

X-38 Program Status/Overview

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Introduction

The X-38 Project consists of a series of experimental vehicles designed to provide the technical "blueprint" for the International Space Station's (ISS) Crew Return Vehicle (CRV). There are three atmospheric vehicles and one space flight vehicle in the program. Each vehicle is designed as a technical stepping stone for the next vehicle, with each new vehicle being more complex and advanced than its predecessor.

The X-38 project began in 1995 at the Johnson Space Center (JSC) in Houston, Texas at the direction of the NASA administrator. From the beginning, the project has had the CRV design validation as its ultimate goal.

The CRV has three basic missions that drive the design that must be proven during the course of the X-38 Project:

- a) Emergency return of an ill or injured crew member.
- b) Emergency return of an entire ISS crew due to the inability of ISS to sustain life

- c) Planned return of an entire ISS crew due to the inability to re-supply the ISS or return the crew.

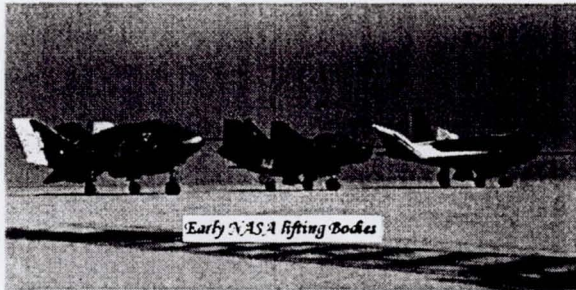
The X-38 project must provide the blueprint for a vehicle that provides the capability for human return from space for all three of these design missions.

Basic Shape Selection

The first task was to select the basic shape of the X-38 vehicle. The project team initially looked at capsules like those flown in the Apollo, Gemini, and Mercury programs. Although the fact that much is known about the re-entry characteristics of these shapes and the simplicity of the capsule design are both positives, there is one primary problem with use of a capsule in the CRV role.

The ballistic re-entry characteristic of a capsule, combined with the CRV requirement to touchdown on land within 30 minutes of a medical facility, leave scenarios of departure from the ISS that would have the capsule loitering in space for up to 24 hours waiting on a single landing

opportunity. This fact drove the project to look at alternate shapes that would provide more lift and therefore quicker times from ISS departure to CRV landing.



The X-38 team turned to programs that NASA undertook in the late 1960's and early 1970's. These NASA programs developed and successfully flew the first lifting body vehicles.

After researching all aspects of the various lifting bodies from the early NASA programs, the X-38 team began to focus on the X23 and X24A vehicles.



X24A

The X23/24A shape proves enough cross range capability to ensure that no matter where, in the ISS orbit, the CRV departs, there is always a minimum of 3 landing opportunities within any 9 hour period of time. This provided the team with a shape that would re-enter reliably (X23) and that could fly effectively once in the atmosphere (X24A).

The only problem inherent with the lifting body shape is the fact that to maintain stability through landing, the vehicle must maintain a relatively high rate of speed. The X24A had landing speeds in excess of 250 kts. The low altitude, low MACH handling qualities of a lifting body are also challenging, even to a skilled test pilot. Since the CRV must be a fully automated vehicle, the project decided to look into ways to mitigate the landing risk of a lifting body design by augmenting the vehicle once it has flown safely into the lower atmosphere.

The solution to the high speed landing problem was found in the parachute world. Atmospheric flight of a parachute is quite simple, and it was determined that if the X-38 could transition from a lifting body vehicle to a vehicle flown under a parachute, then landing could be better automated and controlled.

The X-38 would implement a system of parachutes that would slow the vehicle from lifting body flight using a decelerating round drogue chute. The drogue chute would deploy from the aft of the vehicle to initially slow it down. It would then be repositioned directly over the lifting body put the lifting body in a "belly to earth" attitude. Once the vehicle was slowed to an acceptable level for parafoil deployment, the drogue chute would be cut away and it would extract the main parafoil from within the lifting body.

Once the basic shape and landing concepts were chosen, the project began its selection of technologies to complement the shape, provide a soft landing and ultimately develop into what was necessary to meet the CRV design mission requirements.

Initial Core Technologies

The project initially focused on three primary new technologies for inclusion in the atmospheric test program and ultimately inclusion into the space flight test. Those three new technologies are:

- a) Large scale parafoil for terminal flight
- b) Laser initiated pyrotechnics
- c) Electromechanical Actuators (EMA's) for surface movement

Although many other exciting technologies are part of the atmospheric test program, most are either "Off the Shelf" or have some space, aviation, or military heritage.

The first two technologies are present on all three X-38 atmospheric test vehicles. The EMA's were added on the second and third vehicles.

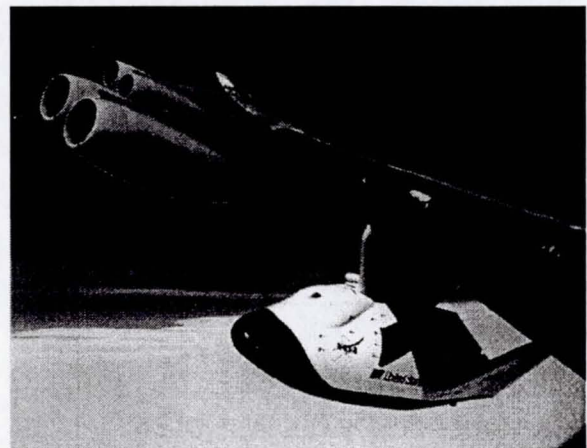
The project made a conscious decision to limit new technologies to areas that truly needed them. The overall project goal was to use existing technologies where they were available and to only create new technology were absolutely required by project requirements. In some cases the requirements were adjusted to fit within the scope of existing technology to allow focus on the technology development that was absolutely mandatory for success of the X-38 mission.

X-38 Flight Testing

After the required technologies were selected, it was mandatory to develop a way to validate and verify the technologies in preparation for the CRV program initiation. X-38 relies heavily on actual flight testing for this verification and validation process.

There are two basic flight aspects of the X-38 program. The first is the atmospheric flight test program. The second is the space flight test program. Each program has its associated technology development, integration and test challenges. The atmospheric test program consists of three test vehicles, each with its own unique numerical designator (V131, V132 and V131R). Vehicle 201 (V201) is the single space flight demonstrator in the X-38 program. Each vehicle has its own unique test objectives with a focus on progressive increase of complexity all leading to the ultimate X-38 test, the space flight test of V201.

Atmospheric Test Program



Captive Carry flight of Atmospheric Test Vehicle

The primary goals of the atmospheric test program are focused on the integration of the new technologies utilized in flight of the lifting body vehicle and parachute systems in the atmosphere. The test flights are designed to validate the last 50Kft of flight. Each flight builds up in altitude and speed to ultimately put the atmospheric vehicles into the same flight conditions that V201 will be at when it returns from space.

Since the V201 will transition from lifting body flight to parafoil flight at approximately 30Kft, the atmospheric drops also make that transition at the same relative altitude. Early flights of each vehicle are at lower speeds with a progressive buildup to speeds that will put the lifting body into the reentry profile prior to the initiation of the parachute sequence. All deployments of the final parafoil have been and will be made at the exact condition that will be seen at space flight reentry. The final objective of the lifting body atmospheric program is to demonstrate flight of the parafoil system with the lifting body.



Yuma flight of 7500 Sq. Ft. Parafoil

The atmospheric test program also consists of parafoil systems tests that are performed in Yuma, Arizona at the U.S. Army's Yuma Proving Grounds (YPG). These tests are designed to validate changes in the parafoil and other parachute systems prior to use in

the lifting body test program. To date, over 30 full-scale X-38 parachute tests have been performed at YPG.

Atmospheric Demonstrators

V131

Vehicle 131 was the first X-38 atmospheric demonstrator. V131 was an 80% scale demonstrator designed for release from the NASA NB52 aircraft.



V131 during Captive Carry #1

V131 consisted of a fiberglass structure designed for maximum flight dynamic pressures and landing loads with a design factor of 3.0. The structure was manufactured by Scaled Composites in Mojave, California, and then shipped to Johnson Space Center, in Houston, Texas. The vehicle was outfitted with single string avionics systems and test flight parachute systems. There were separate compartments for the drogue chute, 5500 sq. ft. parafoil, and backup round parachute. The parafoil was guided by a separate Parafoil Guidance Navigation and Control computer that would take over from the lifting body avionics computer after deployment. This computer was utilized to quickly integrate the parafoil into the lifting

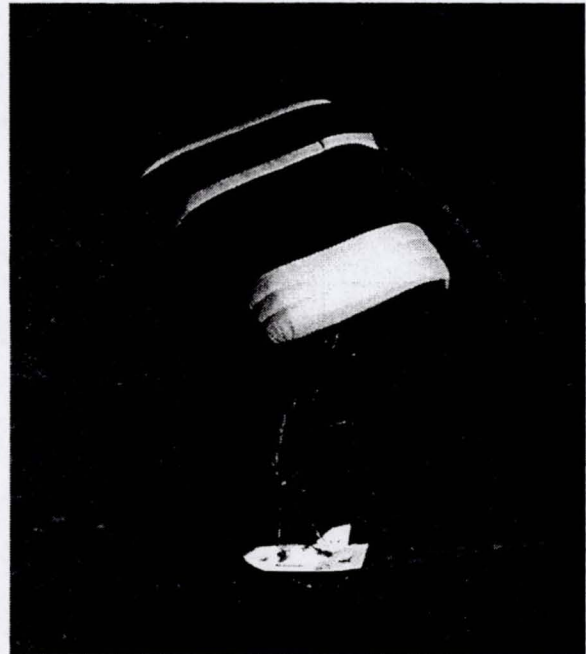
body, with the ultimate goal of eventually moving this function into the overall X-38 avionics computer system.

V131 was designed to fly for only 4 seconds as a lifting body prior to deployment of the parachute systems. There was no active flight control system in this vehicle, and all four flight surfaces were pinned in a predetermined "trim" position. There were no EMA's flow onboard V131. The purpose of V131 was to show successful deployment of the parachute systems from the lifting body vehicle, and successful flight of the integrated lifting body systems and parafoil guidance systems, as well as successful performance of the vehicle landing systems.

V131 flew several captive carry flights attached to the B52. The captive carry flights consisted of structural clearance points that tested for interaction between the B52 and X-38 vehicle and ensured that there would be no adverse aerodynamic or structural flutter effects during ascent or steady state flight in preparation for actual release of the X-38. The flight envelope was cleared for all expected flight drop point relative to altitude and speed. The captive carries were also used to validate onboard systems performance in the actual flight environment prior to the first lifting body flight. The B52 would loiter at maximum drop altitude to perform a "cold soak" of the onboard X-38 systems. Then ensured that all systems worked as planned at the maximum cold temperature extremes. The team would then perform a simulated drop, making the vehicle think that it was actually flying on its own, separated from the bomber. Although the parafoil was not deployed, all pyrotechnic events were exercised to ensure that they systems would perform as planned after maximum cold soak. The captive flights proved invaluable to the project.

Systems problems that were not found on the ground, but were only visible in the actual flight environment were identified and corrected during the course of these flights. All X-38 vehicles were captive carried and "cold soaked" prior to first free flight as a result of lessons learned during V131's captive carry campaign.

Free Flight #1 (FF1) of V131 occurred March 12, 1998 at Edwards Airforce Base California. The vehicle was dropped from an altitude of 23,000 feet, and 4 seconds later began its parachute deployment sequence.



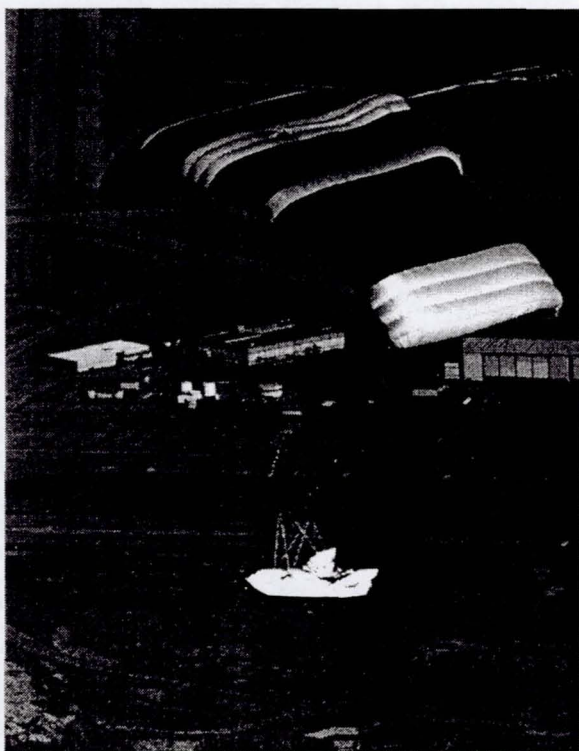
Vehicle 131 Free Flight #1

Vehicle systems performed well and the parafoil guidance system performed as planned. The deployment of the parafoil was sub par, and after the flight, the project went back to Yuma to test modifications to the parafoil leading to almost 1 year between the first and second lifting body flight of V131.

Also noted during FF1 was the large pitch dynamics at reposition of the drogue chute

from aft attachment to overhead attachment. These dynamics would be the topic of much discussion and techniques to damp these to acceptable limits is still underway and expected to be totally eliminated during the V131R atmospheric test campaign. Modifications are being tested at Yuma prior to implementation into the lifting body drops.

Free Flight #2 of V131 occurred on February 5, 1999 at Edwards Airforce Base California. This flight utilized the same drop conditions as FF1. Modifications to the parafoil system, proven during testing at Yuma, were successfully tested during this flight. Vehicle systems also performed well.



Free Flight #2 of V131

FF2 was the last flight of V131. The project had obtained a large amount of valuable data from the flight program, and the project was ready to proceed to the more complex V132 vehicle.

V131 was retired from service immediately after FF2 and was sent back to Scaled Composites in Mojave California for modifications. These modifications were put in place to make the vehicle consistent with the shape of V201, the X-38 space flight test vehicle. The fins were removed from the original vehicle and replaced, and a new upper surface was bonded to the original structure. The outcome of these modifications was to become the third vehicle in the atmospheric test program, V131R.

V132

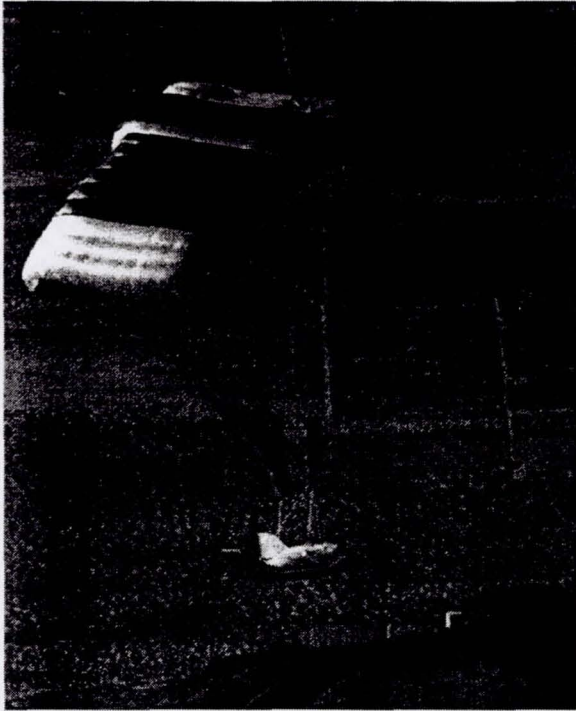
The second vehicle in the X-38 atmospheric test program was designated V132. This vehicle, from all outward appearances, was exactly like V131. It had the same shape and size as V131, but was, in fact, a much more complex vehicle.

V132 introduced the use of EMA's in a real flight environment and added a full flight control system to the lifting body vehicle. V132 retained all the systems previously flown in V131, including the parafoil guidance computer, separate from the main vehicle avionics computer.

Just as in the flight program of V131, V132 underwent several captive carry flights in preparation for its first free flight. Lessons learned during V131's captive flights allowed for a shorter captive flight program, and most of the focus was on EMA performance in the flight environment.

Free Flight #1 (FF1) of V132 occurred March 3, 1999 at Edwards Airforce Base California. The vehicle was dropped from the B52 and flew as a lifting body, under its own computer control, using a classically

derived flight control system for 13 seconds before initiation of the parachute sequence.



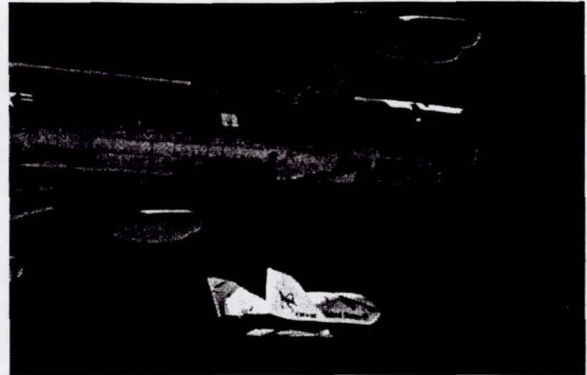
V132 Free Flight #1

FF1 was a success. All systems performed very well and the project was very satisfied with the performance of the EMA's and the flight control system.

After the flight, the vehicle was immediately put into turn around and the parachute systems were sent to Yuma for repacking in preparation for a quick turnaround to a July flight.

During this time the flight control team verified detailed success of the control system and certified a new set of laws for the next flight.

Free Flight #2 (FF2) of V132 occurred on July 9, 1999 at Edwards Airforce Base California. The vehicle was dropped from an altitude of approximately 34000 ft. and flew as a lifting body for 30 seconds prior to parachute sequence initiation.



V132 Free Flight #2 at release

Although the EMA's performed well during FF2, a problem that was seen only once prior to the flight revealed itself during post flight turnaround. A flaw in the microcode logic within the EMA controllers forced a change to the box. This change, although difficult to detect and resolve ended up setting the stage for design of a much more robust and tolerant EMA for the space flight X-38 vehicle. The time taken between FF2 and FF3 that was used to resolve and test this change was invaluable to the success of future X-38 flights.

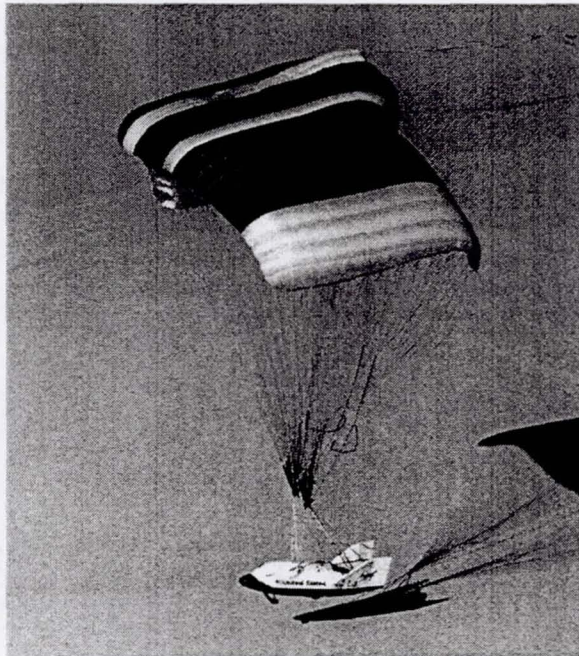


V132 Free Flight #2

Further work was done on the parafoil system at Yuma in preparation for the third flight of the vehicle. Most of the work

focused on refining the opening dynamics of the parafoil. The parafoil team took advantage of the down time that resulted due to the EMA problem, and implemented several outstanding improvements to the parafoil that improved the opening characteristics dramatically. Implementing these changes during this time allowed the project to get flight test data on the concepts before pressing into development of the 7500 square foot parafoil with would be the final size and design used in both V131R and the space flight X-38 vehicle.

Free Flight # 3 of V132 occurred on March 30, 2000 at Edwards Airforce Base California.



V132 Free Flight #3 at touchdown

This was by far the most complex and challenging flight at that time. The project implemented a dramatic change within the flight control area. For the first time, the lifting body was controlled by software developed using the Dynamic Inversion technique. To the projects knowledge, this was the first atmospheric vehicle of any time

to utilize this technique successfully in the primary flight control system.

Dynamic Inversion was the next technological addition to the X-38 suite, and proved to work very well in cutting the development and verification time required for certification of the vehicle for flight.

FF3 was a very successful flight and proved to the team that dynamic inversion could successfully be utilized in the X-38 project. Advances in the parafoil deployment were also very encouraging, and set the stage for utilization of the larger 7500 square foot chute for the V131R vehicle.

FF3 marked the end of the V132 atmospheric flight program. It also marked the end of flights of the smaller 5500 square foot parafoil. All future flights will utilize the larger 7500 square foot parafoil. Shortly after FF3, V132 was retired and sent back to Johnson Space Center in Houston.

V131R

At the time of this writing, V131R is the active flight vehicle within the X-38 atmospheric flight program. V131R is the redesigned and modified V131 vehicle. This vehicle is different from the previous two in several ways.

First, this vehicle has the same outer mold line as the space flight vehicle. This modification came about as a result of the team's partnership with the European Space Agency (ESA). ESA's partnership had contributed several components for V201 that will be discussed later in this paper. The shape change came as a result of looking at expendable launch vehicles as potential carriers for V201 and CRV. Part of the shape change was required to stiffen

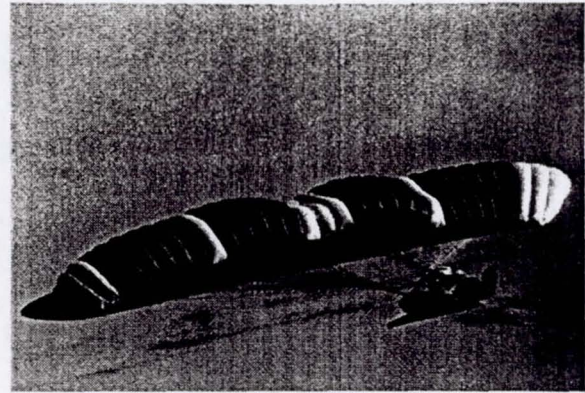
the aft end of the vehicle. Other subtle changes came from wind tunnel experience and testing in Europe.

Second, V131R utilizes the 7500 sq. ft. parafoil and 80 ft. drogue chute. These are the same size and configuration that will be used in V201. This is the first in the series to utilize the final size chutes. The vehicle had to have ballast added to increase the weight to approximately 18Klbs to ensure proper interaction with the parafoil and drogue chutes.

Third, the vehicle avionics computer contains the parafoil guidance algorithms and control (PGNC) developed by ESA. The same computer now controls lifting body flight as well as parafoil flight. Separate software controls each phase, and a hand off occurs after parafoil deploy from lifting body control laws to parafoil control laws. This is the same way control will occur in the space flight vehicle. This vehicle is also controlled by dynamic inversion control laws just as V132 was.

V131R required one captive carry flight to clear the entire flight envelope and certify all systems as ready for Free Flight. The lessons learned from the previous two flight vehicles were instrumental in planning for this vehicles captive campaign. Although V131R is the most complex of the atmospheric vehicles, testing techniques developed during V131 and V132 ensured that the vehicle was in the best possible configuration prior to initiation of the captive carry.

Free Flight #1 (FF1) of V131R occurred on November 2, 2000 at Edwards Airforce Base California.

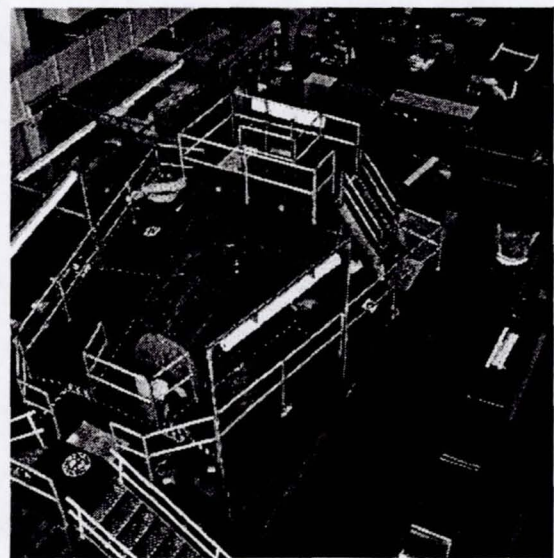


V131R after touchdown

FF1 of V131R marked the first flight of a new lifting body configuration in almost 30 years.

V131R will continue to fly as the primary test vehicle for the X-38 project until approximately 18 months prior to the space flight of V201. At least 5 more flights are planned for this vehicle. The objectives of these flights will include: refining lifting body flight control laws, reducing pitch rates at drogue repositions, refining ESA PGNC laws, and potentially some off nominal testing.

V201



V201 in Assembly

V201 is the final, and by far, most complex vehicle in the X-38 project. V201 is the space flight test vehicle. Although V201 will not fly until late calendar year 2002, the design, production, build up, and testing of this vehicle has been ongoing for over 3 years.

Unlike the atmospheric test vehicles, which were primarily zero fault tolerant vehicles, V201 will be single fault tolerant in most areas and dual fault tolerant in the most critical areas.

V201 will ascend into space aboard the Space Shuttle Colombia, and will be deployed using the shuttle remote manipulator system. The vehicle will then orbit for approximately to revolutions and perform a deorbit burn and re-enter to land at a designated landing point. All control of the vehicle will reside within the V201 computers. It is planned to be a fully automated flight.

V201 marks the greatest involvement of both ESA and the German Space Agency (DLR) in the X-38 project. Both agencies have contributed time, manpower and systems to the V201 vehicle. Their partnership has been instrumental in the success so far of V201 and the project looks forward to their continued participation through the completion of the X-38 project.

The following is a list of some of the European contributions to the X-38 Project:

France: Aerodynamics and wind tunnel

Germany: Body flaps, Nose Cap, Leading Edge test units, PGNC, members of the aft structure design team.

Italy: Equipment Pallet

Spain: Landing Gear

Netherlands: Rudders

Belgium: members of the aft structure design team

Sweden: Wind tunnel

V201 equipment installation will continue through this spring and full scale environmental and operational testing begins in early summer.

At the completion of the space flight in late calendar year 2002, post flight analysis will occur, and results will be handed over to the prime CRV contractors for inclusion in the final design of the newest human capable spacecraft in the world.



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