NASA/TM—2011–217452

Ares I Scale Model Acoustic Test Overpressure Results

M.J. Casiano, D.A. Alvord, and D.M. McDaniels
Marshall Space Flight Center, Huntsville, Alabama

December 2011

The NASA STI Program…in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and mission, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results…even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI program home page at <http://www.sti.nasa.gov>

- E-mail your question via the Internet to <help@sti.nasa.gov>

- Fax your question to the NASA STI Help Desk at 443–757–5803

- Phone the NASA STI Help Desk at 443–757–5802

- Write to:
  NASA STI Help Desk
  NASA Center for AeroSpace Information
  7115 Standard Drive
  Hanover, MD 21076–1320

NASA/TM—2011–217452

Ares I Scale Model Acoustic Test Overpressure Results

M.J. Casiano, D.A. Alvord, and D.M. McDaniels
Marshall Space Flight Center, Huntsville, Alabama

National Aeronautics and
Space Administration

Marshall Space Flight Center • Huntsville, Alabama 35812

December 2011

Available from:

NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076–1320
443–757–5802

This report is also available in electronic form at
<https://www2.sti.nasa.gov/login/wt/>

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF ACRONYMS

ASMAT	Ares I Scale Model Acoustic Test
CFD	computational fluid dynamics
DOP	duct overpressure
ESD	energy spectral density
IOP	ignition overpressure
IOP 1	ignition overpressure test 1
IOP 2	ignition overpressure test 2
IOP 3	ignition overpressure test 3
IOP SS	ignition overpressure suppression system
KSC	Kennedy Space Center
LM	launch mount
ML	mobile launcher
MLP	mobile launch platform
MSFC	Marshall Space Flight Center
NEP	nozzle exit plane
RATO	rocket assisted takeoff
RCS	reaction control system
RSRM	reusable solid rocket motor
RSRMV-DM1	five-segment reusable solid rocket motor demonstration motor number 1
SOP	source overpressure
SRB	solid rocket booster

LIST OF ACRONYMS (Continued)

SRM	solid rocket motor
STS	Space Transportation System
TM	Technical Memorandum
TS116	test stand 116
TSM	tail service mast
Vert01	first vertical firing configuration
Vert02	second vertical firing configuration
Vert03	third vertical firing configuration
VSS	vehicle stabilization system

TECHNICAL MEMORANDUM

ARES I SCALE MODEL ACOUSTIC TEST OVERPRESSURE RESULTS

1. INTRODUCTION

A summary of the overpressure environment from the 5% Ares I Scale Model Acoustic Test (ASMAT) and the implications to the full-scale Ares I are presented in this Technical Memorandum (TM). These include the scaled environment that would be used for assessing the full-scale Ares I configuration, observations, and team recommendations. The ignition transient is first characterized and described, the overpressure suppression system configuration is then examined, and the final environment characteristics are detailed. Preliminary results were presented in reference 1.

ASMAT was a development test that was performed on a 5% scale model of the Ares I vehicle mounted on the mobile launcher/launch pad to obtain data that will be used in analytical models to update the predicted Ares I lift-off acoustic and ignition overpressure environments. ASMAT was performed at the Marshall Space Flight Center (MSFC) East Test Area Test Stand 116 (TS116).

Several transient events occur during the startup of the solid rocket motor (SRM) for each test in the ASMAT ignition overpressure (IOP) test series. Each event produces a complex transient signal and requires systematically assessing each instrument's waveform individually. The events discussed are the source overpressure (SOP), IOP, and duct overpressure (DOP).

The ASMAT IOP test series consists of three motors that were fired in the vertical configuration as shown in figure 1. The first vertical firing configuration is identified as Vert01, which is a configuration with below-deck water from the IOP suppression system (IOP SS) and includes water bags. The second vertical firing configuration is identified as Vert02, which is a configuration with water from the IOP SS and does not include water bags. The third vertical firing configuration is identified as Vert03, which is a dry configuration with no water from the IOP SS and does not include water bags.[1] The horizontal firing is not discussed in detail in this TM but is identified as horizontal. Table 1 can be used as a quick reference for the test identification nomenclature.

1.1 Ares I Scale Model Acoustic Test Ignition Overpressure Series Configuration and Objectives

The ASMAT IOP test series consisted of Vert01, Vert02, and Vert03 firings. The Vert01 test used an IOP SS and water bags. The Vert02 test used an IOP SS only with no water bags. The Vert03 test did not contain any IOP suppression. The IOP SS developed for Vert01 and Vert02 stems from the space shuttle IOP SS, which comprises three primary components: Launch mount (LM) duct water, mobile launcher (ML) duct water, and crest water. Water is injected at 146 gpm in both the LM and the ML exhaust ducts in the ASMAT configuration. The crest water subsystem feeds water at a total flow rate of 873 gpm into both sides of the flame trench in the ASMAT configuration.

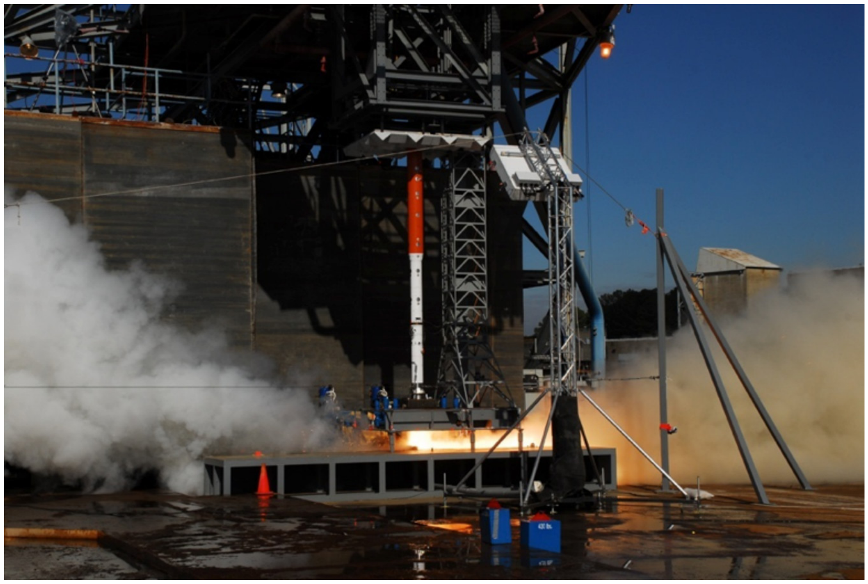


Figure 1. ASMAT vertical firing of Vert03 at MSFC TS 116 on November 18, 2010.

Table 1. Test nomenclature.

Nomenclature 1	Nomenclature 2	Designation	Description	Date
	Horizontal	P8019-001	No IOP SS or water bags	7/30/2010
IOP 1	Vert01	P8019-002	IOP SS with water bags	11/5/2010
IOP 2	Vert02	P8019-003	IOP SS without water bags	11/10/2010
IOP 3	Vert03	P8019-004	No IOP SS and no water bags (dry)	11/18/2010

The vehicle model was held down in the launch configuration (figs. 2 and 3) with the nozzle exit plane located 0.539 in below the top deck of the LM in all three ASMAT tests. For the ASMAT case with water bags, the base of the water bags was located 1.3 in below the LM top deck with a water fill depth of 0.8 in. Since water was injected into the ASMAT exhaust duct through horizontal slits to better represent the full-scale water spray patterns, dummy splash plates were welded 2.1 in below the top deck of the LM for geometric similarity (see fig. 4).[2] The instrumentation suite comprises 78 unsteady pressure sensors with 31 sensors on the vehicle, 14 on the tower, 10 on the mobile launcher, 14 within the exhaust duct, and 9 within the flame trench. Two pressure measurement devices were located inside the igniter assembly and four strain gages were mounted on the rocket assisted takeoff (RATO) motor case used to estimate the transient chamber pressure.[3] Other instrumentation details can be found in reference 4.

The primary objectives for the ASMAT IOP test series were to validate and improve upon the Ares I overpressure environments and to determine the effect of the IOP SS and water bags on the Ares I overpressure environment. The secondary objective was to obtain overpressure data for computational fluid dynamics (CFD) validation. Several other details and characteristics were addressed and reviewed including general IOP waveform characteristics, knockdown factors for the water bags and IOP SS, comparisons to the shuttle and Ares I-X environment, aft skirt/thermal curtain environments, and the locations and amplitudes of the highest environments.

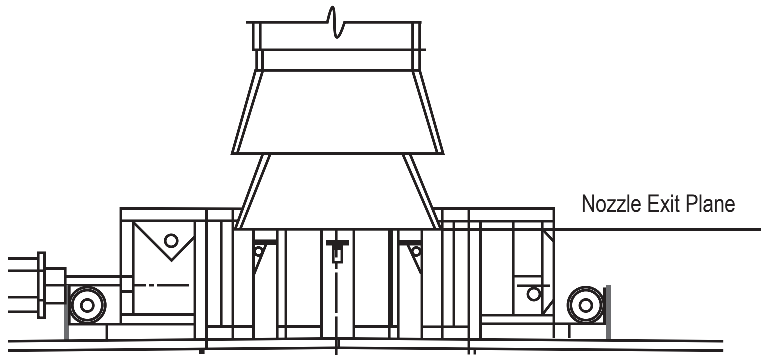


Figure 2. Vehicle in hold-down configuration on the LM.

Figure 3. Pretest photograph of ASMAT Vert02 at MSFC TS116 on November 11, 2010.

1.2 Overpressure Background

The overpressure (IOP and DOP) is a transient environment at lift-off resulting from fluid compression of the accelerating plume gas, subsequent rarefaction, and subsequent propagation from the exhaust trench and duct holes. These high-amplitude unsteady fluid-dynamic perturbations can adversely affect the vehicle and surrounding structure.

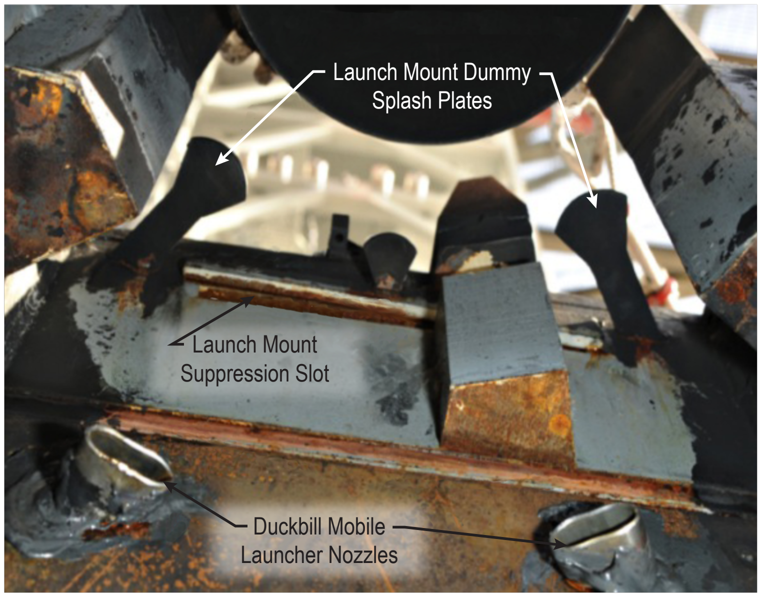


Figure 4. ASAMAT below-deck IOP SS (exhaust duct).

There were several overpressure related issues for the launch of the first space shuttle flight, Space Transportation System 1 (STS-1). Accelerations measured at the wing, body flap, vertical tail, and crew cabin exceeded the 3σ liftoff design environment.[5] The forward reaction control system (RCS) oxidizer tank aft Z strut was deformed due to accelerations exceeding the design limits that were caused by the solid rocket booster (SRB) overpressure.[5,6] Excessive environments were found on the orbiter flap with a pressure pulse that peaked at 2 psi, causing a 6-g acceleration.[5] The STS-1 IOP waveform also excited the orbiter wing symmetric bending mode at approximately 6 Hz, causing a 12-g acceleration.[5] A full-scale STS-1 overpressure waveform from measurement KSPF034A (low-pass filtered at 50 Hz) just 20.9 in below the mobile launch platform (MLP) deck-0, inside of the top of the primary exhaust duct, is shown in figure 5.[7] A solution to these exceedances and damage was developed in 4 months. The below-deck water in the MLP was diverted to spray directly into the SRM plume inside the exhaust ducts. A limp-wall barrier was placed at the top of the exhaust ducts in the space shuttle configuration. The barrier, shown in figure 6, consisted of water bags that contained 12 in of standing water. The important lesson from STS-1 was that inadequate suppression of the overpressure led to vehicle damage, delays, and unsafe flight.

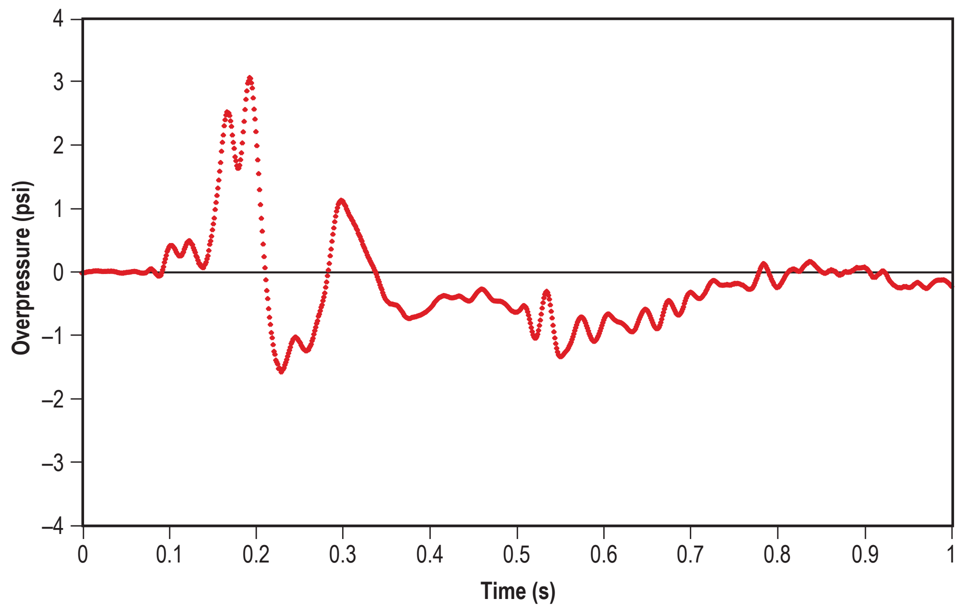


Figure 5. STS-1 overpressure measurement KSRPF034A with 50-Hz low-pass filter (STS-001 SRB IOP top of MLP).

Figure 6. Space shuttle configuration with water bags in MLP secondary exhaust duct.

2. GENERAL DESCRIPTION AND DATA CHARACTERIZATION

2.1 Ignition Transient Characterization

In general, an igniter starts the burning process of an SRM. Subsequently, there is an abrupt change in pressure inside the motor from its original ambient pressure to its final steady state pressure. This abrupt change in pressure corresponds to an abrupt change in flow through the nozzle. Somewhere outside the nozzle, the fluid compression due to the accelerating plume gas causes an increase in pressure at a location within the plume. This location is called the apparent source. Pressure waves propagate from the apparent source within the flame trench as the SOP, out the flame trench as the DOP, and up through the exhaust duct as the IOP.

Some very useful guidance for understanding overpressure is also given through CFD analysis. Figure 7 shows a full-scale CFD transient simulation for STS-1 in the form of a pressure contour plot at an instant in time during the source overpressure development (J.S. West, Personal Communication, 2008). The apparent pressure source is below the pad between the exhaust duct and the deflector.

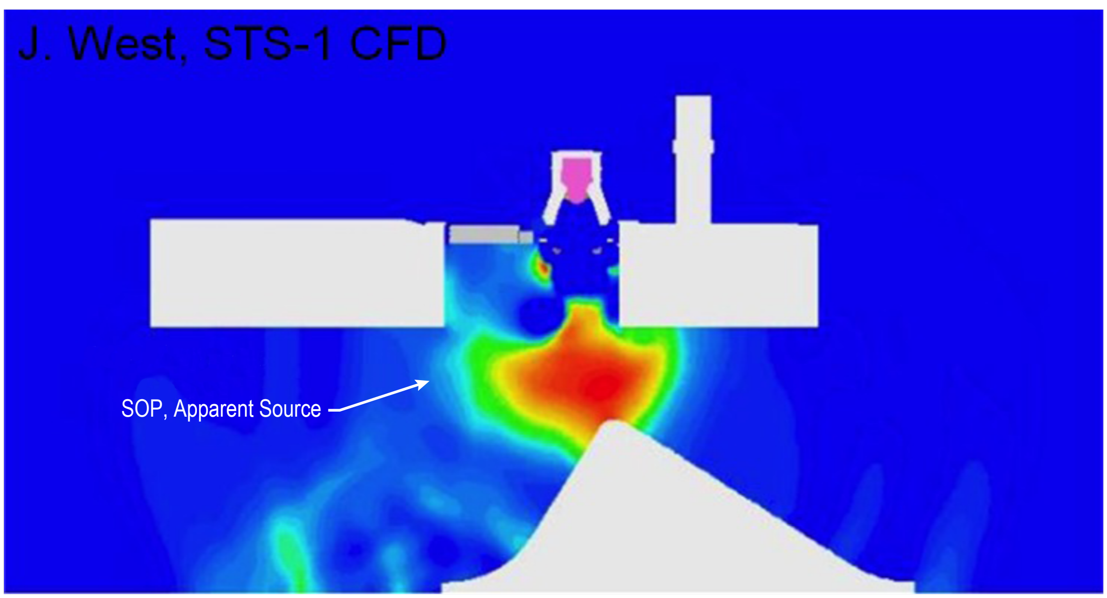


Figure 7. Pressure contour from an unsteady CFD transient simulation for STS-1.

Figure 8 shows a cartoon with a series of snapshots describing instants during the transient events for Ares I or ASMAT. The following progression of steps occurs:

(1) The fire command is sent and the initiator ignites the propellant (fig. 8(a)).

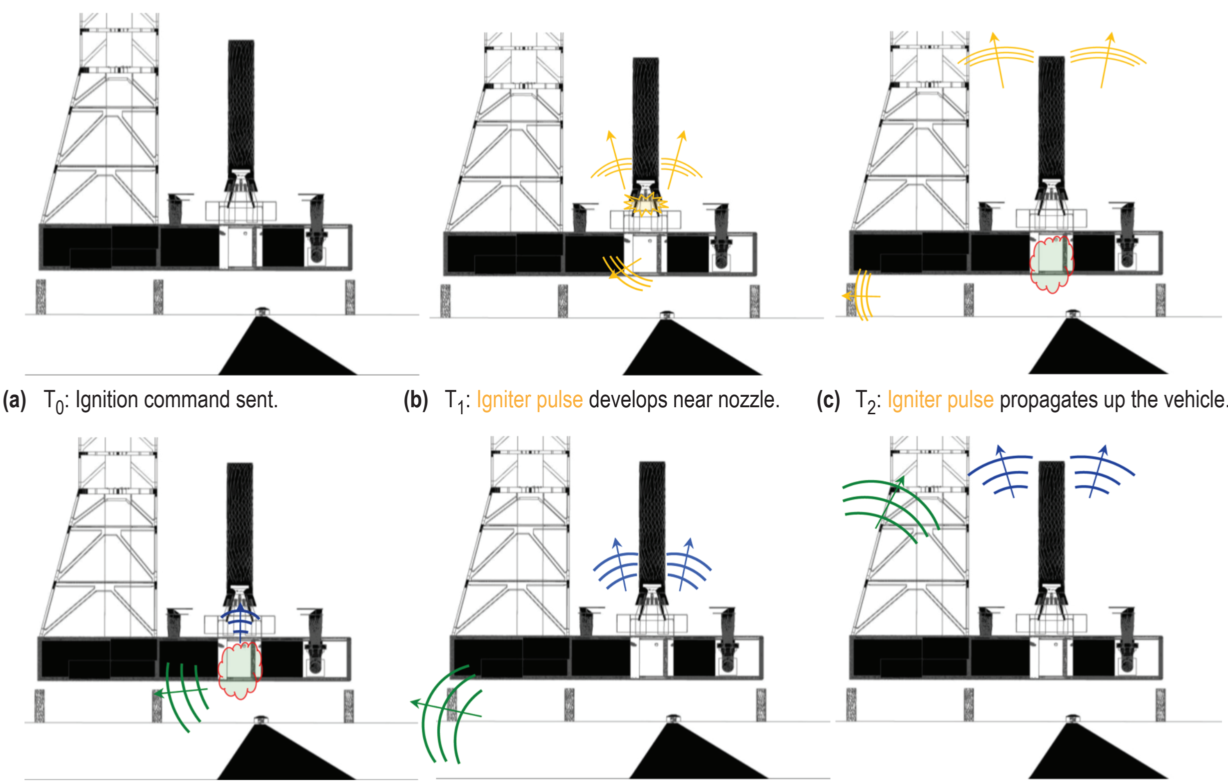
(2) The igniter pulse exits the nozzle (fig. 8(b)).

(3) The igniter pulse begins to propagate up the vehicle as the plume gas accelerates out of the nozzle (fig. 8(c)).

(4) The SOP develops first as the apparent source and propagates through the flame trench and exhaust duct (fig. 8(d)).

(5) The IOP propagates out the exhaust duct and the DOP propagates out the flame trench exits (fig. 8(e)).

(6) The IOP propagates up the vehicle and the DOP impinges the vehicle primarily from the tower side of the ML (fig. 8(f)).



(a) T_0: Ignition command sent. **(b)** T_1: Igniter pulse develops near nozzle. **(c)** T_2: Igniter pulse propagates up the vehicle.

(d) T_3: SOP develops. **(e)** T_4: IOP and DOP propagate out exhaust duct and trench. **(f)** T_5: IOP and DOP impinge along the vehicle.

Figure 8. Illustration of the Ares I and ASMAT ignition transient timing.

The overpressure waveform behaves proportionally to the chamber pressure rise rate. Figure 9 shows the abrupt change in chamber pressure over the short duration for each test in the IOP test series and the horizontal test.

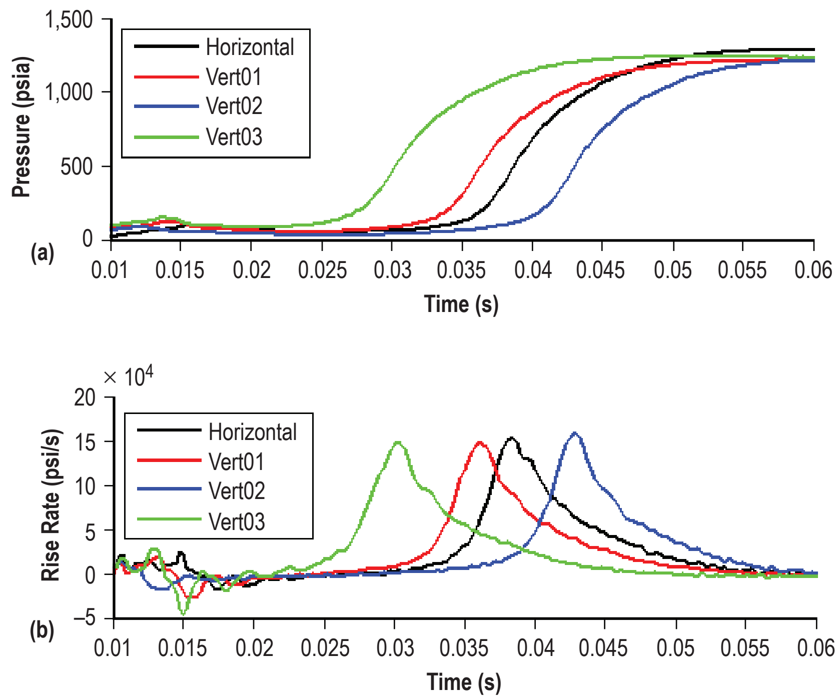


Figure 9. Abrupt change in chamber pressure: (a) Chamber pressure and (b) chamber pressure rise rate.

A few measurements are chosen that show the ignition transient events. The time histories shown in figure 10 are filtered to represent the same scaled frequency content that would be present in the Ares I vehicle up to 100 Hz.[3,8] Note that the time history scales are not the same. The igniter pulse contains nonnegligible spectra out to a very high frequency so the filtering significantly reduces their amplitude. The purpose of figure 10 is primarily for identification and characterization of the overpressure events. Figure 11 indicates the instrument locations for the measurements shown in figure 10.

The earliest occurrence of the SOP waveform was evident near the bottom of the exhaust duct. The instruments here also exhibited some of the highest overpressure amplitudes. The SOP waveform, shown in figure 10(b), propagated through the trench and finally reached the exit as the DOP waveform, shown in figure 10(a). Figure 10(c) shows the SOP waveform once it exited the exhaust duct. It is here that the waveform became the IOP waveform.

The colored windows in figure 10 show the extent of each event. The primary variable that determined the timing, location, and distribution of the overpressure source was the chamber pressure rise rate. This was used to select the window. It was then slid in time based on the amount of time needed for the wave to propagate to each measurement. A logical set of consistent rules was then used to identify each of the overpressure events at the multitude of measurement locations. A detailed discussion on the physical mechanisms and timing window selection is reported in reference 3.

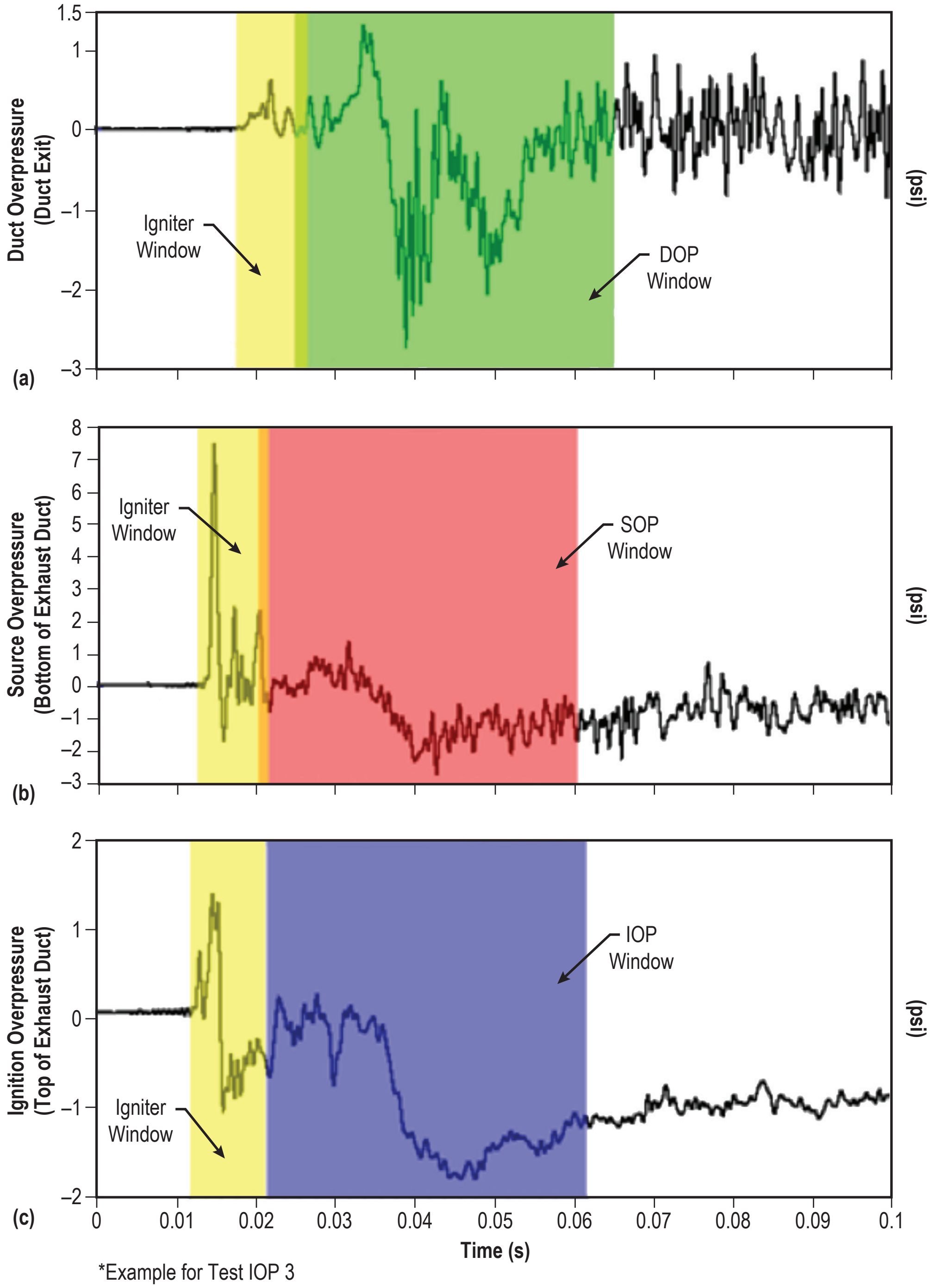


Figure 10. Waveform event timing and identification: (a) DOP, (b) SOP, and (d) IOP.

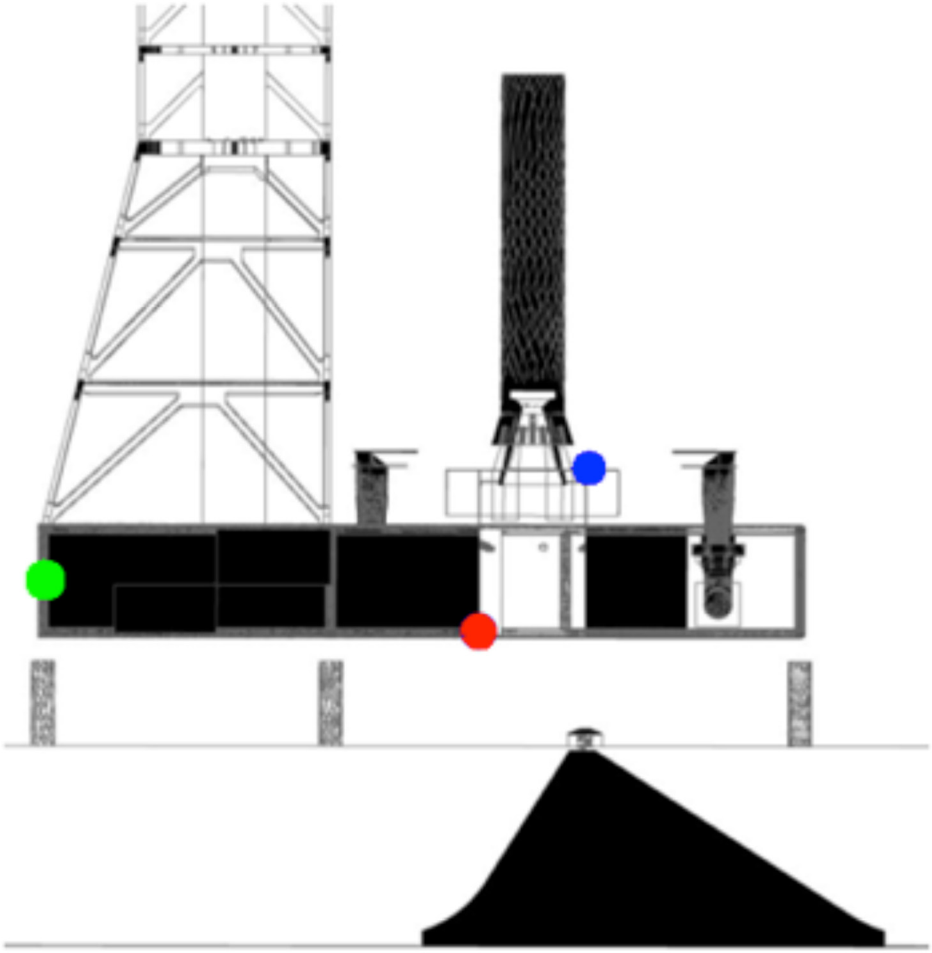


Figure 11. Measurement locations for data in figure 10.

Figure 12 shows an example of the IOP and DOP waveforms in a series of ASMAT time history plots that helped provide verification of the selected events. It shows the IOP wave progressing upwards and away from the exhaust duct and the DOP wave progressing away from the duct exit. It can be tracked by recognizing that the measurements shown in the subplots are at separate heights but are also along the vehicle in figure 12(a), the south-side tower in figure 12(b), and the north-side tower in figure 12(c). The illustrations at the left of each subplot show these locations; it should also be noted that the measurement heights are approximately the same when compared between each illustration.

Considering that a pressure wave emanates from the top of the exhaust duct and travels in the direction from the vehicle to the north-side tower, the IOP should appear to move forward in time through each frame from the vehicle to the north-side tower. The DOP should appear to move backward in time through each frame from the vehicle to the north-side tower, since the wave emanates from the trench exit and propagates in the direction from the north-side tower to the vehicle. The black curve should be the most exaggerated in its progression because the waveforms travel nearly horizontally near the top of the ML. The colored dashed lines help emphasize these points by connecting the peaks of each waveform. The slopes are not parallel because the distance traveled by the wave is different for each measurement.

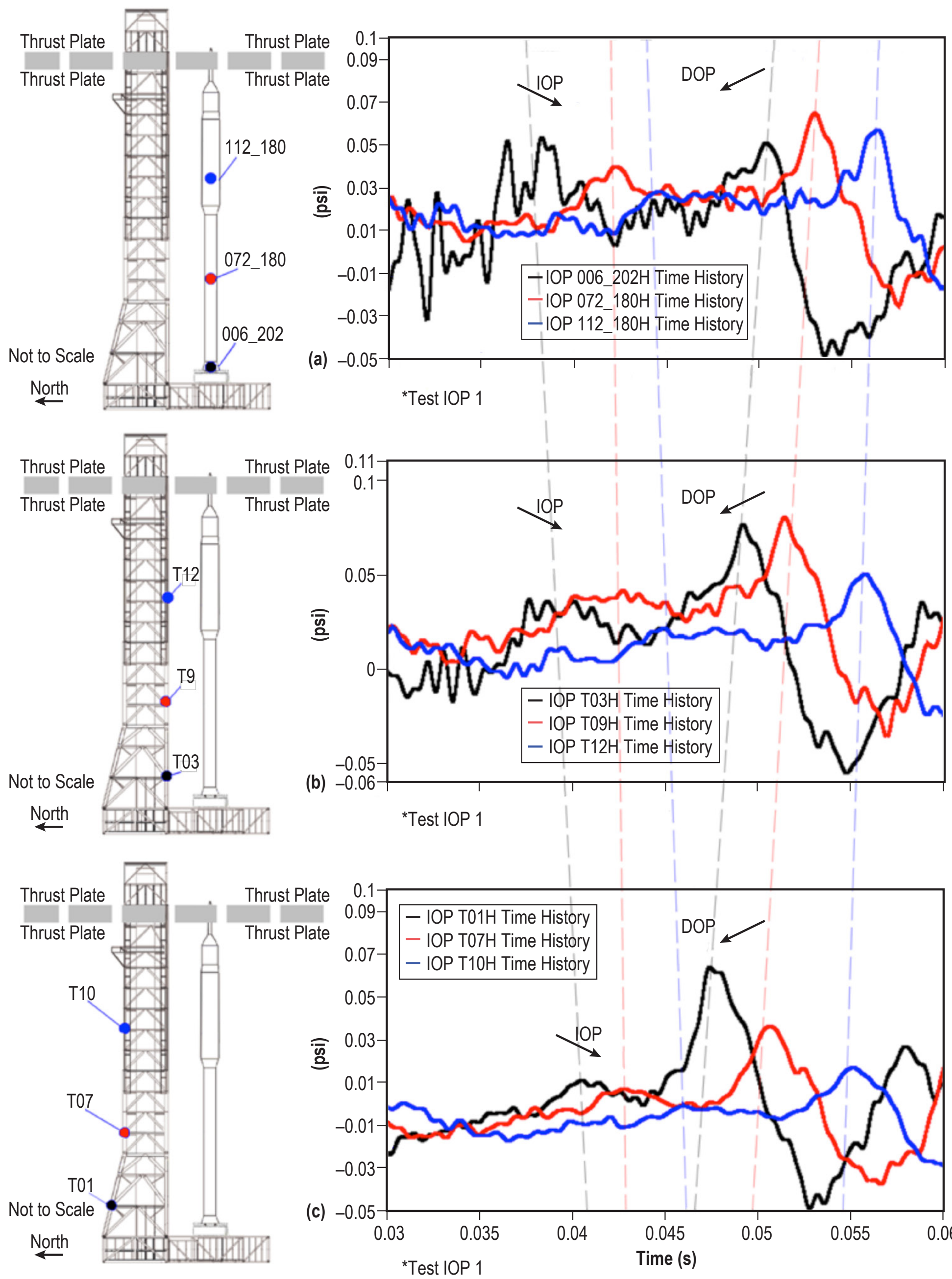


Figure 12. IOP and DOP wave progression in changing instrument frame (ASMAT data).

2.2 Scaling Methodology

The scaling methodology is detailed in references 8 and 9. The primary scaling factors are based on the differences in geometry and the motor performance parameters. Table 2 shows the resulting scale factors for each test. The RATO performance parameters used were estimated using strain gage and igniter pressure measurements (i.e., steady state chamber pressure and peak chamber pressure rise rate).[3,10] The full-scale Ares I motor performance parameters were obtained from five-segment reusable SRM (RSRM) demonstration motor number 1 (RSRMV-DM1) data and the upper and lower bounds of the approved RSRMV MODEL5V ballistic dispersion curves. These curves are based on heritage flight data and account for historical motor variability in the RSRM. The horizontal motor scale factors and the details on the approach used to determine the scale factors in table 2 are discussed in references 3 and 8.

Table 2. Range of ASMAT to Ares I overpressure scale factors for each IOP test.

ASMAT to Ares I Overpressure Scale Factors			
Scale Factor	**IOP 1**	**IOP 2**	**IOP 3**
Lower bound (n/a)	1.43	1.35	1.46
RSRMV DM-1 (n/a)	1.46	1.38	1.49
Upper bound (n/a)	2.39	2.25	2.43
Frequency scaling (Hz)	1,365	1,452	1,345

2.3 Overpressure Suppression

The details of the overpressure suppression system are documented in the ASMAT IOP Series Test Report.[2] Figure 13 shows a snapshot during the RATO motor start. Steam from the IOP SS is observed on test 1 and test 2. Table 3 shows the design flow conditions for the ASMAT IOP test series. The water bag design is detailed in reference 11. Figures 4, 14, and 15 show some views of the below-deck IOP SS.

ASMAT knockdown factors were estimated from the ASMAT data. Knockdown factors are values that represent ratios of the overpressure peak amplitude in a dry configuration to the overpressure peak amplitude in a suppressed configuration. ASMAT amplitude and timing information was characterized for every measurement and every overpressure event for each test. Figures 16 and 17 show knockdown factor plots comparing IOP test 3 (IOP 3) with IOP test 1 (IOP 1) and IOP test 2 (IOP 2) with IOP 1, respectively. Statistical information is labeled on each plot. This information includes the mean knockdown factor, the standard deviation, and the coefficient of variation (which is a measure of dispersion). The distance axis is also scaled to full-scale distance.

The mean knockdown factor due to the water bags and IOP SS is 7.03. Comparison of the IOP SS configuration with the IOP SS and water bag configuration indicated the effectiveness of the water bags alone. The mean knockdown factor in the vicinity of the aft skirt was 1.52; however, this value is not indicative of the knockdown factor of water bags without the IOP SS. Subscale shuttle 6.4% model results indicate that the effect of the water bags was different with and without the IOP SS. The IOP SS and water bags show excellent suppression throughout. The water bags are effective near the exhaust duct and aft skirt and not effective away from this area. The knockdown factors exceed those used in the shuttle configuration and will be shown to bring the environment to within the Ares I data book environment.

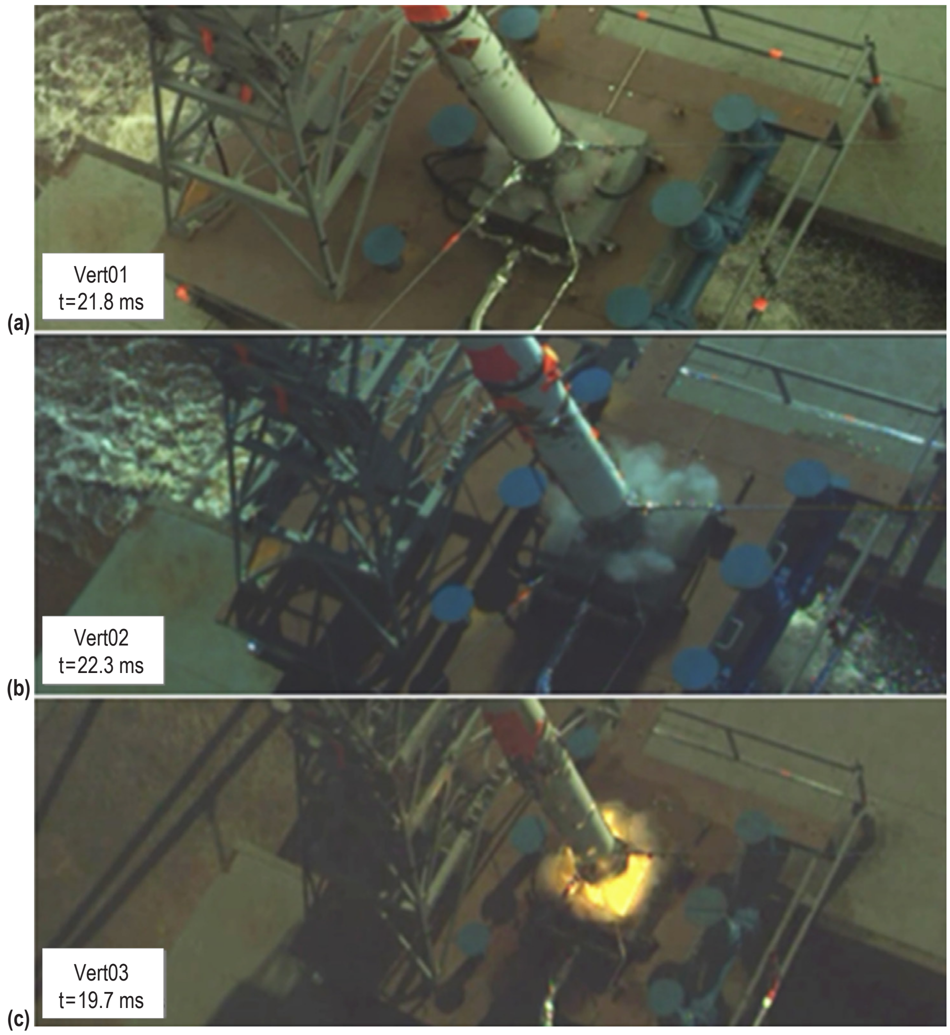


Figure 13. Snapshot during motor start of (a) test IOP 1, (b) test IOP 2, and (c) test IOP 3.

Figure 14. ASMAT below-deck IOP SS (main flame deflector with crest water).

Figure 15. ASMAT IOP suppression (water bags).

Table 3. ASMAT IOP SS and water bag configuration.

	IOP 1	IOP 2	IOP 3
Water bags	Yes	No	No
Main flame deflector water north (gpm)	640	640	N/A
Main flame deflector water south (gpm)	233	233	N/A
Exhaust duct water (gpm)	291	291	N/A

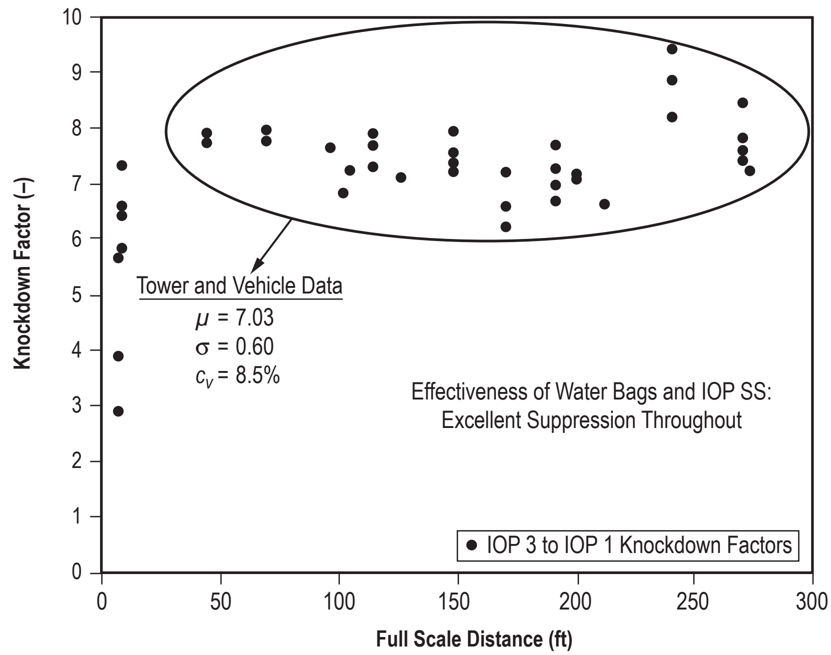


Figure 16. Knockdown factor: Dry compared to IOP SS/water bags.

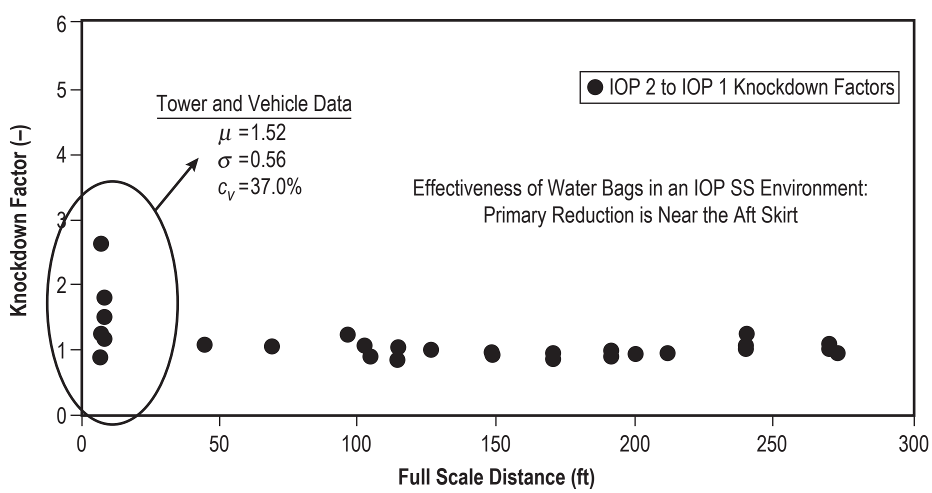


Figure 17. Knockdown factor: IOP SS compared to IOP SS/water bags.

2.4 Environment Characteristics

The ASMAT overpressure environment was scaled to the full-scale Ares I configuration. To characterize the differences between the tests, the scaled ASMAT environments (scaled to Ares I environments) were compared. The maximum measured overpressure (which includes both the IOP and DOP waves) is selected for comparison purposes. This maximum measured overpressure waveform would impinge on the vehicle and surrounding structure. Using the previously mentioned scaling method and the appropriately filtered data (i.e., low-pass, 100-Hz, full-scale equivalent), the maximum overpressure from each ASMAT IOP test was scaled to Ares I conditions.[8] The over-pressure environment is compared from each ASMAT IOP test was scaled to Ares I conditions.[8] The overpressure environment is compared for each test along the vehicle and separately along the tower. The worst-case (scaled upper bound), full-scale, peak-to-peak overpressure amplitude is shown in figures 18 and 19. The distance axis is also scaled to full-scale distance.

On the first stage (fig. 18), the overpressure at the top of the exhaust duct near the nozzle exit plane (NEP), the thermal skirt and curtain, and the aft skirt were carefully examined. The data again show that the water bags are most effective at the aft end. Table 4 provides a list of pressure values that are the worst-case scaled Ares I peak-to-peak values (scaled from ASMAT to Ares I).

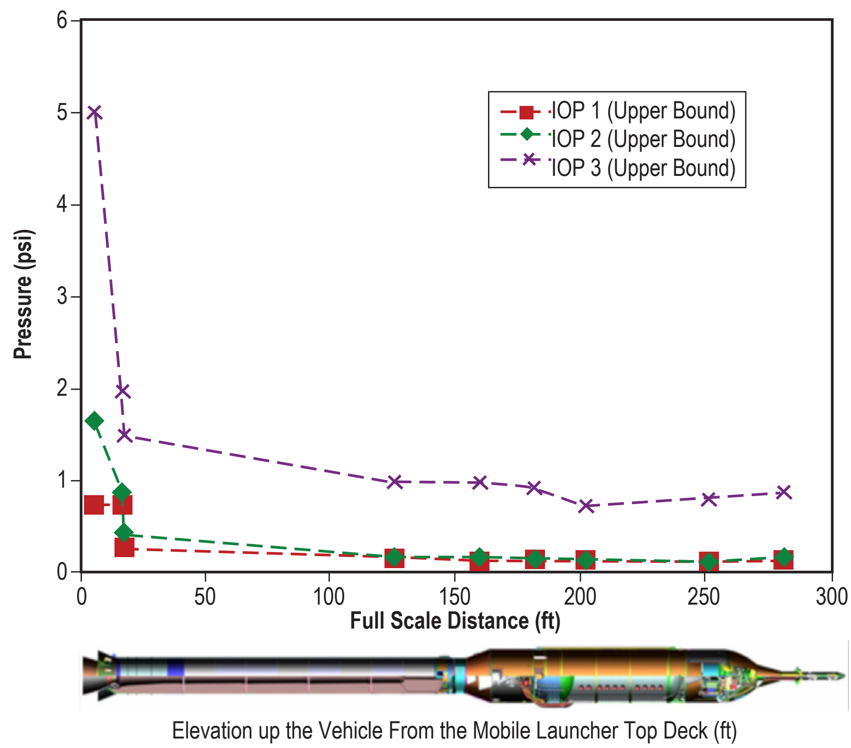


Figure 18. Vehicle maximum ASMAT peak-to-peak overpressure amplitude scaled to Ares I.

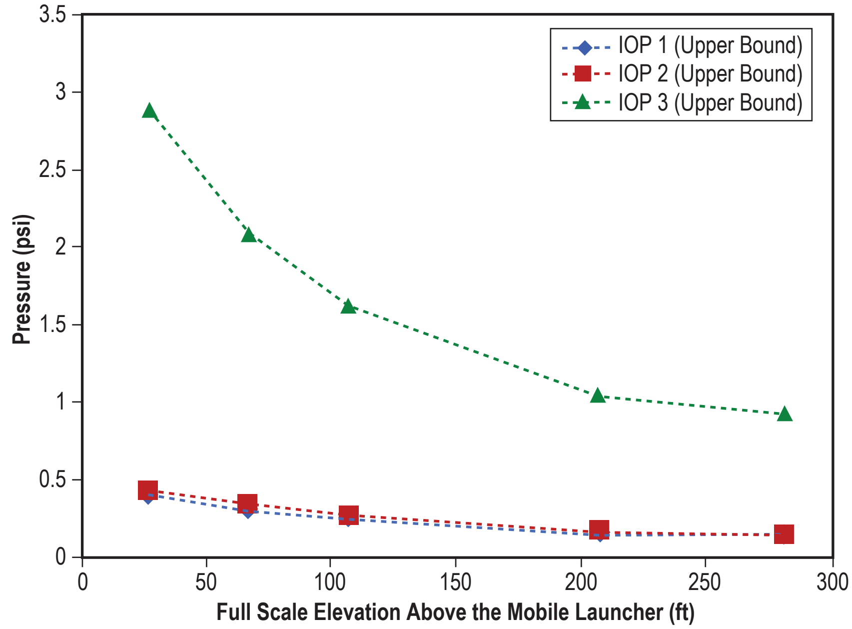


Figure 19. Maximum ASMAT peak-to-peak overpressure environment amplitude along the tower scaled to Ares I.

Table 4. Worst-case scaled Ares I peak-to-peak values.

	Top of Exhaust Duct (psi)	Thermal Curtain (psi)	Aft Skirt (psi)
IOP SS + waterbags	0.7	0.7	0.2
IOP SS	1.7	1.0	0.4
No suppresion	5.0	2.0	1.6

The overpressure data on the tower shown in figure 20 are again the worst-case scaled Ares I peak-to-peak values. A pressure measurement at the vehicle stabilization system (VSS) (measurement KSAPE047A during the Ares I-X launch) is compared to the predicted Ares I data (worst-case scaled from ASMAT). The Ares I-X VSS is 156 ft above the MLP and the instrument measures 0.2 psi. There is not an instrument in the scaled ASMAT tower location; however, the data along the tower can be interpolated from figure 20. Because the decay of finite waves and acoustic waves follow a power law, an estimate is based on a power curve fit to the tower data. The interpolated amplitude at 156 ft is 0.2 psi for the comparable configuration with IOP SS and water bags. This provides a good comparison at a particular location (at the VSS) between the amplitude of the Ares I-X overpressure (0.2 psi) and the overpressure for the analogous ASMAT configuration scaled to Ares I (0.2 psi). It is an analogous configuration in that the Ares I-X configuration uses the below-deck IOP SS and space shuttle water bags. The other predicted Ares I configurations give 0.2 psi (IOP SS only) and 1.2 psi (no IOP SS and no water bags).

The maximum overpressure environment was also characterized. As expected, the maximum amplitudes occurred below the deck, specifically at the bottom opening of the exhaust duct near the apparent source. This is shown in figure 20. The blue diamonds are data scaled from IOP 1, the red squares are data scaled from IOP 2, and the green triangles are data scaled from IOP 3.The distance axis is also scaled to full-scale distance. The bottom opening of the exhaust duct is expected to be near the overpressure source as shown in figure 7. Here, the predicted Ares I peak-to-peak overpressure amplitude is in the range of 13 to 18 psi for all three suppression configurations. In fact, the maximum amplitudes with IOP SS are higher than the cases without the IOP SS near the source location. This is expected because the water takes up much of the volume underneath the deck during the formation of the overpressure events. However the maximum amplitudes away from the source for the case without the IOP SS (IOP 3) remain consistently higher than the cases with IOP SS due to the attenuating features of the IOP SS.

The overpressure wave that exits the side from underneath the deck has the frequency content shown in figure 21. Although this spectrum is specific to one instrument, it gives a sense of the relative amplitude as a function of frequency for the Ares I prediction. The pressure amplitude was not scaled to Ares I (only the frequency); however, the purpose of the energy spectral density (ESD) plot is to get a sense of the Ares I frequency content. The dominant frequency bandwidth is clearly in the 0- to 10-Hz range peaking at approximately 4 Hz.

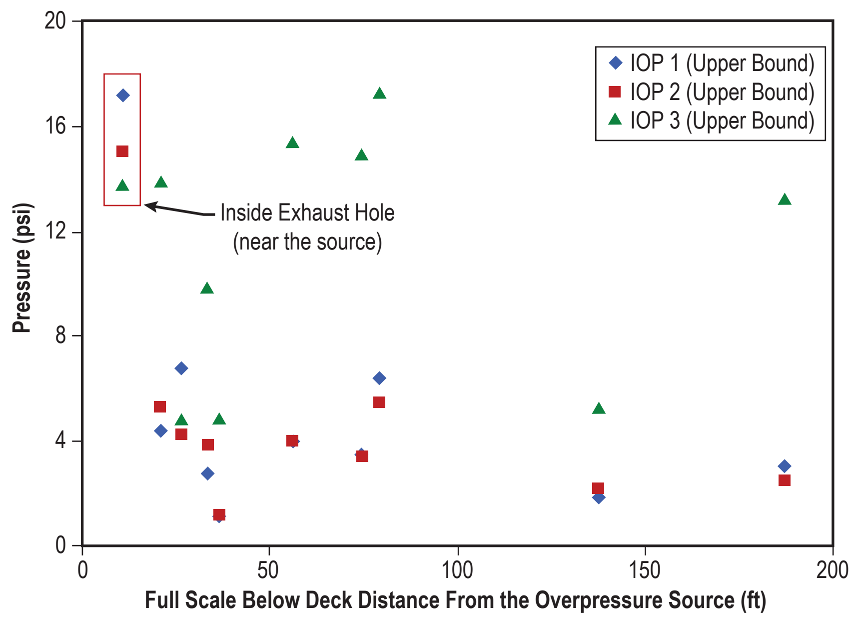


Figure 20. Maximum ASMAT peak-to-peak overpressure amplitude below the deck scaled to Ares I.

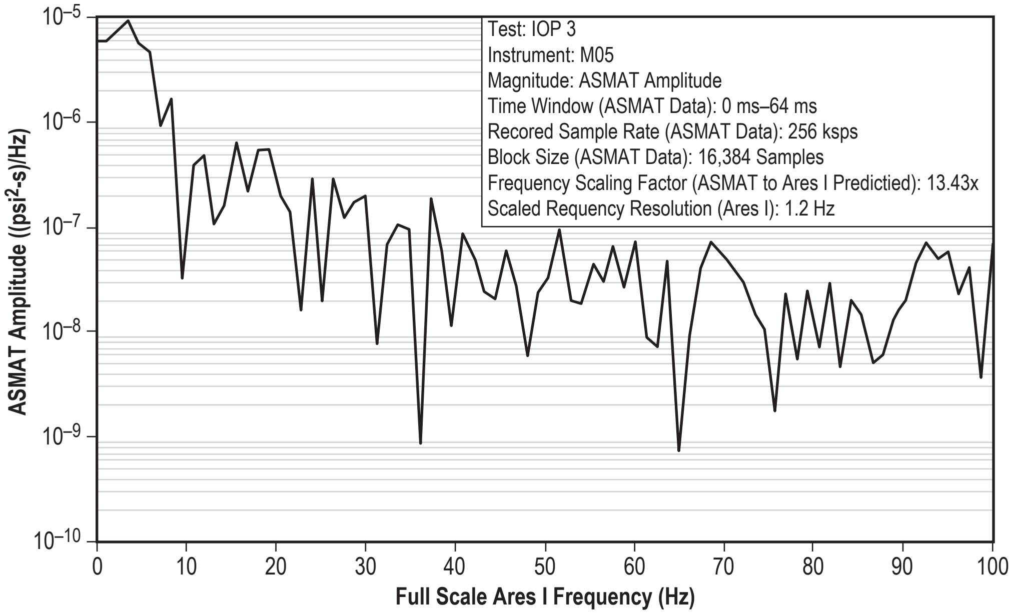


Figure 21. ASMAT frequency spectrum scaled to Ares I, amplitude not scaled (energy spectral density plot: Test-P8019-004, sensor-IOP_M05H.

Figure 22 is a single frame from a data visualization video interpolating the vehicle pressure measurements across the surface of the vehicle. The full animation is available on Zhora, the secure MSFC Fluid Dynamics ER42 data server. It shows several subplots for ASMAT IOP 3. The subplot on the left is a pressure contour plot at an instant in time occurring at 47 ms. The middle subplot shows the ASMAT vehicle pressure profiles along orientations of 0°, 90°, 180°, and 270°. The final column of subplots on the right contains instrument time histories at locations shown with the marker of the associated color in the contour plot. The contour plot and the vehicle profile plot show a differential pressure between the forward and aft end of the vehicle. For this case with no IOP SS or water bags, the differential pressure is approximately equivalent to a scaled Ares I value of 2 psi. The instrument time histories on the right show the progression of the overpressure wave up the vehicle.

2.5 Scaled Environment

Figures 23 and 24 provide a concise summary of the ASMAT IOP test series environment results. The ASMAT data are scaled to the Ares I configuration and plotted versus STS-1 data for the case with no IOP SS or water bags (fig. 23) and is plotted versus STS-2 data and Ares I-X data for the case with IOP SS and water bags (fig. 24). These comparisons provide the best possible one-to-one comparison for overpressure with and without water suppression. Additionally, the location at the top of the tail service mast (TSM), which is a consistent location for all the MLPs for shuttle and Ares I-X, was chosen for comparison. This measurement does not exist for the ASMAT or Ares I configuration because there is no TSM. However, the ASMAT data were scaled and fitted appropriately based on the nearest instrumentation. The timing of the overpressure event cannot be easily scaled from the ASMAT test data partly because of differences in motor igniter burning and timing. However, the waveform peak amplitude time is adjusted based on the Ares I Broadwell and Tsu predictions.[12,13] The envelope from the previous predictions, shown with the dashed lines, is correctly estimated for the location of the TSM measurement.

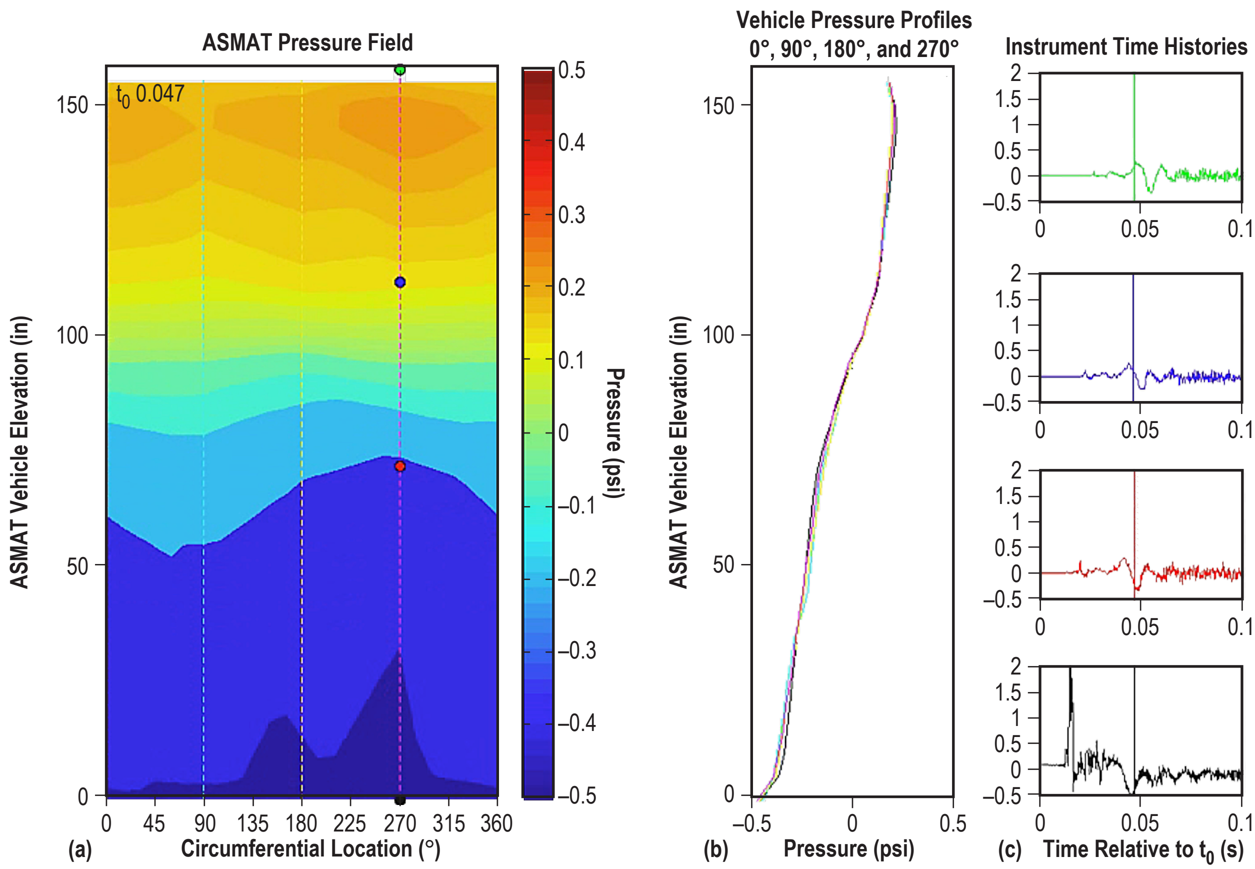


Figure 22. ASMAT test IOP 3 (a) instantaneous pressure contour, (b) vehicle pressure profiles, and (c) instrument time histories at time t = 47 ms.

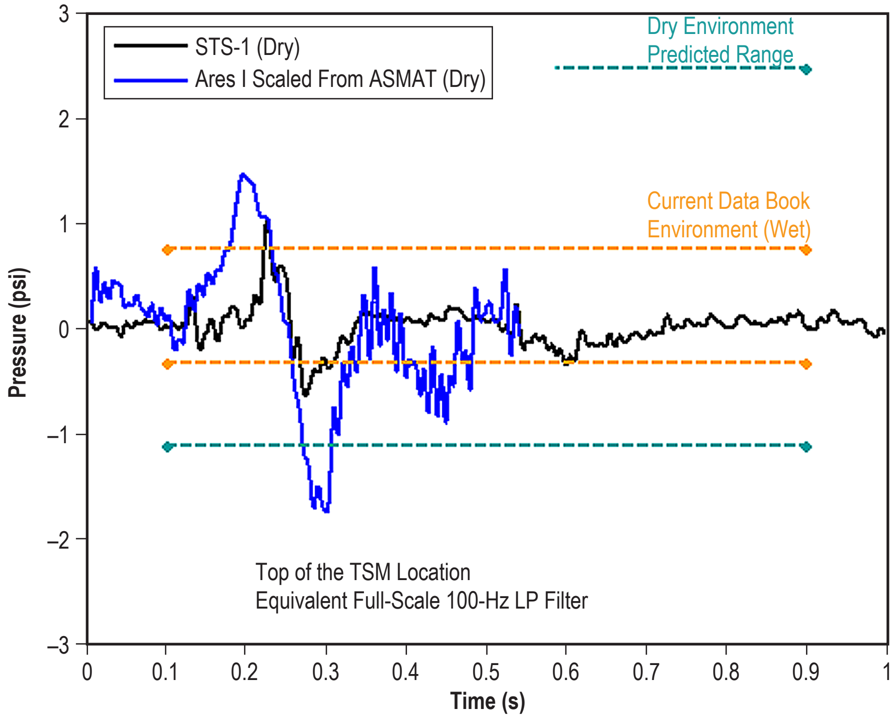


Figure 23. Dry comparison: Data at the top of the TSM location for STS-1 and Ares I (scaled from ASMAT test IOP 3).

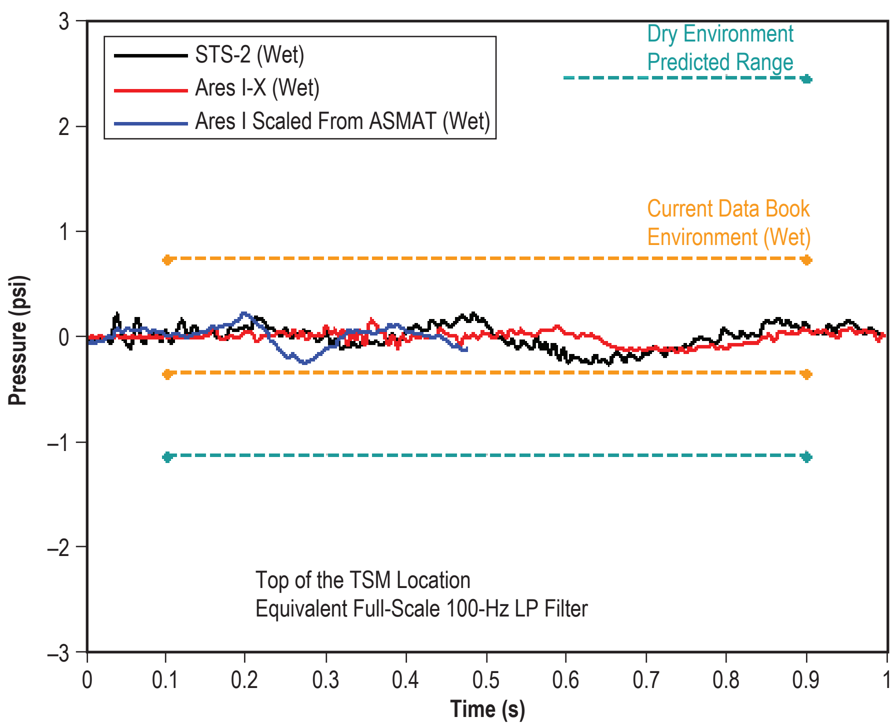


Figure 24. Wet comparison: Data at the top of the TSM location for STS-2, Ares I-X, and Ares I (scaled from ASMAT test IOP 1).

Figures 23 and 24 show several features of interest. First, the dry ASMAT-scaled Ares I prediction is slightly higher than the STS-1 flight data but lower than the dry Broadwell and Tsu Ares I environment. The ASMAT-scaled Ares I prediction is a prediction that can be used to remove much of the conservatism in the Broadwell and Tsu model predictions.[12] This is shown in figure 23 by comparing the blue Ares I prediction to the green dashed lines (which is the range of the previous dry predictions). It also shows that the dry Ares I prediction (scaled from ASMAT) is higher than the orange dashed lines or the current data book environment, which considers IOP water suppression and water bags.[13] Future work for vehicle design would have to include a new ASMAT IOP environment evaluated by an additional loads cycle. Finally, the wet (IOP SS and water bags) Ares I prediction (scaled from ASMAT) (fig. 24) meets the environment specified in the data book. The wet environment is also consistent with the wet environment from STS-2 and the Ares I-X flight data. The predicted Ares I overpressure environment with the IOP SS and water bag configuration is within the family of data from Ares I-X and space shuttle.

3. OBSERVATIONS AND RECOMMENDATIONS

The key observations can be taken from figures 16, 17, 23, and 24. The IOP SS and water bags successfully knocked down the overpressure events. Figures 16 and 17 detail the effectiveness of the IOP SS and water bags. The combined knockdown factor was 7.03 along the majority of the vehicle and tower. Water bags appear to be effective in knocking down the overpressure near the aft end of the vehicle. The IOP SS is effective over the entire pad, tower, and vehicle. Figures 23 and 24 show that the dry Ares I prediction (scaled from ASMAT) is higher than the current data book environment. Also, the wet Ares I prediction (scaled from ASMAT) meets the environment specified in the data book.

The Broadwell and Tsu prediction with water suppression has a higher amplitude than the ASMAT-scaled Ares I prediction with water; therefore, it is most likely that the vehicle design would also withstand the new ASMAT-scaled water-suppressed Ares I prediction. However, future work would include a new ASMAT-scaled Ares I overpressure environment evaluated under a subsequent-loads cycle. This environment would consider more representative frequency and amplitude content of the overpressure transient. Review of the first stage, upper stage, and crew module component requirements and design limits should be reviewed with respect to the new environment. The recommendation for Ares I is to keep the space shuttle heritage IOP SS (below-deck IOP water in the LM and ML and also the crest water on the main flame deflector) and water bags.

REFERENCES

1. Alvord, D.A.; Casiano, M.J.; and McDaniels, D.M.: "Ares I Scale Model Acoustic Test: Ignition Overpressure Characterization and Analysis Presentation to KSC-LXD10," *ESTSG-FY11-00502*, Marshall Space Flight Center Internal Memo, Huntsville, AL, 2011.

2. Houston, J.D.; Alvord, D.A.; and Vargas, M.B.: "ASMAT IOP Series Test Report," *ESTSG-FY11-00327*, Marshall Space Flight Center Internal Memo, Huntsville, AL, 2011.

3. Casiano, M.J.; Alvord, D.A.; and McDaniels, D.M.: "ASMAT IOP Series Analysis Report," Marshall Space Flight Center, Huntsville, AL, to be published.

4. Casiano, M.J.: "ASMAT IOP Instrumentation and Configuration Assessments," *ER42 (11-021)*, NASA Marshall Space Flight Center Internal Memo, Huntsville, AL, 2011.

5. Dougherty, N.S.: "Shuttle SRB Ignition Overpressure (IOP)—STS-1 and STS-2 and Subsequent Data," *ERC/EV-33-06-01*, NASA Marshall Space Flight Center Internal Memo, Huntsville, AL, 2006.

6. Bejmuk, B.I.: "Space Shuttle Integration—Lessons Learned," Boeing Presentation, 2005, <http://search-www.boeing.com/search?q=Space+Shuttle+Integration—Lessons+Learned&site=www_boeing&btnG=Search&client=www_boeing&proxystylesheet=www_boeing&output=xml_no_dtd&btnG.x=0&btnG.y=0&sort=date%3AD%3AL%3Ad1&entqr=0&oe=UTF-8&ie=UTF-8&ud=1>, Accessed April 2011.

7. Casiano, M.J.: "Ignition Overpressure Benchmarking and Parameters and Launch Acoustics Parameters," *ER42 (07-39)*, NASA Marshall Space Flight Center Internal Memo, Huntsville, AL, 2007.

8. Alvord, D.A.: "Ares I Scale Model Acoustic Test: Ignition Overpressure Scaling Analysis," *ESTSG-FY11-00001*, NASA Marshall Space Flight Center Internal Memo, Huntsville, AL, 2010.

9. Casiano, M.J.: "Ignition Overpressure Scaling Methodologies Summarized," *ER42 (08-006)*, NASA Marshall Space Flight Center Internal Memo, Huntsville, AL, 2007.

10. Alvord, D.A.: "Ares I Scale Model Acoustic Test: Chamber Pressure Rise Rate for the Rocket-Assisted Take Off Solid Rocket Motor," *ESTSG-FY10-02462*, NASA Marshall Space Flight Center Internal Memo, Huntsville, AL, 2010.

11. Alvord, D.A.: "Ares I Scale Model Acoustic Test Water Bag Design Considerations and Development," *ESTSG-FY10-00074*, NASA Marshall Space Flight Center Internal Memo, Huntsville, AL, 2009.

12. Broadwell, J.E.; and Tsu, C.N.: "Transient Pressures Caused by Rocket Start and Shutdown in Ducted Launcehers," J. Spacecraft Rockets, Vol 4, No. 10, pp. 1323–1328, 1967.

13. "Ares I Acoustic Environments Data Book," CxP 72164, Marshall Space Flight Center, Huntsville, AL, 2009.

REPORT DOCUMENTATION PAGE					*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
01-12-2011

2. REPORT TYPE
Technical Memorandum

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Ares I Scale Model Acoustic Test Overpressure Results

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
M.J. Casiano, D.A. Alvord, and D.M. McDaniels

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
George C. Marshall Space Flight Center
Huntsville, AL 35812

8. PERFORMING ORGANIZATION REPORT NUMBER
M–1328

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITOR'S ACRONYM(S)
NASA

11. SPONSORING/MONITORING REPORT NUMBER
NASA/TM—2011–217452

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Publicly Available
Subject Category 71
Availability: NASA CASI (443–757–5802)

13. SUPPLEMENTARY NOTES
Prepared by the Fluid Dynamics Branch (ER42) in the Propulsion, Structural, Thermal, and Fluid Analysis Division, Engineering Directorate, Marshall Space Flight Center, Huntsville, AL

14. ABSTRACT
A summary of the overpressure environment from the 5% Ares I Scale Model Acoustic Test (ASMAT) and the implications to the full-scale Ares I are presented in this Technical Memorandum. These include the scaled environment that would be used for assessing the full-scale Ares I configuration, observations, and team recommendations. The ignition transient is first chracterized and described, the overpressure suppression system configuration is then examined, and the final environment characteristics are detailed. The recommendation for Ares I is to keep the space shuttle heritage ignition overpressure (IOP) suppression system (below-deck IOP water in the launch mount and mobile launcher and also the crest water on the main flame deflector) and the water bags.

15. SUBJECT TERMS
ignition overpressure, ASMAT, acoustics, scaled environment

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			STI Help Desk at email: help@sti.nasa.gov
U	U	U	UU	36	19b. TELEPHONE NUMBER *(Include area code)* STI Help Desk at: 443–757–5802

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

National Aeronautics and
Space Administration
IS20
George C. Marshall Space Flight Center
Huntsville, Alabama 35812