Preliminary EDL Aeroshell Design Performance from a Newtonian Theory Simulation Tool

Abstract No. 8042

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Introduction

An investigation was undertaken to assess suitability of the commercial software package Matlab to enable preliminary mission design planning. The 3 key objectives of this investigation were:

1.Research into Atmospheric Entry technology, Previous Mars Missions, Hypersonic Flow theory and Newtonian Impact Theory

2.Creation and testing of a simulation code within Matlab; using Newtonian Flow on an Mars Entry mission to generate Aeroshell Flight dynamic metrics and pressure coefficient distributions

3.Analysis of results and validation against prior mission data to discuss code performance and future improvements

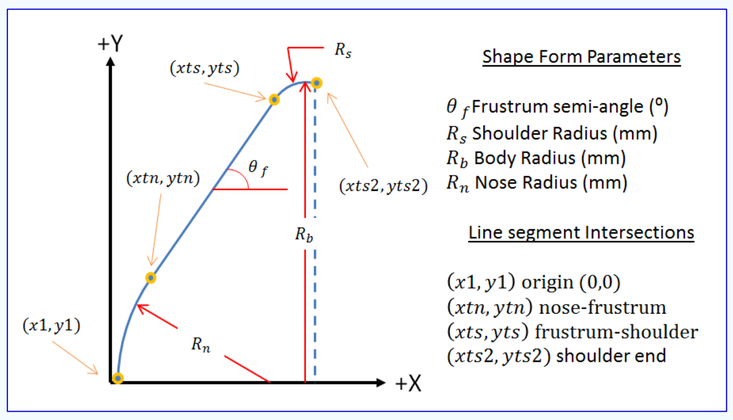

Figure 1: Forebody surface parameters

Forebody Surface Creation

To provide a universal simulation tool, creation of any generic sphere-cone forebody surface was essential. In reference to the work of Prabu & Saunders [1] the forebody surface is created using the parameters of nose radius, body diameter, shoulder radius and half-cone angle common parameters for all blunted sphere cones seen in figure 1. The 2D plane is rotationally transformed to give the 3D forebody surface compared in figure 2 below.

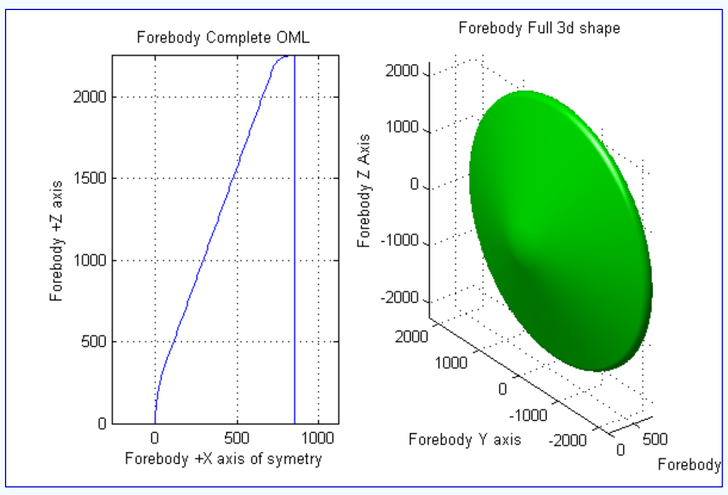

Figure 2: MSL Forebody in 2D & 3D from simulation

Newtonian Solver

To provide rapid determination of vehicle performance, Newtonian impact theory [2] was modified to determine the angular product between freestream velocity and local surface unit vectors, taking the form $C_p = 2cos^2\theta$. Figure 3 shows the forebody with unit normal vectors mapped onto the surface co-ordinate points. The array of Cp values is stored to resolve flight forces and provide pressure distribution results.

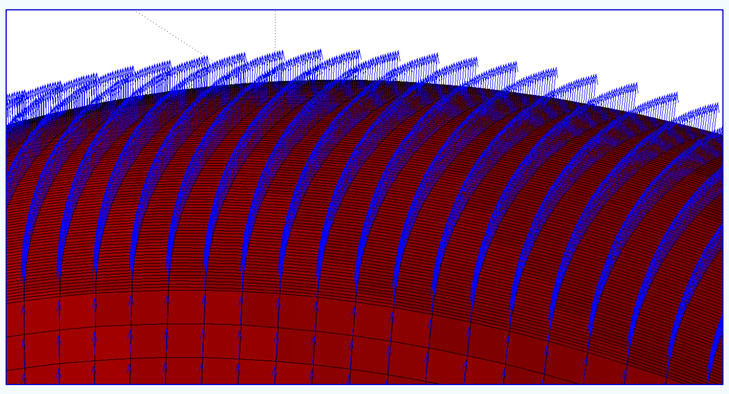

Figure 3: MSL Forebody with surface normal vectors

Flight Force Implementation

Extraction of the Coefficient of Lift and Drag, Axial and Normal forces will enable aeroshell performance characteristics to compare with previous missions; therefore enabling preliminary trajectory design and shape refinement if required. Figure 4 shows the elemental area from which the pressure coefficient is resolved into the resulting forces, with figure 5 the chosen axis scheme for the forebody surface.

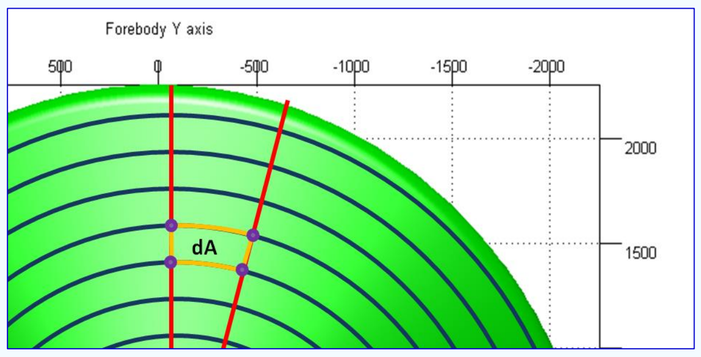

Figure 4: MSL Forebody with elemental area

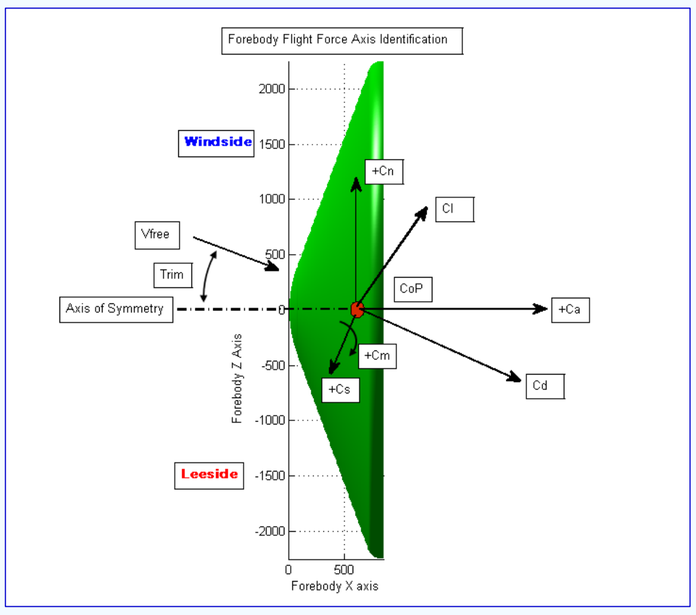

Figure 5: Flight-Force Axis Scheme

Pressure Distribution Results

Figure 6 identifies Cp resolution for MSL, with effects of the surface shape for Mars & Titan probes which are described in figure 7, with the effect of altering trim angle for MSL Cp distribution in figure 8 on Z and Y plane surface distributions.

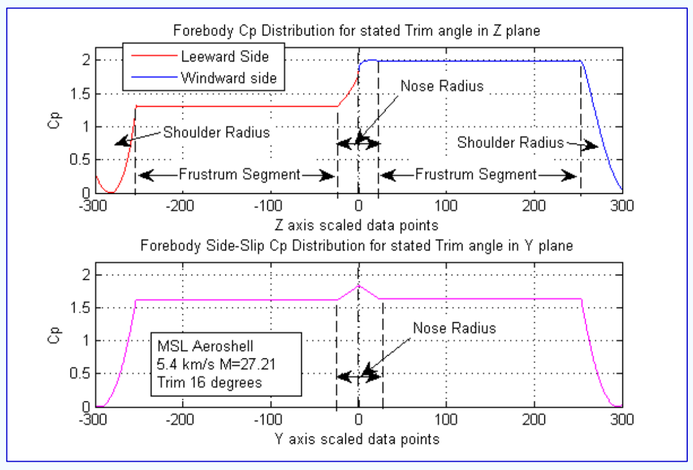

Figure 6: MSL Pressure Distribution with surface features identified

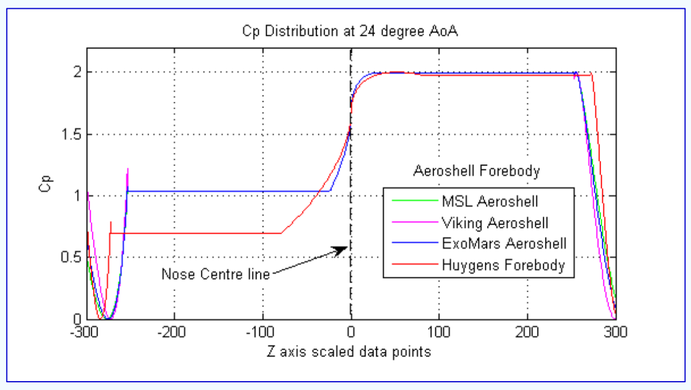

Figure 7: Shape Impact on Pressure Distribution $60^0/70^0$ Sphere-cone forebody

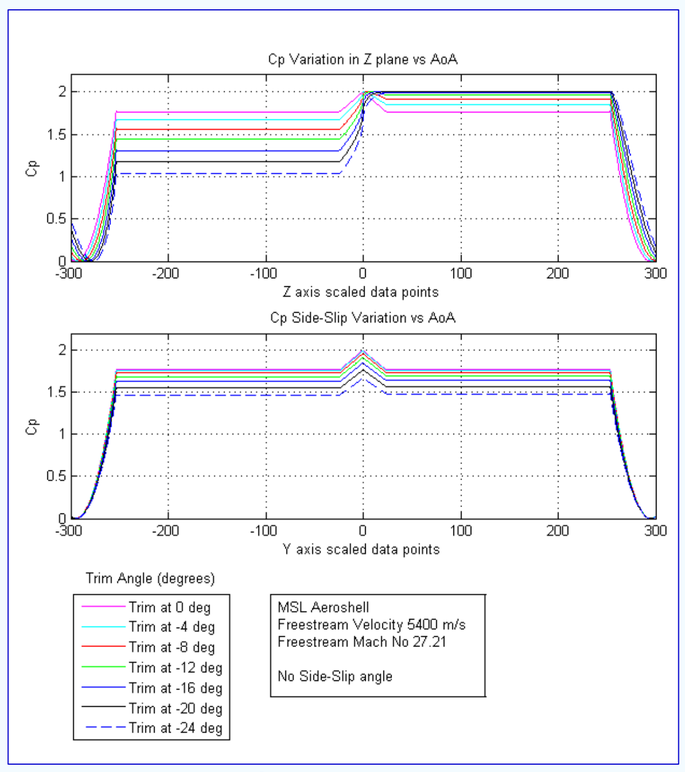

Figure 8: Trim angle (α^0) effect on Pressure Distribution for MSL 70^0 Sphere-cone forebody

Flight Force Results

Simulations for MSL, Viking and ExoMars are presented figures 9-11, with MSL and Viking compared to published data [3] & [4].

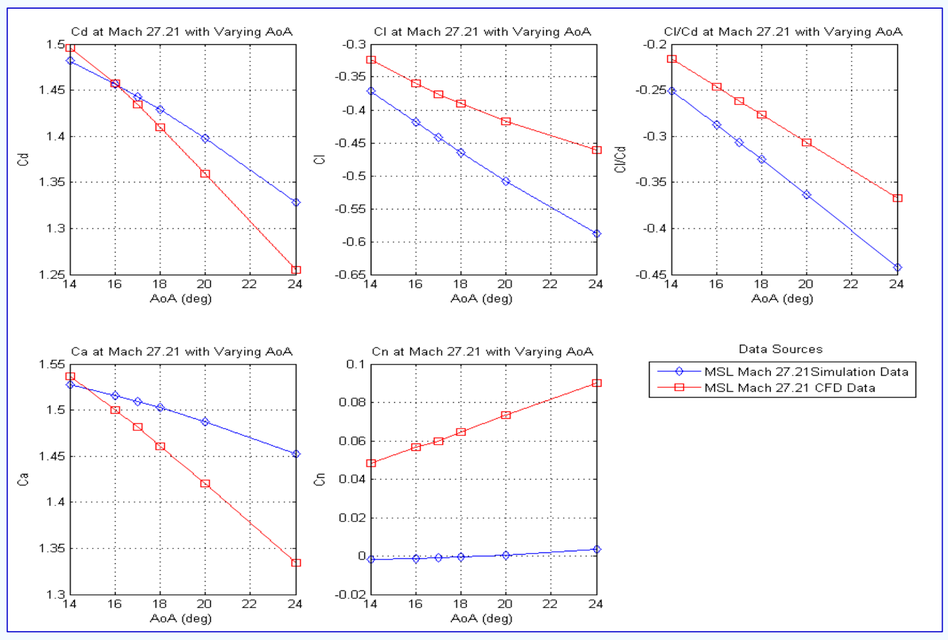

Figure 9: MSL Mach 27.21 flight force coefficient results comparison

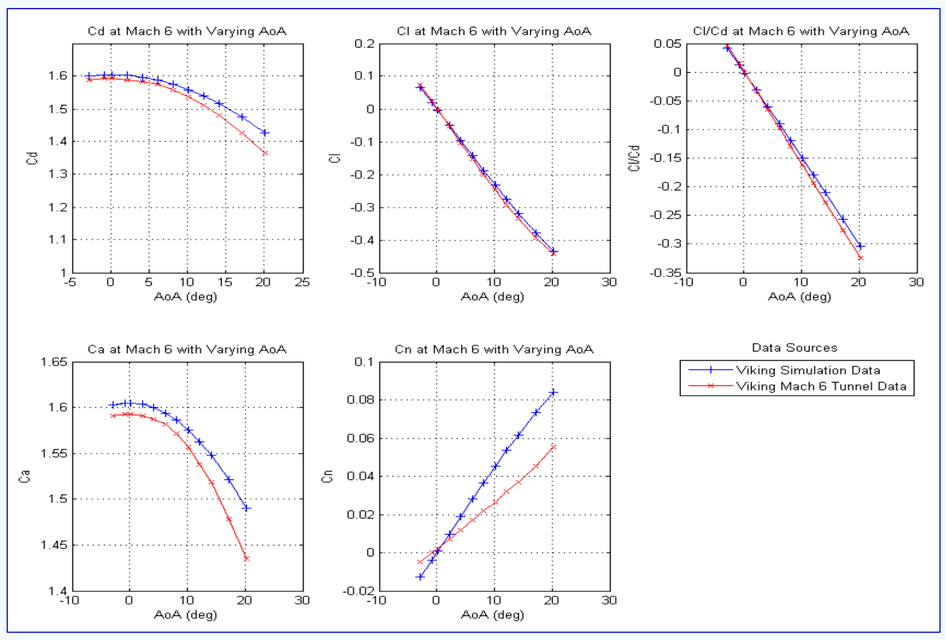

Figure 10: Viking Mach 6 flight force coefficient results comparison

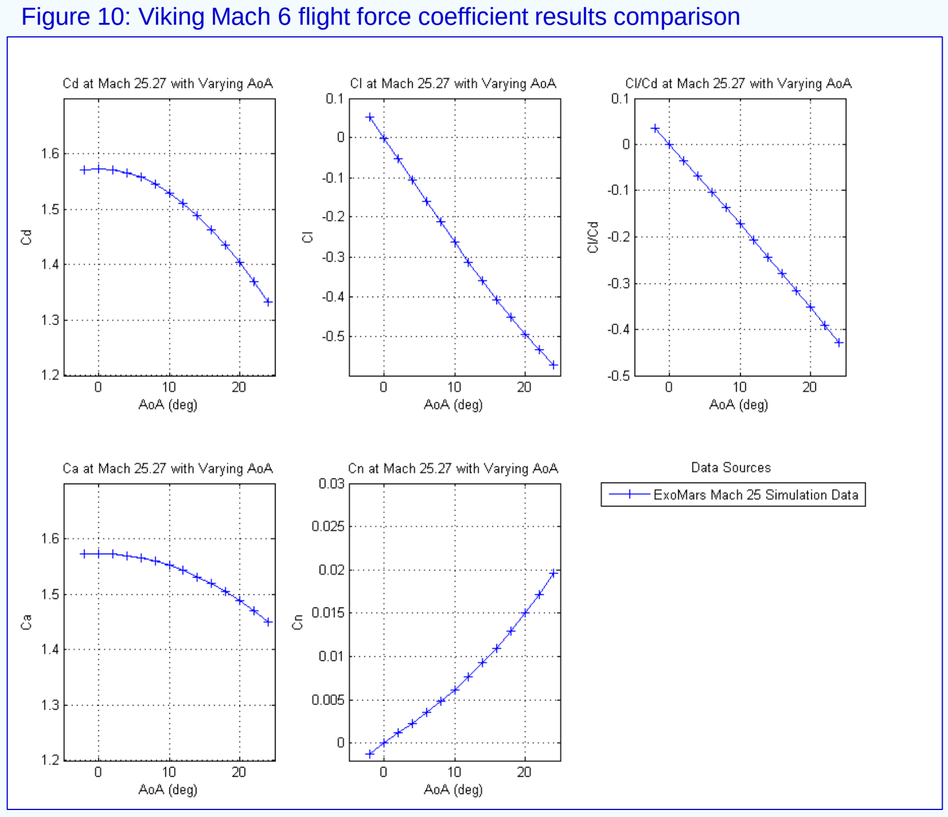

Figure 11: ExoMars Mach 25.27 Predicted Flight Force Coefficient results

Conclusions & Future Work

The simulation is able to provide good agreement of results between predictions and published data for Viking and MSL, with an anomaly seen in all normal force coefficient plots for MSL. Surface discontinuities result in spikes in the Cp distribution and nodes present on the back surface result in Cp increase from 0 value. ExoMars predicted values appear rational, given close fit of all Mars 70^0 sphere-cone forebodies, with the Huygens probe providing the most significant deviation due to its 60^0 shape.

Future work:

1. Refinement of Cp solver to negate forebody back nodes
2. Enable generation of blunted sphere forebody and non axisymmetric surfaces
3. Improvement of flight force extraction from surface Cp distribution & inclusion of pitching, rolling and yaw moment coefficients.
4. Inclusion of a global atmospheric reference model to allow EDL performance metrics and trajectory design

References

(1) Prabu, D. K., Saunders, D. A. (2012) 'On Heatshield Shapes for Mars Entry Capsules' [online] available from<http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa gov/20120004297.pdf.> [10 September 2013]

(2) Anderson, J.D. (2006) *Hypersonic and High Temperature Gas Dynamics* 2nd ed. Virginia: AIAA

(3) Goldberg, T. J., Emery, J. C. (1971) 'Longitudinal Aerodynamic Characteristics of the Viking Lander Capsule at Mach 6 NASA TM X-2205' [online] available from http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19710007778.pdf > [17 September 2013]

(4) Dyakonov, A.A., Schoenenberger, M., Van Norman, J. M. (2012) 'Hypersonic and Supersonic Static Aerodynamics of the Mars Science Laboratory Entry Vehicle' [online] available from <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120011936.pdf > [13 September 2013]