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Splashdown Testing for the Titan Mare Explorer (TiME) Mission

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Lorenz, R. D. M. V. Paul, J. Walsh, D. W. Olds, E. B. Bierhaus, 2015. Inversion of a Capsule impacting Water: Flip by Resurge Jet, ASME Journal of Offshore Mechanics and Arctic Engineering, 137, 044501-1 to 044501-6, August 2015

And

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See also my PhD thesis and

Lorenz, R. D., Splashdown and Post-Impact Dynamics of the Huygens Probe : Model Studies, pp.117-124 in Proceedings of the International Workshop on Planetary Entry and Descent Trajectory Reconstruction and Science, Lisbon, October 2003, ESA SP-544

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Determination of physical properties of a planetary surface by measuring the deceleration of a probe upon impact: Application to Titan

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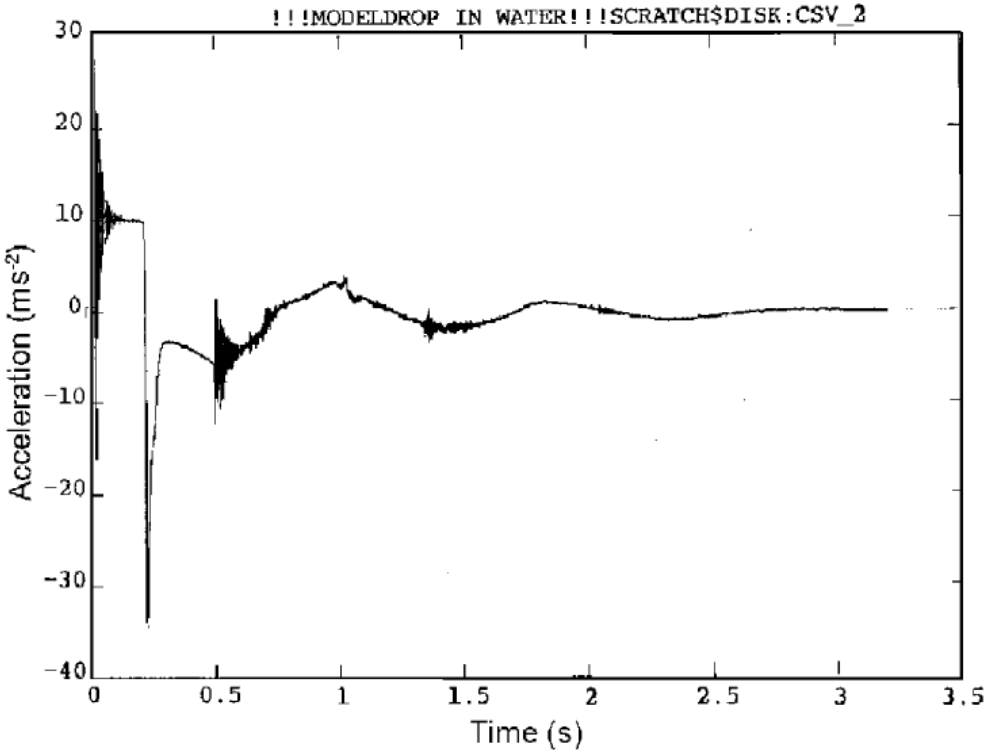
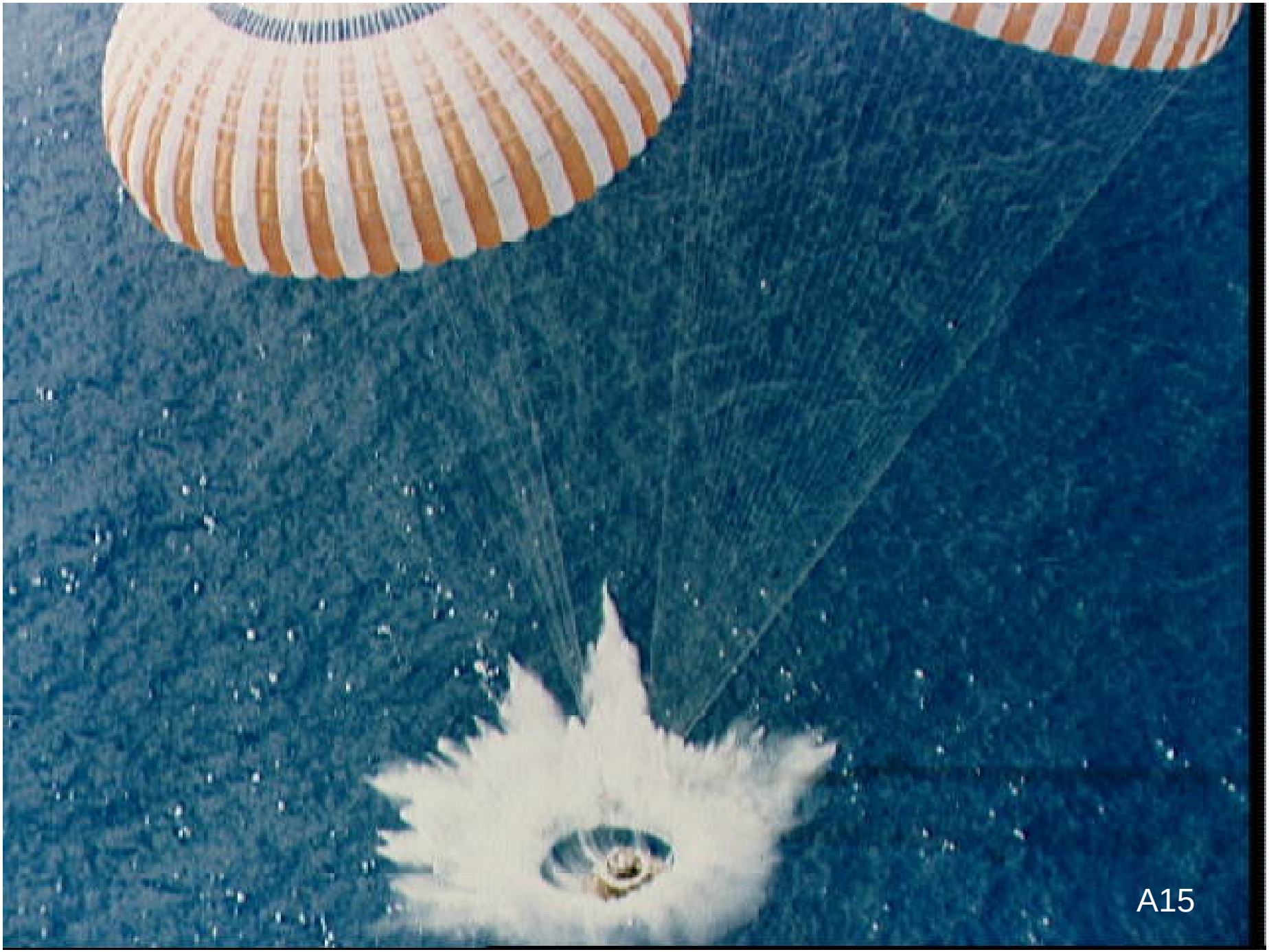
✠Deceased.



A Brief History of TiME

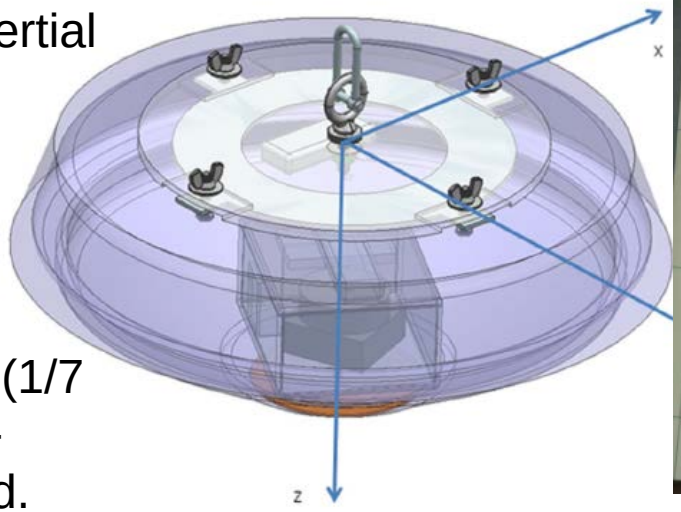
Proposed to DSMCE call in 2007 for ASRG-enabled missions
Concept refined, proposed to Discovery 2010 (with 27 others.)
One of 3 missions selected for Phase A.
Start July 2011, CSR due in March 2012
TiME Site visit June 2012
ASRG failed FDR June 2012
MSL lands in triumph, selection of InSight as next Discovery flight program announced August 2012

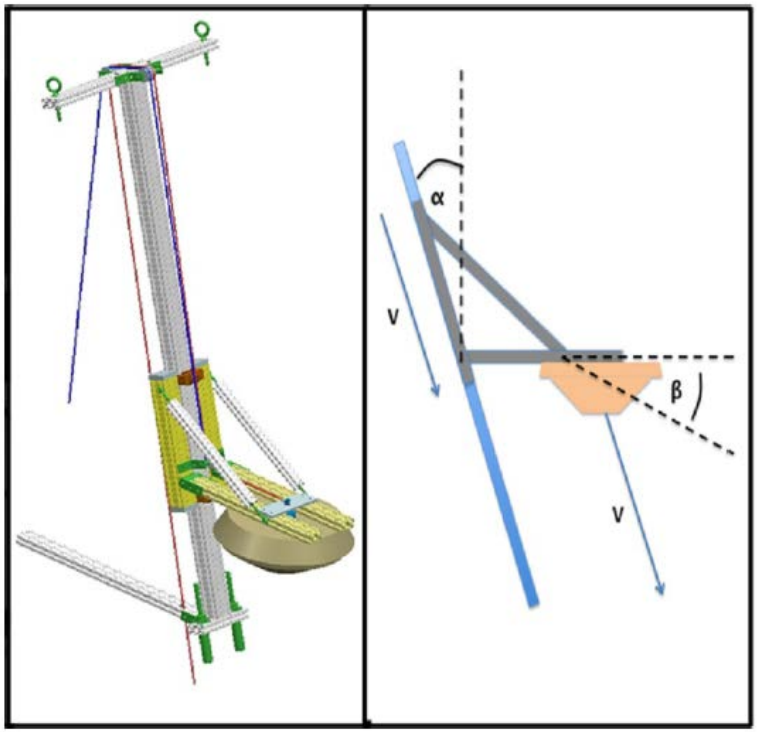

A15

Dimensionless similarity parameter for Gravity-Inertial motions is the Froude Number

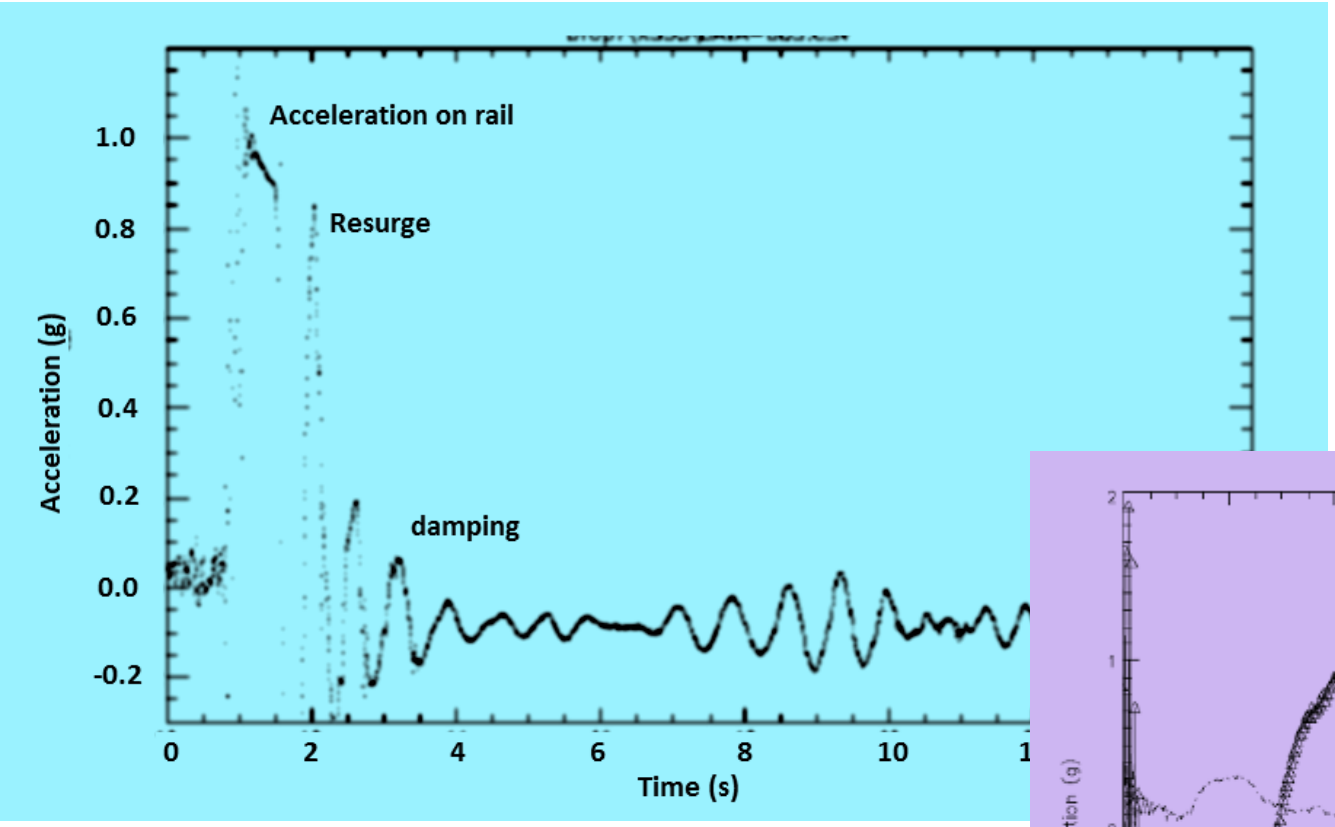
$F = V / (gD)^{0.5}$

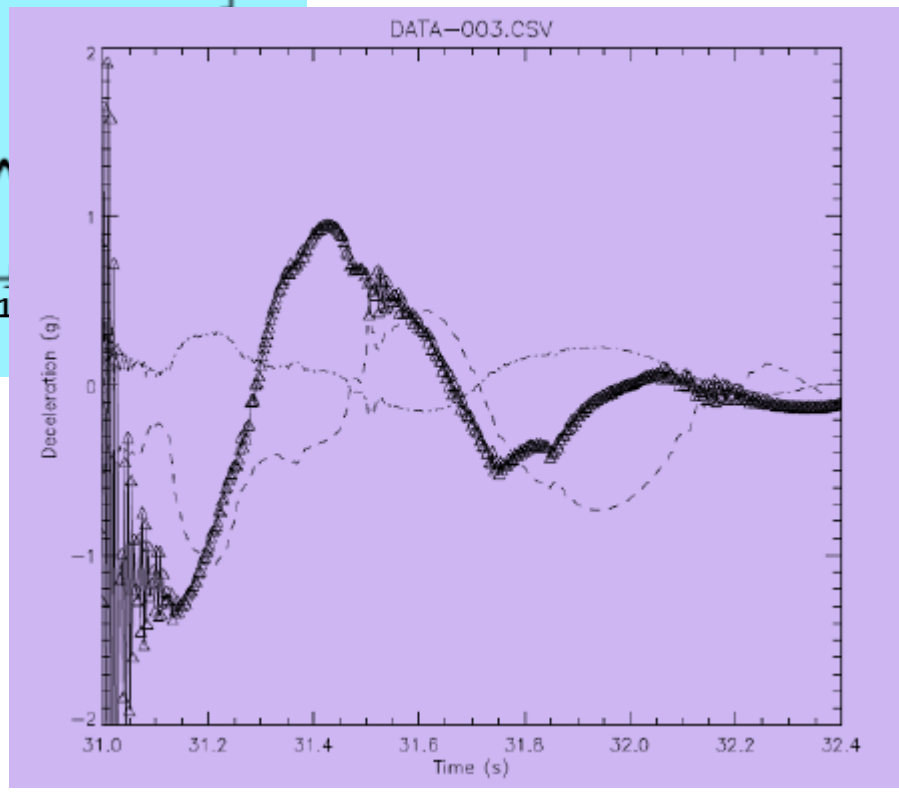
Can match Titan gravity (1/7 Earth's) by having a 1/7-scale model. 3-D printed.

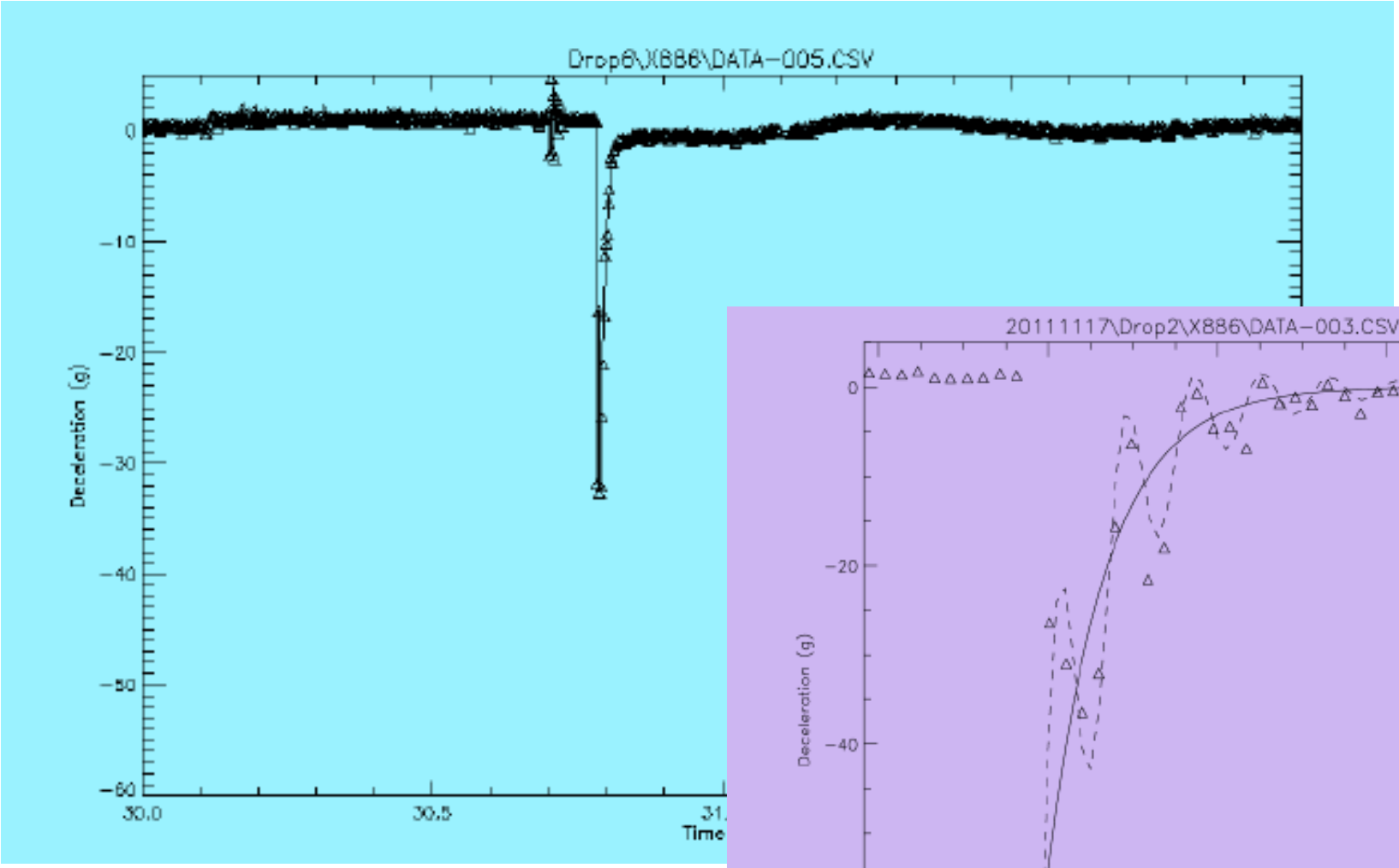


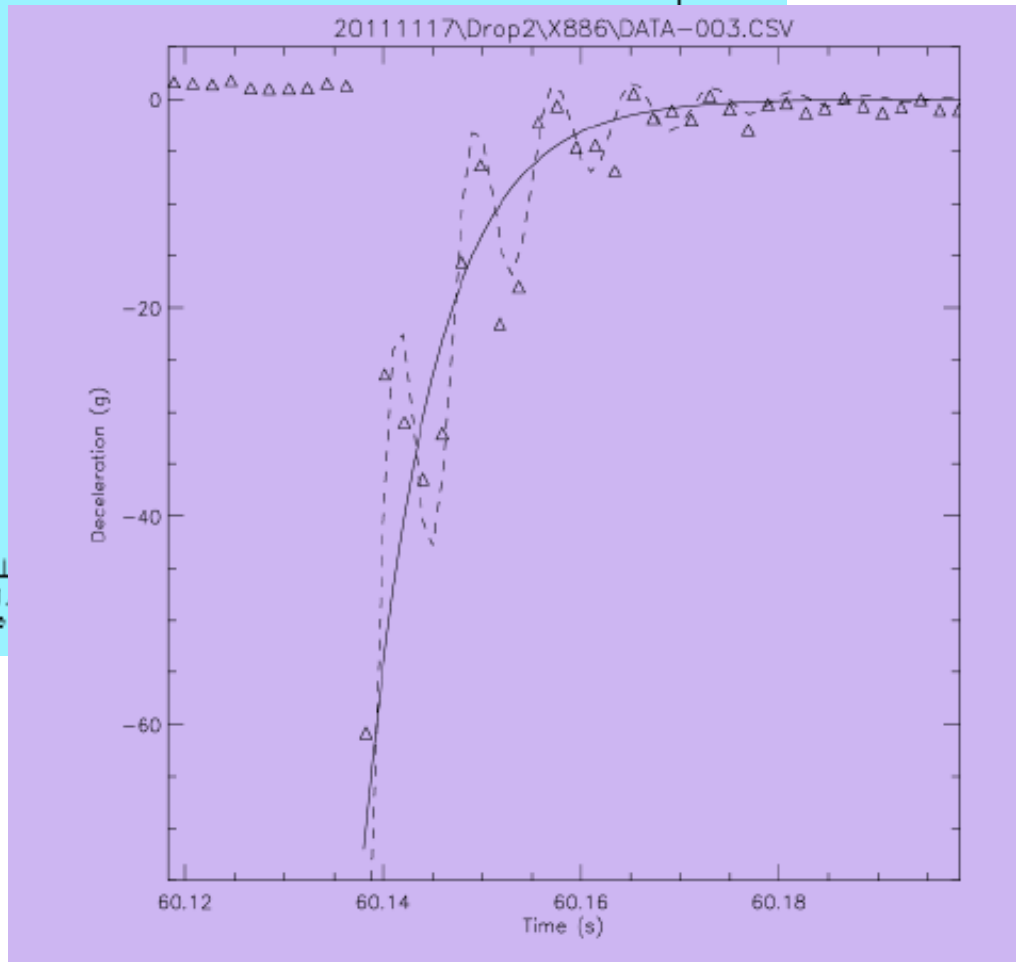


Test Video 1

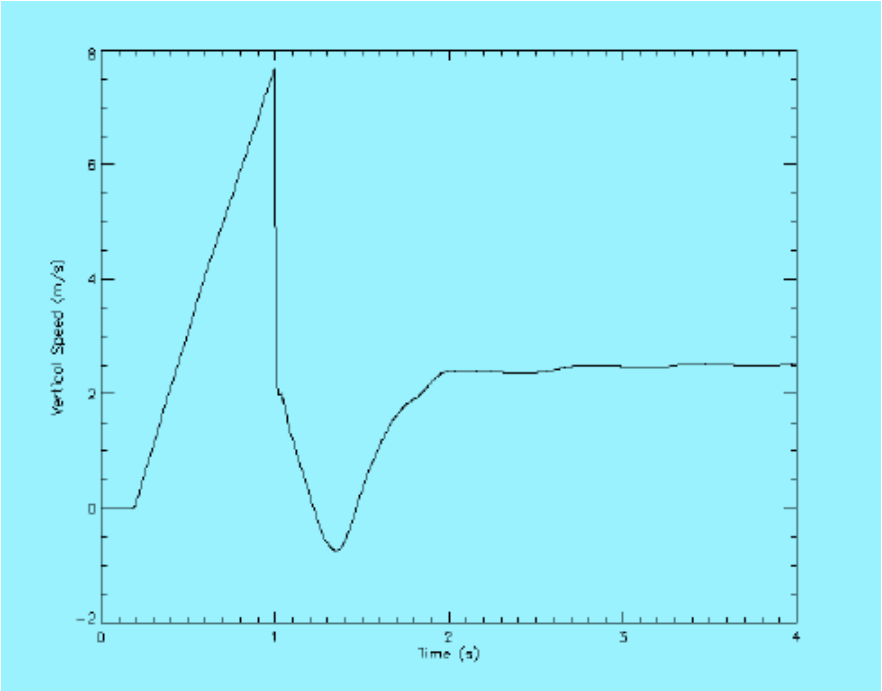

Acceleration on rail
Resurge
damping
Acceleration (g)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
2
4
6
8
10
Time (s)


DATA—003.CSV
Deceleration (g)
2
1
0
−1
−2
31.0
31.2
31.4
31.6
31.8
32.0
32.2
32.4
Time (s)



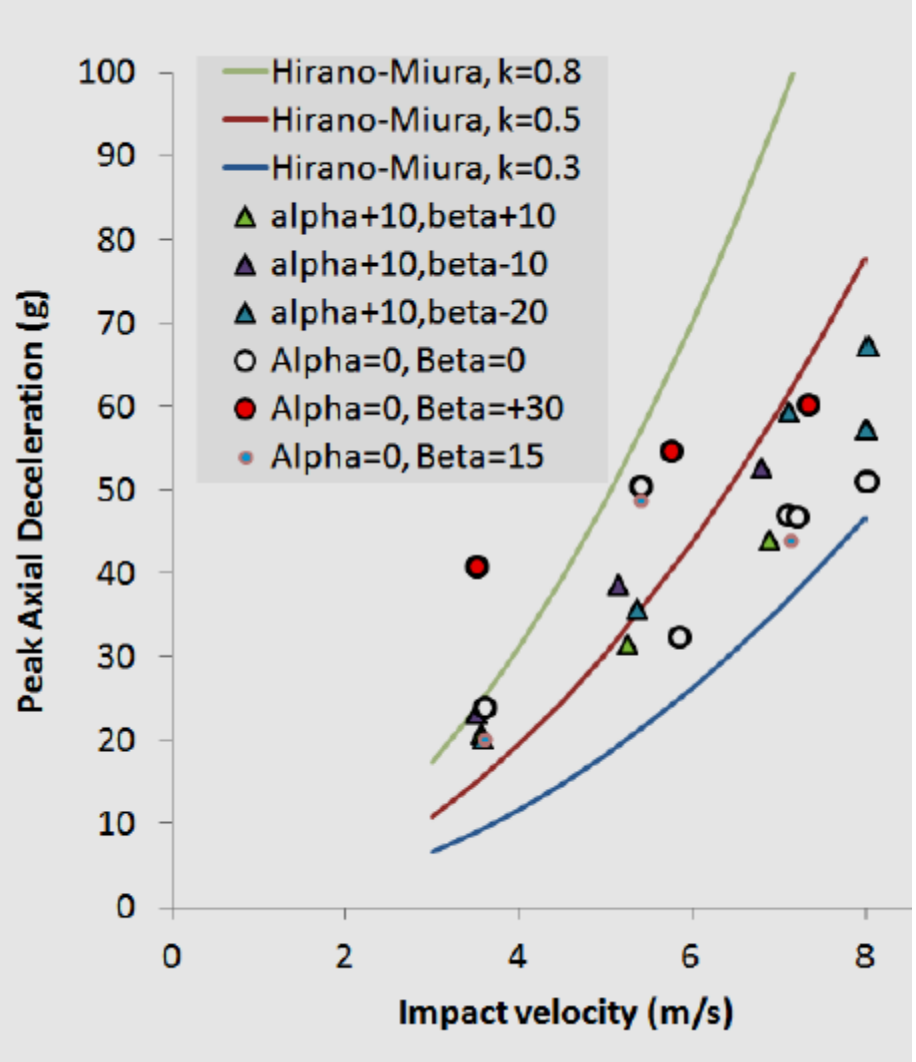


Peak deceleration captured (just) by 512Hz sampling. Close inspection shows structural ringing at ~100Hz



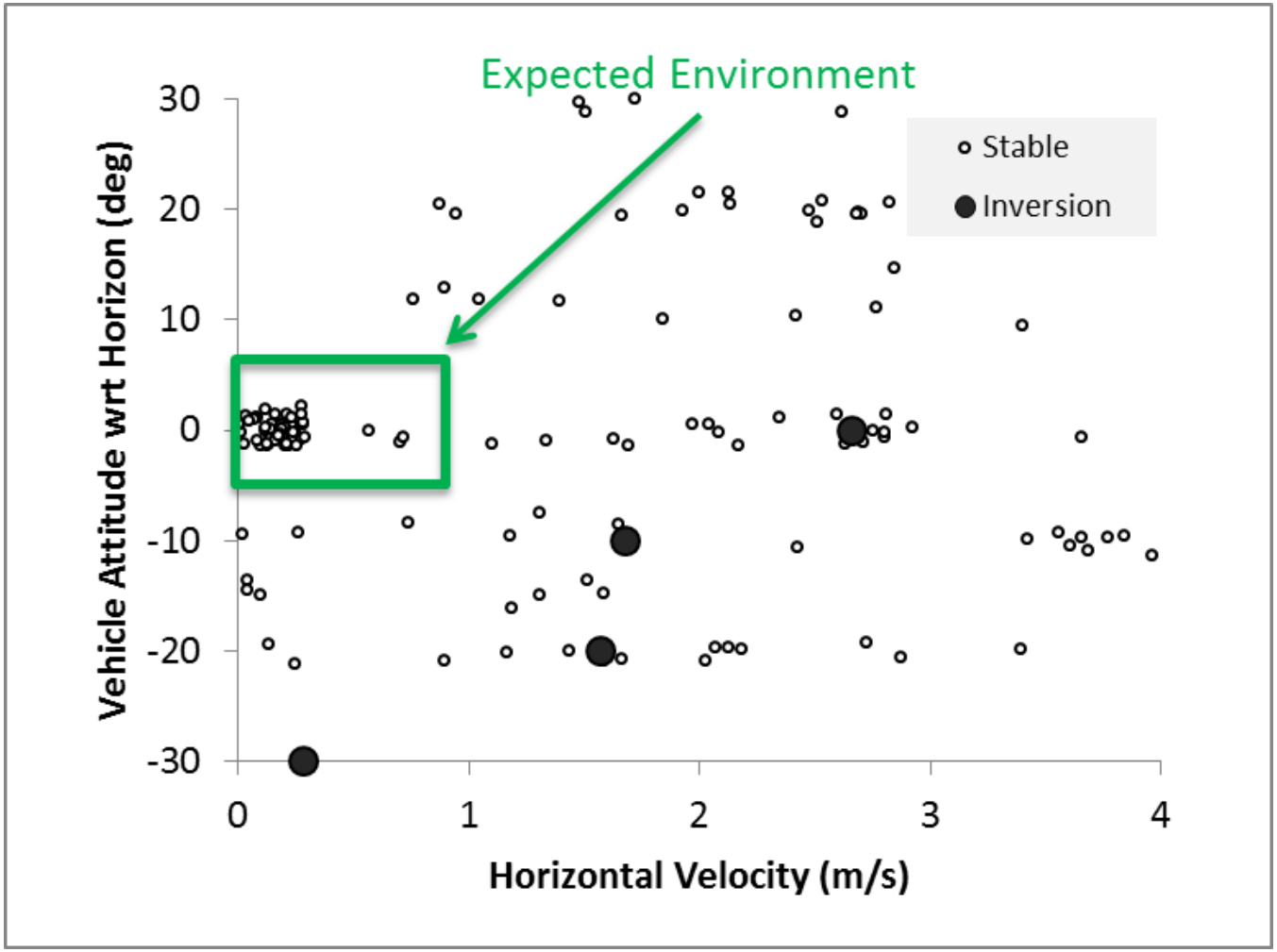
About 75% of impact velocity is removed at impulsive contact.

Using Hirano-Miura scaling (Peak load proportional to F^2 and relative density m^-0.66 allowed estimation of impact loads at Titan in liquid ethane. Validated with a few CFD spot runs. Safely below ASRG limits.

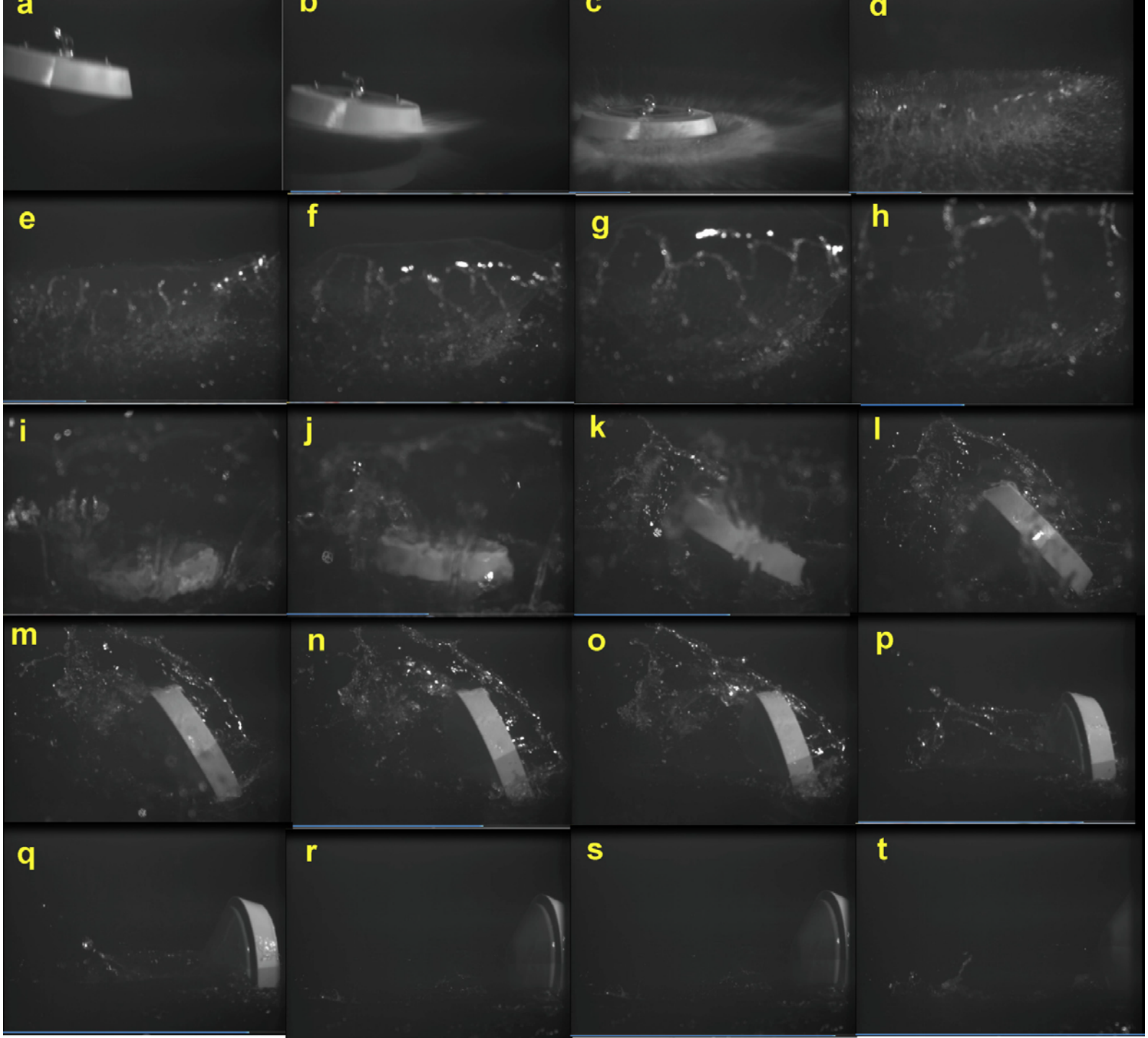


CFD runs can take days. Scale model test turnaround ~10 minutes.

Kinematics video 2



Results in December 2011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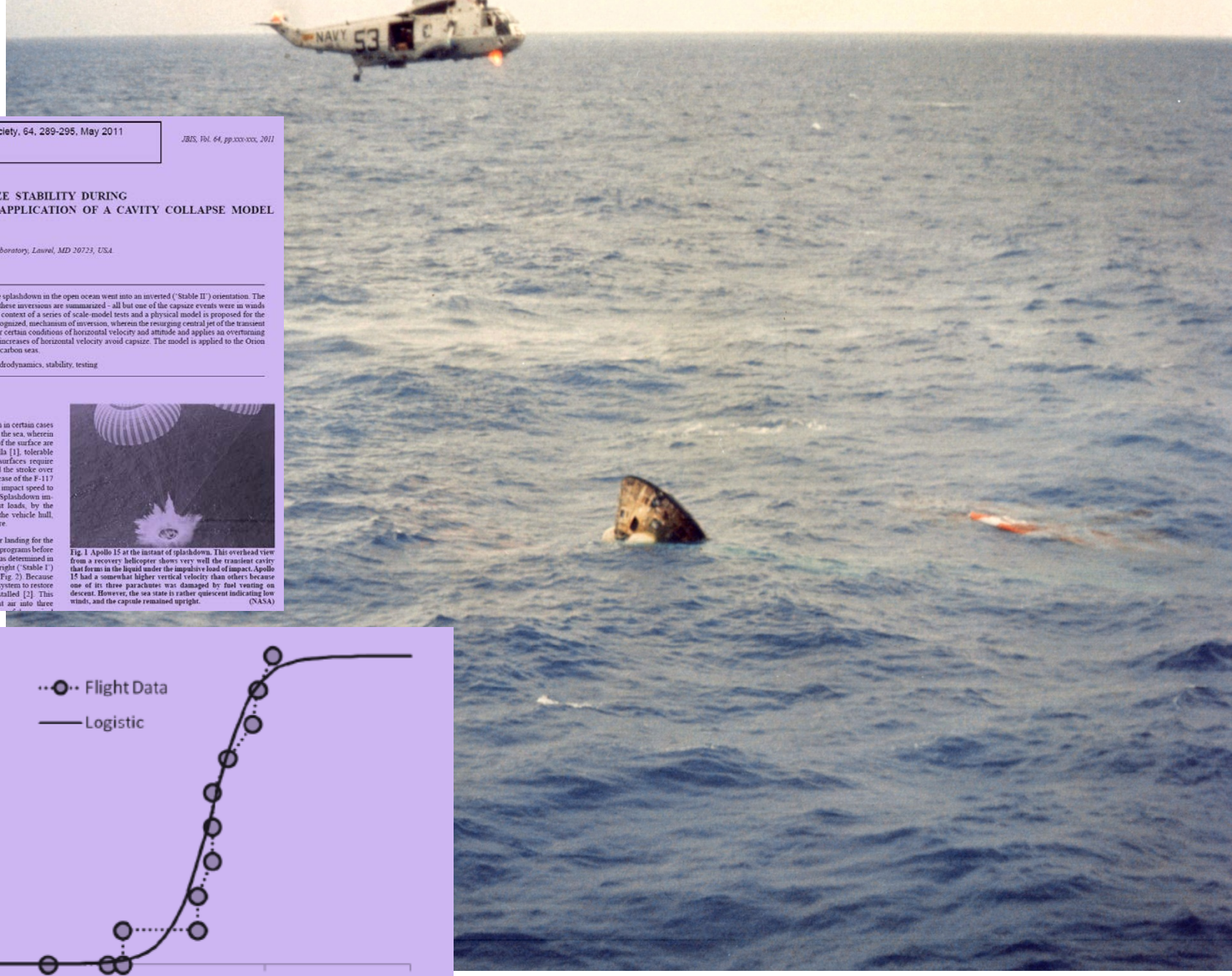

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JBIS, Vol. 64, pp.xxx-xxx, 2011

APOLLO CAPSULE CAPSIZE STABILITY DURING SPLASHDOWN: APPLICATION OF A CAVITY COLLAPSE MODEL

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Some 9 of the 19 Apollo capsules that made splashdown in the open ocean went into an inverted ('Stable II') orientation. The wind and wave conditions associated with these inversions are summarized - all but one of the capsize events were in winds >6 m/s. The flight data are reviewed in the context of a series of scale-model tests and a physical model is proposed for the dominant, but apparently heretofore-unrecognized, mechanism of inversion, wherein the resurging central jet of the transient cavity catches the edge of the capsule under certain conditions of horizontal velocity and attitude and applies an overturning moment. This model explains how further increases of horizontal velocity avoid capsize. The model is applied to the Orion capsule and to splashdown in Titan's hydrocarbon seas.

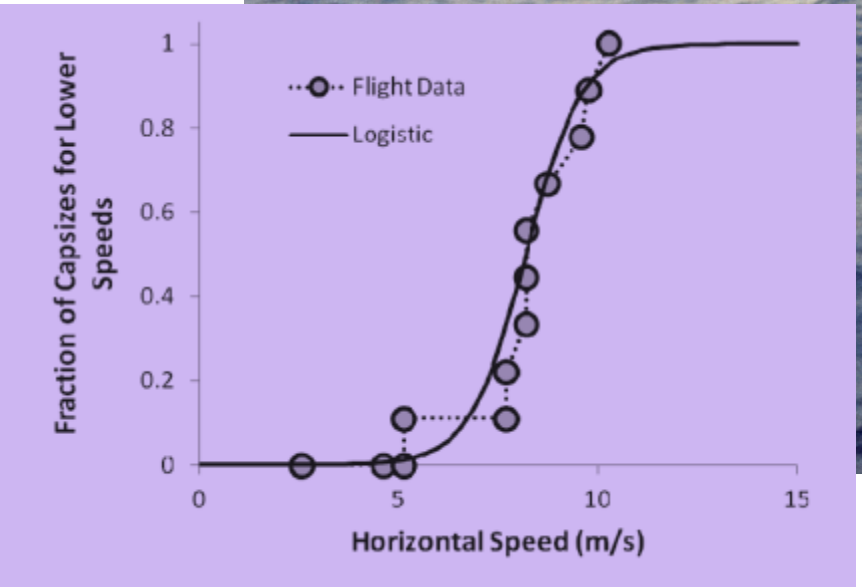
Keywords: Splashdown, water landing, hydrodynamics, stability, testing

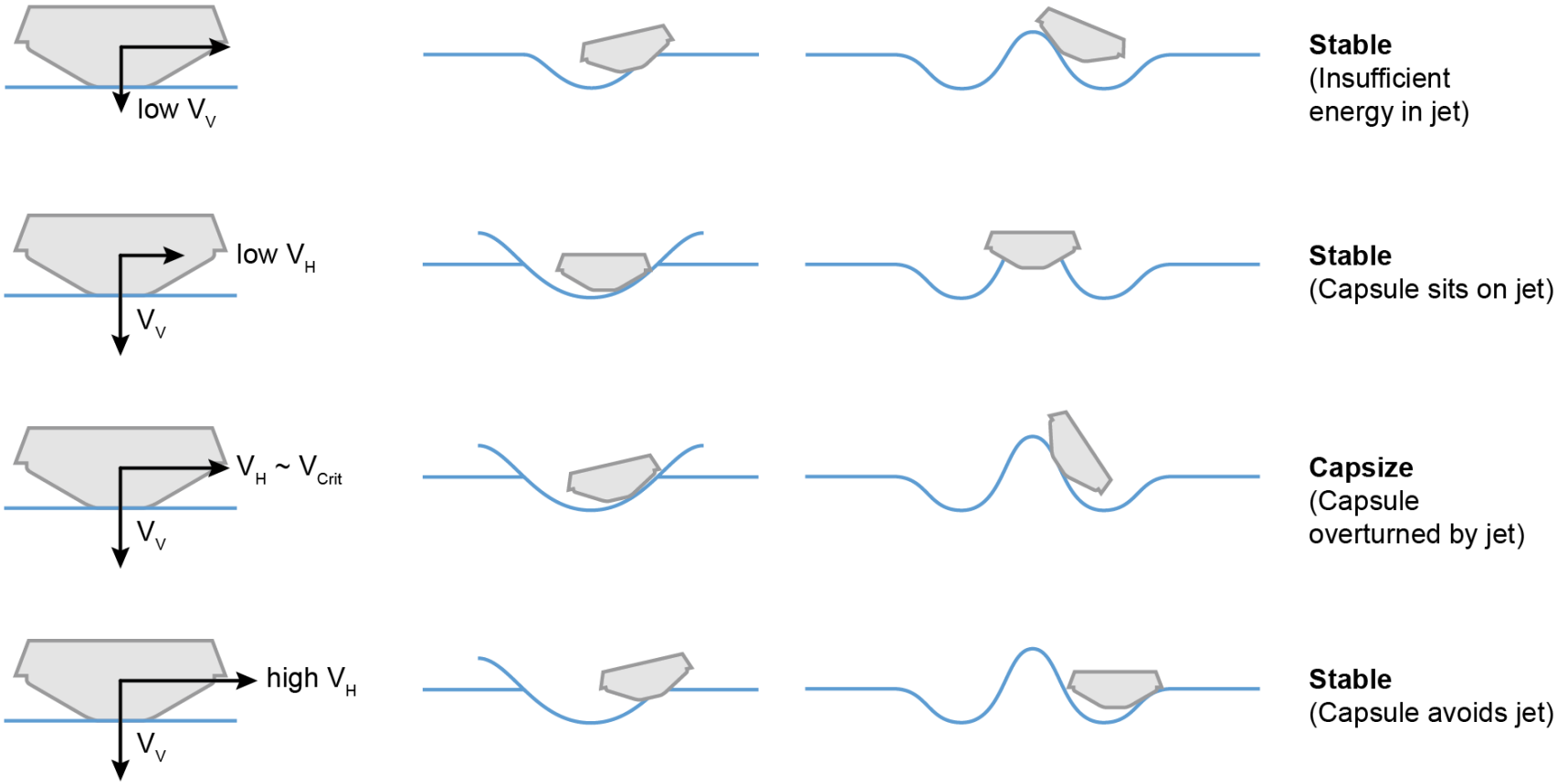
1. INTRODUCTION

Delivery of a vehicle to a planetary surface can in certain cases be most conveniently performed by landing on the sea, wherein the mechanical properties of a large expanse of the surface are uniform and forgiving . As noted by Fasanella [1], tolerable impact loads for crewed capsules on land surfaces require additional hardware, either airbags (to extend the stroke over which the deceleration event occurs, as in the case of the F-117 escape module) or retrorockets (to reduce the impact speed to very small values, as in the Soyuz capsules). Splashdown impact allows a large stroke, and thus modest loads, by the hydrodynamic interaction of the water with the vehicle hull, without generally requiring additional hardware.

This convenience led NASA to adopt water landing for the Apollo program (and the Mercury and Gemini programs before it) - see Fig. 1. However, the Apollo capsule was determined in early tests to be statically stable in both an upright ('Stable I') and partly inverted ('Stable II') condition (see Fig. 2). Because crew egress was more difficult in Stable II, a system to restore the vehicle to an upright condition was installed [2]. This system used a compressor to pump ambient air into three

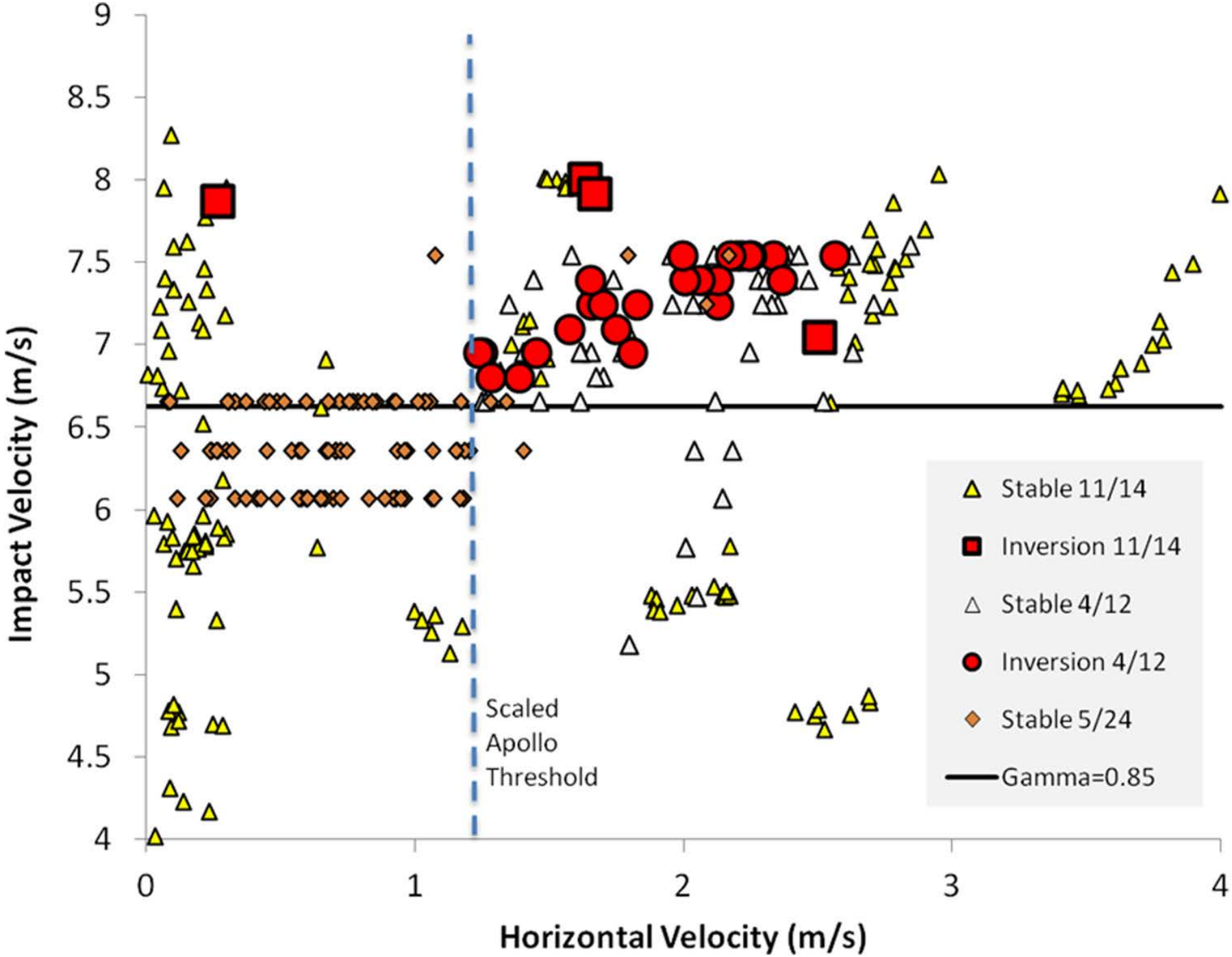
Fig. 1. Apollo 15 at the instant of splashdown. This overhead view from a recovery helicopter shows very well the transient cavity that forms in the liquid under the impulsive load of impact. Apollo 15 had a somewhat higher vertical velocity than others because one of its three parachutes was damaged by fuel venting on descent. However, the sea state is rather quiescent indicating low winds, and the capsule remained upright. (NASA)





2 necessary conditions for capsize :

- resurging jet must have enough energy to overturn capsule
- jet timing must be right, to catch edge of capsule


Impact Velocity (m/s)
Horizontal Velocity (m/s)
9
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
0
1
2
3
4
Scaled
Apollo
Threshold
Stable 11/14
Inversion 11/14
Stable 4/12
Inversion 4/12
Stable 5/24
Gamma=0.85

Conclusions

Attention in splashdown has traditionally focussed on the first milliseconds after contact. This is an analytically appealing problem with a rich pedigree, and is when the peak deceleration is generated.

The late stages are computationally-demanding and complex. They are, however, critical in the stability of the vehicle. While complex, the phenomena are deterministic. A simple physical mechanism has been proposed, with a critical horizontal velocity range which defines where capsize may occur. This mechanism, curiously, does not appear to have been discussed in the literature to date. Orion?

Scale model testing remains an important element of development (and can be much more efficient than CFD for some tasks). Demonstrated safe conditions for TiME.

Review of Apollo flights (9 capsizes out of 19) indicated threshold horizontal speed, related to resurge timescale (Lorenz, IPPW-9 and JBIS 2012)