Testing Status of the X-38 Large Parafoil Autonomous GN&C System

This paper shall review the status, progress and results made in testing of the GN&C software and supporting avionics designed for the control of a large parafoil in support of the X-38 Program. This will include a high level overview of the GN&C design selected for use on the X-38 orbital return test article, as well as an overview of the requirements and test objectives for the parafoil flight portion of the orbital return flight, and of the testing results to date. These flight objectives will be mapped into flight and ground testing requirements and test beds currently in use by the X-38 Program, building sufficient confidence in the selected parafoil GN&C system, in order to proceed with the flight of the orbital test article.

The X-38 Program itself is a NASA led technology development and demonstration program with its premier goal being the development and orbital return flight test of an emergency Crew Return Vehicle (CRV) prototype for the International Space Station. The unmanned prototype vehicle, denoted as V201, will be released on-orbit from the Shuttle in 2002, and flown autonomously to a precision landing on earth. This flight will include on-orbit loiter, a de-orbit burn with a disposable expendable upper stage, hypersonic and supersonic atmospheric flight as a lifting body, followed by the deployment of a stabilizing drogue chute around 26000 ft, then followed by deployment of a large parafoil around 15000 ft. The parafoil, a 7500 square ft canopy developed by Pioneer Aerospace, shall be used to maneuver the test article, via differential deflection of the parafoil trailing edges, through the last 7 minutes of flight down to touchdown. The lifting body shape selected, sized to carry a full space station crew of seven and to be ferried up in the shuttle payload bay, flies well in the hypersonic and supersonic flight regimes, but flies poorly sub-sonically requiring a runway touchdown speed significantly greater than the shuttle. The large parafoil system, with its own dedicated GN&C design and avionics, flies significantly slower and in a very stable manner in the sub-sonic regime, and can be maneuvered to a soft precision touchdown into the local wind.

The GN&C design selected for this return from orbit flight test, is the Parafoil Guidance Navigation and Control (PGNC), developed by Uwe Soppa and Hans Strauch supporting the European Space Agency (ESA), in cooperation with NASA on the development of the X-38 Program. This software design has had limited flight testing in an ESA sponsored parafoil flight test program flown in Germany about three years ago, and is now being tested, both on the ground and in flight, by the NASA X-38 Program with help from ESA and the PGNC designers. This design was selected for its simplicity and robustness as well as its ability to integrate cleanly with the X-38 software and avionics hardware. Avionics required to support the PGNC design and flight testing include a hosting flight computer, a position and attitude navigation sensor (an Integrated INS GPS in this case), a command uplink system and a mechanism (winches) for independently deflecting left and right canopy trailing edges.

All this PGNC software and hardware require extensive testing, both on the ground and in flight, to gain confidence for its use on the V201 test article. Test objectives that need

to be explored and demonstrated prior to the orbital flight, and that will be reported on in detail in this paper, include:

- demonstrate and characterize the ability to achieve a precision landing (accuracy)
- demonstrate the ability to maintain a desired heading, either fixed or with a desired turn rate, as commanded by the PGNC
- demonstrate and characterize the ability to estimate wind real-time and to steer into the wind at landing
- demonstrate ability to use real-time sensor information while generating and flying a necessary reference trajectory to achieve the desired touchdown
- demonstrate ability to correctly interface with and command canopy deflecting actuators (winches)
- demonstrate ability to respond reliably to ground based commands sent to the test article in real time
- demonstrate ability to accurately sense above ground altitude and to properly and reliably trigger a touchdown flare
- generate accurate ground based simulations that compare to flight performance and that can be used for further PGNC testing in single and Monte Carlo simulations

Some of these test objectives are specific to a large parafoil, while others or more generic to any flight test aircraft. However all are required for the successful execution of the parafoil system, and all most be demonstrated thoroughly before performing a critical and hi-visibility return from orbit flight test with a multi-million dollar test article, requiring the support of a multi-million dollar shuttle flight. As such an incremental testing approach has been adopted by the X-38 Program for testing, characterizing and demonstrating virtually all its requisite sub-elements, including software, avionics, structure, and including the PGNC system. In most cases, PGNC testing will involve test beds and phases common to many different vehicle systems and disciplines. The test phases of relevance to the parafoil GN&C include the following, all of which are currently underway at various levels of completion, testing or development:

- Ground testing
  - GNC performance, both in single run and Monte Carlo simulation
  - Integrated software and hardware testing, including testing of PGNC in a flight computer communicating with a 6-DOF simulation, and with sensors and effectors

- Flight testing
  - Small scale flight testing, involving the use of an ultralight type powered parafoil, built by the Buckeye company and modified by Southwest Research Institute of San Antonio, running PGNC software, interfacing with onboard avionics, and being used as a sub-scale test bed for GN&C performance, heading control and wind estimation

- Full scale flight testing, involving the integration of the PGNC and required avionics into a full weight test article with a full size parafoil and effectors, providing a relatively in-expensive full scale test bed, supporting testing of GNC performance, heading control, wind estimation, sensor and effector interfaces, and ground commanding
- Lifting Body testing, involving the full suite of PGNC and interface software and avionics on a full size V201 lifting body shape, steering a full size parafoil, and demonstrating all the above test objectives prior to the orbital flight test

Results will be elaborated on substantially in the actual paper, though to date, they have been educational and encouraging with no apparent insurmountable problems or issues. Extensive ground based simulations have been performed showing promising PGNC targeting performance for a variety of test conditions. Integrated testing of the PGNC and hardware interface software has been conducted in flight computers and interfaced with flight components (INS/GPS, etc). Full scale Lifting body flights have also been performed with the PGNC communicating with navigation sensors and generating reference trajectories and commands in an open loop manner. Aside from demonstrating targeting performance, ground and flight testing to date has already flushed out sensor and effector limitations, along with interface, communication and coordinate transfer issues that mostly have been worked to solution. Additional issues have been identified including wind estimation capability and response to potential failure contingencies, that are currently being worked. Over the next 6 months, much flight testing is scheduled for the sub-scale 'Buckeye' and full-scale platform, along with the continuation of lifting body flight tests, and additional ground based testing and simulation. Already a meaningful amount of data and results have been acquired, with much more anticipated prior to the delivery of this paper.