

Research Article

Determination of Aerodynamic Characteristics for a Vehicle with Wraparound Arc Fins by DATCOM and Fin Segment Approximation Method

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Abstract

In evaluating the system performance, such as vehicle stability, controllability, guidance accuracy, etc., the analysis of aerodynamic characteristics of the vehicle is a priority. In vehicle preliminary design it is necessary to quickly and economically estimate the aerodynamic characteristics of a wide variety of configuration designs. Since the aerodynamic performance are so dependent upon the subsystems utilized, such as payload size, propulsion system selection and launch mechanism, the designer must be capable of predicting a wide variety of configurations accurately. The fundamental purpose of DATCOM is to provide an aerodynamic design tool which has the predictive accuracy suitable for preliminary design, and the capability for the user to easily substitute methods to fit specific applications. However, DATCOM tool has not yet been able to interpret WAF (wraparound arc fin). In this paper, a methodology for determining aerodynamic characteristics of a vehicle with a WAF is presented based on the DATCOM method and the segment approximation of the WAF. First, based on the DATCOM analysis capability of the fin, a mathematical method was developed to approximate the WAF by a combination of finite numbers of plane segmented fins. Next, the validity of the proposed method is verified by comparison and analysis with wind tunnel test data. The proposed method can be effectively used for the preliminary design phase of the vehicle.

Keywords

Segment Approximation, Wraparound Arc Fin, DATCOM, Aerodynamic Characteristics Analysis

1. Introduction

Determination of aerodynamic characteristics is an indispensable first step in vehicle configuration design and has a great impact on system performance.

The aerodynamic characteristics analysis methods used worldwide are listed in [Table 1](#).

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Received: 12 August 2025; **Accepted:** 9 September 2025; **Published:** 10 October 2025



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Table 1. Methods of the Aerodynamic Analysis of Vehicle.

No	Method	Principle	Advantage	Defect	Application	Tools
1	Wind tunnel test Method	Similarity theory	Accurate, Reliable	High Cost, Limit of Measure Items	Preliminary design	-
2	Semi-empirical method	Test data and Theory	Fast	Less Accurate	Preliminary design	DATCOM, AP, MISL, PRODA ...
3	System identification method	Error-minimum principle	Accurate, Reliable	Unusable in Design Stage	Modified design	MATLAB, Lab-View ...
4	Boundary element method (Panel)	Boundary Integral principle	Fastness	Inviscid, Linear	Preliminary design	PANAIR, Panel3D, VSAERO ...
5	Finite element method	Principle of variation	Accurate, General	High Calculation Cost, Requirement Expert	Preliminary and detailed design	COMSOL, COSMOS, ...
6	Finite volume method	Integral conservation principle	Accurate, General	High Calculation Cost, Requirement Expert	Preliminary And detailed design	Fluent, StarCCM, ...

As can be seen in Table 1, semi-empirical analysis tools can be used effectively to reduce design cost and cycle time during the preliminary design owing to the ease of analysis, robustness and very low analysis cost compared to CFD tools.

There are many semi-empirical analytical tools available to analyze aerodynamic characteristics of vehicles, such as DATCOM, AP, MISL, PRODA, etc., and each has certain advantages and disadvantages. [1-4] In the world, the semi-empirical analysis tool DATCOM is widely used in aerodynamic analysis of vehicles at the preliminary design phase. However, this tool has not yet been able to interpret wraparound arc fin.

Currently, the use of wraparound arc fin for different vehicles finds very wide applications. The vehicle with a wraparound arc fins is in a sealed barrel before launch, which is good for the long-term storage and transportation, increase

the reliability and loading capacity, and thus improve the operational efficiency of the system. Also, the aerodynamic characteristics of vehicle with WAF were determined by wind tunnel test and CFD method. [5-10]

This paper presents a methodology for determining the aerodynamic characteristics of a vehicle with a wraparound arc fin based on the DATCOM method and a segment approximation of the fin, and verifies its feasibility in the design phase of the vehicle through comparison and analysis with wind tunnel test data.

2. DATCOM Analysis Scope

The scope of the DATCOM analysis tool is shown in Table 2.

Table 2. Scope of Missile DATCOM 1999 (2011).

No	Items	Analysis Range
1	Flight Conditions	Mach: 0~10, α : -180 ~180°, β : -180 ~180°, ϕ : 0 ~180°, Attitude, Re number, Free stream data input
2	Reference Quantities	Reference length and area, Horizontal and Vertical center of gravity, Rough, Model scale, Turbulent type input
3	Body Geometry	Cross section- Axisymmetric, Elliptical body Longitudinal input- Parameter or Coordinate input mode for body Body fitness ratio: 2~28 Nose shape- CONE, OGIVE, POWER, KARMAN, HAACK, Truncation flag Nose fitness ratio: 0~7 After body shape: CONE, OGIVE Base-Jet plume interaction inputs
4	Fins Geometry	Finset: 1~4 sets (2011 Version: 8 sets), Number of panels for a fin set: 1~8 Cross section: Hexagonal, NACA, Circular Arc, User defined airfoil section Fin install input: Distance from nose, Roll angle of each fin, Dihedral of each fin, Flap chord to fin chord ratio

No	Items	Analysis Range
		Fin aspect ratio: 0.1~10, Fin Exposed Span to Diameter: 0~10, Sweep Angle: 0~90°
5	Panel Deflection Angles	Deflection angles for each panel Position of the panel hinge line for each fin set Hinge line sweepback for each fin set
6	Protuberance Geometry	Number of protuberance sets: 0~20, Number of protuberances in set: 0~20, Protuberance set type: VCYL (HCYL, LUG, SHOE, BLOCK, FAIRING), Geometry and installation parameters
7	Inlet Geometry	Type of inlet: 2DSIDE (AXI, 2DTOP), Geometry and installation parameters
8	Experimental Data Substitution	Experimental Data from The Wind Tunnel Test or Identification etc.

DATCOM can output the aerodynamic and equilibrium characteristics of a vehicle, its components, i.e. the geometry and aerodynamic characteristics of the fuselage, wing, inlet, etc., and the bending and hinge moments, pressure distribution, etc., with a file.

3. Fin Segment Approximation Method

The development angle of the wraparound arc fins when viewed from the rear of the fuselage is shown in Figure 1. The segment approximation method is one that approximates a wraparound arc fins by a combination of finite number of straight plane segmented fins, as shown in Figure 2. Each fin segment is then assumed to be a planar segment fin, with the fin segment obtained by dividing the central angle of arc θ of the wraparound arc fins by n .

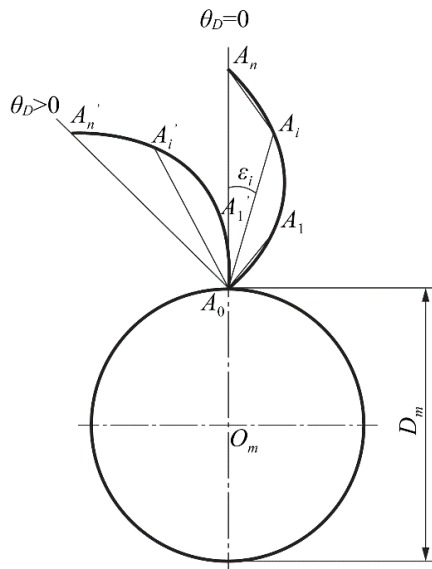


Figure 1. Development Angle of the wraparound arc fin.

Given the span length S_w and the radius of the arc R_w , θ can be determined by the following equation:

$$\theta = 2 \cdot \arcsin\left(\frac{S_w}{2 \cdot R_w}\right) \quad (1)$$

When the development angle $\theta_D = 0$, the corresponding parameters of the wraparound arc fins are determined as follows:

When the fully expanded fin arc angle is n -divided, as shown in Figure 2, the coordinates of the starting point A_i of the i th arc line in the circle-centered coordinate system are determined by the following equation:

$$\begin{cases} A_{i,y} = R_w \cdot \sin\left(-\frac{\theta}{2} + \frac{\theta}{n} \cdot i\right) \\ A_{i,z} = R_w \cdot \cos\left(-\frac{\theta}{2} + \frac{\theta}{n} \cdot i\right) \end{cases} \quad (2)$$

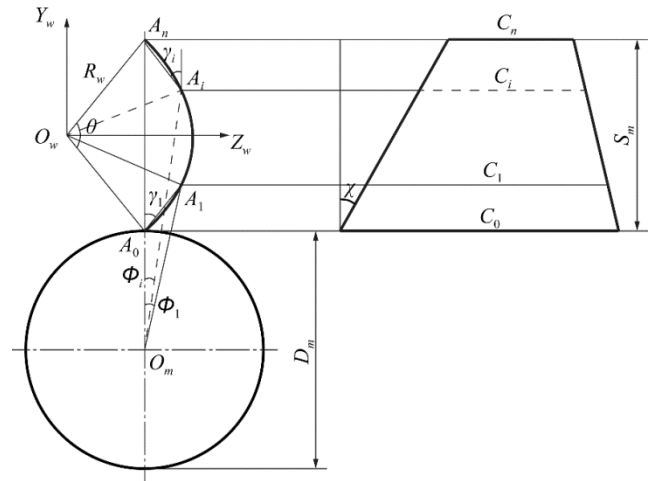


Figure 2. Segment approximation of fully developed wraparound arc fin ($\theta_D = 0$).

The position of the longitudinal position of the i th arc segment, the length of the arc segment, the dihedral angle of the arc segment, and the length of the arc chord are determined by the following equations:

$$X_{wi} = X_{w0} + \left(R_w \cdot \sin\left(\frac{\theta}{2}\right) + A_{i,y}\right) \cdot \tan(\chi)$$

$$S_{wi} = 2 \cdot R_w \cdot \sin\left(\frac{\theta}{2 \cdot n}\right)$$

$$\gamma_i = 90 - \arctan\left(\frac{A_{i,y} - A_{i-1,y}}{A_{i,z} - A_{i-1,z}}\right)$$

$$C_i = C_n + \frac{(A_{n,y} - A_{i,y})}{S_w} \cdot (C_0 - C_n)$$

The distance of the i th arc line to the starting point A_i at the vehicle body center O_m is determined by the following equation:

$$R_{mi} = \sqrt{(A_{i,z} - A_{0,z})^2 + (A_{i,y} - A_{0,y} + D_m/2)^2} \quad (3)$$

The angle of mounting of the i th arc line at the vehicle body center O_m is determined by the following equation:

$$\Phi_i = 90 - \arcsin\left(\frac{A_{i,z} - A_{0,z}}{R_{mi}}\right) \quad (4)$$

Then, when the development angle $\theta_D > 0$, the corresponding parameters in the segment approximation of the wraparound arc fins are determined as follows:

The distance from point A_0 to the starting point A_i of the i th arc line is determined by the following equation:

$$R_{A0i} = \sqrt{(A_{i,z} - A_{0,z})^2 + (A_{i,y} - A_{0,y})^2} \quad (5)$$

Then the coordinates of the starting point A'_i of the i th arc intersection in the initial circle-centered coordinate system are determined by the following equation:

$$\begin{cases} A'_{i,y} = R_{A0i} \cdot \cos(\theta_D - \varepsilon_i) - A_{0,y} \\ A'_{i,z} = R_{A0i} \cdot \sin(\theta_D - \varepsilon_i) - A_{0,z} \end{cases} \quad (6)$$

Where

$$\varepsilon_i = 90 - \arctan\left(\frac{A_{i,y} - A_{0,y}}{A_{i,z} - A_{0,z}}\right)$$

The dihedral angle of the i th arc line is determined by Eq. 7.

$$\gamma'_i = 90 - \arctan\left(\frac{A'_{i,y} - A'_{i-1,y}}{A'_{i,z} - A'_{i-1,z}}\right) \quad (7)$$

The distance from the vehicle body center O_m to the

starting point A_i of the i th arc line is determined by Eq. 8.

$$R'_{mi} = \sqrt{(A'_{i,z} - A_{0,z})^2 + (A'_{i,y} - A_{0,y} + D_m/2)^2} \quad (8)$$

The length of the string of the i th arc line is used as the value of the full expansion.

The angle of installation of the i th arc line at the vehicle body center O_m is determined by the expression.

$$\Phi'_i = 90 - \arcsin\left(\frac{A'_{i,z} - A_{0,z}}{R'_{mi}}\right) \quad (9)$$

4. Verification

The configuration and main dimensions of the vehicle with the wraparound arc fin for validity are shown in Figure 3. Due to the modeling capability of DATCOM, the WAF may be approximated by 1 to 8 segments.

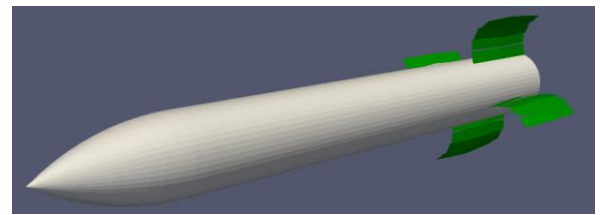
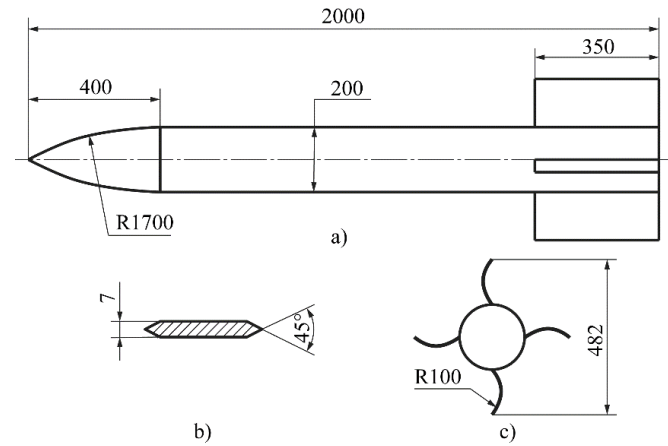


Figure 3. Vehicle with 4 segments approximation WAF (a- Side view, b- Fin profile, c- Front view, d- Perspective view).

Table 3. Summary of Results.

Ma	CNA			XCP			CD		
	Exp.	DATCOM	Error, %	Exp.	DATCOM	Error, %	Exp.	DATCOM	Error, %
0.5	0.031	0.032	3.6	1.374	1.394	1.5	0.279	0.268	3.9

Ma	CNA			XCP			CD		
	Exp.	DATCOM	Error, %	Exp.	DATCOM	Error, %	Exp.	DATCOM	Error, %
0.8	0.163	0.169	3.7	1.465	1.402	4.3	0.279	0.266	4.7
1.0	0.179	0.172	3.9	1.517	1.435	5.4	0.457	0.516	12.9
1.2	0.185	0.176	4.9	1.459	1.417	2.9	0.575	0.623	8.3
1.5	0.203	0.197	3.0	1.375	1.376	0.1	0.493	0.604	22.5
2.0	0.196	0.204	4.1	1.367	1.316	3.7	0.392	0.516	31.6
2.5	0.185	0.198	7.0	1.306	1.259	3.6	0.357	0.433	21.3
3.0	0.156	0.176	12.8	1.265	1.224	3.2	0.273	0.349	27.8

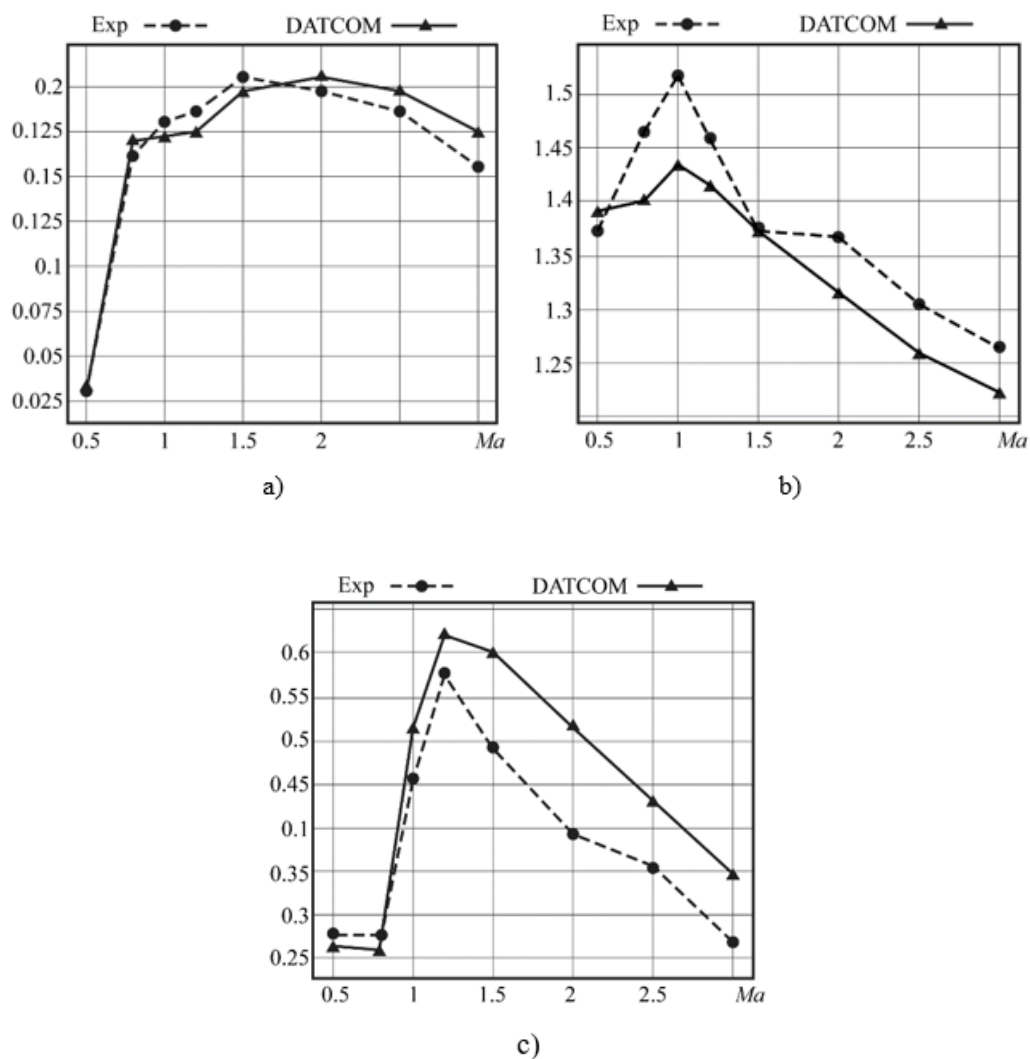


Figure 4. Experiment and DATCOM Results (a- CNA , b- XCP , c- CD).

As can be seen from the comparison of the results of the analysis with the wind tunnel test data, the accuracy of the analysis for the derivative of the normal force coefficient and the pressure center position at Mach number $0.5 < Ma < 3$ and angle of attack $\alpha = 0^\circ$ is relatively high.

However, the axial force coefficient is relatively large, about 30% for $Ma < 1.2$.

It can be seen that this analytical error is caused by the segment approximation.

It can be seen that the trend is similar to wind tunnel test

data, although it has a certain analytical error, and thus can be used in the preliminary design phase.

5. Conclusions

In this paper, a segment approximation method is proposed to determine aerodynamic characterization of a vehicle with a wraparound arc fin with DATCOM method.

Finally, the accuracy of the proposed method was verified by comparison with wind tunnel test data for the applicability in the preliminary design phase.

In vehicle preliminary design, the aerodynamic characteristics of vehicles with a wraparound arc fin can be quickly and economically evaluated.

Abbreviations

WAF	Wraparound Arc Fin
CFD	Computational Fluid Dynamics
DATCOM	Data Compendium

Nomenclature

MACH	Mach Number
α	Attack Angle
β	Sideslip Angle
ϕ	Roll Angle
Re	Reynolds Number

Acknowledgments

The authors would like to thank Kim Jong Nam, Han Chol Min who participated in the development and the instructor Kim Song Dong and the Missile DATCOM developers.

Funding

This work was partially supported by Kim Chaek University of Technology.

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] STEVEN R. VUKELICH etc. 4, Missile DATCOM VOLUME I - FINAL REPORT, AFWAL- TR-86-3091, McDonnell Douglas Missile Systems Company, DECEMBER 1985.
- [2] Lamar Auman etc. 4, Missile DATCOM User's Manual-2011 Fortran 90 Revision, AFRL-RB- WP- TR-2011-3071, Air Force Research Laboratory, MARCH, 2011.
- [3] Lamar M. Auman and Kristina Kirby-Brown, MissileLab User's Guide, TR-RDMR-SS- 12-08, Commander, U.S. Army Research, Development, and Engineering Command, October 2012.
- [4] Hediye Atik etc. 6, Prediction Capabilities and Comparison of Panel, Semi-Empiric and CFD Codes for Missile Aerodynamic Analysis, AIAA 2008-6224, August 2008.
- [5] Jerry M. Allen and Carolyn B. Watson, Experimental Study at Low Supersonic Speeds of a Missile Concept Having Opposing wraparound Tails, NASA Technical Memorandum 4582, Hampton, Virginia, November 1994.
- [6] Brett Landon Wilks, AERODYNAMICS OF WRAP-AROUND FINS IN SUPERSONIC FLOW, Thesis, Auburn, Alabama, Master of Science, December 16, 2005.
- [7] Sharma, N., Saini, P., Chaudhary, H., Nagi, G., & Kumar, R., Comparison of Flow field in the proximity of A Single Planar & Wrap-around Fin, International Journal of Aviation, Aeronautics, and Aerospace, 6(4).
<https://doi.org/10.15394/ijaaa.2019.1393>
- [8] Nayhel SHARMA, 1, Rakesh KUMAR1, A Ready Reckoner of CFD for Wrap-around Fins, INCAS BULLETIN, Volume 11, Issue 2/ 2019,
<https://doi.org/10.13111/2066-8201.2019.11.2.13>
- [9] Hamad Al KAABI, Zlatko PETROVIĆ, Gordana DJUKANOVIĆ, Numerical and Experimental Determination of Canard Controlled Missile Aerodynamic Coefficients in Subsonic Regime, Technical Gazette 26, 3(2019), 674-680,
<https://doi.org/10.17559/TV-20180724143418>
- [10] J. Morote and G. Liaño, Stability Analysis and Flight Trials of a Clipped Wrap Around Fin Configuration, AIAA Atmospheric Flight Mechanics Conference and Exhibit, AIAA 2004-5055.