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STATUS, PLANS, AND INITIAL RESULTS FOR ARES I CREW LAUNCH VEHICLE AERODYNAMICS

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ABSTRACT

Following the completion of NASA's Exploration Systems Architecture Study in August 2004 for the NASA Exploration Systems Mission Directorate (ESMD), the Exploration Launch Office at the NASA Marshall Space Flight Center was assigned project management responsibilities for the design and development of the first vehicle in the architecture, the Ares I Crew Launch Vehicle (CLV), which will be used to launch astronauts to low earth orbit and rendezvous with either the International Space Station or the ESMD's earth departure stage for lunar or other future missions beyond low Earth orbit. The primary elements of the Ares I CLV project are the first stage, the upper stage, the upper stage engine, and vehicle integration. Within vehicle integration is an effort in integrated design and analysis which is comprised of a number of technical disciplines needed to support vehicle design and development. One of the important disciplines throughout the life of the project is aerodynamics. This paper will present the status, plans, and initial results of Ares I CLV aerodynamics as the project was preparing for the Ares I CLV Systems Requirements Review. Following a discussion of the specific interactions with other technical panels and a status of the current activities, the plans for aerodynamic support of the Ares I CLV until the initial crewed flights will be presented.

INTRODUCTION

On January 14, 2004, President George W. Bush announced a new Vision for Space Exploration (VSE).[1] Included in the President's announcement were specific guidelines, including returning the Space Shuttle safely back to flight, completing the International Space Station (ISS) prior to retirement of the Space Shuttle, and development of a new space architecture to allow for robotic and human exploration beyond low Earth orbit, including extended stays on the Moon and human exploration of Mars. This is known as NASA's Constellation program. A schedule included with these guidelines called for ISS completion and Space Shuttle retirement by 2010, an operational Crew Exploration Vehicle (CEV) by 2014, and the first extended human expedition to the lunar surface as early as 2015, but no later than 2020.

Shortly after the President's announcement, the Exploration Systems Mission Directorate (ESMD) was formed to oversee the design, development, test, and verification of the system of vehicles needed to fulfill the new space architecture. On April 14, 2005, Dr. Michael Griffin began his duties as NASA Administrator. In one of his first significant actions to jumpstart ESMD activities, Dr. Griffin initiated the Exploration Study Architecture Study (ESAS), to study a wide range of architecture options and determine a suitable one based on schedule, funding, and technology development status.[2] In the end, a design for the Ares I Crew Launch Vehicle (CLV) emerged that consisted of a two-stage system to deliver the crew exploration vehicle (CEV) with up to six astronauts to low earth orbit. The first stage of the Ares I CLV is a modified Space Shuttle solid rocket booster and the second (or upper) stage includes a liquid-hydrogen/liquid-oxygen rocket propulsion system.

Formal activities following the announcement of the ESAS results began in the fall of 2005. An organizational structure for the Exploration Launch Office (responsible for the Ares I CLV) was established at the Marshall Space Flight Center (MSFC) to effectively manage the three hardware and one Vehicle Integration (VI) elements. Vehicle integration is a critical element needed to bring the overarching disciplines together with the three hardware elements for Ares I CLV; namely, first stage, upper stage, and upper-stage engine. Furthermore, CEV interactions are needed when discussing the entire launch stack on nominal ascent or during ascent abort. Within the VI office, an Integrated Design and Analysis (ID&A) office oversees the focused Ares I CLV design and analysis activities across the different technical disciplines.

The Ascent Flight Systems Integration Group (AFSIG) reports to the ID&A office and is responsible for integrating, managing, scheduling, and monitoring all activities involving vehicle flight performance. The AFSIG is responsible for the integrated flight performance analysis preparation for flight, launch, and post-flight evaluation of the launch vehicle and its elements. This encompasses all Ares I CLV engineering activities to establish requirements for the performance of the flight vehicle. Technical panels and working groups are one of the principal mechanisms in fulfilling these responsibilities.

The AFSIG activities emphasize technical trades, requirements impacts, and new design/development activities. The AFSIG is responsible for proposing new requirements or changes to existing system design requirements. This activity includes implementation, review, and evaluation of the systems analysis and synthesis, trade studies, test planning, data analysis, and the interface relationships necessary to complete the definition of the integrated flight systems and assure compliance with Ares I CLV requirements. The AFSIG provides technical integration across the following technical areas involving all flight phases: aerodynamics; flight performance; loads and structural dynamics; tracking and communications; acoustics; guidance, navigation and control integration; integrated propulsion and fluids; thermal design (active and passive); integrated avionics; and day-of-launch requirements. The Aerodynamics Panel resides within the AFSIG, as shown in Figure 1.

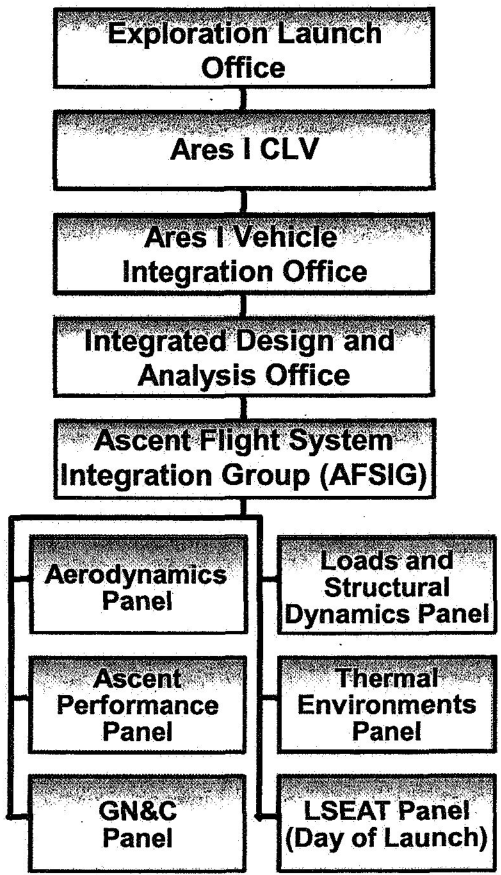


Figure 1. Organizational location of the Ares I CLV Aerodynamics Panel.

The Aerodynamics Panel reviews, assesses, advises, guides, and integrates all analysis and tests required to assure the aerodynamic design will satisfy the Ares I CLV program requirements. The chairman is responsible for ensuring sound analysis and tests are defined, executed, and continually assessed; for coordinating the flight test and wind tunnel test requirements for aerodynamics with other subsystem managers and develops, schedules, and maintains the flight test, wind tunnel test, and verification program; and for maintaining aerodynamic data bases and data books and distributing aerodynamic data to all Ares I CLV elements as required. Through periodic technical reviews and studies, the panel identifies aerodynamic problems, determines corrective actions, and recommends required actions.

Figure 2 shows the interactions of the Aerodynamics Panel with other disciplines, elements, and other projects within the Constellation program. Regular interfaces occur with four of the five other panels within AFSIG for communication of data and information. Occasional meetings take place with the first-stage and upper-stage hardware elements, who have requested data for such things as first-stage recovery and upper-stage breakup analysis. Finally, the CEV and Launch Abort System (LAS) Projects have a need to understand the aerodynamic phenomena occurring near the front end of the launch stack. Discussions with these groups happen on an as-needed basis.

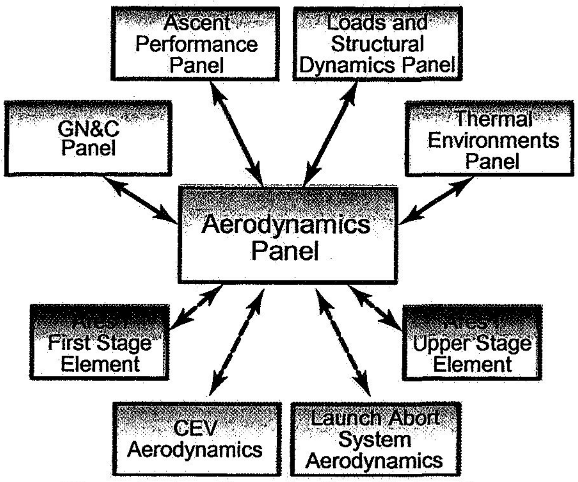


Figure 2. Aerodynamics Panel Interactions.

The Aerodynamics Panel is made up of personnel fulfilling a number of primary functional roles, including the chairman (from NASA Langley Research Center (LaRC)), the co-chairman (from NASA MSFC), a lead engineer for aerodynamic test and analysis, a lead engineer for aeroelastic test and analysis, a lead database developer, a data analysis lead, a VI lead in the Ares I CLV Project Implementation Office at LaRC, a representative from Ames Research Center (ARC) for computational ascent and abort, and an aerodynamic representative responsible for flight test development. A number of other members are identified as ex officio members, including the chairmen from other discipline panels and points of contact from the other elements and projects. The Aerodynamics team consists of approximately 60 individuals from LaRC, MSFC, and ARC who perform the work that comes to the Aerodynamics Panel for review and action.

The work to date has been a balance of wind tunnel testing and computational fluid dynamic (CFD) analyses. The objectives of the wind tunnel testing have been to populate required force and moment databases, provide data for CFD validation, provide understanding of flow physics via visualization techniques, and assist in determining load distributions along the length of the Ares I CLV. The experimental approach being taken includes conducting wind tunnel tests across a variety of wind tunnel facilities with overlap of critical data between facilities and extensive repeatability studies within facilities. To date, four wind tunnel facilities have been used for early experimental testing in support of CLV aerodynamics. They include the MSFC 14-Inch Trisonic Wind Tunnel at the Aerodynamic Research Facility (ARF), the ARC 11-Foot Transonic Tunnel, the LaRC Unitary Plan Wind Tunnel (UPWT), and the Boeing St. Louis Polysonic Wind Tunnel (PSWT).

The objectives of the CFD analyses are to generate loads and pressure distributions, provide a means of rapid assessment of possible outer mold line (OML) design changes, determine scaling effects between wind tunnel testing and flight conditions, and provide a method for detailed flow field diagnostics and understanding. Initial CFD studies have been conducted with multiple flow solvers in order to understand the uncertainty associated with code algorithms (formulation of flow equations), different grids (structured versus unstructured), and turbulence models. The computational team is highly experienced and includes individuals from four NASA field centers. The flow physics understanding realized by experimental and computational techniques also provides support of configuration maturation.

Efforts are also being made to develop credible databases with quantified uncertainty regardless of whether the origin is wind tunnel testing or CFD. It is important to understand the uncertainty requirements of the project so that the appropriate resources can be applied to data acquisition to meet those requirements. Steps are also being taken toward the design certification process by addressing verification, validation, and accreditation of tools, models, and databases starting early and continuing throughout the life of the project.

Confidence building is also of prime interest in the early stages of aerodynamic development for the Ares I CLV. Experimentally, tunnel-to-tunnel data consistency, Reynolds number effects, and scaling to flight are being addressed. Computationally, uncertainties from code-to-code comparisons, impacts of grid refinement, and effects of turbulence models are being addressed.

AERODYNAMIC ACTIVITY OVERVIEW

Initial Studies

Experimental wind tunnel testing began in December 2005 on the ESAS point of departure configuration. This configuration included a 0.548%-scale model of a 216-inch diameter CEV and upper stage with a modified four-segment first stage booster. This OML was tested in the MSFC ARF, the ARC 11-Foot Transonic Tunnel, and the LaRC UPWT. By mid-January, the Ares I CLV configuration changed in two significant ways: an additional motor segment was added to the first stage, and the CEV diameter was reduced to 198 inches for what was known as Ares I CLV design and analysis cycle zero (DAC-0). At that time, two different upper stage diameters were being considered, 198 inches and 216 inches. The 0.548%-scale models of these configurations are shown in Figure 3. Testing of the DAC-0 models took place in the MSFC ARF.

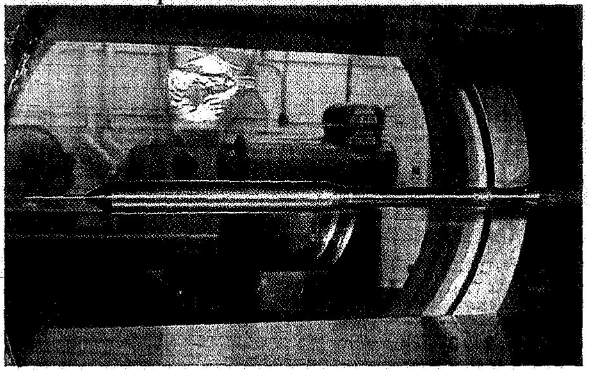


Fig. 3a. ESAS point-of -departure wind tunnel model.

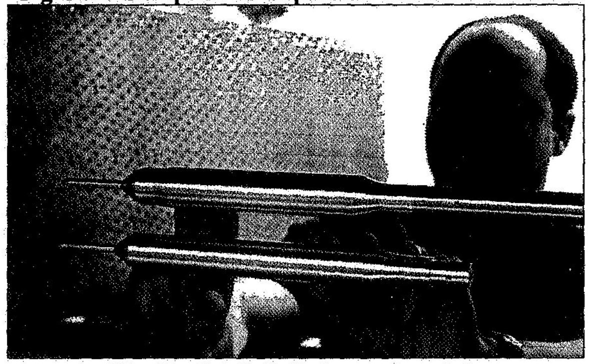


Fig. 3b. DAC-0 wind tunnel models.

Figure 3. Initial Ares I CLV wind tunnel models in the ARF 14-Inch Trisonic Tunnel.

Computational efforts also began with the ESAS CLV configuration and then transferred to the DAC-0 configuration. Sample flow field solutions are shown in Figure 4.

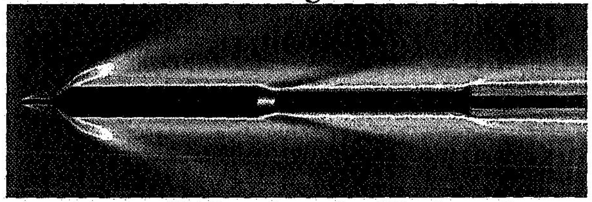


Fig. 4a. ESAS configuration, M = 4, $\alpha = 0°$.

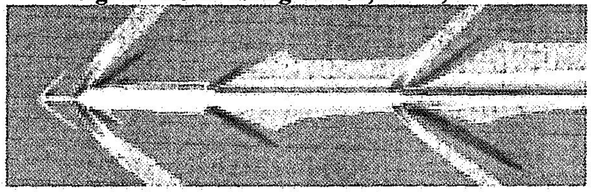


Fig. 4b. DAC-0 configuration, M = 1.6, $\alpha = 4°$.

Figure 4. Initial representative Ares I CLV CFD solutions.

Design and Analysis Cycle One (DAC-1)

In March 2006, design and analysis cycle one (DAC-1) began for the Ares I CLV that would provide the design and analysis data needed for the vehicle Systems Requirements Review scheduled for the fall of 2006. At that time, a new OML was provided for performing analyses during DAC-1. The major efforts for aerodynamics during DAC-1 were to provide a more complete set of load distributions for the new OML and generate aerodynamic force and moment data on a larger-scale, higher-fidelity model. Other activities addressed during DAC-1 will also be discussed.

Ares I CLV DAC-1 Loads Distribution Database Development

The purpose of this database was to provide the Ares I CLV Loads and Structural Dynamics Panel with credible load distributions to be used in their analysis of the bending and other structural loads imparted to the vehicle due to steady aerodynamics during ascent. An initial generation of load distributions was created during DAC-0 and was incorporated into the analysis conducted by the Loads and Structural Dynamics Panel. For DAC-0, the Aerodynamics Panel was requested to provide loads and pressure distributions only at the maximum flight dynamic pressure conditions.

During a discussion between these two panels following DAC-0, the decision was made to provide load distributions for the clean DAC-1 configuration (no protuberances or LAS flare) at flight conditions across the Mach number range from 0.5 to 5.0 for angles of attack of zero and seven degrees.

Because detailed wind tunnel models generating loads data are both expensive and time-prohibitive for the DAC-1 schedule, the decision was made to generate these results using CFD. Three different viscous Navier-Stokes solvers were used to each generate the solutions at the fourteen Mach numbers and two angles of attack of interest. These codes were NASA's FUN3D, USM3D, and Overflow. The reason all three codes were employed in this fashion is that there is insufficient experimental or computational validation data and, therefore, rationale to choose one code over another. Thus, using the three codes was considered an important risk reduction step and provided at least a minimal look at possible uncertainties in the CFD data being generated.

The load distributions to be illustrated involve normal and axial sectional loadings. The variables to illustrate the sectional normal and axial loadings are $d(C_N)/d(x/d)$ and $d(C_{AF})/d(x/d)$. This symbology is the same as was used during the Saturn program. If either variable is integrated over the length of the vehicle, the integrated value will be equal to the traditional values of CN or CAF.

An example comparing the distributions generated from the three CFD codes is shown in Figure 5 at M=1.63 and flight Reynolds number. Two important conclusions can be made from this comparison. First, the major features in normal force coefficient distribution $[d(C_N)/d(x/d)]$ (fig. 5a) at geometric changes along the vehicle body are captured in the same location by all three codes. Second, only small differences in the magnitude of the normal force coefficient distribution are observed and only at limited x/d locations. The comparisons are even better for the axial force coefficient distribution $[d(C_A)/d(x/d)]$, as shown in Figure 5b. Because there is no experimental data to identify which CFD code best predicts the measured distributions, the decision was made to use an average of the results from all three codes.

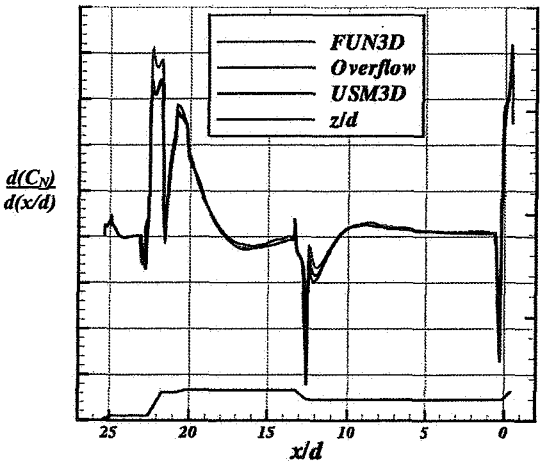


Figure 5a. Comparison of normal force coefficient distributions predicted by three CFD codes at $M = 1.63$, $Re,d = 42.0 \times 10^6$, $\alpha = 7°$.

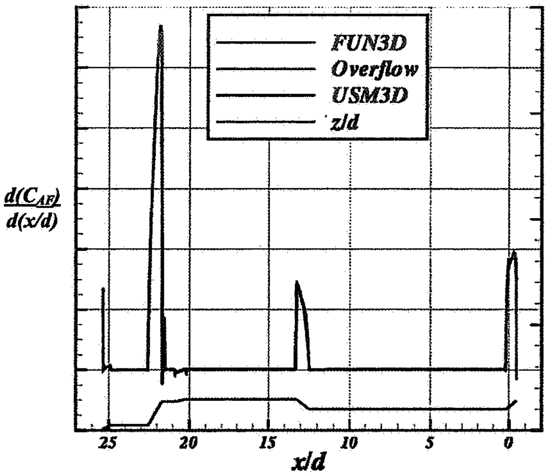
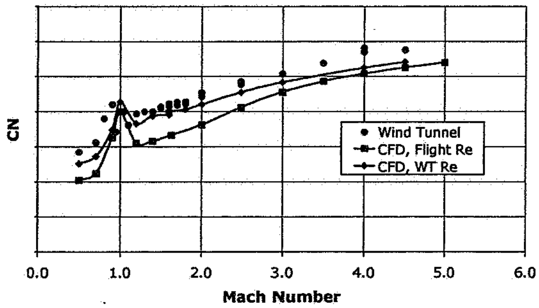


Figure 5b. Comparison of axial force coefficient distributions predicted by three CFD codes at $M = 1.63$, $Re_{,d} = 42.0 \times 10^6$, $\alpha = 7°$.

CFD solutions were also performed at wind tunnel conditions and compared with DAC-1 force and moment data. This comparison enabled an assessment of the ability of the CFD codes to predict integrated forces and moments and provided a rationale to adjust the flight load distributions to account for any differences found in wind-tunnel-to-CFD comparisons. The comparisons for CN and CM demonstrate the importance of Reynolds number for the CFD predictions. It is clear that the agreement with wind tunnel data is improved by running the CFD at the correct values of Reynolds number. Because of the good agreement of wind tunnel normal-force (CN), forebody axial-force (total axial force with the axial base force removed, CAF), and pitching-moment (CM) coefficient data with CFD results performed at wind tunnel conditions (Figure 6), a need for significant adjustments to the CFD distributions in the future are not anticipated except possibly at the higher Mach numbers.



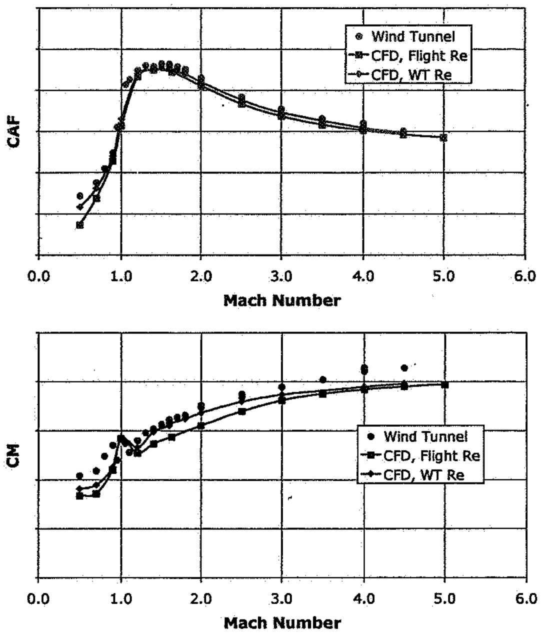


Figure 6. Comparison of DAC-1 wind tunnel data and CFD results at flight and wind tunnel conditions, $\alpha = 7°$.

The loads database consists of distributions at the fourteen different Mach numbers from 0.5 to 5.0. They have been generated with origins at both the nose tip and at the first-stage gimbal location. Representative plots of data at transonic, low supersonic, and high supersonic conditions are shown in Figure 7 and underscore the large variation in load distributions that the vehicle will encounter during ascent.

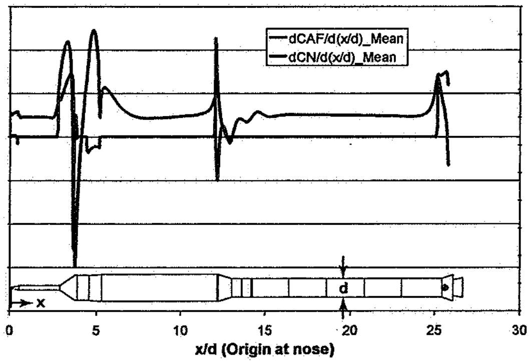


Fig. 7a. Mach 0.9, $Re_{,d} = 46.1 \times 10^6$.

Figure 7. Representative load distribution plots for Ares I CLV DAC-1 configuration, $\alpha = 7°$.

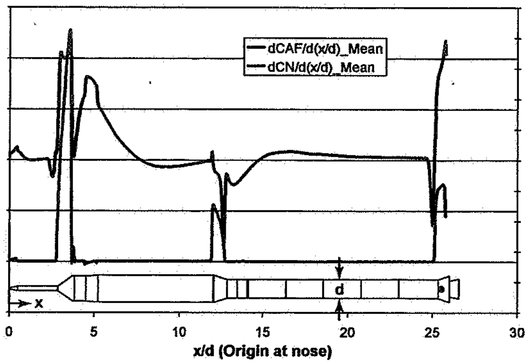


Fig. 7a. Mach 1.63, Re,d = 42.0 x 10^6.

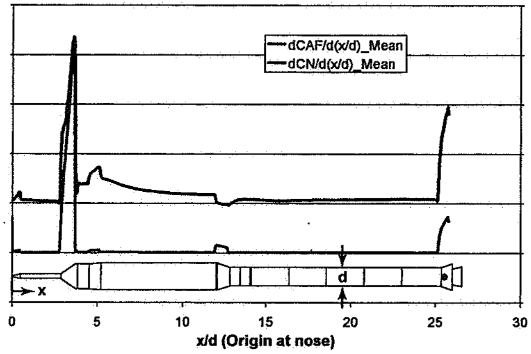


Fig. 7c. Mach 5.0, Re,d = 1.82 x 10^6.

Figure 7 (concluded). Representative load distribution plots for Ares I CLV DAC-1 configuration, $\alpha = 7°$.

The results from the computational effort will also be used in venting analysis. Distributions of pressure coefficient (Cp) identify areas of high and low pressure to assist in determining the proper location of vent ports where needed for Ares I CLV. Figure 8 shows representative plots of pressure coefficient at M=1.63 for two viscous CFD solvers. The agreement provides some additional confidence in the ability of these CFD codes to predict flows about these configurations.

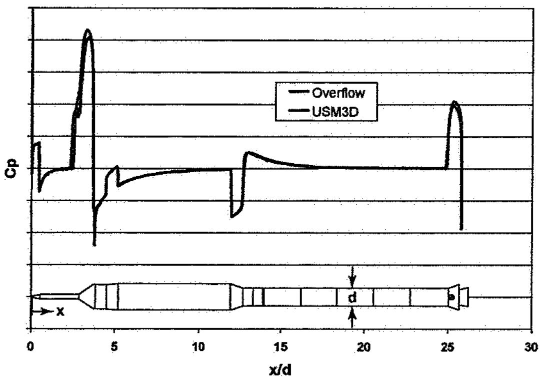


Figure 8. Pressure coefficient distribution for Ares I CLV DAC-1 configuration at M = 1.63, Re,d = 46.1 x 10^6, $\alpha = 0°$.

Ares I DAC-1 Force and Moment Database Development

The second major aerodynamic deliverable during DAC-1 was the force and moment database. The purpose of this database is to provide the latest update to the force and moment coefficients that are used by a number of disciplines but most importantly by the Ascent Performance and Guidance, Navigation and Control (GN&C) Panels.

Aside from differences to the database due to OML changes since DAC-0, this release includes data on a larger model (1.0%-scale compared to 0.548%-scale) and the effects of major protuberances. Details of these protuberances as they were known on April 4, 2006, are shown in Figure 9. They include the first-stage systems tunnel and aft-skirt wedges; the interstage reaction control system (RCS) fairings and booster separation motors; and the upper-stage systems tunnel, liquid hydrogen feedline fairing, and RCS fairings. The Launch Abort System (LAS) flare (a proposed LAS motor nozzle covering) and the protuberances could be removed during the wind tunnel entries, allowing two basic configurations to be tested; namely, the full-protuberance configuration (including the LAS flare and all protuberances) and the clean configuration (no LAS flare or protuberances). Two identical models were fabricated to allow for parallel testing in the two facilities used to complete the updated force and moment database, given the very tight DAC-1 schedule and tunnel availability. Both models utilized six-component force and moment balances and base pressures as the primary data acquisition sources.

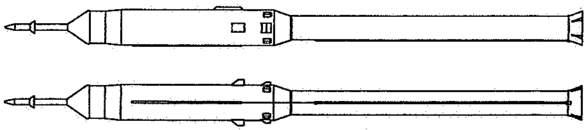


Figure 9. Protuberance details included in the 1.0%-scale Ares I DAC-1 force and moment models.

Wind tunnel testing of these models took place in the Boeing PSWT in St. Louis and the LaRC UPWT. Figure 10 shows the model installed on the PSWT model support mechanism and, with the research engineer, provides a perspective of the approximately 38-inch long model. Figure 11 shows the two primary Ares I CLV model configurations as installed in the low-Mach number test section of UPWT.

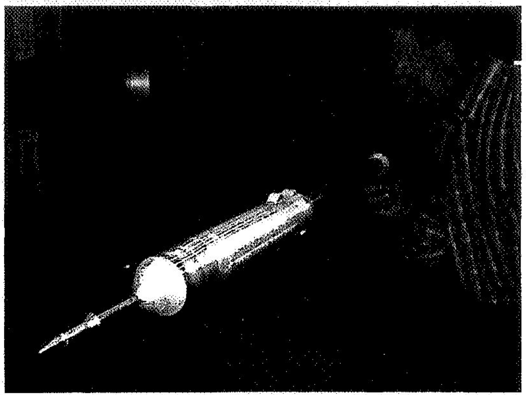


Figure 10. Ares I CLV DAC-1 1.0%-scale, full-protuberance model installed in the Boeing Polysonic Wind Tunnel.

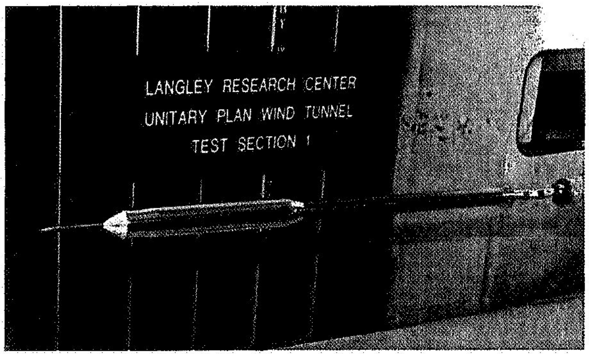


Fig. 11a. Clean configuration

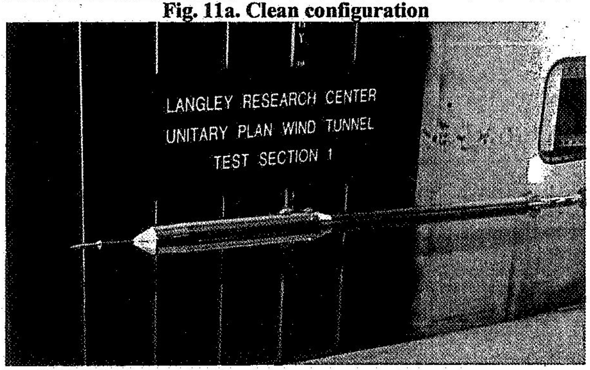


Fig. 11b. Full protuberance configuration

Figure 11. Ares I CLV DAC-1 1.0%-scale model installed in the Langley Unitary Plan Wind Tunnel.

The force and moment database was developed by utilizing data from PSWT from Mach 0.5 to 1.6 and from UPWT from Mach 1.7 to 4.5 at the highest Reynolds numbers tested. All appropriate repeat data were averaged and used to generated polynomial curve fits of the normal-force, forebody axial-force, and pitching-moment coefficient data at angles of attack from -9° to +9°. During testing in both tunnels, an anomalous, but repeatable, flow behavior related to the LAS flare was identified from Mach 1.45 to 1.7 resulting in a bi-modal flow condition. When this bi-modal behavior was present, the decision was made to use the higher-magnitude axial-force data values in the initial database.

Figures 12 and 13 show the force and moment results of primary interest to Ascent Performance and GN&C Panels, respectively. Figure 12 presents the forebody axial force coefficient data at $\alpha = 0^\circ$ (CAF0) for the two DAC-1 configurations. The effects of full protuberances and the LAS flare are seen. At subsonic Mach numbers and at supersonic Mach numbers greater than 1.4, the effect of these protuberances is to significantly increase axial force. However, this increased drag for Mach number greater than 1.7 is offset by reduced drag from Mach 1.05 to Mach 1.4 that is enough to more than offset the additional axial force caused by the protuberances along the sides of the vehicle at those Mach numbers. Finally, the bi-modal flow phenomenon caused by the LAS flare is reflected in the higher values of axial force at Mach 1.5, 1.6, and 1.7.

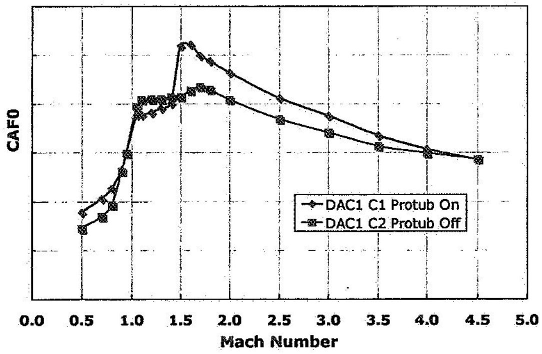


Figure 12. Forebody axial force coefficient versus Mach number, $\alpha = 0^\circ$.

Figure 13 presents the pitching moment derivative $C_{M,\alpha}$ (based on C_M at $\alpha = 4^\circ$) as a function of Mach number. A vehicle is considered aerodynamically stable when $C_{M,\alpha}$ is negative about the vehicle's center of gravity. As can be seen, the full-protuberance configuration is less stable than the clean configuration at lower Mach numbers, but the trend reverses at the highest Mach numbers up to M=4.5. It will be incumbent upon the GN&C

Panel to determine if the amount of instability shown is significant enough to impact the plans for controlling the vehicle.

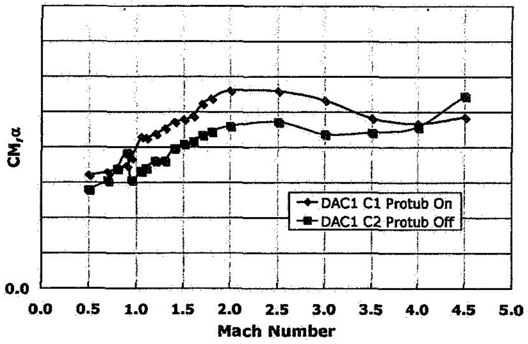


Figure 13. $C_{M,\alpha}$ (for $\alpha = 4°$) versus Mach number (moment reference is first stage gimbal location).

SUPPLEMENTARY TESTING AND ANALYSIS

Throughout DAC-1, a number of other requests and studies have been performed by the Ares I aerodynamics team other than the major deliverables that have been previously described. These supplementary activities include a LAS geometry trade study and understanding the LAS flare flow phenomenon.

LAS Geometry Trade Study

Based on preliminary wind tunnel results obtained during DAC-0, it was observed that the LAS can offer an aerodynamic performance improvement on ascent because it functions very much like a drag-reducing aerospike. A trade study was initiated to understand the sensitivity of ascent performance on the geometric parameters of the LAS geometry to characterize this possible improvement. A two-phase approach was approved for performing this trade using both CFD and wind tunnel testing.

As of the date of this report, the computational effort has been completed, but the wind tunnel test has been delayed due to other higher-priority testing that has been identified by the Ares I CLV project. While this delay does not impact a major deliverable for DAC-1, information gathered during this study has the potential to impact the design of the final LAS geometry.

First, a CFD study was initiated to understand which geometric parameters had the largest influence on the forebody axial force coefficient at zero degree angle of attack. Next, an assessment of the different geometric parameters was made to determine which parameters could be varied and by how much. It was determined that four geometric parameters were of interest for a LAS tower without a flare. These parameters are the length of the tower, the diameter of the tower, the tip shape and the tip fineness ratio (Figure 14a).

When the LAS flare was added, three additional parameters were addressed: the flare diameter ratio, flare angle, and the longitudinal flare location on the tower (Figure 14b). Most of these parameters were ascribed three values corresponding to values at, above, and below those of the baseline LAS geometry.

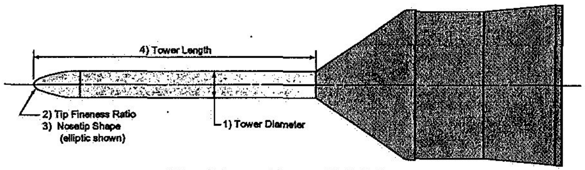


Fig. 14a. without LAS flare.

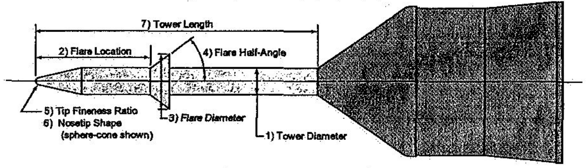


Fig. 14b. with LAS flare.

Figure 14. LAS geometry parameters.

A design of experiments approach was used to create a subset of 84 configurations out of a possible 1,566 to determine the sensitivity of individual parameters or groups of parameters to improving integrated drag. Axisymmetric viscous CFD using the Overflow code was performed on each of these configurations at ten Mach numbers from 0.7 to 4.0 and flight Reynolds numbers.

For the LAS tower without a flare and within the range of parameters analyzed, the largest contributors to reduced drag were the tower diameter (wider is better) and tip fineness ratio (blunter is better) as seen in Figure 15a. Note also the beneficial effect of any of the tower configurations over the configuration with no tower. Interestingly, the tower length (over the lengths addressed in the CFD study) was not an important factor. For the LAS tower with a flare, the largest contributors included the tower diameter (wider is better), the flare location (farther forward is better), and the flare diameter (wider is better), as shown in Figure 15b. Neither the tower length nor the tip shape were important factors due to the flowfield dominance of the flare.

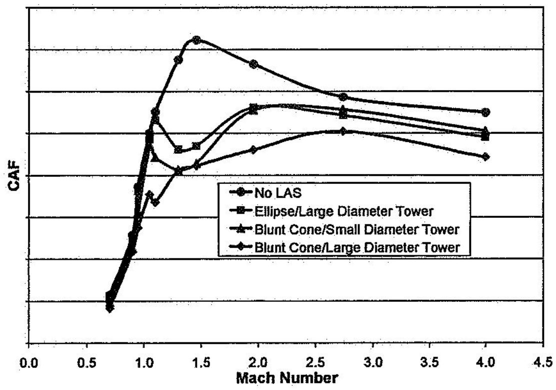


Figure 15a. LAS tower without flare.

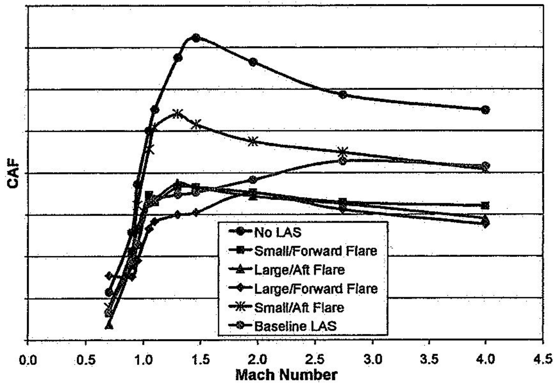


Figure 15b. LAS tower with flare.
Figure 15. Drag coefficient versus Mach number for select LAS parametric configurations at flight Re,d.

Based on this computational analysis, a reduced set of parameters was chosen to experimentally address LAS geometry effects in wind tunnels. However, prior to fabrication and testing, an anomalous behavior was discovered during wind tunnel testing of the complete Ares I configuration with LAS flare and protuberances (see next section) that may justify a re-examination of the LAS geometry study.

LAS Flow Anomaly

The LAS flow anomaly was first observed in force and moment wind tunnel testing of the Ares I CLV DAC-1 configuration in the Boeing PSWT. It was also seen in subsequent testing in the LaRC UPWT. The hysteretic nature of the flow anomaly was visually confirmed in LAS flow characterization tests conducted in the MSFC ARF 14-Inch Trisonic Wind Tunnel on a 1.5%-scale truncated Ares I DAC-1 configuration. The model used in this test represented the LAS, CEV, spacecraft adapter, and part of the upper stage only, and is shown in Figure 16. The LAS tower was removable in order to test a variety of LAS geometries as well as to acquire flow visualization data without a LAS tower at all.

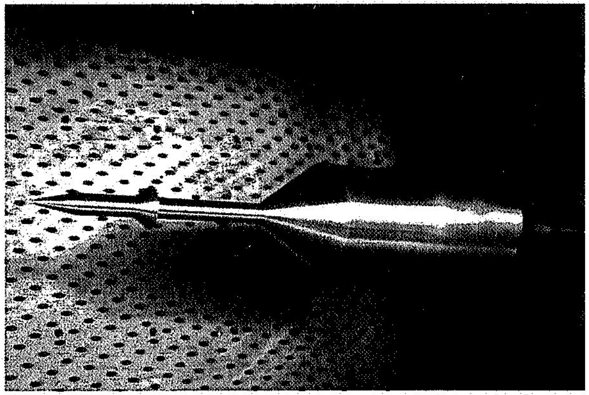


Figure 16. 1.5% LAS-CEV truncated model in the MSFC ARF 14" Trisonic Wind Tunnel.

Figure 17 presents schlieren images on this model with the baseline LAS geometry with flare at M = 1.46. Figure 17a shows the flow pattern at α = 0° just after the tunnel flow conditions were established. A symmetric, low-pressure, separated-flow region is established behind the LAS flare. At α = -3° (Figure 17b), the flow is still separated, but the separation region shows signs of becoming smaller. As the model is pitched to α = -4° (Figure 17c), a dramatic change in the flow field details is seen. The large separation region has been replaced by a small separation zone confined to just aft of the LAS flare, and a series of shock waves that exist between the LAS flare and the CEV. This flow condition is consistent with a significant increase in drag as observed in the PSWT and UPWT force and moment data. When the model was rotated back to α = 0° (Figure 17d), the flow maintained its "high drag" features. Comparing figures 17a and 17d shows two drastically different flow fields and confirms the bi-modal nature of the flow downstream of the LAS flare to jump between two different axial force values for the same model at the same attitude and conditions.

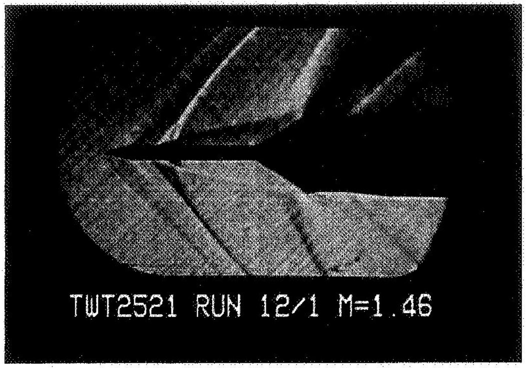


Fig. 17a. α = 0° at beginning of run

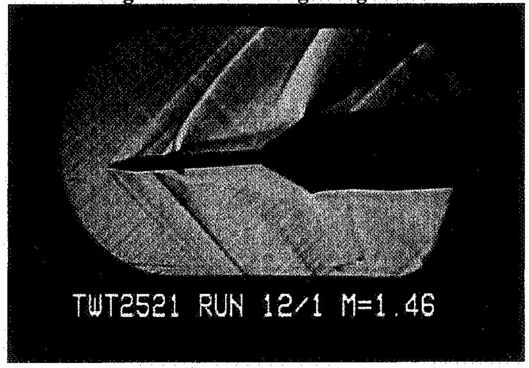


Fig. 17b. α = -3°

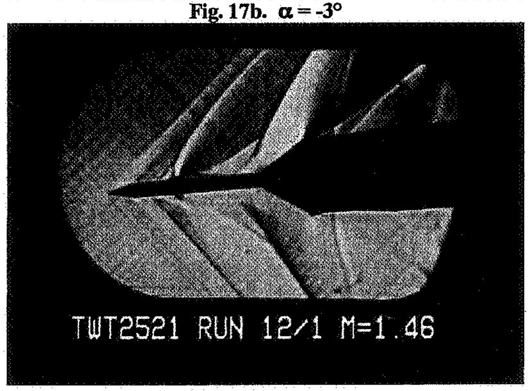


Fig. 17c. α = -4°

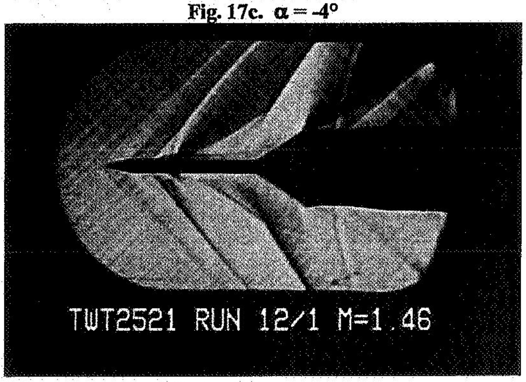


Fig. 17d. α = 0°, near end of run

Figure 17. Schlieren images for 1.5%-scale Ares I DAC-1 with baseline LAS and flare, M = 1.46, Re,d = 1.2 x 10^6.

To summarize, the LAS axial force anomaly was identified, studied, and confirmed in three separate wind tunnel tests during DAC-1. The effect appears to be limited to low supersonic Mach numbers (between 1.3 and 1.7), but is sensitive to Reynolds number and angle of attack. It is uncertain whether this anomaly would exist at flight vehicle scales and flight conditions. The information obtained by the Ares I aerodynamics team has been provided to the LAS Project Team.

FUTURE PLANS

Aerodynamic database updates will be generated to support both design/development cycles and Ares I CLV Project milestones. The fidelity and maturity of the aerodynamic database will increase as the maturity of the overall vehicle configuration increases from conceptual design trade studies and the Ares I CLV Systems Requirements Review (SRR) through Critical Design Review (CDR), and ultimately operational flight of the vehicle. The aerodynamic database development approach is outlined below. At the same time, the uncertainties associated with the aerodynamic database will be better defined and utilized in analyses of trajectory and performance of the Ares I CLV.

Preliminary Design Review Aerodynamic Database

Preliminary Design Review (PDR) aerodynamic environments will be generated based upon the most current vehicle OML configuration. SRR aerodynamic methodology will be refined by a synthesis of engineering level analysis, CFD flowfield solutions, and wind tunnel tests of higher-fidelity models. In addition, other aerodynamic analyses such as compartment venting and purge, ignition overpressure, and second stage break-up and disposal will be addressed. The results of these analyses and database updates will be documented in the appropriate aerodynamic data book and an analysis report.

Critical Design Review Aerodynamic Database

Critical Design Review (CDR) aerodynamic environments will be generated based upon higher fidelity vehicle OML configuration data files that will include the latest details of vehicle protuberances such as cable trays, feedlines, RCS nozzles, etc. The aerodynamic environments will be anchored by high-fidelity, larger-scale wind tunnel models tested over the latest ascent trajectory performance envelope. Localized protuberance aerodynamic force and moment increments, air loads, and aeroelastic effects will be defined. The CDR aerodynamic database will include support for refined compartment venting and purge system analysis, ignition overpressure environments, launch platform plume impingement, and acoustic environments.

Verification Aerodynamic Database (Post CDR)

Final verification of the aerodynamic database will be performed utilizing the pre-flight aerodynamic database and data obtained from initial development flight test(s). Included in this database will be the best understanding of uncertainties that have been tracked through the design and development cycles.

Operational Flight Aerodynamic Database

The operational flight aerodynamic database will be verified by a synthesis of data obtained from the CLV development flight instrumentation, ground based test data, and computational fluid dynamics.

Test and Analysis Topics

As the design and development process continues, additional aerodynamic tasks will be performed. These tasks will incorporate appropriate levels of computational effort to complement the wind tunnel testing. Among the full-stack experimental tasks are higher-fidelity force and moments tests with updated OMLs and protuberances, static pressure tests for CFD validation data acquisition, stage-separation testing, transonic rigid buffet loads testing, ground winds aeroelastic model testing, transonic aeroelastic buffet response testing, and first stage RCS jet-effects testing. Partial Ares I model testing will be used to acquire force and moment data on the post-abort stack, post-separation ascent vehicle, post-separation first stage during descent, and the upper stage RCS with jet effects. Tests that have been identified specifically for the first flight demonstration vehicle (designated Ares I-1) include stage-separation force and moment testing, transonic rigid buffet loads testing, ground winds aeroelastic model testing, transonic aeroelastic buffet response testing, first stage RCS jet-effects testing, and first stage descent testing.

SUMMARY/CONCLUSIONS

The purpose of this paper was to present the status, plans, and initial results of Ares I CLV aerodynamics as the project was preparing for the Ares I CLV Systems Requirements Review. Following a discussion of the specific interactions with other technical panels and a status of the past and current activities with emphasis on results from the latest design and analysis cycle, the plans for aerodynamic support of the Ares I CLV until the initial crewed flights was presented. The Ares I CLV Aerodynamics Panel/Team has been supporting the Ares I CLV project since October 2005 with the planning and execution of experimental and computational tasks to provide the best aerodynamic data to other Ares I CLV disciplines and elements throughout the design and development of the vehicle and will continue to do so in the future.

ACKNOWLEDGEMENTS

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