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An Investigation Into the Aerodynamics and Structural Integrity of the 155-mm M898 Projectile

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An Investigation Into the Aerodynamics and Structural Integrity of the 155-mm M898 Projectile

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Abstract

The M898 sense-and-destroy armor (SADARM) projectile is a 155-mm counterbattery artillery projectile that ejects two submunitions against battlefield combat vehicles. The U.S. Army Armament Research, Development, and Engineering Center (ARDEC) recently funded an experiment designed to analyze the structural integrity and aerodynamic characteristics of the projectile. In particular, the experiment sought to investigate the possibility of a compromise in integrity at the base-body juncture. No evidence of this was discovered.

The secondary aim of obtaining a complete set of aerodynamic coefficients for the M898 was related to recent minor design changes made to the round. The objective was to ensure that these changes did not result in a noticeable change in flight characteristics. All shots were temperature-conditioned to 120° F, thus providing a higher-than-normal launch Mach number. This resulted in an extension of the Mach-number regime of the existing spark range database. When compared with existing spark range data, no significant differences were noted.

Aerodynamically, the M898 projectile is very similar to the M483A1. Despite a large existing aerodynamic database, three M483A1 projectiles were fired concurrently with the M898's in an effort to solidify the close comparison of the two round types. Comparison of the new M898 and M483A1 data confirms the aerodynamic similarity noted previously.

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1. Introduction

The 155-mm M898 sense-and-destroy armor (SADARM) projectile is used primarily in a counterbattery role against self-propelled artillery assets, infantry fighting vehicles (IFVs), and other armored combat vehicles. The rounds contain two submunitions that are expelled from the rear of the projectile during the terminal phase of the flight. It is currently in low-rate initial production (LRIP) under development by the U.S. Army Armament Research, Development, and Engineering Center (ARDEC) at Picatinny Arsenal, NJ. A schematic of the projectile is shown in Figure 1.

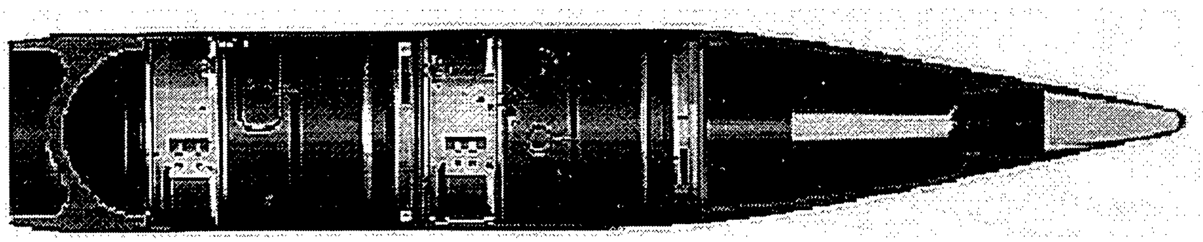

Figure 1. 155-mm M898 SADARM Projectile.

The primary purpose of the current test was to investigate the structural integrity of the base-body joint. Specifically, prior testing has revealed approximately 2–3% higher-than-normal drag for some rounds (Koenig 1999). Careful analysis of this observation lead to the hypothesis that the projectile base could potentially disengage partially from the main projectile body, thus causing higher drag (Kalinowski 1999).

Recently, the projectile configuration underwent a number of minor design changes. Most importantly were the changes aimed at reducing the possibility of collision of the two submunitions during or after expulsion (Kalinowski 1998). First, a split pusher plate was incorporated for greater radial dispersion of this piece after ejection. Next, two modifications were made to enhance lateral separation of the munitions after exiting the carrier projectile. A Bellville spring (washer-shaped) was used between the two submunitions, and a six-bladed Kevlar drag device was added to the aft submunition. Finally, a drag device was added to the base plug in an effort to improve separation between the plug and submunitions. As a result of these weight additions, and some weight reductions in the ogive section, the overall mass properties of the round were changed slightly from those prior to modification. Therefore, a second objective of the test was to measure the aerodynamic and stability characteristics of the current round to ensure no significant change in these characteristics relative to those measured prior to the modifications described previously.

Four identical inert M898 projectiles were fired at the U.S. Army Research Laboratory (ARL) Transonic Experimental Facility at Aberdeen Proving Ground (APG). Since the M898 aerodynamics duplicate those of the M483A1 projectile (Davis 1992), three M483A1s were also fired. Firing these rounds provided valuable instrumentation checkout information. More importantly, although an extensive database already exists for the M483A1, it was felt that comparison of the M898 data to that of M483A1 data fired on the same occasion under the same conditions would increase confidence in the comparison. All shots were fired using a top-zone charge temperature-conditioned to 120° F in order to produce the most severe launch environment possible.

2. Experiment Instrumentation and Methodology

The test plan called for use of a standard M199 155-mm first-quarter (minimum 75% usable life remaining) gun tube with muzzle brake. The weapon was mounted in a fixed mount at the ARL Transonic Experimental Facility.

Orthogonal sets of flash x-rays were located at approximately 1 m and 3 m from the muzzle, respectively. These two stations were utilized to obtain structural integrity data, as well as projectile position and orientation at two adjacent locations near the muzzle.

Orthogonal smear cameras were located 14.3 m, 18.3 m, and 21.3 m from the muzzle and were used to capture detailed still photographs of the projectile in flight. As described previously, the primary test objective was the assessment of structural integrity of the base-body joint. To aid in this investigation, eight axial stripes were painted along the body of the projectile from midbody to base, using heat-resistant white paint. This was done with the expectation that any relative motion between the projectile base and body would be evident in the smear photographs as a discontinuity in the painted lines at the base-body junction.

Finally, the 25 orthogonal shadowgraph stations of the spark range were employed. The range contains approximately 210 m of instrumented length and is used for studying projectile aerodynamics in a wide range of medium and large calibers (Rogers 1958). An interior view of the facility is shown in Figure 2. Each station captures an orthogonal set of shadowgraphs of the projectile in flight and yields extremely accurate position and angular orientation data vs. range. Generally, shadowgraph quality is very high, and any lack of base-body integrity could possibly be evident in the shadowgraphs, thus providing a backup data source to the x-rays and smear photographs. Since the overall projectile yawing and swerving motion is intimately related to its spin, the spin was also measured using a pin installed in the projectile base. High-strength steel pins were welded to the inner surface of the projectile base cavity, protruding from the aft end so as to be visible in each shadowgraph.

3. Experimental Results

3.1 Structural Integrity of the Base. As stated earlier, one key objective of the test was the determination of the structural integrity at the base-body juncture of the M898 under severe firing conditions. This objective was achieved primarily through examination of smear-camera film. The smear camera operated by the high-speed motion of 35-mm film past a tiny slit and lens. When the projectile passes the slit, it is recorded on the moving film. A typical smear photograph is shown as Figure 3. The upper projectile image in the figure is a view from below the line of fire (LOF) looking up, and the lower projectile image is a view looking from the gunner's right to left of the LOF. As stated earlier, the numbered painted lines on the projectile were applied along the axial direction. From the photograph, the lines are clearly visible but

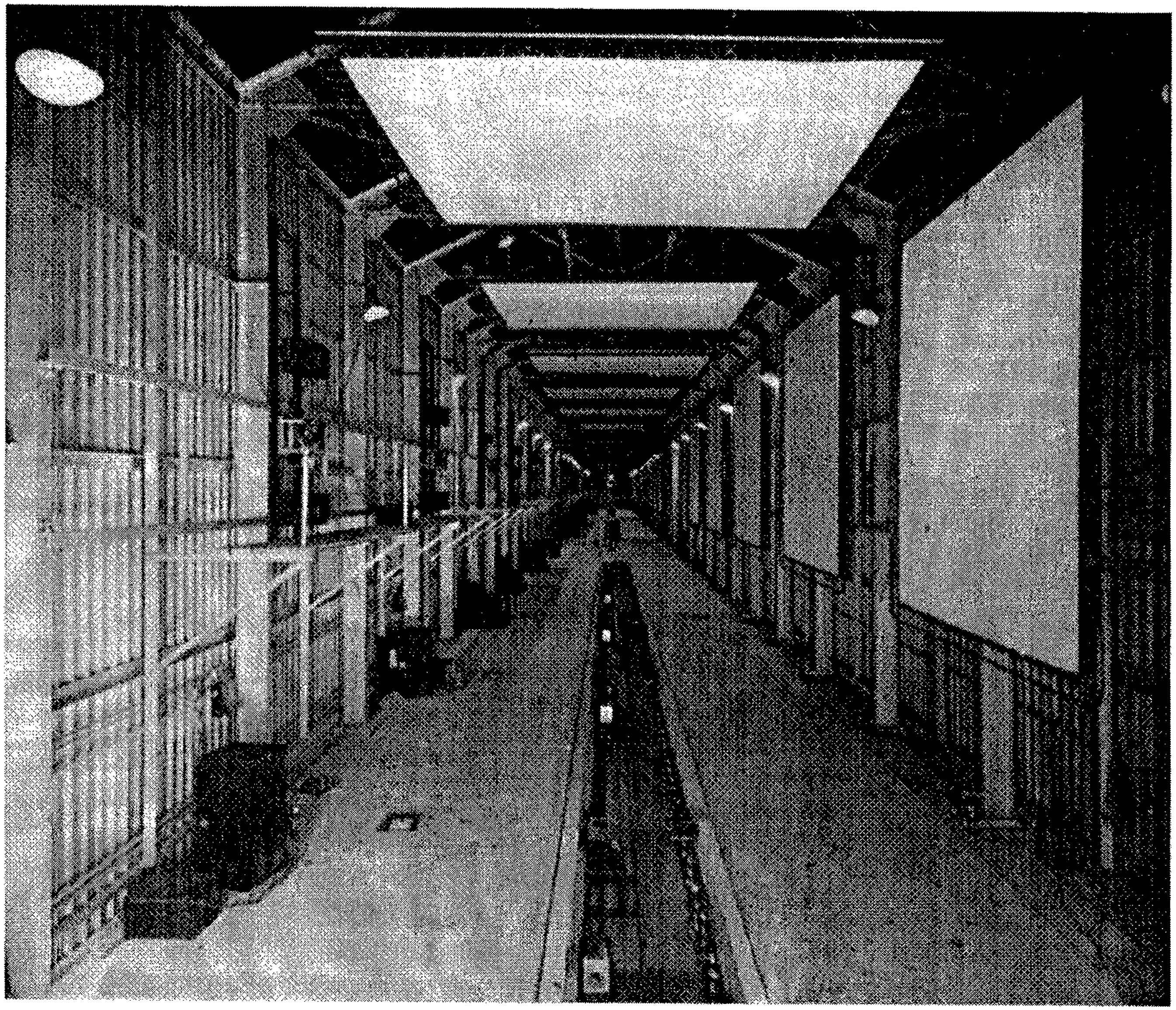

Figure 2. Transonic Experimental Facility, Interior View.

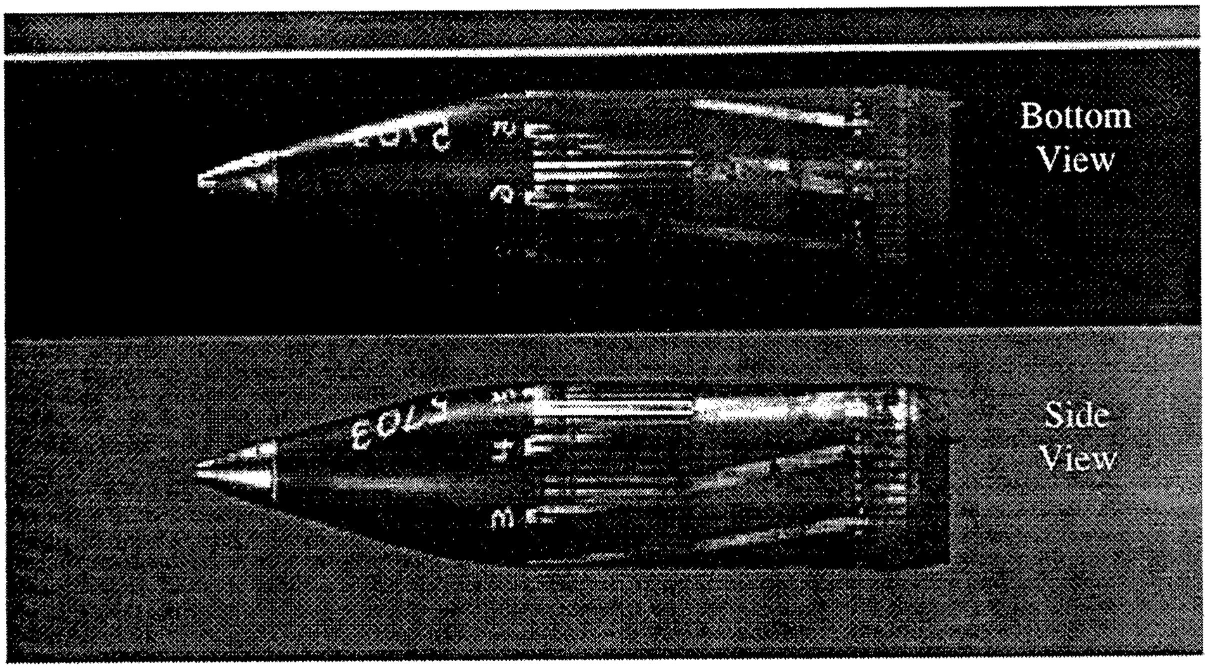

Figure 3. Typical M898 Smear Photograph.

appear slanted (helical) relative to the projectile axis. This appearance is due to the fact that the projectile is spinning rapidly as it passes by the very small aperture of the smear camera, and, hence, the straight lines appear in the helical pattern, which is traced by the projectile body. Additionally, a fine set of scoring lines is evident from the midsection of the projectile to the base. These lines are the result of scoring of the projectile body on the bore rifling, and they appear to be approximately parallel to the projectile axis. However, the projectile body is actually scored in a helical pattern consistent with the twist rate of the gun's rifling. But, since the projectile is spinning at the muzzle exit twist rate, the projectile body is simply traveling in a helical pattern. This means that, as the projectile travels past the camera slit, the scoring lines must appear straight in the photograph. The scoring was usually evident in a discontinuous pattern.

In order to verify structural integrity at the body-base joint, the high-resolution photographs were enlarged in the region of the joint. A typical example of this is shown is Figure 4. From this figure, the painted white lines do appear discontinuous at the joint. However, the

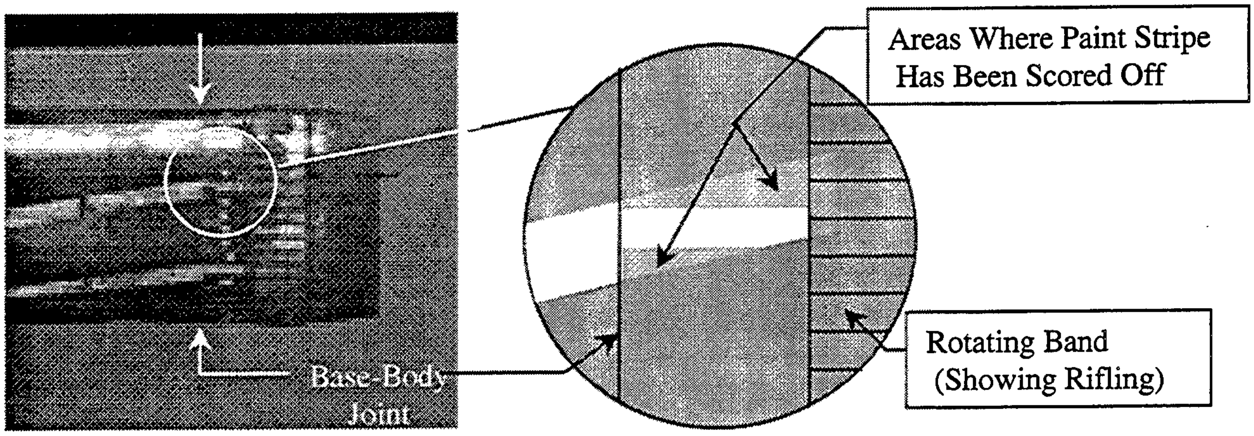

Figure 4. Expanded View of Base-Body Joint.

discontinuity appears to be from uneven helical scoring on the bore rifling rather than from relative motion of the projectile base. That is, forward of the junction along the body, the painted stripes are mostly intact and show only minor damage. However, between the joint and the rotating band, scoring of the bore rifling lands on the base surface seems to have stripped away more significant portions of the paint. This is also drawn schematically in Figure 4. This result was typical of all the M898 smear data for which this area was clearly visible. Even in cases where the smear images were slightly unclear, neither x-rays nor range shadowgraphs indicated any relative motion between the base and body. Hence, it is postulated that there was no motion of the base relative to the projectile body in any of the four shots fired. Because of the effect of scoring on the painted stripes on the projectile base, this cannot be conclusively proven. However, if any relative motion did occur, it was very minute. This follows because the areas of white that remain on the base surface are aligned with the stripes on the projectile body forward of the joint.

3.2 Aerodynamics. Aerodynamic characteristics of the projectiles were obtained using the inverse procedure of the Aeroballistic Research Facility Data Analysis System (ARFDAS) data reduction code currently in use (Hathaway and Whyte 1981). Research engineers use this code to examine the projectile flight in four separate steps, ending with a full 6-degree-of-freedom (DOF) analysis. Given the acquisition of high-quality position, angle, and roll data, mathematical fits to the data are obtained. Next, the aerodynamic coefficients are extracted as those that were necessary to have produced the experimentally observed motion.

In addition to individual shot analysis, the data reduction code possesses two extremely valuable assets. The first is dynamic calibration, through which individual station biases can be removed from the raw data, yielding a better fit to the measured motion. Second is the multiple-fit capability. This allows the user to obtain a single set of aerodynamic characteristics for a group of individual shots. This typically results in higher quality aerodynamic coefficient values (lower error) and can often be used to extract nonlinear aerodynamic characteristics and Mach-number variations, which are normally difficult or more costly to determine.

The aerodynamic coefficient data derived from the present experiment was compared to M898 coefficients obtained by Davis in testing at the same facility in 1992. Although a significant aerodynamics database exists for the M898 and M483A1, these data are the most recent spark range data, and thus provide the best basis for comparison (Koenig 1999). In this work, Davis presents M898 (referred to as XM898 at the time) aerodynamic data calculated from multiple-fit runs on a previous version of the ARFDAS code. The data are compared with existing M483A1 data, which show that the two rounds are aerodynamically very similar. This result is expected since the rounds are identical in shape except for slight differences in the base region. Coefficients for the XM898 are presented at seven different Mach numbers, ranging from 0.72 to 2.25. In the current test, all shots were fired using hot-conditioned top-zone charges, resulting in a Mach-number range between 2.38 and 2.41. Thus, the comparison made between Davis' data and current data is not an exact comparison but rather a comparison by extrapolation. These new M898 data therefore serve to broaden the Mach-number range of the aerodynamic database for the round. In addition to the comparison with the older data, confidence in the results and conclusions is further enhanced by the presence of M483A1 data in the same Mach regime, fired concurrently with the M898 shots. Comparisons between the current M898 data and both the older XM898 data and current M483A1 data are discussed in detail next.

3.2.1 Drag Coefficient. Zero-yaw drag is presented first in Figure 5. Although Davis presented data for Mach numbers as low as 0.72, only the data at the two highest Mach numbers, 1.54 and 2.26, are used for comparison. From Figure 5, we see that the earlier data compare favorably with the current data. Strictly speaking, extrapolation of the existing data curve would lead to slightly higher drag than was observed in the present test; however, the difference is not significant (about 3%). This figure also shows excellent agreement between the M898 and M483A1 data.

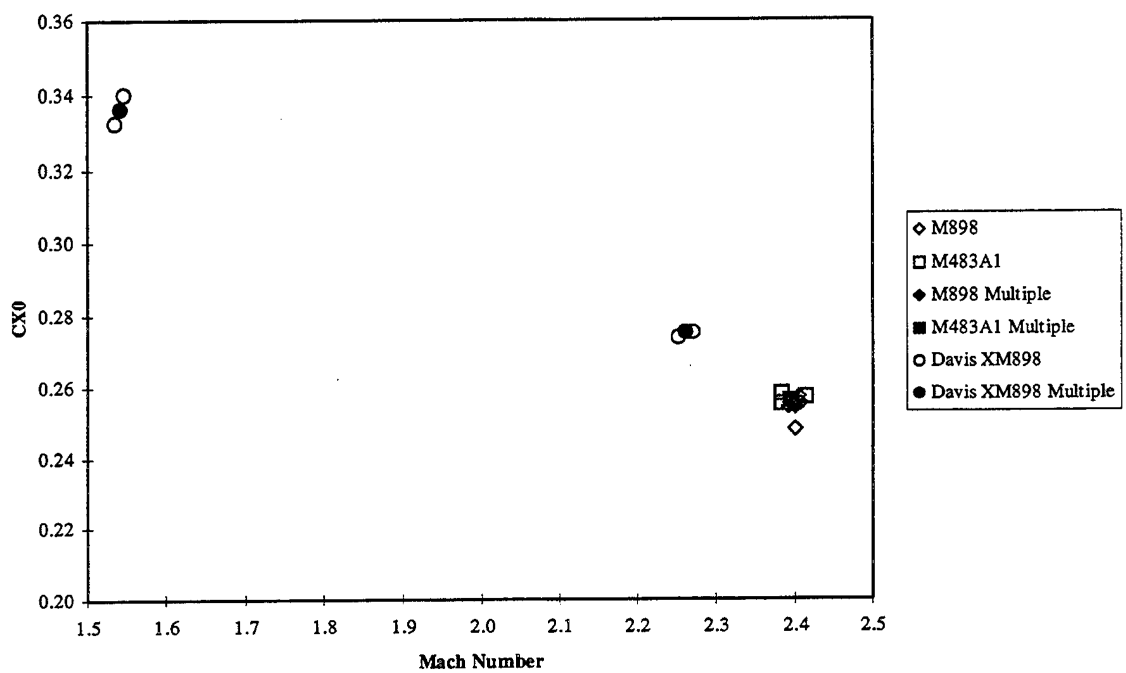

Figure 5. Zero-Yaw Drag vs. Range.

3.2.2 Pitching Moment Coefficient Derivative ($C_{m\alpha}$). Figure 6 plots the linear $C_{m\alpha}$ vs. Mach number. Here, we see very little variation of $C_{m\alpha}$ with Mach number and an excellent comparison between Davis' data and the new range data. A linear extrapolation of the older XM898 data tracks almost exactly to the data of the current experiment. A comparison of multiple-fit M898 data with that of the M483A1 reveals a difference in $C_{m\alpha}$ of about 4%. Slight differences in $C_{m\alpha}$ between the two rounds have been noted previously (Davis 1992). All $C_{m\alpha}$ values were obtained to within a standard error of approximately 1%, with the exception of one shot, which had extremely low yaw.

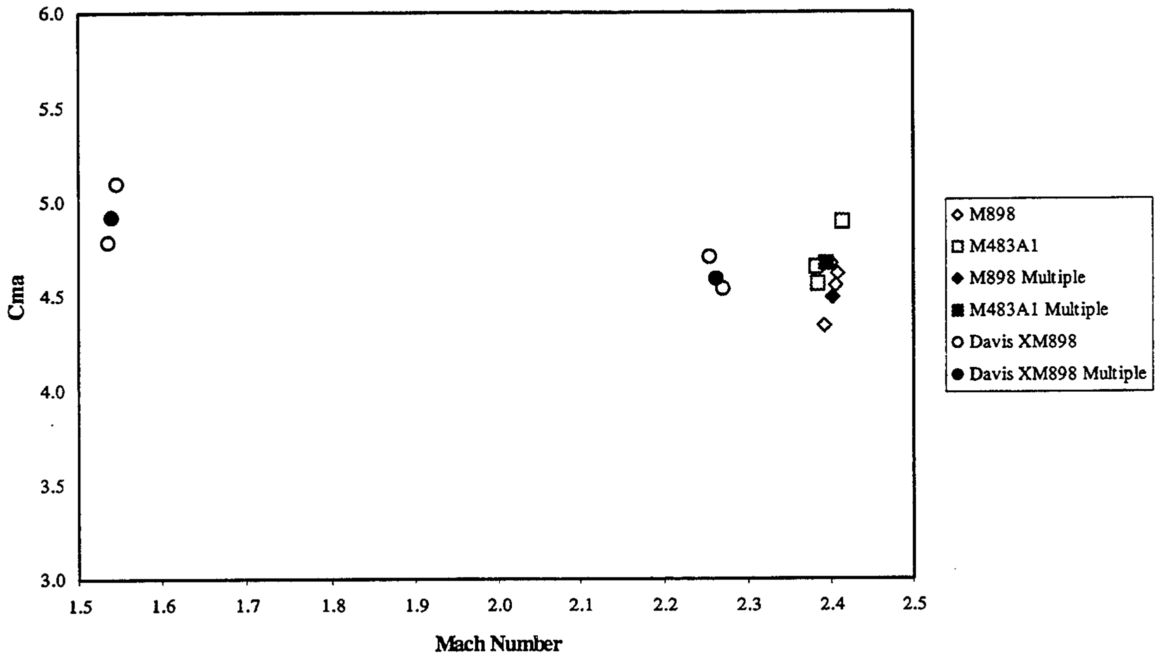

Figure 6. $C_{m\alpha}$ vs. Range.

3.2.3 Pitch Damping Moment Coefficient (C_{mq}). C_{mq} is presented in Figure 7 and, again, shows a strong correlation with the data from 1992. As in the case of $C_{m\alpha}$, a difference is noted between the multiple-fit data of the M898 and M483A1. However, errors in the calculation of C_{mq} are typically much higher than those pertaining to $C_{m\alpha}$, and, hence, the data scatter is not unexpected. In this case, most of the coefficient errors ranged between 8% and 15%.

3.2.4 Magnus Moment Coefficient ($C_{np\alpha}$). Figure 8 shows a continued good match between an extrapolation of Davis' data and the current M898/M483A1 data for the case of $C_{np\alpha}$. The coefficient is shown to be only weakly dependent on Mach number in this regime. Again, scatter is evident, but this is to be expected by the nature of the data reduction. The extreme differences in Davis' Mach 1.5 data are due to the fact that both of these shots produced very low yaw levels. For the recent data, errors in the $C_{np\alpha}$ were on the order of 10% to 30%.

3.2.5 Normal Force Coefficient Derivative ($C_{N\alpha}$). A comparison of $C_{N\alpha}$ values is shown in Figure 9. Again, the correlation is good and Mach-number variations are trivial. The coefficient

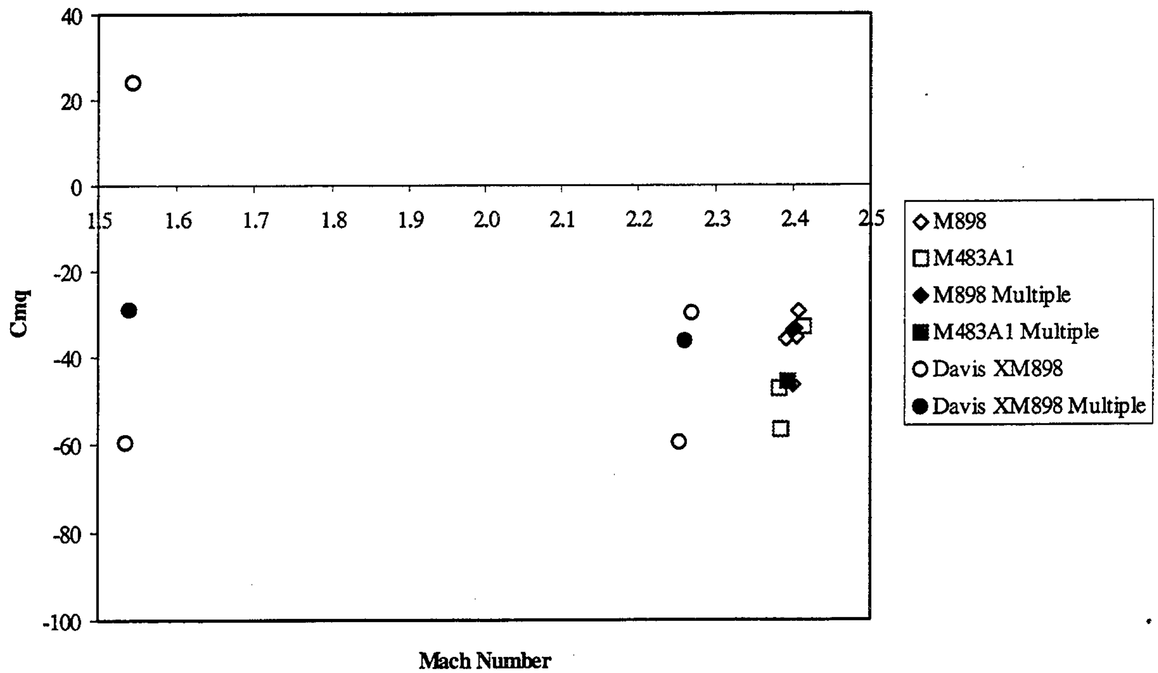

Figure 7. C_{mq} vs. Range.

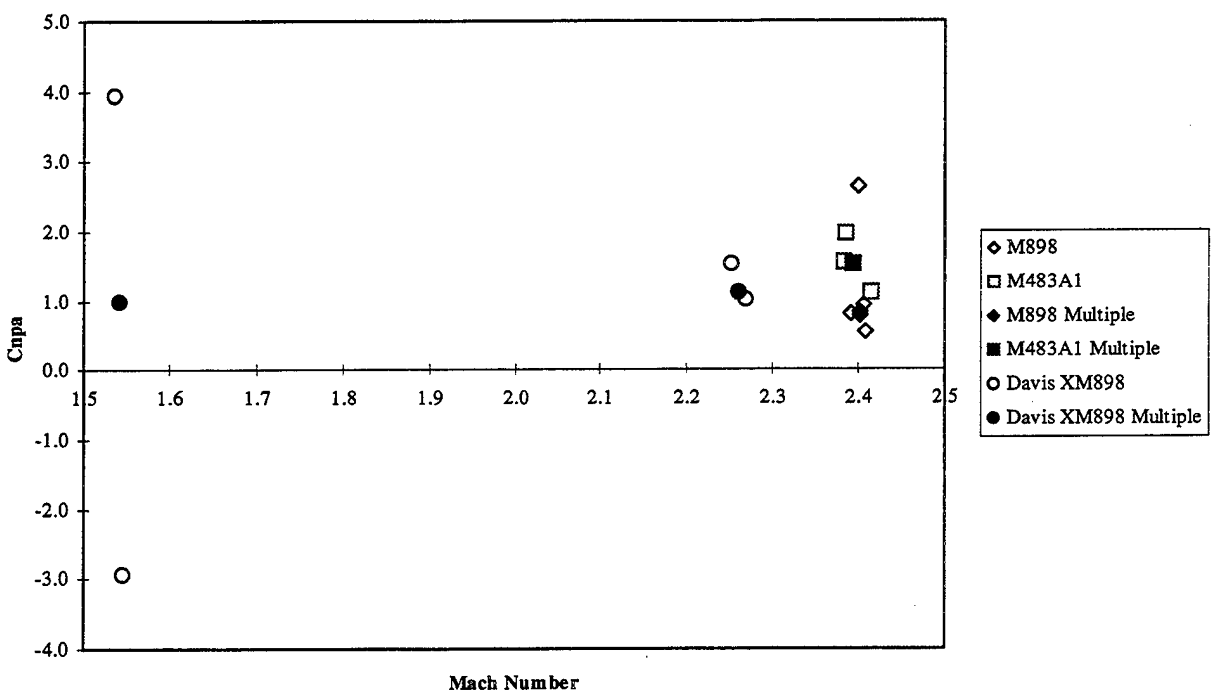

Figure 8. $C_{np\alpha}$ vs. Range.

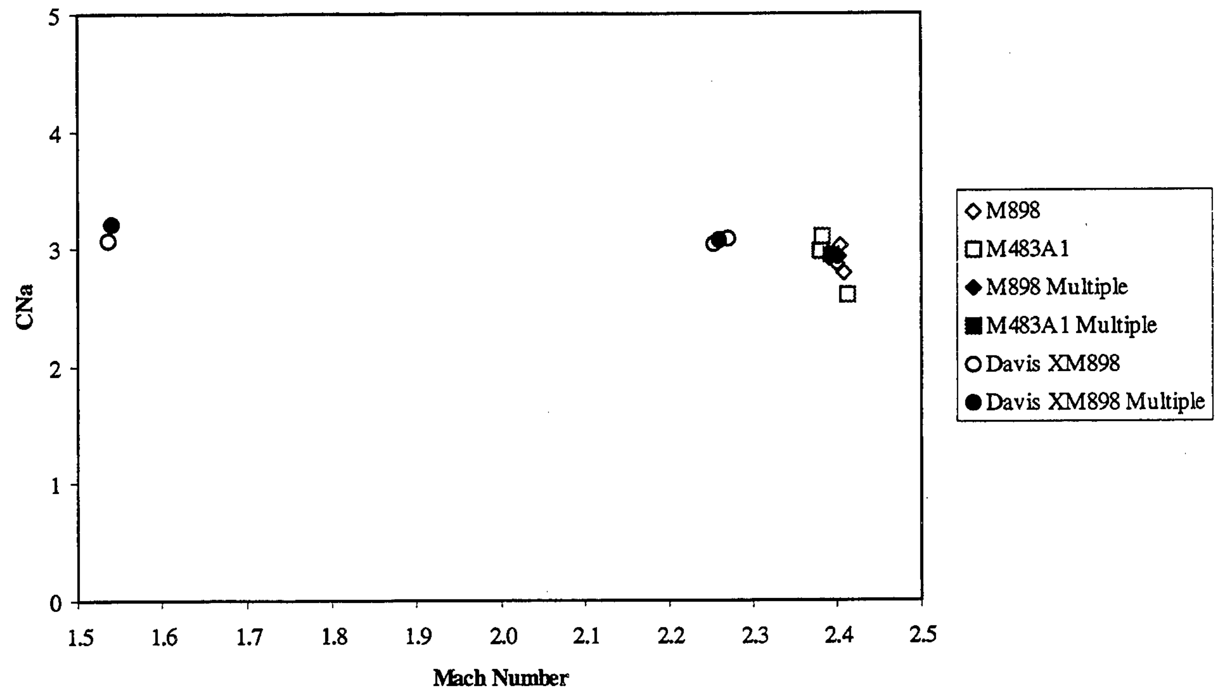

Figure 9. $C_{N\alpha}$ vs. Range.

value calculated from one of Davis' shots at Mach 1.5 was greater than 6 and is not plotted because it is most likely unreliable, especially in light of the value calculated from the multiple fit at this Mach number. Such anomalies in $C_{N\alpha}$ generally arise in shots that demonstrate very small swerving motion (Murphy 1963). $C_{N\alpha}$ is found to be essentially identical for both the M898 and M483A1. Scatter in the data is small since coefficient errors were generally in the range of 2% to 6%.

4. Conclusions

Experimental testing of four 155-mm M898 SADARM projectiles and three M483A1 projectiles was performed at the ARL Transonic Experimental Facility at APG. This experiment was prompted by several recent minor design changes to the M898 and by the hypothesis that some rounds were experiencing an increase in drag due to a relative motion created between the projectile base and body on launch.

Of the four hot-conditioned M898 projectiles fired, none showed evidence of a gap, relative motion, or any other structural anomaly between the base and body of the projectile. This determination was initially based on careful analysis of smear-photographic data and is supported by the data match in drag between the M898 and M483A1 shots, as shown in Figure 5.

The aerodynamic coefficients obtained from the current test were compared to similar data analyzed by Davis (1992). The new data broaden the Mach-number regime of the existing database of spark range data from 2.25 to 2.40. In general, when prior XM898 data are extrapolated, good agreement is evident with the characteristics just derived. Even better agreement would probably have been achieved, given a larger number of shots. In consideration of this, it is noted that the design changes recently implemented on the M898 projectile have caused no noticeable change on the aerodynamics of the round.

Except for small-percentage differences, the aerodynamic coefficients of the M898 continue to mimic those of the M483A1. Larger percentage differences are noted only for coefficients like pitch damping moment and Magnus moment, which typically display larger scatter because they are more difficult to accurately determine from experimental data. Hence, given the small number of shots, these variations cannot be used to conclude an aerodynamic difference between the M898 and M483A1.

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