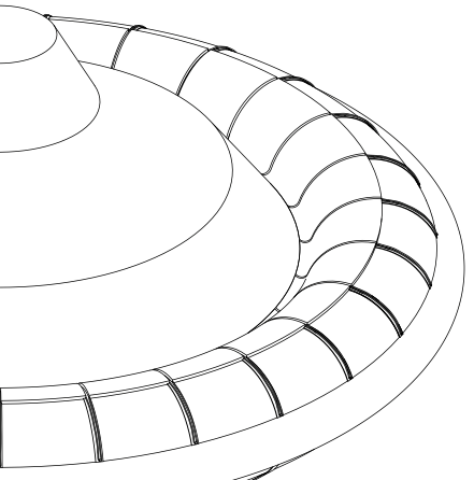
Construction of Super-sonic Flight Dynamics Test (SFDT-2) Vehicle Monte Carlo Splashdown Footprints for use in Range Safety and Recovery Planning



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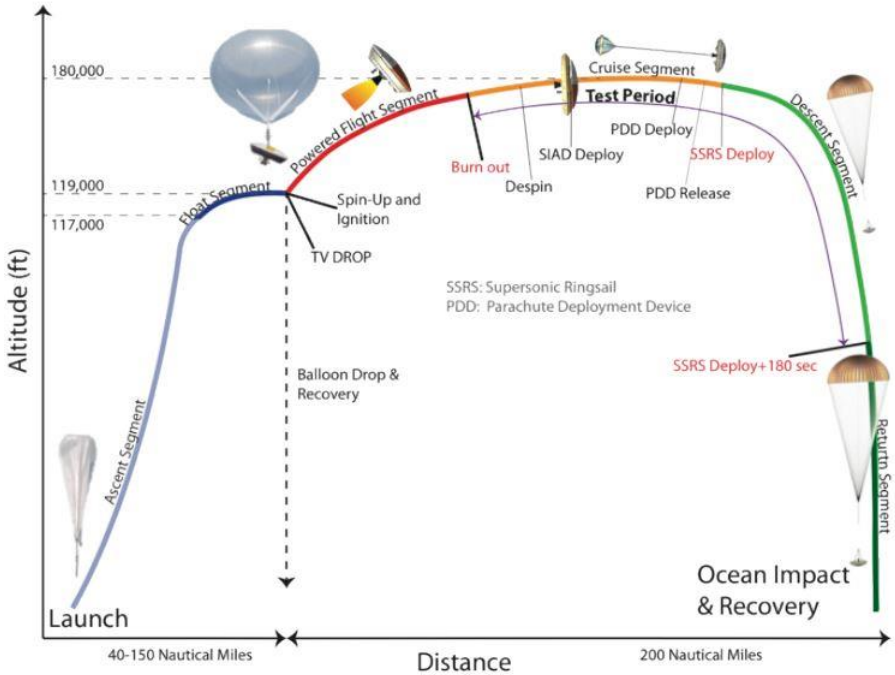
2/15/16

Agenda

- Overview of Low Density Supersonic Decelerator (LDSD) SFDT-2 flight profile
- Description of Monte Carlo flight dynamics simulations performed
- Modeling and uncertainties
- Results with statistical prediction of test vehicle splashdown location
- Use of Monte Carlo results for range safety and recovery planning

Nominal SFDT Flight Profile and Event Timeline

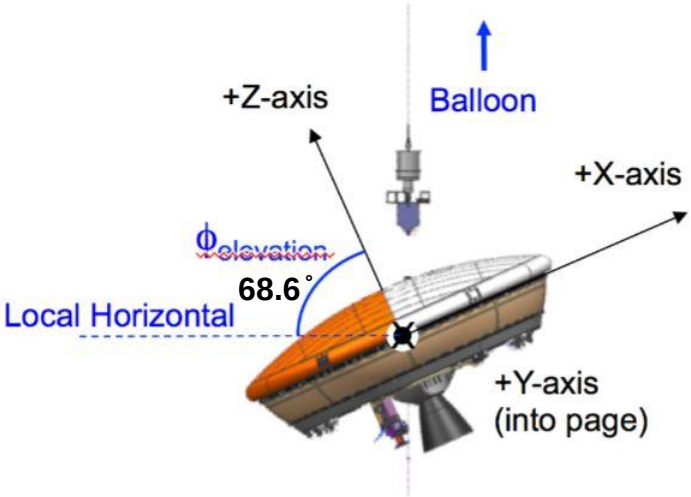


Event	Time [sec]
TV Release	0.0
Spin-up first motor pair	0.36
Spin-up second motor pair	1.66
Star 48 main engine ignite	2.16
Star 48 main engine burnout	72.6
Spin-down first motor pair	73.6
Spin-down second motor pair	74.1
SIAD Deploy	118.3
PDD Mortar Fire	127.3
Parachute Deploy	140.0
End Science Phase	320.0
Altitude 15,000 ft	1850.0
Splashdown	2450.0

- Balloon launched from Pacific Missile Range Facility (PMRF) in Kauai delivers test vehicle to its release altitude ~36.5 km over the Pacific ocean
- Vehicle spun-up to 300 deg/s for stability using two pair of solid rocket motors
- Star 48 main engine accelerates TV to Mach 4 at altitude ~ 50 km
- Inflatables are deployed during the test phase:
  - SIAD : Mach 3.0
  - PDD (ballute): Mach 2.8
  - Ringsail Parachute: Mach 2.35
- TV splashes down west of Kauai ~ 40 minutes after release

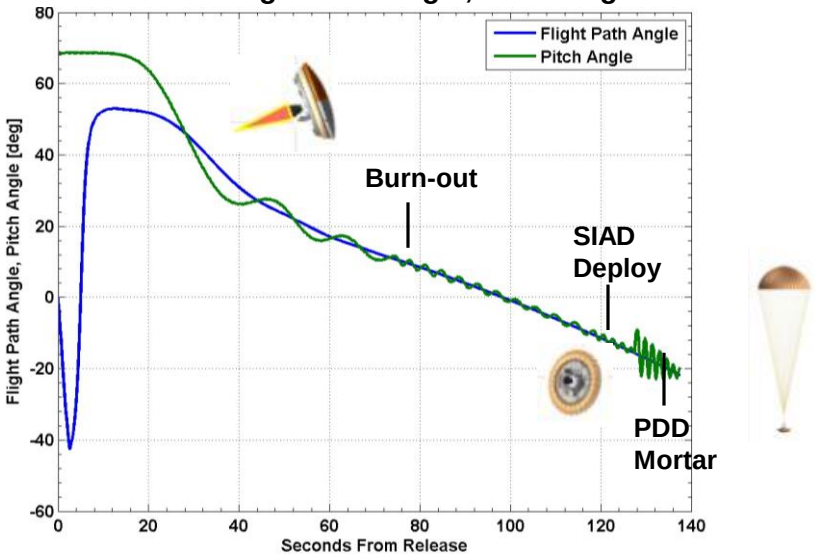
Vehicle Orientation During Phases of Flight

Connected to Balloon

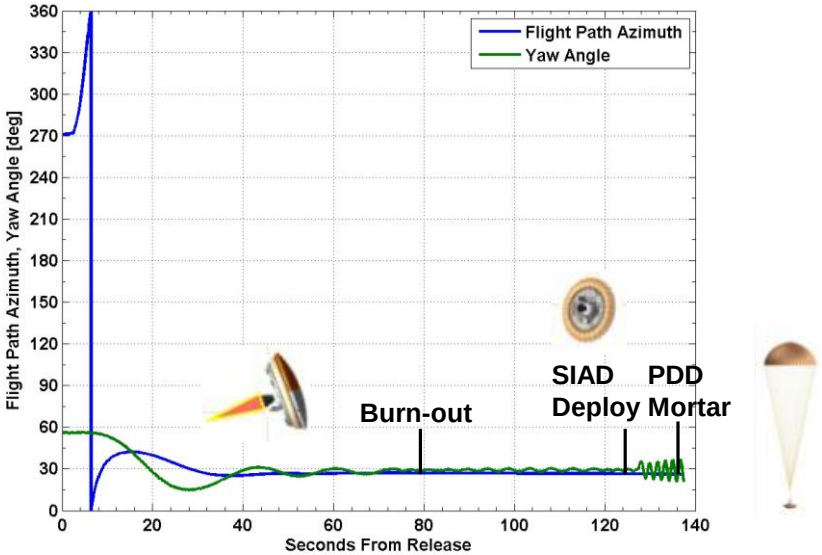


- Initial hang (elevation) angle while attached to balloon 68.6 deg
- Initial heading angle selected on launch day
- During the powered phase, TV spin-axis pitches over to the velocity vector due to the aerodynamic trimming torque
- TV also rotates out-of-plane due to the aerodynamic torque causing a gyroscopic precession
  - Flight path azimuth rotates ~ 30 degrees between TV release and splashdown

Simulated Flight Path Angle, Pitch Angle



Simulated Flight Path Azimuth, Yaw Angle



DSENDS Simulation

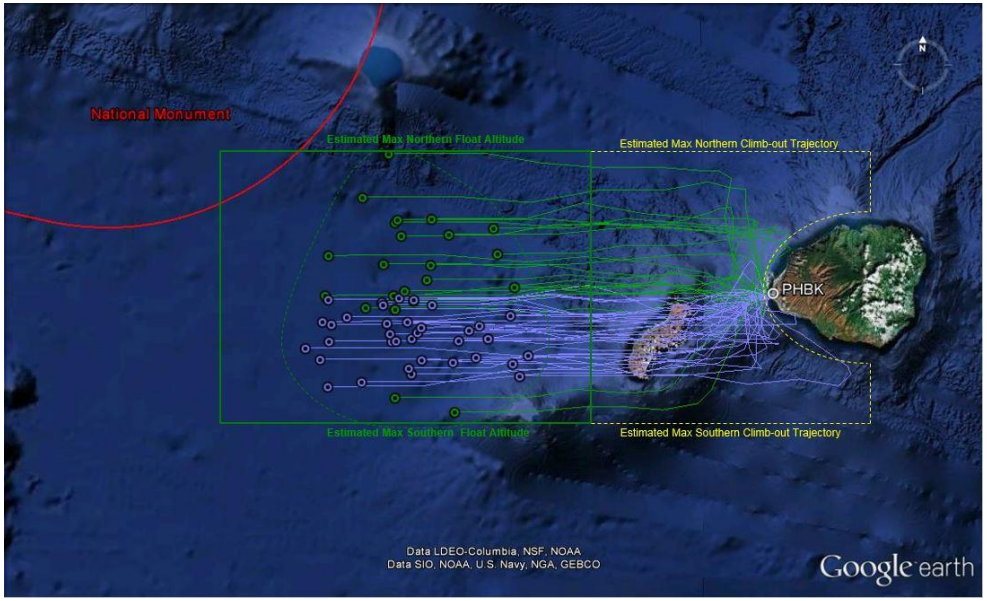
- JPL flight dynamics simulation DSENDS used for producing range safety results presented here
- DSENDS is capable of modeling both 3-DOF and 6-DOF equations of motion. For the SFDT-2 simulation, DSENDS combined both DOF modes.
  - 6-DOF from TV release through parachute full inflation
  - 3-DOF from parachute inflation through splashdown
- Interfaces with Fortran code for aerodynamics and atmosphere model
  - NASA LaRC aerodynamic database code
  - EarthGRAM 2010 atmosphere model
- Python user modules were created to apply external forces/torques to the vehicle for the models:
  - Star 48 engine
  - Spin-up/spin-down thrusters
  - Inflatables: ballute and parachute
- DSENDS simulations can be run in parallel processing mode so that thousands of runs can be generated for producing Monte Carlo statistical results
- TV splashdown results were verified through comparison test cases with LaRC POST simulation

Description of Range Safety Work

- Range safety requirements specified for SFDT-2:
  - to aid recovery ships in the safe and rapid extraction of the TV hardware from the ocean
  - to meet requirements in the interest of safety to the population of the islands of Kauai and Nihau
  - to ensure the TV could not splashdown anywhere in the region of the Papahanaumokuakea Marine National Monument
- In order to meet requirements, statistical estimates of the splashdown locations were produced for nominal and off-nominal test scenarios
  - Monte Carlo simulations were performed using statistically varied conditions to produce a dispersed set of splashdown locations
  - Gaussian probability ellipses were used to represent the sets of splashdown points
    - Dimensions of the ellipse semi-major, semi-minor axis, and azimuth are derived from the standard deviations of the splashdown points
    - Size of ellipse is scaled according to the number of standard deviations desired to fit the set of points: 3σ was used for range safety work
  - Ellipses are used to verify that the splashdown prediction does not violate any of the restricted areas specified by the range

Simulation Variations Performed

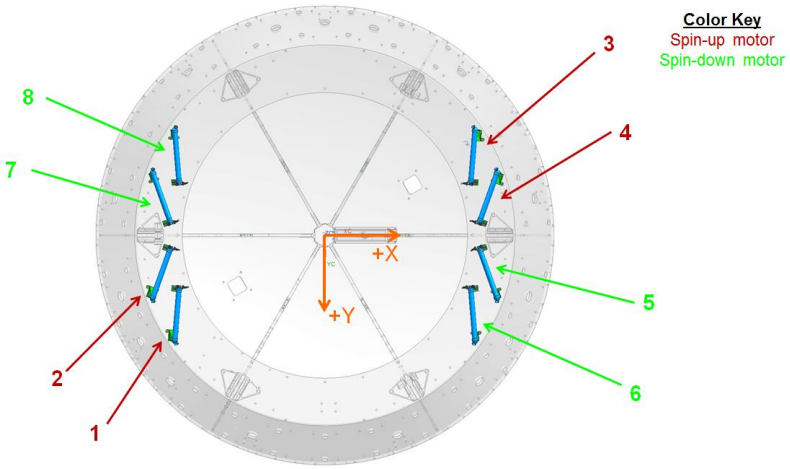
- Initial altitude:
  - Due to varying atmospheric conditions balloon might not achieve desired float altitude of 36.5 km
    - Anomalous conditions altitude range = 20 km – 34 km
    - Over performance of balloon could reach float altitudes up to 38 km
- Initial Heading:
  - Variation in atmospheric wind results in a large variation in TV release locations
  - Selection of the test vehicle heading on launch day could vary considerably due to location at float altitude
  - Splashdown footprint dimensions vary in size (up to 10%) and azimuth due to the selection of the spacecraft heading relative to the prevailing winds



Simulated balloon ground track from launch to float using PMRF wind files for June 2007-2009
Balloon simulation performed by NASA Columbia Scientific Balloon Facility (CSBF)

Off-Nominal Scenarios Considered

- Ignition failure of any combination of spin-up motors
  - 4 Spin-up motors mounted radially
  - Thrust vector directed tangentially in X-Y direction to provide rotational acceleration about +Z
  - Motors canted in Z direction to avoid plume impingement
  - Motors fired in pairs with 1.3 sec separation
    - First pair: #1 and #3
    - Second pair: #2 and #4
  - 14 combinations of one, two, and three motors out
- Off-nominal deployment scenarios
  - No SIAD Deployment
  - No Parachute Deployment
  - No SIAD or Parachute Deployment
  - Partially opened parachute (streamer)
  - Varying drag conditions
    - Tumbling and trimming capsule
    - Tumbling and trimming SIAD



Summary of Monte Carlo Cases Performed

Monte Carlo Scenario Permutations Used to Construct SFDT-2 Range Safety Splashdown Footprints							
Flight Test Configuration Variant	**Simulation Input Value/Configuration**						
Altitude at TV Release (km)	**20**	**25**	**30**	**32**	**34**	**36.5***	**38**
Heading at TV Release (deg)	**56***	**90**	**120**	**240**			
Deployment Conditions (Zero Spin-Up Motors Out)	**Full Parachute and SIAD Deploy***	**Partial Parachute Deploy (Streamer)**	**No Parachute Deploy (Trimming SIAD)**	**No Parachute Deploy (Tumbling SIAD)**	**No SIAD Deploy**	**No Deploy (Trimming Capsule)**	**No Deploy (Tumbling Capsule)**
Spin-Up Motor Out (14 Combinations)	**Single Motor Out (4 combinations)**	**Two Motors Out (6 combinations)**	**Three Motors Out (4 combinations)**				
Deployment Conditions (For Spin-Up Motor Out Cases)	**Full Parachute and SIAD Deploy**	**Partial Parachute Deploy (Streamer)**	**No Parachute Deploy (Trimming SIAD)**				

* Nominal test flight configuration

- A total of 1372 Monte Carlo simulations were performed for all scenarios in table

Major Contributors to Splashdown Footprint Dimensions

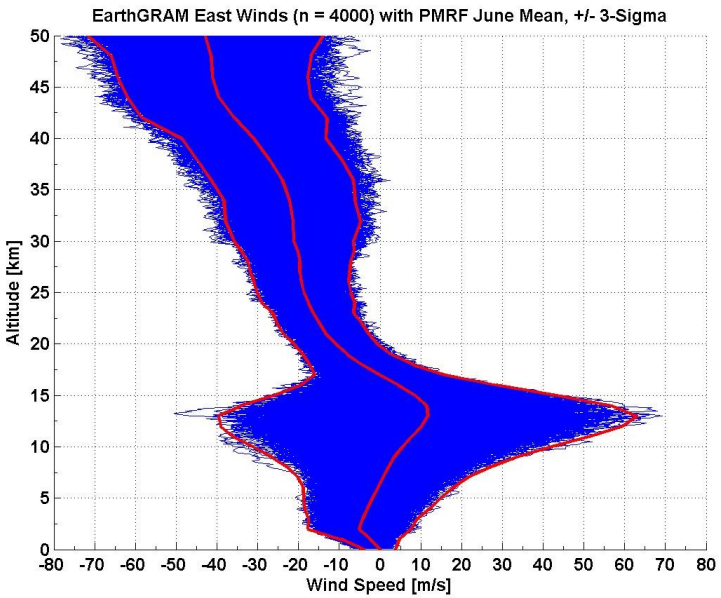
- The largest contributors to the size/shape of the splashdown footprint:
  - Star 48 main engine
    - Uncertainties in thrust level and burn time result in large variations in downrange distance traveled
    - Engine mounting and thrust vector misalignments
    - Vehicle c.g. offsets from thrust vector centerline
  - Winds during the parachute phase
    - Prevailing westerly winds contribute to East-West splashdown dispersion
    - Monthly wind variations at PMRF used in simulation
  - Flight software triggering of deployments for spin-up motor scenarios
    - Large variation in Mach number at SIAD deployment
    - In some cases backup timer must be used for SIAD/parachute deploy, resulting in very low altitudes at parachute deploy
  - Aerodynamic uncertainties

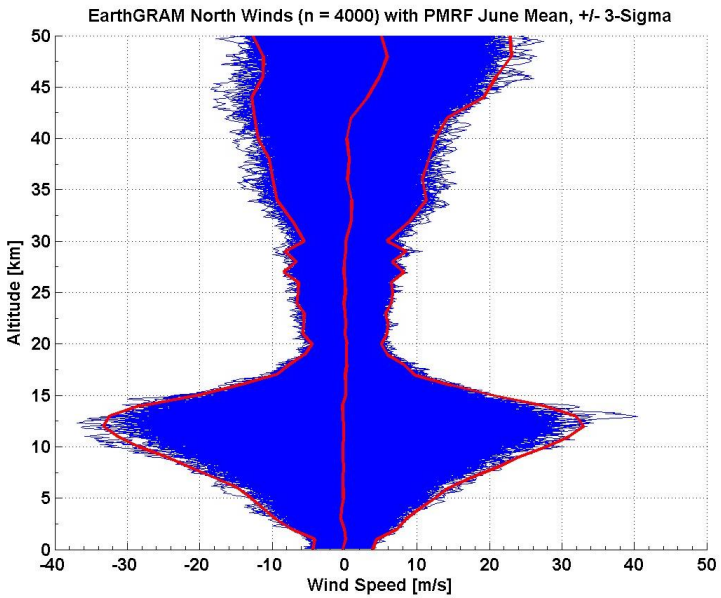
Dispersion of Initial Conditions

- ~ 250 parameters varied in Monte Carlo simulation, largest contributors to dispersions in splashdown footprint shown
- 2000 dispersed simulations were shown to be sufficient for computing footprint dimensions
- Altitude variations defined by uncertainties in atmospheric density
- No lat/lon dispersions at TV release. GPS measurements used.

Category	Error Source	Uncertainty (3σ or min/max)	Distribution
Mass Properties	Total Dry Mass	+/- 11.5 kg	Gaussian
Mass Properties	Dry Mass CG Location (x / y / z)	43.0 / 42.0 / 34.0 mm	Gaussian
Mass Properties	Dry Moments/Products of Inertia	Ixx,Iyy,Izz: 100.0 / 82.0 / 160.0 kg-m^2 Ixy, Ixz, Iyz: 100.0 / 20.0 / 17.0 kg-m^2	Gaussian
Mass Properties	Star48 CG Location	start/end: 12.7, 25.4 mm long axis start/end: 9.0, 18.0 mm lateral	uniform
Mass Properties	Star48 Mass Properties: Prop, Dry, Burnout, Slag Mass & MOI	Prop: 5 kg; Dry: 6.3 kg; BO: 10.2 kg Slag: +/- 50% Ixx,Iyy,Izz: 16.6 / 16.6 / 16.4 kg-m^2 Ixx, Iyy, Izz: 3.9 / 3.9 / 2.4 kg-m^2	Gaussian uniform uniform uniform
Propulsion	Star48 Mounting Tilt Alignment	0 to 0.3 deg	uniform
Propulsion	Star48 Mounting Location	+/- 9.0 mm long axis 0 to 10.0 mm lateral	uniform
Propulsion	Star48 Thrust Reaction Offset	+/-20.0 mm long axis 0 to 1.0 mm lateral	uniform
Propulsion	Star48 Thrust / Isp	3.88% / 0.5%	Gaussian
Propulsion	Star48 / Spin Motor Thrust Dir	0 to 0.3 deg / 0 to 2.0 deg	uniform
Propulsion	Spin Motor Delay; Burnout; Temp	0.0075s; 5%; 1.5%	Gaussian
Propulsion	Spin Motor Impulse	5%	Gaussian
Propulsion	Spin Motors Reaction Location	+/-10.0 mm long axis 0 to 10.0 mm lateral	uniform
Aerodynamics[3]	TV/SIAD (6-DOF)	Per sfdt_aero_v1.3.f, 3/11/2013	Gaussian
Aerodynamics[3]	TV/SIAD (Drag Only) Trimming/ Tumbling	+/- 15%	uniform
Aerodynamics[3]	Parachute Full Deployment (3-DOF)	+/-12.5% to 25.0 %	uniform
Aerodynamics[4]	Parachute Partial Deployment (3-DOF)	0.05 to 0.25	uniform
Aerodynamics[3]	Ballute (3-DOF)	Ballute +/- 20.0%	Gaussian
Staging	Balloon Release Density	+/-0.000245 kg/m^3	uniform
Staging	Release Mech / Pendulum Angle	+/- 0.35 deg / 0.34 deg	uniform
Staging	Release Azimuth	+/- 5.0 deg	uniform
Staging	Release Mech/Pendulum Rates	+/- 0.1 / 0.08 deg/s	uniform
Atmosphere[5]	Atm Density,Temp,Press,Winds	EarthGRAM 2010_v3 / PMRF 1983 Range Reference Atmosphere	Gaussian

Wind Dispersions

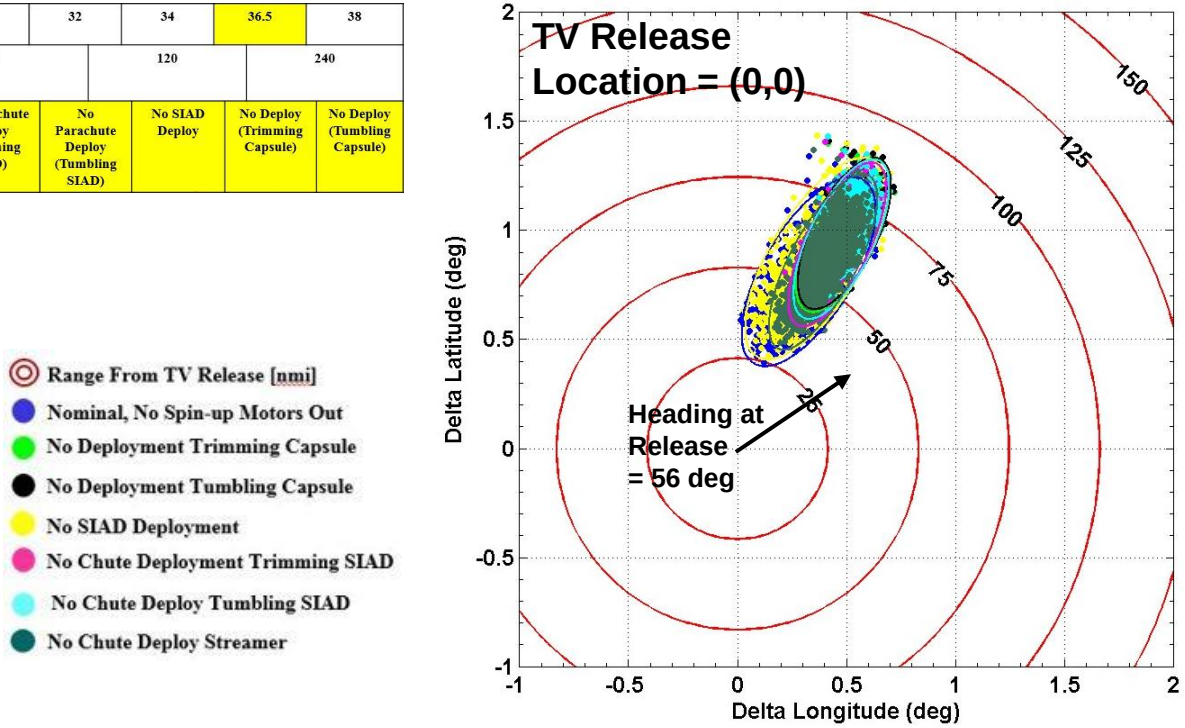




- Atmosphere model was provided for PMRF as tabular data
  - Density, pressure, east-west winds, north-south winds as a function of altitude
  - Valid for Barking Sands, HI, Latitude 22.03 N, 159.78 W
  - Valid for year 1983, with altitude range 0 to 70 km
  - Data was available for 2006, but only with altitude range 0 to 30 km
  - Standard deviations for data also provided as function of altitude
- Tables are used within EarthGRAM code so that Monte Carlo dispersions can be applied
- Because the TV is launched over the ocean, atmospheric data must be blended with EarthGRAM Global Climate Model (GCM) as function of distance from Range Reference Atmosphere (RRA) latitude/longitude

Monte Carlo Splashdown Footprints for Nominal, Off-Nominal Deployment Scenarios. Altitude 36.5 km, Heading 56 deg

Altitude at TV Release (km)	20	25	30	32	34	36.5	38
Heading at TV Release (deg)	56		90		120		240
Deployment Conditions (Zero Spin-Up Motors Out)	Full Parachute and SIAD Deploy	Partial Parachute Deploy (Streamer)	No Parachute Deploy (Trimming SIAD)	No Parachute Deploy (Tumbling SIAD)	No SIAD Deploy	No Deploy (Trimming Capsule)	No Deploy (Tumbling Capsule)

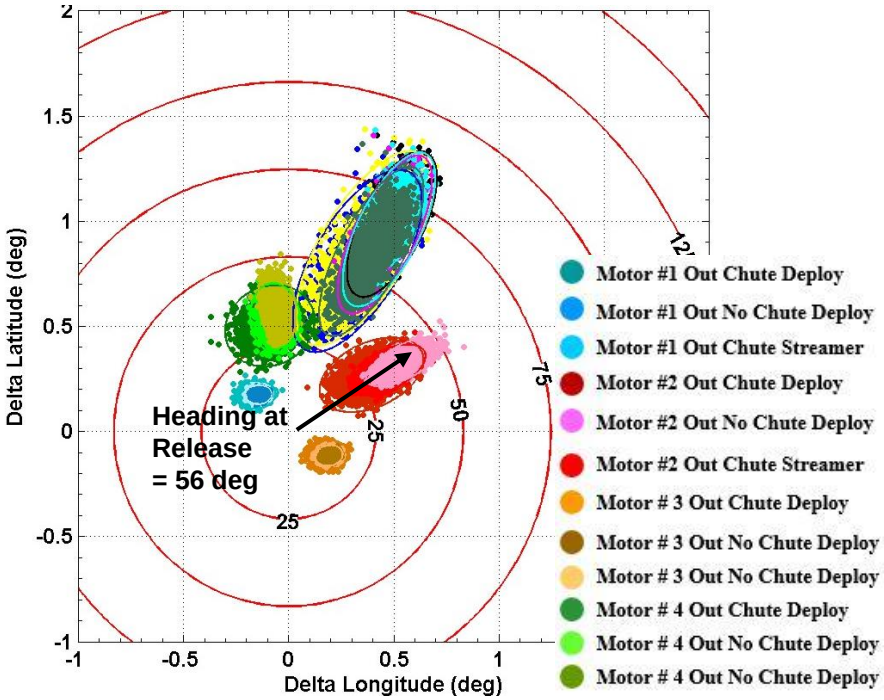


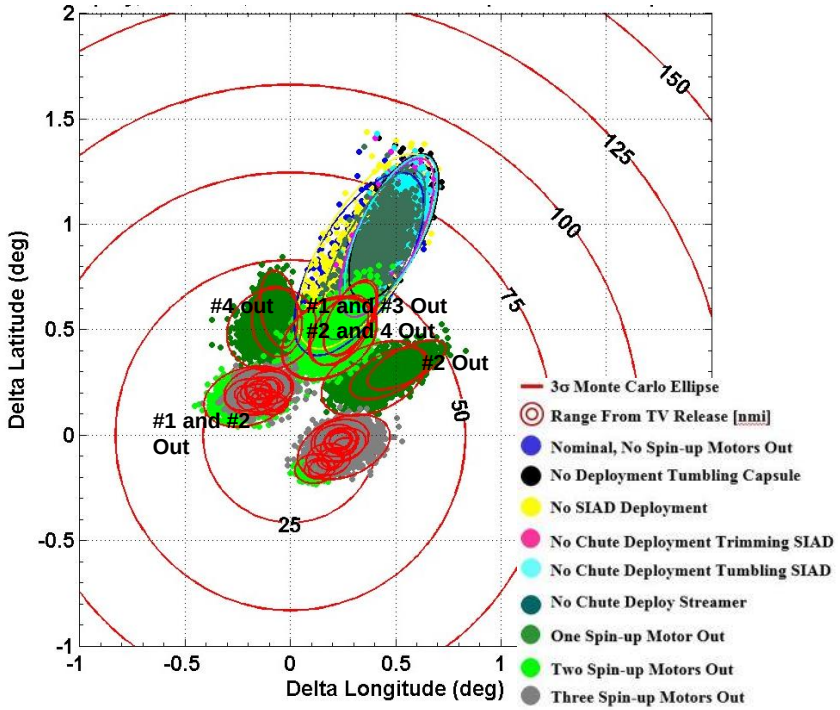
- Nominal semi-major X semi-minor axis 29.5 X 12.5 nmi 3σ
- Largest ellipse no-SIAD with full chute deployment: (31.6 X 12.6 nmi 3σ)
- As expected, no deployment of inflatable cases travel furthest downrange, 65 nmi mean, 88 nmi 3σ
- Effect of westerly wind drift apparent for chute deployment cases, resulting in some asymmetry in the fit of ellipse to data in semi-minor axis

Monte Carlo Splashdown Footprints for Nominal, Spin-up Motor Out and No-Deployment Scenarios, Alt 36.5 km, Heading 56 deg

Altitude at TV Release (km)	20	25	30	32	34	36.5	38
Heading at TV Release (deg)	56		90		120		240
Deployment Conditions (Zero Spin-Up Motors Out)	Full Parachute and SIAD Deploy	Partial Parachute Deploy (Streamer)	No Parachute Deploy (Trimming SIAD)	No Parachute Deploy (Tumbling SIAD)	No SIAD Deploy	No Deploy (Trimming Capsule)	No Deploy (Tumbling Capsule)
Spin-Up Motor Out (14 Combinations)	Single Motor Out (4 combinations)		Two Motors Out (6 combinations)			Three Motors Out (4 combinations)	
Deployment Conditions (For Spin-Up Motor Out Cases)	Full Parachute and SIAD Deploy		Partial Parachute Deploy (Streamer)			No Parachute Deploy (Trimming SIAD)	

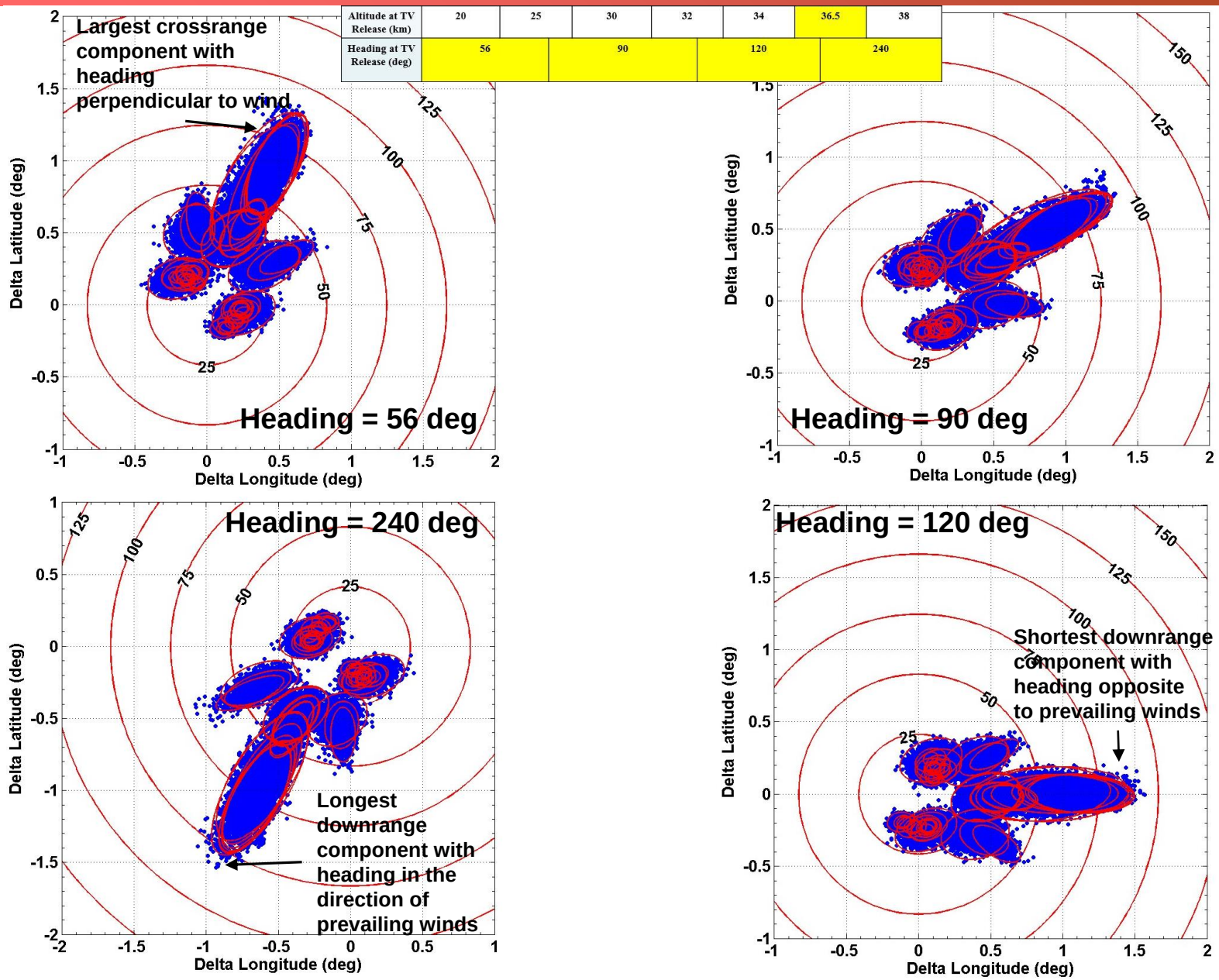
Altitude at TV Release (km)	20	25	30	32	34	36.5	38
Heading at TV Release (deg)	56		90		120		240
Deployment Conditions (Zero Spin-Up Motors Out)	Full Parachute and SIAD Deploy	Partial Parachute Deploy (Streamer)	No Parachute Deploy (Trimming SIAD)	No Parachute Deploy (Tumbling SIAD)	No SIAD Deploy	No Deploy (Trimming Capsule)	No Deploy (Tumbling Capsule)
Spin-Up Motor Out (14 Combinations)	Single Motor Out (4 combinations)		Two Motors Out (6 combinations)			Three Motors Out (4 combinations)	
Deployment Conditions (For Spin-Up Motor Out Cases)	Full Parachute and SIAD Deploy		Partial Parachute Deploy (Streamer)			No Parachute Deploy (Trimming SIAD)	





Variations in Initial Heading

Altitude at TV Release (km)	20	25	30	32	34	36.5	38
Heading at TV Release (deg)	56	90	120	240			



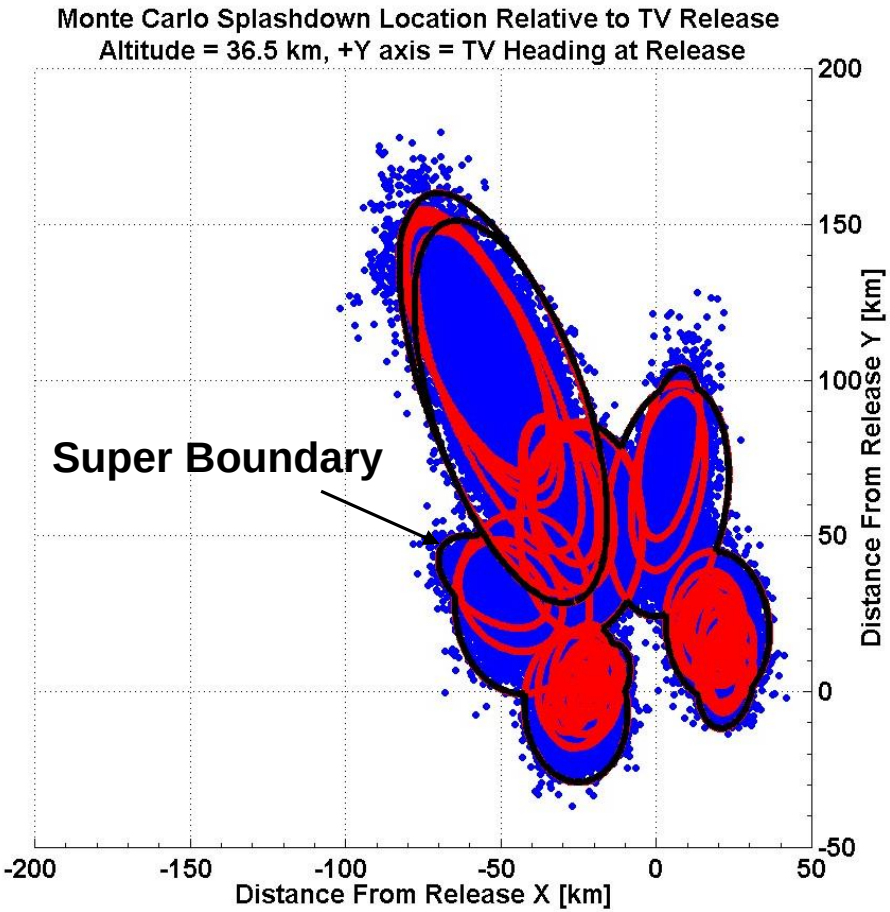
Summary of Splashdown Footprint Dimensions for Varying TV Heading

Case	Heading at Release	Nominal SIAD, Nominal Chute	No SIAD, No Chute, Tumbling Capsule	No SIAD, Nominal Chute	No Chute Deploy, Trimming SIAD	No Chute Deploy, Tumbling SIAD	No Chute Deploy Streamer
3-s Semi-major Axis [nmi]	56.0	29.5	23.1	31.6	24.9	24.1	27.0
3-s Semi-Minor Axis [nmi]		12.5	9.1	12.6	8.8	9.0	9.2
Azimuth at Splashdown [deg]		30.8	26.1	31.0	26.2	25.9	27.8
Ellipse Center Distance From TV Release [nmi]		52.1	64.6	56.1	61.8	63.6	56.0
3-s Semi-major Axis [nmi]	90.0	30.4	23.4	32.9	25.1	24.3	27.5
3-s Semi-Minor Axis [nmi]		10.8	8.1	10.8	7.8	8.0	7.9
Azimuth at Splashdown [deg]		62.3	63.0	62.8	62.5	62.5	62.3
Ellipse Center Distance From TV Release [nmi]		48.4	63.0	52.7	59.6	61.5	53.4
3-s Semi-major Axis [nmi]	120.0	29.1	22.6	31.8	24.4	23.6	26.5
3-s Semi-Minor Axis [nmi]		11.3	8.1	11.4	7.8	8.0	8.1
Azimuth at Splashdown [deg]		86.7	92.3	87.4	91.6	91.9	89.7
Ellipse Center Distance From TV Release [nmi]		47.2	62.2	51.6	58.6	60.4	52.6
3-s Semi-major Axis [nmi]	240.0	30.9	25.6	33.7	26.6	26.0	28.6
3-s Semi-Minor Axis [nmi]		12.2	9.7	12.4	9.4	9.5	9.8
Azimuth at Splashdown [deg]		210.9	205.6	213.7	206.6	206.0	208.6
Ellipse Center Distance From TV Release [nmi]		63.9	73.1	67.2	70.0	71.8	66.7

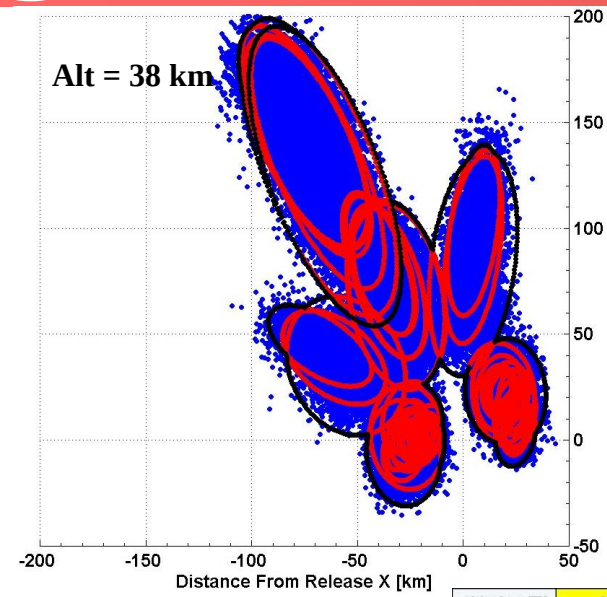
- Downrange distance to ellipse center decreases as TV heading is directed toward the East into prevailing winds
- Largest difference in ellipse dimensions 12% when comparing TV heading 120 and 240 degrees, for the case of no SIAD/no Chute deploy
- The change in flight azimuth between release and splashdown varies with TV heading at release

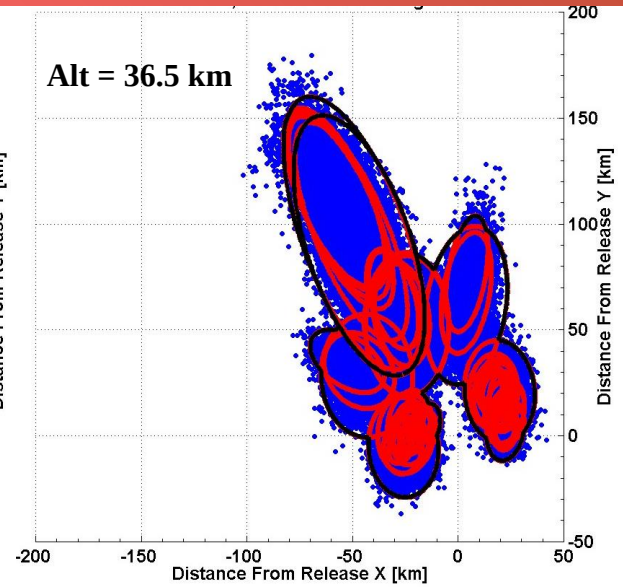
Monte Carlo Splashdown Footprint Delivered to Range: Combined TV Heading Results

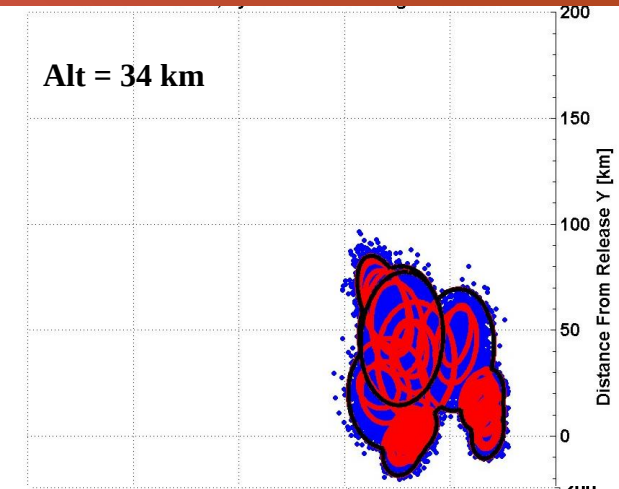
- Due to the varying size and shape of splashdown footprints as a function of TV heading, it was necessary to combine the data from all four headings into one larger ellipse
  - 8000 points total
  - Results in larger ellipse dimensions for each scenario. Nominal: 35.1 X 14.3 nmi 3σ
- Splashdown points needed to be transformed to a reference frame that was independent of TV heading and release location
  - Origin (0,0) at TV release location
  - +Y axis in the direction of heading at release
- After ellipses were computed in the new reference frame, a 'super boundary' was constructed, circumscribing all nominal and off-nominal ellipses
- The 'super boundary' was independent of both TV release location and heading
  - Used to predict the size of the splashdown footprint at any release location
  - User could translate and rotate boundary to desired location and determine the heading that fit within range boundaries



Super Boundaries for Remaining Release Altitudes







Altitude at TV Release (km)	20	25	30	32	34	36.5	38
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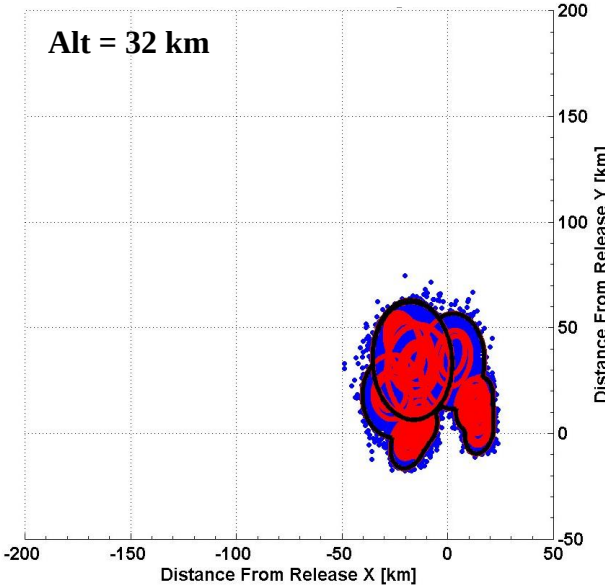
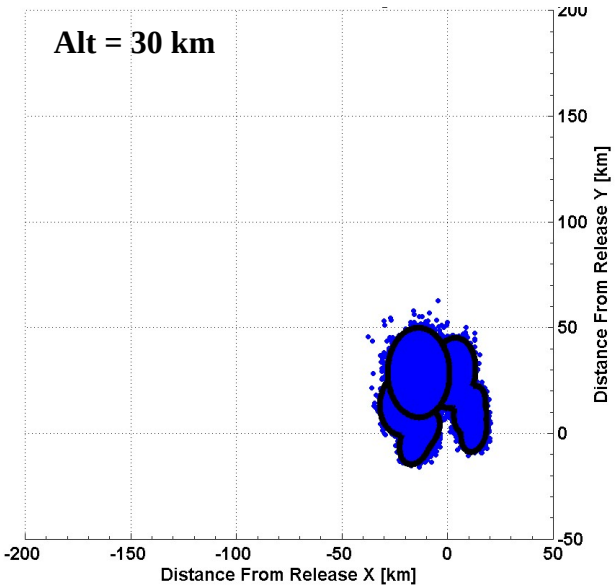
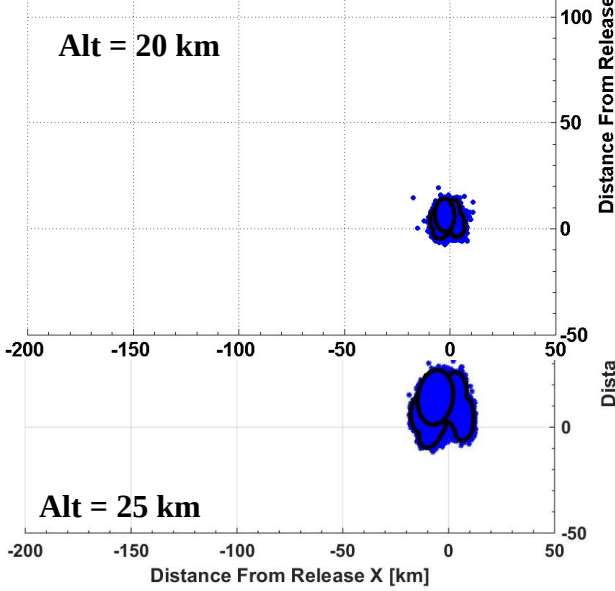
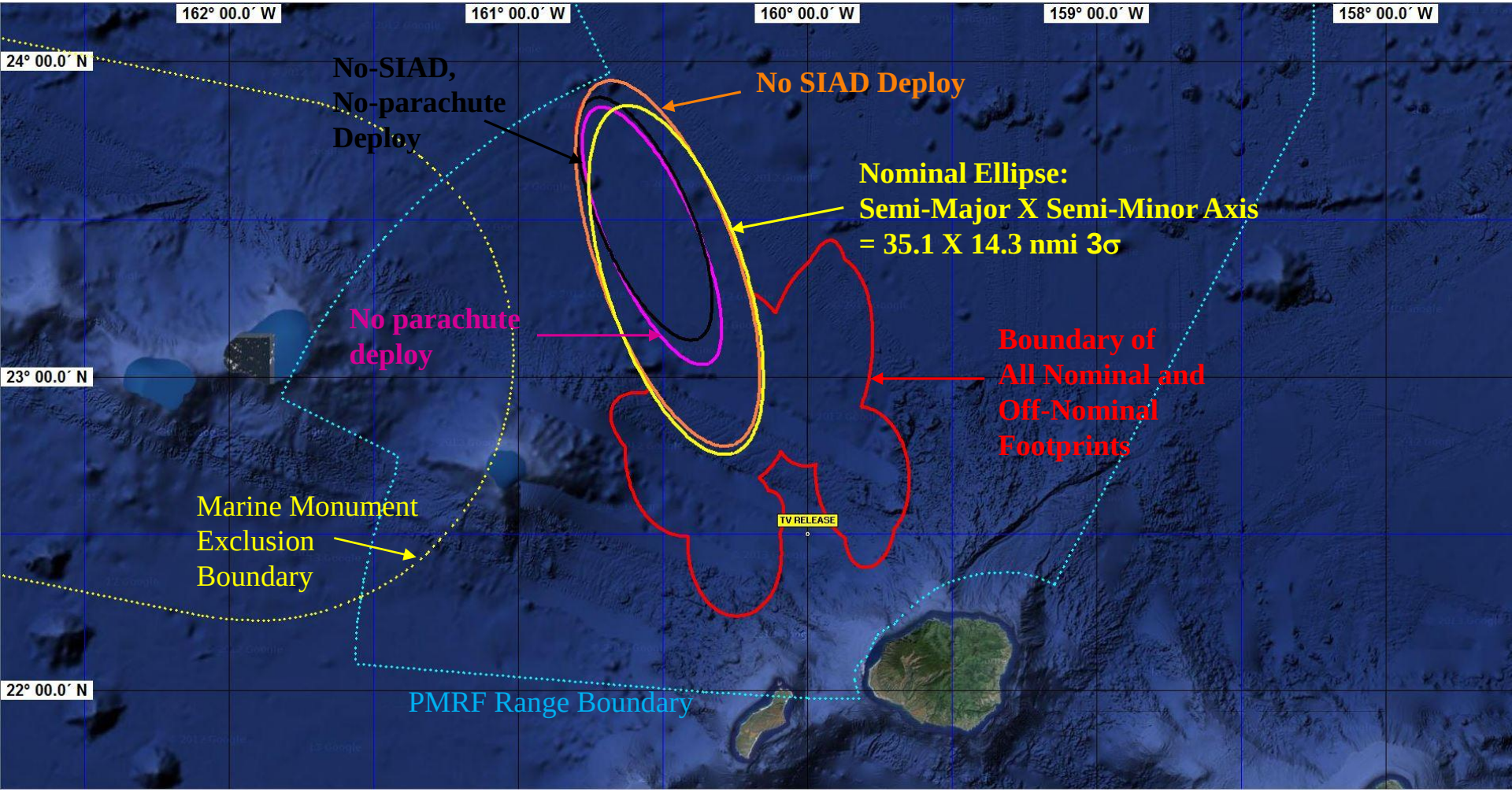


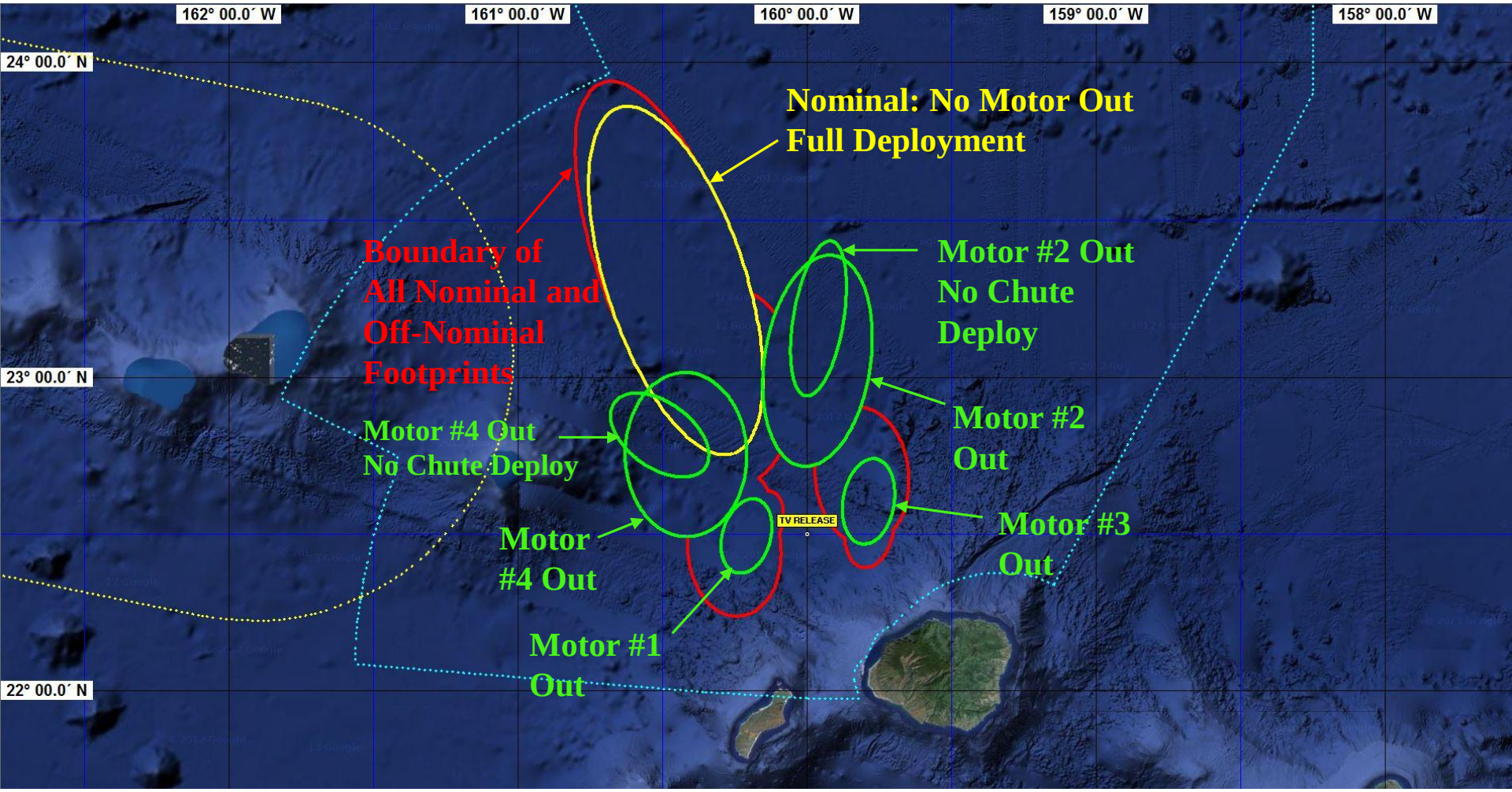




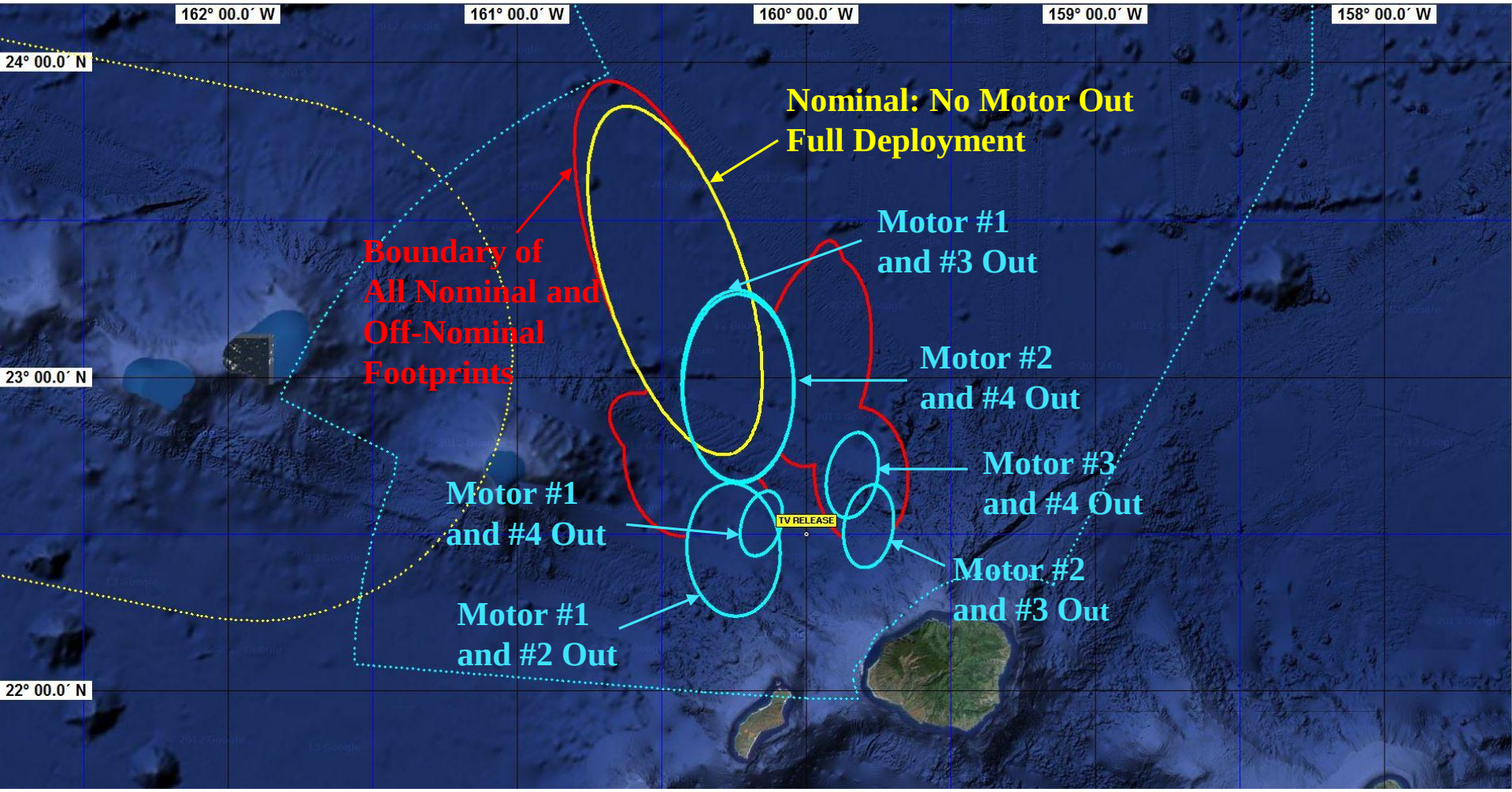
Super boundary at 36.5 km Altitude Shown in Context to PMRF Range Boundaries



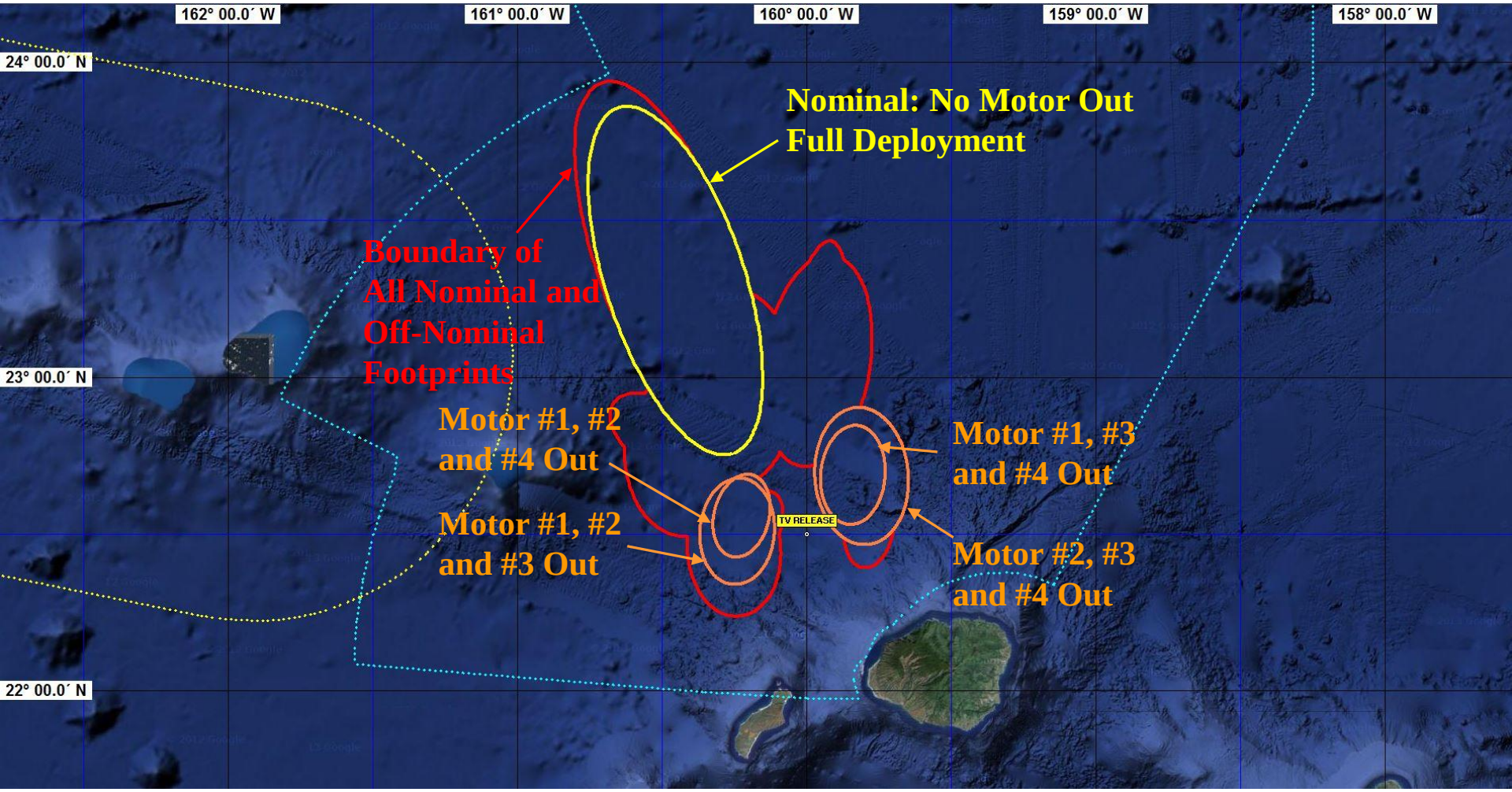
Contribution of One Spin-up Motor Out Footprints to Super Boundary



Contribution of Two Spin-up Motor Out Footprints to Super Boundary

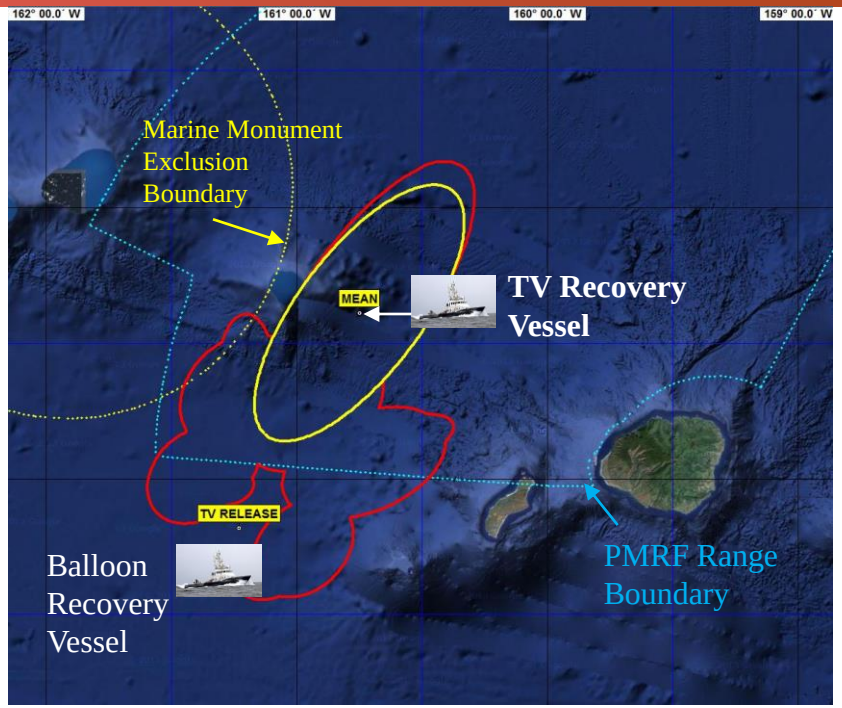


Contribution of Three Spin-up Motor Out Footprints to Super Boundary



Use of Super Boundary During Launch Planning

- The super boundary was used to aid in selection of an initial test vehicle heading and predict the splashdown location up until Launch minus 1 day (L-1)
  - Heading was selected that satisfied the constraints:
    - Camera lighting requirements
    - PRMF range boundary
    - Marine Monument
    - FAA boundary



- L-1: Predicted balloon trajectory was supplied by CSBF using the wind predictions for launch day

- L-1: Recovery vessels were sent to the predicted splashdown location of TV and balloon
  - TV recovery vessel was placed at the mean of the nominal splashdown footprint
  - Balloon recovery vessel was placed close to the TV release location but outside of super boundary

- On the morning of launch, wind predictions were updated based on measurements and the nominal splashdown footprint was updated using LaRC POST simulation

- During balloon ascent, real time POST2 predictions of TV splashdown location were performed

Super Boundary Placement Constraints

- Requirements regarding encroachment on populated areas
  - According to PMRF range safety requirements, the probability of casualty in a populated area due to the TV and its hardware must not be greater than 1e-8/1000ft^2
  - The most conservative approach to this requirement was to impose the constraint that *no* region of the super boundary cross *any* area of populated land masses
- Requirement regarding Marine National Monument
  - The constraint was imposed that no *planned* splashdown of the TV and its hardware cross the exclusion area surrounding the monument
  - A ‘planned’ splashdown was defined as a case of nominal deployment with no spin-up motors out.
  - It was acceptable to have spin-up motor out cases cross the Marine monument boundaries.

Q & A

Backup

Verification of Range Safety Population Requirement (1 of 3)

- In order to satisfy the range safety population requirement of 1e-8/1000 ft^2, it was necessary to show that the selection of a 3σ sized ellipse for the TV splashdown footprint boundary was sufficiently large
- Verification is accomplished by solving for the scale factor on the number of standard deviations needed to size an ellipse with probability density 1e-8/1000 ft^2
- The probability density function for a bivariate normal distribution is:

$$P(X,Y) = \frac{1}{2\pi\sigma_x\sigma_y\sqrt{1-\rho^2}}\left[exp\ \frac{-1}{2(1-\rho^2)}\left\{\frac{(X-\mu_x)^2}{{\sigma_x}^2} - \frac{2\rho(X-\mu_x)(Y-\mu_y)}{\sigma_x\sigma_y} + \frac{(Y-\mu_y)^2}{{\sigma_y}^2}\right\}\right]$$

$P(X,Y)$	= probability density function of X and Y
σ_x, σ_y	= standard deviation of X and Y
ρ	= correlation coefficient between X and Y
μ_x, μ_y	= mean of X and Y

- Assuming a mean of zero and no correlation between X and Y, the term under the exponential function in the above equation is equivalent to family of ellipses equal to a constant λ^2:

$$\frac{x^2}{{\sigma_x}^2} + \frac{y^2}{{\sigma_y}^2} = \lambda^2$$

Verification of Range Safety Population Requirement (2 of 3)

- Substituting the equation λ^2 into the equation for the probability density function results in:

$$P(\lambda) = \frac{1}{2\pi\sigma_x\sigma_y} exp\ \frac{-\lambda^2}{2}$$

- Solving for λ provides a function for computing the scale factor applied to the standard deviation in terms of the probability density per unit area. The area of the ellipse is $2\pi\sigma_x\sigma_y$

$$\lambda = \sqrt{-2\log(\mathrm{P}\ (2\pi\sigma_x\sigma_y))}$$

Using the nominal (full deployment, no motors-out) splashdown ellipse as an example, substitute in the dimensions of the splashdown ellipse σ_x = 35.3/3 nmi and σ_y = 14.3/3 nmi, and P = 1e-8/1000 ft^2:

$$\lambda = \sqrt{-2\log[(\frac{1\mathrm{e}^{-8}}{1000\mathrm{ft}^2}) * (\ 6076.12\ \mathrm{ft/nmi})^2\ 2\pi(\frac{35.1\ \mathrm{nmi}}{3})(\frac{14.3\ \mathrm{nmi}}{3})]}$$

λ = 2.02

- Therefore, an ellipse of size 2.02σ would have been sufficient to satisfy the population probability of casualty requirement for the nominal ellipse

Verification of Range Safety Population Requirement (3 of 3)

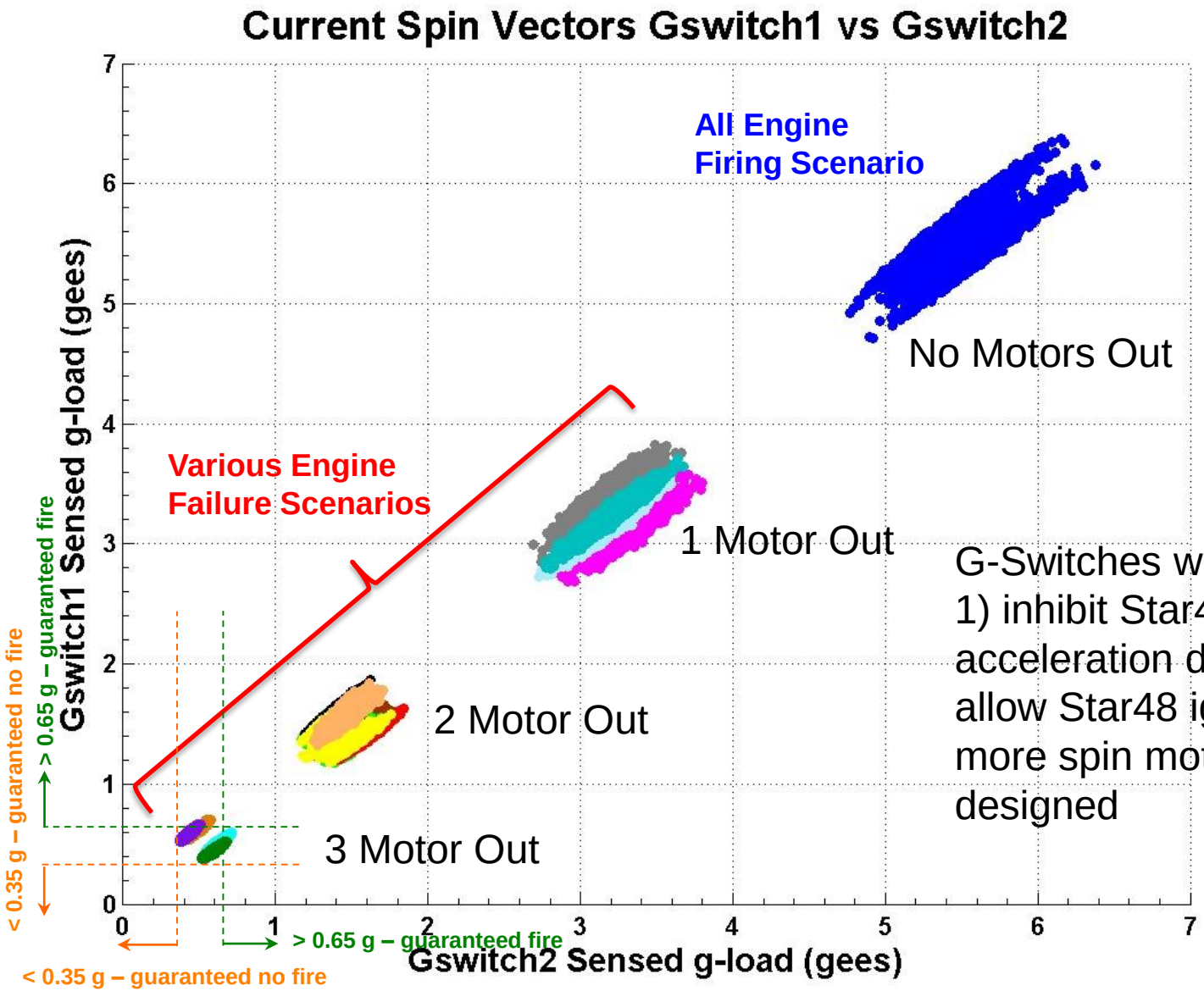
- Because any area of the super boundary was not allowed to encroach on land, the probability of casualty requirement needed to be satisfied for all of the ellipses that contribute to the super boundary.
- Computing λ for each case in the super boundary verifies that all ellipses satisfied the population requirement for <= 3.0 σ

Splashdown Ellipses Contributing to the Super Boundary Around All Ellipses	Semi-Major Axis [nmi]	Semi-Minor Axis [nmi]	λ (Number of Stdev Needed to Satisfy Population Req)
Nominal Deployment, No Motor Out	35.1	14.3	2.0
No Deployment, No Motor Out	25.1	9.3	2.4
No SIAD Deployment, No Motor Out	37.1	14.2	2.0
Motor #2 Out, Nominal Deployment	20.4	11.0	2.4
Motor #2 Out, No Parachute Deployment	15.0	5.2	2.8
Motor #4 Out, Nominal Deployment	15.7	12.6	2.4
Motor #4 Out, No Parachute Deployment	11.3	6.4	2.8
Motor #1 and #2 Out, Nominal Deployment	12.8	9.7	2.6
Motor #2 and #3 Out, Nominal Deployment	8.0	5.1	3.0
Motor #2, #3, and #4 Out, Nominal Deployment	13.2	9.7	2.6

Additional Off-nominal Scenarios Simulated for Consideration of Range Safety

- There were several other off-nominal scenarios that were simulated for the purpose of range safety:
- **Case**: All four spin-up motors-out
  - **Result**: The use of an on-board g-switch sensor that would inhibit Star 48 ignition if no rotational acceleration was sensed during spin-up
- **Case**: Spin-down motor-out combinations
  - **Result:** Spin-down motors were shown to have a small effect on splashdown footprint
- **Case:** Variations in timing offset between firing of first and second pair of spin-up motors
  - **Result:** Location of splashdown footprints highly sensitive to timing offset in the motor-out scenarios, when timing offset varies by more than +/- 0.2 sec
- **Case**: Minimum altitude at TV release
  - **Result**: Determined the lowest altitude (15 km) at TV release such that parachute will be still be deployed.
- **Case**: Maximum downrange distance theoretically possible given no-restriction of initial hang angle on balloon
  - **Result**: Required initial pitch angles > 78 deg, much greater than nominal 70 deg pitch angle

G-Switch Star48 Inhibit



No Motors Out:
Dark Blue

1 Motor Out Cases:
Gray, turquoise, light blue, maroon

2 Motor Out Cases:
Peach, yellow, red, dark brown, black, lime

3 Motors Out Cases:
Purple, light brown, green, cyan

G-Switches will guarantee to 1) inhibit Star48 ignition if no acceleration detected and 2) allow Star48 ignition if 2 or more spin motors fire as designed

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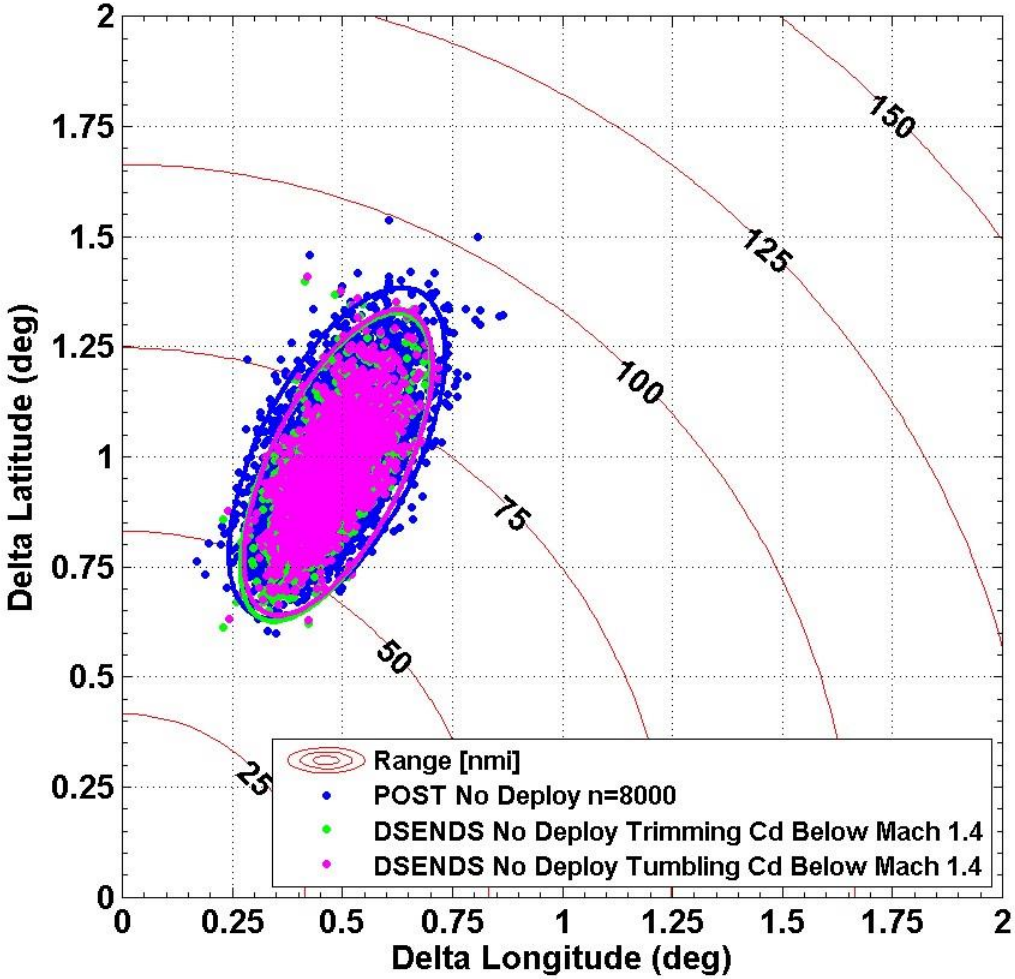
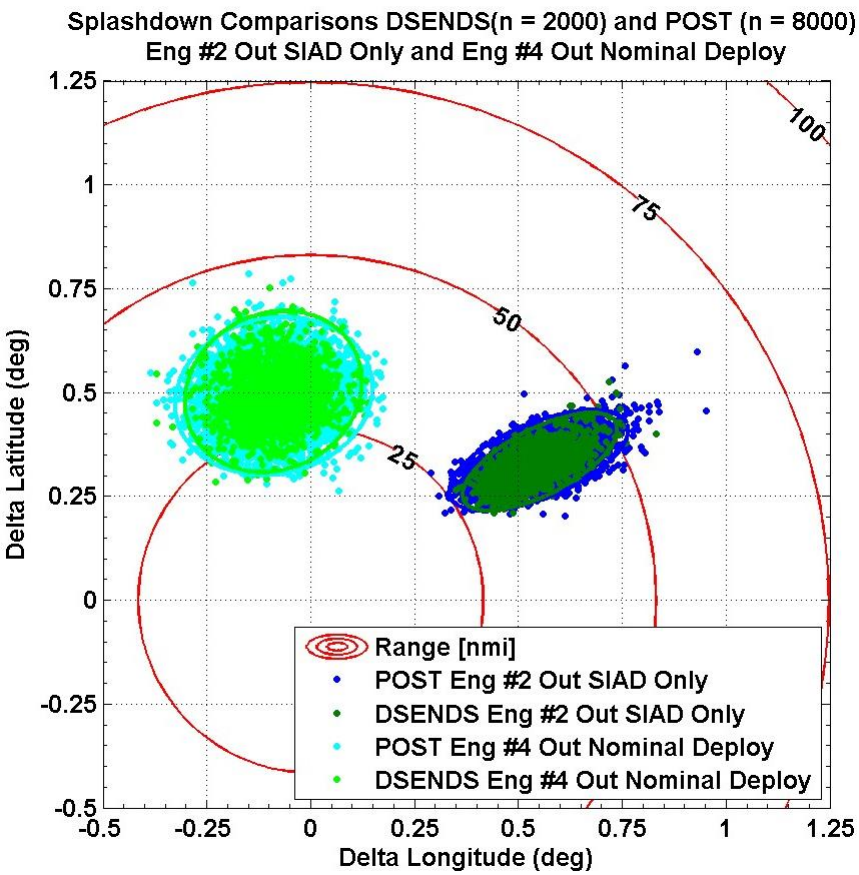
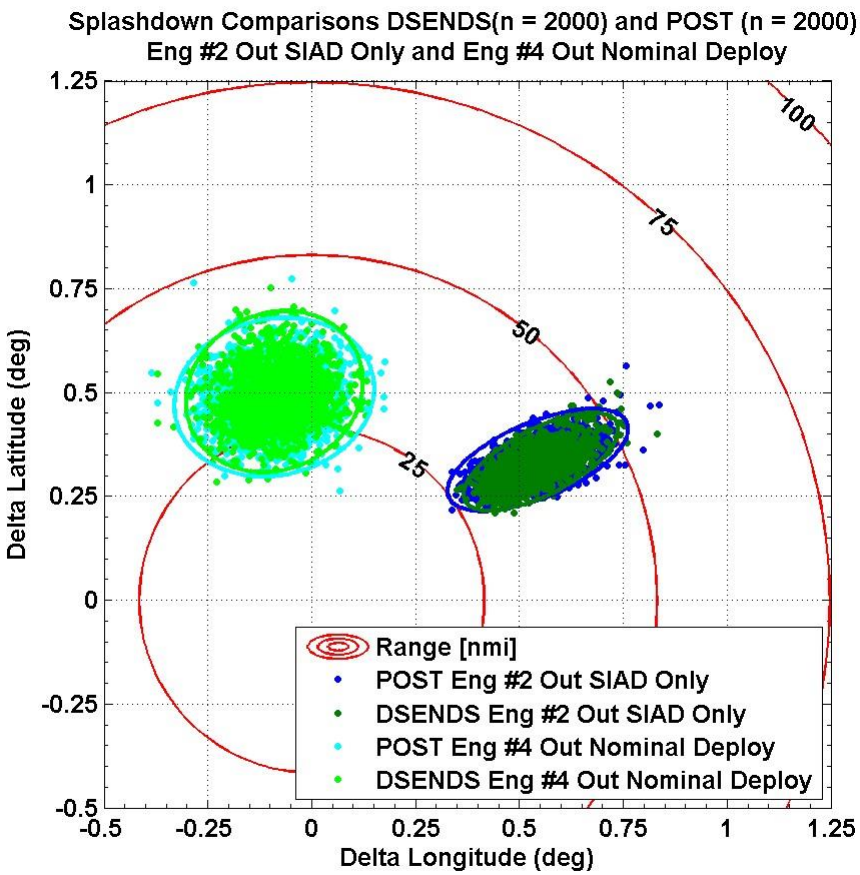
POST - DSENDS Comparisons: No SIAD, No Chute Deployment Case



POST – DSENDS Comparisons: Engine #4 Out Nominal Deploy and Engine #2 Out No Chute Deploy