

PRELIMINARY RESULTS FROM FIRST FLIGHT OF THE STRATOSPHERIC PROJECTILE EXPERIMENT OF ENTRY DYNAMICS (SPEED)

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Brief Presenter Biography (35 word limit): Cole Kazemba is an EDL system engineer in the Entry Systems and Vehicle Development Branch at NASA Ames Research Center with 12 years of experience doing technology development, instrumentation, and systems engineering for EDL applications.

Introduction: The dynamics of blunt-body vehicles in the transonic regime of atmospheric entry often play a dominant role in the design of atmospheric entry missions [1]. Passage through these flight regimes can pose one of the greatest mission risks due to instabilities which can cause divergent and potentially catastrophic behavior. Most NASA entry missions encounter transonic dynamic stability challenges that drive system requirements and architecture choices.

Experimental facilities capable of characterizing dynamic stability are sparse, with only one forced-oscillation facility (NASA Langley Transonic Dynamics Tunnel) and two free-flight ballistic ranges (NASA Ames Hypervelocity Free-Flight Aerodynamic Facility and Aberdeen Proving Grounds) operational nationwide to support testing needs. These facilities have minimal overlap in Mach number (Fig. 1) and suffer from known and substantial shortcomings which directly contribute to uncertainties in the resultant pitch damping parameter [1]. Computational methods for predicting dynamic stability are improving in capability, but have yet to be adopted by missions, partially due to the sparse and non-flight-like nature of the experimental data that is currently used for validation.

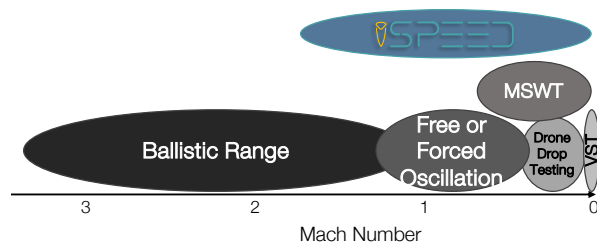


Figure 1: Mach Coverage for Dynamic Tests

A novel test technique for characterizing entry vehicle dynamics via stratospheric balloon-dropped, free-flight testing has been developed. The Stratospheric Projectile Experiment of Entry Dynamics (SPEED) is a new stratospheric free-flight test

architecture that is capable of delivering entry capsules to dynamically scaled conditions up to Mach 2. SPEED will complete its initial demonstration flight in May of 2024 on board a stratospheric balloon operated by World View Enterprises via a Flight Opportunities Program grant. This presentation will briefly describe the ground testing and low-speed testing done prior to the balloon flight, discuss the balloon flight operations, and present preliminary analysis and results from the balloon flight test.

SPEED Architecture: The SPEED test architecture can achieve the high subsonic or low supersonic test conditions of interest to missions using an innovative two-stage flight system (Fig. 2). The initial configuration of each flight system when it is released from the balloon has a high ballistic coefficient that allows it to accelerate rapidly to supersonic Mach numbers. When the target condition is sensed, the entry capsule is released from the aft portion of the flight system and is exposed to flight conditions that produce dynamics representative of the full-scale (operational) vehicle. Thereafter, the capsule decelerates through the transonic and subsonic regimes until it reaches terminal velocity. The ability to observe representative dynamics continually across this Mach span typically only occurs in the full-scale flight trajectory. Unlike other test methods, this approach enables the vehicle dynamics to evolve throughout this entire regime of interest and collect valuable data which can be used to characterize vehicle dynamics and inform mission design.

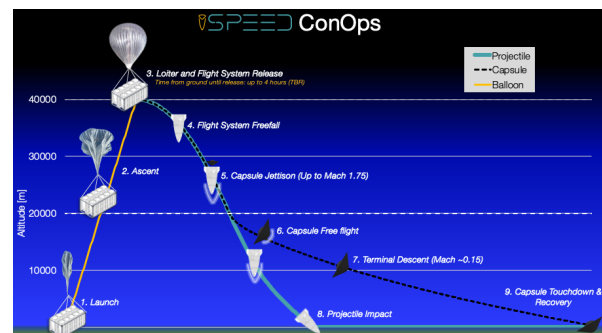


Figure 2: SPEED Concept of Operations

Balloon Flight Description:

The goal of the first demonstration flight of the SPEED concept is to advance the TRL of the hardware,

avionics, and operations such that this test technique can be deployed for future mission or scientific use. In the first flight, four capsules approximating the geometric and scaled mass properties of the Mars Sample Return Earth Entry System (EES) and four approximating the Dragonfly entry vehicle will be flown. Conducting this test with four models of each vehicle configuration allows for controlled repeatability and produces a statistical set of data for use in characterizing the vehicle dynamics. In addition, by testing two different capsule shapes, data will be collected from one capsule that is known to be stable in the transonic regime (EES) and one that is known to have dynamic instabilities (Dragonfly). Contrasting the behavior of these two vehicles will provide valuable insight into possible test artifacts that might affect vehicle dynamics.

The balloon will lift off from southeastern Arizona, ascend to the stratosphere, and traverse to the target drop area. Each flight system will be released from the stratospheric balloon at an altitude of 40km. At approximately 27km altitude, the avionics on board the projectile will send a signal to a hot-wire cutter to initiate the capsule separation event. The hot wire cutter releases an ejection mechanism that imparts a relative velocity between the two flight system elements via a set of tensioned springs. The transition from a single flight system to two free-flying bodies represents both the enabling innovation of this test concept and the event that has the highest degree of risk. Figure 3 shows the complex flow structures present during this transition.

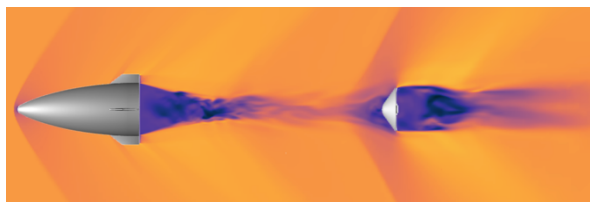


Figure 3: CART3D Results Showing Velocity Contours with the EES Capsule Trailing the Projectile at Two Projectile-Body-Lengths at Mach 1.3

To mitigate against the risk of adverse behavior during this transition event, the SPEED team has conducted ground, drone-drop, and helicopter-drop tests. These tests served to validate the function of the ejection system and to collect data about the dynamic behavior of the flight system to inform system design. Ultimately, a flight test at relevant conditions is required to fully validate this event.

Anticipated Results:

Successful delivery of the test capsules into free-flight conditions is a key objective that this initial flight

will seek to demonstrate. Initial analysis of the flight data will focus on assessing whether this transition was executed without imparting any moments on the capsule that prevent it from achieving a quasi-steady state to initialize the phase of the experiment that is of primary scientific interest.

The test capsules will be heavily instrumented such that the entire time history of the vehicle state is measured and recorded. Each capsule will measure three-axis accelerations, angular rates, and magnetic fields. Surface pressure distributions on the capsule forebody are measured with one stagnation and four orthogonal pressure transducers in a cruciform. Finally, a horizon camera mounted inside each vehicle aftbody provides video footage to help contextualize the vehicle behavior and on-board measurements. The capsules will be retrieved following ground impact and the on-board data will be recovered and processed.

Further analysis conducted on this rich data set enables a comprehensive assessment of the dynamic behavior of the vehicle using reconstruction methods that have been employed to determine best estimated trajectories on previous missions [2]. The resultant data can provide valuable aerodynamic data to assess mission flight readiness and allows for general evaluation of vehicle stability and behavior.

References: [1] Kazemba C. D., et al., "Survey of Blunt-Body Supersonic Dynamic Stability," (2017). *Journal of Spacecraft and Rockets*, Vol. 54, No.1, pp 109-127.

[2] Karlgaard, C.D., et al., "Mars Science Laboratory Entry Atmospheric Data System Trajectory and Atmosphere Reconstruction," (2014). *Journal of Spacecraft and Rockets*, Vol. 51, No.4, pp 1029-1047.