Apollo Splashdowns Reviewed
Influence of Cavity Resurge on Stability

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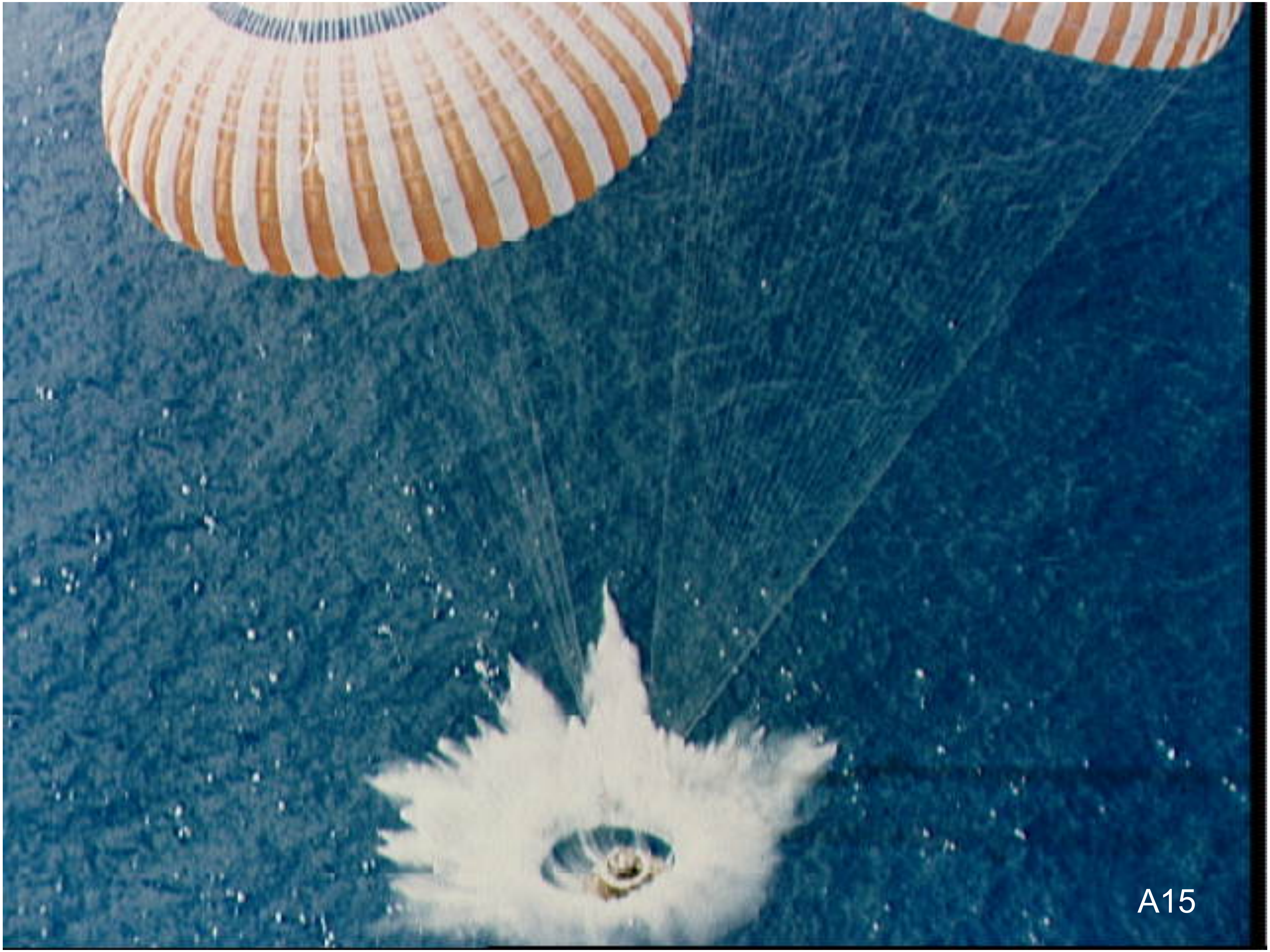
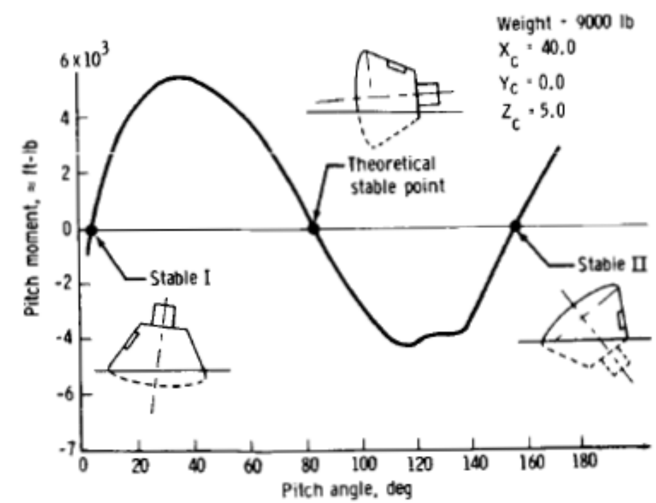
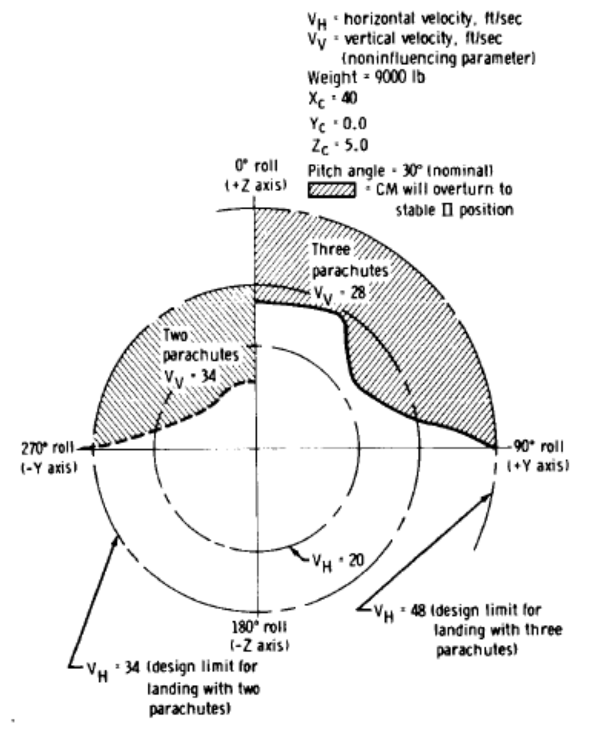
With thanks to Space Historian Daviid Harland, and filmmaker Stephen Slater


A15

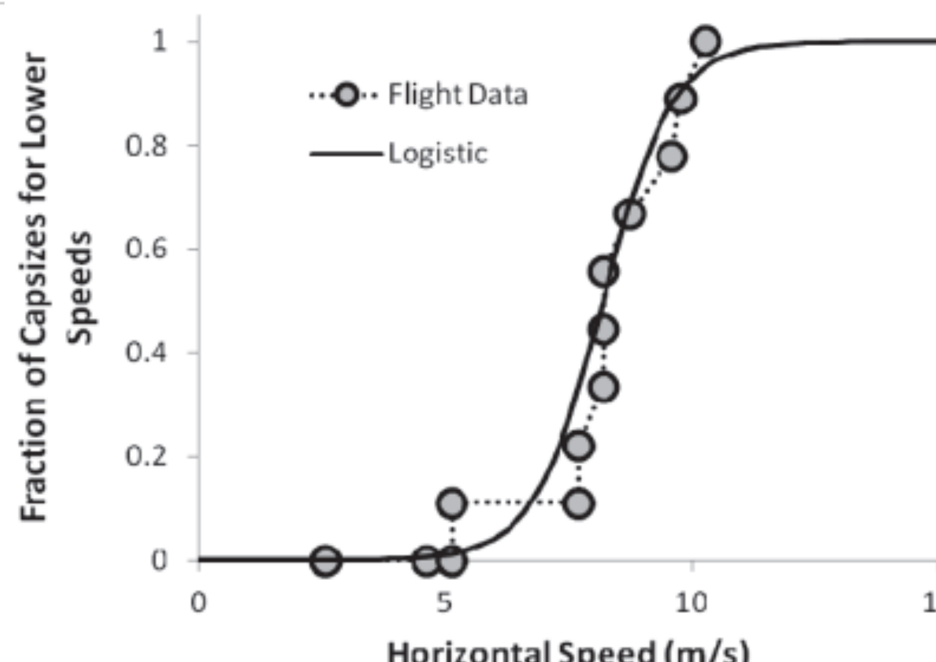

NAVY
53
A11


Weight - 9000 lb
X_c = 40.0
Y_c = 0.0
Z_c = 5.0
6 x 10^3
Pitch moment, = ft-lb
Theoretical stable point
Stable I
Stable II
Pitch angle, deg
0
20
40
60
80
100
120
140
160
180
4
2
0
-2
-4
-6
-7


A16


V_H = horizontal velocity, ft/sec
V_V = vertical velocity, ft/sec
(noninfluencing parameter)
Weight = 9000 lb
X_c = 40
Y_c = 0.0
Z_c = 5.0
Pitch angle = 30° (nominal)
= CM will overturn to stable II position
0° roll (+Z axis)
Three parachutes V_V = 28
Two parachutes V_V = 34
270° roll (-Y axis)
90° roll (+Y axis)
V_H = 20
180° roll (-Z axis)
V_H = 48 (design limit for landing with three parachutes)
V_H = 34 (design limit for landing with two parachutes)

	Wind (m/s)	Waves (m)	Capsize?	Time (mins) to Stable I	Weather from transcripts (Forecast unless otherwise noted) or from mission reports (Skylab, ASTP)
AS 201	5.1	0.3			recovery photo estimate
AS 202	7.7	0.6			recovery photo estimate
Apollo 4	7.7	1.2			Two reports 15kts, 4ft waves w/ 8ft swell. One report 17-25kts, 8ft waves
Apollo 6	10.3	1.8	Y	1	
Apollo 7	8.2	0.9	Y	12	
Apollo 8	9.8	1.8	Y	6	12 kts, waves 4ft (after says 19kts, 6ft swell)
Apollo 9	4.6	2.2			Light/variable, 2-3 ft
Apollo 10	2.6	0.9			12kts, waves 5ft
Apollo 11	8.2	0.9	Y	7.6	18kts, waves 3-6ft
Apollo 12	7.7	0.9	Y	4.5	15kts, 3ft waves w/ 6ft swell (Ortloff/Harland says 15ft swell)
Apollo 13	5.1	1.2			10kts, waves 4ft
Apollo 14	7.7	1.2			15kts, 2ft waves@2s period with 4ft waves@3s
Apollo 15	5.1	0.9			18kts, waves approaching 6ft. Then 15kts, 4ft. One chute failed
Apollo 16	5.1	1.2	Y	4.5	10kts, 3ft waves
Apollo 17	5.1	0.6			10kts, 3ft waves
Skylab	2.6	0.3			0.3m waves on 1.2m swell. 2.6m/s
Skylab	9.6	0.5	Y	5	0.5m waves. Wind 35 km/h
Skylab	8.2	0.6	Y	5	0.6m waves 2s period on 0.9m swell. 8.2 m/s
ASTP	8.7	1.1	Y	4.5	17kts. 1.1m waves



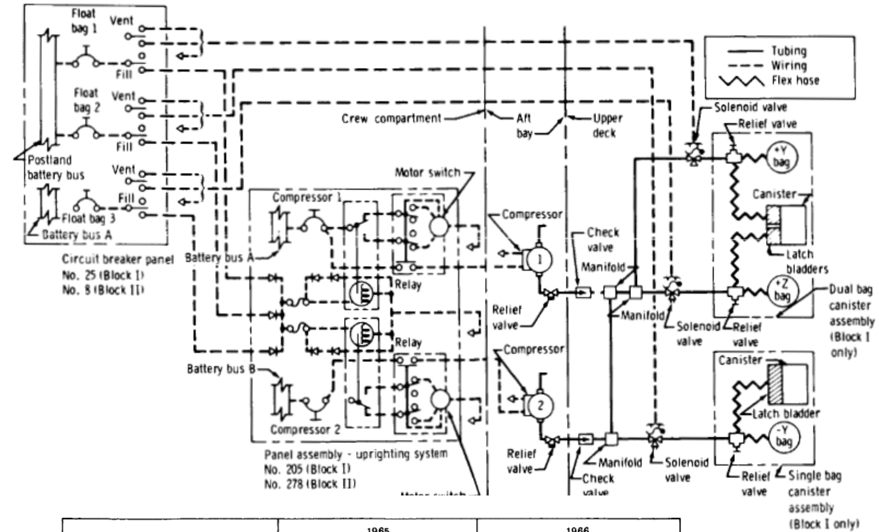
APOLLO EXPERIENCE REPORT - COMMAND MODULE UPRIGHTING SYSTEM

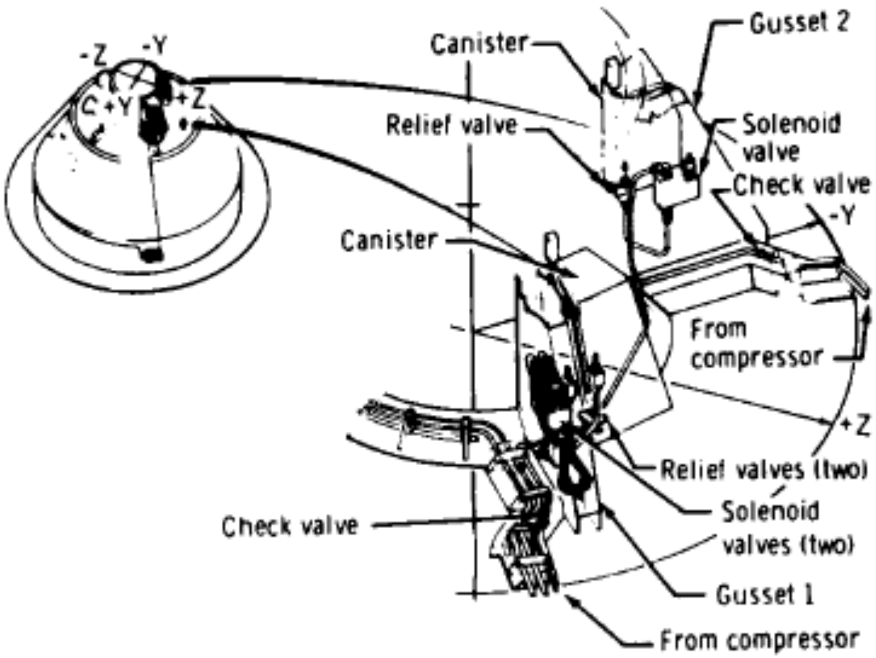
NASA TN D-7081

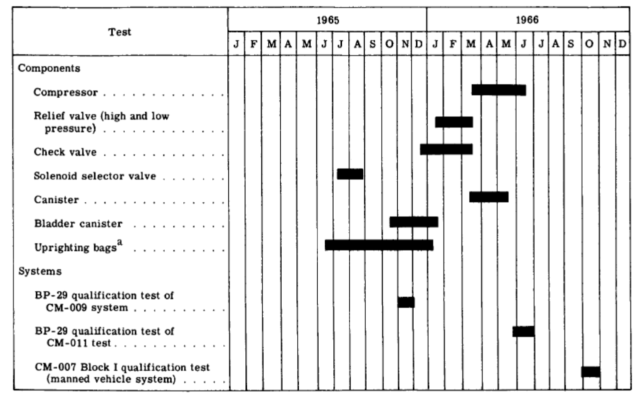
by Robert D. White

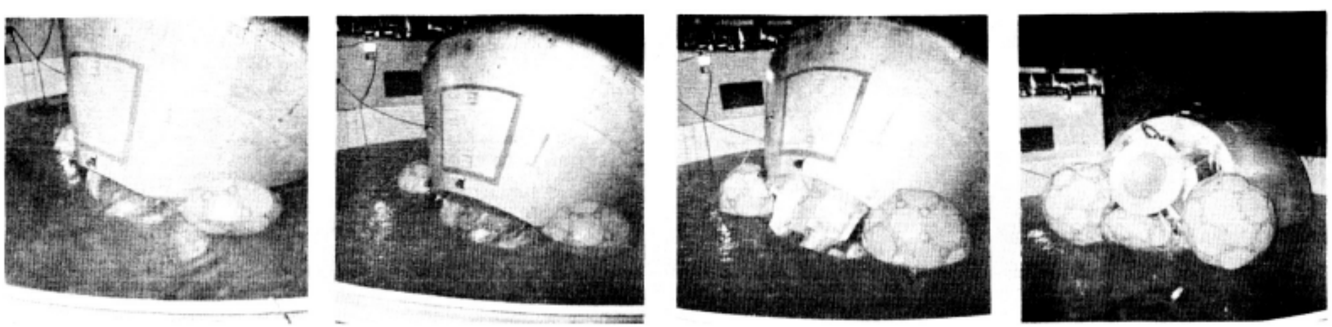
Manned Spacecraft Center

Houston, Texas 77058

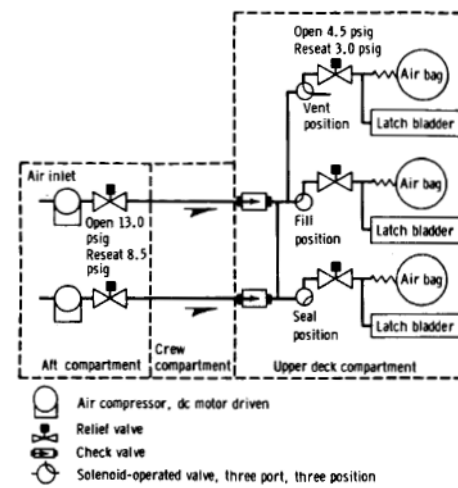




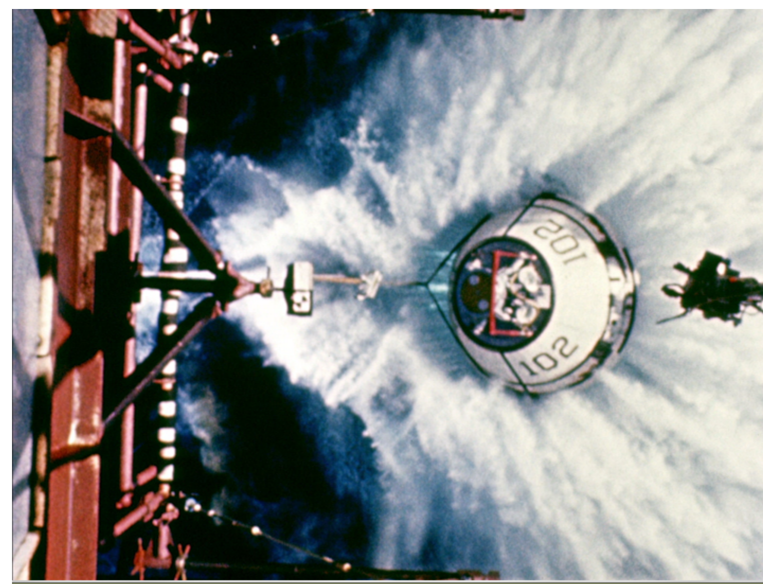


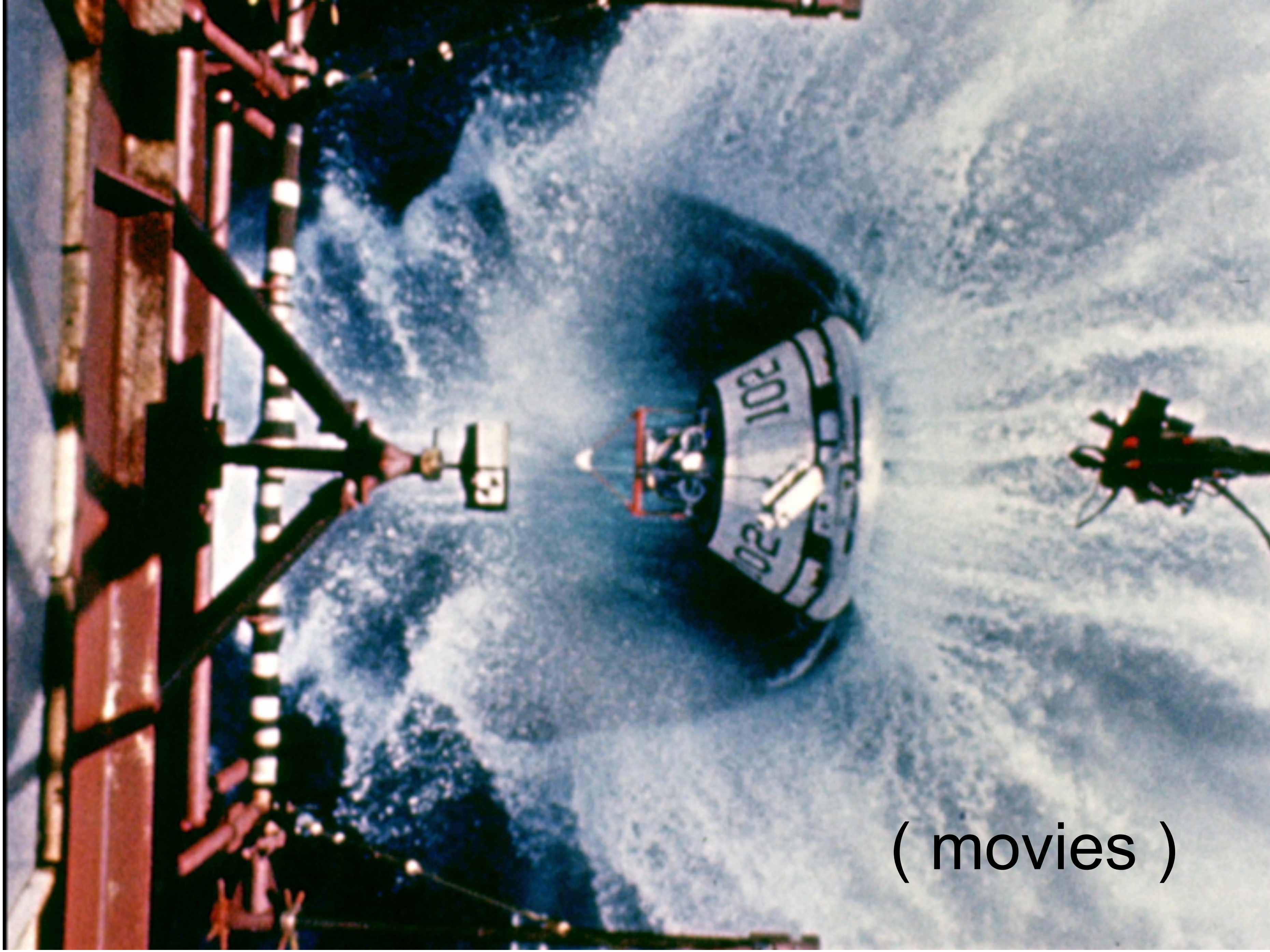


(a) Nominal uprighting (three-bag) in the tank.



Full-scale splashdown tests at North American Aviation





(movies)

DYNAMIC MODEL INVESTIGATION OF WATER PRESSURES AND ACCELERATIONS ENCOUNTERED DURING LANDINGS OF THE APOLLO SPACECRAFT

NASA TN D-3980

c.1

TECH LIB

by Sandy M. Stubbs

Langley Research Center

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1963-L-01954

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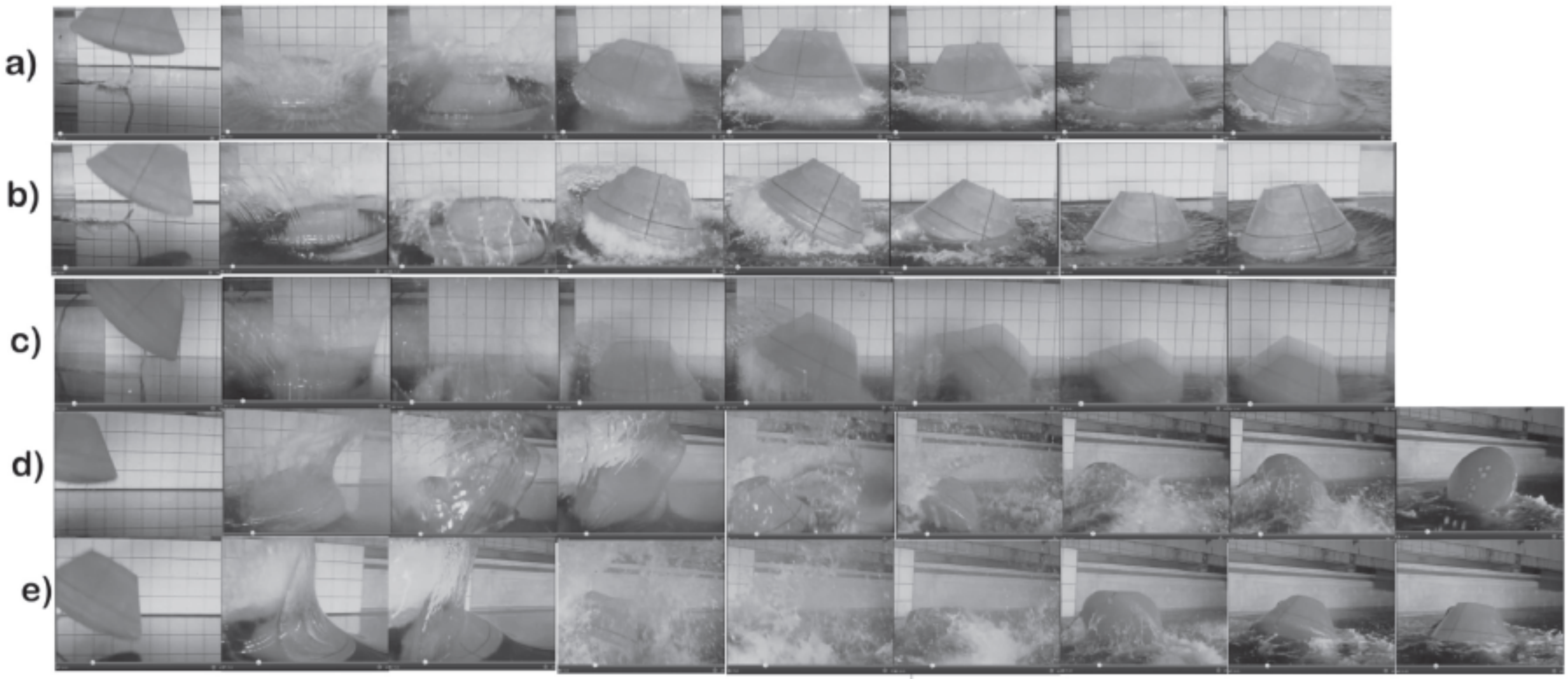
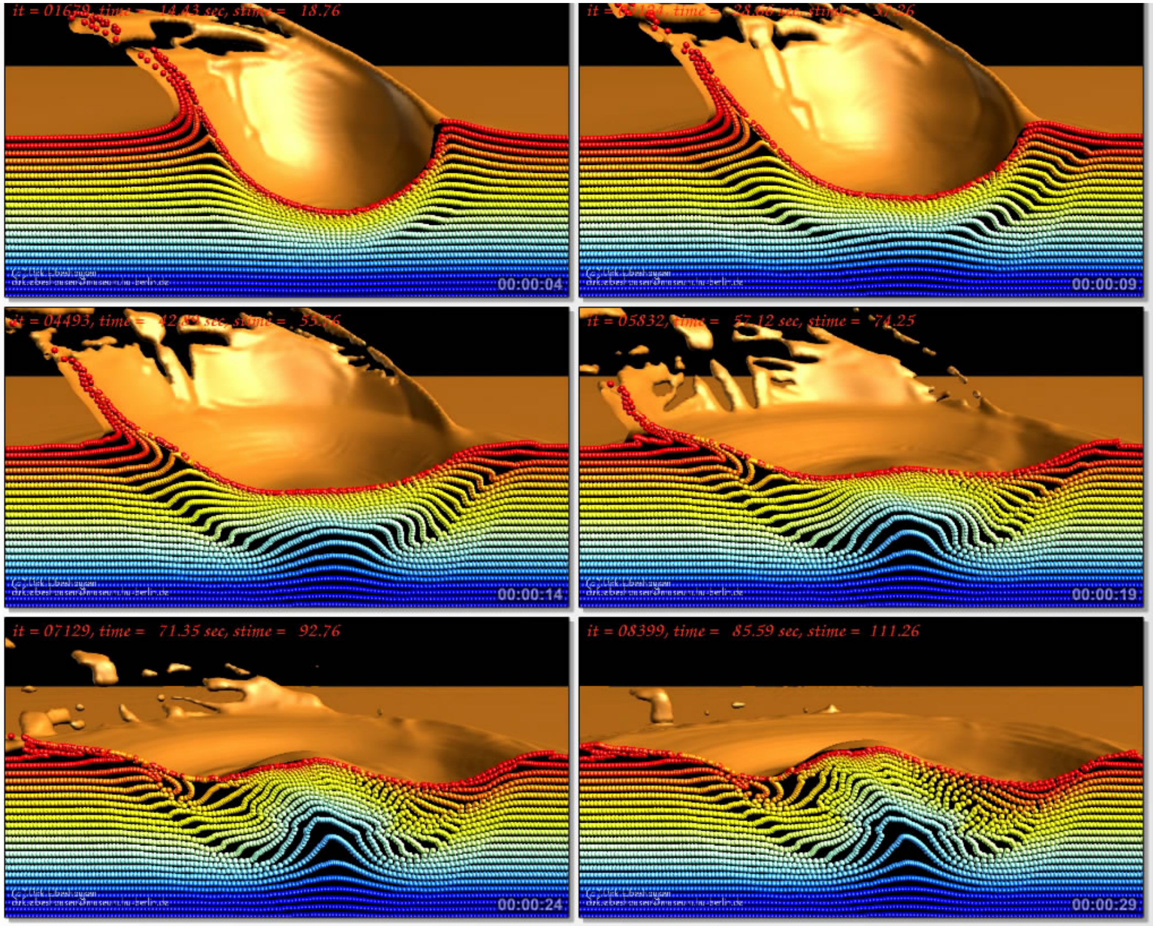
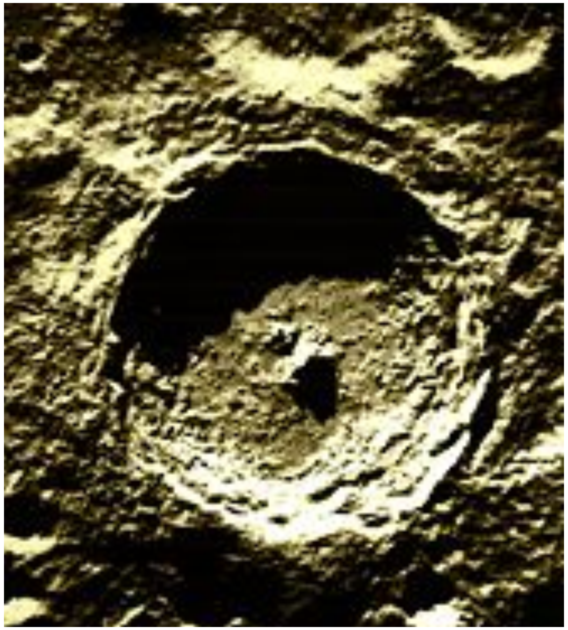
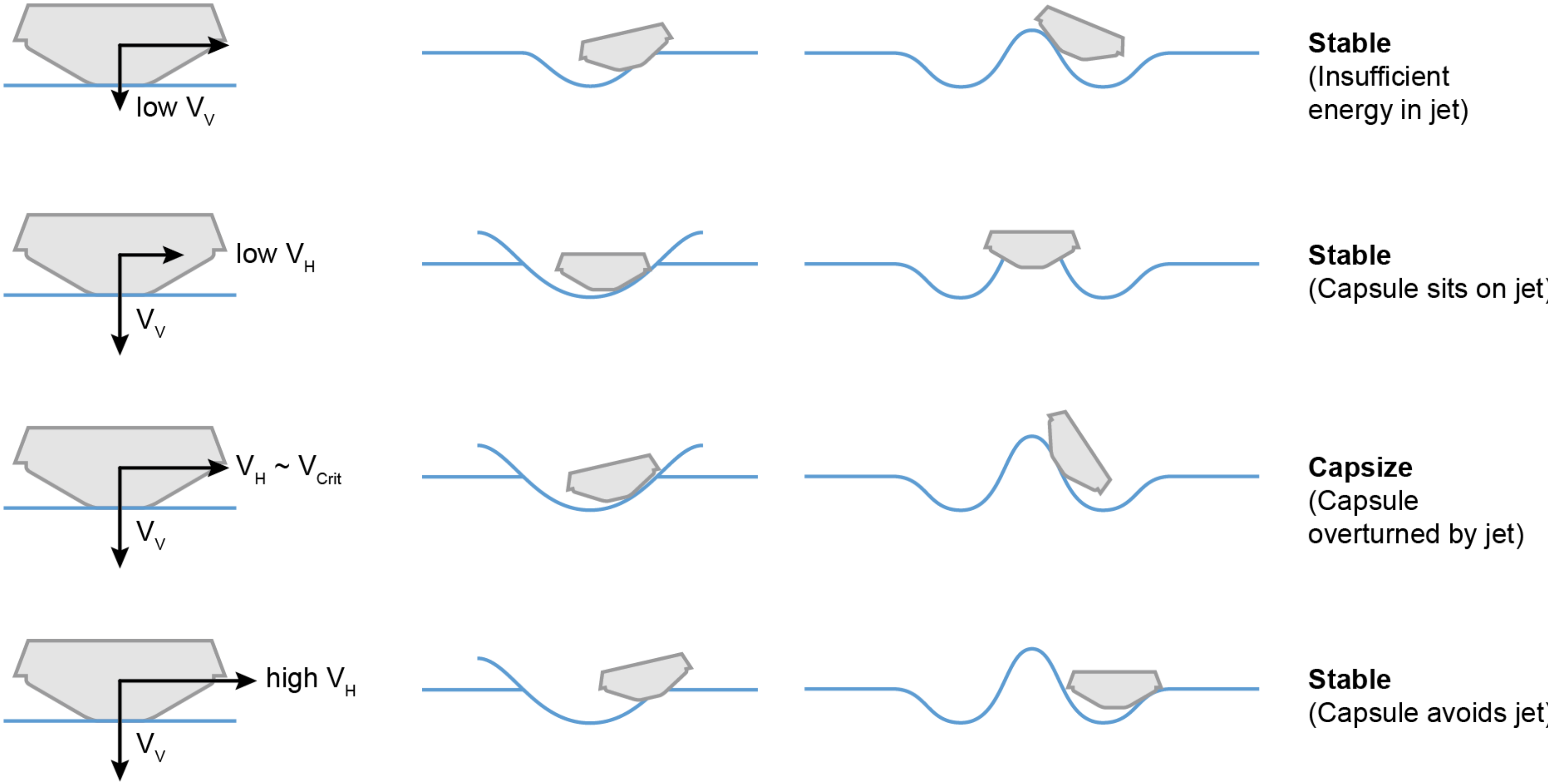

a)
b)
c)
d)
e)



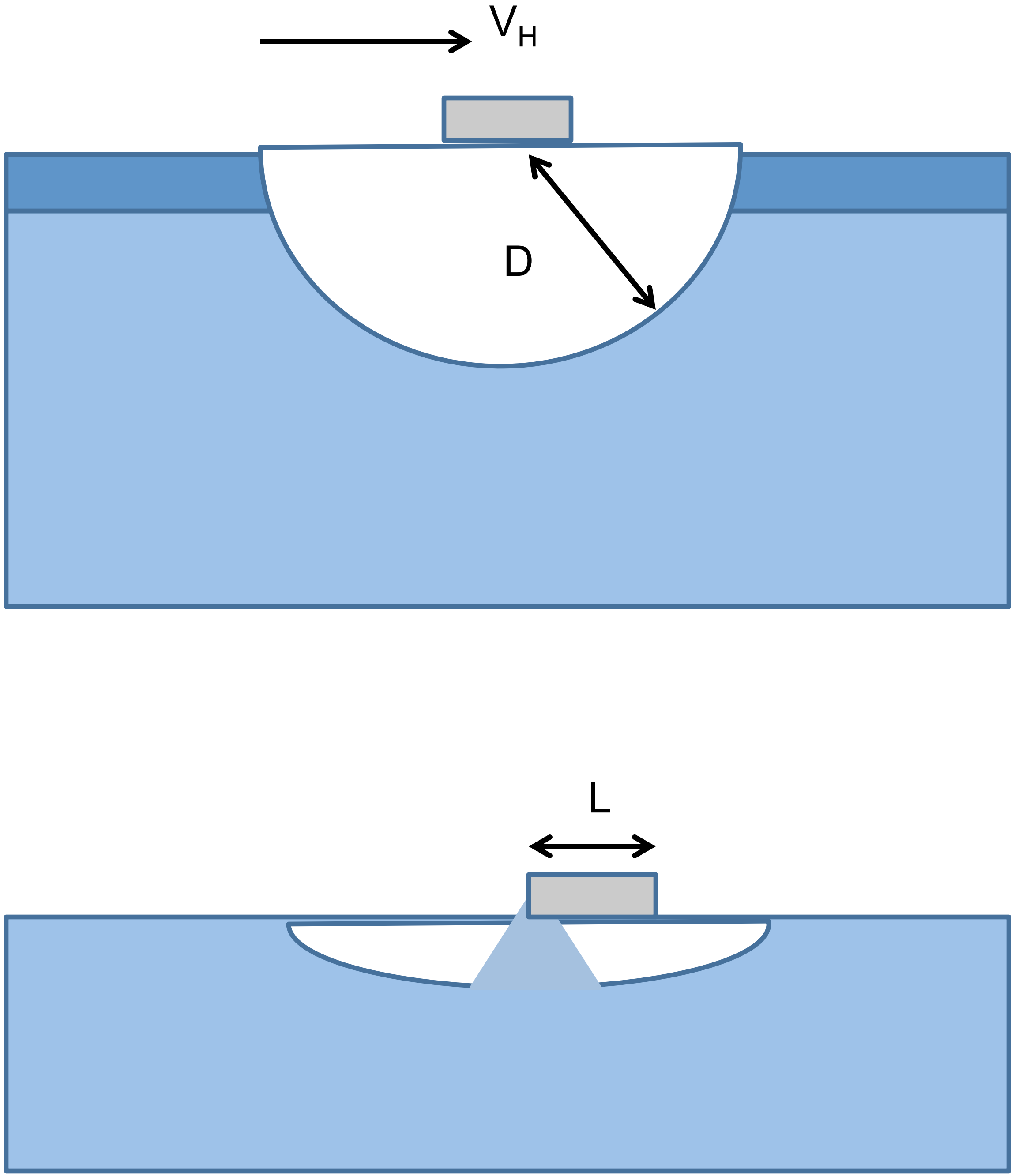
Resurge is well-known in impact cratering as the mechanism for central peak formation.





2 necessary conditions for capsize :

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

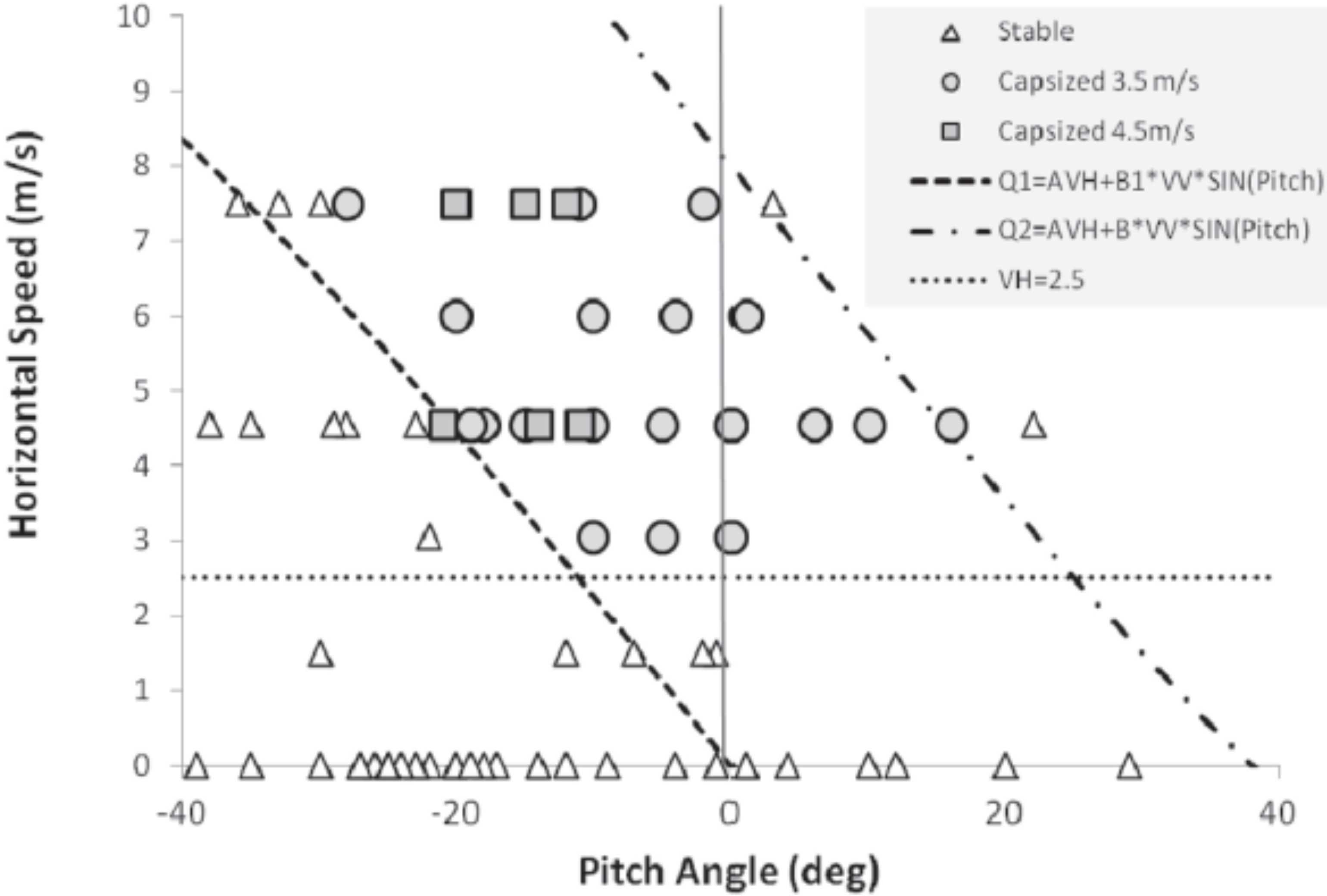


Resurge timescale
$t = 2(D/g)^{0.5}$

If average V_H applies, then critical velocity is $V_H \sim L/2t$

In reality some correction factor applies, since resurge is not impulsive, and horizontal velocity of vehicle changes throughout event. To fit a threshold speed V_t for full-scale Apollo of 5m/s we obtain

$$V_t \sim 0.65 L g^{5/8} \rho^{1/8} m^{-1/8} V_v^{-1/4}$$



Applying the formula $V_t \sim 0.65 L g^{5/8} \rho^{1/8} m^{-1/8} V_v^{-1/4}$ to ¼ scale Apollo, we find a threshold speed of 2.65 m/s, which agrees nicely with Stubbs' results. This formula can be applied to other vehicles, and other planets/liquids.

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.

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