23rd AIAA Applied Aerodynamics Conference
6 - 9 June 2005, Toronto, Ontario Canada

AIAA 2005-5086

High Angle of Attack Aerodynamic Predictions Using Missile Datcom

Eric J. Abney*
Dynetics, Huntsville, AL 35806

Melissa A. McDaniel†
U.S. Army Aviation and Missile Research Development and Engineering Center, Redstone Arsenal, AL, 35898

The USAF Missile Datcom is an industry standard tool used for predicting the aerodynamics of conventional missile configurations. Typical aerodynamic models are constructed from wind tunnel data and used to simulate the flight profile and behavior of a missile. However, certain configurations require data beyond the usual 20 degrees angle of attack obtained in the wind tunnel. Comparisons have been made with existing subsonic high angle of attack wind tunnel data in order to assess Datcom's capabilities in predicting the aerodynamics of a configuration to angles of attack in excess of 20 degrees. Results presented herein indicate that Missile Datcom can reasonably predict the aerodynamics of standard body, fin, and body-fin configurations to angles of attack up to 90 degrees.

Nomenclature

CA	=	axial force coefficient
C_{Do}	=	drag coefficient
C_{Lo}	=	lift coefficient
CN	=	normal force coefficient
CNF	=	fin normal force coefficient
X_{CP}/L_{REF}	=	longitudinal center of pressure

I. Introduction

The use of helicopter launched missiles has necessitated the need for high angle of attack, six-degree-of-freedom aerodynamic models for simulation purposes. While most missiles will never experience a geometric angle of attack of 90 degrees, a missile that flies through a helicopter rotor wake will experience a crossflow that can equate to an effective 90 degree angle of attack. For example, as the missile leaves the launch rail at a zero degree angle of attack, the rotor wake will impart a velocity perpendicular to the missile. Depending on the missile launch profiles, the rotor downwash can result in angles of attack approaching 90 degrees. Although the missile may not remain within the rotor wake for a significant amount of time, it is important to have the aerodynamics modeled properly for the conditions the missile will experience. Hence, there is a requirement to predict the aerodynamics of a missile at very large angles of attack.

The USAF Missile Datcom is an industry standard aerodynamic prediction tool commonly used to supplement aerodynamic models. The code was originally developed in 1985 and has been incrementally enhanced over the last twenty years. The subject of this investigation is to assess the capability of Missile Datcom to predict the aerodynamics of a missile configuration at high angles of attack. Comparisons between wind tunnel test data and Missile Datcom predictions are presented followed by an assessment of the results and conclusions. All predictions have been made using the 9/02 release of Missile Datcom.[1]

---

* Aerospace Engineer, AIAA member
† Aerospace Engineer, AMSRD-AMR-SS-AT, AIAA member

II. Missile Datcom Methodology

Missile Datcom employs several prediction methods in order to accurately predict the aerodynamics of multiple missile configurations. A combination of empirical and theoretical methods is used throughout the code, and method choice is based on the configuration geometry and flight conditions. Missile components are analyzed separately and then joined using various carryover and synthesis methods. The interest of this paper is a cylindrical missile configuration with four tail fins flying at subsonic speeds.

A. Body Alone Methodology

For body alone data at subsonic speeds, Missile Datcom employs a combination of aerodynamic prediction methods. At low angles of attack (less than 5-10 degrees), the normal force and pitching moment are computed using both empirical correlations and slender body theory.[2] At high angles of attack, Allen and Perkins' viscous crossflow method is utilized.[3,4] Axial force is also computed using two distinct methodologies. Below 30 degrees angle of attack, a modified version of Allen and Perkins' method is used, and above 30 degrees angle of attack, Jorgensen's slender body theory is used.[5] This gives the contribution to axial force due to angle of attack. Contributions due to skin friction, wave, and base drag are also included in the total axial force computation and are assumed to be independent of angle of attack.[2]

B. Fin Alone Methodology

The fin alone aerodynamics are calculated using a similar approach as that used for the body. Linear and non-linear contributions are calculated for the normal force and pitching moment and these contributions are then summed. In general, lifting line, lifting surface, and empirical methods are used depending on the fin planform geometry. The pitching moment, or hinge moment, of the fin is derived from the linear and non-linear portions of the fin normal force. The linear, or potential, term is assumed to act at the quarter chord of the fin. The non-linear, or viscous contribution, acts at the fin center of pressure, which is assumed to be the fin centroid. Axial force is calculated in the same manner as the body. Angle of attack independent values of the skin friction, pressure, wave, and base drag are calculated and then added to the axial force due to angle of attack[6].

C. Component Buildup Methodology

Component interference effects are used to combine the aerodynamics of the body and fins. For angles of attack in the linear range (i.e. less than 5 degrees angle of attack), the method outlined by Nielsen, Pitts, and Kaattari is used to calculate the body and fin carryover loads.[7] Although this method is only valid in the linear range, it can be applied up to 10 degrees angle of attack with reasonable confidence. Beyond this point, an equivalent angle of attack method is used that provides accurate predictions up to approximately 30 degrees angle of attack. The equivalent angle of attack method assumes the contributing factors to the fin normal force can be expressed as increments in angle of attack and summed to create an equivalent, or effective, angle of attack.[8,9] There are no mentions of the validity of this approach above 30 degrees angle of attack, although the code will still run at these conditions.

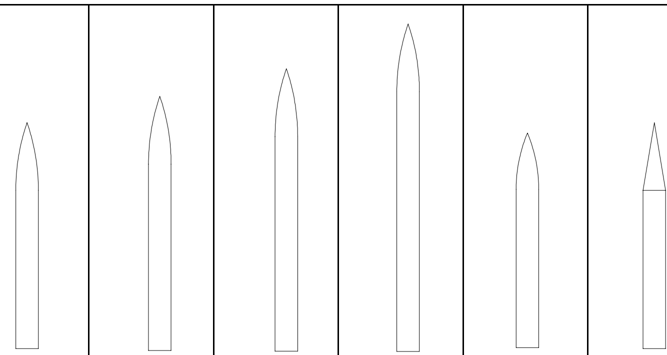
III. Missile Datcom Validation

Comparisons have been made between Missile Datcom and select high angle of attack wind tunnel data to determine if Datcom is suitable for making high angle of attack predictions. All of the data presented is for a Mach number of 0.8.[10] All body alone and body-fin data is at a Reynolds Number per foot of 2.3×10^6; fin alone data is at a Reynolds Number per foot of 2.5×10^6. Normal force is defined as positive up, and axial force is defined as positive aft. It should be noted that the referenced test data does not provide any indication of its accuracy. Some data, particularly axial force, have been determined to be incorrect.

A. Body Alone Comparisons

In order to validate the body alone prediction capabilities of Missile Datcom, six different body shapes were chosen for comparison with wind tunnel test data. The geometries are described in detail in Table 1. For all body alone configurations the reference area and length are the body cross sectional area and body diameter, respectively.

Table 1. Body Geometries.



Identifier	B1	B2	B3	B4	B5	B6
Nose Type	tangent ogive	tangent ogive	tangent ogive	tangent ogive	tangent ogive	cone
Nose Length (calibers)	3.0	3.0	3.0	3.0	2.5	3.0
Cylindrical Aftbody Length (calibers)	7.00	8.25	9.50	11.50	7.00	7.00
Total Body Length (calibers)	10.00	11.25	12.50	14.50	9.50	10.00

To partially address the uncertainty of the wind tunnel data and provide data at angles of attack where wind tunnel data is not available., estimates of the normal force and axial force of an inclined circular cylinder as presented by Hoerner are included in the body alone comparisons. This method calculates the lift and drag of a circular cylinder using the following equations.[11]

$$C_{Lo} = 1.1\sin^2\alpha\cos\alpha \tag{1}$$

$$C_{Do} = 1.1\sin^3\alpha + 0.02 \tag{2}$$

The standard definition of lift and drag can then be rearranged to find the normal force and axial force in order to make a direct comparison to the wind tunnel data. The resulting equations are as follows.

$$C_A = \left[\frac{1}{1+\tan^2\alpha}\right]\left[\frac{C_{Do}}{\cos\alpha} - \frac{C_{Lo}\tan\alpha}{\cos\alpha}\right] \tag{3}$$

$$C_N = \frac{C_{Lo} + C_A\sin\alpha}{\cos\alpha} \tag{4}$$

The coefficients presented in Eqs. 1 through 4 are referenced to an area comprised of the body length times the body diameter. In order to equate these results with the wind tunnel data, the reference area must be adjusted to match the test reference area.

Figures 1 through 3 compare test data, missile Datcom predictions, and Hoerner predictions of the normal force coefficient for B1, B2, and B3, respectively. These three configurations have the same nose and body diameter, and differ only in total body length.

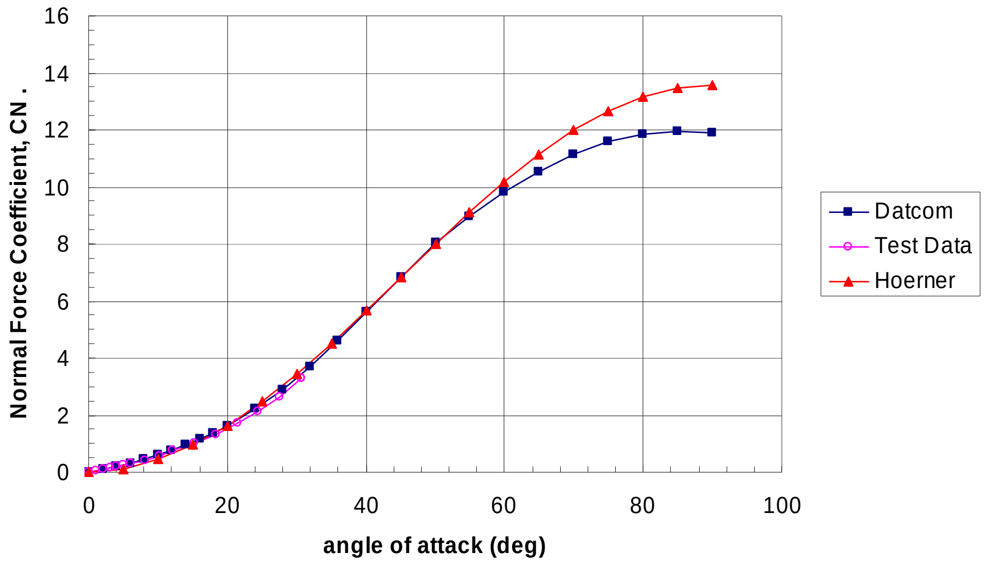


Figure 1. Normal Force Coefficient for B1.

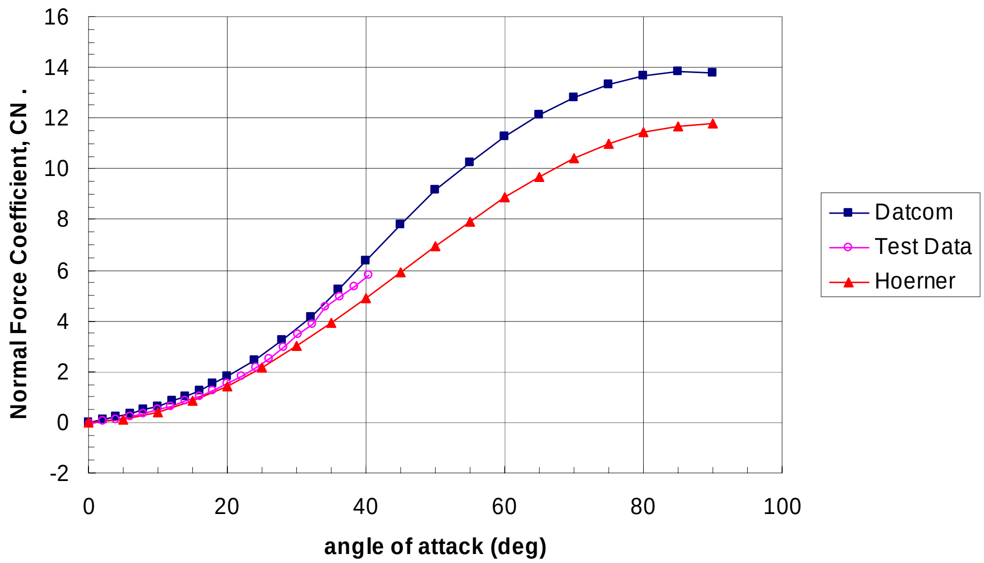


Figure 2. Normal Force Coefficient for B2.

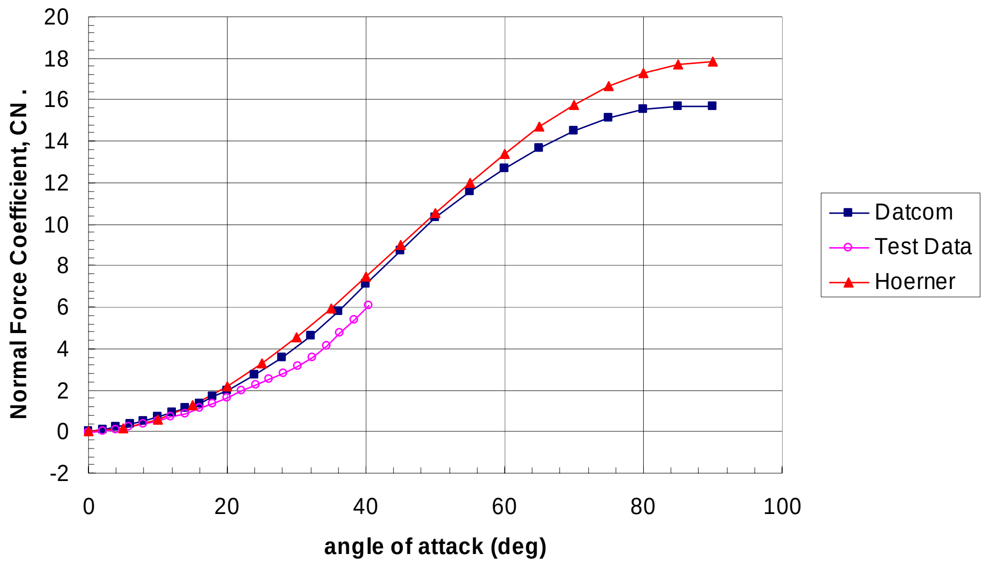


Figure 3. Normal Force Coefficient for B3.

As shown in the above figures, the Missile Datcom prediction shows excellent agreement over the full range of angles of attack studied. It appears that the accuracy of the prediction deteriorates slightly as total body length is increased, but the error is less than fifteen percent in all cases. The method of Hoerner agrees well with the trends of both the test data and the Datcom predictions. There is a slight discrepancy at very high angle of attack; however, the Hoerner method is for a circular cylinder does not account for the nose shape of the missile. Figure 4 and Figure 5 show the normal force coefficient comparisons for B5 and B6.

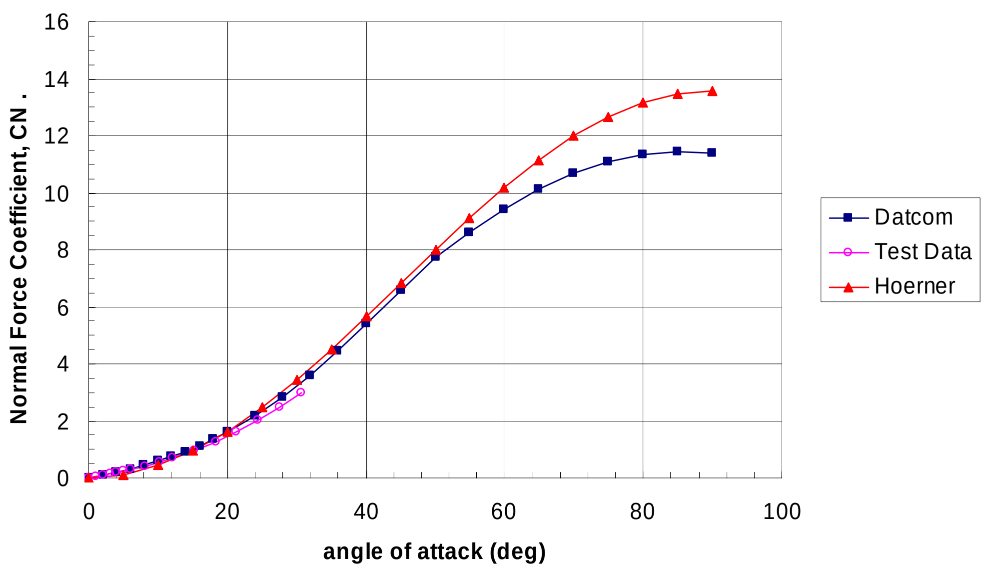


Figure 4. Normal Force Coefficient for B5.

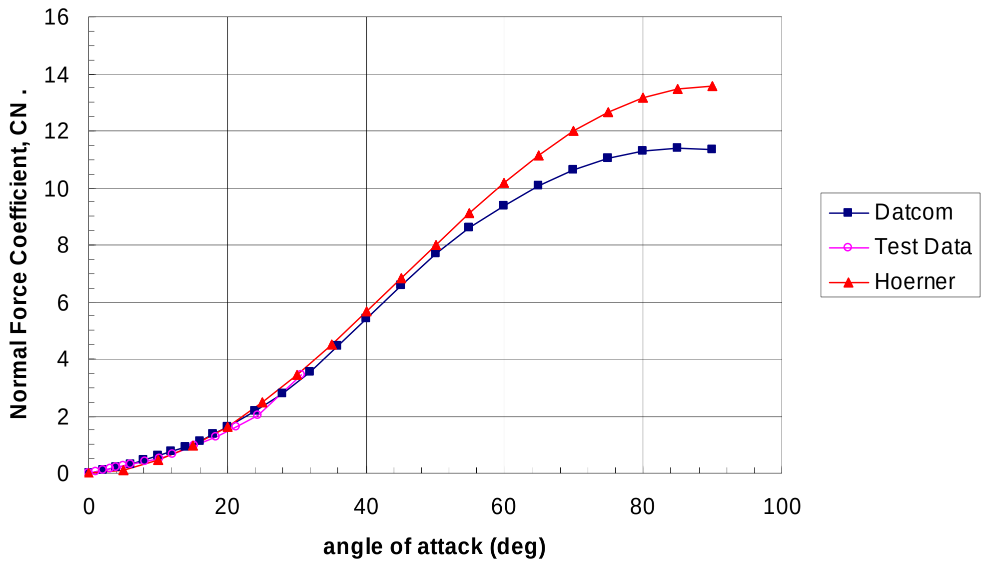


Figure 5. Normal Force Coefficient for B6.

Again, the agreement between the predictions and test data is excellent. For an identical cylindrical aftbody length (B1, B5, and B6), the accuracy of the Datcom prediction does not seem to depend on nose type or length for the cases presented here.

Figures 6 through 8 compare the longitudinal center of pressure location, (X_{CP}/L_{Ref}), for the B1, B5, and B6 configurations, respectively. The data is referenced to the missile nose tip, with negative values indicating a center of pressure aft of the nose tip. Center of pressure was calculated for the test data by taking the ratio of the measured pitching moment coefficient and normal force coefficient.

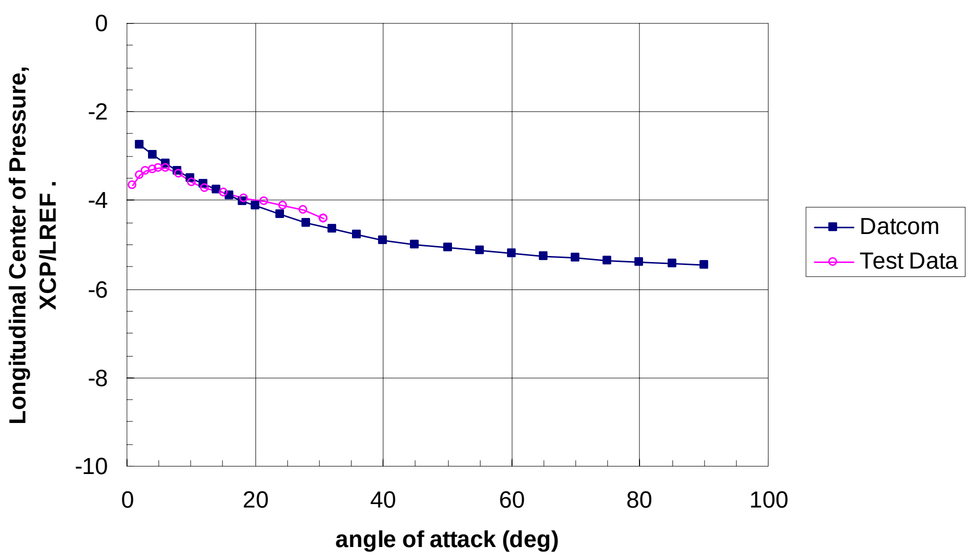


Figure 6. Longitudinal Center of Pressure for B1.

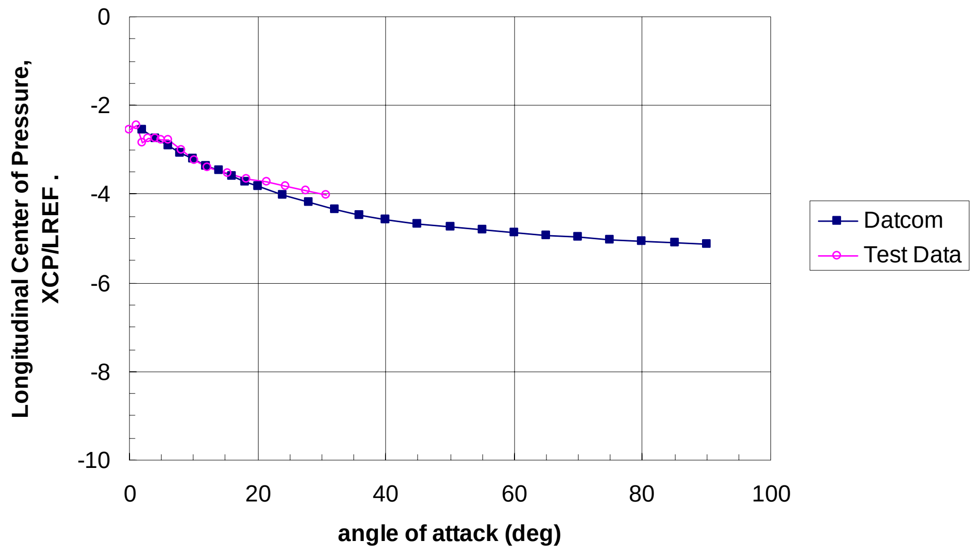


Figure 7. Longitudinal Center of Pressure for B5.

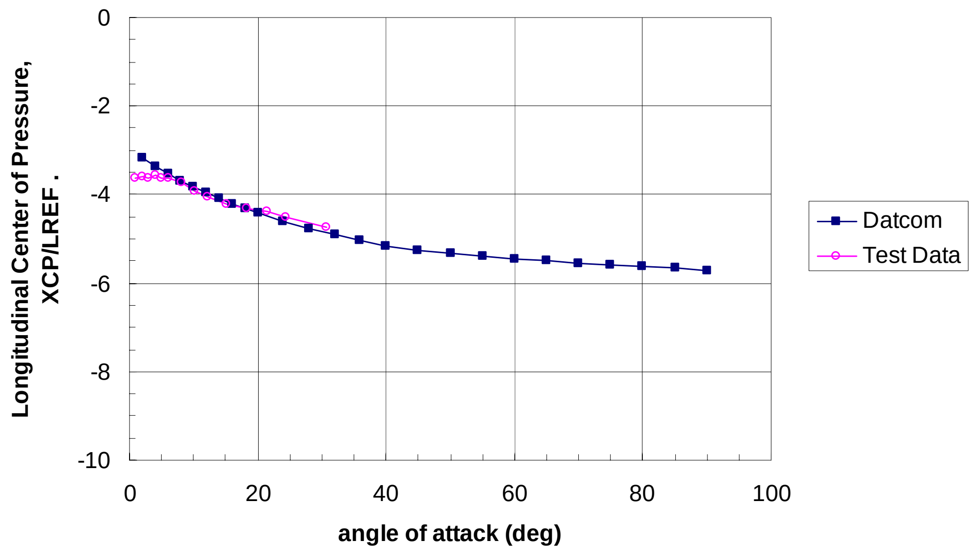


Figure 8. Longitudinal Center of Pressure for B6.

In general, Datcom predicts the center of pressure reasonably well. At very low angles of attack (less than 5 degrees) the prediction is in error by as much as one caliber, but beyond that both the trends and the magnitudes of the Datcom predictions match very well with test data. For the ogive noses (B1 and B5), the prediction becomes slightly less accurate above 20 degrees angle of attack, but is still within one-quarter of a caliber. For the cone nose (B6) the error is even smaller.

Comparisons of axial force coefficient for B1, B5, and B6 are shown in Figures 9 through 11. As previously noted, the accuracy of this test data is uncertain.

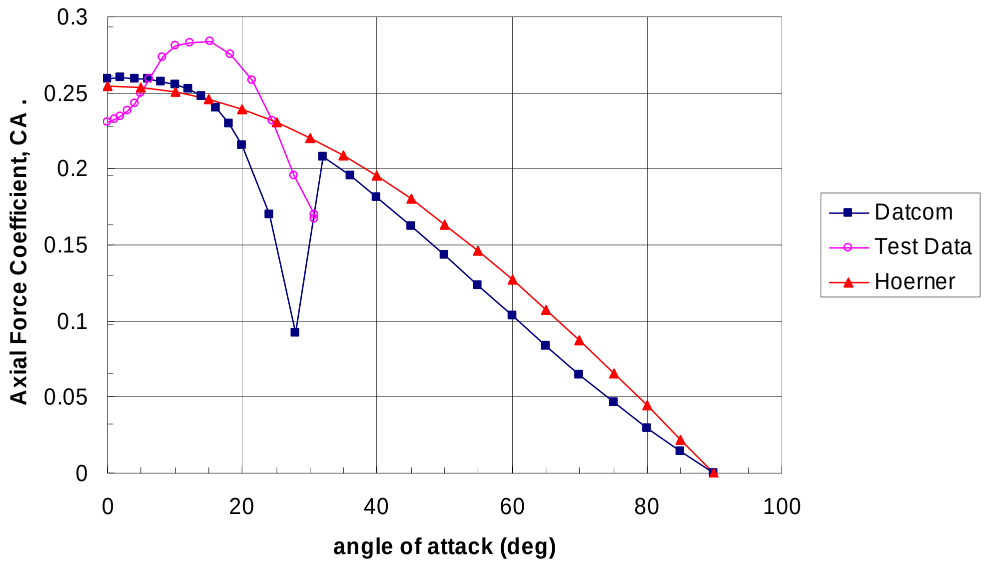


Figure 9. Axial Force Coefficient for B1.

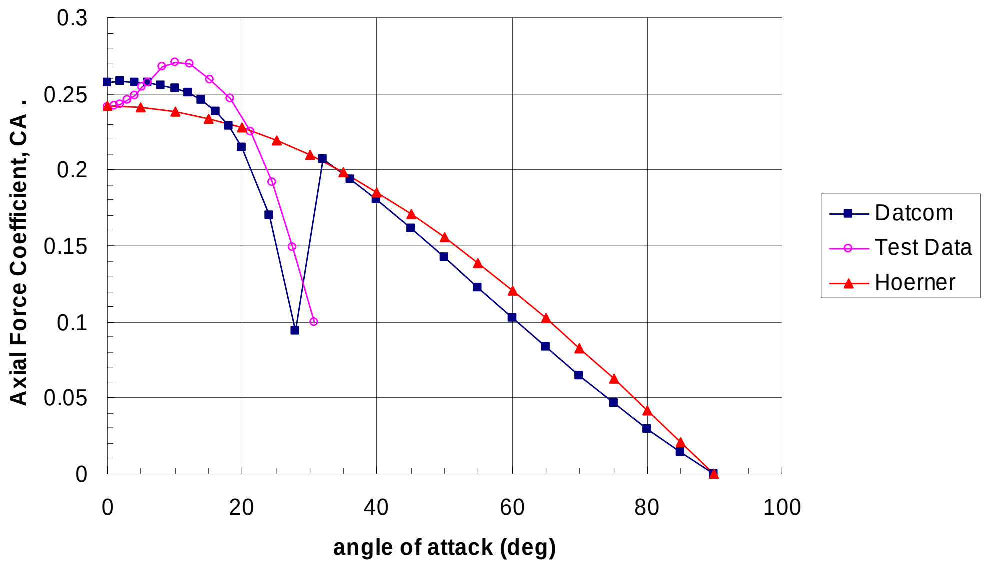


Figure 10. Axial Force Coefficient for B5.

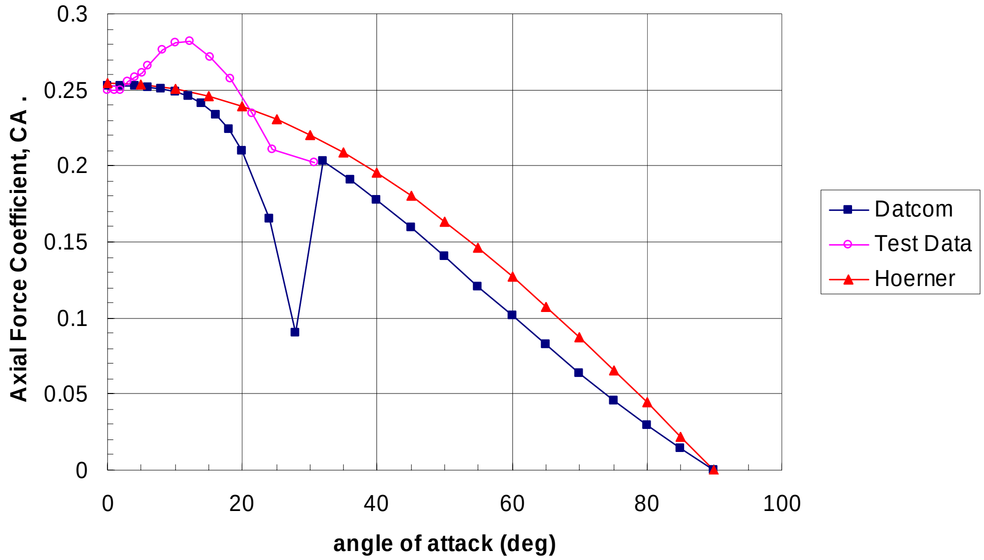


Figure 11. Axial Force Coefficient for B6.

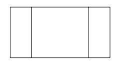
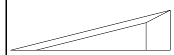
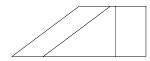
The axial force coefficient predictions do not follow the test data as accurately as the normal force coefficient or longitudinal center of pressure. The zero angle of attack axial force is predicted quite well for the cone nose (B6) but not for the ogive noses (B1 and B5). Note that near 30 degrees angle of attack, the Datcom prediction exhibits a discontinuity that is due to the switchover in calculation methods described in Section II. This discontinuity does not reflect the real aerodynamics of the vehicle and is an inherent limitation in the current version of Missile Datcom. Hoerner provides an estimate of the axial force at very high angles of attack where wind tunnel data is unavailable. This data seems to verify that the trends predicted by Missile Datcom above 40 degrees angle of attack are correct and the discontinuity caused by the method switchover at 30 degrees angle of attack is incorrect.

From this analysis, it can be concluded that Missile Datcom is suitable for predicting the aerodynamics of simple, body alone configurations at high angles of attack. Normal force coefficient predictions are accurate to within fifteen percent. Longitudinal center of pressure position is predicted within one-quarter caliber at angles of attack greater than 5 degrees for a body with either a cone nose or a tangent ogive nose. Although validated axial force test data is not available, comparison with empirical correlations from Hoerner indicate that Datcom is capable of predicting the trends quite well.

B. Fin Alone Comparisons

Four fins were chosen to compare with Missile Datcom predictions of fin alone aerodynamics. The geometries are described in Table 2. For the fin alone configurations, the reference area is the fin planform area and the reference length is the fin root chord.

Table 2. Fin Descriptions.

				
Identifier	T1	T2	T3	T4
Planform Shape	Rectangular	Delta	Clipped Delta	Delta
Leading Edge Sweep Angle	0.0˚	76.0˚	53.1˚	83.0˚
Single Panel Aspect Ratio	0.50	0.50	0.50	0.25
Cross-Section Shape	Modified Double Wedge	Modified Double Wedge	Modified Double Wedge	Modified Double Wedge
Max Thickness/Chord	3.75%	2.50%	3.75%	1.67%
Hinge Line – aft of Leading Edge	0.45 c_r	0.62 c_r	0.55 c_r	0.55 c_r

A comparison of fin normal force coefficient is shown in Figure 12, Figure 13, and Figure 14 for T1, T2, and T4, respectively.

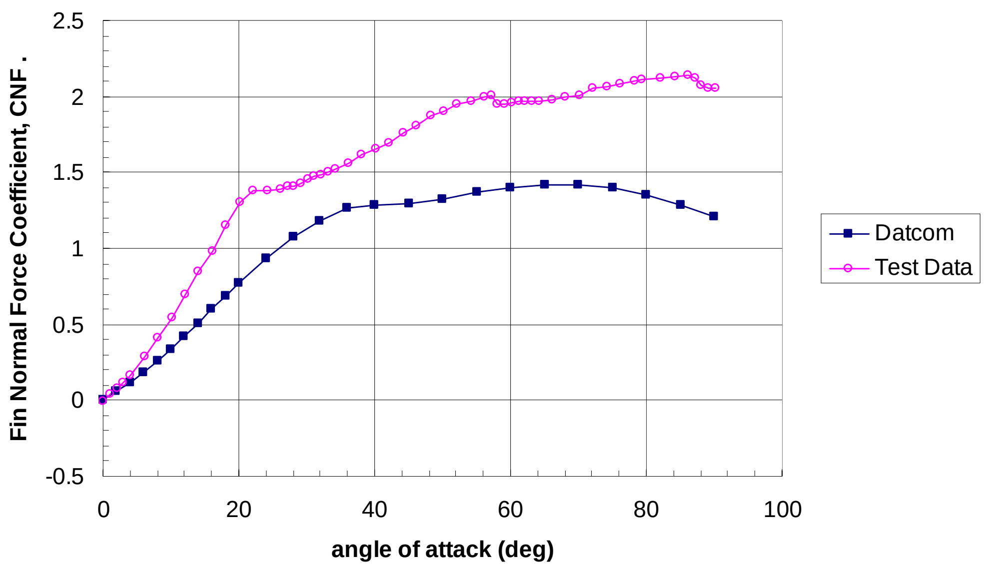


Figure 12. Normal Force Coefficient for T1.

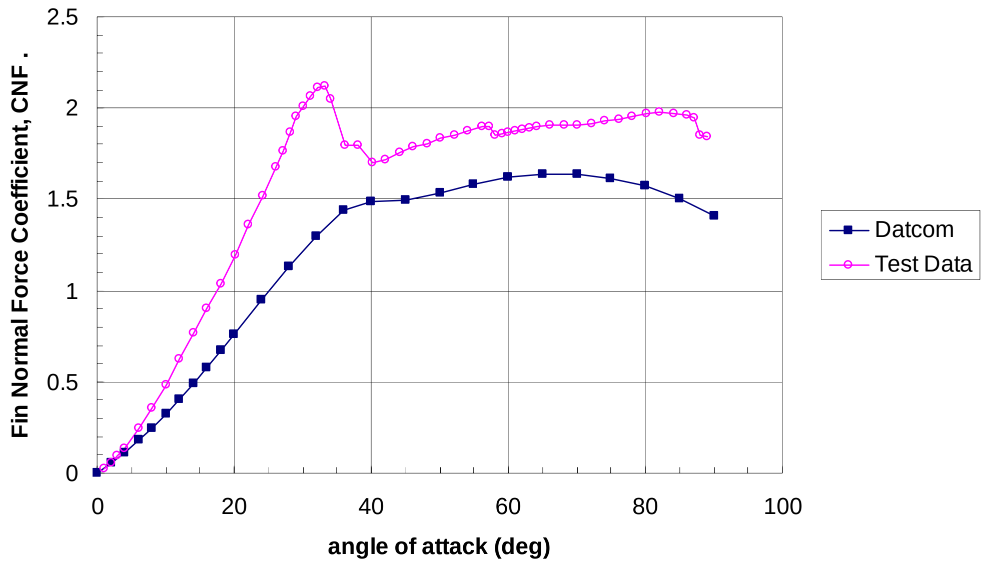


Figure 13. Normal Force Coefficient for T2.

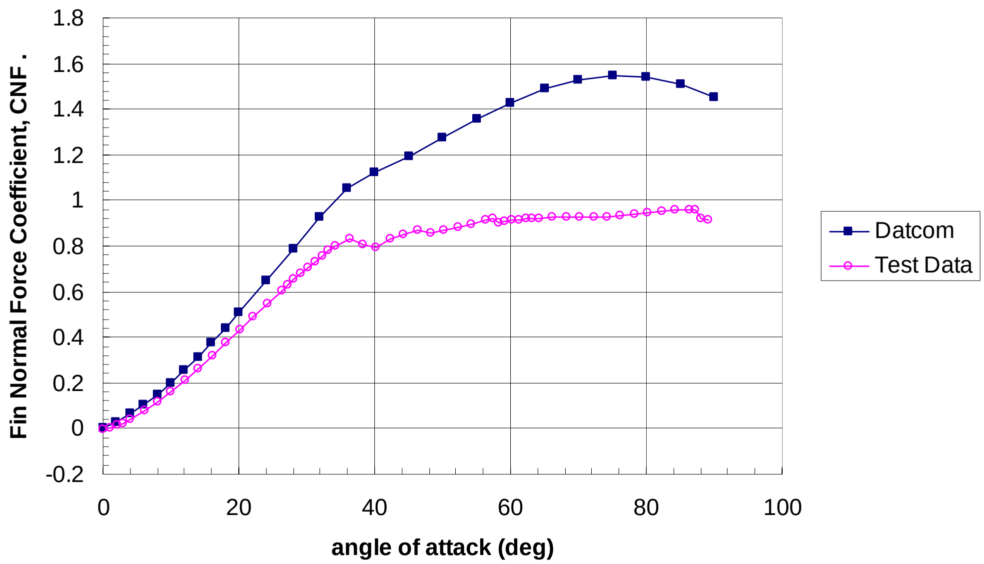


Figure 14. Normal Force Coefficient for T4.

As illustrated in the figures, Datcom predicts the trends of the test data reasonably well up to angles of attack of 90 degrees. For T1 and T2 at angles of attack less than 30 degrees, Datcom under predicts the slope of the normal force coefficient by forty percent. Consequently, the predicted value of the maximum normal force coefficient near stall is roughly thirty to forty percent lower than the test data. This is the location of the greatest error, and is due to the fact that Datcom is not capable of predicting flow separation and stall. However, at angles of attack greater than the stall angle, Datcom follows the trends fairly accurately, with errors in magnitude generally within thirty percent.

Comparisons of fin longitudinal center of pressure are shown in Figures 15, 16, and 17. Data is referenced to the fin root leading edge, with negative values indicating a location aft of the leading edge.

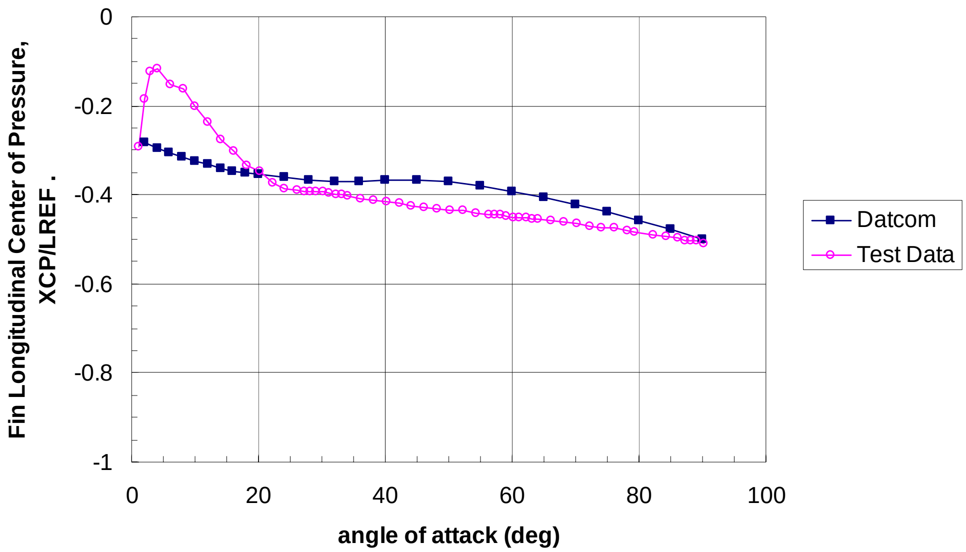


Figure 15. Fin Longitudinal Center of Pressure for T1.

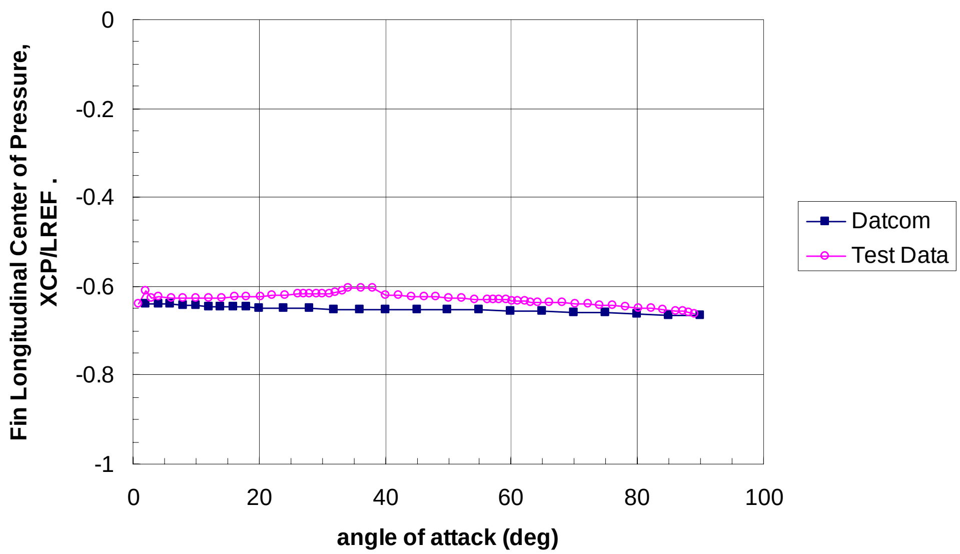


Figure 16. Fin Longitudinal Center of Pressure for T2.

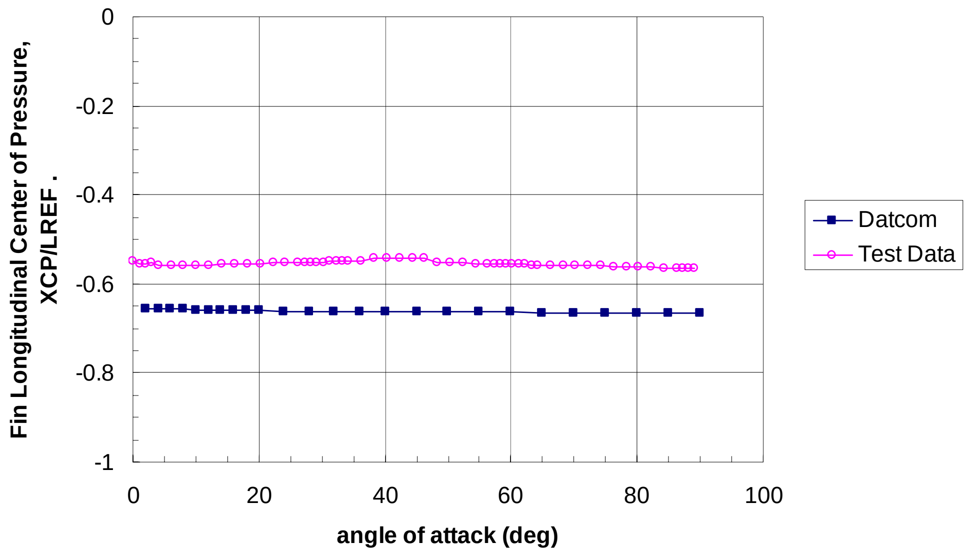


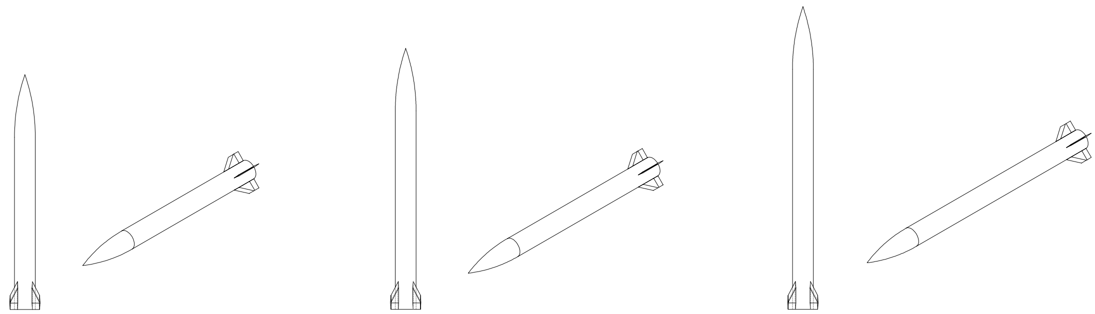
Figure 17. Fin Longitudinal Center of Pressure for T4.

For all three fin configurations, the center of pressure trends are predicted quite well at all angles of attack. For the rectangular fin (T1) at low angles of attack the test data shows a forward moving center of pressure that Datcom does not predict, resulting in a maximum error of roughly twenty percent of the root chord length. At angles of attack greater than twenty degrees, however, the error drops to within seven percent of the root chord. The center of pressure for T2 is predicted extremely accurately for all angles of attack, with a maximum error of approximately seven percent of the root chord length. For fin T4, the Datcom prediction is fifteen percent aft of the actual location for all angles of attack.

Based on these comparisons, it can be concluded that Missile Datcom is capable of predicting the normal force and longitudinal center of pressure location for fin alone configurations. Although the magnitudes of the predictions may contain significant errors, the predicted trends follow closely with the measured results. Errors in magnitude can be corrected with the use of available test data.

C. Body-Fin Comparisons

Three configurations have been chosen for the body-fin comparisons. The first is a combination of body B2 and fin T3, the second is a combination of body B3 and fin T3, and the third is a combination of body B4 and fin T3. For each configuration, the fins are positioned in a standard “plus” arrangement with the trailing edge of the fin in line with the base of the body. For these configurations, the reference area and length are the body cross sectional area and body diameter, respectively. The geometries are illustrated in Figure 18.



B2T3 B3T3 B4T3

Figure 18. Body-Fin Configuration Geometries.

The following figures show comparisons of normal force coefficient.

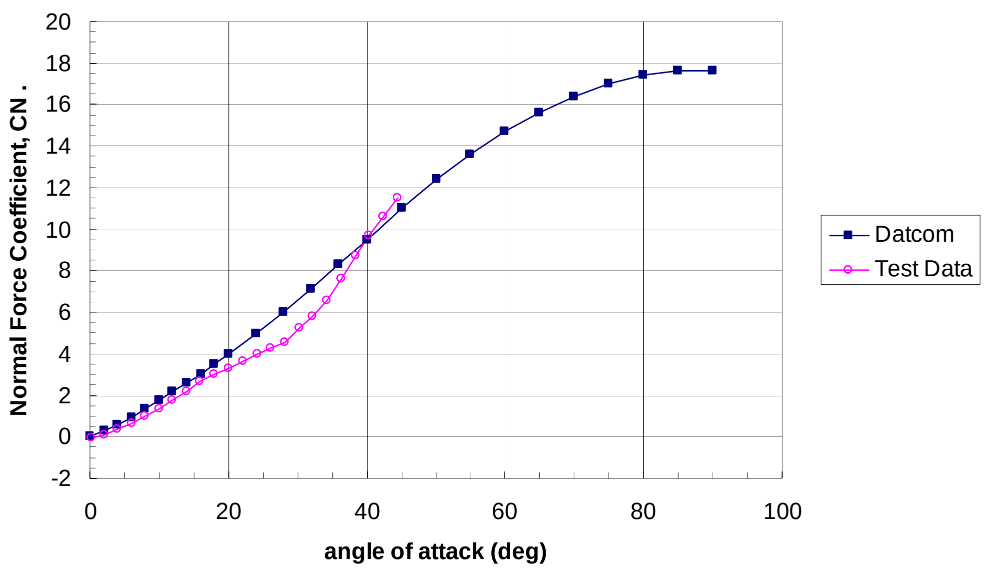


Figure 19. Normal Force Coefficient for B2T3.

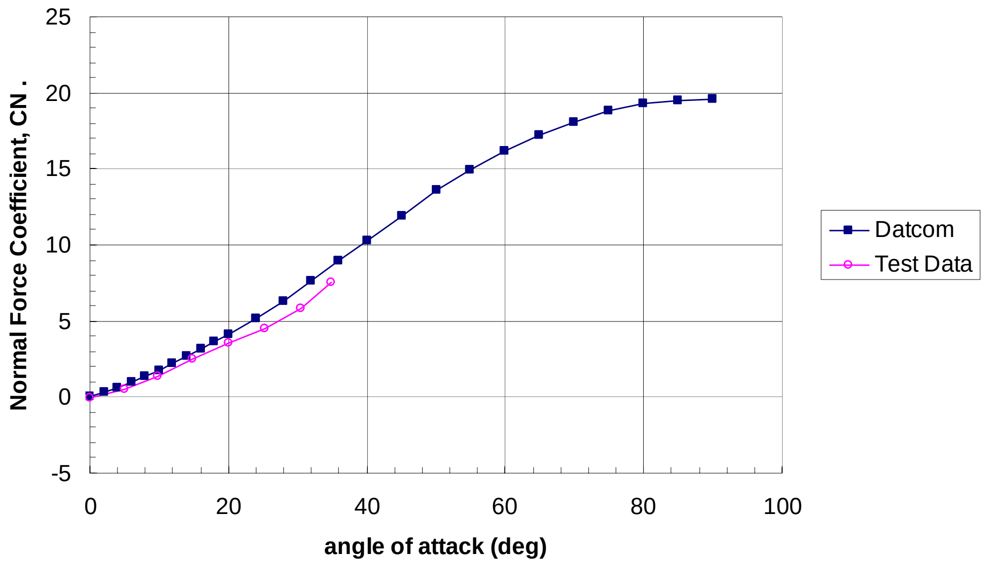


Figure 20. Normal Force Coefficient for B3T3.

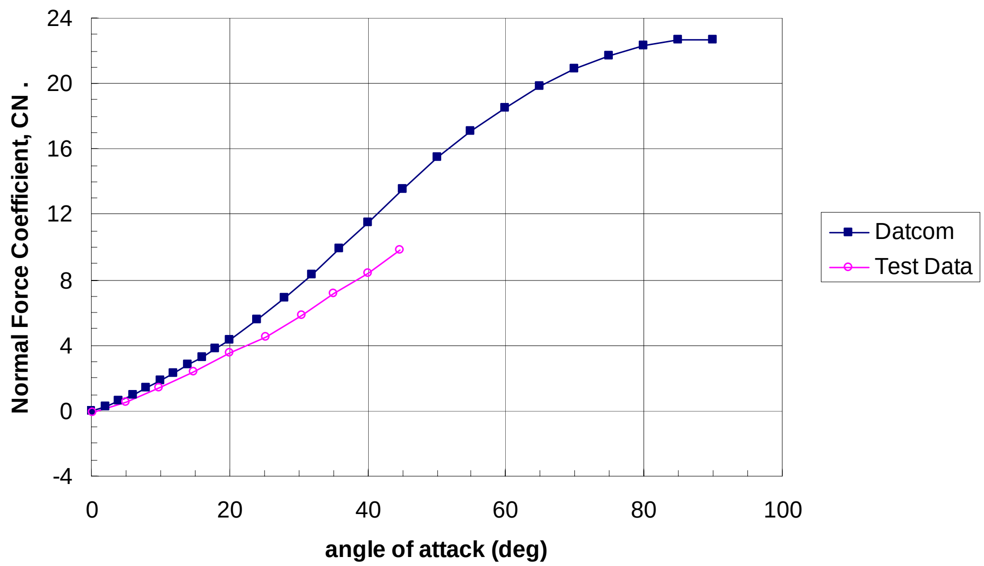


Figure 21. Normal Force Coefficient for B4T3.

As expected, the normal force trends match well. However, the magnitudes of the predictions are not as accurate, particularly for the longer configuration. Below approximately 25 degrees angle of attack, Missile Datcom is within twenty percent of the wind tunnel data B4T3. However, as angle of attack increases, the discrepancy becomes larger. At 45 degrees angle of attack, the Missile Datcom prediction is forty percent higher than the wind tunnel data. B2T3 provides a much better match across the angle of attack range. Below 20 degrees and above 35 degrees angle of attack, the normal force predicted by Missile Datcom is within fifteen percent of the wind tunnel data. Between 20 and 35 degrees angle of attack, the discrepancy rises to thirty percent. The Datcom prediction for B3T3 is also very accurate, although test data is only available up to 35 degrees angle of attack for this configuration. Overall, the predicted trends agree well with the wind tunnel data. The inaccuracies in the Datcom predictions can be linked to the limitations of the carryover method described in section II.

Due to unverified test data, axial force and longitudinal center of pressure predictions are not presented for the above configurations. However, in order to have a complete set of comparisons, two additional body-fin configurations were modeled. Configuration B7T5[12] has a 3.0 caliber tangent ogive nose with a 9.0 caliber cylindrical aftbody (total length of 12.0 calibers). Four fins are mounted symmetrically around the body with the root leading edge located 8.4 calibers from the nose tip. Each fin has a clipped delta planform with a 45 degree leading edge sweep angle, a single panel aspect ratio of 0.5, and a modified double wedge cross section with a maximum thickness-to-chord ratio at the root of 6.7%. Data was taken at a Mach number of 0.6 and at a Reynolds Number per foot of 2.7×10^6. Configuration B8T6[13] has a 3.0 caliber tangent ogive nose with a 9.3 caliber cylindrical aftbody (total length of 12.3 calibers). Four fins are mounted symmetrically around the body with the root leading edge located 9.9 calibers from the nose tip. Each fin has a clipped delta planform with a 53.1 degree leading edge sweep angle, a single panel aspect ratio of 0.5, and a modified double wedge cross section with a maximum thickness-to-chord ratio at the root of 6.25%. Data was taken at a Mach number of 0.8 and at a Reynolds Number per foot of 1.4×10^6. Figures 22-23 show comparisons of normal force coefficient for B7T5 and B8T6.

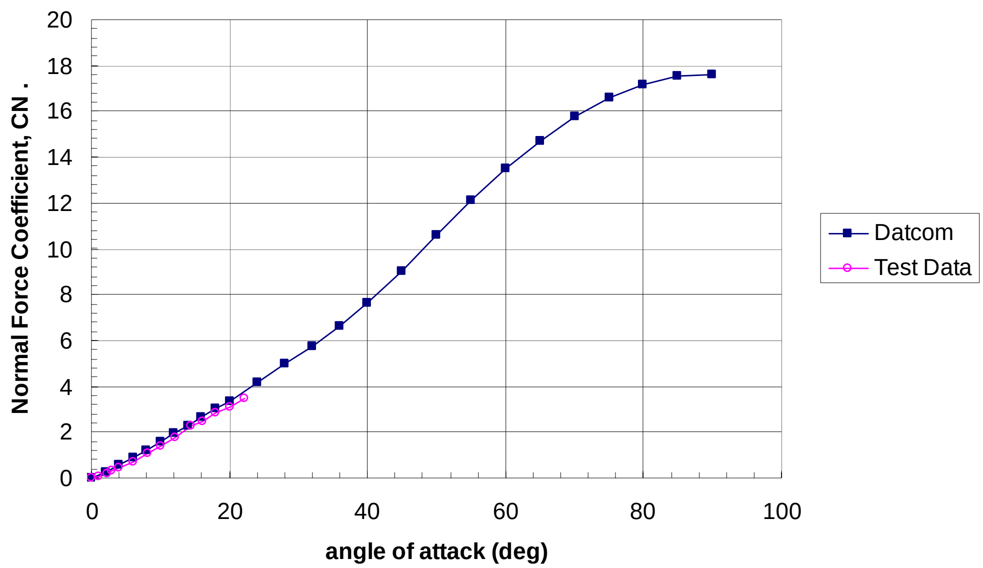


Figure 22. Normal Force Coefficient for B7T5.

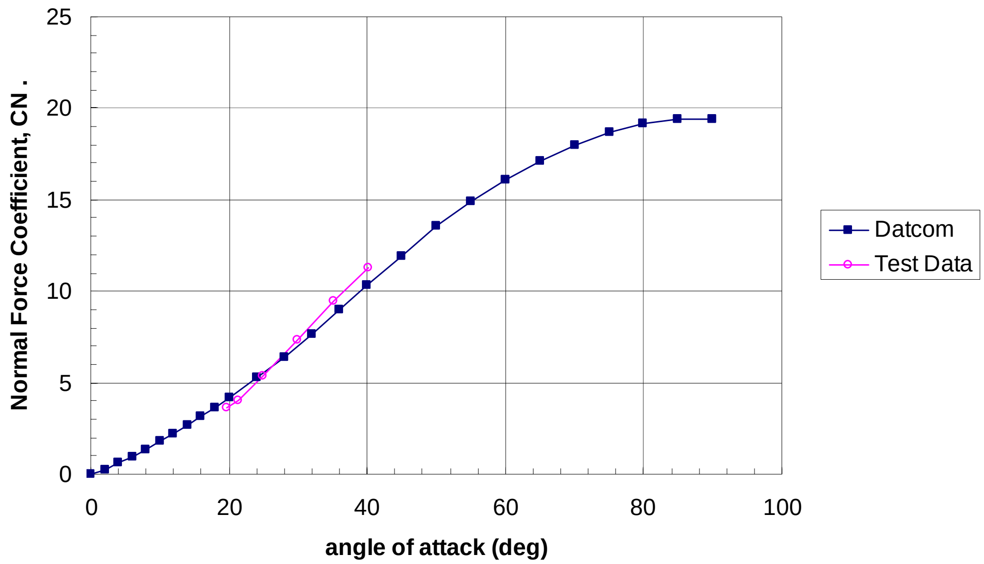


Figure 23. Normal Force Coefficient for B8T6.

For both configurations, the trends and the magnitudes of the normal force predictions are very accurate. Errors are less than ten percent for all angles of attack. Figures 24-25 show the longitudinal center of pressure location for B7T5 and B8T6.

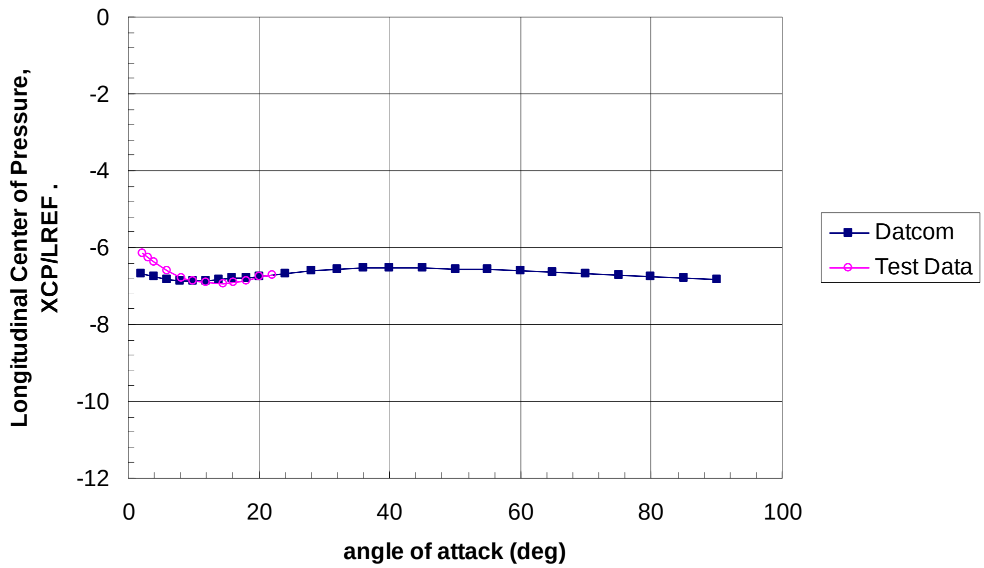


Figure 24. Longitudinal Center of Pressure for B7T5.

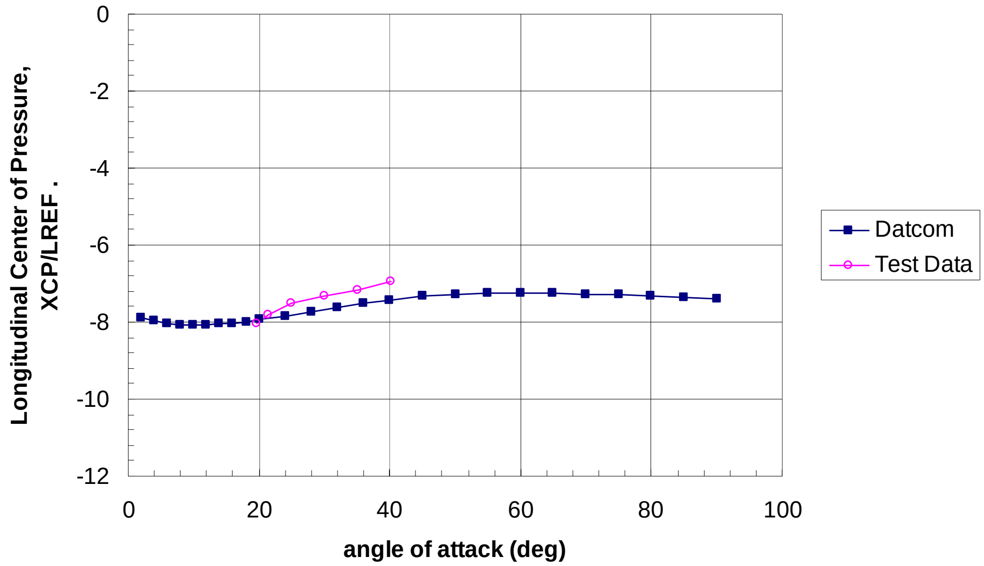


Figure 25. Longitudinal Center of Pressure for B8T6.

The longitudinal center of pressure predictions also match well with the test data for both configurations. For B7T5 at low angles of attack, there is a one-half caliber error, but beyond 6 degrees angle of attack, the error drops to less than one-tenth of a caliber. For B8T6 the prediction is not quite as accurate, but the maximum error near 40 degrees angle of attack is still less than one-half caliber.

IV. Conclusions

Comparisons show that Missile Datcom is suitable for high angle of attack predictions for aerodynamic models at subsonic Mach numbers. Obtaining test data to validate Missile Datcom at angles of attack above 45 degrees is difficult, but methods obtained from Hoerner lend credibility to the Datcom predictions at very high angles of attack. For traditional missile configurations, the predicted trends for normal force and longitudinal center of pressure location match well with experimental data up to 45 degrees angle of attack. This is true for both body alone and fin predictions. Axial force discrepancies are noted near 30 degrees angle of attack due to a method change. This error could be eliminated with the use of Hoerner or better wind tunnel data.

For the body-fin configurations studied in this effort, the longitudinal centers of pressure predicted by Datcom are in close agreement with test data. Normal force trends also match well, although there can be significant errors in the magnitudes of the predictions. This, however, does not preclude the use of Missile Datcom for high angle of attack predictions. By comparing available test data with Datcom predictions, corrections can be calculated to account for the inaccuracies of Datcom at low angles of attack. These same corrections can then be applied to the high angle of attack predictions. In this way, it is possible to construct an accurate aerodynamic model that contains data covering the full range of flight conditions encountered by the missile.

References

[1]Blake, W. B., "Missile DATCOM: User's Manual – 1997 FORTRAN 90 Version," Air Force Research Laboratories Document AFRL-VA-WP-TR-1998-3009, Feb. 1998.

[2]Vukelich, S.R., "Missile DATCOM Volume 2 – Body Alone Aerodynamic Methodolgy," unpublished, March 1984.

[3]Allen, J. H., and Perkins, E.W., "A Study of the Effects of Viscosity on Flow Over Slender Inclined Bodies of Revolution," NACA TR 1048, 1951.

[4]Simon, J. M., and Blake, W. B., "Missile Datcom: High Angle of Attack Capabilities," AIAA Paper 99-4258, August 1999.

[5]Jorgensen, L. H., “Prediction of Static Aerodynamic Characteristics for Slender Bodies Alone and with Lifting Surfaces to Very High Angles of Attack,” NASA TR-R-474, Sept. 1977.
[6]Vukelich, S. R., “Missile DATCOM Volume 3 – Fin Alone Aerodynamic Methodology,” unpublished, March 1984.
[7]Pitts, W.C., Nielsen, J.N., and Kaattari, G.E, “Center of Pressure of Wing-Boyd-Tail Combinations at Subsonic, Transonic, and Supersonic Speeds,” NACA Report 1307, 1957.
[9]Vukelich, S.R., “Missile DATCOM Volume 4 – Component Interference and Configuration Synthesis,” unpublished, March 1984.
[9]Vukelich, S. R., et. al., “Missile DATCOM: Volume 1 – Final Report,” AFAWL TR-86-3091, December 1988.
[10]Chafin, J.M., “User’s Guide for the High Angle of Attack (HIALFA) Aerodynamic Data Base,” Technical Report TR1003 U.S. Army Research and Development Command, December 1978.
[11]Hoerner, S. F., “Fluid Dynamic Drag,” published by the author, 1965.
[12]Allen, J. M., “Parametric Fin-Body and Fin-Plate Database for a Series of 12 Missile Fins,” NASA TM 2001-210652, January 2001.
[13]Allen, J. M., “The Triservice Missile Database,” NASA TM 2002-211653, June 2002.