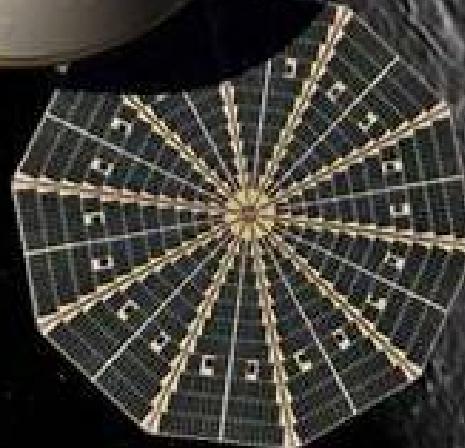




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Chief Engineer
Airborne Systems North America
Space Systems

An Status Report on the Parachute Development for NASA's next Manned Spacecraft





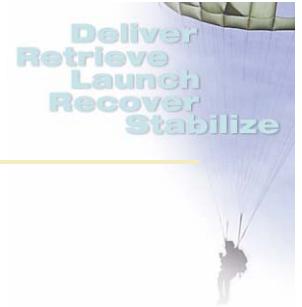
Introduction and Program Team



- NASA has determined that the parachute portion of the Landing System for the Crew Exploration Vehicle (CEV) will be Government Furnished Equipment (GFE)
- The Earth Landing System has been designated CEV Parachute Assembly System (CPAS)
- Thus a program team was developed consisting of NASA Johnson Space Center (JSC) and Jacobs Engineering through their Engineering and Science Contract Group (ESCG)
- Following a rigorous competitive phase, Airborne Systems North America was selected to provide the parachute design, testing and manufacturing role to support this team.
- The development program has begun with some early flight testing of a Generation 1 parachute system
- Future testing will continue to refine the design and complete a qualification phase prior to manned flight of the spacecraft
- The program team will also support early spacecraft system testing, including a Pad Abort Flight Test in the Fall of 2008

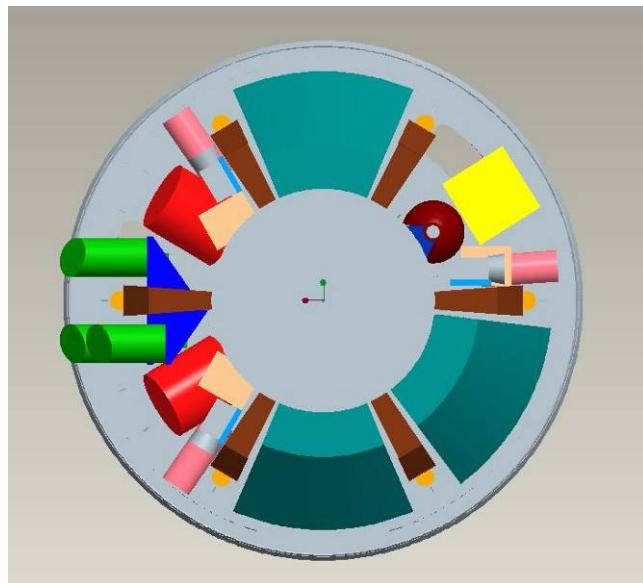


High Level Requirements



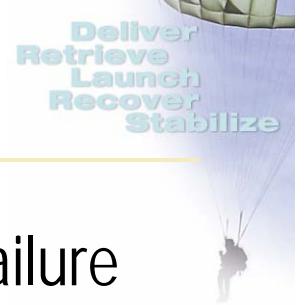
- The vehicle weight at drogue deploy is assumed to be 17,000 lbs
- The vehicle weight at touchdown is assumed to be 14,400 lbs.
- CPAS shall nominally deliver no greater than 26 ft/sec rate of descent and no greater than 33 ft/sec with one main failed using an air density of 0.00182526 sl/ft³ (representing a three sigma dispersed hot day at White Sands Missile Range).
- CPAS shall be two fault tolerant for catastrophic hazards and single fault tolerant for critical hazards, with the exception of elements approved to use Design for Minimum Risk criteria (such as confluence fittings).
- CPAS shall be capable of withstanding any single parachute skipping a reefing stage during deployment and still function properly.
- The load bearing elements of the CPAS shall be designed with a minimum factor of safety of 1.6, a factor of 2.0 is used on critical elements (such as reefing system, Riser and Vent Bands) and items not verified by testing.
- CPAS components shall be spaceflight and vacuum compatible with expected mission durations of up to 180 days.

Available Parachute Stowage



- Compartment is toroidal in nature
- Sectioned into six individual compartments due to spacecraft structure
- Unique shape provides challenges for parachute packaging
- Additionally, the individual main parachute stowage locations begin to dictate parachute sequence
 - Deploying each parachute with a pilot parachute becomes favorable due to the potential for geometric lock if all parachutes deploy together
 - Additional compartment details serve to further reinforce this decision

System Definition

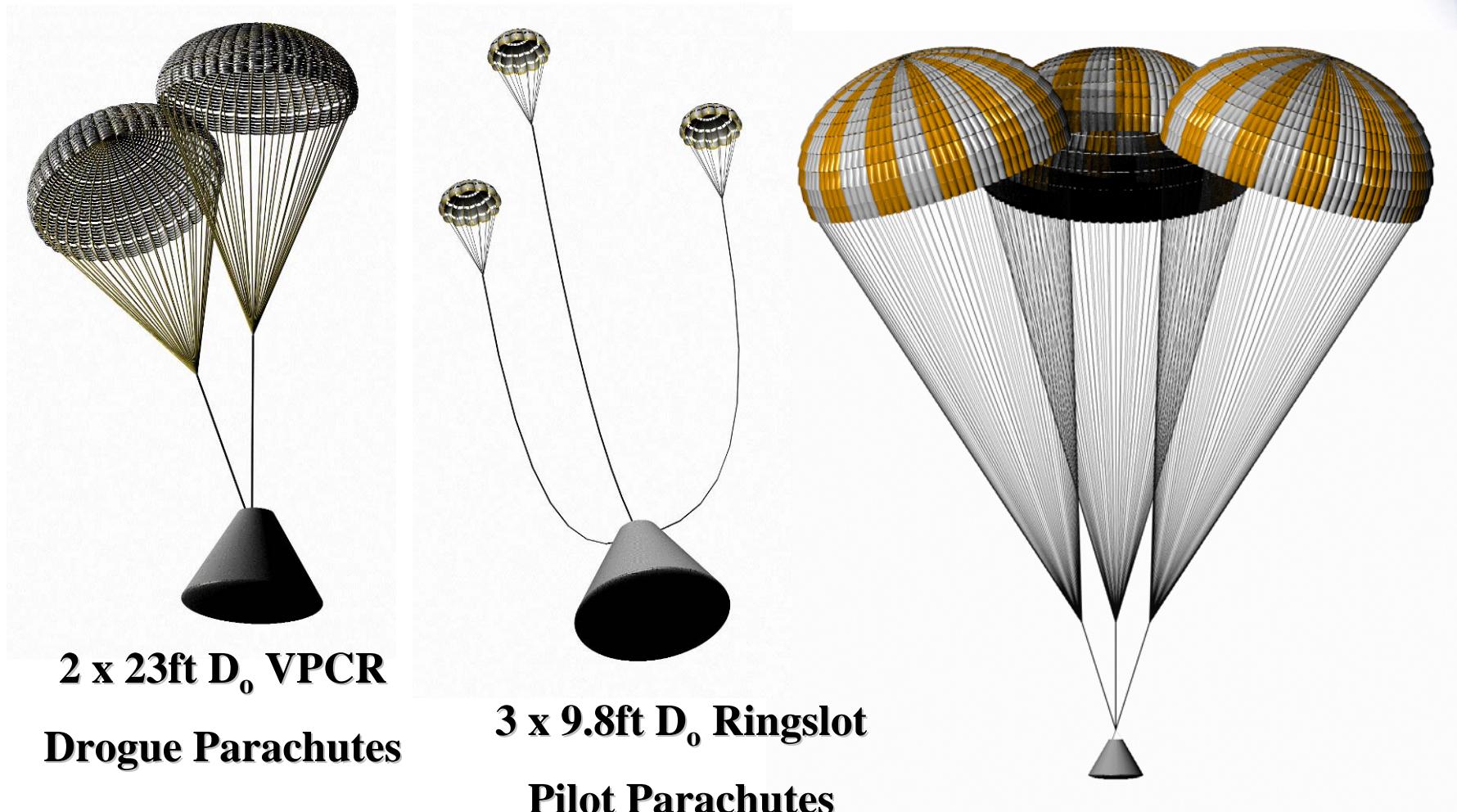


- Each Parachute Stage is designed for a single parachute failure
 - Philosophy is that 1 Drogue Parachute and 2 Main Parachutes are primary landing system
 - Additional drogue and Main are deployed in parallel to simplify parachute control (no fault detection required)
- Drogue Parachutes are initiated at an appropriate altitude and a Mach number less than 0.8
- Following Drogue parachute release, Pilot parachutes are mortar deployed and initiate Main parachute deployment
- Same deployment sequence – or possibly slightly modified – completes recovery from all abort modes, including Pad Abort



CPAS Parachute Elements

Deliver
Retrieve
Launch
Recover
Stabilize



2 x 23ft D_o VPCR

Drogue Parachutes

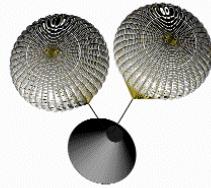
3 x 9.8ft D_o Ringslot

Pilot Parachutes

3 x 116 ft D_o Ringsail

Main Parachutes

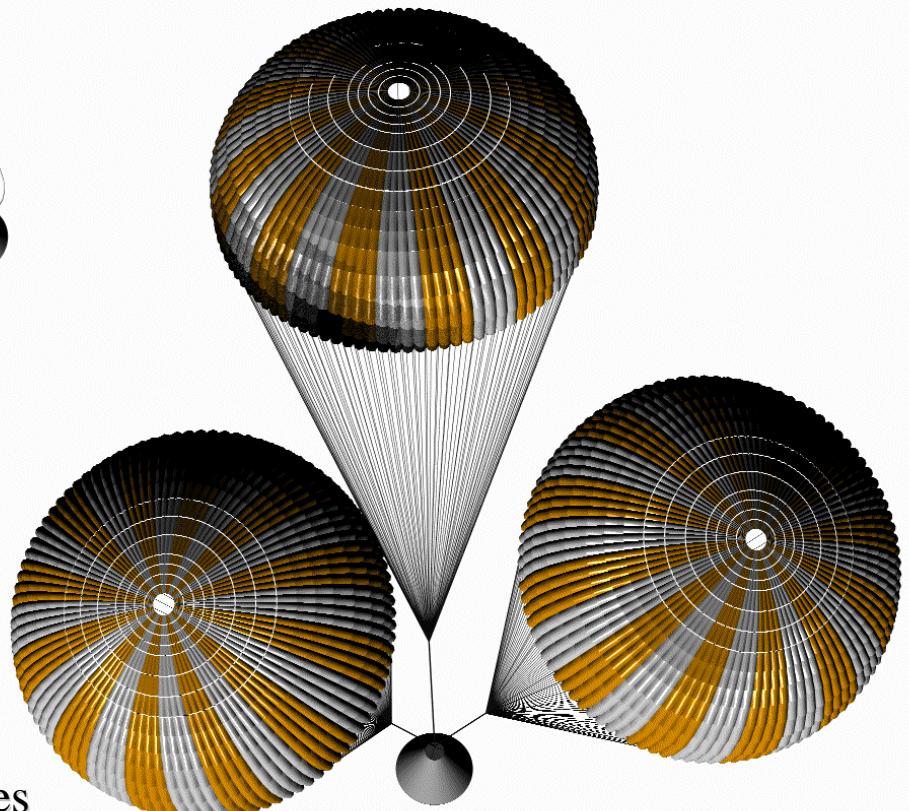
Nominal Recovery Sequence



2 x Drogues are mortar deployed
single stage of reefing



Drogues are released
3 x Pilot parachutes are
mortar deployed

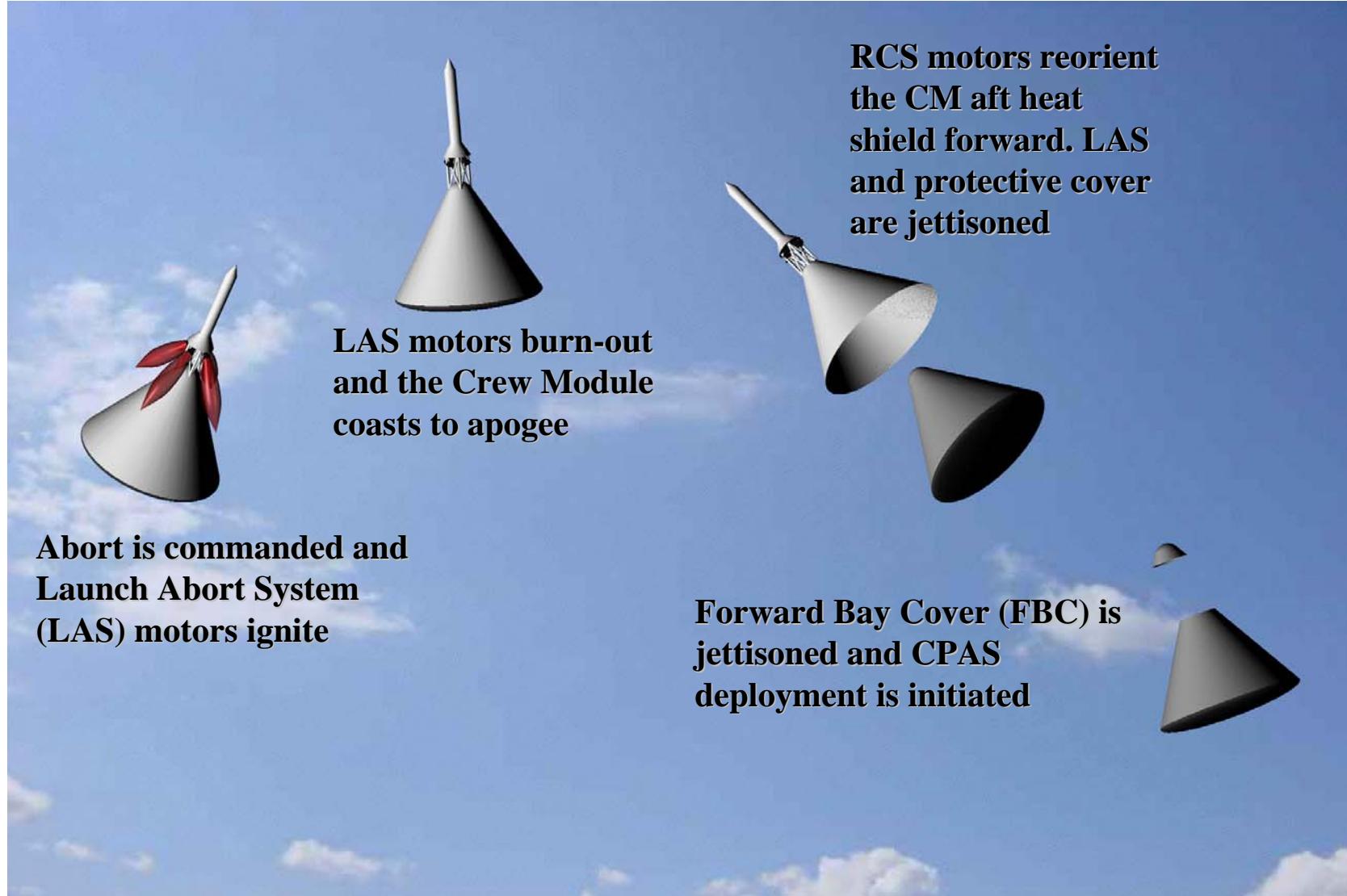


Pilot parachutes deploy 3 x
Main parachutes with 2 stages
of reefing

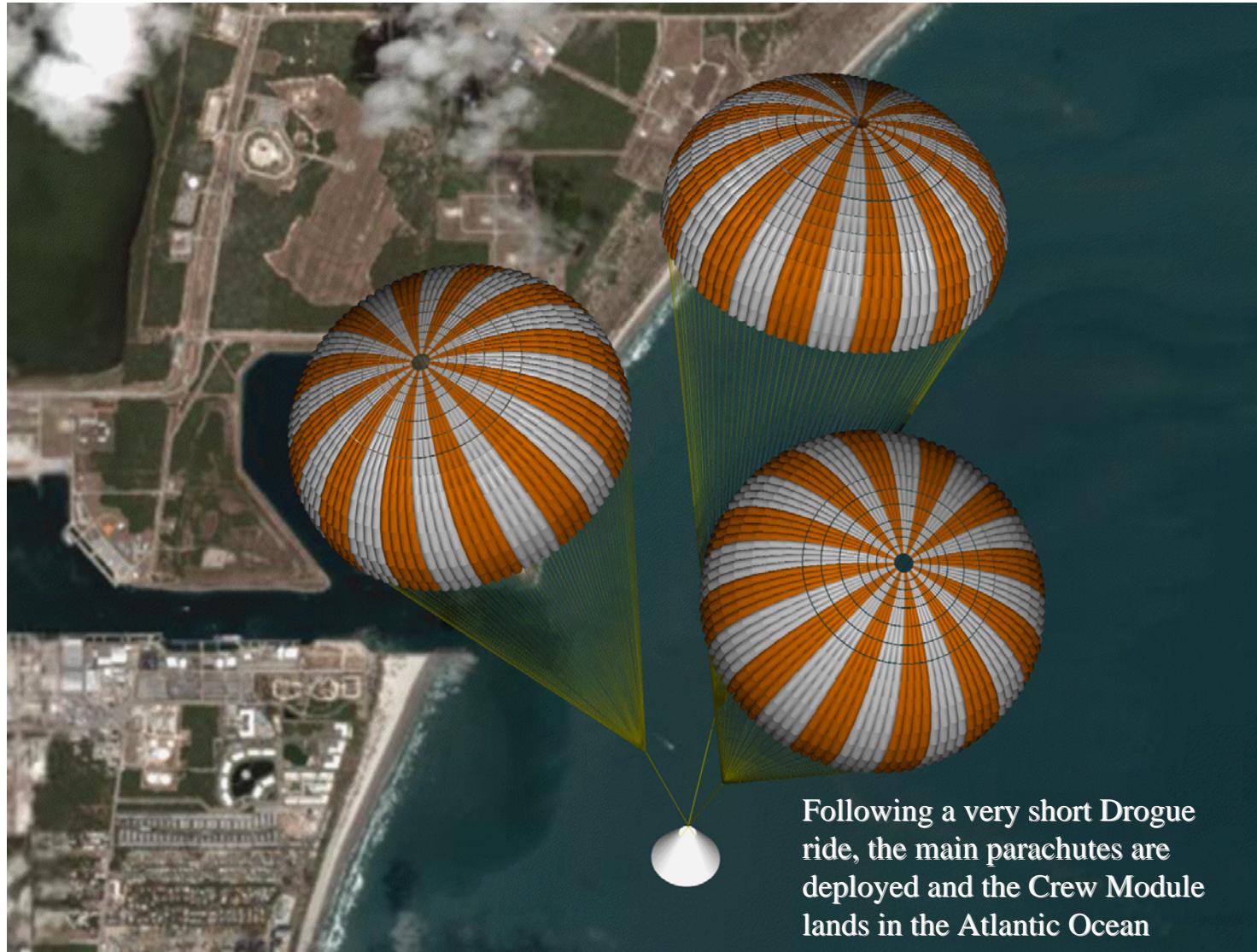


Pad Abort Recovery Sequence

Deliver
Retrieve
Launch
Recover
Stabilize



Pad Abort Sequence





Drogue Parachute Legacy

Deliver
Retrieve
Launch
Recover
Stabilize



Shuttle Landing Brake provides a Legacy of Manned Spaceflight and High Stability in the Parachute



F-16 Landing Brake retains Shuttle Aerodynamic Design and is directly related to CPAS Drogue Design – Brings 10s of Thousands of Parachute Deployments to design Heritage



Main Parachute Legacy

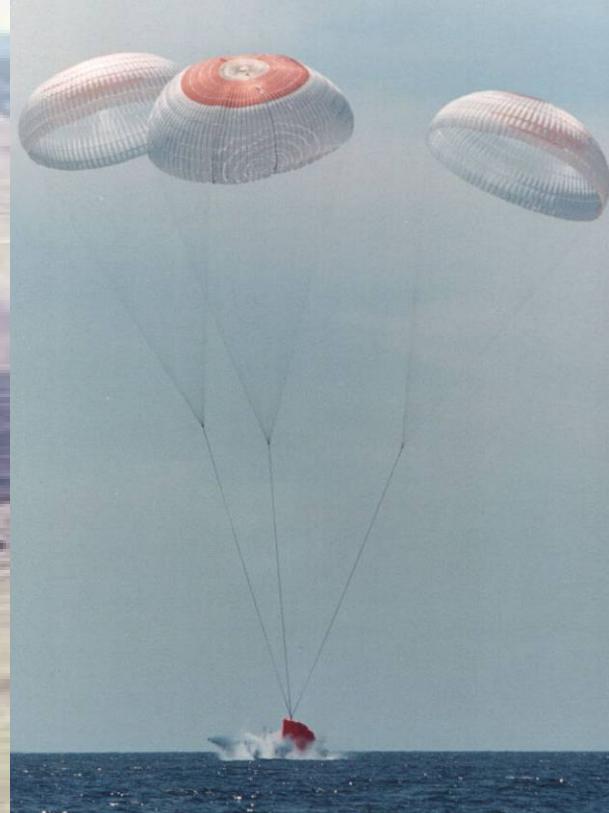
Deliver
Retrieve
Launch
Recover
Stabilize



F-111 CEM Upgrade Program

Circa 1988

85.6 ft Ringsail



Boeing EELV Demonstration

1996

3 x 136 ft Ringsails



LMA/NASA PAD Program

2003

4 x 156 ft Ringsails

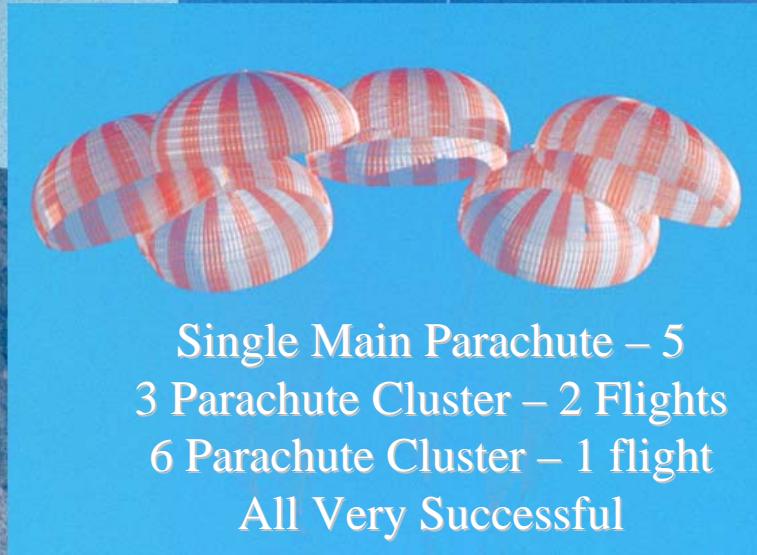


Main Parachute Legacy (2)

Deliver
Retrieve
Launch
Recover
Stabilize



Kistler Program Flight Testing
156 ft Ringsail Parachute
1997 to 1998



Single Main Parachute – 5
3 Parachute Cluster – 2 Flights
6 Parachute Cluster – 1 flight
All Very Successful



Parachute Test Program



- The program has been very successful in conducting tests on the following sub-systems
 - Mortars
 - Pilot Parachutes
 - Drogue Parachutes
 - Main Parachutes
 - Drogue Clusters
 - Main Clusters

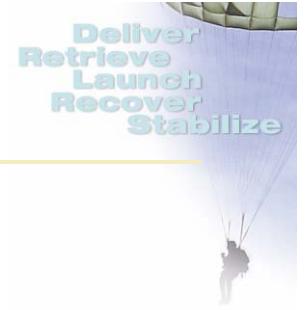
Mortar Development Tests

- Tested mortars to measure the following parameters
 - Reaction loads
 - Muzzle velocity





Pilot Parachute Development Testing

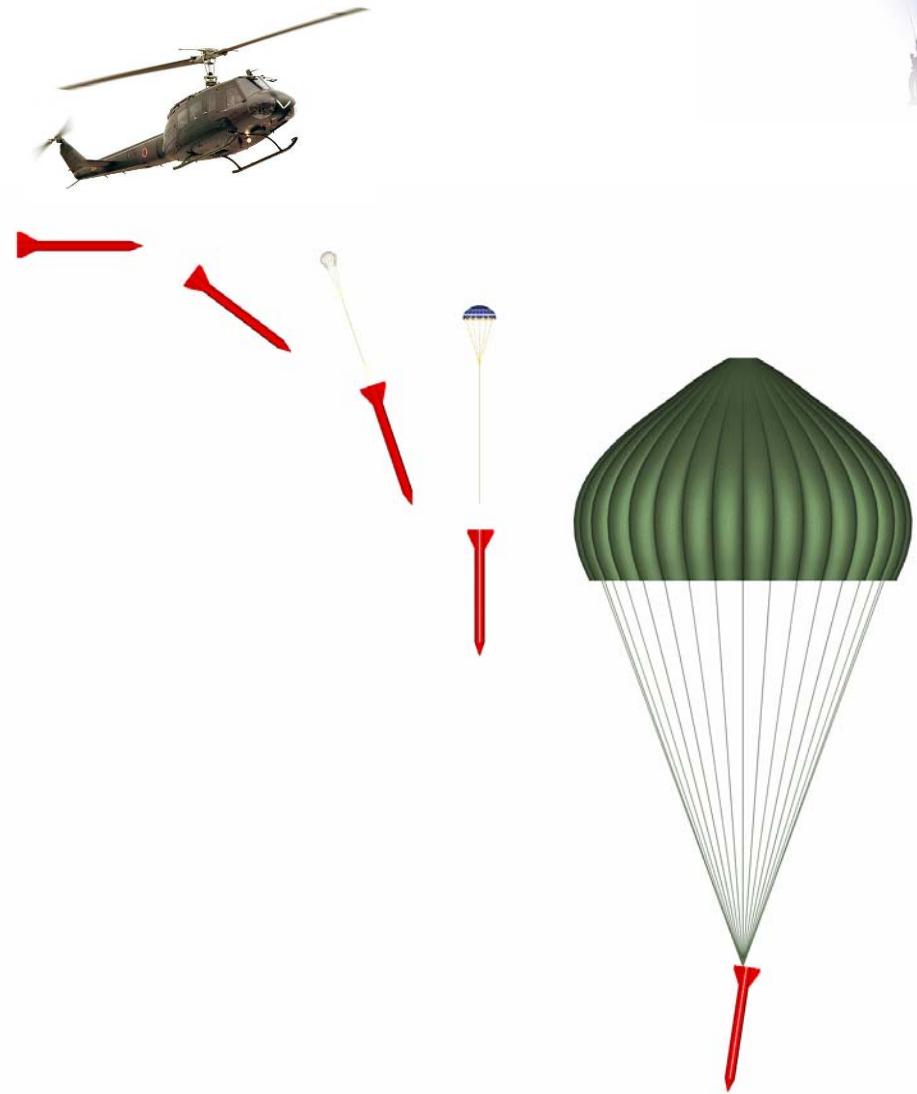


- Tested Pilot Parachutes to evaluate
 - Inflation profile
 - Filling distance
 - Drag Area time history
 - Structural capability
- Should be a simple flight test – Right?
 - Just drop from a helicopter and off we go!
- Actually no!
 - Need a parachute to set the airspeed for the test parachute
 - Then the test parachute deploys
 - Then we need to recover the test vehicle
 - We need our Lawn Dart, Sequencer and Instrumentation Back!
- Details on next slide show some of the intricate rigging
 - Multiple Cutters and Attachment points
- Video to follow will illustrate the multiple parachute sequence
- Lesson: It only gets more complicated going forward



Pilot Parachute Development Testing

Deliver
Retrieve
Launch
Recover
Stabilize





Pilot Parachute Development Testing

Deliver
Retrieve
Launch
Recover
Stabilize

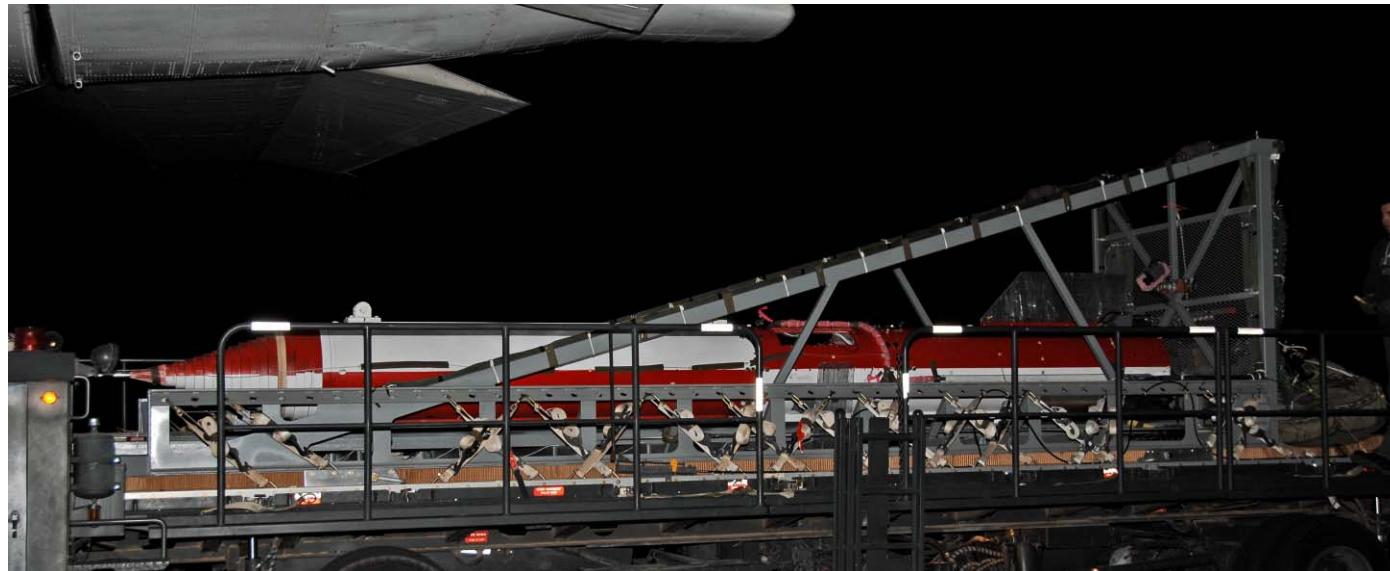




Drogue Parachute Development Testing



- First low q Drogue test was conducted from a CH-47 at relatively low altitude
- Higher dynamic pressures were required moving forward
- Altitude became prohibitive using rotary wing aircraft
- How do we get the lawn dart to an altitude that will give enough distance to accelerate to the right dynamic pressure?
- Roy Fox designed the solution
 - A carriage system that enabled a cylindrical test vehicle to interface with a cargo aircraft with a type V aerial delivery floor system





Drogue Parachute Development Testing

Deliver
Retrieve
Launch
Recover
Stabilize



View of First Drogue Parachute constructed for CEV



Release of Test Vehicle from cradle



Test Parachute Deployed

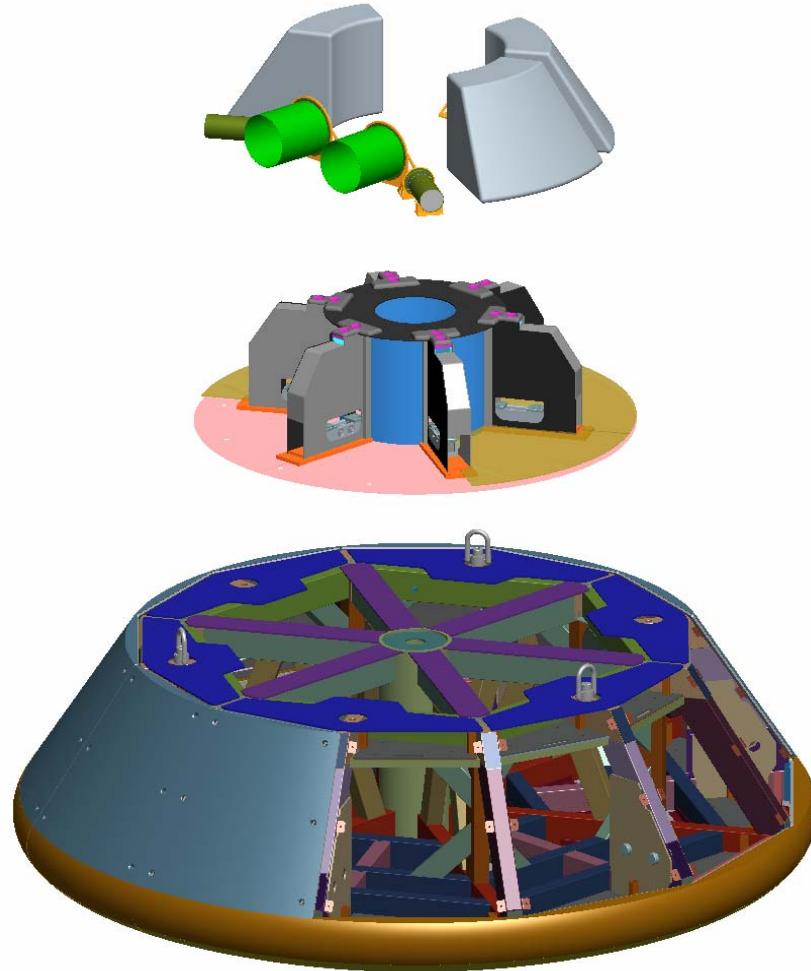


Drogue Parachute Development Testing

Deliver
Retrieve
Launch
Recover
Stabilize



Main Parachute Testing



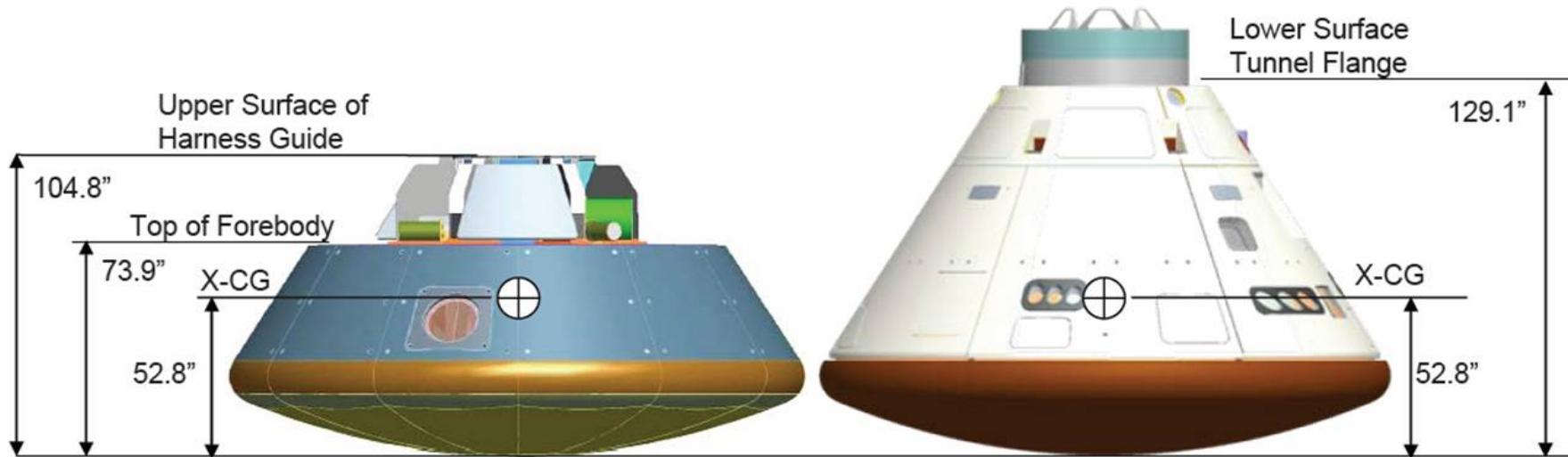
- Parachute to Spacecraft interfaces are rather complex, thus we are building detailed Drop Test Articles to mimic the true parachute deployment
- The Parachute Test Vehicle (PTV) mimics the capsule as much as possible, but truncates vertical height to allow delivery from military cargo aircraft
- Upper parachute compartment can also be installed on low fidelity weight tubs (mass simulators) to provide additional test opportunities





Parachute Test Vehicle and CEV Capsule

Deliver
Retrieve
Launch
Recover
Stabilize



Comparison shows difference between PTV and Actual Spacecraft

Truncations are designed to keep important features such as vehicle diameter and compromise on structure height, which is not possible in available delivery aircraft

Main Parachute Testing



- A number of single main parachute tests have been conducted
- Each Drogue test provides an opportunity to test the Main as a recovery chute for the Test Vehicle.
 - Stabilizer parachutes are used to control the line stretch Dynamic Pressure
- One cluster test has been conducted with a CEV upper deck mock-up mounted on a load tub.



Cluster Testing

- Cluster Development Test 1 conducted at Yuma Proving Grounds
- A cluster of 2 un-reefed CPAS Drogues were used to achieve the desired Main Parachute deployment conditions
- 3 x Pilot Parachutes were mortar deployed at Drogue release
- Pilot parachutes deployed the Main Parachutes

Cluster Testing

Deliver
Retrieve
Launch
Recover
Stabilize



Drogue Cluster

**Pilot
Parachute
Deployment**

**Reefed
Mains**

Main Parachute Cluster



Cluster Test CDT-1

Deliver
Retrieve
Launch
Recover
Stabilize



CPAS
Cluster Development Test
CDT-1