Orion’s
Capsule Parachute Assembly System
Overview

STMD ESI Parachute FSI Workshop

Brian Anderson
Koki Machin
Jessica Powell
Benjamin Kirk

2017
Capsule Parachute Assembly System (CPAS)

• CPAS is a Government Furnished Equipment (GFE) project responsible for: the design, development testing, performance modeling, fabrication, qualification, and delivery of the Orion Capsule parachute system to support the pad/ascent abort tests, and the first three space flight tests (including the first human flight, EM-2)

• CPAS has three basic operational phases
  – Mortar deployed Forward Bay Cover parachutes, to assist FBC separation
  – Mortar deployed drogues to decelerate and stabilize the capsule
  – Mains to achieve the steady state landing velocity and hang angle
    • Mains are individually deployed by mortar deployed pilot parachutes following drogue release, or possibly (low altitude abort) directly to mains (skipping drogues)

• First Order Drivers to CPAS design
  – Drogue deploy: dynamic pressure and Mach number (165 psf, 0.7)
  – Touchdown: landed vehicle weight (~20,000 lbs), landing rate of descent (<33 ft/sec std day sea level), minimum deploy altitude (~4,000 ft MSL during Pad Abort), maximum drogue deploy altitude (25,000 ft MSL)
  – Additional critical design drivers:
    • Crew Module (CM) attitude or horizontal velocity at touchdown
    • Fault tolerance, system mass (not to exceed 1,200 lbs), volume/shape for each parachute, environments (temperature, vibration), maximum load into structure, maximum torque to orient CM at touchdown (full open mains)
CPAS Main Components

- x3 Forward Bay Cover Parachutes (7’ Do, Conical Ribbon, 100% Kevlar, 8 lb. ea.)
- x2 Drogue Parachutes (23’ D₀, Conical Ribbon, Kevlar/Nylon, 80 lb. ea.)
- x3 Pilot Parachutes (9.85’ D₀, Conical Ribbon, Kevlar/Nylon, 11 lb. ea.)
- x3 Main Parachutes (116’ D₀, ⅛ Spherical Ringsail, Kevlar/Nylon, 310 lb. ea.)
CPAS Operations

Nominal Mission and High Altitude Abort Deployment Sequence
Low Altitude and Pad Abort Sequence (direct to mains)

FBCPs
Assist in extraction and separation of the FBC

Drogues
Provide drag for stabilization and deceleration of Crew Module and bring it within the pilot/main deployment envelope

1st Stage
2nd Stage

Pilots
Provide drag to deploy its respective main parachute from the Crew Module

1st Stage 2nd Stage

Mains
Provide drag for further stabilization, deceleration, and landing of the Crew Module

1st Stage 2nd Stage

System is designed to meet requirements with one of each type of parachute failed
Parachute Fabrication – Airborne Systems

Production of a EDU Main Canopy

Forward Bay Cover Parachute

Pilot Parachutes

Production of a EDU Main Canopy
CPAS Flight Hardware Configuration

Stowed Configuration

Drogue Parachute (Bay A)

Pilot Parachute (Bay A)

Main Parachute (Bay B)

Main Parachute (Bay C)

Pilot Parachute (Bay D)

Pilot Parachute (Bay F)

Drogue Parachute (Bay F)

Programmer Parachutes (Bay D)

Forward Bay Cover Parachutes not shown

(Zero Gusset / Fairlead)
CPAS EDU Full-Scale Test Vehicles

PCDTV
Parachute Compartment Drop Test Vehicle (our cylindrical test vehicle)

PTV
Parachute Test Vehicle (our boilerplate test vehicle)
https://www.youtube.com/watch?v=GYzH-qNcx0o
Parachute modeling is almost exclusively empirical
- Some predictions, like loads, torque, and terminal rate of descent, are physics based models anchored to test reconstructions
- Other aspects, like packing & integration, deployment, and inflation, are not modeled with enough confidence to verify with analysis alone

Parachute deployment is a dynamic, semi-chaotic event
- Many uncontrollable factors (atmospheric conditions, angle of attack, altitude, dynamic pressure, packing and routing variations, minor sequence differences, lead/lag, etc.) can independently or in combination affect the quality of the deployment
- Deployment can only be validated by repeated observation of airdrop tests with mortars and a representative parachute compartment
- Verifying performance in regimes where data is not available or cannot be collected should be avoided

The parachute system must assemble itself in midair at a wide variety of possible velocities and orientations
- For human spaceflight, deployment conditions vary widely due to vastly different pad abort, ascent abort, and nominal entry requirements

Imagery from CDT-3-7
Motivation: Apollo Experience

- Chuck Lowry, North American Rockwell Forward Bay Lead of Apollo Spacecraft, in a 3/30/12 email to CPAS:

“Dale Myers was PM of Apollo at Rockwell during most of the Program. He then was Assoc Administrator of Manned Flt at NASA 1970-1974. Later President of Jacobs and then Deputy Adm of NASA till 1989. He has seen it all. Early career was as aerodynamicist, but ended up a true technical and management giant in the biz. 3-4 years ago an interviewer asked him what Apollo System worried him the most as we launched men into space. Without hesitation he said it was the parachute system. Later, I asked him about his comment and he reaffirmed it – said he worried about all the things that could go wrong with them. This, after 147 drop tests!!”

Dale Myers
Risks for Loss of Vehicle on EM-1

CPAS is a top Orion LOV driver

Failure Probability
• **Apollo Program had 151 parachute drop tests in total**
  – 128 development (99 Block 1, 4 Block 2, 25 Block 2 Heavy)
  – 23 qualification (12 Block 1, 4 Block 2, 7 Block 2 Heavy)
• **Orion Program (CPAS) projected to have 44 drop tests in total**
  – 36 development (13 Gen1, 6 Gen2, 17 EDU) completed
    • Includes Orion PA-1 (Gen1) and EFT-1 (EDU) Flight Tests
  – 8 qualification tests
    • First qual test completed on 9/30/16

  – In addition, CPAS has also completed a significant number of ground tests including wind tunnel, mortar fire, riser abrasion, vibration, retention system/deployment bag strip, seam and joint, and packing
<table>
<thead>
<tr>
<th>Test Count</th>
<th>Date</th>
<th>Test ID</th>
<th>Test Vehicle</th>
<th>config</th>
<th>Delivery Technique</th>
<th>Test Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9/21/11</td>
<td>CDT-3-1</td>
<td>PCDTV1</td>
<td>2D3M</td>
<td>C-130</td>
<td>Nominal System, w/o wake, collect torque data.</td>
</tr>
<tr>
<td>2</td>
<td>12/20/11</td>
<td>CDT-3-2</td>
<td>PCDTV2</td>
<td>2D2M</td>
<td>C-130</td>
<td>Pilot mortar fails to fire (One Main Out), w/o wake, collect ROD data.</td>
</tr>
<tr>
<td>3</td>
<td>2/29/12</td>
<td>CDT-3-3</td>
<td>PTV1</td>
<td>2D3M</td>
<td>C-17</td>
<td>Nominal System, with wake, collect torque data.</td>
</tr>
<tr>
<td>4</td>
<td>4/17/12</td>
<td>CDT-3-4</td>
<td>PCDTV3</td>
<td>2D3M</td>
<td>C-130</td>
<td>Higher Q drogue deploy, one skipped 2nd stage main, w/o wake, torque data.</td>
</tr>
<tr>
<td>5</td>
<td>7/18/12</td>
<td>CDT-3-5</td>
<td>PTV2</td>
<td>2D3M</td>
<td>C-17</td>
<td>Nominal drogues, one skipped 1st stage main, with wake, collect torque data.</td>
</tr>
<tr>
<td>6</td>
<td>8/28/12</td>
<td>CDT 3-6</td>
<td>PCDTV4</td>
<td>2D3M</td>
<td>C-130</td>
<td>Maximum Q drogue deploy (i.e. nominal for Orion), w/o wake.</td>
</tr>
<tr>
<td>7</td>
<td>12/20/12</td>
<td>CDT 3-7</td>
<td>PTV3</td>
<td>1D3M</td>
<td>C-17</td>
<td>Drogue mortar fails to fire (one drogue out), nominal mains, with wake.</td>
</tr>
<tr>
<td>8</td>
<td>2/12/13</td>
<td>CDT 3-8</td>
<td>PCDTV 5</td>
<td>2D2M</td>
<td>C-130</td>
<td>3 FBCPs as programmer. Staggered drogue mortar firing, 1 drogue skipped 1st stage, both drogues skip 2nd stage. One main parachute fails after deployment (flagging main), w/o wake.</td>
</tr>
<tr>
<td>9</td>
<td>5/1/13</td>
<td>CDT 3-9</td>
<td>PTV4</td>
<td>1D3M</td>
<td>C-17</td>
<td>Single drogue programmer, Main Max Load - One drogue mortar fails to fire, one skipped 1st stage main, with wake.</td>
</tr>
<tr>
<td>10</td>
<td>7/24/13</td>
<td>CDT 3-11</td>
<td>PTV5</td>
<td>2D3M-</td>
<td>C-17</td>
<td>Two 70% drogue programmer, 2 drogues, updated main 2nd stage reefing, one main parachute skips 1st stage followed by steel riser failure (releases early) in 2nd stage, 35,000 ft extraction, LM PC.</td>
</tr>
<tr>
<td>11</td>
<td>1/16/14</td>
<td>CDT 3-10</td>
<td>PTV6</td>
<td>2D3M</td>
<td>C-17</td>
<td>Nominal system, with wake, with three forward bay cover parachutes and FBC, with wake, 25,000 ft extraction, 2 drogue programmer, 2 drogues, 3 mains, Steel Risers</td>
</tr>
<tr>
<td>12</td>
<td>2/26/14</td>
<td>CDT 3-12</td>
<td>PCDTV6</td>
<td>2D2M</td>
<td>C-17</td>
<td>35,000 ft extraction, 3 FBCP as programmer, Maximum Q drogue deploy (i.e. nominal for Orion), 2 drogues, 2 mains.</td>
</tr>
<tr>
<td>13</td>
<td>4/23/14</td>
<td>CDT 3-13</td>
<td>PTV7</td>
<td>0D3M</td>
<td>C-17</td>
<td>Straight to 3 mains deploy (pad abort), shallow gamma main deploy, 2 prog, no drogues, Textile Risers.</td>
</tr>
<tr>
<td>14</td>
<td>6/25/14</td>
<td>CDT 3-14</td>
<td>PTV8</td>
<td>2D3M</td>
<td>C-17</td>
<td>LM PC, 2 drogues, 3 FBCPs mortar deployed &amp; three FBC thrusters w/Qual FBC, with wake, higher q, 35,000 ft, Steel Risers, 1 main skips second stage.</td>
</tr>
<tr>
<td>15</td>
<td>12/18/14</td>
<td>CDT 3-15</td>
<td>PTV9</td>
<td>2D2M</td>
<td>C-17</td>
<td>2 drogues w/textile riser mods, 2 mains w/textile riser mods, reduced riser length, and OICL, improved pilot bridle, bag handle energy modulator, 25,000 ft.</td>
</tr>
<tr>
<td>16</td>
<td>8/26/15</td>
<td>CDT 3-16</td>
<td>PTV10</td>
<td>1D2M</td>
<td>C-17</td>
<td>2 mortar deployed FBCPs, 1 drogue, 2 mains, 85% PRL 35,000 ft, textile risers.</td>
</tr>
<tr>
<td>17</td>
<td>1/13/16</td>
<td>CDT 3-17</td>
<td>PCDTV 7</td>
<td>2D3M</td>
<td>C-17</td>
<td>Nominal System, over Q drogues &amp; mains, 30,000 ft, Textile Risers, 2 mortar deployed FBCPs as programmers, 85% PRL.</td>
</tr>
</tbody>
</table>
Engineering Development Tests with EFT-1

Drogue Contingency Deploy Envelope

FBCP Mortar Fire/Jettison
Drogue Inflation

PCDTV: CDT-3-1 (9/8/2011)
PCDTV: CDT-3-2 (12/20/2011)
PTV: CDT-3-3 (2/29/2012)
PCDTV: CDT-3-4 (4/17/2012)
PTV: CDT-3-5 (7/18/2012)
PCDTV: CDT-3-6 (8/28/2012)
PTV: CDT-3-7 (12/20/2012)
PCDTV: CDT-3-8 (2/12/2013)
PTV: CDT-3-9 (05/01/2013)
PTV: CDT-3-10 (01/16/2014)
PCDTV: CDT-3-11 (07/24/2013)
PTV: CDT-3-11 (07/24/2013)
PCDTV: CDT-3-12 (02/26/2014)
PTV: CDT-3-12 (02/26/2014)
PCDTV: CDT-3-13 (04/23/2014)
EFT-1 Nominal Entry
CPAS Products Linked to Testing

• Demonstrate the system functions as intended, repeatedly achieving an orderly in sequence deployment

• Performance Modeling
  – Reflected in the Parachute Model Memo released semi-annually
    • Published the equations and parameters used to model all aspects of parachute performance, ranging from: mortar deployed parachutes, snatch loads, apparent and added mass, elastic spring damper relationship, inflation, disreefing, to steady state terminal performance parameters
    • Steady State (Drogues coupled damping to CM, Mains rate of descent, cluster fly-out, torque for CM orientation)

• Reliability

• How we interface to the vehicle (ICD compliance)

• Mass and indirectly mortar loads
CPAS Analysis Validation Through Test

- Parachutes are designed and modeled on an empirical basis
  - CPAS modeling challenge is in characterizing a series of bounded random events
- Parachute Model Memo released semi-annually for GN&C ‘runs for record’
  - Equations and parameters used to model all aspects of Drogue, Pilot and Main Parachute Model Parameters and Characteristics

**Modeling performed:**
- Inflation Loads, Vehicle Loads, Snatch Load Modeling
- Vehicle Stability Modeling (including drogue dampening)
- Line Sail Modeling
- Sabot re-contact modeling
- Canopy Fly-Out Modeling
- Torque Modeling
- Main Parachute Instantaneous Cd Model
- Skipped Stage Modeling
- Reefing Cutter Timing Modeling
- Deployed Parachute Footprint and Debris Awareness Modeling
- Individual parachute model
- Forward Bay Cover Separation Modeling

**Demonstration of proper parachute deployment not modeled**
- Packaging, deployment, inflation, and coupling are not modeled with enough confidence to verify by analysis

<table>
<thead>
<tr>
<th>Performance Requirements</th>
<th>Verification Technique</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>108</td>
<td>Analysis</td>
<td>92% (108 of 118)</td>
</tr>
<tr>
<td>7</td>
<td>Test</td>
<td>6% (7 of 118)</td>
</tr>
<tr>
<td>3</td>
<td>Demonstration</td>
<td>2% (3 of 118)</td>
</tr>
</tbody>
</table>

92% of Performance Requirements Verified by Analysis
Validated by Airdrop Testing
Parachute Reconstruction Process

**Parachute Data**
- Riser and Resultant Loads: \( T_i \)
- Steady-State Drag Area: \( (C_D S)_i (t) = \frac{T_i}{q} \)

**Computed Parachute Performance**
- Steady-State Reefed Drag Area: \( (C_D S)_R \)
- Steady-State Full Open Drag Area: \( (C_D S)_o \)
- Reefing Ratios: \( \epsilon_i = \frac{(C_D S)_R}{(C_D S)_o} \)
- Over-Inflation Factors (infinite mass only): \( C_k = \frac{(C_D S)_{peak}}{(C_D S)_R} \)

**Initial Conditions from BET**
- Altitude: \( H \)
- Velocity & Airspeed: \( V_{East}, V_{North}, V_z, V_{air} \)
- Attitudes: \( \theta, \psi, \phi \)
- Body Rates: \( P, Q, R \)
- Stage Initial Airspeed: \( V_i \)

**Output Optimized Constants for Stage \( j \)**
- Canopy Fill Constant: \( n \)
- Opening Profile Shape Exponent: \( \text{expopen} \)
- Fall Time (infinite mass only): \( t_k \)

**Drag Area Simulations for Stage \( j \) in MATLAB**
- Canopy fill time:
  \[ t_f = n \cdot D_o \cdot \frac{\sqrt{\epsilon_{i+1} - \epsilon_i}}{V_i} \]
- Parachute Drag Area Growth:
  \[ (C_D S)(t) = (C_D S)_a + ((C_D S)_b - (C_D S)_a) \cdot \left( \frac{t - t_i}{t_f} \right)^{\text{expopen}} \]
- Drag Area Ramp Down Curve (infinite mass only):
  \[ (C_D S)(t) = (C_D S)_{peak} \cdot (C_k)^{(t_f+t_i-1)/\text{tk}} \]

**Drag Area Optimization Process**
- ‘fminsearch’ function
- Minimize error between computed and test \( (C_D S)(t) \)

**Stage Comparison**
- Do peak parachute loads match?
- Does Altitude match?
- Does dynamic pressure match?

**Reconstruction Complete**

**Modify fill constants using engineering judgment**

**DSS 6-DOF Trajectory**

**Yes**
- Stages Completed?
- Continue to next stage

**No**
- Do peak parachute loads match?
- Does Altitude match?
- Does dynamic pressure match?

**Yes**
- Stages Completed?
- Continue to next stage

**No**
- Modify fill constants using engineering judgment
Infinite Mass Drag Area Growth Curve Fit

1. Determine Parachute Parameters:
   - Reference Diameter, $D_o$
   - Drag coefficient, $C_D$
   - Start time, $t_i$
   - Reefing Ratios, $\varepsilon_i$, $\varepsilon_{i+1}$
   - Start Drag Area, $(C_D S)_a$
   - End Drag Area, $(C_D S)_b$
   - Initial Airspeed, $V_i$

2. Find the point $[(C_D S)_\text{peak}, (t_{fp} + t_i)]$
   - $C_k = (C_D S)_\text{peak} / (C_D S)_b$

3. Generate inflation growth curve with initial estimate parameters:
   - Profile shape, $\expopen$
   - $n$ as $f(\expopen)$

4. Compute difference between inflation curve and test data

5. Sum the difference to compute area between curves (error)

6. Iterate $\expopen$ to minimize the error area
Example of Reconstruction and Modeling Parameters

### Table of Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Model Memo rev8 Nominal</th>
<th>Flight Test Uniform Dispersion</th>
<th>DCLDYN Composite Reconstruction</th>
<th>DSS Composite Reconstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill Constant, n</td>
<td>22.6</td>
<td>18.2 to 27.5</td>
<td>18.2</td>
<td>15.71</td>
</tr>
<tr>
<td>expopen</td>
<td>1.2</td>
<td>0.9 to 1.45</td>
<td>1.20</td>
<td>1.71</td>
</tr>
<tr>
<td>Reefing Ratio, ε₁</td>
<td>3.5%</td>
<td>3.5%</td>
<td>3.9%</td>
<td>3.9%</td>
</tr>
</tbody>
</table>

### Graph:

- **Title:** Main 1st Stage Composite Reconstruction
- **Y-axis:** CD (ft²)
- **X-axis:** Time (s - RC)
- **Legend:**
  - Sum of Load Cells
  - Analytical Total Main Growth
Challenges #1: Test Technique

• Getting the test article onto the desired test point can be very challenging and should not be underestimated
  – Whether out of an airplane or using balloons
  – Can be as challenging as the design of the flight parachute system itself

• Example:
  – Deployment line failure at 35K feet
Challenges #2: Computational & Subscale Test Techniques

• Computational techniques are not mature enough to primarily rely on for human spaceflight parachute design, although they are getting close
  – Fluid structure interaction capabilities are improving and there is great work being done by some of the parachute vendors (and others) using LS-DYNA

• Methods for testing subscale parachutes and test vehicles require additional detailed study and investment
  – Could ultimately result in cost savings or reduction in logistical complexity

Example: Pilot snatch load predictions and energy modulator sizing

Example: Pendulum Subscale Testing
Challenges #3: Adequate System Level Testing

- The number of system level tests needs to be adequate to find “hidden” failure modes
  - Successful designs are ‘given the opportunity to fail’ with repeated demands during development testing
  - Sufficient instrumentation and video coverage is required to truly understand the system and to have confidence in reliability growth
- The “adequate number” is design dependent and also depends on the relationship of the current design to previous, similar designs
  - CPAS has benefited greatly from Apollo; Commercial partners have benefited from CPAS experience
  - “Design dependent” includes parachute planform, packing methods/shapes, integration with vehicle, concept of operations, etc.

Example: Impacts of pendulum phenomenon were not realized until after 3rd 2-main test
DATA SOURCES
Orion Parachute System

Nominal Deployment Sequence

<table>
<thead>
<tr>
<th>Parachute</th>
<th>Diameter (ft)</th>
<th>Mach range</th>
</tr>
</thead>
<tbody>
<tr>
<td>FBCP</td>
<td>7</td>
<td>0.15-0.7</td>
</tr>
<tr>
<td>Drogues</td>
<td>23</td>
<td>0.15-0.7</td>
</tr>
<tr>
<td>Pilots</td>
<td>10</td>
<td>0.15-0.3</td>
</tr>
<tr>
<td>Mains</td>
<td>116</td>
<td>0-0.3</td>
</tr>
</tbody>
</table>
Main Sources of Data

• Full scale drop tests
• Special main parachute subscale test campaign
Full Scale Drop Tests

- Full scale parachutes with modified Orion and dart forebodies
- Series of development and qualification tests covering off-nominal conditions and a range of points in the deployment envelope
Full Scale Drop Tests

- **Instrumentation**
  - Forebody GPS/IMU
  - Wind/Atmosphere measurements
    - Windpacks
    - RAWIN Balloon
  - Approximate Riser line loads
  - Flush Air Data System (FADS) on PTV
  - Up to 96 pressure taps on PTV
Full Scale Drop Tests

- **Photogrammetry**
  - Full time histories of parachute positions relative to forebody
  - Main parachute projected area tracking
  - Main Parachute volume estimation
  - High speed video for tracking deployment
Subscale Campaign

- **35% scale main parachutes (41’)**
- **Wind Tunnel Test**
  - 80’x120’ NFAC at Ames
  - Tested many variations of the EDU design
  - Mostly 1 chute
- **Drop tests**
  - 1,2,3 chute configurations
  - 3 parachute designs
• Wind Tunnel Test
  – Static and dynamic data
    • 0-25deg
    • Controlled releases from set angles of attack
  – Riser Line loads
  – Photogrammetry
    • Vent tracking
    • Tether angles
    • Shape estimation

• Drop Tests
  – Tested different forebody masses
  – GPS/IMU
  – Photogrammetry for vent tracking
  – Wind/atmosphere measurements
Relevant Papers

• Improved CPAS Photogrammetric Capabilities for Engineering Development Unit (EDU) Testing, E. Ray
• Photogrammetric Volume Estimation of CPAS Main Parachutes, E. Ray
• Reconstruction of Orion EDU Parachute Inflation Loads, E. Ray
• Reefing Line Tension in CPAS Main Parachute Clusters, E. Ray
• Pendulum Motion in Main Parachute Clusters, E. Ray
• Sub-Scale Orion Parachute Test Results From the National Full-Scale Aerodynamics Complex 80- by 120-ft Wind Tunnel, B. Anderson
Any Questions?
BACKUP
CPAS EFT-1 Test Flight Hardware Support
CPAS vs. Apollo Airdrop Parachute Testing

Orion Parachute Architecture Milestones / Changes

1st Major Parachute Architecture Change (Drogue deployed FBC, FBC deployed Mains)

Baseline Parachute Architecture (PA-1 configuration)

2nd Major Parachute Architecture Change (IDAT)

Dual Drogue Confluence, Pilot Deployed Mains

CPAS SRR

Flower Pot

Baseline Parachute Architecture (PA-1 configuration)

1st Major Parachute Architecture Change (Drogue deployed FBC, FBC deployed Mains)

2nd Major Parachute Architecture Change (IDAT)

Dual Drogue Confluence, Pilot Deployed Mains

Flight Qualification

First Human Flight

Recovery CM Mass, lbm

Block 1 Development

Gen1 Development

PTV (CDT-2) Failure

Gen2 Development

13 Airdrops

6 Airdrops

17 Airdrops

12 Airdrops

99 Airdrops

12 Airdrops

7 Airdrops

25 Airdrops

4 Airdrops

APOLLO

ORION

EDU System Development

Flight Qualification

First Human Flight


Apollo =>

Orion =>

CPAS PDR, Engineering Development Unit (EDU) Design

CPAS SRR

Flower Pot

Dual Drogue Confluence, Pilot Deployed Mains

Baseline Parachute Architecture (PA-1 configuration)

1st Major Parachute Architecture Change (Drogue deployed FBC, FBC deployed Mains)

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First Human Flight


Apollo =>

Orion =>

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99 Airdrops

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7 Airdrops

25 Airdrops

4 Airdrops

APOLLO

ORION

EDU System Development

Flight Qualification

First Human Flight


Apollo =>

Orion =>
Ground Tests

• HIVAS at China Lake
  – FBCP and pilot parachutes
  – 25-136 psf
  – Load cell on riser

• Subscale wind tunnel
  – 10% scale drogue and forebody
  – Up to 100 psf
  – Load cell, high speed imaging, PIV

• Others...