

A STRATOSPHERIC TEST METHODOLOGY FOR CHARACTERIZING FREE-FLIGHT DYNAMICS OF ENTRY VEHICLES

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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 11 years of experience doing technology development, instrumentation, and systems engineering for EDL applications.

Introduction: The dynamics of blunt-body vehicles in the supersonic and transonic regimes 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. All of NASA's ongoing entry missions (MSR SRL, MSR EES, and Dragonfly) currently have dynamic stability challenges that drive system requirements.

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 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.

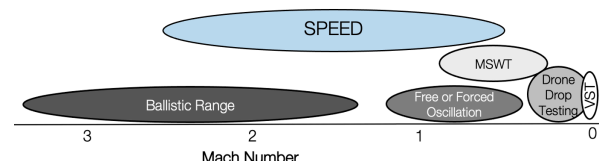


Figure 1: Mach Coverage for Dynamic Tests

This presentation will introduce a novel test technique for characterizing entry vehicle dynamics via stratospheric balloon-dropped, free-flight testing. Stratospheric Projectile Experiment of Entry Dynamics (SPEED) is a test architecture that provides a cost-competitive alternative to the existing experimental facilities (Fig. 1), while providing vastly richer experimental data and offering improvements in the achievable similarity to full-scale flight conditions. This

test technique can be applied to entry vehicles in a variety of configurations and can be tailored to match dynamic similitude requirements for missions at several planetary destinations.

Architecture Description: This stratospheric balloon drop concept can achieve the high subsonic or supersonic test conditions of interest to missions through the use of an innovative two-stage flight system (Fig. 2). The initial configuration of the flight system when it is released from the balloon at the target altitude has a high ballistic coefficient that allows it to accelerate rapidly and achieve conditions up to approximately Mach 2. 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 vehicle. Thereafter, the capsule decelerates through the transonic and subsonic regimes until it reaches terminal velocity. The ability to observe representative dynamics continually across these flight regimes 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.

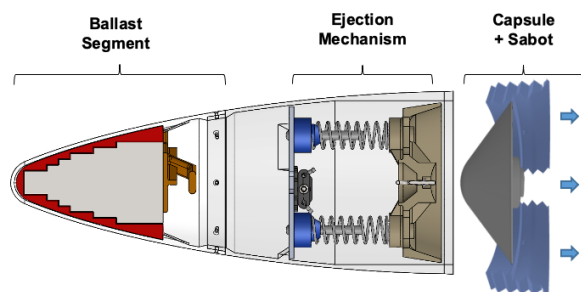


Figure 2: Preliminary Design of Two Stage Flight System

The concept of operations for SPEED (outlined in Fig. 3) centers around the use of a stratospheric balloon to take several flight systems to the desired initial altitude. The set of flight systems are housed in a drop platform that will release them upon command from the balloon gondola. The initial altitude is dependent on the target flight regime where the dynamics of interest occur, but typical conditions would require an initial altitude of 25–40 km. For the class of balloon available through the NASA Flight Opportunities program, the associated lift

capability of the balloon to these initial altitudes would allow approximately eight complete flight systems to be carried in one flight up to 40 km. Lift mass capability increases exponentially as the required initial altitude decreases. The ability to drop many capsules through the same or very similar atmospheric profile in each experiment is key to the value of this test methodology. This allows for controlled repeatability and produces a statistical set of data for use in characterizing the vehicle dynamics.

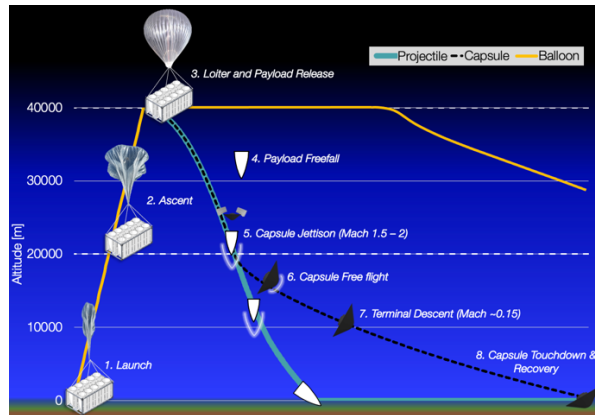


Figure 3: SPEED Concept of Operations

The design of a test campaign using the SPEED architecture includes a fundamental trade between the total lift mass of the balloon, the number of flight systems tested, the size and mass of each capsule being tested, and the peak Mach number that is reached prior to separation and the onset of the “experiment” for each capsule. Fig. 4 shows the peak Mach number that can be reached for a representative set of design parameters. The diminishing returns with increased flight system mass present a practical upper bound on the Mach number that can be reached for a given starting altitude.

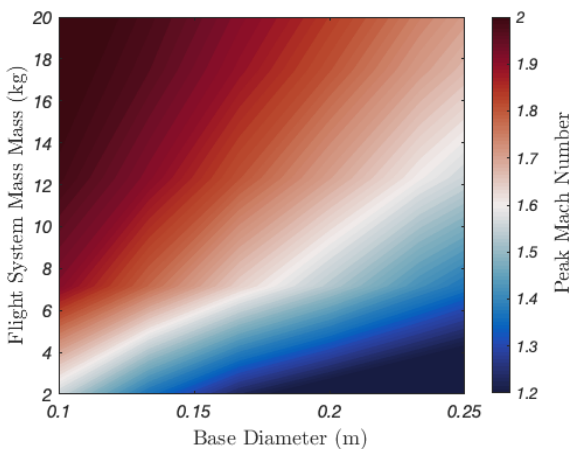


Figure 4: Peak Mach number vs. flight system mass and base diameter of the capsule for a drop altitude of 40km and a capsule separation altitude of 20km.

Example trajectories and similitude performance of SPEED for the Mars Sample Return Earth Entry System (MSR EES) and the transonic regime of the Dragonfly capsule with a drogue parachute are shown in Fig. 5 and Fig. 6, respectively.

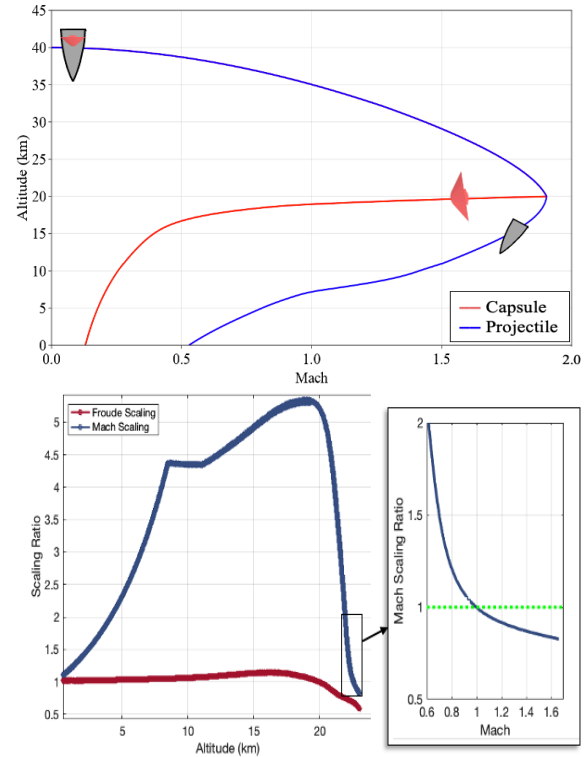


Figure 5: Altitude vs. Mach number (top) and similitude performance (bottom) for a SPEED test designed to match the dynamics of the MSR EES. Test capsule is 25cm diameter and 1.3kg.

The test capsule is heavily instrumented such that the entire time history of the vehicle state is measured and recorded. The capsules are retrieved following ground impact and the on-board data is recovered and processed. 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. The similarity to full-scale flight conditions, the richness of the measured data, and the ability for controlled and repeatable tests enable this data set to be a standard against which other test facilities and computational predictions can be compared.

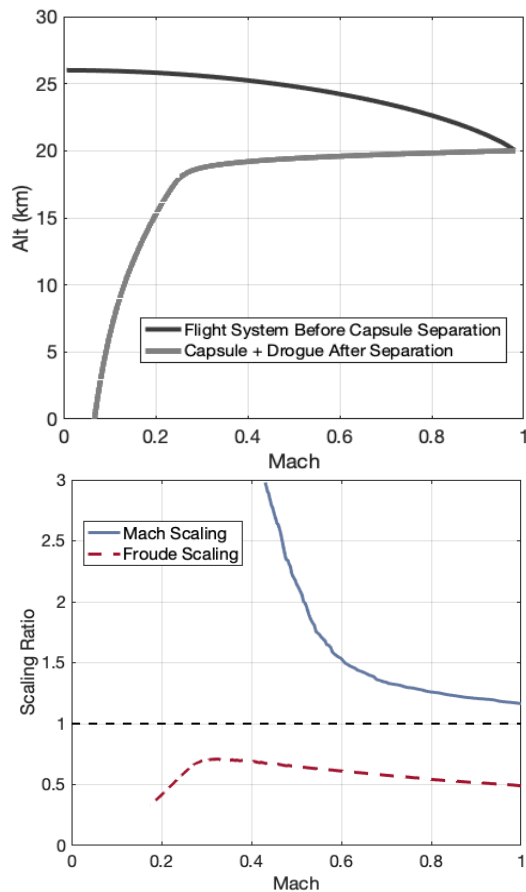


Figure 6: *Altitude vs. Mach number (top) and similitude performance (bottom) for a SPEED test designed to match the dynamics of Dragonfly under drogue parachute. Test capsule is 16 cm diameter and 1.5 kg.*

Focus of Presentation: This presentation will first introduce the test technique. Next, a variety of example applications will be presented including supersonic capsule testing for Mars, Earth, and Titan and testing for the Dragonfly capsule with the drogue parachute included. The achievable trajectory parameters and similitude performance will be presented. Finally, a discussion regarding the benefits of using this technique as a complementary method to the existing dynamics test and analysis portfolio will be presented.

Note that a complementary presentation (Author: Libben) is being submitted for a deep dive into the details of a technology demonstration flight that has been chartered through the NASA Flight Opportunities Program. That talk will outline the technology maturation path that is being executed to prepare for the balloon test and the details regarding the mechanical system, avionics and instrumentation, and flight operations.

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.