Modeling & Testing of the Capsule Parachute Assembly System (CPAS)

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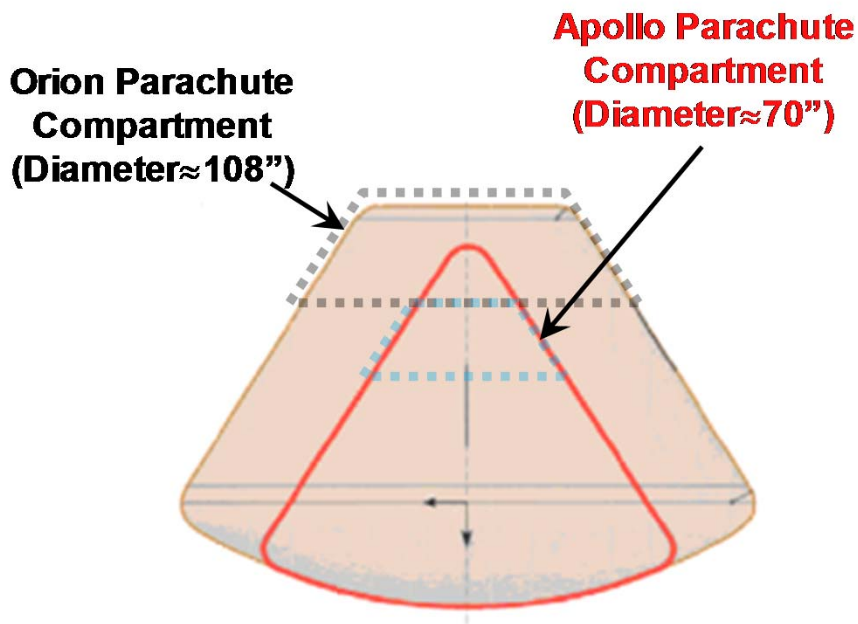
CPAS OVERVIEW

CPAS Overview

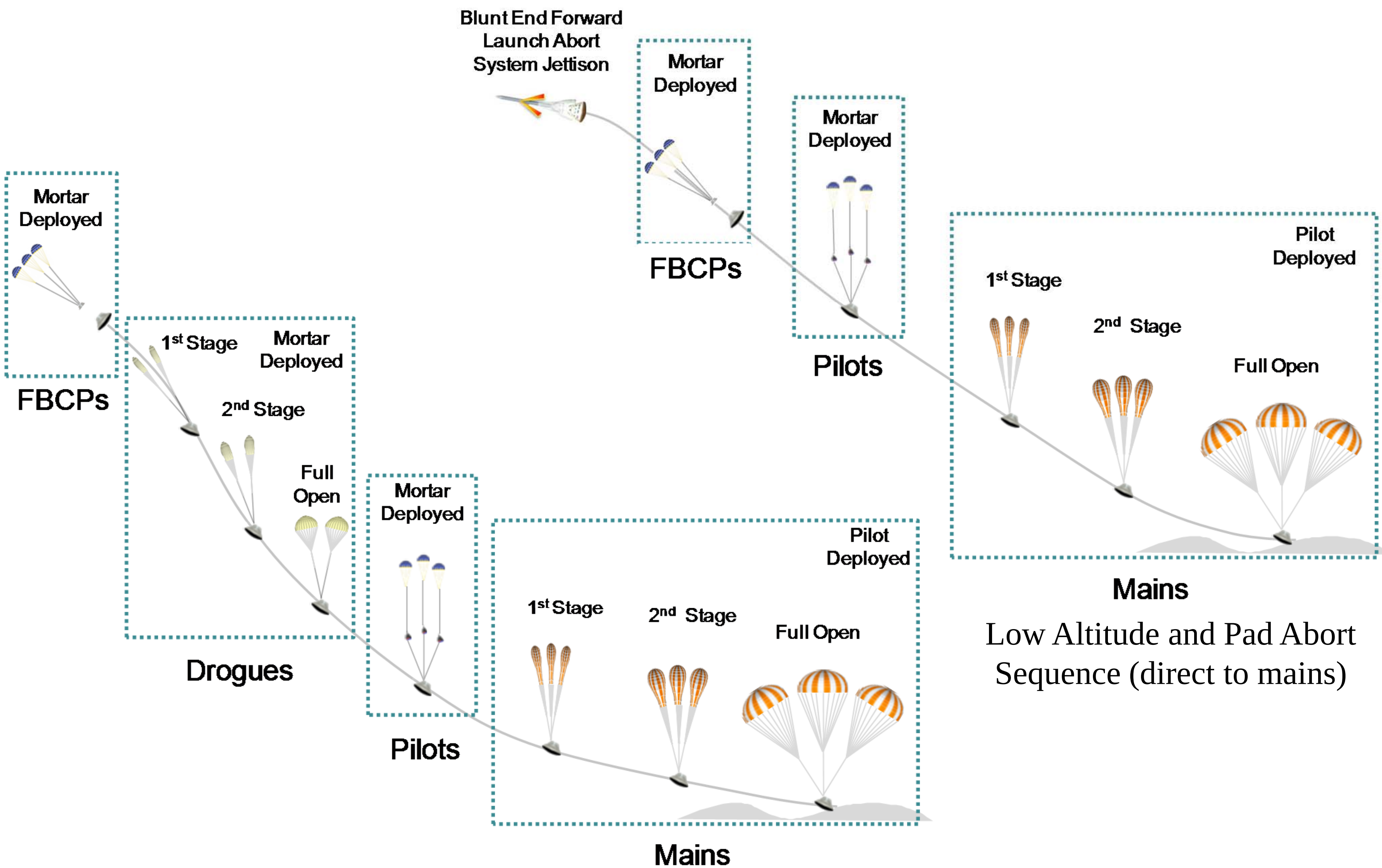
- Capsule Parachute Assembly System (CPAS) is the parachute system for the Orion vehicle used during re-entry
  - Similar to Apollo parachute design
- A Government Furnished Equipment (GFE) project responsible for:
  - Design
  - Development testing
  - Performance modeling
  - Fabrication
  - Qualification
  - Delivery



- Collaboration between NASA JSC, ESCG, and Airborne Systems

CPAS Concept of Operations

Capsule Parachute Assembly System

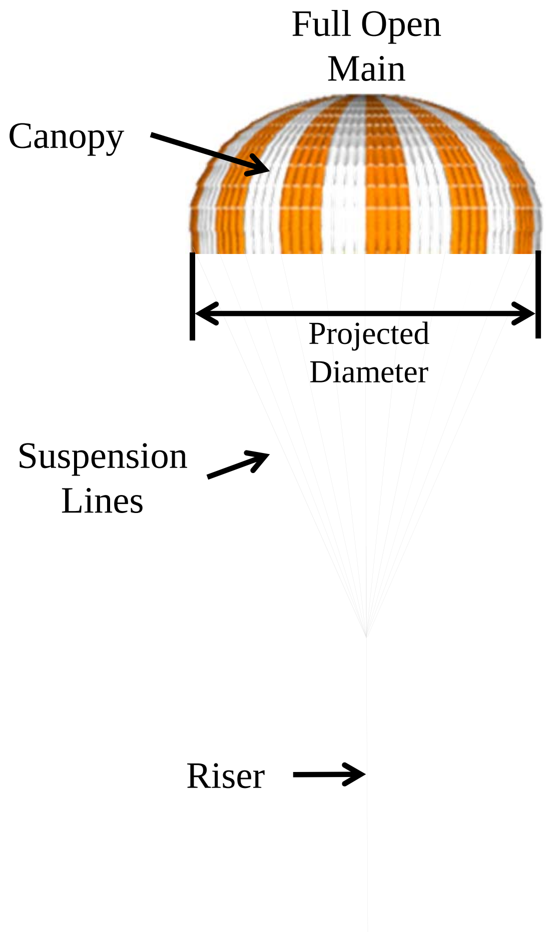


Low Altitude and Pad Abort Sequence (direct to mains)

Nominal Mission and High Altitude Abort Deployment Sequence

CPAS Analysis Focus

- Flow from flight performance requirements from the CPAS Project Technical Requirements Specification (PTRS) Revision
  - Meet during specified failure conditions
- Rate of Descent (ROD)
  - Crew and vehicle structure safety
- Parachute Loads
  - Drogue and Main single riser loads
    - Individual parachute failure
  - Drogue and Main cluster loads
    - Sum of individual riser loads
    - Vehicle structural failure
- Rotation Torque Limit
  - Main risers induce rotation
  - Orient vehicle edge into water for landing



Agenda

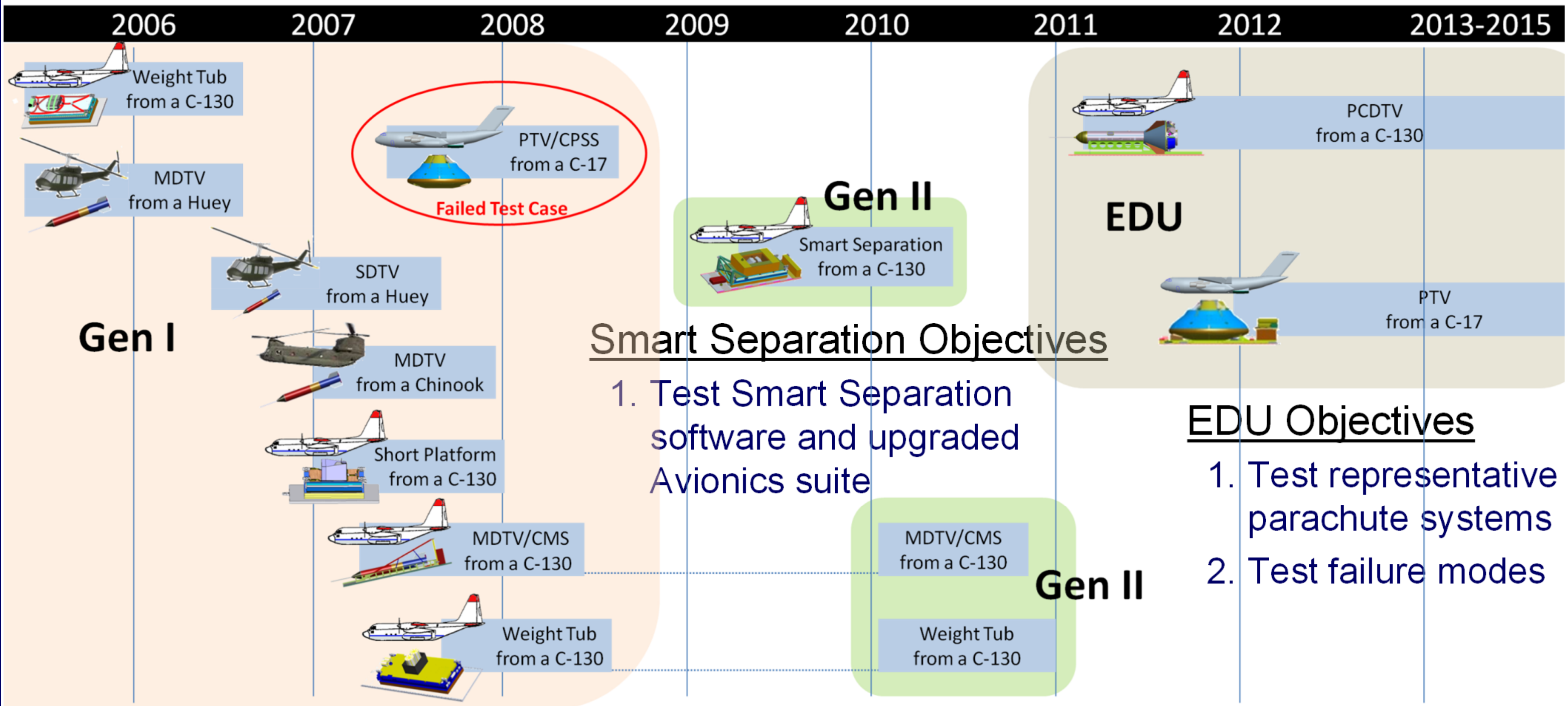
- Airdrop Testing
  - Gen I & II
  - EDU
- Parachute Analysis
  - Simulations
  - Preflight Analysis
  - Post-Flight Analysis
- Development of a Parachute Model
  - Reconstructions
  - Statistically Derived Parameters
- System Verification
- Future of CPAS

Gen I & II

EDU

AIRDROP TESTING

Evolution of Test Vehicles & Techniques



*All vehicles extracted from an aircraft used a Type V LVAD Platform.

Gen I Objectives

1. Characterize single parachute inflation parameters
2. Demonstrate the system

Smart Separation Objectives

1. Test Smart Separation software and upgraded Avionics suite

Gen II Objectives

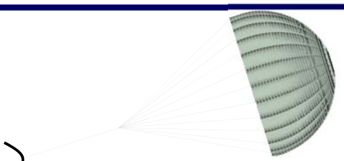
1. Test failure modes
2. Investigate potential design changes

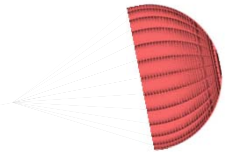
EDU Objectives

1. Test representative parachute systems
2. Test failure modes

CPAS Parachutes

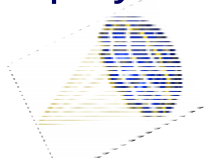
- Extraction Chutes (~28 ft)
  - Pulls the vehicle out of the aircraft. Used for testing only.
- Programmer Parachutes
  - Used to create the proper test conditions for the Drogue, Pilot, or Main chutes. Used for testing only.
  - Can sometimes be an identical chute as the Drogues, but the use is different.
- Forward Bay Cover Parachutes (FBCPs) (~7 ft)
  - Pulls off Forward Bay Cover (FBC) from vehicle
- Drogue Parachutes (~23 ft)
  - Stabilizes the vehicle for Main deployment.
- Pilot Parachutes (~10 ft)
  - Pulls out the Main chutes.
- Main Parachutes (~116 ft)
  - Slow the vehicle to landing

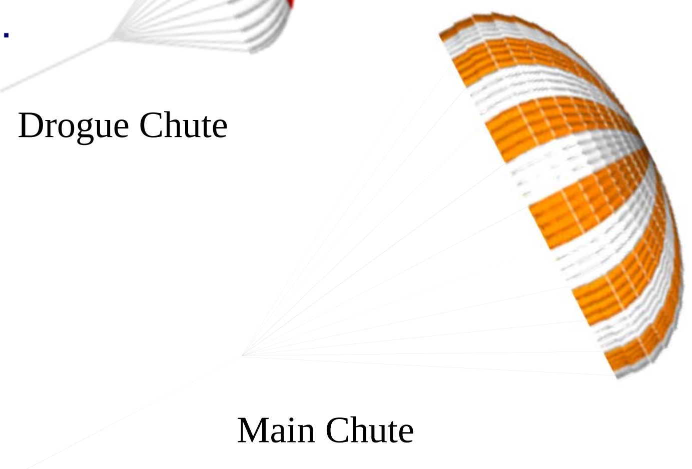

Extraction Chute


Programmer Chute


FBCP


Drogue Chute


Pilot Chute


Main Chute

Not to Scale

Gen I & II

EDU

AIRDROP TESTING

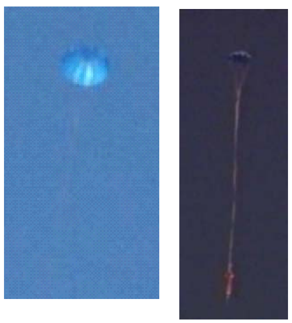
CPAS Gen 1 and Gen 2 Test Progression

Capsule Parachute Assembly System

Gen 1 Testing

Jan – Mar '07
4 Tests

Pilot Chute Tests



Jun – Dec '07
3 Tests

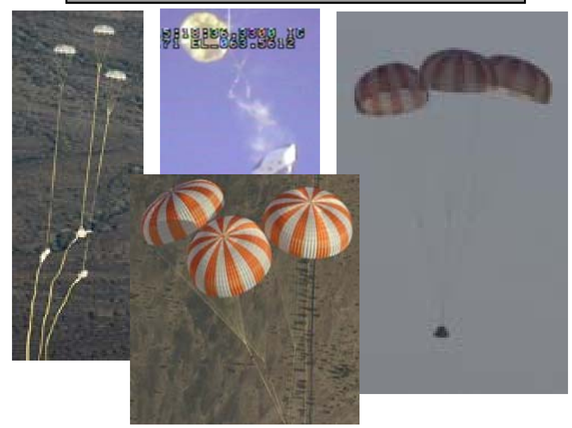
Drogue Chute Tests

Aug '07 – Jan '08
3 Tests

Single Main Chute Tests

Oct '07 – Jul '08, May '10
2 Tests, PA-1, 1 Failed Test

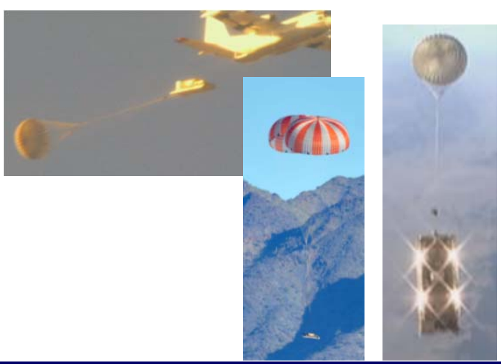
Cluster Chute Tests



Gen 2 Testing

Sept' 09 - Mar '10
2 Tests, 1 Failed Test

TSE-1 A, B, & C
"Smart Separation"



April 2010
2 Tests

MDT 2-1, 2-2
Skipped Stage

July 2010
1 Test

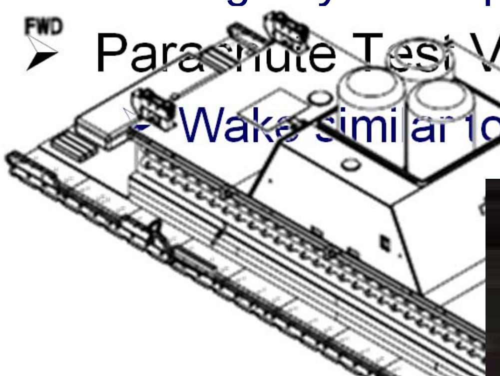
CDT 2-1
Main Line Length Ratio

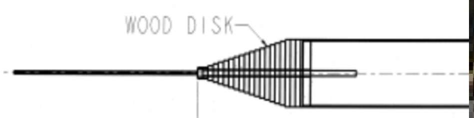
Sept - Dec 2010
3 Tests

MDT 2-3, CDT 2-2, 2-3
Increased Porosity

Gen I & II Test Vehicles

- Each test vehicle was designed to achieve a specific test objective
- Weight Tub
  - Test the parachute system with a representative weight
  - Significantly tested and proven operations with a quick turn around
- Small or Medium Drop Test Vehicle (SDTV or MDTV)
  - Heritage vehicle from the X-38 program
  - High dynamic pressure
- Parachute Test Vehicle (PTV & PT
  - Wake similar to the Orion capsule





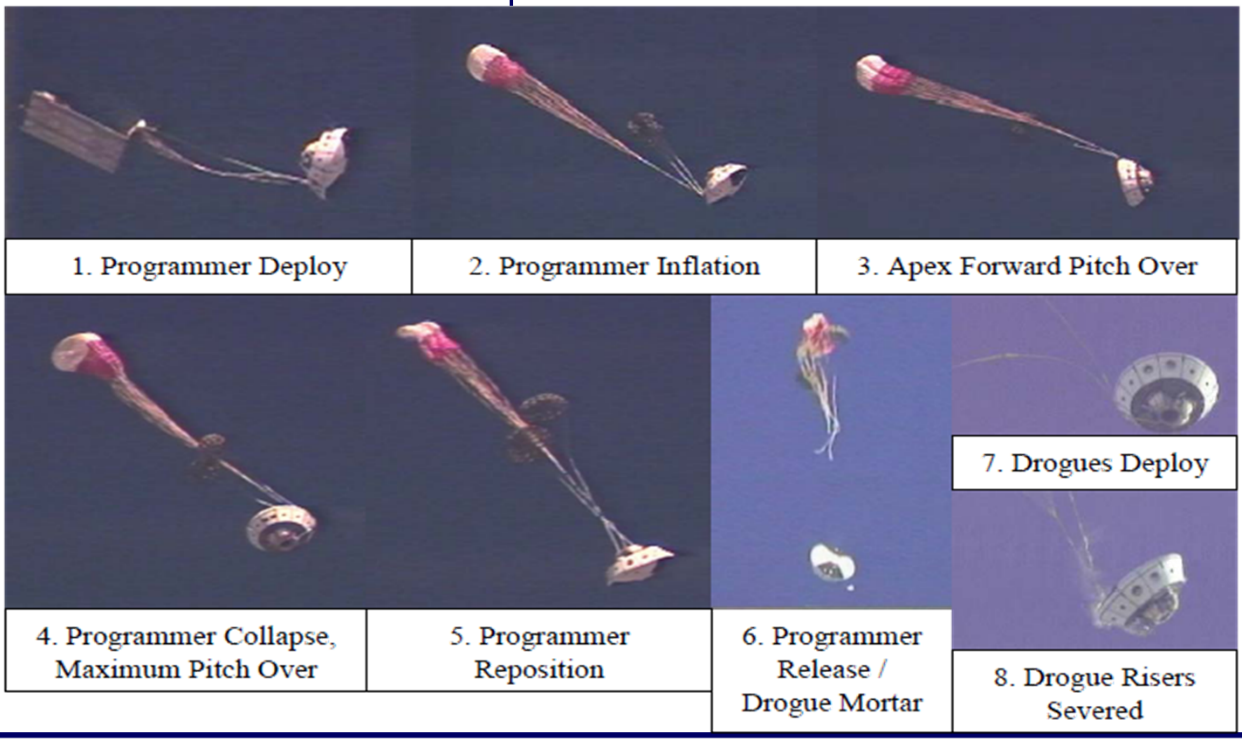
Gen I MI
Gen II CDT-2-

Gen I PTV (CDT-2)

Gen I MDT-3 Build Up

Gen I CPAS PTV Failure (CDT-2)

- Cause of failure
  - Inability of programmer to remain inflated due to test vehicle wake
    - Programmer trailing distance was insufficient
    - Stabilization parachutes caused additional, not simulated wake
- Contributing factors
  - Late completion of ConOps
  - Small, unproven reefing used on the programmer (20%)
  - Lack of robust extraction and separation simulations

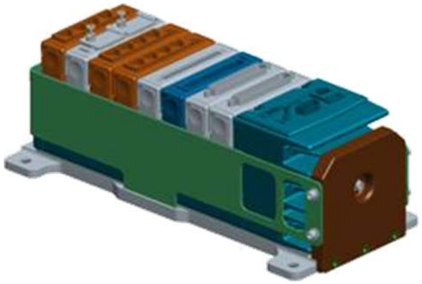


Boilerplate Failure Recovery

- Increased knowledge regarding wake effects
  - Computational fluid dynamics (CFD) anchored to wind tunnel testing
- Improved understanding of vehicle separation
  - Smart separation algorithm was created
    - Validated on 3 Gen II tests – Test Support Equipment (TSE) series
  - Separation simulations
    - Two-body 6-Degree of Freedom (DOF)
    - Models the separation and close proximity dynamics
- Lessons learned from boilerplate failure
  - Smart separation algorithm used to separate the PTV2 from the CPSS
  - Aerodynamic databases will be based on PTV wind tunnel data
  - Stabilization parachutes will not be used
  - Simulations will account for wake effects
  - All protuberances will be eliminated or rounded

Gen II Avionics Advancements

- Data Acquisition System (DAS) - cRIO
  - Centralized unit for controlling and storing data from multiple instruments
    - Allowed for time-synchronization of data
  - Larger storage capacity
- Upgraded Velocity Measurement Instrumentation
  - NovAtel SPAN-SE
    - Accurate measurement assists in ROD
  - Crossbow Nav440
    - Higher velocity uncertainties than NovAtel
    - Triggers smart separation
  - Both are integrated GPS/IMU
    - Mitigates drop outs during extraction phase



cRIO

NovAtel SPAN-SE

Crossbow Nav440

Gen II Avionics Advancements

- Upgraded Load Measurements
  - Gen I used Tension Measuring System (TMS) units attached to each riser - had high uncertainty
  - Gen II used 30,000 lbf strain links attached between the riser and confluence fitting
    - Provide adequate data for the Main parachutes
    - Provided noisy data on the Drogue parachutes due to the turbulent wake environment
- Increased Fidelity in Atmospheric Data
  - Windpack and balloon released to travel through similar air column as test
  - Ground weather stations on the drop zone
    - Anchors windpack and balloons with ground surface winds

Gen I & II

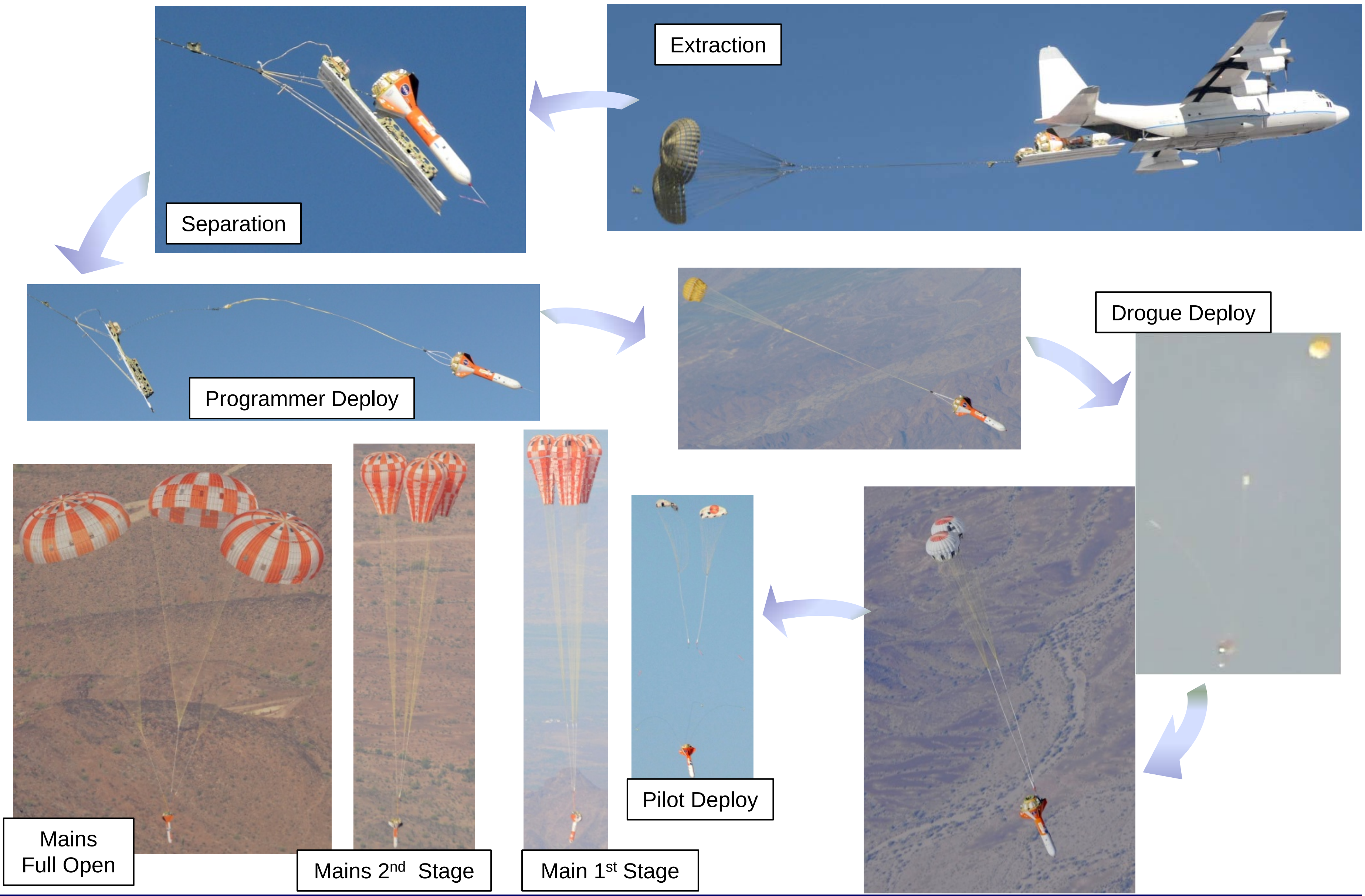
EDU

AIRDROP TESTING

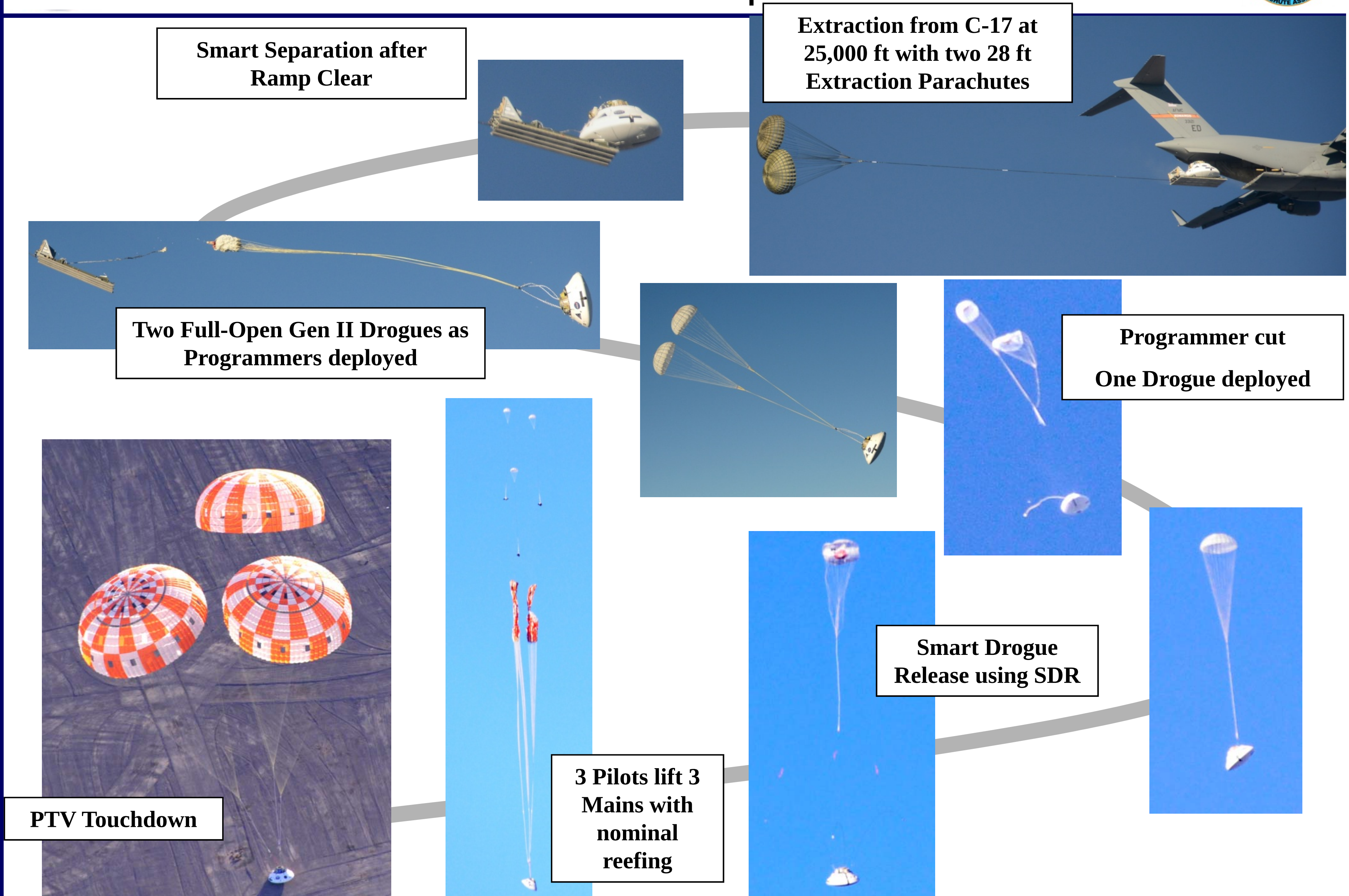
EDU Test Vehicles

- Mid-Air Delivery System (MDS) & Cradle and Platform Separation System (CPSS)
  - Allows the PCDTV and PTV to be deployed from an aircraft cargo bay
- Parachute Compartment Drop Test Vehicle (PCDTV)
  - Tests the full CPAS system utilizing a stable vehicle
  - Dart shape based on the Solid Rocket Booster and Ares booster parachute test program
    - Allows for achievement of high dynamic pressure
- PTV/CPSS
  - Tests the full CPAS system with representative vehicle aerodynamics
  - Unable to achieve high dynamic pressure with current test techniques

PCDTV Test Sequence



PTV Test Sequence



Simulations

Preflight Analysis

Post-Flight Analysis

PARACHUTE ANALYSIS

Simulation Tools

- CPAS uses numerous simulation tools for preflight predictions, mission support, and post-flight data analysis and reconstructions
  - Determine configuration design
  - Ensure safety of test and personnel
  - Assess test objectives and solve unexpected test results
  - Parachute model development
- Tools have evolved from low fidelity spread sheets to high fidelity independent parachute simulations
- End-to-end trajectories currently require use of multiple simulations
  - Desired to consolidate number of simulations
- Many of the simulations are developed and maintained by NASA JSC EG
- Support and processing tools developed and maintained by ESCG

Capsule Parachute Assembly System (CPAS) - ESCG Analysis Team

Evolution of Simulation & Analysis Tools

Capsule Parachute Assembly System

Time		2006	2007	2008	2009	2010	2011	2012	2013
Preflight Predictions		**DSSA** v.Beta_5a, v.Beta_5b4, v.Beta_5b5	v.Beta_8e	v.Beta_8f1	v.Beta_8f3, v.Beta_8f5	v.Beta_8g, v.Beta_8g1 Monte Carlo capability	v.Beta_8g2 through v.Beta_8g5a	v.Beta_8g6 through v.Beta_8h1	v.Beta_8h1
		DTV-Sim v.14		v.15		v.16 Monte Carlo capability	v.17		
				Pallet Sim					
				CAP Sim			**Separation Simulation**		
				DSS	Monte Carlo capability				
							ADAMS		
								FAST	
Mission Support		**X-38 Legacy Footprint Tool**	(Primary)	(Primary)	(Primary)				
					Sasquatch (Secondary)	(Primary) Pressure Altitude Calculation		**Polygons**	
Post Flight Reconstruction		**Spreadsheets**							
			DSSA v.Beta_8e	v.Beta_8f1	v.Beta_8f3, v.Beta_8f5	v.Beta_8g, v.Beta_8g1 Monte Carlo capability	v.Beta_8g2 through v.Beta_8g5a	v.Beta_8g6 through v.Beta_8h1	v.Beta_8h1
		DTV-Sim v.14		v.15					
				DSS					
			FDP v.1.07		v.1.09, v.1.10				
					BET/BEA/ BEW Scripts				
								ADAMS	
								FAST	
		←	**Gen I**	→	← **Gen II**	→	←	**EDU**	→

2/22/2013

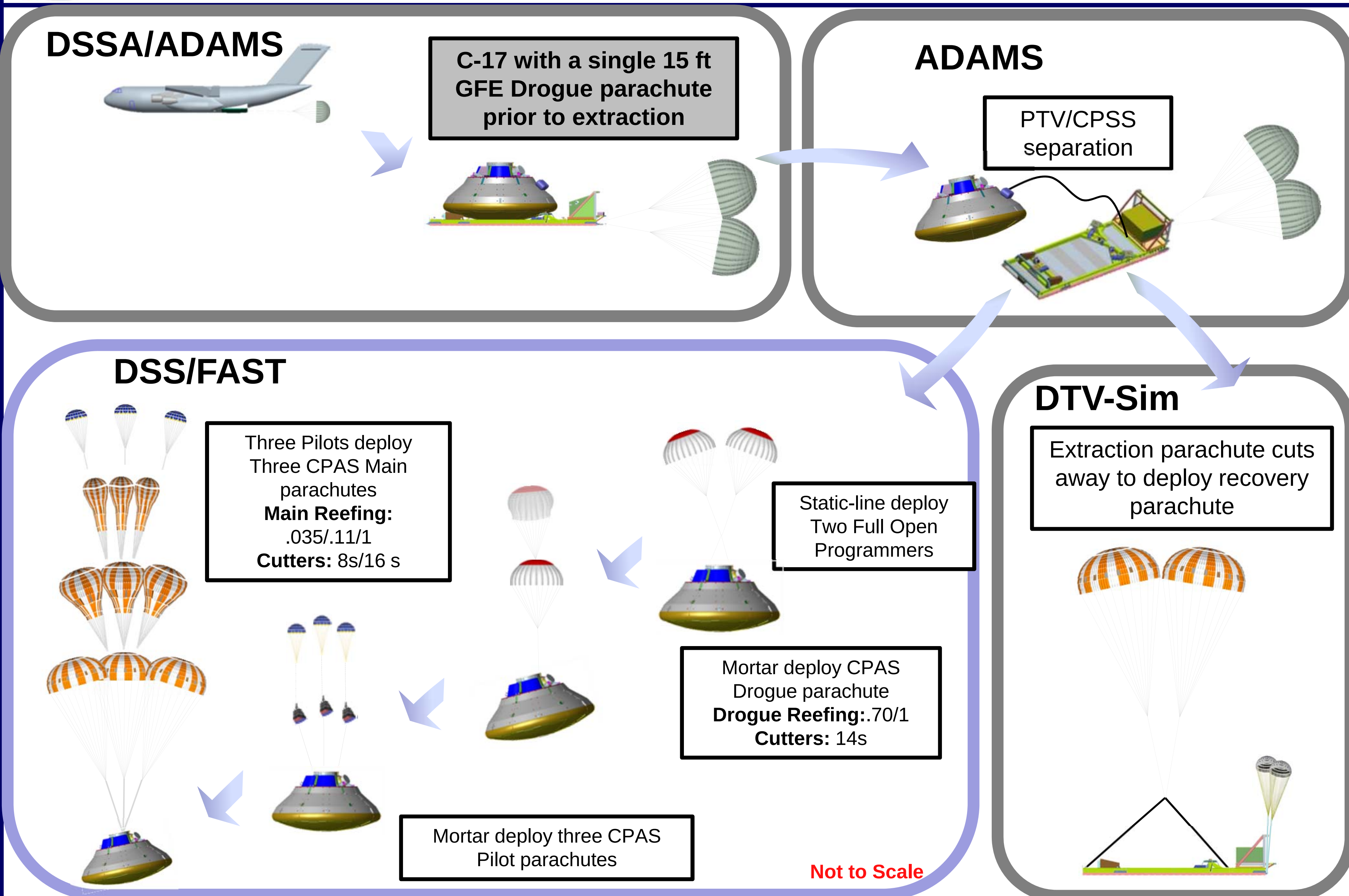
Simulations

Preflight Analysis

Post-Flight Analysis

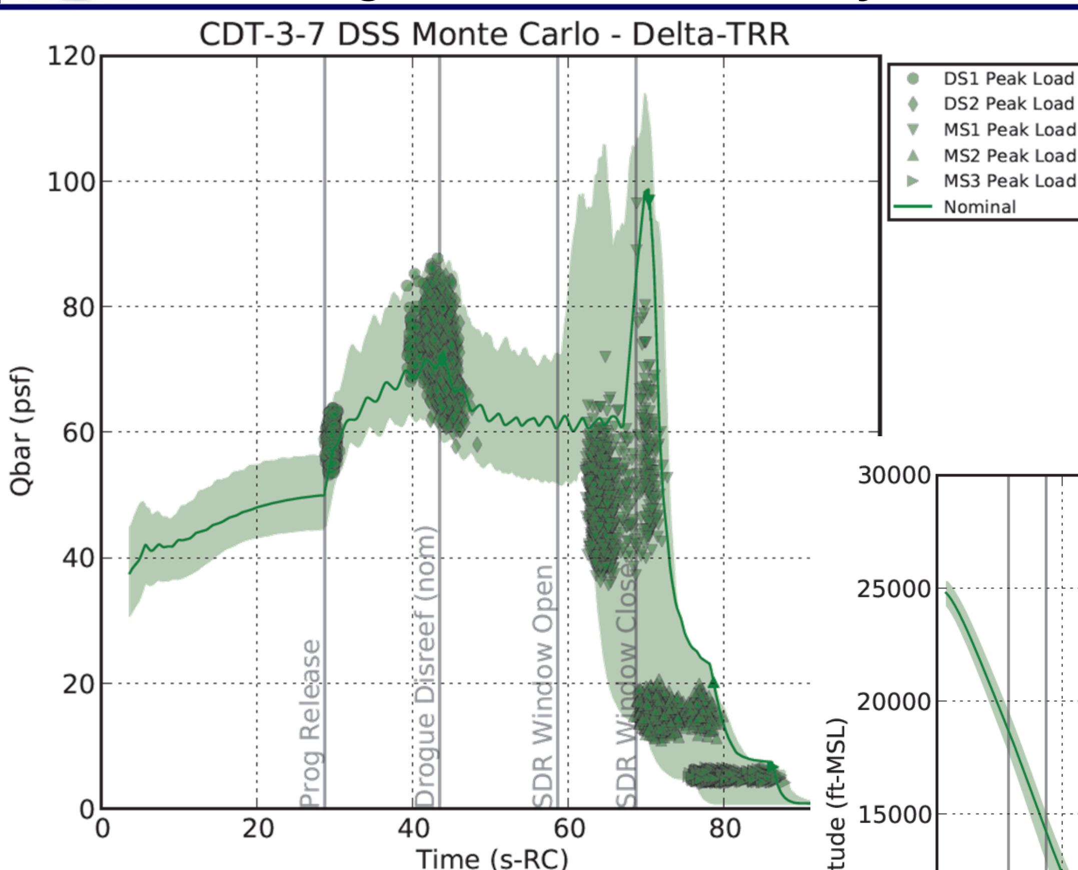
PARACHUTE ANALYSIS

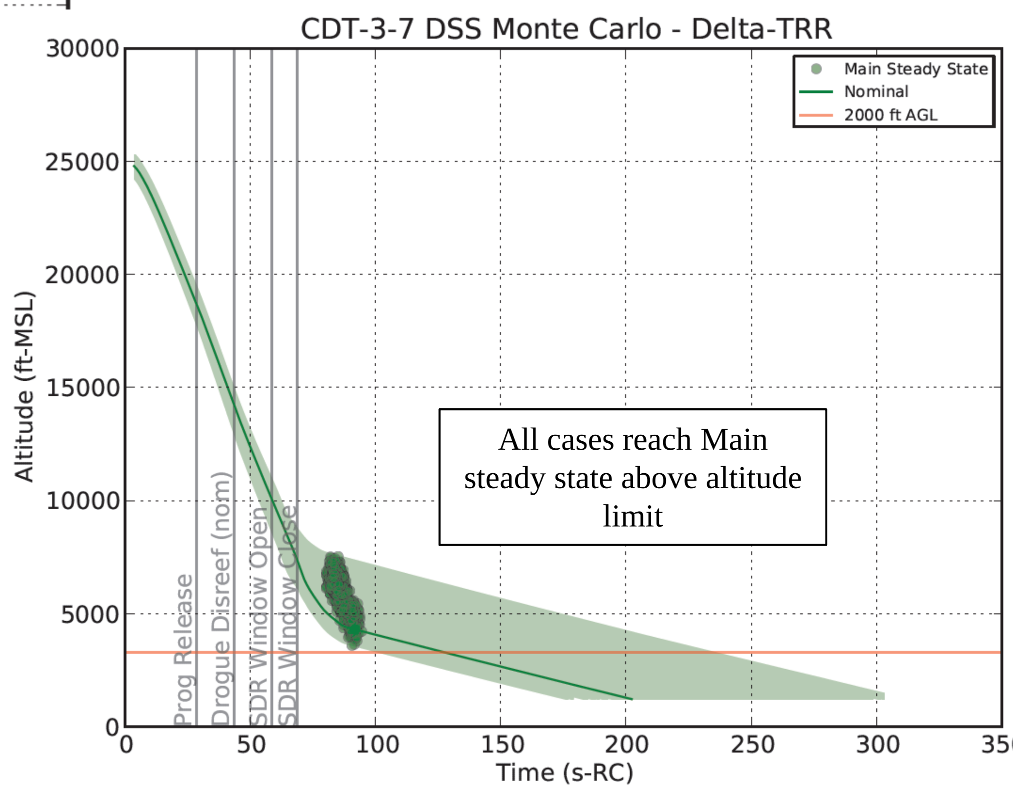
EDU-A-CDT-3-7 Test and Simulation Architecture



Preflight Predictions: Dynamic Pressure & Altitude

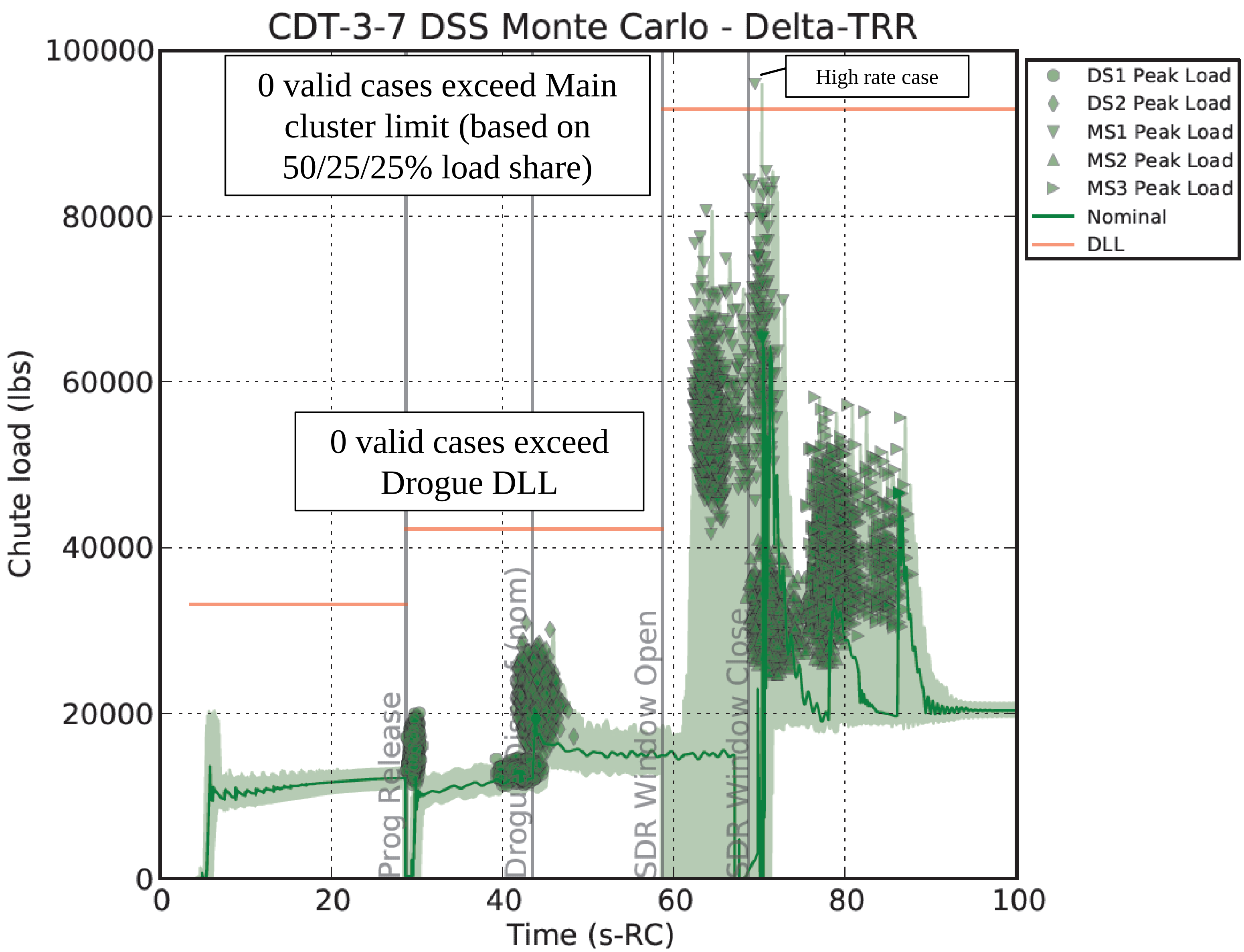
Capsule Parachute Assembly System



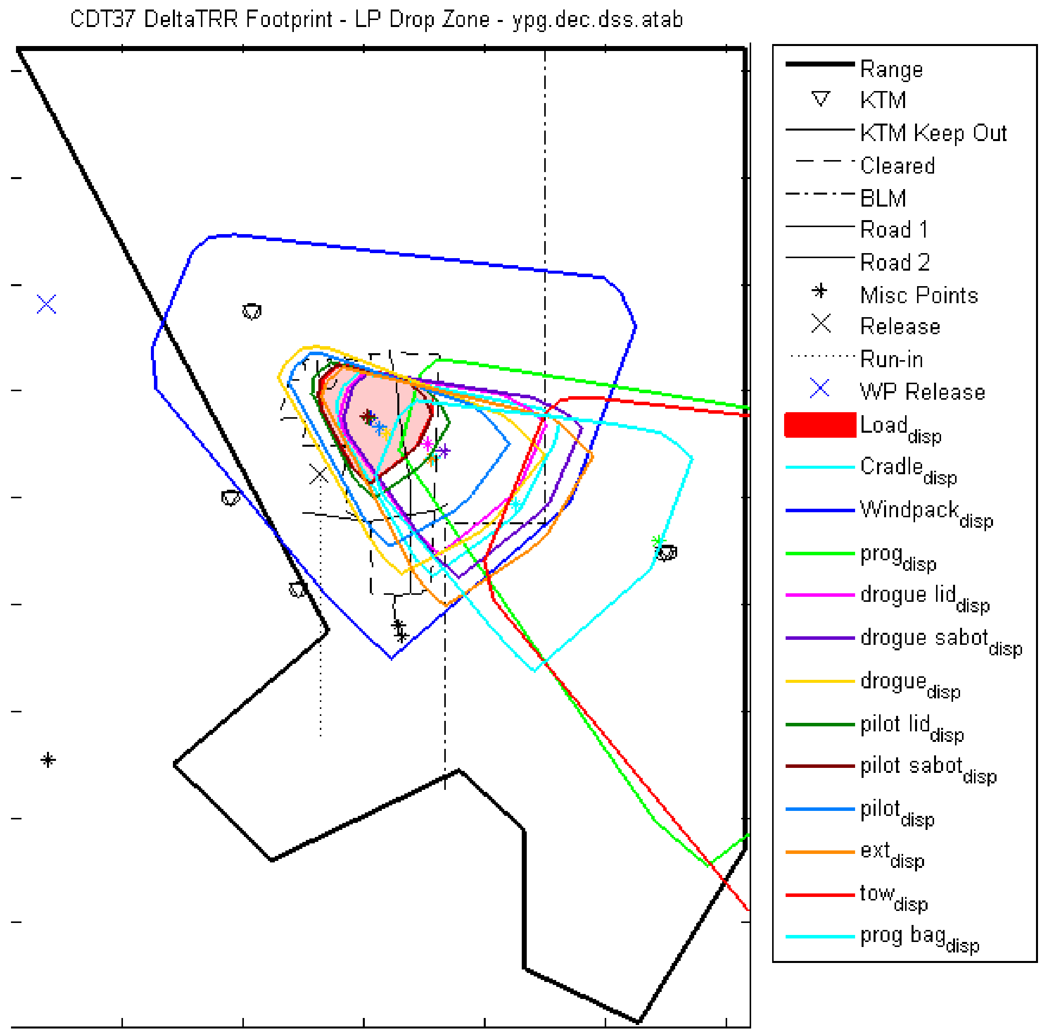


All cases reach Main steady state above altitude limit

Preflight Predictions: Monte Carlo – Loads



Preflight Predictions: Footprint Analysis



Simulations

Preflight Analysis

Post-Flight Analysis

PARACHUTE ANALYSIS

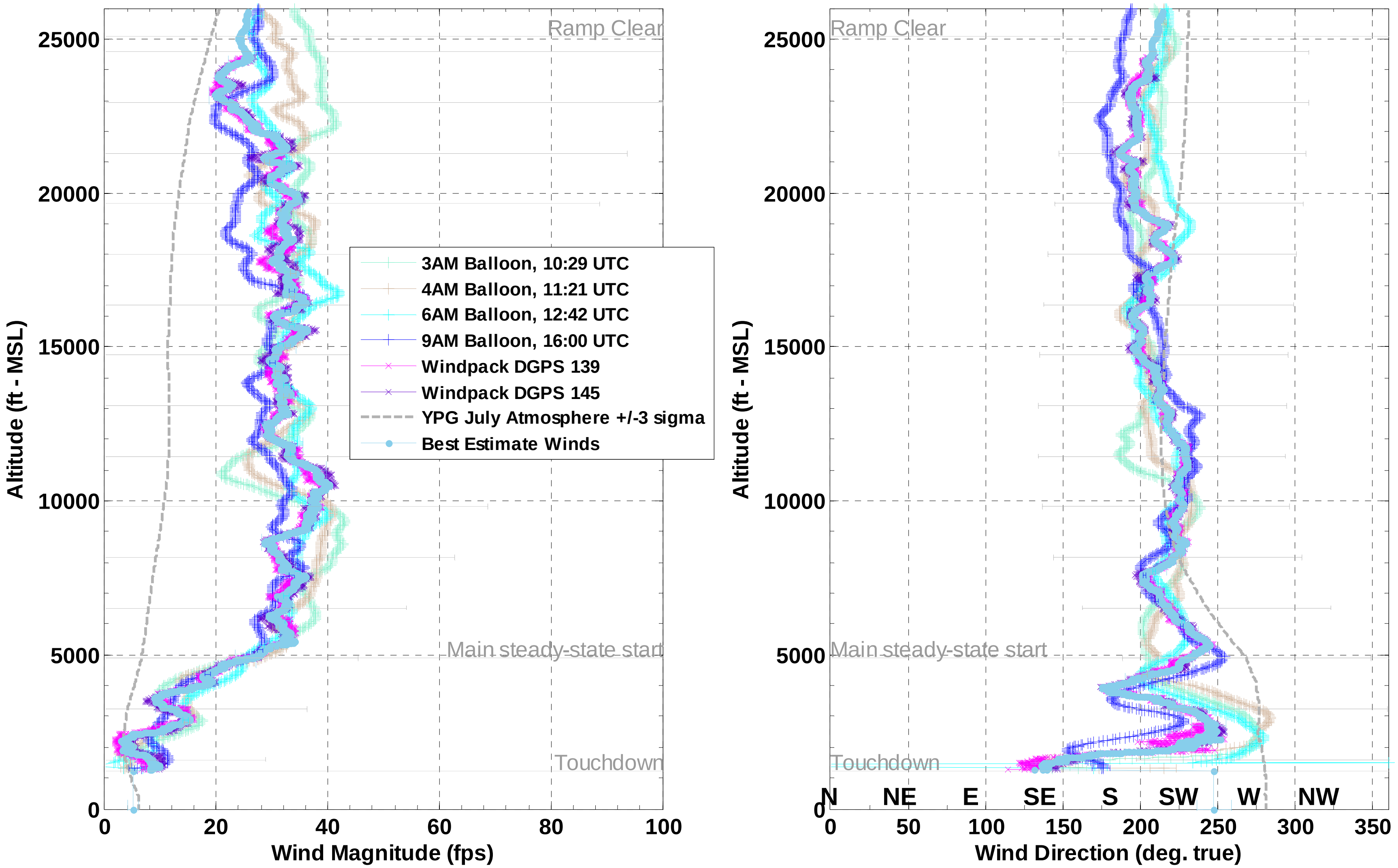
Post-Flight Data Analysis

- Windpack and balloon data
  - BEA: Best Estimate Atmosphere
  - BEW: Best Estimate Winds
- Vehicle Data used to create Best Estimate Trajectory (BET)
  - Dynamic Pressure
  - Loads*
  - Drag Area (C_DS)*
- Photogrammetry
  - Fly-out angles during steady state

*completed for each phase of each parachute

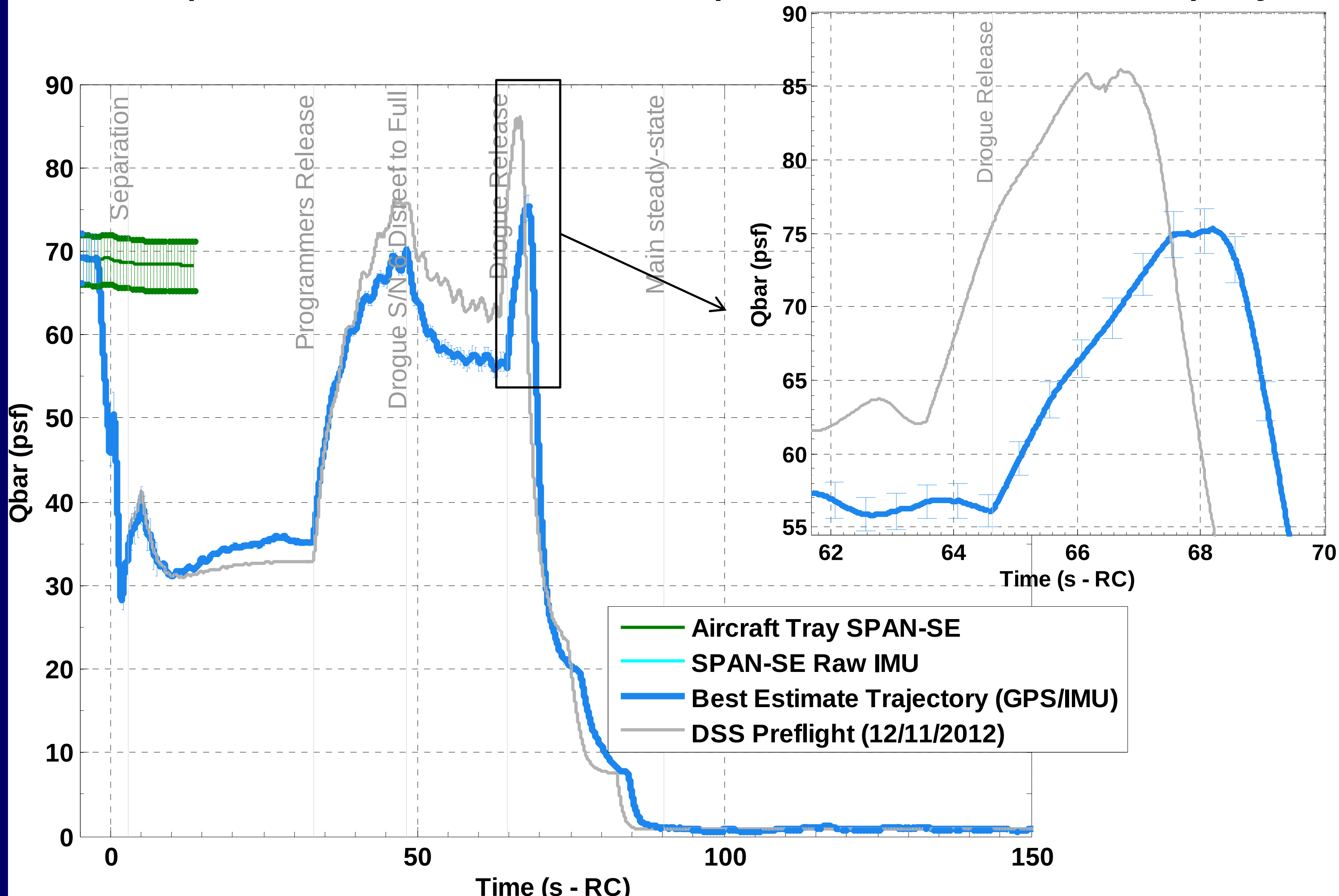
Wind Components Profile (CDT-3-5)

- Winds < 30 ft/s mostly out of SW



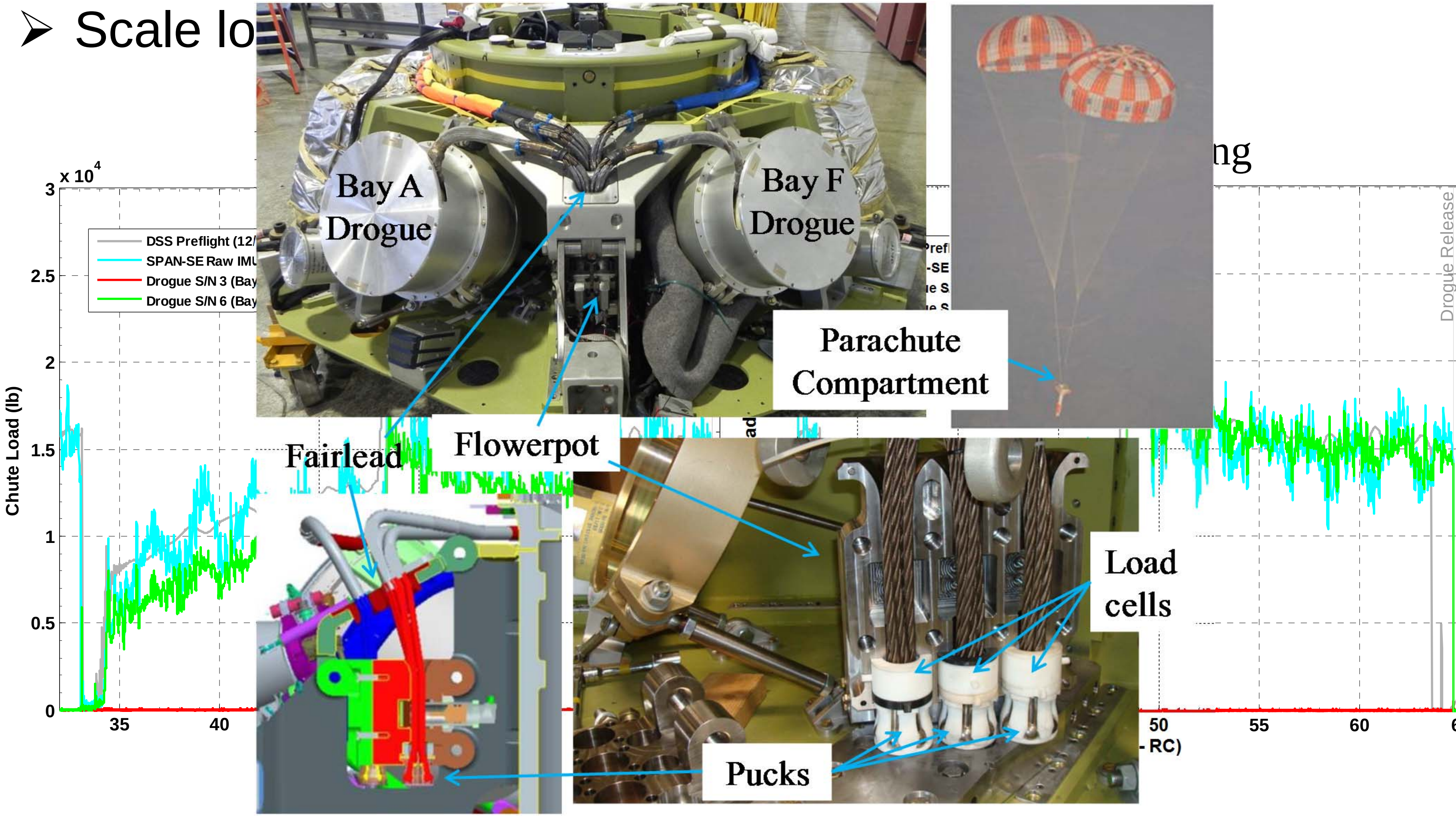
Dynamic Pressure

- ~11 psf lower than nominal prediction at Main deployment



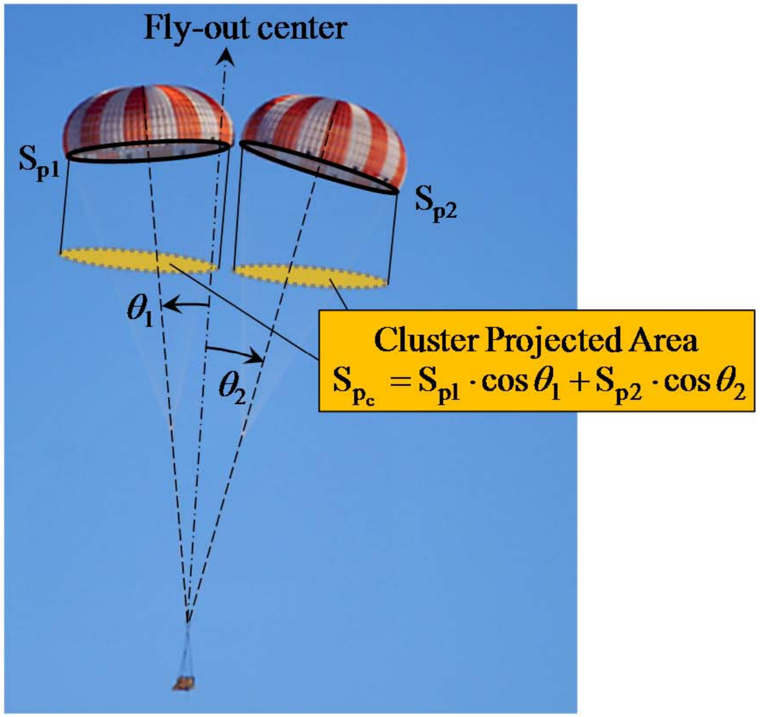
Load Scaling

- Scaling due to load cells being below fairlead
  - Energy lost due to friction
- Scale lo



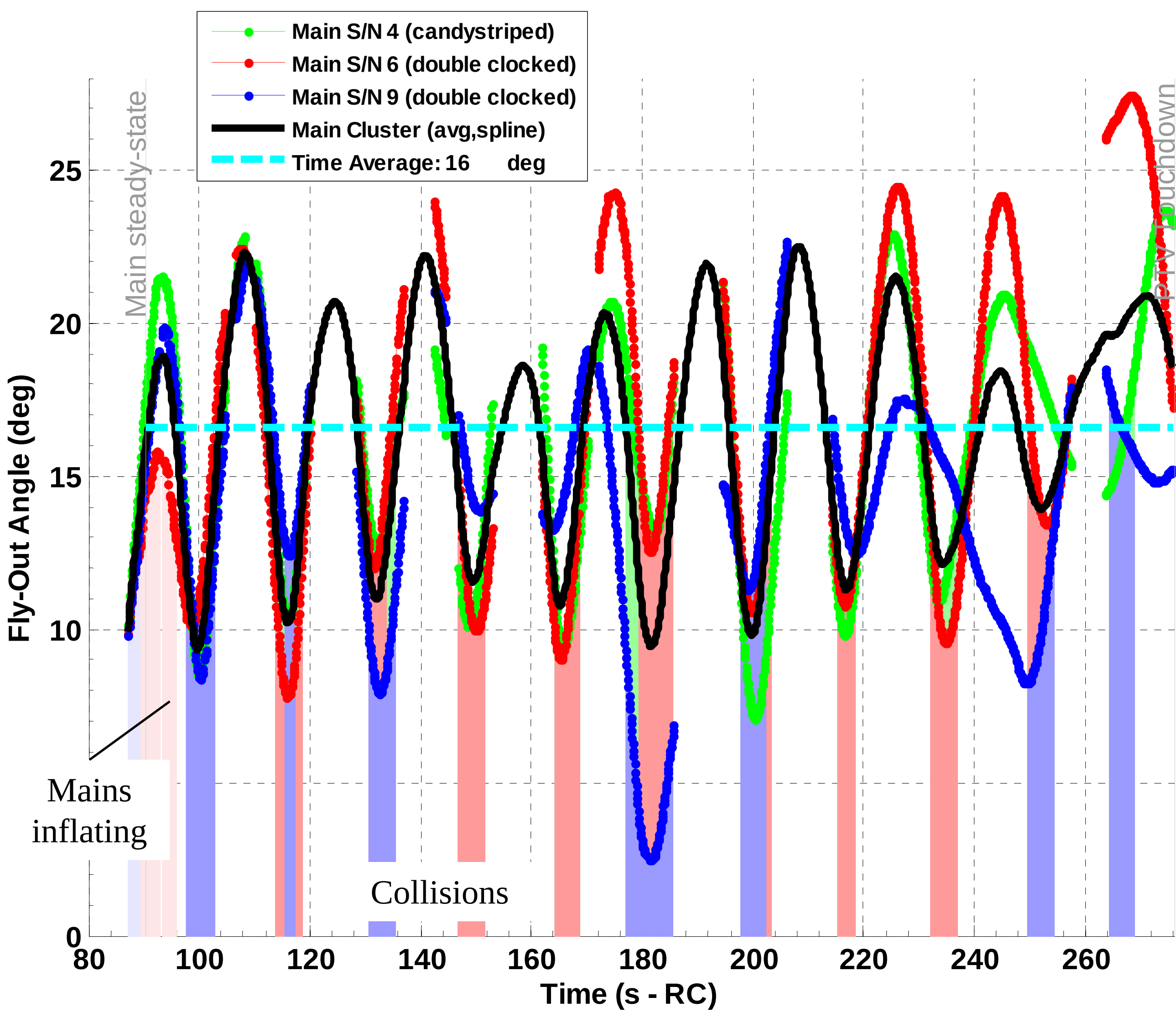
Photogrammetrics

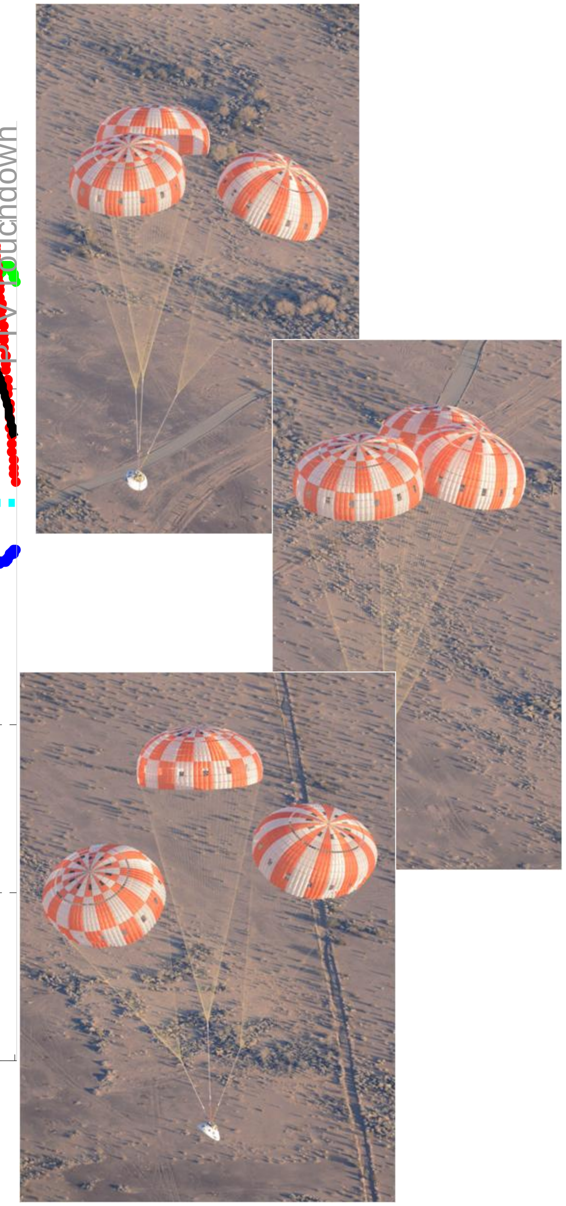
- Used to characterize Main parachute behavior in a cluster
  - Quantify fly-out angles, geometric inlet area, and twist angles
  - Understand collisions and other parachute dynamics
  - Rate of Descent (ROD)
  - Reefing line tension
- Provides insight into dynamics which is related to data gathered



Capsule Parachute Assembly System

Fly-Out Angles During Steady State





Reconstructions

Statistically Derived Parameters

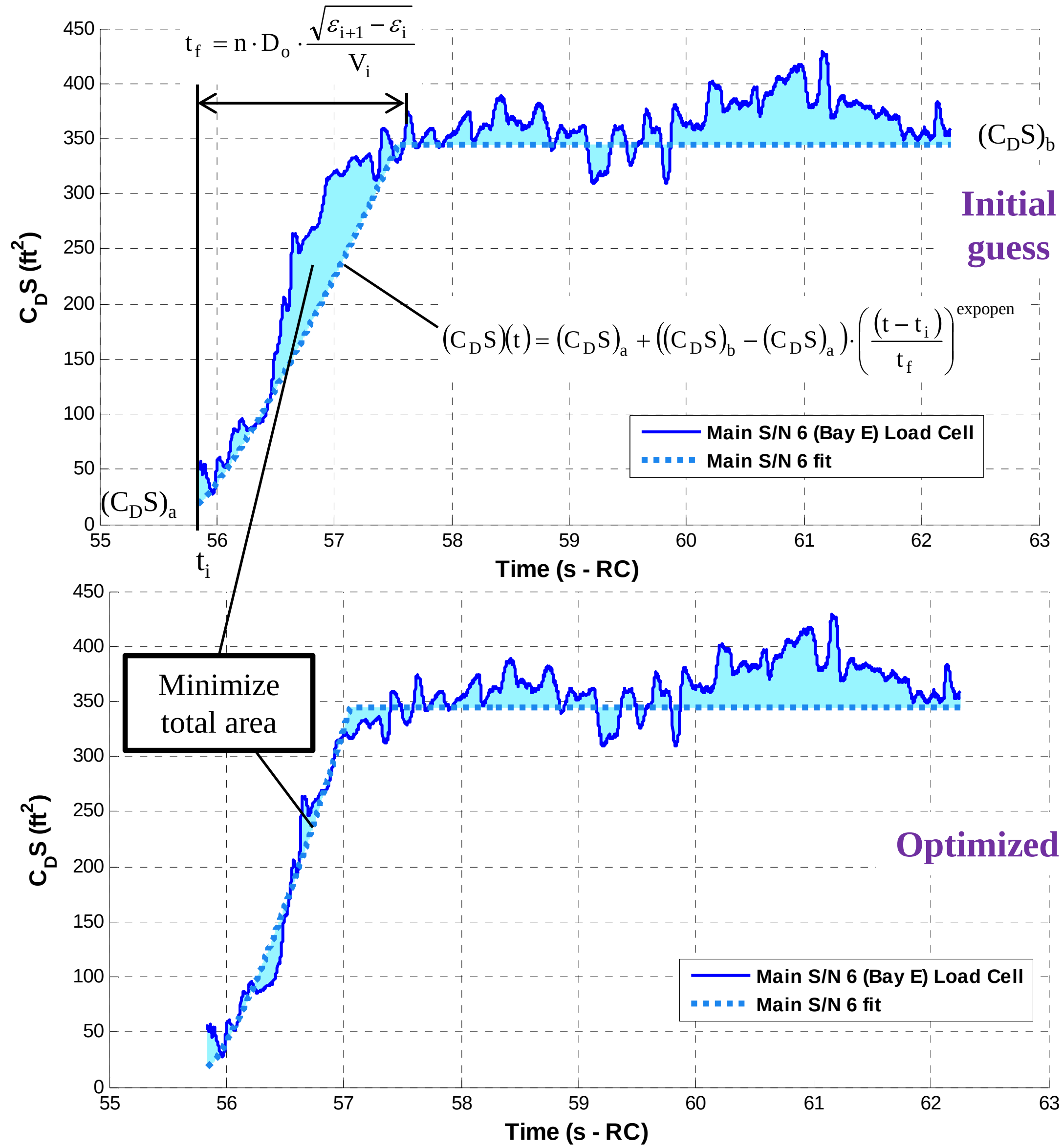
DEVELOPMENT OF A PARACHUTE MODEL

Test Reconstruction

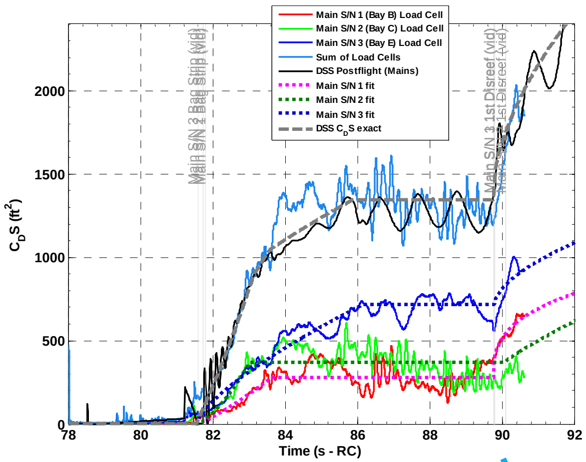
- Use BEA/BEW/BET
- Iterate parachute parameters
  - Automated process
  - Start with latest Model Memo values
- Output parachute parameters that cause simulation to match the BET
- Parameters are published in semiannual Model Memo
  - Assess parameters through benchmarks

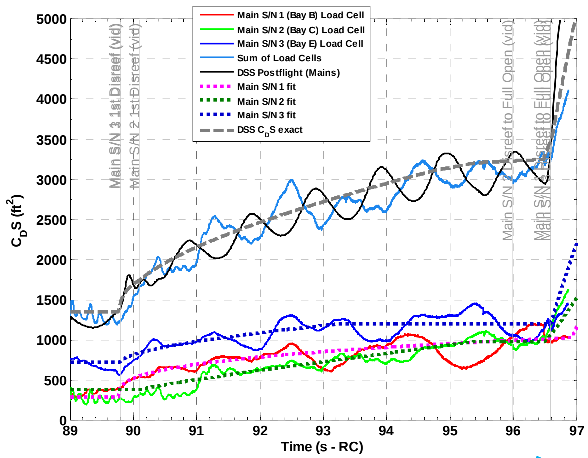
Finite Mass Inflation Curve Fit

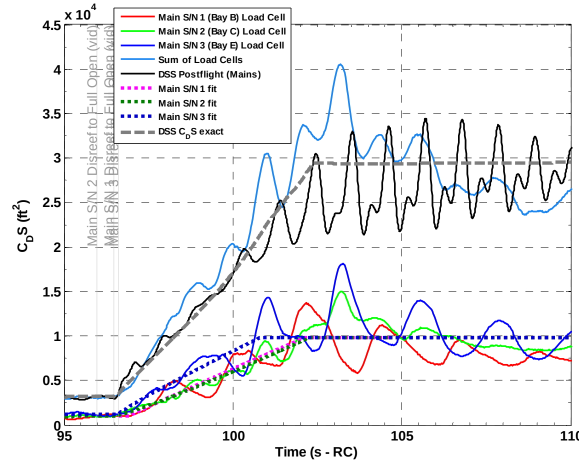
1. Determine Parachute Parameters:
   - Start time, t_i
   - Initial Airspeed, V_i
   - Drag coefficient from equilibrium velocity, C_{D_O}
   - Time average drag areas
     - Start Drag Area, $(C_DS)_a$
     - End Drag Area, $(C_DS)_b$
     - Full open drag area, $(C_DS)_o$
   - Or describe area reefing ratios, ε_i, ε_{i+1}
2. Generate inflation curve with guessed parameters:
   - Fill constant, n
   - Profile shape, expopen,
   - Optional: guess ε_{i+1}
3. Compute difference between inflation curve and test data
4. Sum the difference to compute area between curves (error)
5. Iterate n and expopen to minimize the error area
   - Optional: optimize ε_{i+1}



Main Best Fit Inflation parameters







	Main S/N 1	Main S/N 2	Main S/N 3
Reefing Ratio, ε_1	3%	4%	7%
Reefed Drag Area per canopy, $(C_DS)_R$ (ft^2)	280	372	718
Fill Constant, n	27.6	17.0	38.0
expopen	1.2	1.5	0.7

Reefing Ratio, ε_2	12%	10%	12%
Reefed Drag Area per canopy, $(C_DS)_R$ (ft^2)	1,142	976	1,197
Fill Constant, n	39.8	22.8	16.8
expopen	0.3	0.9	0.6

Drag Coefficient, C_D	0.93	0.93	0.93
Full Open Drag Area per canopy, $(C_DS)_o$ (ft^2)	9,850	9,850	9,850
Fill Constant, n	3.7	4.2	3.1
expopen	1.0	1.1	0.9

Inflation parameters from individual parachute reconstructions for each stage are recorded in a spreadsheet

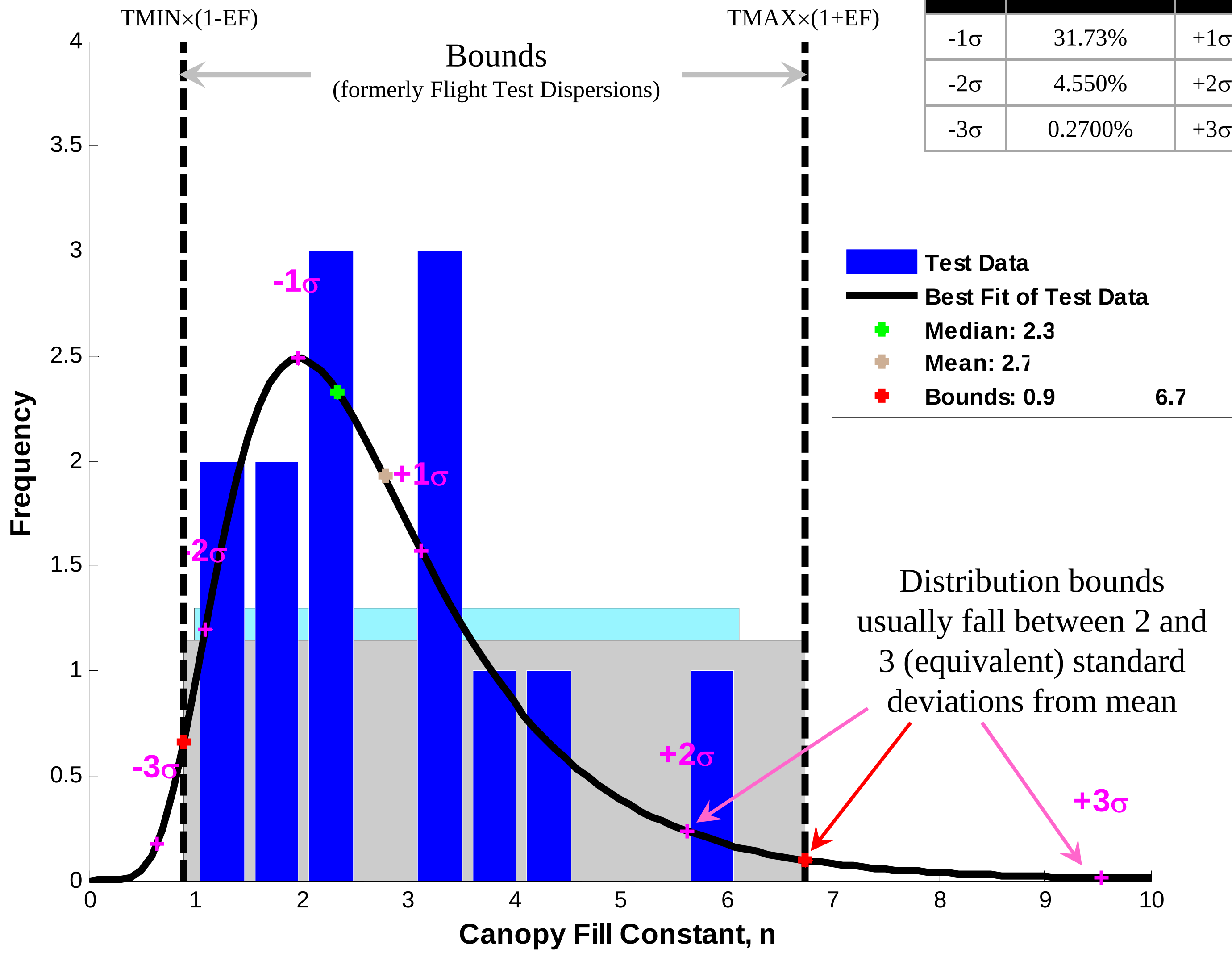
Reconstructions

Statistically Derived Parameters

DEVELOPMENT OF A PARACHUTE MODEL

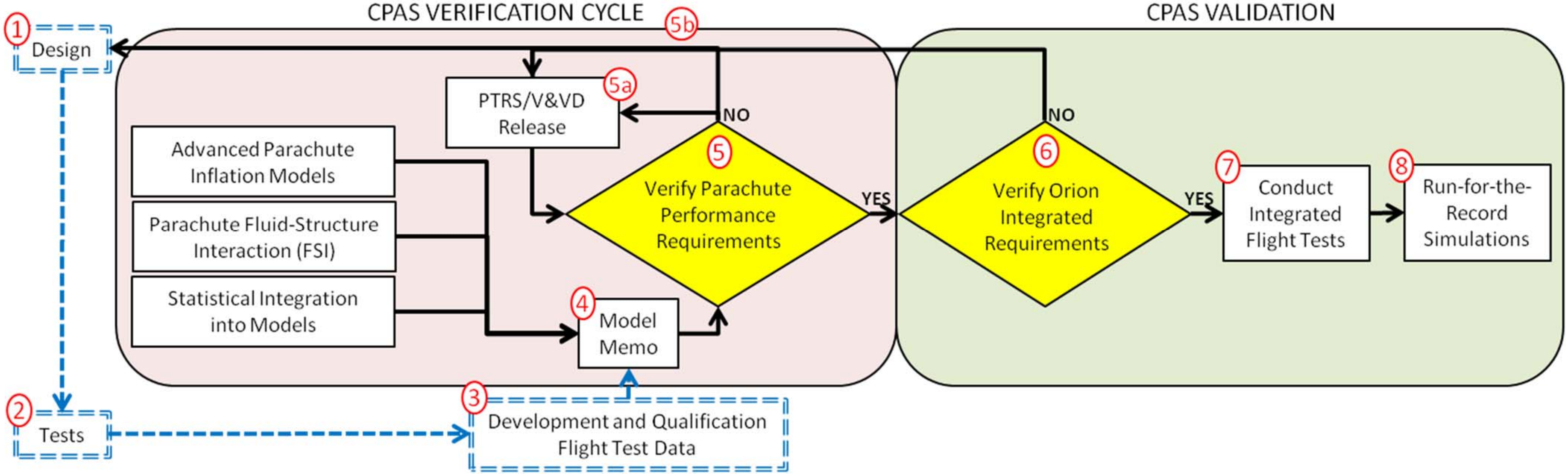
Transition from Uniform to Statistical Distributions

Left Tail		Right Tail	
Zσ	% Outside CI	Zσ	% Inside CI
-1σ	31.73%	+1σ	68.27%
-2σ	4.550%	+2σ	95.45%
-3σ	0.2700%	+3σ	99.73%



SYSTEM VERIFICATION

CPAS Verification & Validation Cycle



1) Design the parachute subsystem
2) Test the design thought flight and ground tests
3) Development and Qualification test data is gathered
4) Document the test data and advancements in parachute physics knowledge
5) Verify the parachute subsystem meets flight performance requirements
   a) If No, update the document for requirement clarification
   b) If No, update the design so that it can meet the requirement
6) Validate flight performance requirements at the integrated Crew Module level
7) Conduct integrated flight tests
8) Run-for-the-record simulations

DSS Credibility Assessment Score (CAS)

Capsule Parachute Assembly System

Level	Verification	Validation	Input Pedigree	Results Uncertainty	Results Robustness	Use History	M&S Management	People Qualifications
4	Numerical error small for all important features.	Results agree with real-world data.	Input data agree with real-world data.	Non-deterministic & numerical analysis.	Sensitivity known for most parameters; key sensitivities identified.	De facto standard.	Continual process improvement.	Extensive experience in and use of recommended practices for this particular M&S.
3	Formal numerical error estimation.	Results agree with experimental data for problems of interest.	Input data agree with experimental data for problems of interest.	Non-Deterministic analysis.	Sensitivity known for many parameters.	Previous predictions were later validated by mission data.	Predictable process.	Advanced degree or extensive M&S experience, and recommended practice knowledge.
2	Unit and regression testing of key features.	Results agree with experimental data or other M&S on unit problems.	Input data traceable to formal documenation.	Deterministic analysis or expert opinion.	Sensitivity known for a few parameters.	Used before for critical decisions.	Estabilished process.	Formal M&S training and experience, and recommended practice training.
1	Conceptual and mathematical models verified.	Conceptual and mathematical models agree with simple referents.	Input data traceable to informal documenation.	Qualitative estimaes.	Qualitative estimates.	Passes simple tests.	Managed process.	Engineering or science degree.
0	Insufficient evidence.	Insufficient evidence.	Insufficient evidence.	Insufficient evidence.	Insufficient evidence.	Insufficient evidence.	Insufficient evidence.	Insufficient evidence.
	M&D Development		M&S Operations			Supporting Evidence		

FUTURE OF CPAS

Future of CPAS

- Testing
  - EDU (plan as of Feb 6, 2013)
    - 2013: 3 tests – 2 PTV, 1 PCDTV
    - 2014: 5 tests – 4 PTV, 1 PCDTV
      - Includes first Forward Bay Cover (FBC) test
    - 2015: 2 tests – 2 PTV
  - EFT-1 in fall 2014
- CDR
- Qualification Tests

Lockheed Martin's MPCV

- Simulation & Model development
  - Transition to end-to-end simulation in an independent parachute model
  - Time varying ROD model using fly-out angles
  - Refinement of statistically derived dispersions

SPECIAL THANKS

- CPAS Analysis Team
  - Pat Galvin
  - Eric Ray
  - Kristin Bledsoe
  - Usbaldo Fraire
  - Joe Varela
  - Johnny Blaschak
  - Fernando Galaviz
- Koki Machin
- Mike Frostad
- Entire CPAS team

For More Information…

Capsule Parachute Assembly System

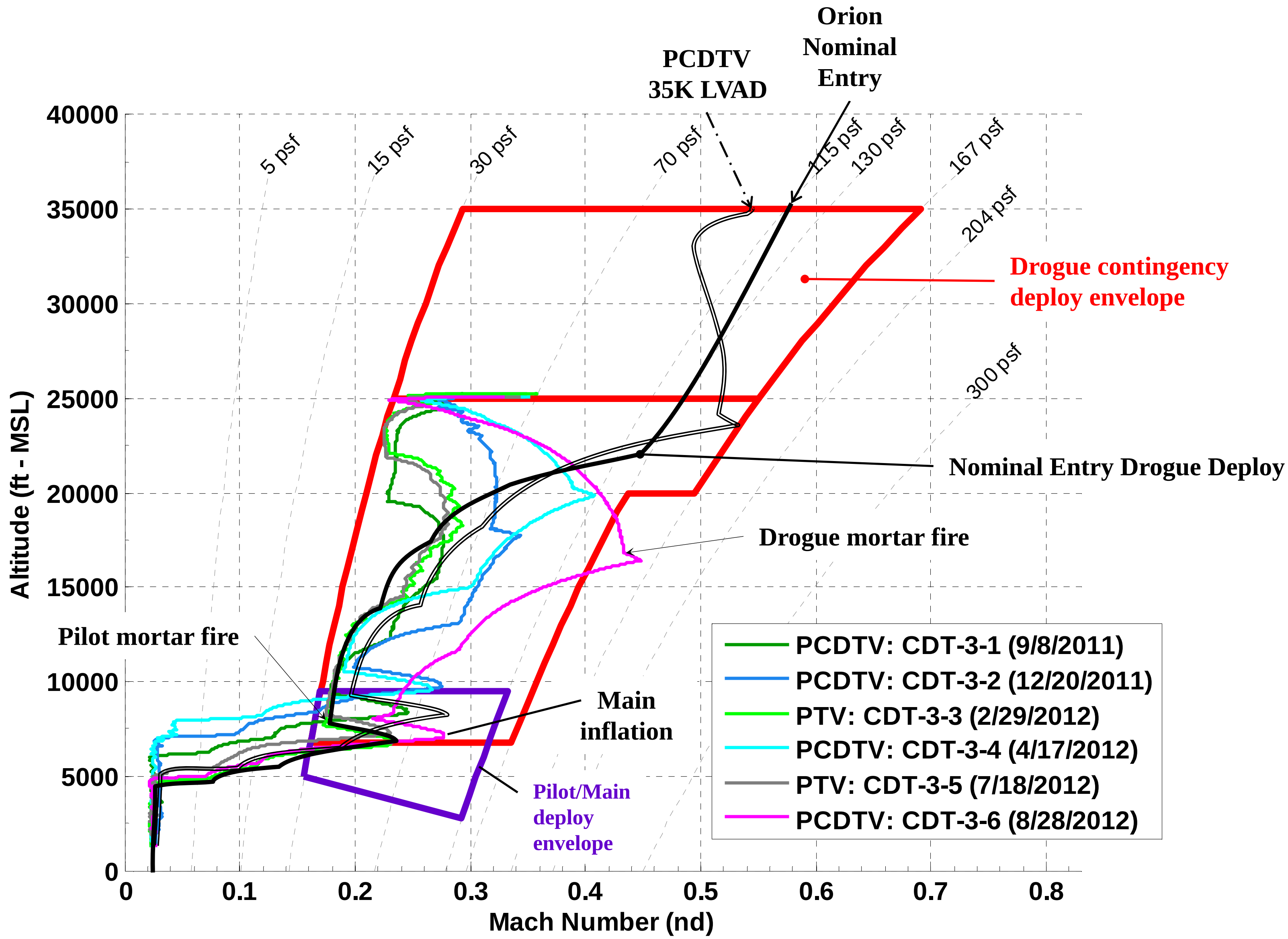
- 2009 AIAA ADS Conference
  - Overview of the Crew Exploration Vehicle Parachute Assembly System (CPAS) Generation I Drogue and Pilot Development Test Results, R. Olmstead
  - Overview of the Crew Exploration Vehicle Parachute Assembly System (CPAS) Generation I Main and Cluster Development Test Results, K. Bledsoe
- 2011 AIAA ADS Conference
  - Proposed Framework for Determining Added Mass of Orion Drogue Parachutes, U. Fraire
  - Summary of CPAS Gen II Testing Analysis Results, A. Morris
  - Load Asymmetry Observed During Orion Main Parachute Inflation, A. Morris
  - Challenges of CPAS Flight Testing, E. Ray
  - Verification and Validation of Requirements on the CEV Parachute Assembly System Using Design of Experiments, P. Schulte
  - Development of Monte Carlo Capability for Orion Parachute Simulations, J. Moore
  - Photogrammetric Analysis of CPAS Main Parachutes, E. Ray
  - A Hybrid Parachute Simulation Environment for the Orion Parachute Development Project, J. Moore
  - Measurement of CPAS Main Parachute Rate of Descent, E. Ray
  - Development of the Sasquatch Drop Test Footprint Tool, K. Bledsoe
  - Development of a Smart Release Algorithm for Mid-Air Separation of Parachute Test Articles, J. Moore
  - Simulating New Drop Test Vehicles and Test Techniques for the Orion CEV Parachute Assembly System, A. Morris
  - Verification and Validation of Flight Performance Requirements for Human Crewed Spacecraft Parachute Recovery Systems, A. Morris
- 2013 AIAA ADS Conference
  - Extraction and Separation Modeling of Orion Test Vehicles with ADAMS Simulation, U. Fraire
  - An Airborne Parachute Compartment Test Bed for the Orion Parachute Test Program, J. Moore
  - Application of a Smart Parachute Release Algorithm to the CPAS Test Architecture, K. Bledsoe
  - Application of Statistically Derived CPAS Parachute Parameters, L. Romero
  - A Boilerplate Capsule Test Technique for the Orion Parachute Test Program, J. Moore
  - Testing Small CPAS Parachutes Using HIVAS, E. Ray
  - Improved CPAS Photogrammetric Capabilities for Engineering Development Unit (EDU) Testing, E. Ray
  - Reefing Line Tension in CPAS Main Parachute Clusters, E. Ray
  - Skipped Stage Modeling and Testing of the Capsule Parachute Assembly System, J. Varela
  - Reconstruction of Orion EDU Parachute Inflation Loads, E. Ray

QUESTIONS?

BACKUP

Capsule Parachute Assembly System (CPAS) - ESCG Analysis Team

Parachute Deployment Envelope



Gen I Helicopter Tests

- Helicopter tests were simple to execute and analyze

- Test Conducted
  - Pilot Development Tests (PDT)
    - Vehicle used: SDTV
  - Drogue Development Tests (DDT)
    - Vehicle Used: MDTV

- Programmer parachute set up the desired dynamic pressure
  - Poor understanding of programmer drag lead to a failure to achieve the desired test condition

Small DTV Suspended
Beneath UH-1

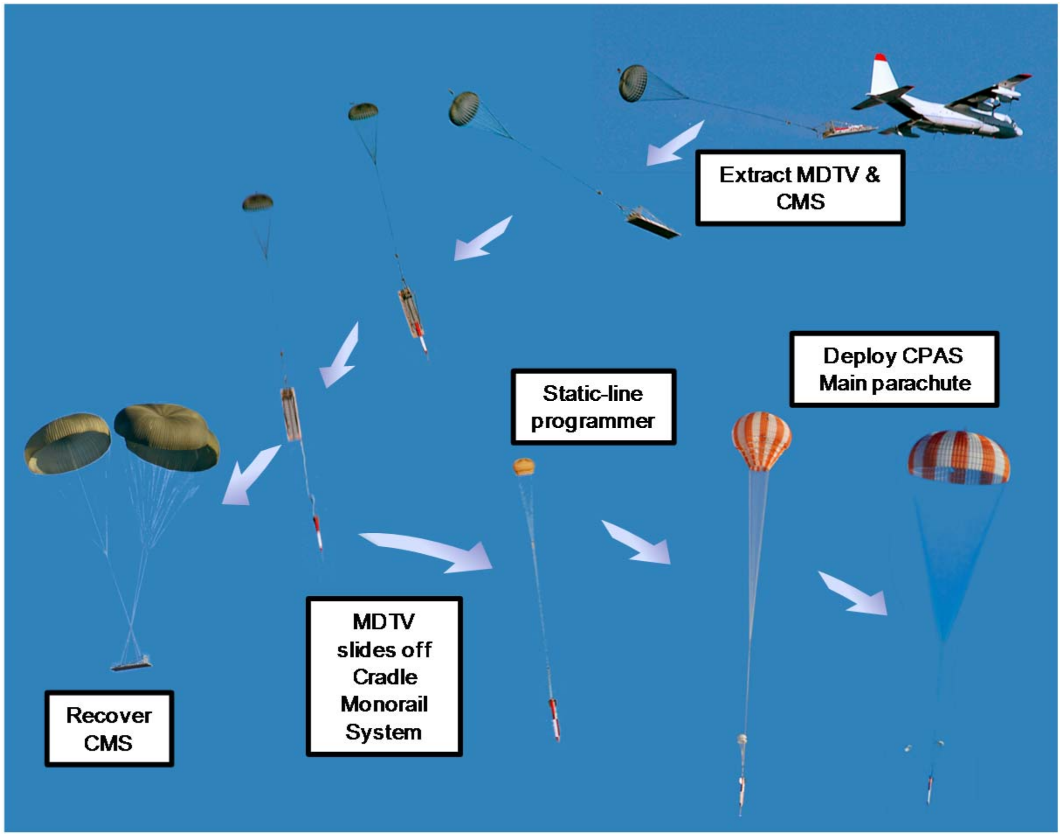
Gen I LVAD Platform with Weight Tub

- Low Velocity Aerial Delivery (LVAD)
  - Certified US Army cargo aircraft extraction method
  - Uses a Type V platform and standard Army extraction parachute
- Short Platforms (12 ft by 9 ft platform)
  - Significant pitch under the programmer by ~180º
    - Pilot or Main parachute slings could have been severed
  - Near-failure causes
    - Unstable & not well-characterized aerodynamics
    - Programmer trailing distance from platform
      - Changed on MDT-2 with no significant stability increase
    - Programmer size

MDT-1 During Main Deploy

Gen I/II Missile Shaped Vehicles

- Cradle Monorail System (CMS)
  - Allowed the MDTV to be deployed by a C-130A aircraft
  - Constructed on a 32 ft by 9 ft Type V platform to use the LVAD extraction technique
- No separation simulation created
  - Used low fidelity analysis methods and engineering judgment
  - Separation occurred at the time of lowest dynamic pressure predicted in preflight simulations
  - Assumed an instantaneous separation
  - Post-test analysis proved that separation occurs in 1.5 seconds



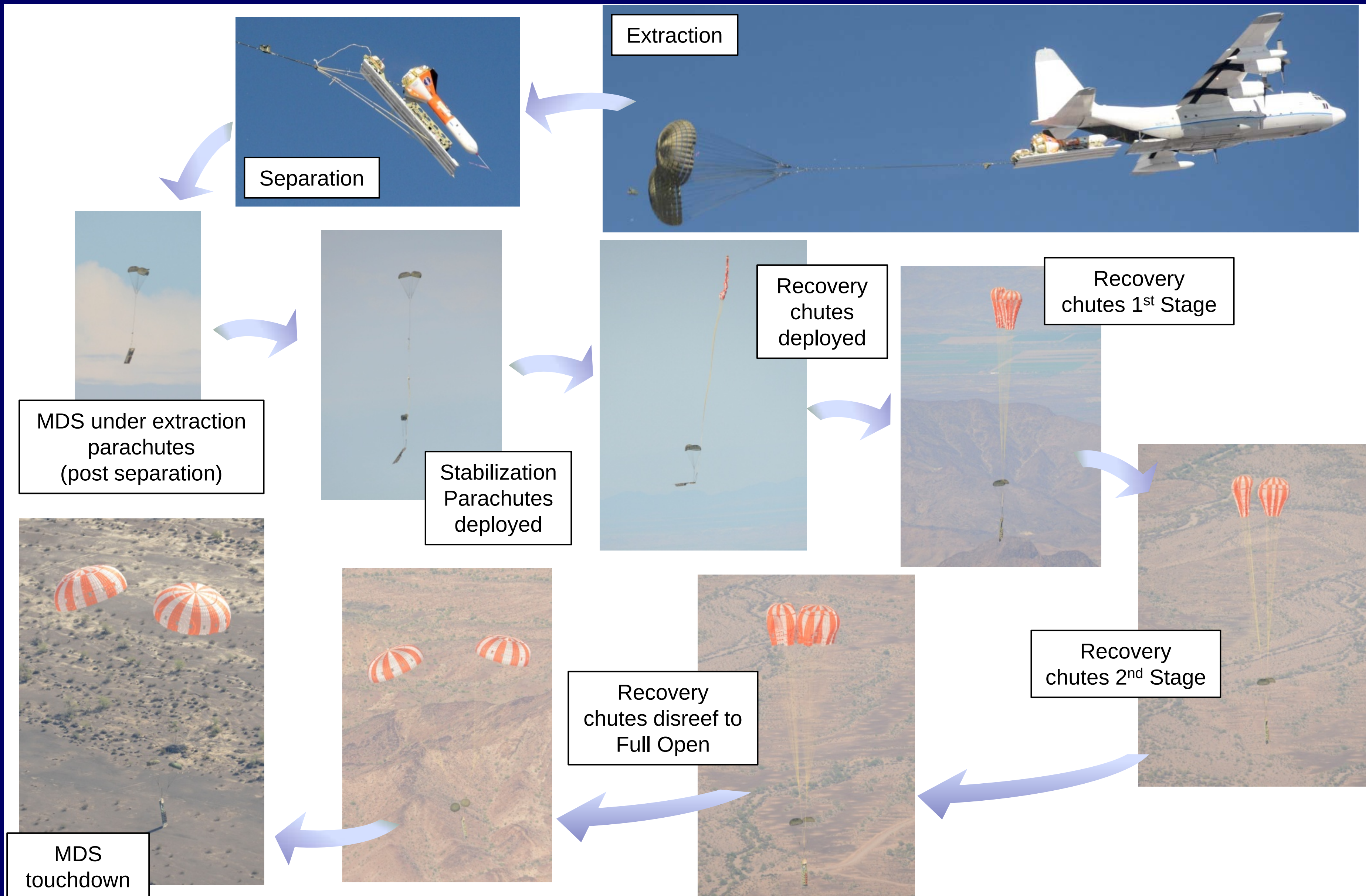
Summary of Generation II Tests

Test Name	Number of Parachutes			Vehicle Type	Primary Test Objective
	Programmer	Drogues	Mains		
MDT-2-1	1 Drogue	1	1	MDTV/CMS	Main skipped 1st reefing stage
MDT-2-2	1 Drogue	1	1	MDTV/CMS	Main skipped 2nd Stage
MDT-2-3	0	1	1	MDTV/CMS	Increased Main Porosity
CDT-2-1	0	2	2	Weight Tub	Main Modified Line Length
CDT-2-2	0	2	2	Weight Tub	Increased Main Porosity
CDT-2-3	0	2	3	Weight Tub	Increased Main Porosity

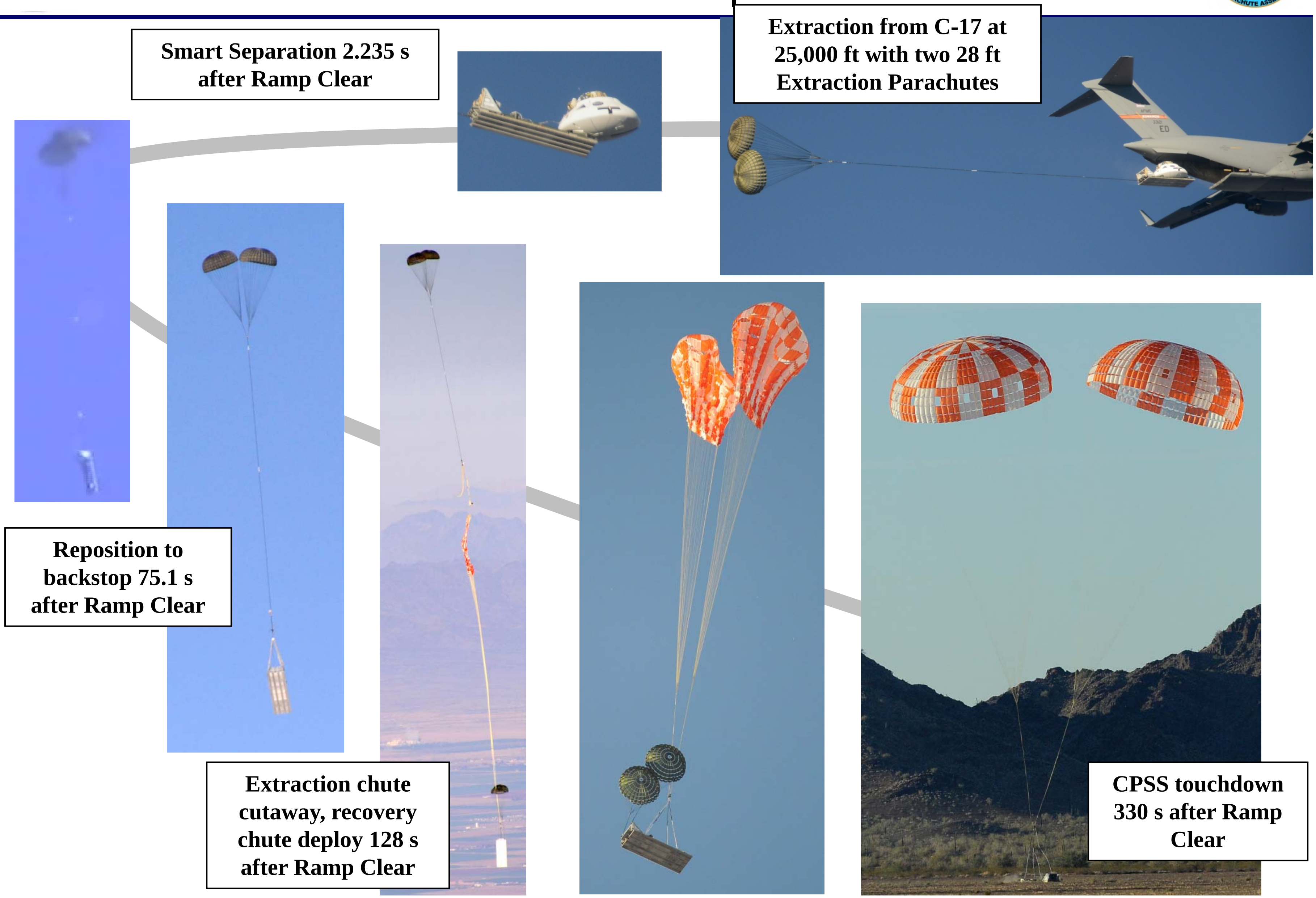
MDT – Main Development Test
CDT – Cluster Development Test

MDTV – Medium Drop Test Vehicle
CMS – Cradle Monorail System

MDS (Mid-Air Deployment System) Sequence

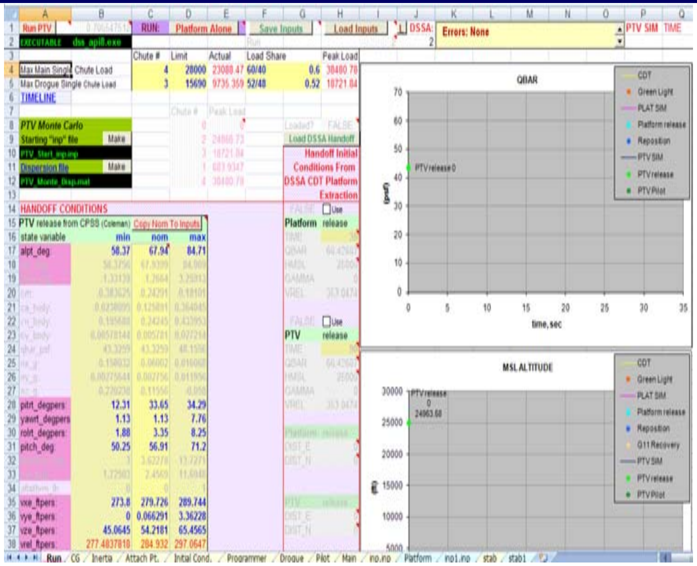


CPSS Test Sequence



Trajectory Simulations

- CAPSIM & PalletSIM
  - Used to independently model two-vehicle systems post separation
  - Not used in EDU test phase
- DSS
  - High fidelity 6-DOF trajectory simulation
  - Does not have multi-body capability
  - Uses a composite model approach to simulation parachute clusters
- ADAMS
  - Commercial multi-body simulation
  - Models contact forces between bodies
  - Used for EDU extraction and separation phases
- Flight Analysis and Simulation Tool (FAST)
  - 6-DOF multi-body trajectory simulator
  - Utilizes Lockheed Martin developed hi-fi parachute model
  - Currently being phased in as primary tool for preflight predictions

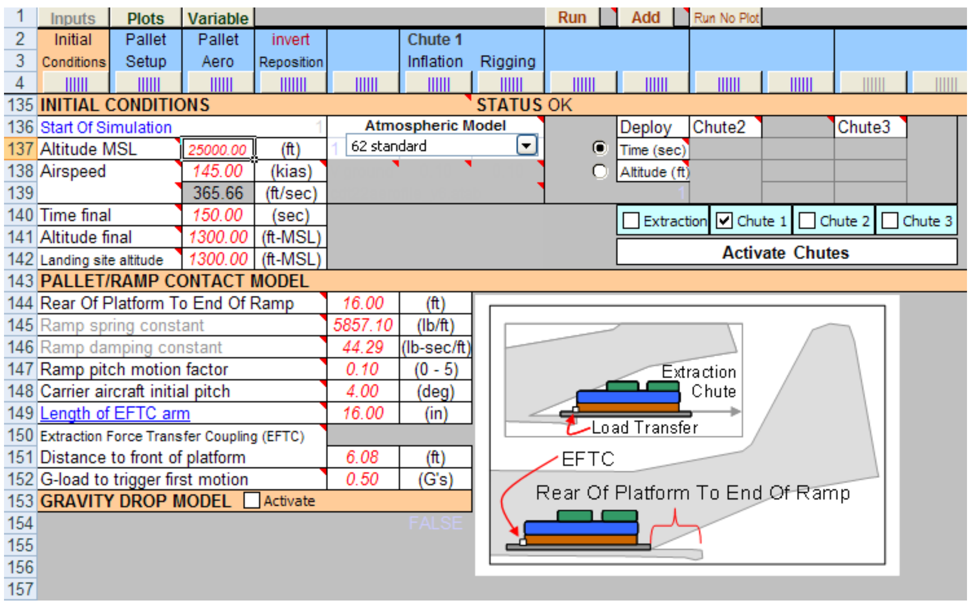


CAPSIM GUI

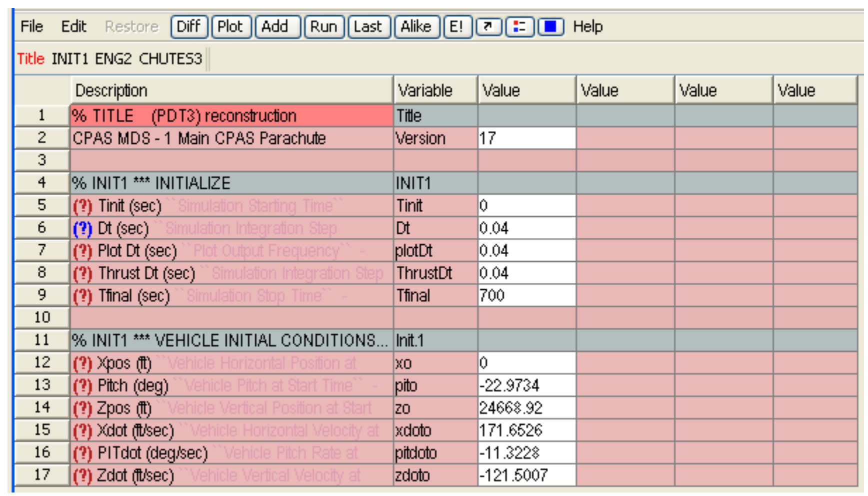
ADAMS Overlay

Trajectory Simulations

- Decelerator Simulation System Application (DSSA)
  - Provides end-to-end 6-DOF simulations of Type V LVAD tests
  - Includes an aircraft extraction model
  - Uses DSS parachute model
- DTV-Sim
  - 2-DOF simulation without an aircraft extraction model
  - Provides a point mass trajectory of any vehicle type
  - Uses DSS parachute model



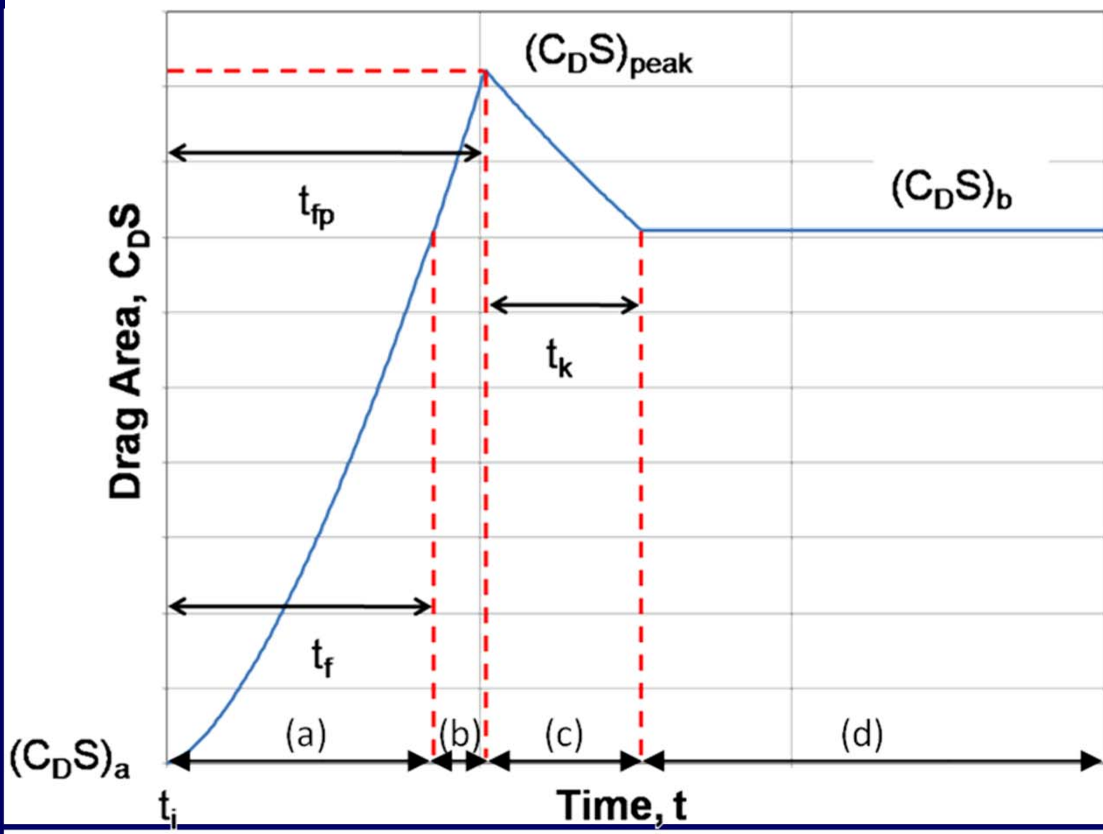
DSSA GUI

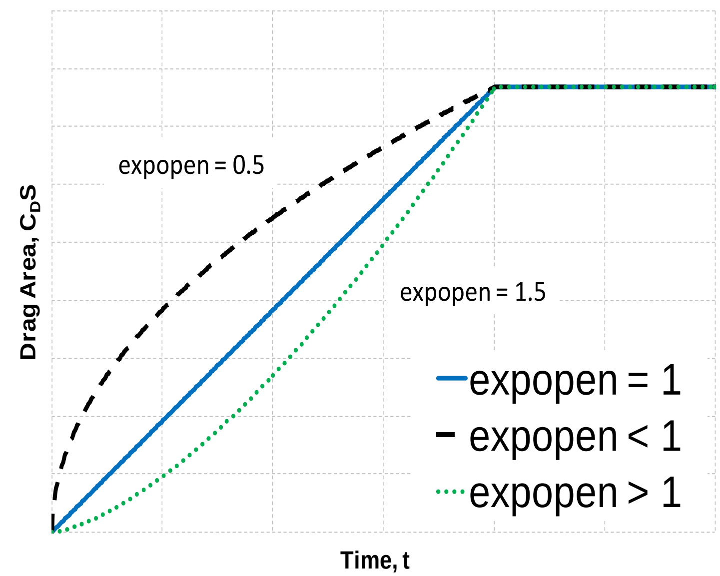


DTV-Sim GUI

Parachute Parameters

Factor	Definition
C_D	Drag coefficient (of full open parachute)
n	Canopy fill constant
expopen	Opening profile shape exponent
C_k	Over-inflation factor
t_k	Time to ramp down after stage over-inflation

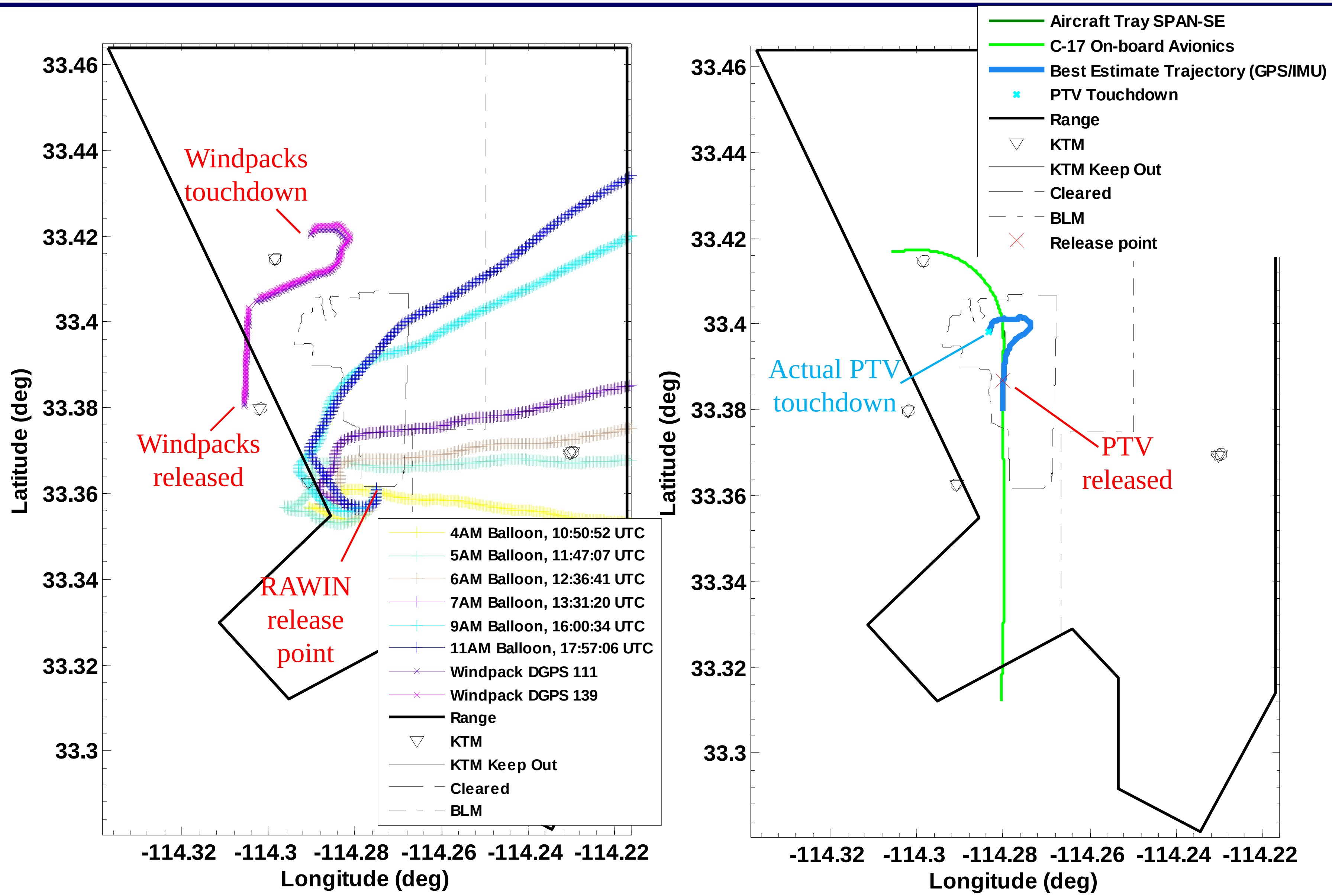




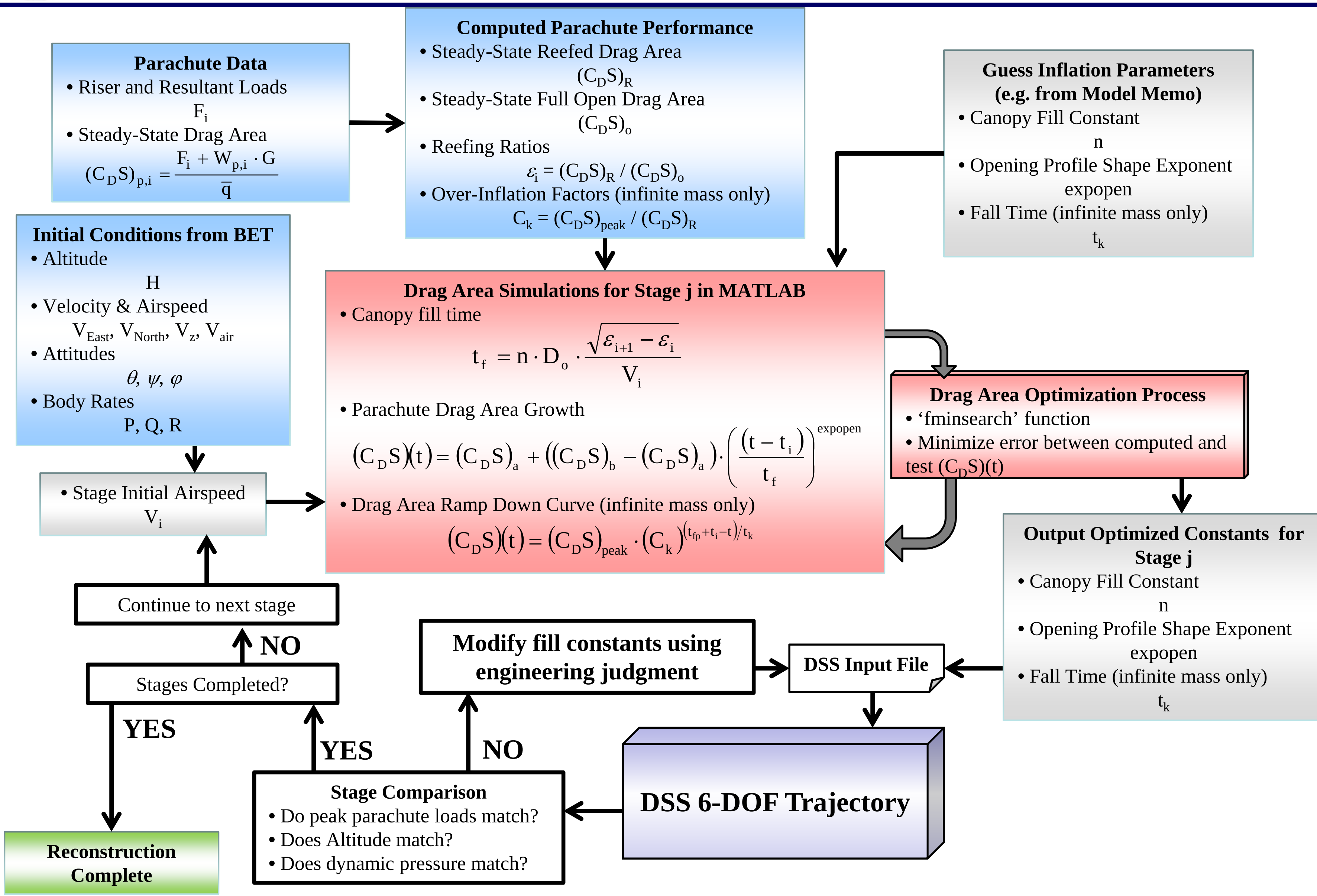
Day of Flight Simulations & Lessons Learned

- Wind data
  - Preflight predictions are done concerning wind contingency release altitudes
  - Wind measurements gathered hourly from RAWIN balloons
    - Balloon data is input into Sasquatch to determine the test article footprints
  - Ground winds can cause parachute and test vehicle damage
    - Tests are timed to occur immediately after sunrise when winds are at a minimum
- Release altitudes
  - Gen I and II data showed higher than planned release altitudes
  - Changes were made to provide the air crew with an indicated pressure altitude instead of the previously used geometric altitude
  - Tests have shown that this procedure causes vehicles to be dropped at the planned altitude

Map of Soundings and PTV Flight



Parachute Reconstruction Process



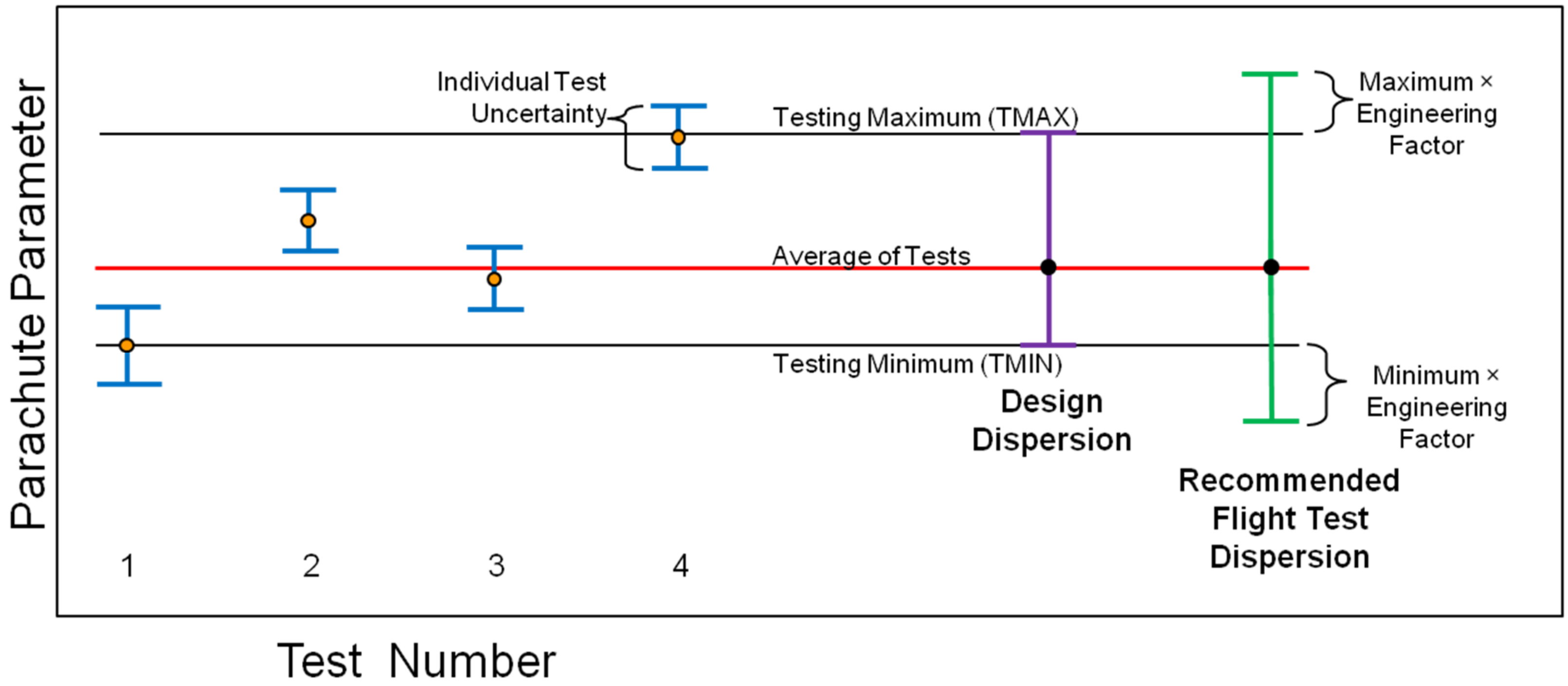
CPAS Flight Performance Requirements

- Probability of meeting requirements
  - Loads
    - Probability per table with 50% confidence
  - ROD (planned for Rev C)
    - 99.87% probability of meeting the requirement with 90% confidence
  - Torque (planned for Rev C)
    - 99.87% probability of meeting the requirement with 90% confidence
- Necessitates the use of statistical assessments

Chute Loads	Reference Mission	Case	Probability of Meeting Design Limit Load
Drogue Loads	High altitude abort/entry	Nominal	0.9987
		One-drogue failure	0.9773
	Low altitude/pad aborts	Nominal	0.9773
		One-drogue failure	0.8413
Main Loads	High altitude abort/entry	Nominal	0.9987
		One-main failure	0.9773
		One-drogue failure	0.9773
		One-main and one-drogue failure	0.8413
	Low altitude/pad aborts	Nominal	0.9773
		One-main failure	0.8413
		One-drogue failure	0.8413
		One-main and one-drogue failure	0.8413

Uniform Dispersions

- Previous Model Memos included uniform dispersions
  - Design dispersions – maximum and minimum seen in test
  - Flight test dispersions – engineer factor around design dispersions
    - 5% for C_DS
    - 10% for other parameters



Further Updates to Statistical Dispersions