batteries.

Left: The first Single Engine Centaur is hoisted into position for booster mating at the launch site. Right: The first Atlas IIIA successfully lifts off the launch pad in May 2000.

Using the common tank philosophy in San Diego and the kitting philosophy in Denver enhances flexibility in configuring the Common Centaur to support the Atlas IIIB and V family of vehicles. It reduces errors in fabrication, minimizes the amount of rework required due to changes in manifest and configuration, and reduces the overall span time for Common Centaur manufacture.

SEC Program heritage

The same team of engineers who developed the Single Engine Centaur (SEC) upper stage for the Atlas IIIA program performed the Common Centaur development. The first SEC was successfully flown when the first Atlas IIIA launched from CCAFS on May 24, 2000. The Common Centaur makes use of a number of new and improved hardware and operational features that were successfully proven on this flight.

On the hardware side, the single-engine mounting beam and side support structure, and the thrust vector control actuator supports enabled the single engine to be located on the centerline of the upper stage, while providing the necessary attach points and equivalent mounting stiffness of previous dual-engine configured vehicles. Newly developed electromechanical actuators (EMA) for thrust vector control were incorporated, reducing prelaunch set-up and test time and improving reliability. New propellant supply ducts for both liquid hydrogen and oxygen were developed to accommodate the relocation of the engine. The liquid oxygen duct incorporates a unique slip-joint feature, which enables engine gimbaling while minimizing engine inlet structural loads. A new single outlet liquid oxygen sump was also flown for the first time. A new overboard vent system allows both prelaunch and inflight chilldown of the engine to occur, reducing the amount of prestart propellants used before ignition, and consequently improving payload lift capability by over 50 lb.

Operational firsts include gaseous helium ground chilldown for the liquid oxygen turbopump, and inflight (boost-phase) cooldown of the hydrogen pump, as mentioned above. The Atlas III vehicle timeline calls for payload fairing jettison during the Centaur burn phase of flight, which was successfully accomplished. Finally, the RCS was used for Centaur roll control during the Centaur burn phase because the single engine configuration does not allow the engine to take out roll moments.

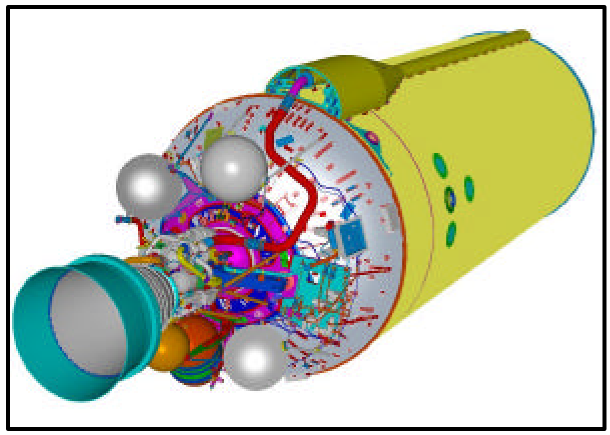
<u>Common Centaur Development</u>

The Common Centaur development team has leveraged greatly off the work that was done for the development of the SEC to support the Atlas IIIA program. The Common Centaur incorporates the features of the SEC mentioned above, and takes the development even further to improve the performance, operability, and reliability of the Centaur upper stage to support the Atlas IIIB and V programs. In a highly competitive launch vehicle environment, it is essential to maintain an advantage by improving this very versatile upper stage. Modifications were performed to the structural, engine, propulsion, and pneumatics systems to enable the Common Centaur to be the upper stage required for the flexible series of launch vehicles provided to the commercial and government markets. Changes to these systems are discussed in the following sections.

<u>Structural System</u>

The shift to a Common Centaur philosophy required a number of structural modifications. The structural modifications can be divided into two categories—changes to the Centaur tank and changes to the adapters. The adapters connect the tank structure to the rest of the rocket.

The most significant structural changes were made to the Centaur tank. The liquid oxygen (LO_2) tank was stretched 16.5 in. and the LH_2 tank was stretched 49.5 in., for a total tank stretch of 5.5 ft. The tank skin thickness had to be increased to accommodate additional loads from heavier spacecraft. The forward bulkhead of the LH_2 tank was changed in shape to an elliptical profile, which now matches the shape of the aft bulkhead. This profile is easier to produce than the previous conical profile. Only one set of common bulkhead tooling is now required in San Diego. The LH_2 feedline sump, which protrudes from the sidewall of the Centaur tank, has been stretched to allow the existing LH_2 feedline to be used. The internal LO_2 standpipe and the external cableway fairing have also been extended to account for the stretched tank.



A Common Centaur CAD model, shown with the fourth helium bottle for the Extended Mission Kit.

A number of tank interfaces have now been upgraded to incorporate a pressure-assisted seal design, minimizing rework requirements caused by seal leakage in final assembly and at the launch site. Changes to the mounting structure for the helium and hydrazine bottles, the addition of mounting brackets for the new single pneumatics panel, and modifications to various insulation systems also are part of the structural upgrades.

The Centaur Interstage Adapter (C-ISA) has been modified from the Atlas IIIA design because of the changes in the length of the Centaur tank. The Atlas IIIB uses the C-ISA Long, which is the same ISA used on the Atlas IIIA program. The Atlas V 400 series uses an ISA shortened by 52 in. called the C-ISA Short, because an adapter on the forward end of the booster gives the vehicle the additional interstage length required. Both interstage adapters use the same flight-proven aluminum/lithium skin/stringer construction.

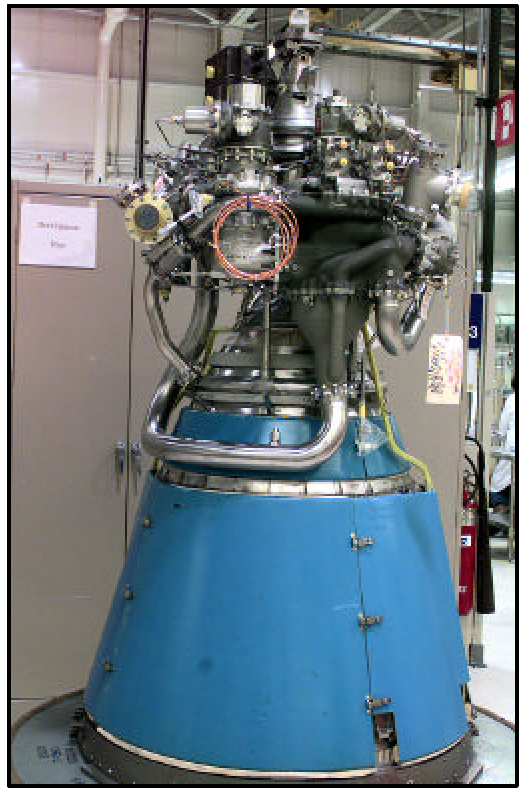
On the forward end of the Centaur, the old equipment module and stub adapter have been structurally combined to form the single piece Centaur Forward Adapter (CFA) constructed in Harlingen, Texas and shipped to Denver for final assembly. This is similar to the Titan Centaur forward adapter. Like all previous Centaurs, the avionics components (that control and monitor all vehicle functions) on the Common Centaur are installed on the CFA in Denver. The avionics layout on the CFA has been updated for better vehicle balance and electrical efficiency/redundancy. The load carrying capability of the CFA has been enhanced so it can react the loads of larger payloads than previous equipment modules. The CFA forward ring mates to a series of available payload adapters, allowing all potential spacecraft to be accommodated. For the Atlas V-500 and Heavy Lift Vehicle, the CFA interfaces with a forward load reactor system that stabilizes the 5-m payload. The Titan Centaur uses a similar forward bearing reactor interface to the payload faring.

Engine System

The Pratt & Whitney RL10A-4 engine is a common element between the Titan Centaur, Atlas III and V family of vehicles. The Titan Centaur uses the RL10A-4-1A. The Atlas IIIA and IIIB vehicles use the RL10A-4-1B version of this engine, which was flight proven on the inaugural IIIA and IIIB launches. The –1B version incorporates Direct Spark Ignition (DSI) and helium ground chilldown features, providing improved reliability and increased performance.

The Atlas V vehicles use the RL10A-4-2 engine, which was successfully flown on the maiden voyage of the Atlas V program. The –2 engine has the benefits of the –1B engine, and also incorporates several new features that improve engine reliability and performance.

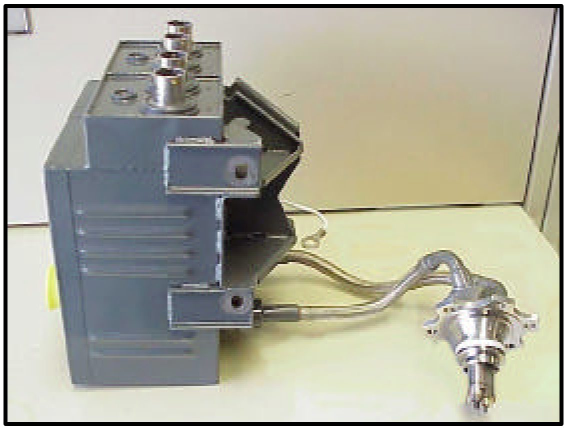
Several significant operational features are incorporated into the –1B and –2 engines. Before launch, a gaseous helium chilldown of the LH_2 and LO_2 turbopumps is performed. During the boost phase, a pre-chill of the LH_2 turbopump is accomplished by flushing LH_2 through the engine and overboard. Both of these operations reduce the amount of propellants that are used immediately before main engine start and the associated wait time after separation, and consequently increase performance. These features were proven out on the first Atlas IIIA, IIIB, and V launches. Another improvement for the –2 engine was the addition of a fourth solenoid valve with plumbing that allowed for independent control of the OFCV bypass. This enables trickle cooldown of the engine before second or third engine starts for increased vehicle performance.



The Common Centaur can be equipped with either one or two Pratt & Whitney RL10A-4 engines

The most significant change that is part of the –2 engine is the incorporation of Dual Direct Spark Ignition (DDSI) system. The DDSI is a fully redundant electronic ignition system that has been fully qualified at the component and system level to the more severe Atlas V environments. The testing included EMC/EMI, vibration, thermal cycling, and thermal vacuum. The incorporation of this system provides a 28% improvement in engine reliability.

The change to a new booster for the Atlas V program provided an opportunity to pre-deploy or fix the Centaur engine nozzle extension before launch. The Atlas II and III families use a deployable nozzle extension that must be actuated just before main engine start. The Atlas V vehicles, all using the –2 engine, have sufficient space in the interstage area to allow the nozzle to be fixed, consequently removing a critical event from the flight sequence, improving reliability and performance. The –2 engine can accommodate either the existing extendible nozzle extension or a fixed nozzle extension.



The Dual Direct Spark Ignition (DDSI) system significantly improves engine reliability

The –2 engine incorporates the improved cryogenic pressure-assisted seals, a lesson learned from our successful use of these seals on the SEC program and in the Common Centaur development. The use of these seals on the engine has minimized leakage during development, qualification, and acceptance testing, helping to reduce engine test costs and improving engine reliability.

The engine is gimbaled during flight by using two different flight-proven systems. EMAs for thrust vector control were developed for the SEC program and are used on all single-engine Common Centaurs. Dual-engine Common Centaurs use the hydraulic thrust vector control system that has been used on all previous Centaurs.

The –2 engine successfully completed a full hot-fire qualification series to demonstrate several capability improvements and full functionality of the features previously explained. The qualification demonstrated expanded propellant inlet conditions, increased operating time at expanded mixture ratios, and increased burn time. Additionally, a full-scale vibration and acoustic test was performed at the higher Atlas V levels. This qualification test series ensured the –2 engine is a very robust system that improves total vehicle reliability and performance. All –2 engine features were successfully proven out on the first Atlas V launch in August 2002.

Propulsion System

The propulsion system consists primarily of the Centaur engine(s) (described above), the propellant feedlines required to bring fuel and oxygen to the engine, and the N_2H_4–based RCS. Changes to these systems were necessary to accommodate the Common Centaur philosophy and make reliability and performance improvements to the Common Centaur.

Upgrades were made to some feedlines for both the single and dual engine configurations. The dual engine LO_2 and LH_2 feedlines have been modified slightly (thicker duct sections, changes in support dampers) from previous designs to withstand the slightly higher vibration environments of the Common Centaur on the Atlas V vehicle. Additional design consideration was given to minimize the loads imparted to the engine by these ducts under gimbaling and vibration conditions. Design modifications to incorporate damping have minimized the loads on the engine.

The single engine LH_2 duct developed for the SEC program is adequate without modification for use on the Common Centaur. The single-engine slip-joint LO_2 duct used on the SEC program was modified for use on the Common Centaur to improve its flow profile and reduce pressure drop from the tank to the engine inlet.

The Overboard Vent System (OVS) on the Common Centaur is an upgrade from the system developed and flown on the SEC program. It has been slightly redesigned to make as many components as possible common across all Atlas IIIB and V vehicle configurations. The system has undergone qualification (gimbaling, vibration, and separation) in the worst-case environment, which turns out to be the Atlas V-500 configuration. A specially designed strut support system was needed to mitigate the high vibration levels of that vehicle. The critical sliding joint and flexible bellows part of the system is unchanged from the previous Atlas IIIA design.

The RCS has been significantly upgraded for the Common Centaur. The stretch to the tank required additional force for vehicle control, so the lateral thrusters were upgraded from 6 to 9 lb. A newly designed, large composite-wrapped N_2H_4 bottle has been developed with a capacity of 340 lb, twice the capacity of the previous bottle. It will accommodate all known mission requirements, and weighs less than the two bottles previously required for some missions. This large bottle will be cut-in for Atlas V use on the second Atlas V vehicle (AV002).

An integrated RCS pyroservice valve was developed and located on the bottle yoke for enhanced thermal control. It provides parallel redundant pyrovalves, a service valve upstream and downstream of the pyrovalves, and a pressure transducer—all in one compact unit. It also increased the system flow area and eliminated 55% of the RCS welds for improved reliability.

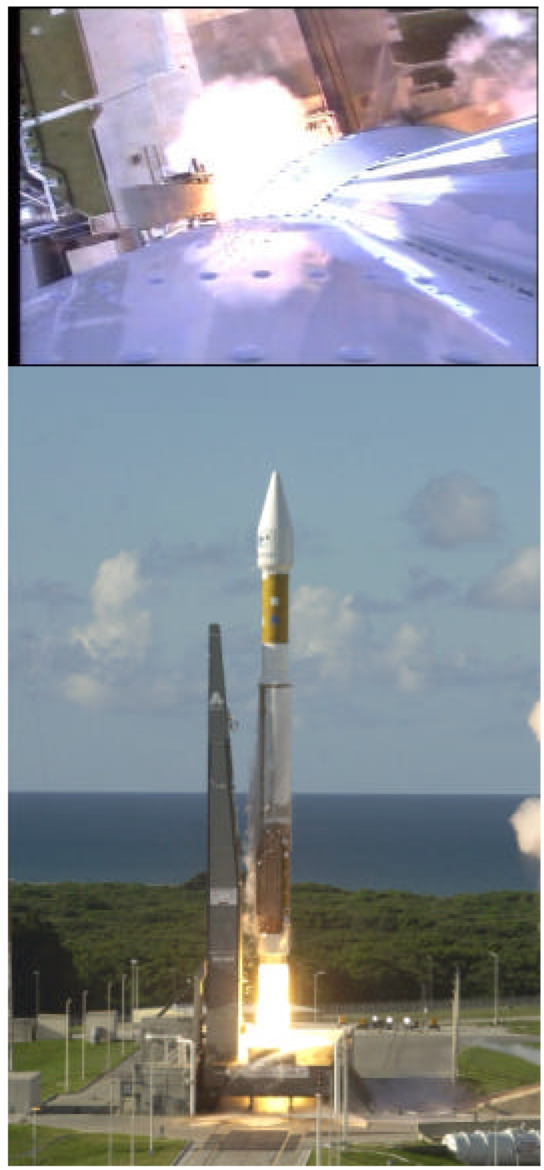
Pneumatics System

Improvements to the pneumatics system were performed on the propellant tank pressurization, the tank vent, and the hazardous gas detection systems.

The tank pressurization system on the Common Centaur consists of three composite-wrapped 26-in. helium storage spheres connected to the propellant tanks through the new single pneumatics panel. Two of the helium bottle locations are common between the single- and dual-engine Common Centaurs, and the third is unique. A fourth helium bottle kit is available to support three-burn mission profiles. The revolutionary single pneumatics panel design combines the hardware (e.g., valves, regulators, transducers) that was previously located on five separate panels onto a single panel. The panel is built and bench-level tested before installation on the vehicle, greatly simplifying the final assembly process and minimizing testing and rework of the high-pressure helium system. The single panel design was flight proven on AV001 and will be flown on all Atlas V vehicles.

The Centaur tank vent system self regulating vent valves were upgraded to account for increases in tank pressure and for greater reliability. The vent ducts were modified to account for changes in vehicle geometry. In the GH_2 vent system, intermediate and outboard duct sections were designed specifically to accommodate the larger diameter 5-m payload fairing, and the inboard duct was changed to account for the new elliptical forward bulkhead design. The GO_2 vent duct design is similar in function to the OVS, using the same flexible duct system and sliding disconnect.

A day-of-launch hazardous gas detection system and the improved cryogenic seals enable the Atlas V Common Centaur to reliably perform its first cryogenic loading on launch day. A set of flexible tubing routed to potential leak points that are actively monitored by a mass spectrometer system enables this system to detect any leaks that could impact mission success. Use of this system reduces the launch-site processing time and increases the launch rate capability by eliminating the need for wet dress rehearsals before each launch.



Liftoff on the maiden flight of Atlas V with onboard video

Conclusion

The Centaur upper stage has been a very successful upper stage since its development in 1958 and first launch in 1963. It has been a workhorse vehicle launching critical lunar missions, planetary missions and satellites on both Atlas and Titan for nearly 40 years. It has been integrated on two versions of the Titan launch vehicle. It currently provides heavy lift capability and assured access to space on the Titan IV launch vehicle. Many of the systems and experience that will be needed for the heavy lift Atlas V missions have already been proven on the Titan Centaur.

Centaur flight after payload faring separation

The Common Centaur is an extremely reliable, high performance, cryogenic upper stage that serves the entire Atlas IIIB and Atlas V family of launch vehicles. A common tank is built in San Diego and assembled in Denver, where it is fitted with the appropriate kits for the final vehicle configuration. It can be equipped with either one or two Pratt & Whitney RL10A-4 engines to accommodate a wide variety of spacecraft and mission profiles. The Common Centaur development builds on the successful SEC program. The same experienced development team stretched the tanks from the SEC version to carry more propellant, allowing greater engine burn times and increased performance. The Common Centaur successfully incorporates significant enhancements in the structural, engine, propulsion, and pneumatics systems to improve vehicle reliability, operability, and performance. This design significantly reduces program cost and risk, and provides an improved, all-purpose, high-energy upper stage for the flexible series of launch vehicles provided to the commercial and government markets.

The Common Centaur has been successfully flight proven on both Atlas IIIB (February 2002) and Atlas V (August 2002) vehicles, and will continue to serve this family of vehicles and its customers for years to come.