ARES I-X RANGE SAFETY ANALYSES OVERVIEW

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ABSTRACT

Ares I-X was the first test flight of NASA's Ares I Crew Launch Vehicle. The flight test was conducted on the Eastern Range with a launch from Kennedy Space Center's Launch Complex 39 Pad B. As a one-time test flight, the Air Force 45th Space Wing required a series of Range Safety data products to be developed for the specified launch date and mission trajectory prior to granting flight approval on the Eastern Range. Range Safety data products were required to ensure that the public, launch area, and launch complex personnel and resources were provided with an acceptable level of safety and that all aspects of prelaunch and launch operations adhered to applicable public laws. The analysis data products, defined in the Air Force Space Command Manual 91-710, Volume 2, consisted of a nominal trajectory, flight envelopes, stage impact footprints, acoustic intensity contours, trajectory turn angles resulting from potential vehicle malfunctions (including flight software failures), potential debris, and debris impact footprints. These data products were developed under the auspices of the Constellation's Program Launch Constellation Range Safety Panel and its Range Safety Trajectory Working Group. A multi-center NASA team and the 45th Space Wing collaborated within the Trajectory Working Group forum to define the data product development processes, perform the analyses necessary to generate the data products, and perform independent verification and validation of the data products. This paper outlines the Ares I-X Range Safety analysis requirements, provides an overview of the analyses, and summarizes the results of the analyses.

INTRODUCTION

Ares I-X was a full scale flight test of the Ares I Crew Launch Vehicle designed to transport crew to low Earth orbit. The Ares I-X Flight Test Vehicle (FTV) was geometrically similar to Ares I but used different propulsion because the development of the Ares I propulsion elements was not completed at the time of the test flight. Ares I was designed as a two stage to orbit vehicle that utilized a five-segment reusable solid rocket motor (RSRM) First Stage (FS) derived from the Space Shuttle Program (SSP) four-segment RSRM and a liquid propellant Upper Stage (US) with a J2-X engine derived from the J2 engine flown on the Saturn V. The Ares I-X FS used an existing SSP four-segment RSRM with an inert fifth segment to maintain geometric similarity with the Ares I five-segment FS. The Ares I-X US had no primary stage propulsion and was considered an Upper Stage Simulator (USS). The FTV is shown in Figure 1.

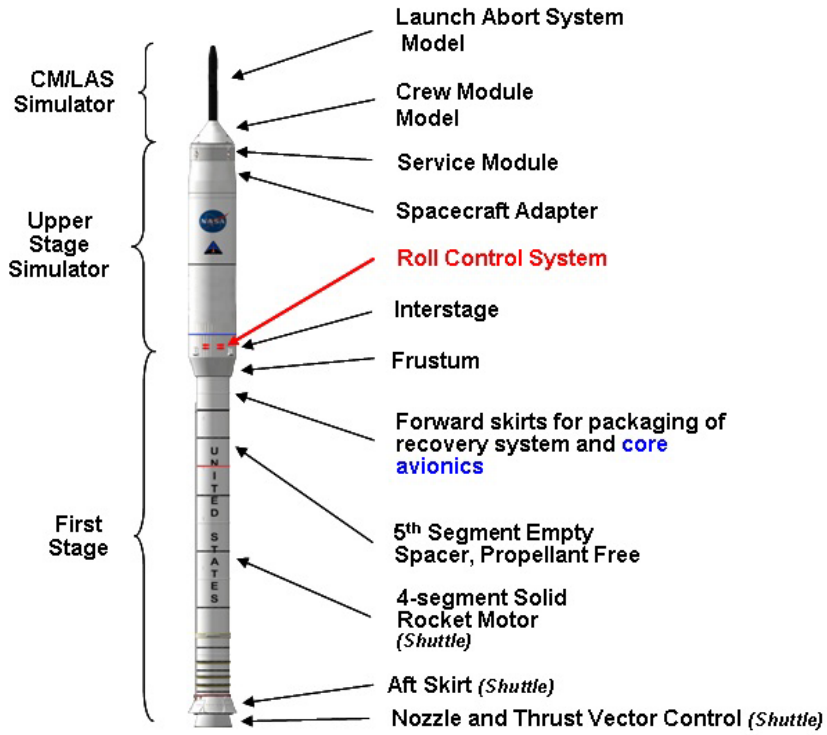


Figure 1 Ares I-X Flight Test Vehicle

The long, slender Ares I geometry with its center-of-gravity well aft of its center-of-pressure presented aerodynamic instability and structural modal response issues that required the development of a robust flight control system to maintain stable flight. As a result, the primary objective of the test flight was to demonstrate controllability of the Ares I design during its boost phase. The Ares I-X trajectory was developed to provide aerodynamic loads similar to those of Ares I by matching the Ares I Mach number-dynamic pressure (Mach-Qbar) relationship to the extent possible with the lower impulse four-segment RSRM. The FTV trajectory launch azimuth and pitch attitude steering commands were designed such that it flew in the Ares I Exploration Mission flight plane and matched its Mach-Qbar relationship to within 40 psf through Mach 4. Matching the Ares I Mach-Qbar relationship also provided a match of the Ares I altitude versus Mach number relationship. The FTV trajectory development is discussed in detail in Reference 1. The four-segment RSRM did not have sufficient impulse to produce an Ares I similar Mach-Qbar relationship beyond Mach 4. The RSRM reached burnout near Mach 4.6 and separation occurred at approximately 129 kft, well below the Ares I Mach 6.1, 184 kft separation point. After separation, both the FS and USS descended uncontrolled. The FS was equipped with a recovery system that began a parachute deployment sequence at approximately 15,000 ft altitude to limit splashdown velocity. The USS descended uncontrolled until water impact and was not recovered. A plot of the trajectory is shown in Figure 2. A summary of the trajectory events is given in Table 1. The values in the table are based on the FTV's best estimated trajectory (BET) developed from fight data. The USS reentry BET stopped at 262 s (28.5 kft) due to the loss of radar tracking data. The USS impact values in Table 1 are based on propagating the USS BET to water impact using the USS reentry simulation.

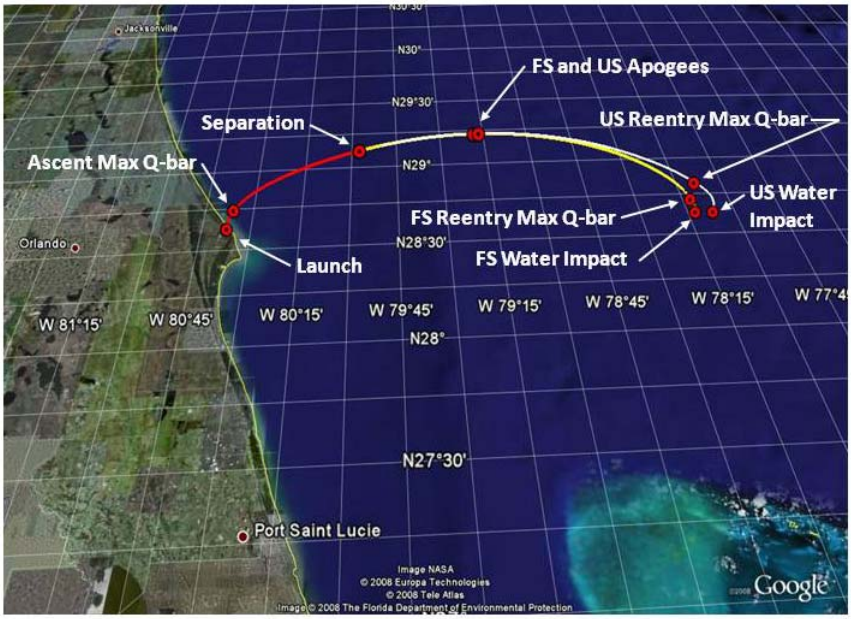


Figure 2 Ares I-X Nominal Trajectory

Table 1 Summary of Ares I-X Test Flight Trajectory Events

Event	Time (s)	Down Range (nmi)	Altitude (kft)	Q-bar (psf)
Ascent max Q-bar	58	3.8	38.9	874
Separation	123	36.4	128.6	102
USS apogee	159	63.9	148.9	37
FS apogee	160	63.9	149.1	35
USS reentry max Q-bar	249	122.6	42.7	2355
FS reentry max Q-bar	254	119.1	51.8	1060
USS water impact	310	130.8	0	503
FS water impact	352	122.1	0	13

The test flight was launched from Kennedy Space Center Launch Complex 39, Pad B and flew on the Eastern Range. Because the test flight was conducted on the Eastern Range, the Ares I-X Test Program was required to obtain flight plan approval from the United States Air Force's 45th Space Wing (45SW) and was subject to flight safety requirements documented in the Air Force Space Command Manual (AFSPCMAN) 91-710, Volume 2, Reference 2 . A preliminary flight data package and a final flight data package (FFDP) were delivered to the 45SW because the flight plan approval effort involved two phases: preliminary flight plan approval and final flight plan approval. Range Safety (RS) analyses were conducted to meet the 91-710 flight safety requirements and the data products from those analyses were submitted to the 45SW in the flight data packages in support of the request for flight plan approval. The 45SW used the data packages to determine the risk of casualty to the public posed by the flight, to develop flight displays for monitoring the FTV during its powered flight, and to develop flight rules regarding what action to take in the event of an anomaly.

This paper provides an overview of the Ares I-X RS flight analyses conducted to obtain flight approval and presents a subset of the analysis results.

RANGE SAFETY ANALYSES OVERVIEW

The AFSPCMAN 91-710, Volume 2 is a general document that defines the range safety flight analyses requirements for all vehicles that fly on the Eastern Range. The 45SW worked with the Ares I-X Test Program to tailor the requirements to the Ares I-X test flight. The FTV was considered a space vehicle, and as such, the 91-710 was tailored to reflect the space vehicle requirements. The tailored requirements are documented in Reference 3. The tailored 91-710 flight safety requirements consisted of the analyses listed below. Each analysis is discussed in more detail in later sections.

1. Trajectory analysis
2. Malfunction turn analysis
3. Debris analysis
4. Buoyancy analysis
5. Acoustic analysis
6. Sonic boom analysis
7. Post flight performance analysis.

All RS analyses were conducted in accordance with, and with the cooperation of, the Launch Constellation Range Safety Panel and its Range Safety Trajectory Working Group (RSTWG). Regular meetings were held in which the Ares I-X System Engineering and Integration (SE&I) trajectory team worked in conjunction with the RSTWG members and 45SW to develop all Range Safety analysis methodologies and data products. RSTWG team members from Johnson Space Center (JSC) had experience developing SSP Range Safety products. Their experience was combined with the SE&I trajectory team's knowledge of the FTV to develop the best method for producing Ares I-X specific data products that incorporated lessons learned throughout the Shuttle program. The RSTWG consisted of personnel from the following NASA centers and support contractors:

- Ares I-X SE&I trajectory team at Langley Research Center (LaRC)
- Range Safety and Probabilistic Risk Assessment teams at JSC
- United Space Alliance (USA) at JSC
- Willbrook Solutions at Marshall Space Flight Center (MSFC)
- Jacobs Engineering at MSFC
- Caltech Jet Propulsion Laboratory (JPL)
- Aerospace Corporation in Los Angeles
- 45SW

The RS data products were developed using a verification and validation approach to ensure the proper data products were developed and that the data products delivered were accurate to the greatest extent possible and free of errors. Due to the critical safety aspect involved with protecting the public, it was imperative that the RS products be correct and timely. Consequences of incorrect data included a launch delay, risk to people/facilities on the ground, and unintended flight termination. A complete description of the IV&V process is documented in Reference 4.

Range Safety data products were validated by the 45SW. Regular RSTWG meetings were held with the 45SW in attendance to provide a forum for identifying all requirements applicable to the FTV and for developing appropriate methods to generate and verify the data products. The 45SW provided guidance in properly understanding and interpreting the Range Safety requirements and validated that the method used to generate the products was acceptable and that the data products generated met their requirements.

The RS data products developed from flight simulations were verified by independent analyses while non-flight simulation data products were verified through organizational reviews. The independent flight simulation analyses were conducted by teams located at the NASA centers listed in Table 2. The verification process consisted of two phases, simulation verification and results verification. The simulation verification process verified that the correct FTV models and environmental inputs were used and that they were implemented in the simulation correctly. It did not seek to verify the correctness or accuracy of FTV specific simulation models. The FTV simulation models were properly validated and verified by their discipline's Constellation Program review panelprior to being incorporated into the flight simulations. The results verification process verified that all simulation runs required to generate the data products had been completed and that the data products were error free. Both simulation and results verification was achieved by demonstrating agreement between the primary and verification data product to within tolerances established in the RSTWG. The verification approach assumed that if a model implementation error occurred or if an error occurred in the results generation, it did not manifest itself in the same manner in both simulations and was identifiable through comparison of simulation results.

Table 2 Roles and Responsibilities for Range Safety Analyses

Product	Primary Source	Verification Source
Trajectory Analysis: Nominal Ascent Trajectories	LaRC	JSC and MSFC
Trajectory Analysis: Nominal Impact Points	LaRC	Aerospace Corp.
Trajectory Analysis: Flight Envelopes	LaRC	MSFC
Trajectory Analysis: Stage Disposal Footprints	LaRC	Aerospace Corp.
Malfunction Turn Analysis	LaRC	JSC
Debris Analysis	LaRC	NESC review
Acoustic Analysis	LaRC	LaRC review
Sonic Boom Analysis	LaRC	LaRC review
Buoyancy Analysis	JPL	LaRC review

TRAJECTORY ANALYSIS

The trajectory analysis consisted of defining the FTV nominal trajectory, its flight envelopes, and the impact footprints of all bodies jettisoned during the flight. The trajectory analyses were performed for a launch season from July 1, 2009 until November 30, 2009 using a six-degree-of-freedom (6-DOF) simulation developed in the Program to Optimize Simulation Trajectories II, Reference 5, that included the FTV's guidance, navigation, and control systems. The nominal and flight envelope trajectory analyses are documented in Reference 6. The impact footprint analyses are documented in References 7 and 8.

Nominal trajectories were developed for each month in the launch season using monthly mean atmosphere, monthly mean winds, and nominal (undispersed) FTV system parameters. An evaluation of the monthly trajectories was made to determine if a single month was representative of the entire season. Comparison of the monthly nominal trajectories steepness and cross-range as functions of time, down-range position, and velocity indicated that a September nominal trajectory was representative of the entire launch season and sufficient for use in developing Range Safety flight displays. The September nominal trajectory sequence of events and time histories of position, velocity, acceleration, attitude, and attitude rate were delivered to the 45SW.

The flight envelope analysis defines the limits of a normally operating vehicle in the Range Safety horizontal and vertical planes. A total of six flight envelopes are required to define the limits of normal operation, four horizontal plane envelopes and two vertical plane envelopes. The horizontal plane is a plan view of the trajectory in which the down-range position and latitude of the FTV's instantaneous vacuum impact point (IIP) is monitored. The four horizontal plane three-sigma envelopes consist of the maximum instantaneous impact point (MaxIIP), minimum instantaneous impact point (MinIIP), left instantaneous impact point (LIIP), and right

instantaneous impact point (RIIP) envelopes. The MaxIIP and MinIIP envelopes define the maximum and minimum IIP down range position of a normally operating FTV as a function time. The LIIP and RIIP envelopes define the maximum left and right IIP latitude of a normally operating FTV as a function of longitude. Figure 3 shows an illustration of the horizontal plane with notional LIIP and RIIP envelopes and an example of the MaxIIP and MinIIP at a single point in time early in flight.

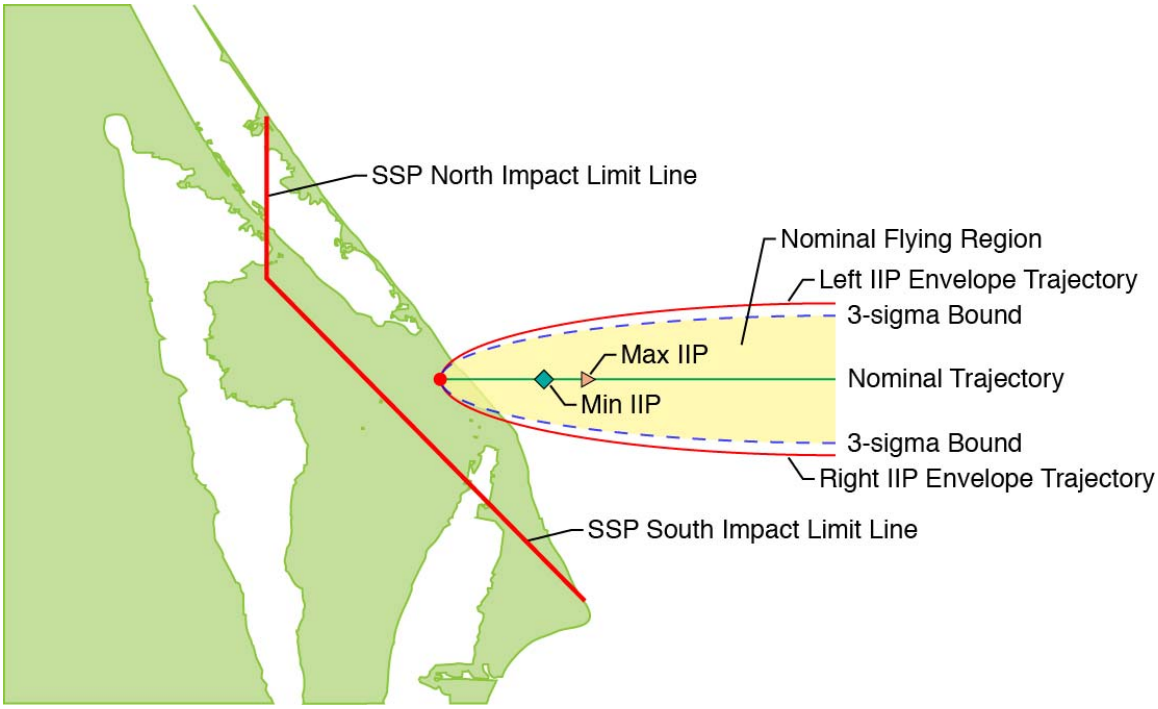


Figure 3 Range Safety Horizontal Plane with LIIP and RIIP Envelopes

The vertical planes, shown in Figure 4, are side views of the trajectory in which the steepness of an ascent is monitored relative to impact limit lines (ILLs). The FTV vertical planes were defined from the Space Shuttle Program (SSP) North and South ILL's by creating a non orthogonal coordinate system with its origin at the launch pad, the X axis normal to the SSP North ILL, the Y axis normal to the SSP South ILL, and Z axis formed by right hand rule. The coordinate system's XZ plane is referred to as the Launch Area Steep (LAS) plane and its YZ plane is referred to as the Launch Area Lateral (LAL) plane. The FTV trajectory was projected into the LAS and LAL planes to define its position in each plane. The LAS and LAL envelopes defined the maximum altitude for a normally operating FTV as a function of its down-range position in each plane. .

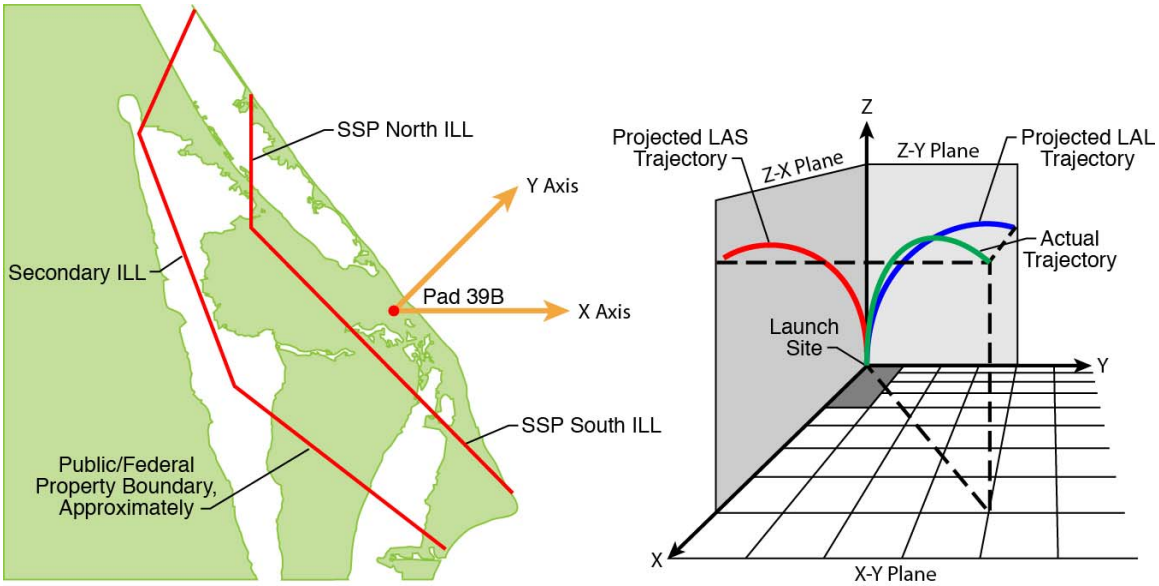


Figure 4 Range Safety Vertical Planes with LAS and LAL Trajectories

Monte Carlo analyses were performed that dispersed the FTV system parameters and each month's environmental parameters to define the 3-sigma dispersion in the direction of each envelope. The Monte Carlo analyses were required by the 45SW to use 3-sigma wind magnitudes applied in the worst case directions rather than randomly dispersed wind magnitudes and directions. Performing a Monte Carlo analysis for each month and worst case wind direction would have required 30 analyses. To reduce the number of analyses, Monte Carlo analyses were only performed for the months and wind directions that produced the largest or smallest (most extreme) LAS, LAL, LIIP, RIIP, MaxIIP, and MinIIP values throughout the entire ascent of a nominal FTV. This was possible because the Monte Carlo dispersions were normally distributed about the nominal FTV system parameter trajectory. For example, a FTV with nominal system parameters had the highest Z position in the LAS and LAL planes throughout the ascent during August with the August 3-sigma wind blowing from the East, i.e. a head wind; thus only a Monte Carlo analysis with August environmental parameters and 3-sigma head wind was required to define the LAL and LAS 3-sigma dispersion. Similarly, during November, the nominal FTV had the largest RIIP and LIIP values throughout the entire ascent with 3-sigma winds blowing from the North and South. A single month in the launch season did not result in the largest MaxIIP and smallest MinIIP values throughout the entire ascent. As a result, Monte Carlo analyses were performed for each month that had the largest/smallest MaxIIP and MinIIP at some point during the ascent.

Six flight envelopes were developed that encompassed the LAS, LAL, RIIP, LIIP, MaxIIP, and MinIIP 3-sigma dispersions of each month in the launch season. Each flight envelope was an individual trajectory of the FTV with its system parameters and environmental parameters adjusted such that its trajectory encompassed the dispersions in the direction of that envelope. The trajectories were developed for a single month and wind direction to be physically consistent rather than changing the environmental conditions to those of different months during the ascent. In the case of the MaxIIP and MinIIP envelope, a 4-sigma bound for one month had to be used in order to encompass the 3-sigma dispersions that occurred throughout the launch season. To be consistent with the MaxIIP and MinIIP approach, 4-sigma bounds were defined for the LAS, LAL, RIIP,and LIIP, dispersions as well. Trajectories that encompassed each of the four-sigma bounds were developed by adjusting the FTV dispersions that most affected flight along a particular boundary. Those six trajectories defined the six flight envelopes. Examples of the RIIP, LIIP, MaxIIP, and MinIIP flight envelopes are shown in Figure 5.

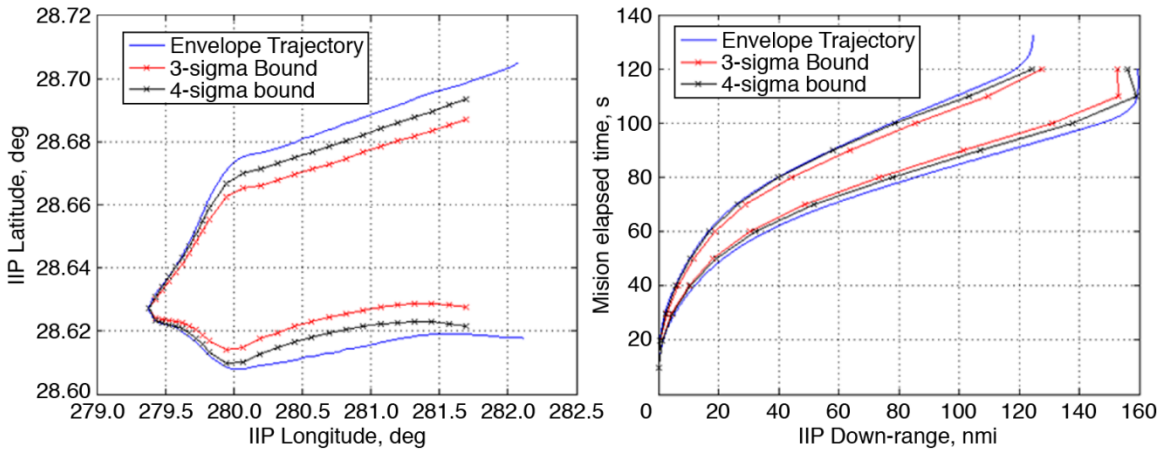


Figure 5 FTV Flight Envelopes

Impact footprints define the area over which each jettisoned body can potentially impact the ocean. An area is provided rather than a single point in order to account for uncertainties in the separation state, weight, aerodynamics, and atmosphere and wind variability. The FTV jettisoned bodies consisted of the USS, FS, FS nose cap, and FS forward skirt extension. Their impact footprints were developed for each month in the launch season using Monte Carlo analyses of the FTV stage separation, FS reentry, and USS reentry. Individual footprints of each jettisoned body were developed by encompassing the 99.73 percentile of the Monte Carlo impact points. In addition, a composite footprint was developed that encompassed the 99.73 percentile of all jettisoned bodies' Monte Carlo impact points. An example of the FS impact footprint is shown in Figure 6. During reentry, the FS could trim in a nose first, broadside, or tail first orientation. The trim classifications were based on the trim attitude at reentry maximum dynamic pressure with nose-first defined as trim between 0° and 40° total angle of attack, broad-side defined as trim between 40° and 140° total angle of attack, and tail-first defined as trim between 140° and 180° total angle of attack. Nose-first trim was undesirable because it adversely affected recovery. The impact footprints were used by the 45SW to place the FS recovery ships and to develop a Notice to Airmen and Mariners for the test flight.

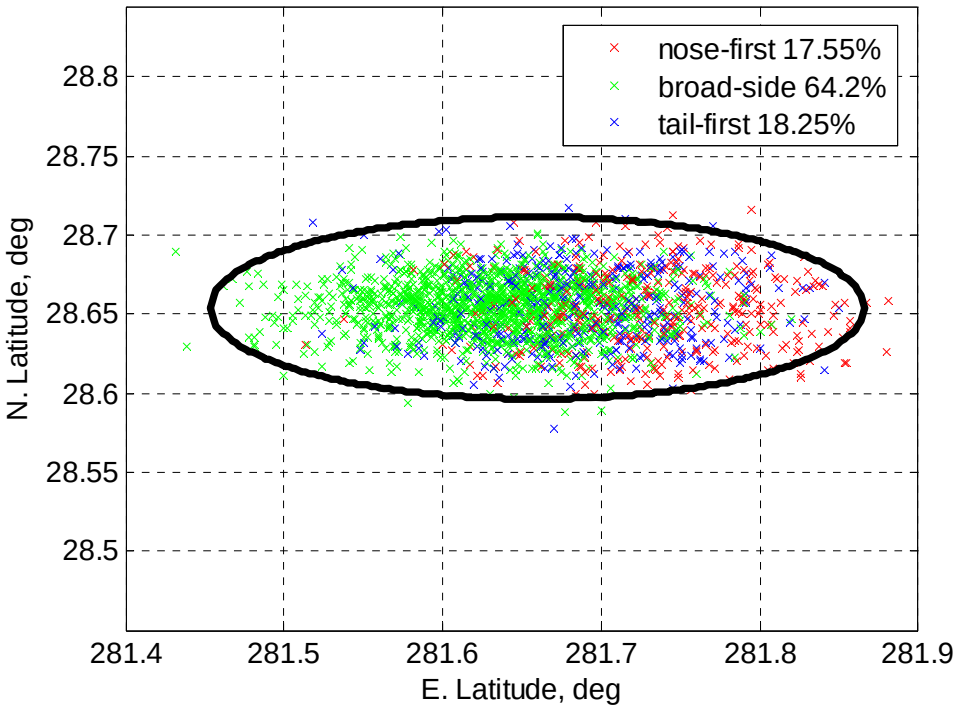


Figure 6 FS Footprint Developed From Monte Carlo Impact Points

MALFUNCTION TURN ANALYSIS

The malfunction turn analysis defined the extent to which the FTV could turn away from its nominal trajectory as the result of a failure. The analysis is documented in Reference 9. Potential failure modes were identified by a probabilistic risk assessment performed by Johnson Space Center's Probabilistic Risk Assessment Team in conjunction with failure analyses performed by the Launch Constellation Range Safety Panel's Trajectory Working Group. The failure modes and the probability of their occurrence are documented Reference 10. The analysis identified the following four categories of failure modes that could potentially occur at any time from ignition to RSRM burnout:

1. Loss of thrust vector control
2. RSRM nozzle burn through
3. RSRM case breach
4. Software failures

The effect of a failure on the FTV trajectory was determined by modeling each failure mode in the 6-DOF simulations and initiating the failure at times ranging from ignition to RSRM burnout in two second intervals. A total of 8423 malfunction turn cases were run to simulate all the potential failures in the categories above at two second intervals throughout the ascent. The FTV's turn angle relative to its nominal trajectory was used as a means of quantifying how much a failure can turn the FTV trajectory. The turn angle is defined as the three-dimensional angle between the nominal FTV velocity vector and the failed FTV velocity vector as shown in Figure 7. The turn angle was calculated in one second intervals after the time of failure initiation up to RSRM burnout, FTV failure, or ground impact. The maximum turn angle time that resulted from all failure modes and the associated FTV velocity was determined up to twelve seconds after failure initiation and submitted to the 45SW in a composite turn angle table. Plots of the maximum turn angle at two, four, six, and eight seconds after failure occurred are shown as a function of the

time failure started in Figure 8. The 45SW used the turn angle information in conjunction with debris ballistic data to develop destruct criteria such as destruct lines.

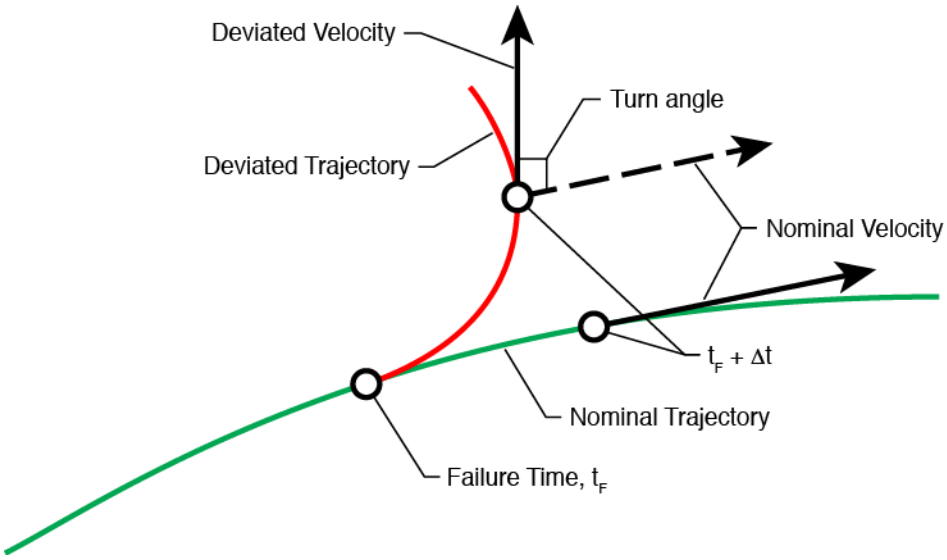


Figure 7 Turn Angle

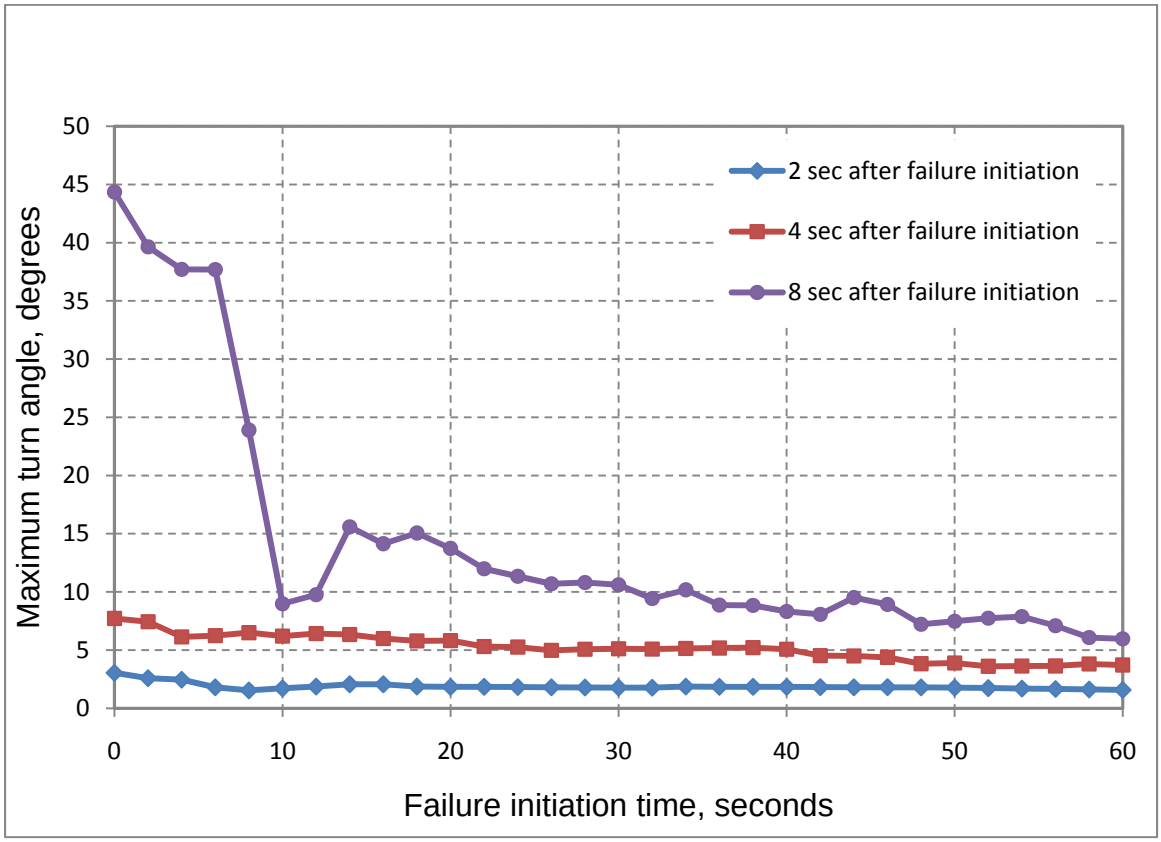
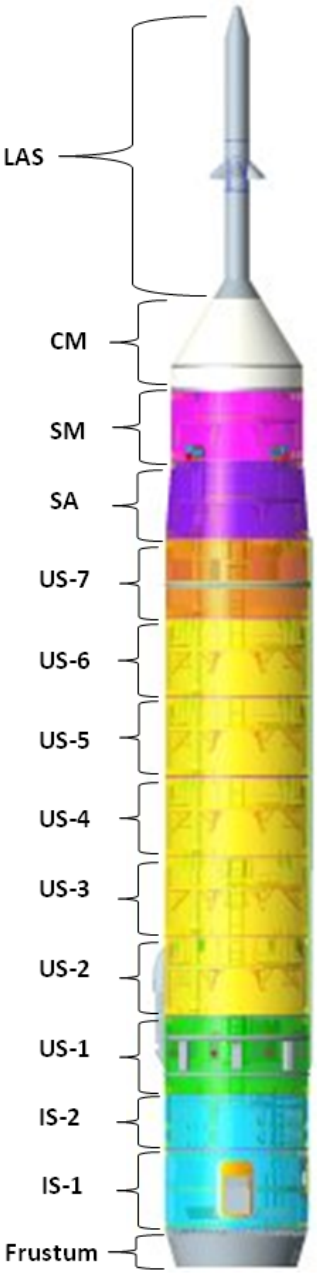


Figure 8 Maximum Turn Angle vs. Failure Initiation Time

DEBRIS ANALYSIS

Debris analysis determines the debris that can arise from vehicle breakup as a result of a malfunction turn, uncontrolled tumble, or activation of the flight termination system (FTS) and characterizes the debris' geometry, weight, aerodynamic drag and lift coefficients, and ballistic coefficient. The Ares I-X debris analysis is documented in Reference 11. The Ares I-X analysis determined the potential debris from breakup of the USS and from FS components not associated with the propellant segments and aft skirt of the SSP RSRM. Debris characteristics of the propellant segments and aft skirt were obtained from SSP debris data. The USS primary structure, shown in Figure 9, consisted of 13 segments bolted together at flange joints. The FS components not associated with the propellant segments consisted of the frustum, forward skirt extension, forward skirt, and inert fifth segment. The joints between those FS segments were also bolted joints. The FS structural segments are shown in Figure 10. Joint tests indicated that tensile failure (required for the segments to break apart) would occur at the segment joints prior to the outer wall material rupturing. As a result, the debris analysis assumed breakup to occur only at the joints. Once the primary structure failed, there was a potential for internal structures to break free. The internal structures of significance consisted of walkway platforms and ballast assembly components. As with the primary structure, joint failure was assumed to be the failure mode that resulted in those components breaking free.



I.D.	Description	Catalog ID
LAS	Launch Abort System	LAS
CM	Crew Module	SEG_CM
SM	Service Module	SEG_SM
SA	Space Craft Adapter	SEG_SA
US-7	Upper Stage Segment 7	SEG_7
US-6	Upper Stage Segment 6	SEG_6
US-5	Upper Stage Segment 5	SEG_5
US-4	Upper Stage Segment 4	SEG_4
US-3	Upper Stage Segment 3	SEG_3
US-2	Upper Stage Segment 2	SEG_2
US-1	Upper Stage Segment 1	SEG_1
IS-2	Interstage Segment 2	SEG_IS_2
IS-1	Interstage Segment 1	SEG_IS_1
Frustum	First Stage frustum	Frustum

Figure 9 Segments of USS primary structure

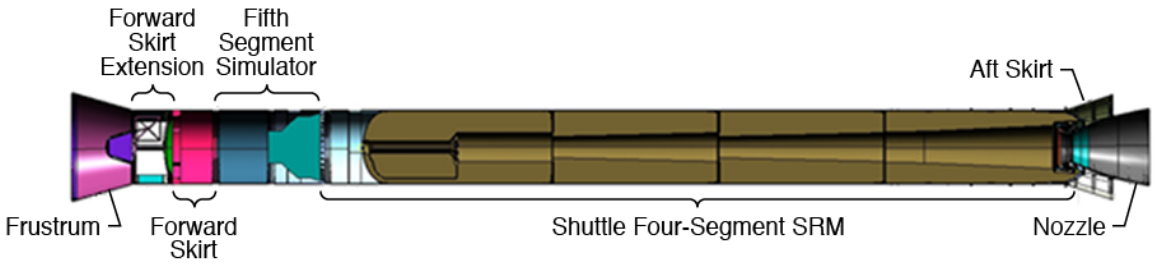


Figure 10 FS structural segments

The FTV stack was analyzed for potential breakup due to each malfunction turn scenario and to FTS activation. The USS was analyzed for breakup during reentry. There was a potential for USS breakup during reentry because it was not designed to be recovered. Instead, its structure was designed to only withstand loads during the controlled ascent phase of flight. The FS was not analyzed for breakup during reentry because it was designed to withstand reentry loads and be recovered.

The FTV malfunction turn and USS reentry breakups were determined by embedding a structural model within the malfunction turn and USS reentry simulations that calculated axial and shear running loads at each joint for the flight conditions and compared those values to the joint's structural load limit. Once a load limit was reached at any joint, breakup was assumed to occur at that joint resulting in two debris configurations. In the USS breakup analysis, the process was repeated by propagating the trajectories of the resulting debris configurations until they broke up or water impact occurred. The malfunction turn breakup analysis stopped at the first joint failure and recorded the trajectory state. The debris configurations that resulted during the USS reentry were assumed to be possible after a malfunction turn. The 45SW developed debris impact footprints resulting from the malfunction turn scenarios by initializing the USS debris configurations with the states provided and propagating their reentry trajectory to ground/water impact.

The geometry, weight, aerodynamic, and ballistic characteristics of the potential debris configurations determined from the breakup analyses were summarized in a debris catalog. The aerodynamic coefficients and ballistic coefficients were determined as a function of Mach number. In the hypersonic regime, the aerodynamic coefficients were obtained from aerodynamic databases developed for the breakup analyses. In the supersonic and subsonic regimes, average tumbling drag coefficients were approximated using data from Reference 12 and average tumbling lift coefficients were approximated using data from Reference 13. The ballistic coefficient versus Mach number relationships for all the potential debris configurations identified in the breakup analysis is plotted in Figure 11. From the figure, it can be seen that the ballistic coefficients range from 35 lb/ft^2 to 900 lb/ft^2 in the supersonic flight regime and from 35 lb/ft^2 to 1250 lb/ft^2 in the subsonic flight regime.

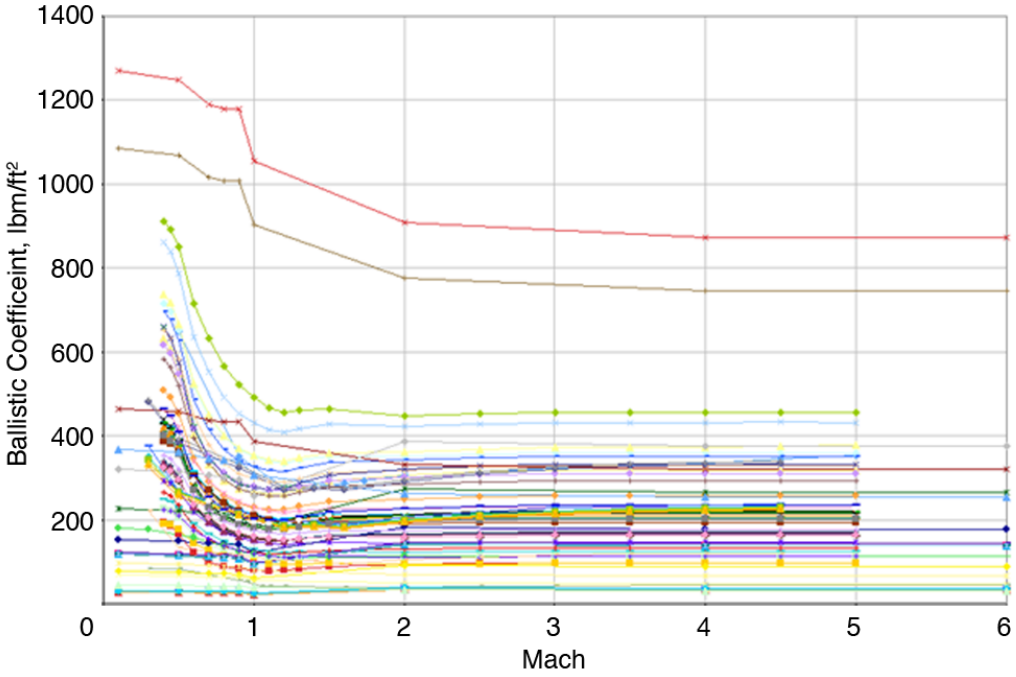


Figure 11 Ballistic Coefficient vs. Mach Number Relations of All Possible Debris Configurations

BUOYANCY ANALYSIS

Buoyancy analysis determines the potential for any jettisoned body or debris to float after water impact. If a jettisoned body or piece of debris has the potential to float, a means of recovering or sinking it must be developed. The bodies jettisoned during the test flight consisted of the FS nose cap, forward skirt extension, and parachutes. They were the same as those for SSP flights and required no analysis to show that they did not have sufficient buoyancy to float. The debris configurations identified in the debris analysis were analyzed for buoyancy. The debris consisted of steel plates, FS and USS segments open at both ends, and USS segments closed at one end by the Crew Module/Launch Abort System (CM/LAS) simulators. The segments closed off by the CM/LAS simulator had the potential to trap air inside them and float when they impacted the water open end first. Fourteen such debris configurations were identified in the debris analysis. As a result, arrangements were made for a United States Coast Guard vessel to locate and sink that debris.

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ACOUSTIC ANALYSIS

The acoustic analysis defines far field sound pressure levels and the acoustic spectra around the launch site. The Ares I-X test flight acoustic analysis is documented in Reference 14. The sound pressure levels generated by the test flight were a function of the FTV's acoustic energy, the directivity of noise propagation, and atmospheric attenuation. The FTV's acoustic energy was calculated to be 203 db using the methods documented in Reference 15 and the SSP four-segment RSRM thrust characteristics. The FTV was represented as a compact source with a directivity angle of approximately 155°. The acoustic energy was propagated using the Atmospheric Noise Propagation Program, Reference 15, taking into account the effects of spherical spreading, characteristic impendence, and atmospheric absorption. The sound pressure levels generated by the FTV are shown in Figure 12. The low frequency content of the acoustic energy traveled with very little attenuation and decreased primarily due to spherical spreading. As a result, sound pressure levels above 85 db extended to the Orlando area. The propagation of low frequency noise could not be accurately predicted at distances beyond Orlando.

The acoustic energy spectra were calculated at down-range and up-range points from 0.5 nmi to 4.0 nmi in increments of 0.5 nmi at the time the overall sound pressure level was a maximum at that point. The acoustic spectra were documented in data tables and delivered to the 45SW.

Figure 12 FTV Sound Pressure Contours

SONIC BOOM ANALYSIS

Sonic boom analysis determines the location and intensity of the sonic boom ground signature. The Ares I-X test flight sonic boom analysis is also documented Reference 14. The FTV's near field pressure signature (NFS) was used in conjunction with its trajectory to determine the location of the sonic boom ground signature. The FTV's NFS was determined from computational fluid dynamics data sets at a distance of 3.5 diameters from the vehicle centerline. The Mach 3.5 data set is shown in Figure 13. The solid black line in Figure 13 indicates the cross sections where the NFS was calculated. The sonic boom ground signature closest to shore occurred at a distance of 26.8 nmi down-range of the launch site. The intensity of the ground signature was not reported because exhaust plume data, which has a significant effect on the intensity, was not available at the time of the analysis. This was acceptable to the 45SW because the location of the ground signature was more than 12 nmi off the coast. U.S. Air Force Airspace Management AFI 13-201 requires a permit to be obtained for sonic booms occurring less than 12 nmi off shore.

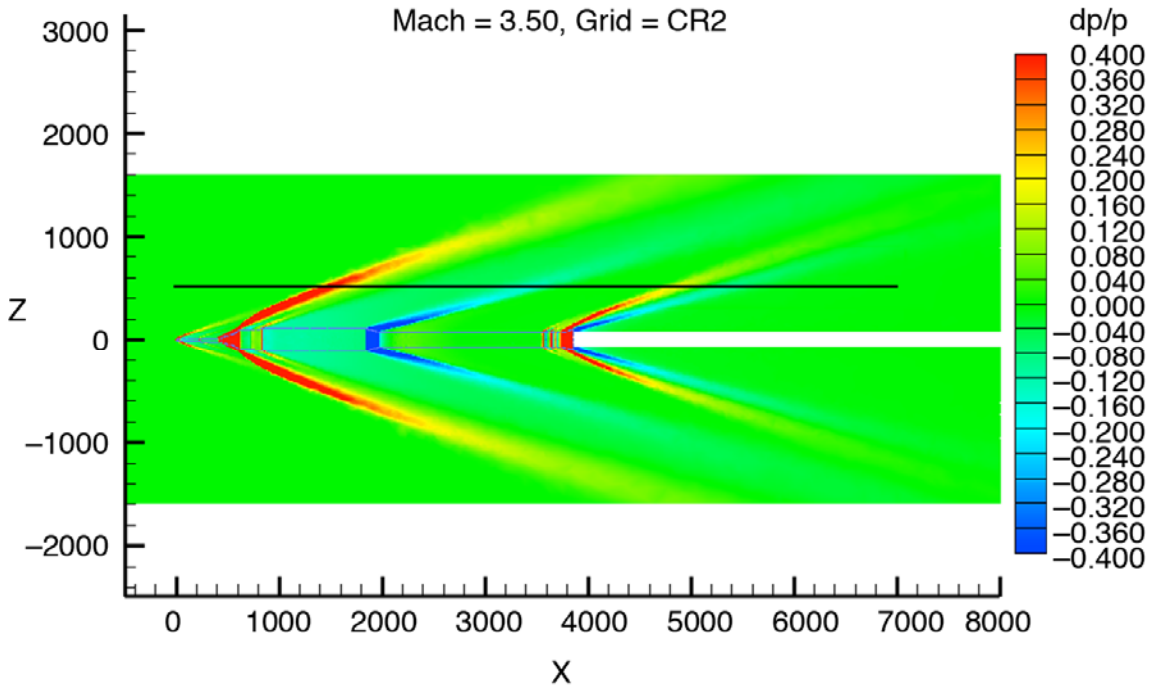

Figure 13 Example of CFD Dataset Used to Calculate NFS

POST FLIGHT ANALYSIS

Post flight analysis provides the 45SW with an assessment of the flight. The Ares I-X post flight analysis is documented in Reference 17. The Ares I-X post flight analysis required the following information:

- Qualitative statement of FS performance.
- Performance of on-board safety instrumentation
- Description of any failures that occurred and the resulting flight condition.
- Probable cause of failure and corrective action.
- Comparison of planned and achieved FS cutoff conditions.
- Estimated impact points of FS and USS.

The FS motor, its thrust vector control system, primary stage separation system, and range safety system, including on-board safety instrumentation, performed within preflight predictions. The recovery system performed normally up to the main parachute deployment. However, at main parachute deployment, one of the three parachutes failed. The failure was due to the parachute being disreefed prior to deployment. The design of the pyrotechnic reefing line cutter is being reviewed to correct the problem.

A best estimate of the FTV's trajectory was constructed from available flight data and used to make post flight comparisons. The BET consisted of the FTV ascent up to separation, FS reentry to water impact, and the USS reentry down to approximately 28.5 kft. The USS reentry BET ended at 28.5 kft due to the loss of radar tracking data at that point which was the only data source available for the USS reentry reconstruction. Below 28.5 kft, the USS reentry was approximated using the USS reentry simulation initialized with the USS BET state at 28.5 kft. The trajectory reconstruction process used to develop the BETs is documented in Reference 18. The planned FS cutoff conditions were within 2.0% or less of the BET values. The BET FS and USS impact points were within the predicted footprints. A comparison of the estimated and preflight stage impact points is shown in Figure 14.

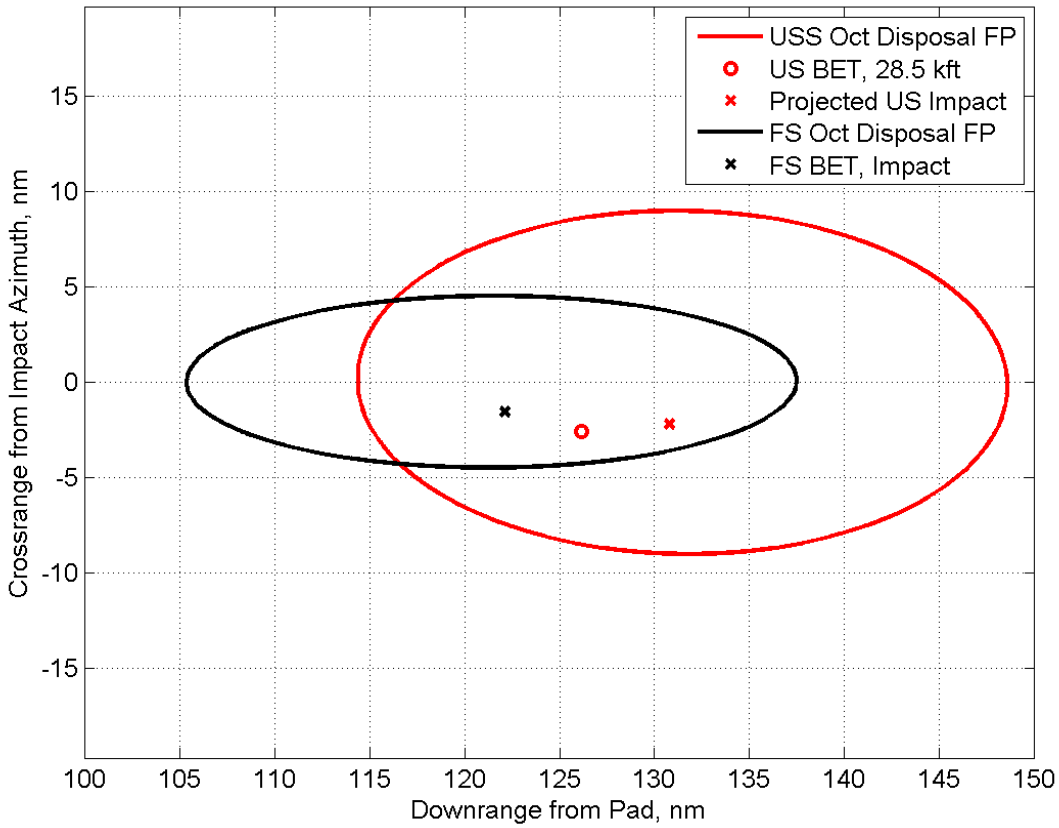

Figure 14 Post Flight vs. Preflight Predicted Stage Impact Points

The FTV ascent trajectory predicted by the flight simulation when updated with day of launch (DOL) data was compared to the BET as a means of assessing how accurately the simulation could predict the actual flight. The FFDP simulation results were expected to differ from the actual flight because it used monthly mean winds and RSRM propellant mean bulk temperature (PMBT). DOL wind measurements and PMBT prediction allowed the simulation to be updated with DOL values to improve its accuracy. The updated simulation is referred to as the post-flight simulation. Figure 15 through 17 are examples of some of the post flight simulation/BET comparisons. With DOL updates, the post flight simulation matched the BET to within the tolerances established in the IV&V process to verify simulation outputs.

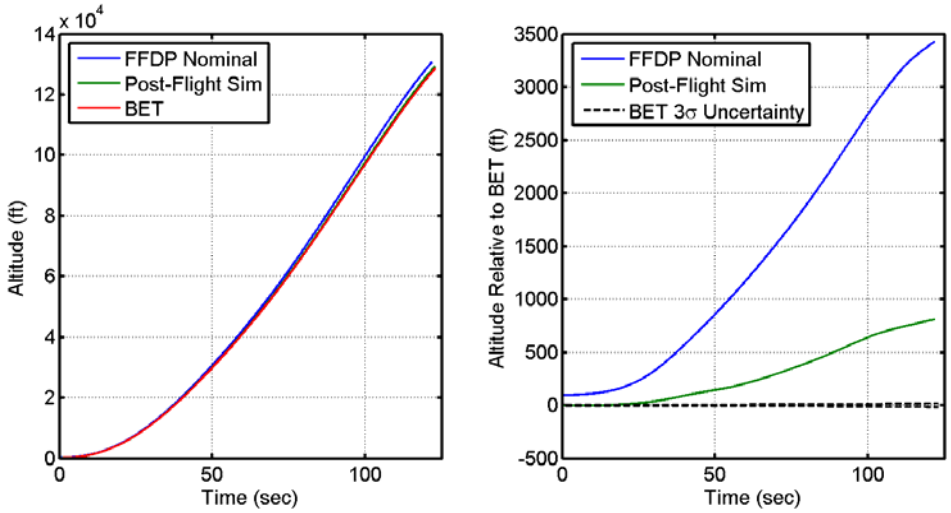

Figure 15 BET/Post Flight Simulation Altitude Comparison

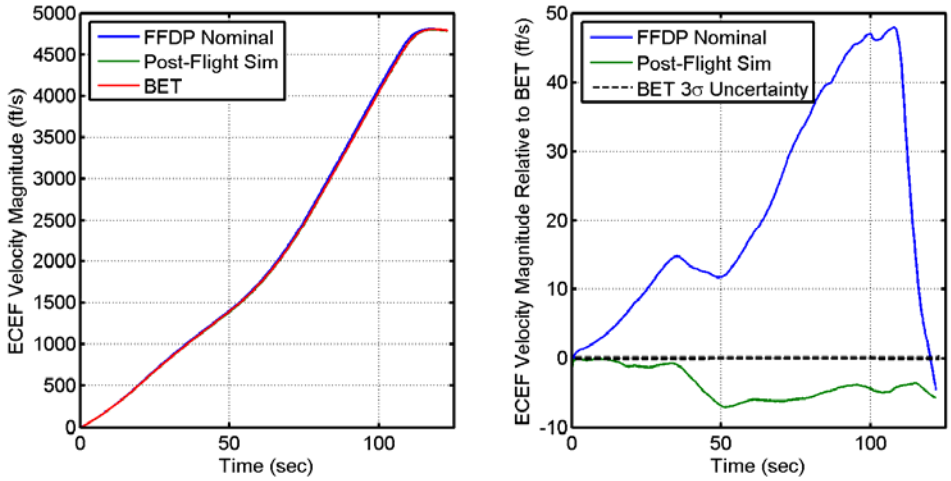

Figure 16 BET/Post Flight Simulation Velocity Comparison

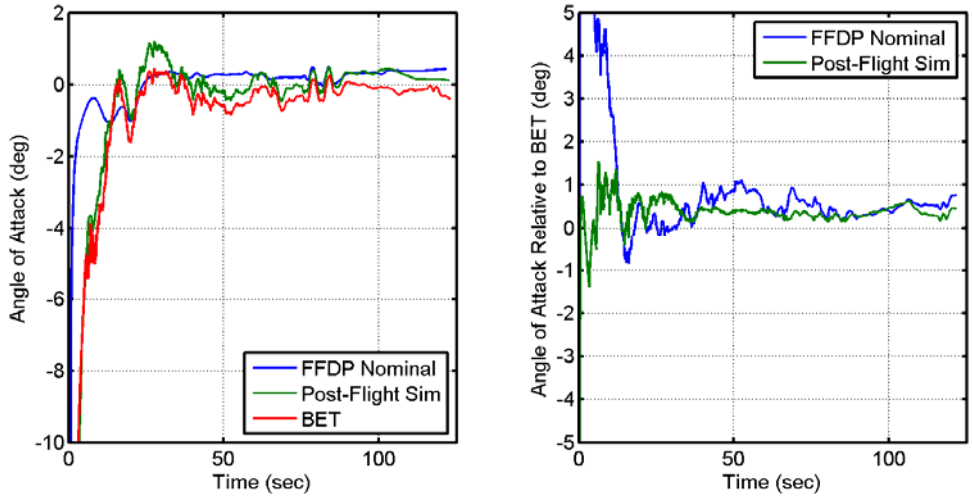

Figure 17 BET/Post Flight Simulation Angle of Attack Comparison

The BET was compared to the FFDP flight envelopes to document that the flight occurred within the envelopes. Examples of the flight envelope comparisons are shown in Figure 18 and 19. The plot on the left shows the comparison to the BET while the plot on the right shows the difference between the flight envelope and the BET. The differences are a measure of the margin between the actual flight and the flight envelope. The BET indicated the flight was near nominal and was well within all flight envelopes. Note that in Figure 19 the BET and Post-Flight Sim values are nearly the same so that the BET cyan curve overlays the Post-Flight Sim red curve.

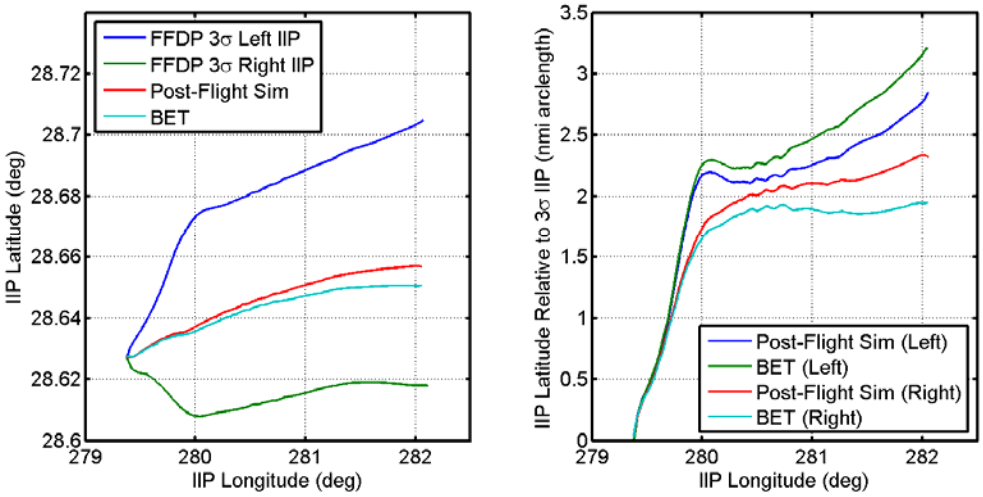

Figure 18 BET Comparison to LIIP and RIIP Envelopes

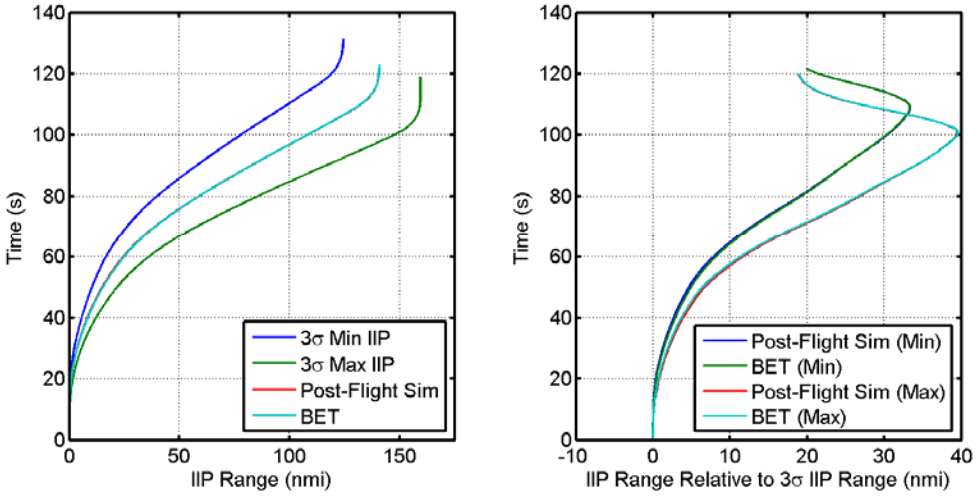

Figure 19 BET Comparison to MaxIIP and MinIIP Envelopes

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ACRONYMS

45SW	45th Space Wing
6DOF	6 Degrees-of-Freedom
AFSPCMAN	Air Force Space Command Manual
BET	Best Estimated Trajectory
CM/LAS	Crew Module and Launch Abort System
DOL	Day of Launch
FFDP	Final Flight Data Package
FS	First Stage
FTS	Flight Termination System
FTV	Flight Test Vehicle
IIP	Instantaneous Impact Point
ILL	Impact Limit Line
IV&V	Independent Verification and Validation
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
LaRC	Langley Research Center
LAL	Launch Area Lateral
LAS	Launch Area Steep
LIIP	Left Instantaneous Impact Point
MaxIIP	Maximum Instantaneous Impact Point
MinIIP	Minimum Instantaneous Impact Point
MSFC	Marshall Space Flight Center
NESC	NASA Engineering and Safety Center
NFS	Near Field Signature
PMBT	Propellant Mean Bulk Temperature
RIIP	Right Instantaneous Impact Point
RS	Range Safety
RSRM	Reusable Solid Rocket Motor
RSTWG	Range Safety Trajectory Working Group
SE&I	Systems Engineering and Integration
SSP	Space Shuttle Program
US	Upper Stage
USA	United Space Alliance
USS	Upper Stage Simulator

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