ONBOARD DETERMINATION OF VEHICLE GLIDE CAPABILITY FOR SHUTTLE ABORT FLIGHT MANAGMENT (SAFM)

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When one or more main engines fail during ascent, the flight crew of the Space Shuttle must make several critical decisions and accurately perform a series of abort procedures. One of the most important decisions for many aborts is the selection of a landing site. Several factors influence the ability to reach a landing site, including the spacecraft point of atmospheric entry, the energy state at atmospheric entry, the vehicle glide capability from that energy state, and whether one or more suitable landing sites are within the glide capability. Energy assessment is further complicated by the fact that phugoid oscillations in total energy influence glide capability. Once the glide capability is known, the crew must select the "best" site option based upon glide capability and landing site conditions and facilities.

Since most of these factors cannot currently be assessed by the crew in flight, extensive planning is required prior to each mission to script a variety of procedures based upon spacecraft velocity at the point of engine failure (or failures). The results of this pre-flight planning are expressed in tables and diagrams on mission-specific cockpit checklists. Crew checklist procedures involve leafing through several pages of instructions and navigating a decision tree for site selection and flight procedures – all during a time critical abort situation.

With the advent of the Cockpit Avionics Upgrade (CAU), the Shuttle will have increased on-board computational power to help alleviate crew workload during aborts and provide valuable situational awareness during nominal operations. One application baselined for the CAU computers is Shuttle Abort Flight Management (SAFM), whose requirements have been designed and prototyped. The SAFM application includes powered and glided flight algorithms.

This paper describes the glided flight algorithm which is dispatched by SAFM to determine the vehicle glide capability and make recommendations to the crew for site selection as well as to monitor glide capability while in route to the selected site. Background is provided on Shuttle entry guidance as well as the various types of Shuttle aborts. SAFM entry requirements and cockpit displays are discussed briefly to provide background for Glided Flight algorithm design considerations.

The central principal of the Glided Flight algorithm is the use of energy-over-weight (EOW) curves to determine range and crossrange boundaries. The major challenges of this technique are exo-atmospheric flight, and phugoid oscillations in energy. During exo-atmospheric flight, energy is constant, so vehicle EOW is not sufficient to determine glide capability. The paper describes how the exo-atmospheric problem is solved by propagating the vehicle state to an "atmospheric pullout" state defined by Shuttle guidance parameters.

A technique for compensating EOW for phugoid oscillations is also discussed. During atmospheric entry, energy may fluctuate between potential and kinetic forms causing large gains and losses in altitude, particularly during certain abort entries. These variations in altitude cause oscillations in the rate of total EOW decay, so that EOW alone is not sufficient to determine vehicle capability. The paper describes how the phase of the phugoid may be determined, and used to compensate EOW to create a "compensated energy" quantity that may be used to more accurately determine glide capability.

Major algorithm components are discussed (Figure 1.), including the vehicle pullout state predictor, the phugoid compensation, and the use of energy/range corridors to determine the vehicle footprint. The techniques used to assign figures of merit to each runway are covered, as well as runway prioritization methods that consider runway facilities in order to make a final landing site recommendation during an abort.

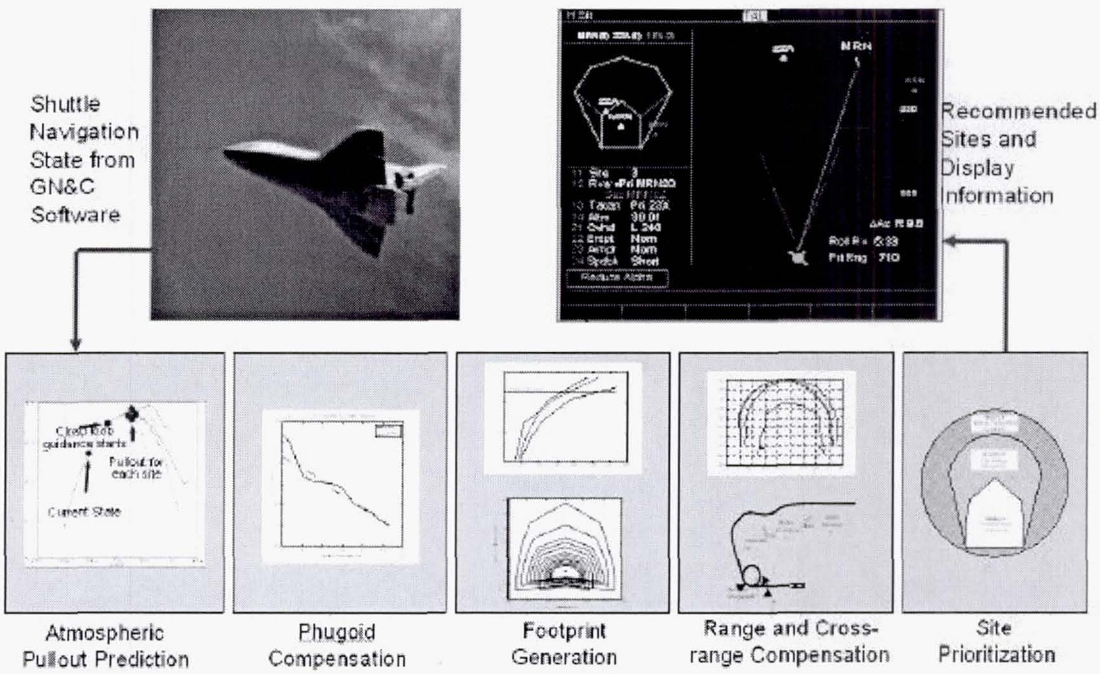

Figure 1. Glided Flight Algorithm Overview

Techniques for expressing vehicle constraints as footprint boundaries are covered, as well as techniques for generating maximum range performance boundaries. Display histories for several abort scenarios are provided as examples of algorithm performance. Finally, potential future applications of this type of algorithm to increase vehicle autonomy are discussed.

Suggested Session: Space Situational Awareness

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Biography

Mark Jackson is a senior member of the technical staff at the Charles Stark Draper Laboratory. He is located at the Draper Field Site office at the Johnson Space Center in Houston, TX, where he currently leads the Glided Flight design team for the Shuttle Abort Flight Management (SAFM) project, and serves as task lead for the On-orbit Flight Control System (FCS) Software Development task. As SAFM Glided Flight team lead, he is responsible for the design and development of the algorithms and software requirements for the entry guidance and landing site selection portion of the SAFM application. In the FCS development role, he oversees the Draper efforts to enhance Shuttle capabilities to provide attitude control for large flexible structures such as the International Space Station (ISS). This includes development and certification of software change requests to improve the Shuttle's capability to control and reboost the mated Shuttle/ISS structure.

From 1992 to 1994, Mr. Jackson was a Draper Fellow at MIT where he developed optimization algorithms to minimize plume impingement and fuel consumption during Spacecraft approaches for docking. During his time at Draper, he worked to develop and certify the Shuttle Control System for docking flights to the Russian Mir Space Station.

Prior to his tenure with Draper, Mr. Jackson was a Navy fighter pilot. Tours of duty included assignment to an F-14 squadron onboard USS America, and a tour as a Topgun instructor. In this capacity, he provided operational and technical consultation for short range infra-red missile design and deployment.

Mr. Jackson received a BS in Systems Engineering from the U.S. Naval Academy in 1982, and an MS in Aerospace Engineering from MIT in 1994.

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