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Preliminary Analysis of Ares I Alternate Launch Abort System (ALAS) Configurations Tested in the Boeing Polysonic Wind Tunnel

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April 2007

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Introduction

A wind tunnel investigation was conducted to investigate the effects of Alternate Launch Abort System (ALAS) Configurations on the aerodynamic characteristics of the Ares I launch vehicle. Recent studies conducted by the ALAS Feasibility Study (Phase I) team headed by Scotti and Camarda, and reported on 5 December 2006, investigated possible alternatives to the baseline Launch Abort System (LAS) for the Orion vehicle. These ALAS configurations are based on developing alternate load paths to transfer the thrust of the abort rocket motor into the base of the Command Module (CM) rather than into the top of the CM. See Figure 1.

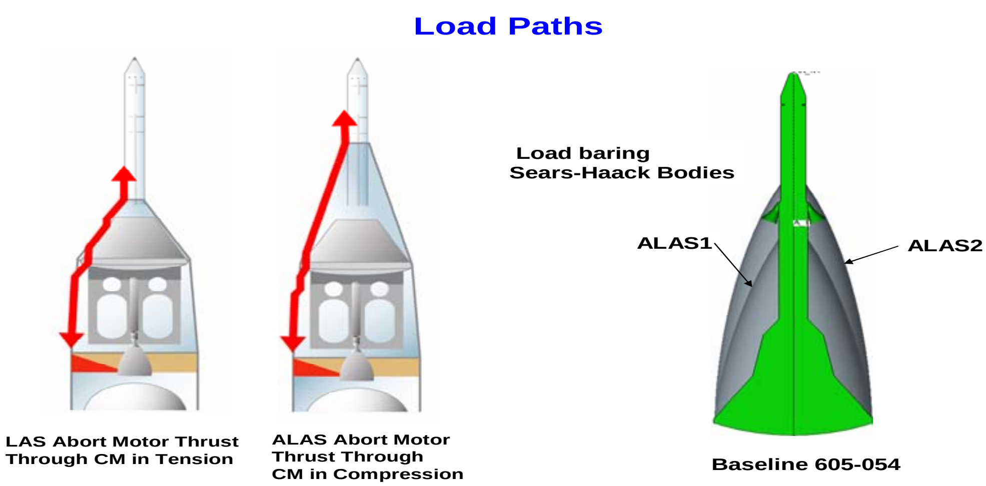

Figure 1. ALAS concepts showing alternate load path concept and Sears-Haack bodies.

Analysis of these alternate load paths indicated some potential mass savings for the CM because of reduced loads through the CM structure. However, when the alternate load path was incorporated as a Sear-Haack shape, Computational Fluid Dynamic (CFD) analysis indicated that a significant reduction in Ares I axial force was possible. Initial parametric analysis from the ALAS team showed that the predicted axial force improvements might yield an increase in pounds of mass delivered to orbit of up to about 1000lbm. See Figure 2.

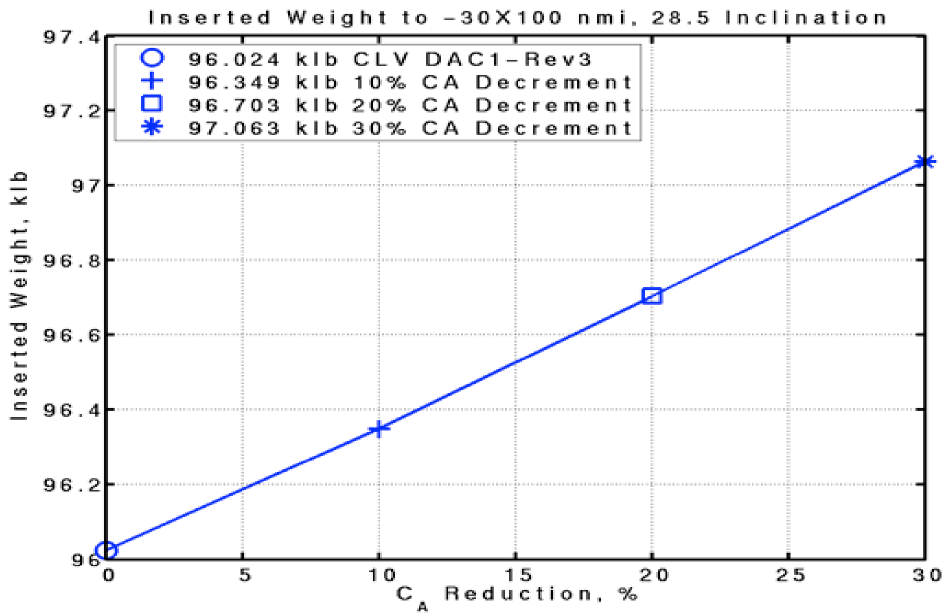

Figure 2. Estimates of increased payload to orbit based on reductions in Ares I axial force.

These preliminary aerodynamic and launch performance results warrant experimental verification of the predicted values of axial force. Thus in Phase II, an existing 1-percent wind tunnel model, which was tested 2006, was modified and tested again in January 2007 to obtain aerodynamic data on five configurations.

This wind tunnel investigation (Test 832) was conducted at the Boeing Polysonic Wind Tunnel (PSWT) in St. Louis, MO during the time frame January 22 to 26, 2007. The goal of the test was to provide an aerodynamic performance evaluation of ALAS configurations relative to the baseline configuration to determine if the CFD predicted reductions of axial for the Ares I vehicle were reasonable. This test was not intended in any way to yield a “6-DOF simulation” quality set of coefficients but rather was to answer the “big picture” question, “is this idea any good at all?”

Wind Tunnel Model

The original identical wind tunnel models were designed and fabricated at NASA-Langley Research Center (LaRC) in Hampton, VA and one was tested in the PSWT in 2006 to provide aerodynamic data from Mach 0.5 up to 1.6 and one was tested in the LaRC Unitary Plan Wind Tunnel (UPWT) from Mach 1.5 to 2.0 and from Mach 2.5 to 4.6 (low and high Mach number test sections). The models were 1%-scale versions of the design of the Crew Launch Vehicle (CLV) configuration, now known as Ares I, and were intended to provide a high quality set of data for use in the CLV Design Analysis Cycle-1 (DAC-1). The models included a five-segment solid rocket booster (SRB) first stage (with an aft skirt assembly), a 216.5”-diameter (full scale) upper stage component, a 198”-diameter (full scale) Crew Exploration Vehicle (CEV), now known as Orion, consisting of the Service Module (SM), Command Module (CM), and a Launch Abort System (LAS) at the front end of the assembly. The models were fabricated with numerous detachable protuberance components along the length of the vehicle. These protuberances included scaled reaction control systems, upper and lower systems tunnels, booster separation motors, and liquid hydrogen (LH2) feedline fairing, etc. The model also provided the ability to test with the LAS with the LAS flare, the LAS by itself (with no flare), or no LAS altogether at the front of the CEV. However, there were no abort motor exhaust nozzles modeled. An assembly drawing of the model is shown in figure 3.

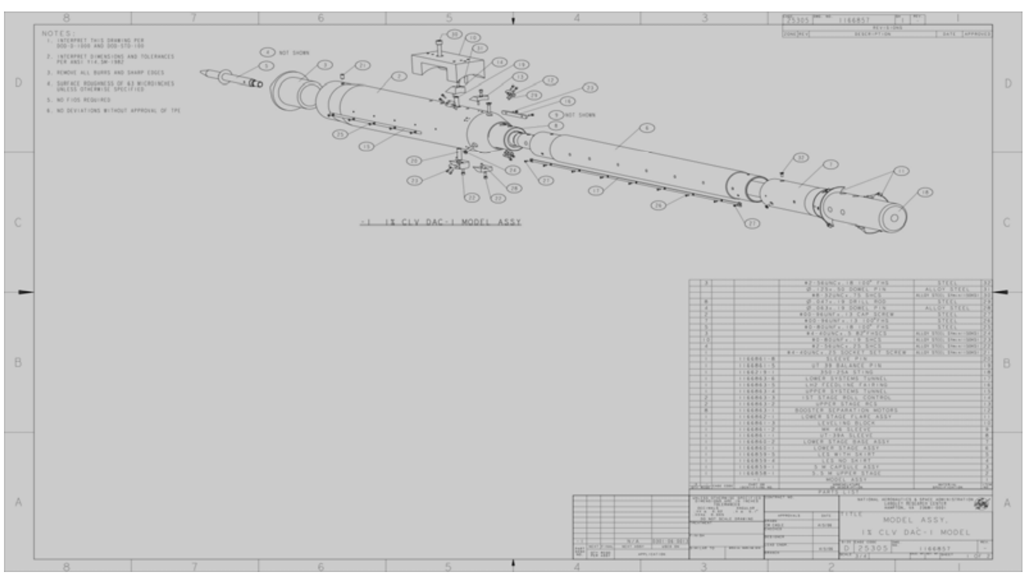

Figure 3. 1% CLV (Ares I) Model details

The model tested in UPWT was modified by cutting the model in two at the top of the upper stage and fabricating new “front ends” which replaced the SM, CM and LAS with new hardware. Five configurations were produced. 1.) The original DAC-1, with LAS flare, which was used only to verify that the “modified” model would reproduce the results of the previous testing (Test 819). Everything aft of the new part line was identical to the DAC-1 configuration with all protuberances, flares and skirts, and was used with the other four configurations. 2.) The current configuration known as 605-054 which is the baseline SM, CM and LAS. 3.) ALAS1 which is a Sears-Haack body from just below the abort motor nozzles to the base of the CM. 4.) ALAS2 which is a Sears-Haack body which covers the abort motor nozzles and extends to the base of the CM. 5.) ALAS3 which is similar to ALAS2 but extends to the top of the upper stage, covering the CM and SM. This last configuration was designed to further reduce axial force and to eliminate some “sharp” corners at the base of the CM and on the SM which are of great concern from an acoustic signature point of view. However, this test made no effort to obtain acoustic measurements due to model scale and schedule limitations. These five configurations are shown in Figure 4 with an installation photo of ALAS1in Figure 5.

ALAS 3
(Extended Fairing)

ALAS 2
(Covered Nozzles)

ALAS 1
(Exposed Nozzles)

605 Baseline CM

DAC-1

Figure 4. Five configurations tested in PSWT Test 832.

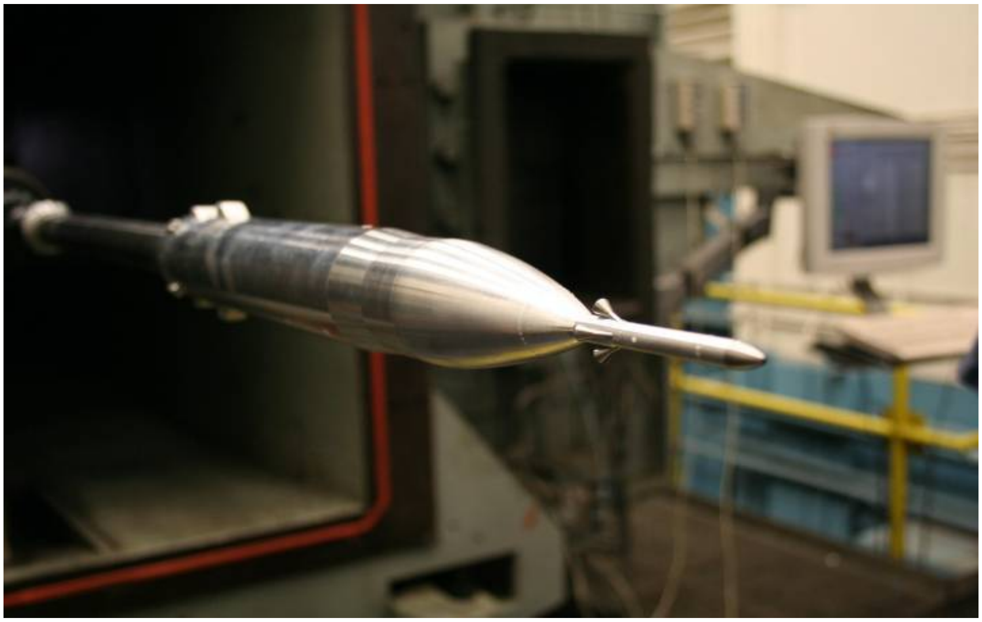

Figure 5. ALAS1 installed in PSWT.

The modified model was instrumented with an internal force and moment balance designated NTF-107, provided by Langley Research Center. The balance had a normal force capability of 160 lbs., an axial force capability of 75 lbs., and a pitching moment capability of 250 in-lb. There were 4 base pressure measurements located at the rear exit plane of the SRB aft skirt and 2 chamber pressures that were internal to the SRB in close proximity to the balance location. There was no on-board angle of attack measurement device, and all model angles of attack were computed from arc sector measurements along with sting bending increments. This reproduced exactly the test set up, including the sting, and data reduction from PSWT Test 819 to reduce or eliminate any differences in the testing of the modified model.

Wind Tunnel Testing

The test plan was designed to include complete testing from a Mach number of 0.7 up to1.6 and then, based on assessment of model performance, Mach number would be pushed as high as possible to obtain low supersonic results. Table 1 shows that ALAS2 and 3 were tested up to Mach 2, ALAS1 was tested up to Mach 1.9 but the

Configuration	Mach Number													
	Transonic Test Section									Supersonic Test Section				
	0.7	0.9	0.95	1.05	1.1	1.3	1.5	1.6		1.5	1.61	1.8	1.9	1.97
DAC-1	X	X			X	X		X						
605-054	X	X	X	X	X	X	X	X						
ALAS1	X	X	X	X	X	X	X	X		X	X	X	X	
ALAS2	X	X	X	X	X	X	X	X		X	X	X	X	X
ALAS3	X	X	X	X	X	X	X	X		X	X	X	X	X

Table 1. Configuration and Mach numbers tested.

DAC-1 and 605 configurations were limited to Mach 1.6. Limits were based on measured balance loads and/or qualitative assessment that the model experienced significant dynamics on start-up or shut-down during testing in the supersonic test section.

Repeatability of Test 819 and Test 832 for DAC-1 Configuration

The initial configuration tested was the new DAC-1 full protuberance configuration included all of the protuberance elements attached to the model except the LH2 feedline faring. It could not be determined whether or not the fairing was never installed or blew off the model on the first run. This configuration was tested at four Mach numbers, 0.7, 0.9, 1.1 and 1.6 to verify that the modified UPWT model gave the same results as the previous model during Test 819. The data in Figure 6 and 7 display the agreement in axial force at Mach 1.1 and 1.6 and it is similar at all Mach numbers. The uncorrected data for Test 819 and Test 832 are in very good agreement with repeat data for Test 832 just about perfect. The very slightly lower axial force for Test 832 could be caused by the lack of the LH2 feedline fairing. Since it was not there, this could have yielded the very slightly lower axial force compared to Test 819 where it was installed.

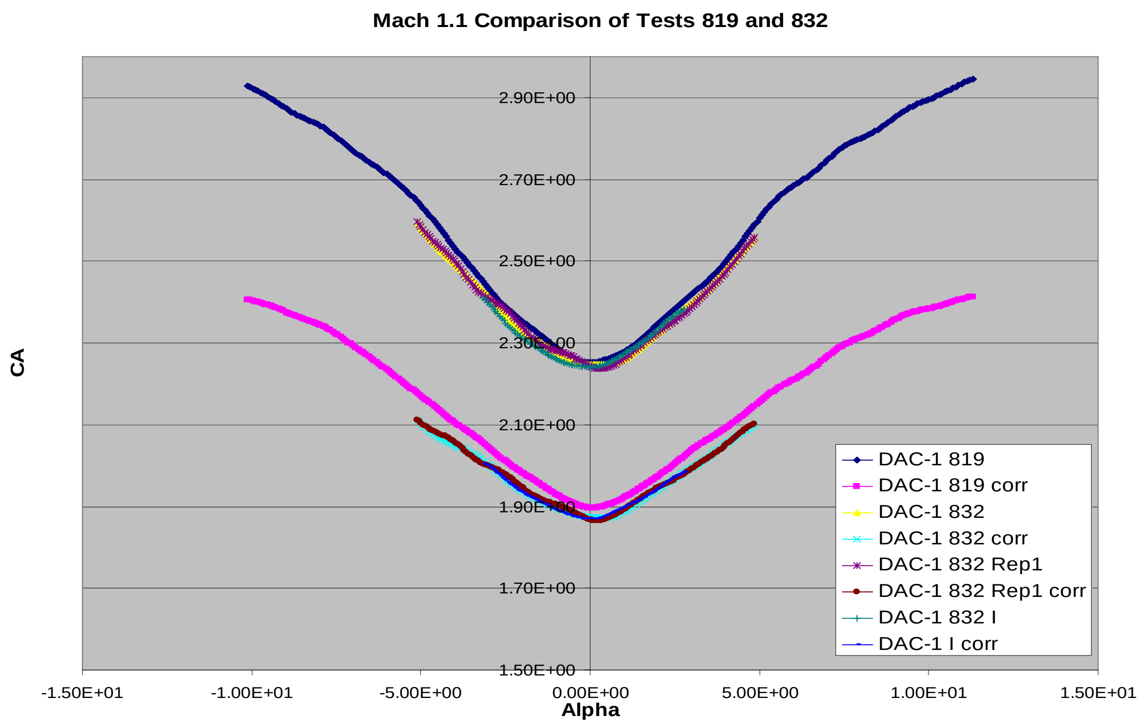

Figure 6. Comparison axial force from of Test 819 and Test 832 at Mach 1.1.

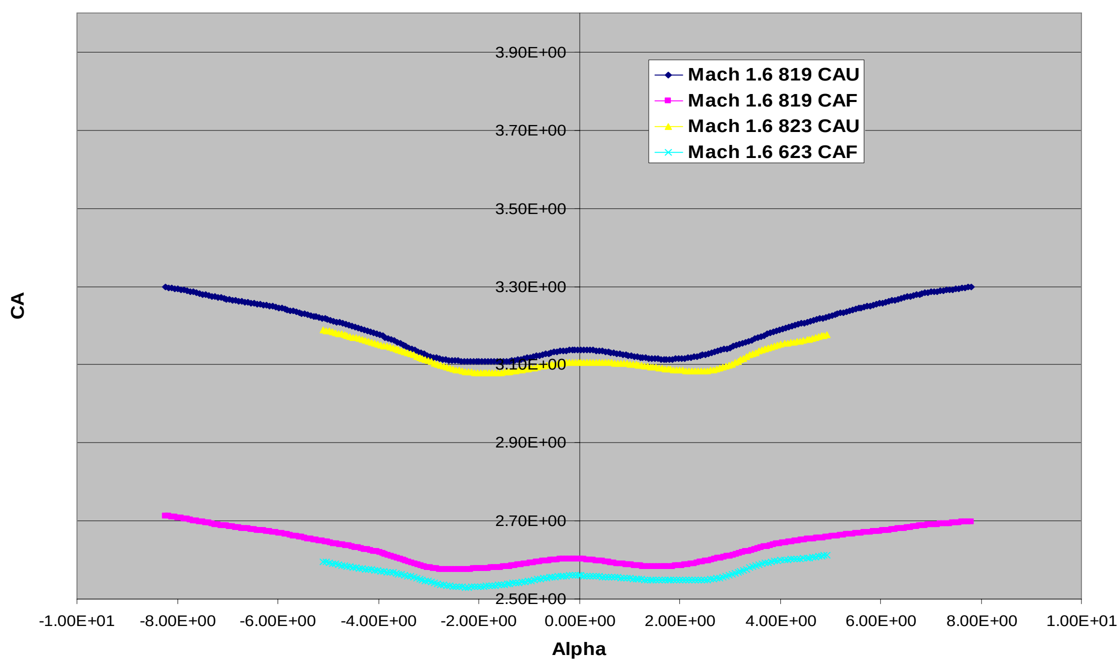

Figure 7. Comparison of axial force from Test 819 and Test 832 at Mach 1.6.

Although still relatively small, there is a bit more disagreement in the data corrected for base pressure. However, there is no way to verify that the base pressure measurement locations are exactly the same in both tests which could lead to slightly different levels. There was a “dent” in the first stage aft skirt (model damaged in transit?) that was “hand worked” by the staff at the PSWT. While they did a great job in repairing the model, the aft skirt of Test 832 was not “identical” to that of Test 819 and thus could have contributed to the small difference in base pressure levels. Also there is no way to know if one test is “a bit one way” and the other test is “a bit the other” which would in effect split the difference in the already small discrepancies. Thus for the purposes of Test 832 and the fact that DAC-1 is no longer a design configuration, it was deemed that the modified 1-percent UPWT model was yielding reasonable data and the test could proceed with evaluating 605-054 and the ALAS configurations.

Analysis of Current 605-054 and ALAS Configurations

The current baseline configuration 605-054 was tested first from Mach 0.7 to 1.6 and was followed in order by ALAS1, 2, and 3. Comparison of uncorrected axial force and pitching moment are presented in figures 8, 9, 10 and 11. It can been seen that the DAC-1 and 605 configurations have similar levels of axial force with 605 being slightly higher at Mach 0.7 and slightly lower at Mach 1.6 (Figures 8 and 9). It is clear that as predicted (and probably would be intuitively thought) the Sear-Haack bodies of ALAS1, 2, and 3 provide significantly lower axial force compared to the DAC-1 and 605 configurations. Also there does not appear to be any significant changes in the axial force differences with angle of attack out to the limits of the test +/- 5 degrees. A concern of the investigation was that changing the forbody geometry would have a detrimental effect on pitching moment and hence Ares I controllability. The data of figure 10 and 11 indicate that this is not evident and there are almost no changes in total configuration pitching moment caused by the significant improvements in axial force. Again this is observed at all Mach numbers but examples are limited here for simplicity.

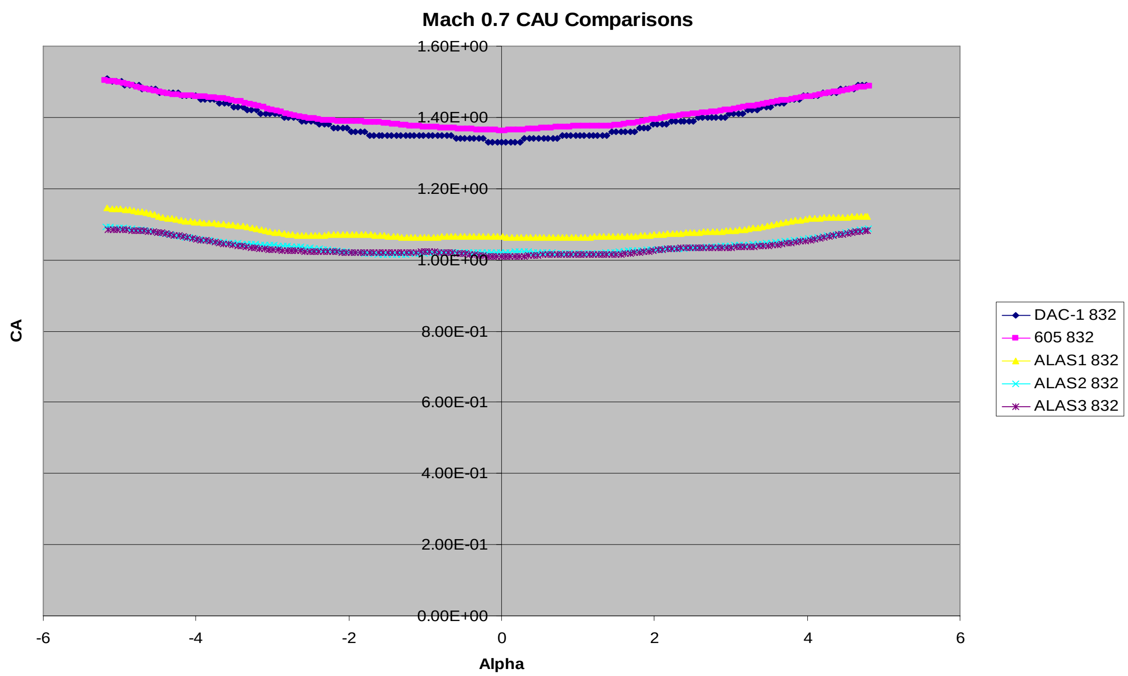

Figure 8. Comparisons of uncorrected axial force at Mach 0.7.

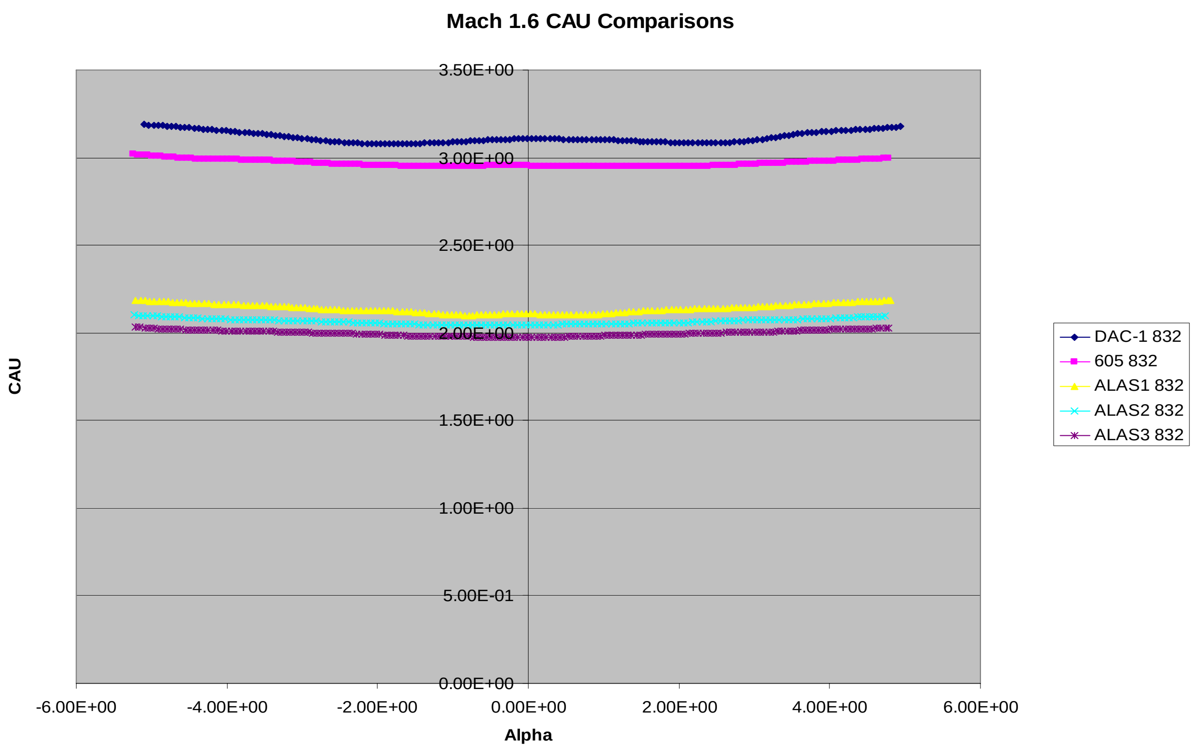

Figure 9. Comparisons of uncorrected axial force at Mach 1.6.

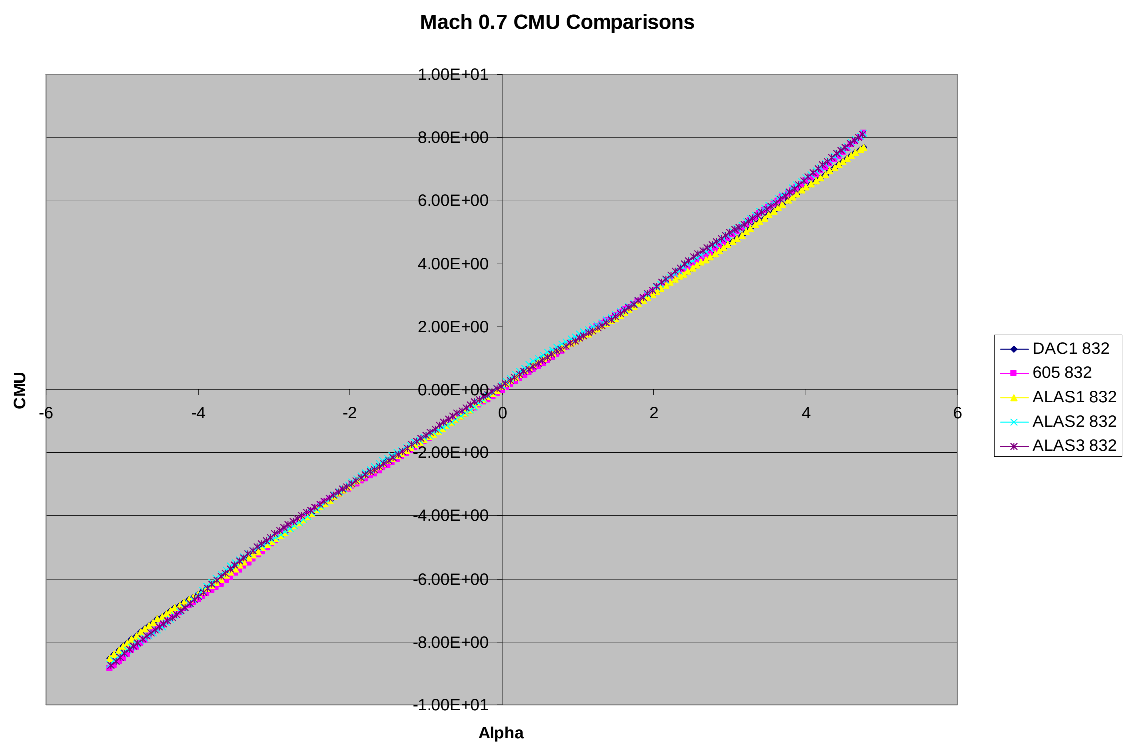

Figure 10. Comparisons of pitching moment at Mach 0.7.

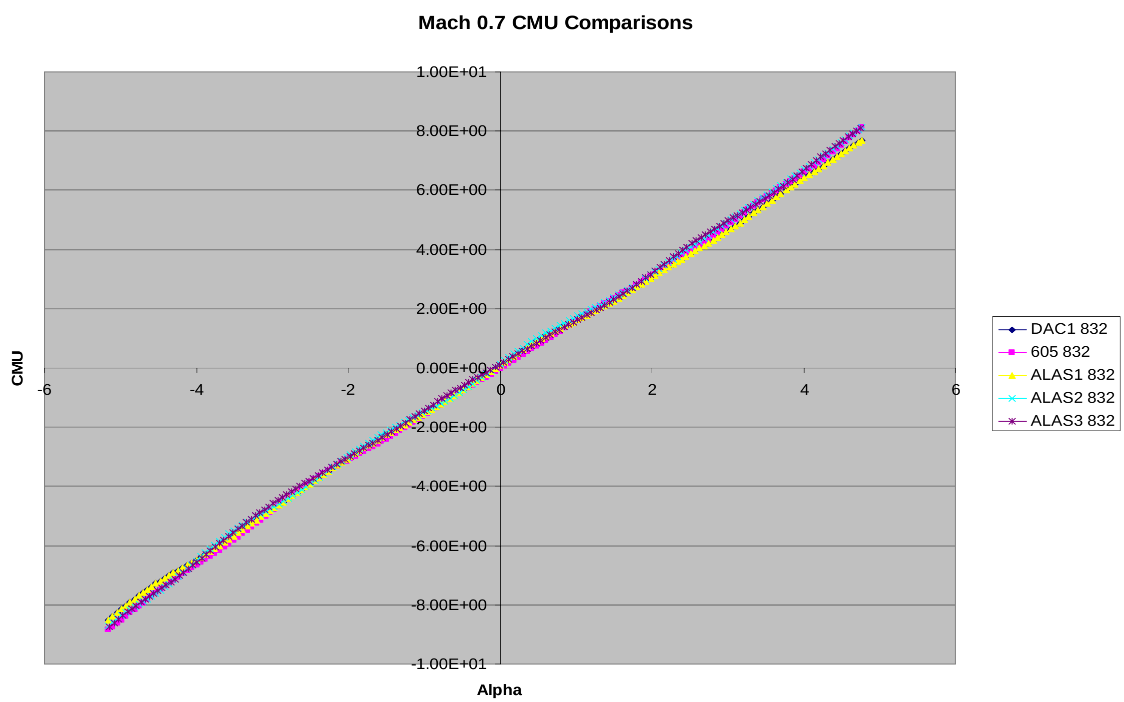

Figure 11. Comparisons of pitching moment at Mach 1.6.

A summary of corrected axial force is presented in figure 12. In this figure the Test 832 data is compared with all data previously obtained, including early configurations tested in the Marshal Space Flight Center 14-inch Aerodynamic Research Facility (ARF), the Ames Research Center 11-Foot Transonic Wind Tunnel as well as the DAC-1 tested in the PSWT and UPWT. This covers the Mach number range 0.5 to 5.0.

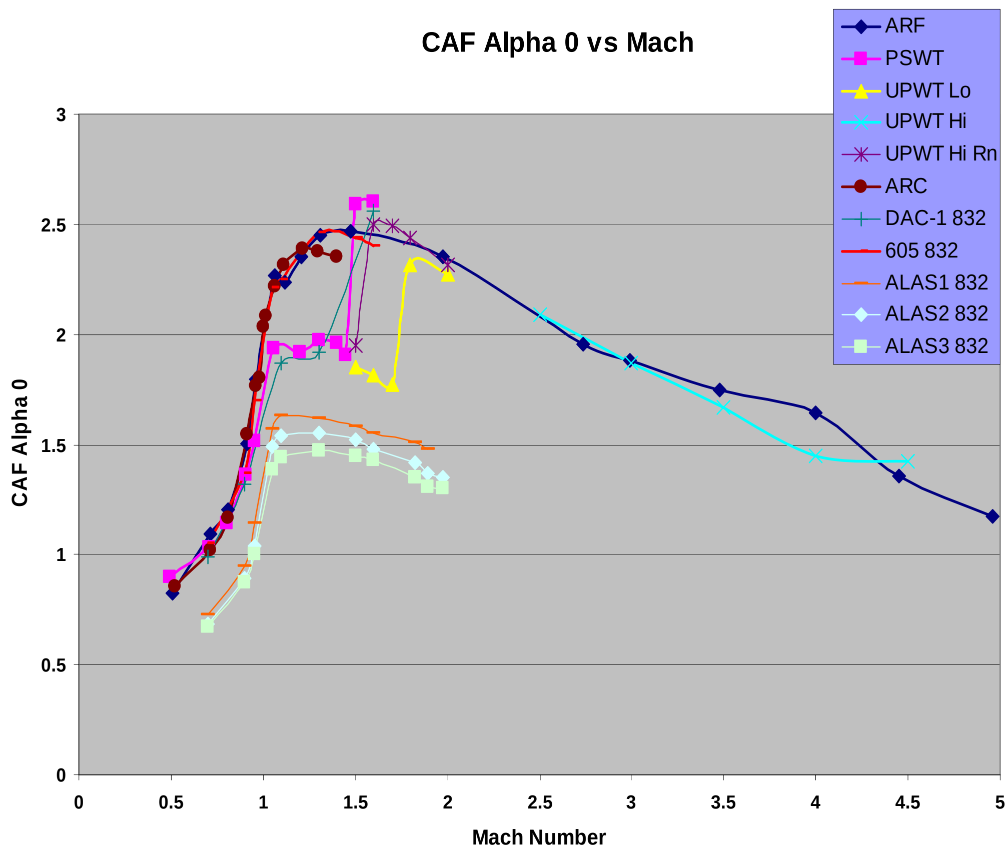

Figure 12. Comparison of corrected axial force for all configurations test to date.

There are several significant points to take from this figure. First, all the previous configurations fall roughly along the same axial force versus Mach number trend. This is actually to be expected as all configurations have roughly the same fineness ratio and roughly equal forward and aft facing surfaces. As shown in Figure 13, the axial force distribution along the configuration is dominated by the forward and aft facing surfaces with the major portion being that from the forward facing CM.

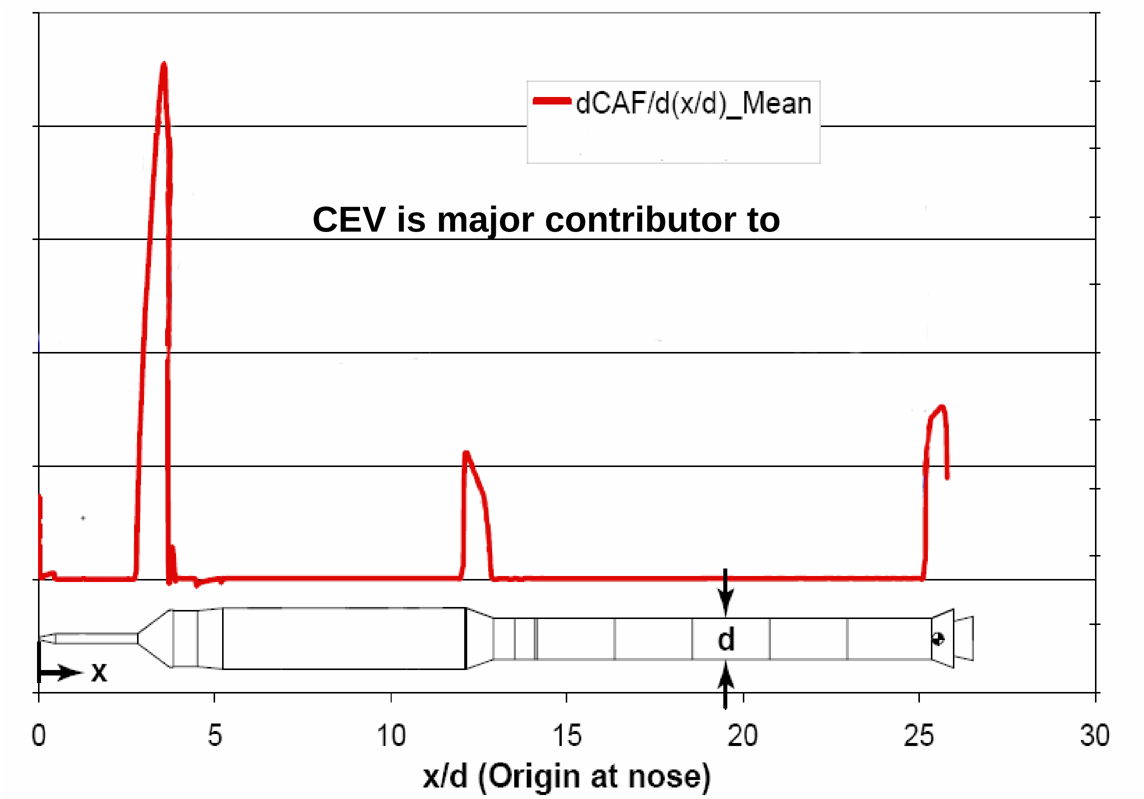

Figure 13. Distribution of axial force along the Ares I configuration.

Second, the “low axial force” values seen for the DAC-1 configuration in the PSWT and UPWT between about Mach 1 and 1.7 are the result of the “flow popping” phenomenon where the flow, at low Reynolds numbers, separated at the LAS flare exposing the CM to a region of low-dynamic-pressure-flow producing lower axial force. This was a function of Mach number and Reynolds number and as Reynolds number was increased the flow tended to remain attached to the LAS downstream of the flare and exposed the CM to high-dynamic-pressure-flow producing higher axial force. Since the high Reynolds number test was still more than an order of magnitude lower than will be the flight case, it is presumed that this is not a valid axial force result for the Ares I. In addition the current and potential forbody designs do not include the flare so this should not be an issue or a benefit for follow-on designs. However, the data are included here for completeness. Finally, it is quite clear that the ALAS configurations provide a significant reduction in axial force out to about Mach 2 (the Test 832 limit).

These new data, when combined with CFD predictions and the trend of previous axial force data, allow an axial force curve to be generated out to and beyond Mach 5. Ascent trajectory analysis using this data indicates that the ALAS configuration may provide an aerodynamic benefit that could allow approximately 1200 more pounds of mass to be delivered to orbit as compared to that for the 605-054 configuration. Significant “engineering details” remain to be solved before an ALAS configuration could be integrated into the Ares I design. However, from a purely aerodynamic perspective this is a significant development in the testing and analysis of the Ares I vehicle.

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