# Vehicle Engineering Development Activities at the Marshall Space Flight Center

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## ABSTRACT

New initiatives in the Space Transportation Directorate at the Marshall Space Flight Center include an emphasis on Vehicle Engineering to enhance the strong commitment to the Directorate's projects in the development of flight hardware and flight demonstrators for the advancement of space transportation technology. This emphasis can be seen in the activities of a newly formed organization in the Transportation Directorate, The Vehicle Subsystems Engineering Group. The functions and type of activities that this group works on are described. The current projects of this group are outlined including a brief description of the status and type of work that the group is performing. A summary section is included to describe future activities.

## INTRODUCTION

The development of space flight hardware and new transportation technology demonstration vehicles require that strong systems engineering applied during the duration of a new project. The emphasis on this in-depth systems engineering for these vehicles and spacecraft have led, in part, to the re-organization of the Marshall Space Flight Center. The formation of the Space Transportation Directorate (see Fig. 1) and its make-up of the projects and engineering in the same organization is new to the current Marshall staff. The engineering departments provide the services and functions, which

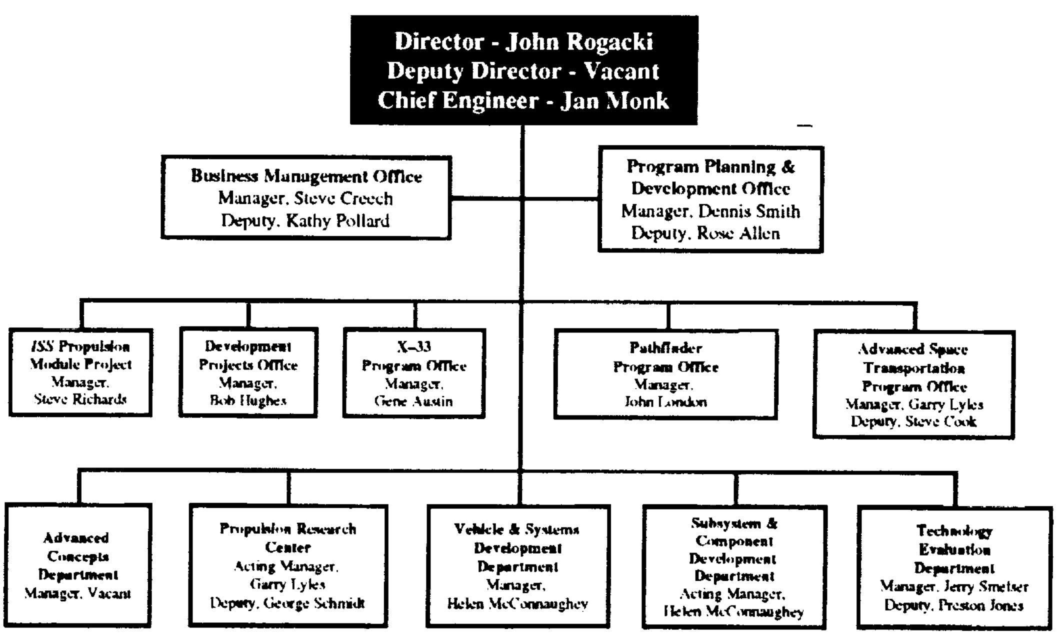


**Fig. 1 Space Transportation Directorate Organization**

the projects require, for the successful completion of their products. The Vehicle Subsystems Engineering Group is a newly formed organizational element with the charter to provide vehicle engineering services for the directorates projects. This organization has as its genesis the vehicle technology and propulsion systems areas. However, this group has brought together engineering expertise from other areas such as spacecraft design, project engineering, vehicle structures, and system testing and continues to develop its current cadre of engineers as it strives to meets its mission goals. The group also draws from the expertise in the Engineering Directorate.

## DESCRIPTION OF ORGANIZATION

The groups work centers around 5 types of activities. The first is vehicle systems technology. The efforts in this area center on the advancement of technologies, which are related to the vehicle as a system. One such example is Cryogenic Fluid Management. The activities in CFM involve the development of new insulation systems, new ways to re-orient fluids on orbit and methods of estimating the amount of propellant on-board a spacecraft. The second activity is the design of MPS and RCS systems including tanks, propellant feed lines, pressurization systems, and reaction control systems. This entails the design of these systems throughout the life of the project from the earliest conceptual design to the final design outputs and the creation of vendor specifications and subsequent qualification and acceptance testing. The third activity is the vehicle integration. The group can lead and coordinate the integration of the various vehicle subsystems into the final package. This includes the development of the assembly manuals, operations manuals handling procedures, interface control documents and the actual presence during the various phases of the integration. The fourth activity is system level hot fire testing. The group has demonstrated experience in the development of timelines, procedures and test requests for the systems level hot-fire testing of booster and spacecraft propulsion systems. The fifth activity includes the support to the operations of aerospace flight vehicles including the Space Shuttle and the Inertial Upper Stage for Chandra.

## DESCRIPTION OF CURRENT ACTIVITIES

The current activities of this group are varied but center around the project listed below:

### D-21 Flight Experiment – Vehicle Conceptual Design

The D-21 Drone, shown in Fig. 2, was originally flown off the back of the SR-71 Blackbird and released from a B-52 in the 1960's. The D-21 is planned to be the flight test bed for the NASA designed RBCC engine. The drone will be released from the DFRC B-52 and demonstrate flight from Mach 0.8 to Mach 4.0. The D-21 will have to be modified to update

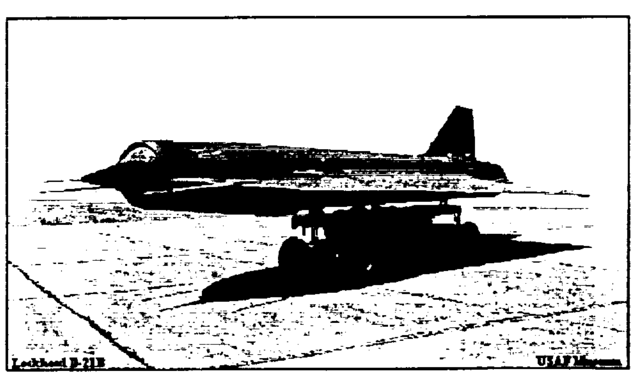

**Fig. 2 D-21 Drone**

the avionics, provide for landing and recovery, and alternate propellants. Our group's role in the project is to direct the removal of the existing Ramjet, integrate the NASA RBCC engine, coordinate the structures, thermal, loads, avionics, ground & flight operations. TD52 will serve as the PDT leads for the effort and direct all engineering aspects for the vehicle development. Current plans for the DRACO vehicle effort are to complete feasibility assessments and trades to develop a high confidence vehicle concept within the next several months. The details of this concept will be baselined and system requirements will be developed, at which point a detailed design phase will begin. Two near term tests will address current uncertainty over D21 aerodynamics, stability & control, and landing procedures. Preliminary wind tunnel testing will be performed to determine lift and drag characteristics throughout the DRACO/D21 flight regime and anchor the understanding of available archival D21 aero data. In a related effort, DFRC will flight test an instrumented, dynamically scaled, remotely piloted model of the D21B. Data from these model flight tests will provide critical stability and control information as well as low speed and ground affect aerodynamics. Our near term product will be to bring the vehicle design to a Systems Requirement Review in early 2000 with a non-powered drop test from a B-52 in late 2001.

**PTA/Fastrac Test Article – MPS Test Bed**

The Propulsion Test Article (PTA) (Fig. 3) was designed as a low-cost propulsion system test bed. The test article consists of LOX and RP-1 tankage, feed, fill and dump lines, pressurization & pneumatics, structures, and avionics. TD52 had the PDT lead responsibility for control of everything from design drawings, analysis results, to program budget, and expenditures. We coordinated the analysis, design, procurement, manufacturing, and testing of the test article. This project exercised our capability to take a program from concept, to development and testing. The PTA/Fastrac project recently completed activation of the test article and performed two hotfire tests (Fig. 4).

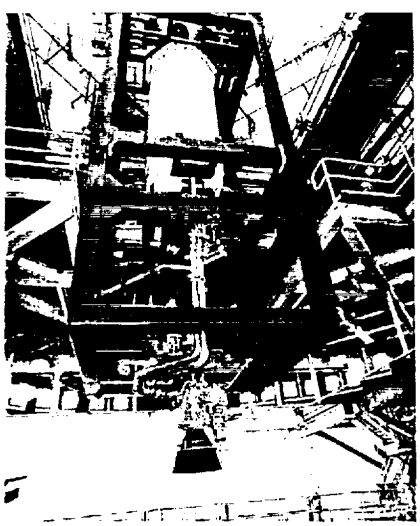

Fig. 4 PTA Assembly

Fig. 3 PTA Hot Fire

## X-34 MPS – Flight Vehicle Design

The X-34 program is a joint industry/government program to develop, test, and operate a small, fully reusable, hypersonic flight vehicle, utilizing technologies and operating concepts applicable to future Reusable Launch Vehicle (RLV) systems. The vehicle is

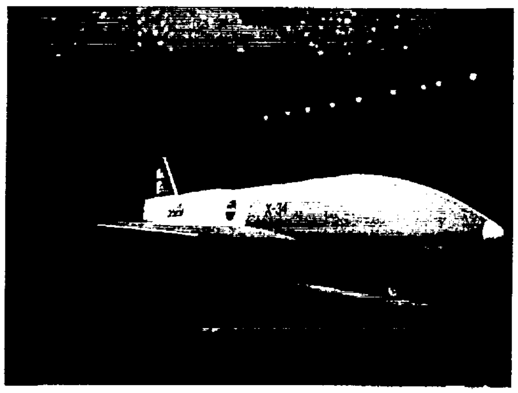

**Figure 6 X-34 MPS Layout**

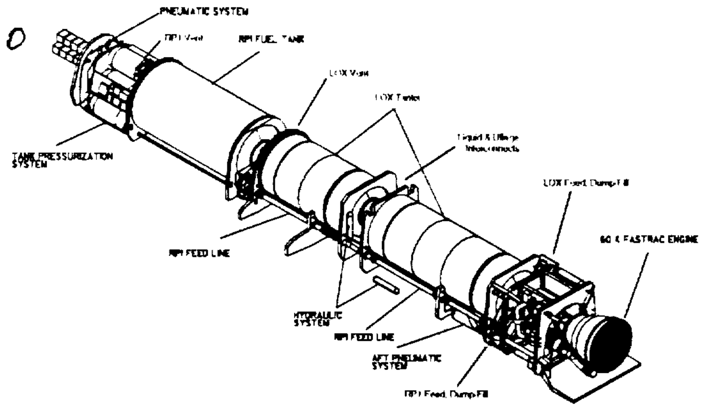


**Figure 5 X-34 Rollout**

designed to achieve Mach 8 flight and 250,000 ft altitude before reentry. The vehicle has all composite structure and is powered by the MSFC developed Fastrac engine. The rollout of the A-1 vehicle was held earlier this year at Dryden Flight Research Center (Fig. 5). Our group's function on the program was to design the MPS for the vehicle including the LOX and RP-1 feed, fill, dump, & vent, pressurization and pneumatic systems, as shown in Fig. 6. We served as the PDT lead and coordinated the fluid, structure, and stress analysis, the component specification generation, the design drawings, operation scenario's and vendor surveys.

## X-38 Deorbit Propulsion System – Flight Vehicle Operation

The X-38 program demonstrates key technologies essential to completing the Crew Return Vehicle (CRV) for the International Space Station (ISS). The X-38, as shown in Fig. 7, consists of a lifting body developed by NASA JSC and a Deorbit Propulsion Stage (DPS) developed by NASA MSFC and its contractor Aerojet. The DPS includes the forward structural adapter (FSA) and deorbit module (DM). The FSA provides the structural interface between the X-38 lifting body and DM, supports the X-38 lifting body while in the STS cargo bay, and includes the separation system between the X-38 lifting body and DPS. Due to launch weight and stiffness constraints, the FSA and DM are composed of a combination of composites and aluminum alloys. The DM includes the monopropellant hydrazine propulsion subsystem that is composed of the

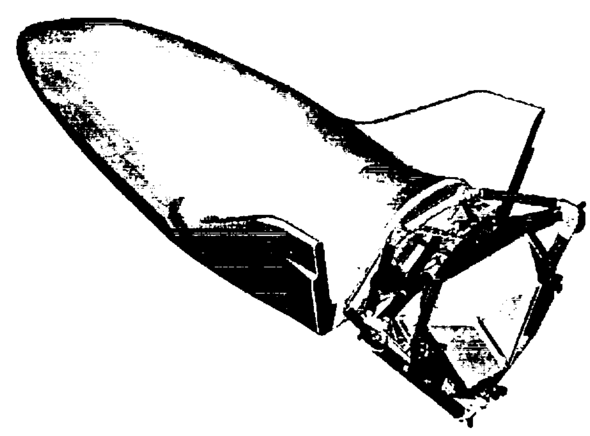

**Fig. 7 X-38 Deorbit System**

propellant supply subsystem and the thruster module subsystem, as well as supporting structure. The DPS propulsion subsystem utilizes off-the-shelf (OTS) proven components (thrusters, tanks, valving, and instrumentation) packaged to meet the performance requirements for X-38 on-orbit attitude control and de-orbit delta-velocity operations. The propellant management system includes three bladder-type propellant tanks, service valves, pyro isolation valves, filters and associated manifolding. The DPS propellant capacity is 1,950 pounds of hydrazine in a 3:1 blowdown mode of operation. The thruster module subsystem is made up of four thruster modules, each containing two 100 lbf axial and two 25 lbf RCS thrusters.

NASA MSFC maintains a role of over-sight in the development of the DPS, assessing the technical design for compliance with requirements and assuring schedule and cost objectives are satisfied. This is done through a series of periodic evaluations of the progress of the DPS development and verification. For the DPS propulsion subsystem, with most components being OTS, emphasis is placed on assuring that the capabilities of and operating requirements for the propulsion subsystem are adequately communicated and understood by NASA JSC, which has the responsibility to operate the integrated X-38 vehicle. Our group is responsible for developing the flight software requirements for the operation of the propulsion system. Importance is also placed on thorough verification that the propulsion components and integrated propulsion subsystem will meet all technical requirements for a safe launch and successful operation of the DPS. The final product will be a flight DPS delivered to NASA JSC for use on the X-38 vehicle and successful completion of the X-38 Shuttle launch, space flight, and re-entry/landing mission.

**International Space Station Propulsion Module – Flight Vehicle Requirements and Design**

The ISSPM is designed to be an augmentation to the Russian Segment (RS) GN&C and Propulsion services. It can operate independently of the RS in a contingency. The ISSPM can evolve to be a replacement of the RS. The purpose of the United States Propulsion Module (PM) is to provide 50% of propulsive attitude control and reboost for the International Space Station (ISS) over a 12-year on-orbit life. As an augmentation of the propulsion capabilities supplied by the Russian Space Agency, the PM will be available as a back-up system in the event of Russian hardware failures or missed propellant resupply opportunities.

The PM, as shown in Fig. 8, features a storable bipropellant propulsion system, using Nitrogen Tetroxide and Monomethyl Hydrazine to power 100-$lb_f$ attitude control thrusters and 200-

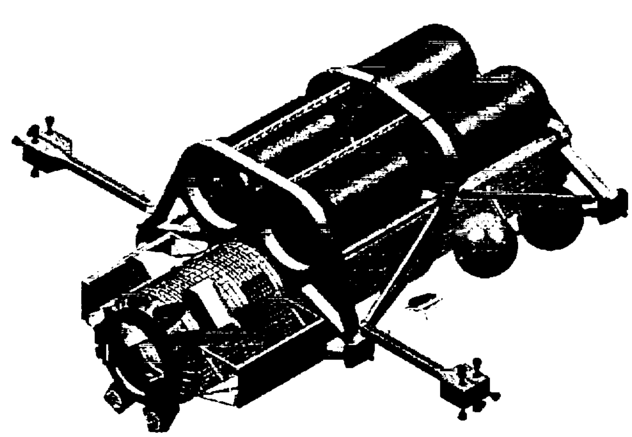

**Fig. 8 ISSPM**

$lb_f$ reboost thrusters. The PM will house the attitude control thrusters on the tips of two retractable booms, which extend outward from the body and will house the reboost thrusters on the aft end of the PM. The PM will be physically mounted on Pressurized Mating Adapter 2 (PMA-2) at the forward end of the ISS with the reboost engines facing forward; thus, the PM will have to rotate the ISS 180° prior to performing a reboost burn. The PM will be designed to scavenge unused propellant from the Shuttle Orbiter whenever the Orbiter docks with the ISS.

The Vehicle Subsystems Engineering Group (TD52) provides in-depth technical oversight of the PM propulsion system development, emphasizing penetration of key risk areas. For example, to address the technical and safety risks inherent in the PM on-orbit propellant transfer, TD52 co-chairs the On-Orbit Propellant Transfer Working Group, a broad-based, NASA-Industry team focussed on the requirements and architecture for the propellant transfer system. Other key areas in our oversight approach include extensive involvement in the definition and planning of system performance and combustion instability testing, independent system level analyses, and assessments of previously qualified components proposed for reuse on PM. Our group is responsible for performing insight of the design at the direction of the program office. We are currently participating in the PDR. Our goal is to follow the ISSPM through development and deployment as the government engineering support arm.

**Advanced Shuttle Upper Stage Rapid Chill/Fill Test – Vehicle Technologies**

A high-energy cryogenic upper stage concept (Fig. 9) that has been proposed by Boeing that would enable the Shuttle to deliver 28,000 pounds to geosynchronous orbit. Basically the Advanced Shuttle Upper Stage (ASUS) would be placed in Shuttle payload bay empty and then filled from the Shuttle External Tank during ascent flight. The filling process would not be initiated until about two minutes into the flight after the Shuttle's solid rocket boosters are separated and the altitude is sufficient to preclude oxygen/hydrogen ignition. The ASUS is to be filled in about five minutes and forty seconds before main engine shutdown. Should the Shuttle have to abort near the end of the Shuttle ascent, the crew would have adequate time, about 13 minutes, to dump and purge the ASUS propellants. This approach eliminates the numerous safety issues that have precluded launching a fueled cyrogenic upper stage in the Shuttle payload bay and more than doubles the payload delivery capability to geoshnchronous orbit. Further, the ASUS concept can also be applied to Reusable Launch Vehicles and similarly eliminate launch safety issues and maximize payload delivery beyond low earth orbit.

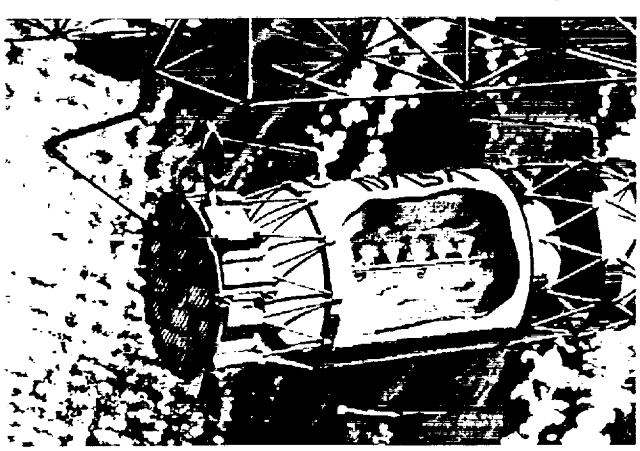

Figure 9 ASUS

A key element of the concept is the ability to rapidly chill and fill a hydrogen tank without substantial propellant losses or excessive tank pressures. TD52 has the test requestor responsibility for this program. Accordingly, a technology project to demonstrate the rapid chill and fill of a large-scale hydrogen tank has been initiated. MSFC's Multipurpose Hydrogen Test Bed (MHTB) 639 cubic foot hydrogen tank will be used to provide experience and test data to anchor analytical modeling of the chill/fill thermodynamics. Installed in the MHTB will be an axially positioned spray bar, designed by Boeing, to assure that the tank walls are uniformly sprayed with the liquid hydrogen during the chilldown phase and that the propellant is uniformly mixed as the fill process proceeds. The spray bar is designed to maximize the efficiency of the chill/fill process and limit pressure excursions to acceptable limits. The propellant transfer data and analytical modeling will provide insight into orbital propellant transfer as well since a similar approach is envisioned. Testing is currently scheduled to occur in the Spring of 2000.

**Solar Thermal – Vehicle Technologies**

The solar thermal engine (Fig. 10) serves as a high temperature heat exchanger, collecting concentrated solar radiation into a "black body" cavity and transferring this energy to a propellant as heat. Propellant gas can be heated to temperatures approaching 4500 R and expanded in a rocket nozzle, creating low thrust (1-20 lb) with a high specific impulse (700 to 900 sec). There are two basic types of solar thermal propulsion, "Direct Gain" and "Thermal Storage", both of which have thermodynamic and operational advantages and disadvantages. The "Direct Gain" approach simultaneously collects energy, transfers this energy to the propellant gas and thrusts. The "Thermal Storage" concept sequentially collects energy, stores it in a thermal storage heat exchanger and then thrusts in a pulse mode. Both a direct gain and a "Thermal Storage" engine are under evaluation by Marshall Space Flight Center and thermal performance tests are planned for late 1999 and early 2000. TD52 is responsible for the design, analysis, testing and operation of the solar thermal engine program at MSFC. The shooting star engines are at MSFC and in the final stages of assembly, instrumentation, and integration performance testing.

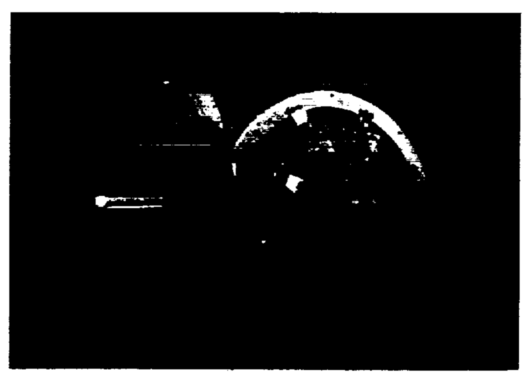

**Fig. 10 Solar Thermal Engine**

## TOOL DEVELOPMENT

One of the tasks, which this group is currently working, is to locate, develop or modify computer tools, which can aid in the design or operation of these new vehicles. The advancement in information technology has opened up new possibilities in terms of vehicle design tools, integration tools, management tools and operational capability. Our group is endeavoring to maintain an understanding of these new developments and make use of these tools where appropriate. In addition we are supporting the development of new tools in this area specifically in the Integrated Engineering Environments arena. Some specific examples are web based drawing servers, web oriented configuration management tools and the ability to review and approve drawings electronically.

## SUMMARY

The new initiatives for low cost, reliable access to space are being met with a battery of new projects, centered on the X-vehicle programs. In order to support the host of new projects and the accelerated schedules of these projects a new approach for systems engineering is being taken at the Marshall Space Flight Center. This new approach centers around a tightly knit team of the project offices and systems engineering organizations which in turn can draw upon the rest of these engineering and support organizations at the center. These new engineering organizations are matrixed, as well, to a variety of different projects. At first blush this seems contrary to fast paced development projects, but we have found that the cross talk between the projects which are related has yielded good lesson learned and we are hoping a good mission success.

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