Cover page for Invited paper for 2011 ASM Conference (Orlando)

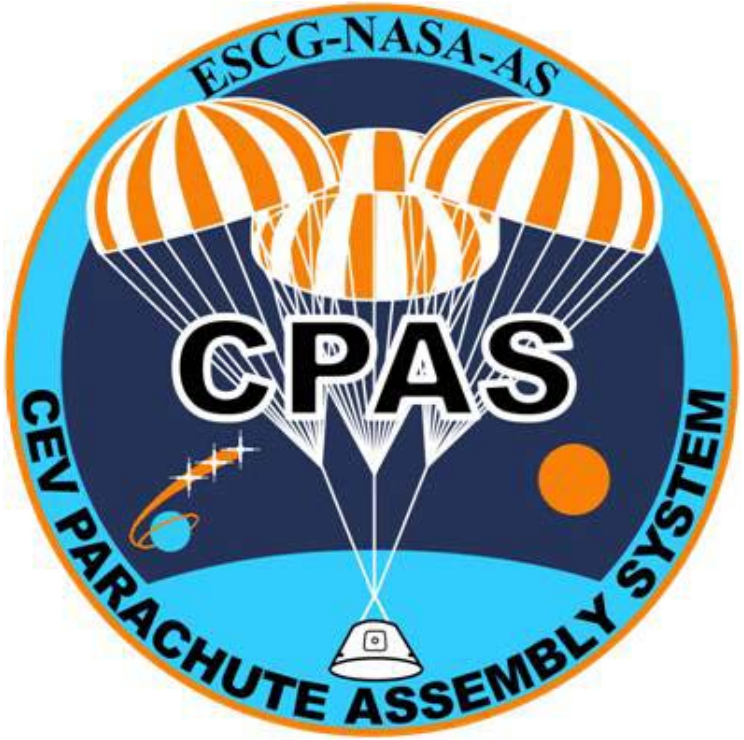
Special Session Organizer(s): Peggy S. Williams-Hayes and Catherine M. Bahm

Special Session Topic: Orion Pad Abort 1 Flight Test

The Parachute System Recovery of the Orion Pad Abort Test 1

The Orion Pad Abort Test 1 was conducted at the US Army White Sands Missile range in May 2010. The capsule was successfully recovered using the original design for the parachute recovery system, referred to as the CEV Parachute Assembly System (CPAS). The CPAS was designed to a set of requirements identified prior to the development of the PA-1 test; these requirements were not entirely consistent with the design of the PA-1 test. This presentation will describe the original CPAS design, how the system was modified to accommodate the PA-1 requirements, and what special analysis had to be performed to demonstrate positive margins for the CPAS. The presentation will also discuss the post test analysis and how it compares to the models that were used to design the system.

Pad Abort 1



CEV Parachute Assembly System

(CPAS)

What is CPAS?

- Crew Exploration Vehicle (CEV) Parachute Assembly System (CPAS) is a Government Furnished Equipment (GFE) project responsible for:
  - the design, development, fabrication, qualification, and delivery of the CEV parachute system to support the pad/ascent abort tests and the first three orbital flight tests (including first human flight)
- CPAS has two basic functions:
  - Drogues to decelerate and stabilize the vehicle
  - Mains to achieve the steady state landing velocity
    - Mains individually deployed by mortar deployed pilot parachutes
- First Order Drivers to the CPAS original (Generation 1) design
  - Drogue deploy maximum: dynamic pressure, altitude, and Mach number
    - 115 psf, 37,200 MSL, 0.6 Mach
  - Touchdown: landed weight, landing rate of descent, minimum deploy
    - 17,167 lbs crew module, less than 33 ft/sec std day sea level, pad abort deploy at no lower than 4,000 ft MSL and no greater than 50 psf for pilot mortar fire
  - Additional important drivers:
    - Two fault tolerance, allotted system mass (not to exceed 1,200 lbs), volume/shape parachute storage, environments (temperature, vibration)

CPAS PA-1 Implementation Summary

- The Orion Project decided early in the test planning process to use CPAS Gen-1 parachutes without design modifications specific to PA-1
  - Reefing schedule changes were made to the drogues, but this is considered a rigging change and not a design modification
  - This decision went beyond the design and hardware, it was applied to the associated documentation, acceptance testing, configuration management, etc.
    - FTO requirements were not flowed down to CPAS, with the exception of pyrotechnic requirements
  - Engineering and the Flight Test Office performed due diligence to maintain the integrity of this early decision
    - FTO reviewed the CPAS Gen 1 QA processes to ensure adequate configuration management
    - The configuration was documented by drawings, engineering orders, procedures, and parachute traveler notebooks
    - CPAS performed 15 drop tests of the Gen 1 components
    - CPAS performed confidence testing to validate tolerance to the predicted launch environment (thermal, vibration, and shock) and safe handling conditions for vulnerable components
    - CPAS provided FTO operating limits (attitudes, rates, and chute loads) which have been used as constraints to trajectory planning
    - CPAS complied with or formally waived the FTO pyrotechnic requirements

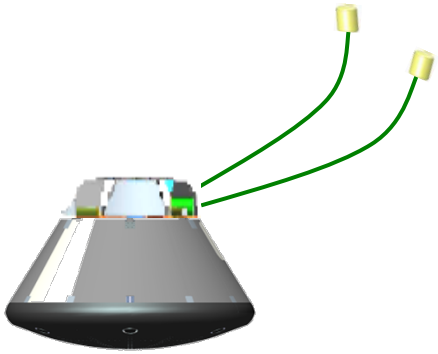
CPAS PA-1 System Overview

The Crew Exploration Vehicle (CEV) Parachute Assembly System (CPAS) project is responsible for providing the main CEV parachute system for the Pad Abort 1 test. The configuration is the Generation 1 architecture, not the latest flight architecture.

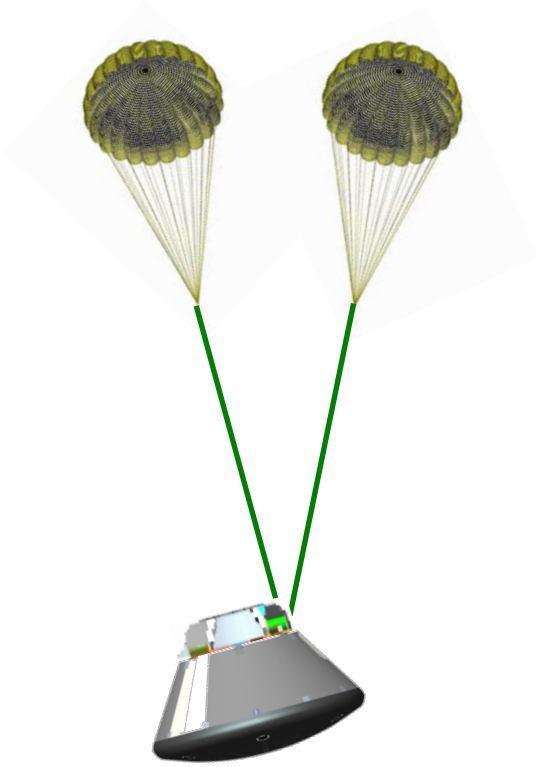
The CPAS PA-1 configuration consisted of:

- Two Variable Porosity Conical Ribbon drogue parachutes
- Three Ringslot pilot parachutes
- Three Quarter Spherical Ringsail main parachutes
- Supporting items such as a confluence fitting and confluence fitting tray, stowage bags, and harness lines
- Pyrotechnic mortars and main parachute reefing line cutters

CPAS PA-1 Deployment Sequence Drogue Parachutes



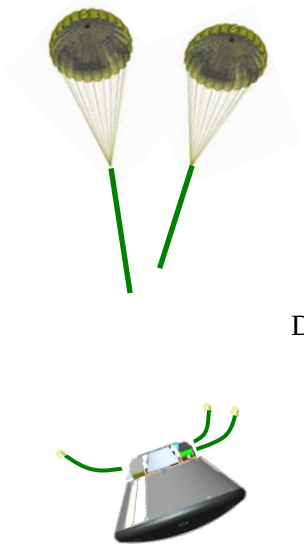
The CM avionics system sends a signal that fires the drogue mortars (takes place after Forward Bay Cover jettison)



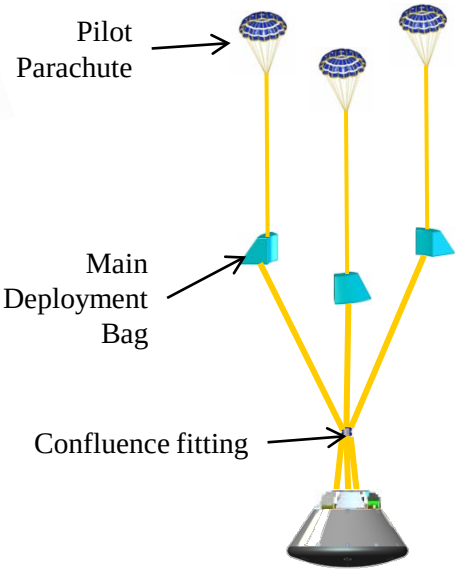
Drogue parachutes open directly to 80% reefing

Not to Scale

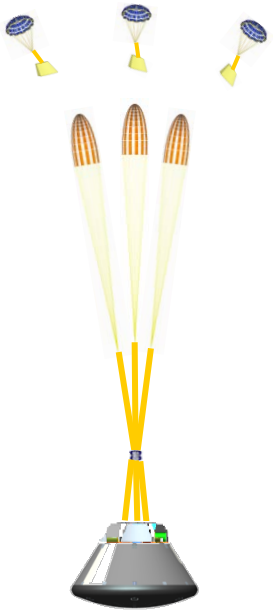
CPAS PA-1 Deployment Sequence Main Parachutes



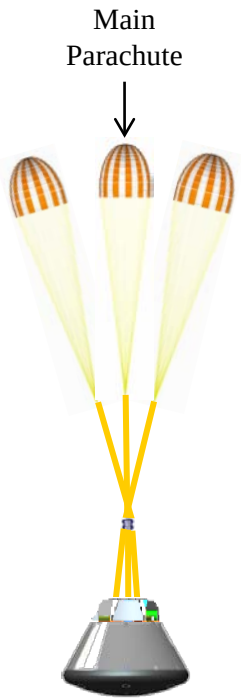
CM avionics command the drogue parachutes release from their attach fittings and fire the pilot mortars



The pilot parachutes open and extract the main deployment bags and the 3 to 3 confluence fitting.



The Main Parachutes extract from their deployment bags with 1st stage reefing of 2.5%



Eight seconds after line stretch, the Main Parachutes disreef to 2nd stage reefing of 10%

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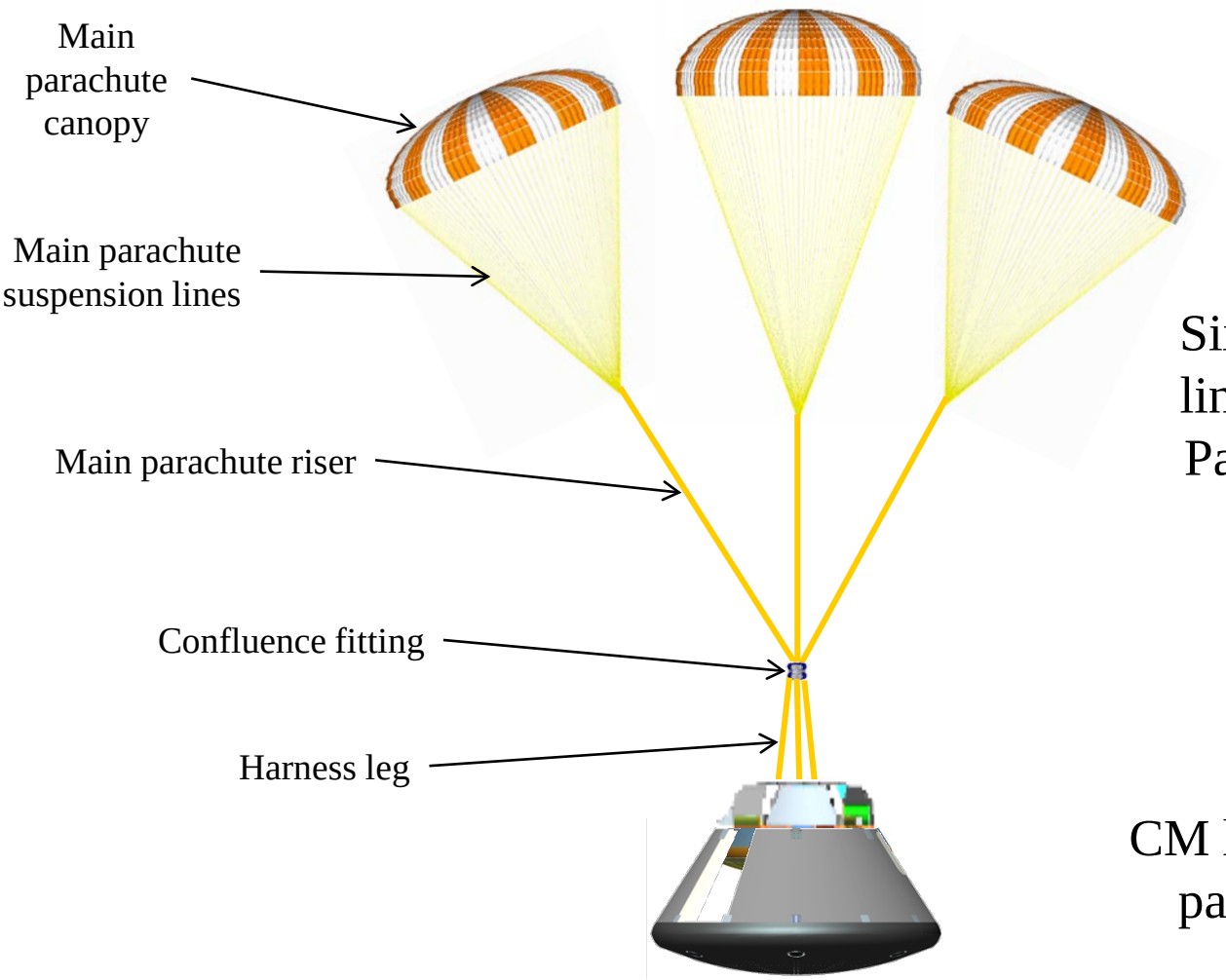
CPAS PA-1 Main Parachute Terminal Descent Phase



Sixteen seconds after line stretch, the Main Parachutes disreef to full open

CM lands under main parachute cluster

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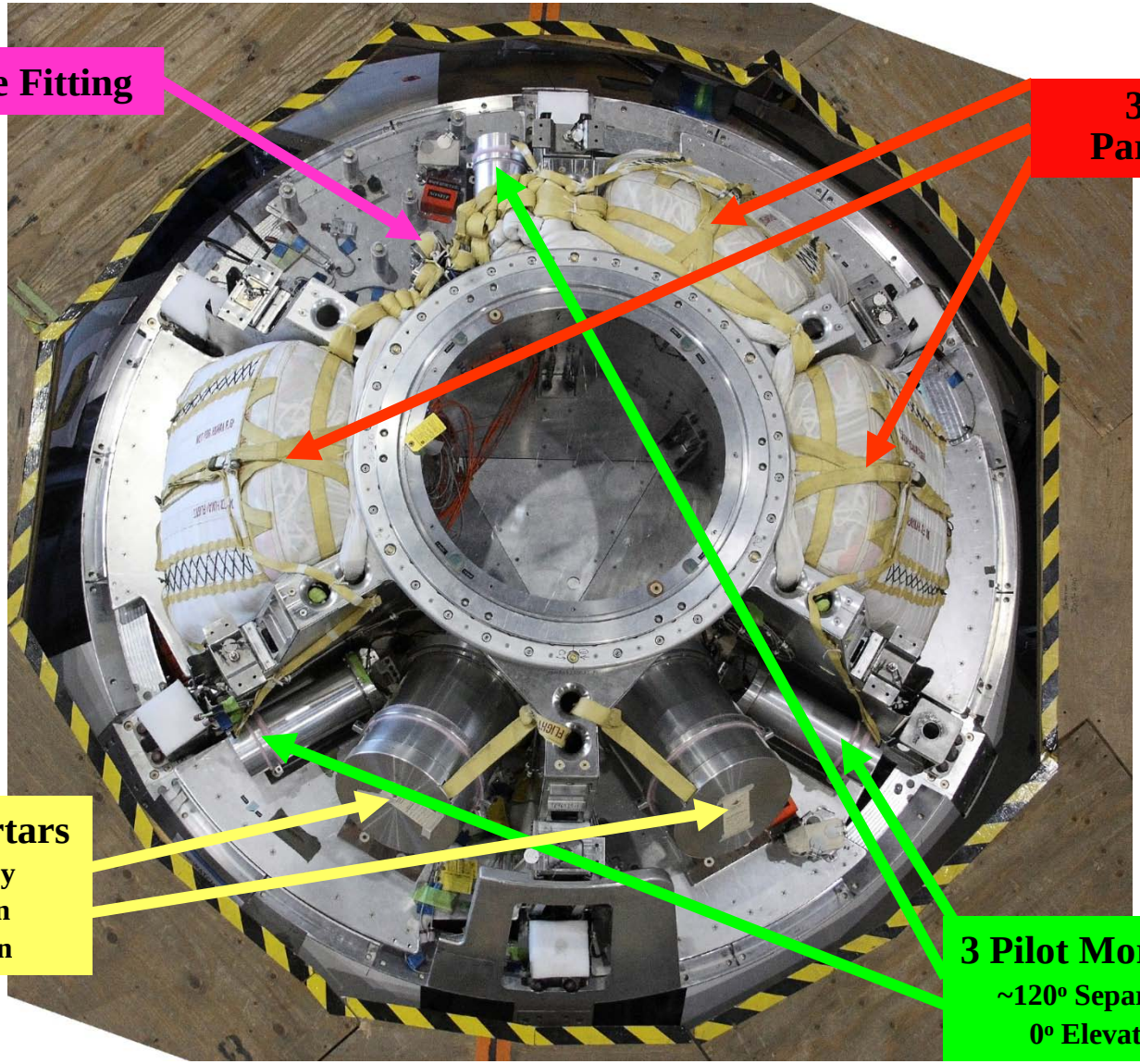
Forward Bay Compartment CPAS Layout



Secondary Structural Interfaces to Forward Bay Compartment

- Confluence Fitting retention
- Large and Small Harness / Riser Stowage Bags
  - Prevents dumping of harness and risers prior to main deployment
  - Includes a flap on bottom of Large Bag to prevent slumping

Confluence Fitting and Small Harness / Riser stowage bag

Main parachute deployment bag retention flaps (during Main installation)

Large Harness / Riser stowage bag (pilot mortar directly beneath the bag)

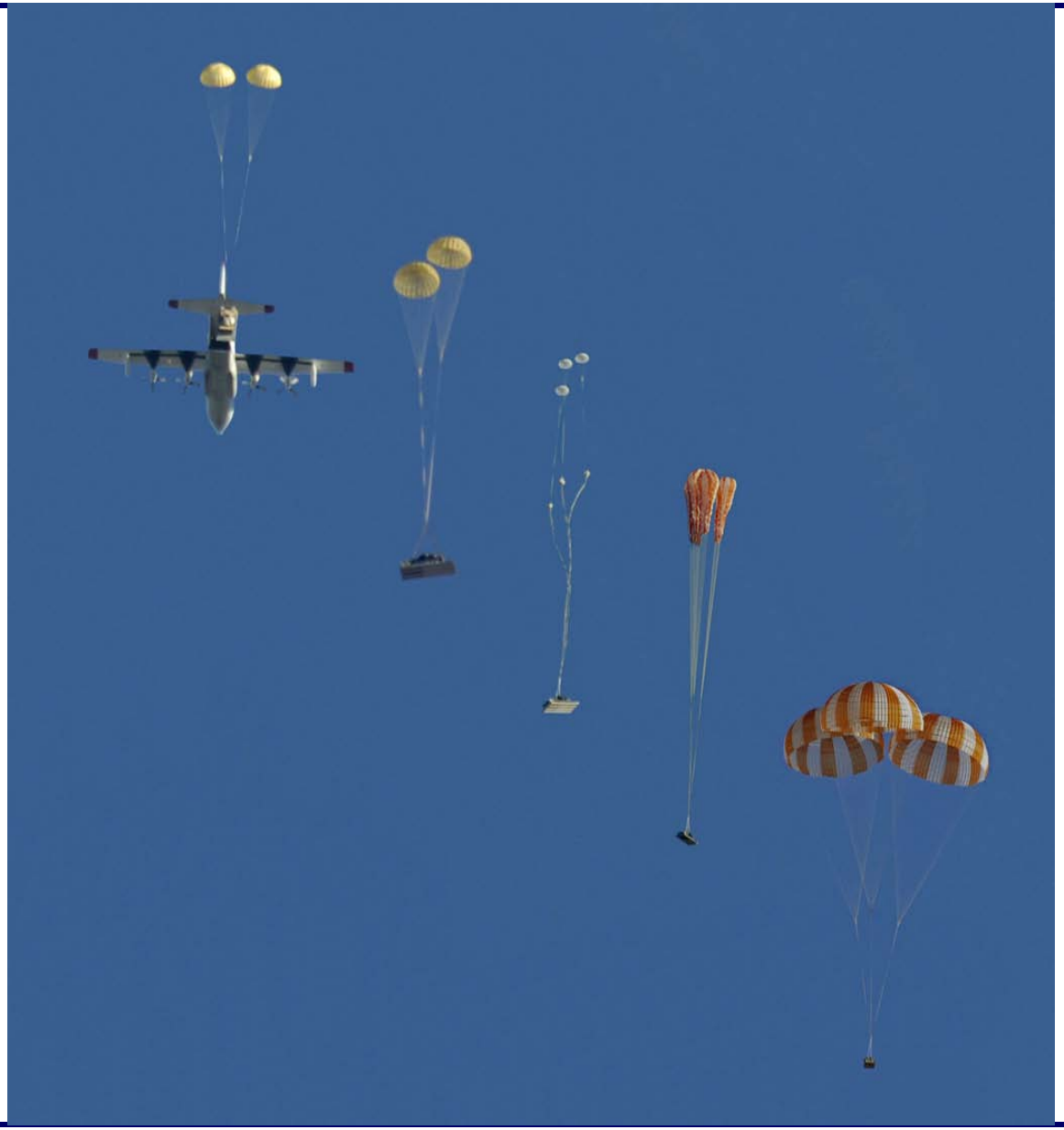
Generation 1 Parachute Development Drop Tests

Jan – Mar ‘07	Jun – Dec ‘07	Aug ‘07 – Jan ‘08	Oct ‘07 – Jul ‘08
4 Tests	3 Tests	3 Tests	3 Tests
Pilot Chute Tests	**Drogue Chute Tests**	**Single Main Chute Tests**	**Cluster Main Chute Tests**
Low q deploy Nominal q deploy High q deploy	Low q deploy Adjusted q deploy PA-1 like deploy	Nominal q deploy Alt reefing deploy 1st stage overload	Nominal q deploy Two main deploy PTV nominal deploy
All four tests successful. Inflation parameters refined.	All three tests successful. Inflation parameters refined. Reefing line lengths determined.	Performance parameters refined. Maximum dynamic pressure limit increased.	Nominal q main cluster of 2. Complete forward bay w/3 mortar deployed pilots deploying cluster 3 mains. Boiler plate test (PTV), the programmer parachute failed to deliver PTV on text condition.

Need better photograph

Need better photograph

Cluster Development Test - 1



CPAS Confidence Testing Overview

- A set of confidence tests were conducted on the CPAS mortars, reefing line cutters, and Confluence Fitting retention
  - Vibration testing of the confluence fitting and tray assembly was successfully
  - Auto-ignition testing was performed on reefing line cutters
  - The following mortar/gas generator test matrix was successfully completed

Group	A	B	C	D	E	F
Gas Generator (12 total)	1	1	1	2	6	1
Mortar Tube Assy (3 Total)	0	0	0	2	0	1
Test						
Workmanship, Paperwork Review	X	X	X	X	X	X
Weights	X	X	X	X	X	X
X-Ray	X	X	X	X	X	X
Auto-ignition	X					
8 ft Drop		X				
40 Ft Drop			X			
Thermal Cycling, Vibe, Shock				X	X	
Ambient Functional Firing				X		
GG Closed Bomb Firing	X	X			X	
85% GG Functional Firing						X

CPAS Design Constraints Summary

- CPAS provided FTO operating limits (attitudes, rates, and parachute loads) which were used as constraints to trajectory planning
  - Two trajectory models (DSS and Osiris) were run as a check and balance
- Additional analysis was performed as the trajectory design matured
  - First time use factors 'reclaimed' (fatigue, contamination, aging) in Margin of Safety analysis
  - Drogue parachutes were permanently reefed to 80% of full open drag area to decelerate the Crew Module sufficiently to assure not overloading the pilot and main parachutes
  - The drogue design limit load was recalculated using actual textile strength and seam & joint values in order to increase the design load limit
  - The dynamic pressure limit for the mains was increased from 60 to 80 psf based on the Gen-1 overload test reconstruction results
- The final PA-1 trajectory predictions (Version 1.7) met these constraints with the exception of the vehicle attitude at Pilot Mortar firing and Main Parachute load limits
  - The predicted range of attitudes at pilot mortar fire was not considered a risk to safely deploying the mains
  - The vehicle attitude at main line stretch met the requirement
  - Osiris was not validated for predicting the loads associated with deploying the confluence fitting, it was returning loads that exceeded the allowable for the main risers

Flight Reconstruction Results

- Need Daniel Matz's charts to show how his reconstruction of PA-1 CPAS performance fell within the uncertainties associated with our modeling memo
- Two charts should be adequate to capture how well they matched

Conclusions

- PA-1 Crew Module successfully recovered with CPAS Gen-1 system!
- Measured parachute system performance was within expected range
- Integration of an ‘as is design’ proved to be difficult with respect to the maturation of the abort trajectory design
- Limited development testing was sufficient to produce the required rigging procedures and parachute models for implementation in abort flight test

Homeward Bound