Comparison between FDM Model and Steel Model as Wind Tunnel Testing Models

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Abstract: This paper describes research into the feasibility of using FDM rapid prototyping in the wind tunnel testing models fabrication. Two models were evaluated. The first model was fabricated from Steel 17-4PH H900 by a CNC machining technique. The other model had the same CAD section but was fabricated by the fused deposition method (FDM) process. A third model was produced by sanding the steel model to reduce surface roughness by covering the full model in a layer of silicon carbide particles called “grit”. The times and costs required for model fabrication were compared. Aerodynamic characteristics of both models were measured in 0.3 to 1.3 Mach and the results were compared. It is shown in this paper that there is an acceptable agreement between aerodynamic characteristics of FDM model and that of metal model. The use of FDM method rather than metal models makes a rewardable reduction in production time and cost.

Key-Words: Rapid prototyping, Wind tunnel testing, Aerodynamic characteristics, Vertical lander, Fused deposition method, Angle of attack

1 Introduction

New production technologies provide a great mutation in the industries of the world, whereas it solved plenty of problems in sophisticated fabrications and reduced the time and cost of production. The time and costs of production significantly increase because of the processes that are used in traditional methods and these parameters are reduced with using a method that doesn’t depend on modeler [1]. We achieve a great successfully in this study, it was investigated the method for using rapid prototyping in wind tunnel test in order to identifying of aerodynamic coefficients for a vertical Lander [2]. As it can be seen from the study results:

a) Is the vertical lander FDM model able to provide all details and tolerances of wind tunnel testing model as well as steel model?

b) Have used materials for fabrication of model required mechanical properties and strength?

c) What notifications need for using RP model at wind tunnel?

In addition, what is the difference between consumed time and cost of this method compared with machined model? Nowadays, there are various RP methods but the most applicable and prevalent methods for fabrication wind tunnel testing models are FDM, SLA, and SLS [3]. The fused deposition method (FDM) involves the layering of molten beaded ABS plastic material via a movable nozzle in thin layers. The ABS material is supplied in rolls of thin ABS line resembling weed trimmer line. The material is heated and extruded through a nozzle similar to that of a hot glue gun. The plastic is deposited in rows and layered forming the part from numerically controlled (NC) data (fig. 1) [4].

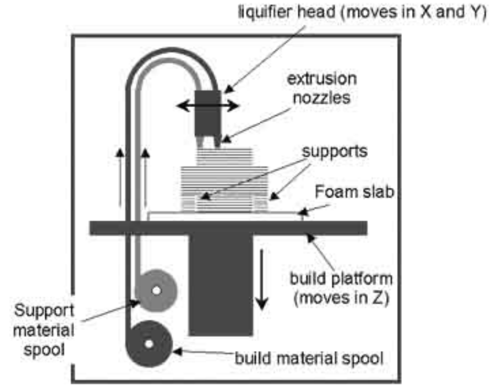

Fig.1 The Fused Deposition Method (FDM)

2 Geometry

The geometry used for the precursor study was that

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of a vertical Lander concept [5]. The vertical Lander was a generic blunted cone followed by a bread-loaf-shaped base with two fins, or fairings, on the base's upper surface. Because this model was being fabricated in a machined metal model format (fig.2), a preliminary computer aided design (CAD) file was available for RP model design and fabrication.

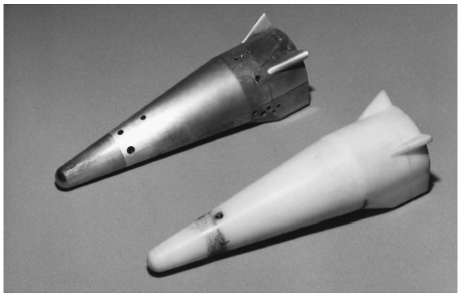

Fig.2 Photograph of Both Steel and FDM –ABS

This geometry provided a basis for comparisons between RP models and machined metal models. The reference dimensions for this configuration were as follows:

S_{REF} =3198.071 mm^2 L_{REF} =228.6 mm

X_{MRP} =158.648 millimeter aft of nose

3 Model Construction

The vertical Lander RP model was constructed using the fused deposition method. The Fused Deposition Method (FDM) is a method used to develop rapid prototypes/plastic models. The FDM process builds the prototype/model by adding heated materials in a programmed pattern onto a base platform. Being an additive process, FDM allows three-dimensional planes to take shape as the model is built. After the first layer is complete, the machine's platform lowers to the next programmed plane and the process continues until all layers have been added. The FDM machine accepts computer-generated to produce finished prototypes and models in a fraction of the time used by older methods. The fused deposition method is used in this experiments involves the layering of molten beaded ABS plastic material via a movable nozzle in 0.25 mm thick layers. The model was constructed in two parts, a nose and a core body. A 19 mm hole was reamed through the center of the body for placement of the aluminum balance adapter, which was then epoxied into place. The nose was attached to the core body with a removable knock pin. The material properties of FDM – ABS, and steel are shown in table 1, and table 2 [6].

Table 1.Material Properties of Steel

Property	**Units**	**Steel 17–4PH H900**
Yield Strength	Kpa	1171.3
Tensile strength	Kpa	1309.1

Table 2.Material Properties of FDM–ABS

Property	Units	FDM-ABS
Tensile Strength	MPa	34.45
Tensile Modulus	MPa	2480.40
Elongation at Break	Percent	50
Flexural Strength	MPa	65.45
Flexural Modulus	MPa	2618.20
Impact Strength	N	107.08
Hardness	(Shore D)	105

4 Wind Tunnel

The Transonic Wind Tunnel is an intermittent blowdown tunnel, which operates by high- pressure air flowing from storage to either vacuum or atmosphere conditions. Mach numbers between 0.2 and 0.9 are obtained by using a controllable diffuser. The Mach range from 0.95 to 1.3 is achieved through the use of plenum suction and perforated walls [7]. Each Mach number above 1.3 requires a specific set of two-dimensional contoured nozzle blocks. Downstream of the test section is a hydraulically controlled pitch sector that provides the capability of testing angles-of-attack ranging from –10 to +10 degrees during each run. Sting offsets are available for obtaining various maximum angles-of-attack up to 90 degrees. The diffuser section has movable floor and ceiling panels, which are the primary means of controlling the subsonic Mach numbers. As an intermittent blowdown-type tunnel, experiences large starting and stopping loads. This, along with the high dynamic pressures encountered through the Mach range, requires models that can stand up to these loads. It is generally assumed that the starting and stopping loads are1.5 times the operating loads. Table 3 shown lists the relation between Mach number, dynamic pressure, and Reynolds number per meter [8].

Table 3.Wind Tunnel Operating Conditions

Mach	Reynolds	Dynamic

Number	Number	Pressure
0.3	9.18×10^4/m	8.96 kPa
0.8	18.03	44.58
0.9	19.34	50.71
1.05	20	58.43
1.15	20.32	61.94
1.25	20.32	64.14

5 Test Model FDM and Steel

Testing was done over the Mach range of 0.3 to 1.25 for the precursor study. These Mach numbers were 0.30, 0.80, 0.90, 1.05, 1.15 and 1.25. Both models were tested at angle-of-attack ranges from +6 degrees to +26 degrees at zero sideslip and at angle-of-sideslip ranges from –8 to +8 degrees at 16 degrees Angle-of-attack. The reference aerodynamic axis system and reference parameters for the precursor study are shown in fig. 3 [9].

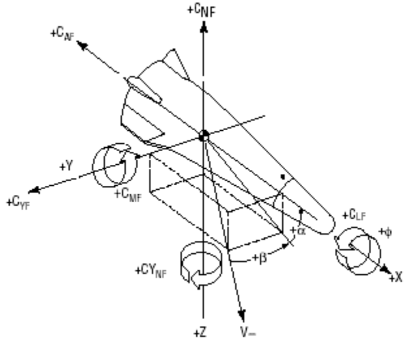

Fig 3.Vertical Lander Aerodynamic Axis System

6 Test Results

The precursor study revealed that between Mach numbers of 0.3 to 1.25, the longitudinal aerodynamic data or data in the pitch plane showed approximately a 2-degree shift in the data between the FDM and metal model for the normal force (fig.4) and approximately a 1-degree data shift for the pitching moment (figs.5). Except for these shifts, the data trends for each model type were consistent with each other. The total axial force was slightly lower for the FDM model than the metal model (figs.6). Part of the noted offset is due to the approximation for a weight tare correction.

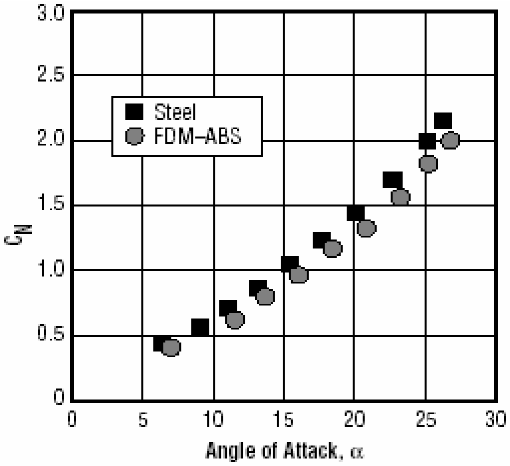

Fig.4 Comparison of Normal Force Coefficient at Mach 1.25

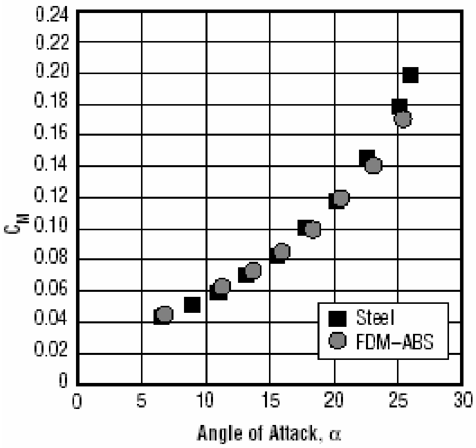

Fig.5 .Comparison of Pitching Moment Coefficient at Mach 1.25

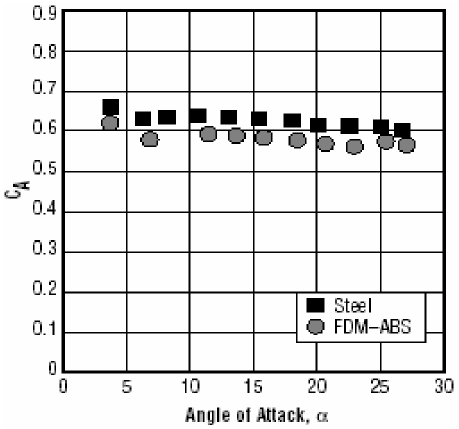

Fig.6 .Comparison of Total Axial Force Coefficient at Mach 1.25

In general, it can be said that the longitudinal aerodynamic data for each model is within 5 percent. The lateral directional aerodynamic data show some small discrepancies between the two model types. Since the vehicle is symmetric in the X–Y plane (the port side is the same as the starboard side) the lateral aerodynamic data should go through zero at zero degrees sideslip angle. Subsonically and transonically both sets of data show slight zero offset shifts, with the RP model showing a larger shift than the metal model (figs. 7 through 9). These zero shifts in the data were caused by an unexpected error in roll during the installation of the balance adapters in the models. The metal model having approximately a 0.2-degree roll, and the FDM model approximately a 2.5-degree roll in the balance adapter installation. The data do, however, show a slight shift in the data trends between the models. On average, there is a .003 shift in the side force data trends slope and a .0002 shift in the yawing moment data trends slope between the metal and the FDM model as shown in figures 7 and 8 Representative Mach numbers 1.25 have been used to display the data trends.

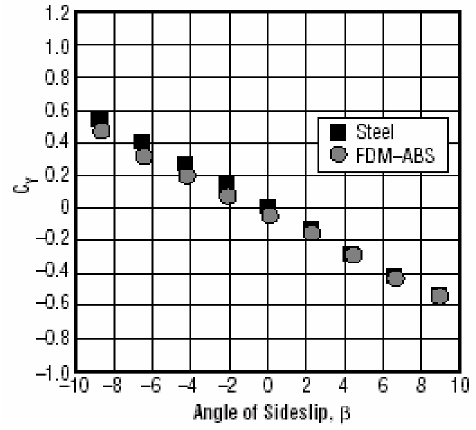

Fig.7 .Comparison of Side Force Coefficient at Mach 1.25

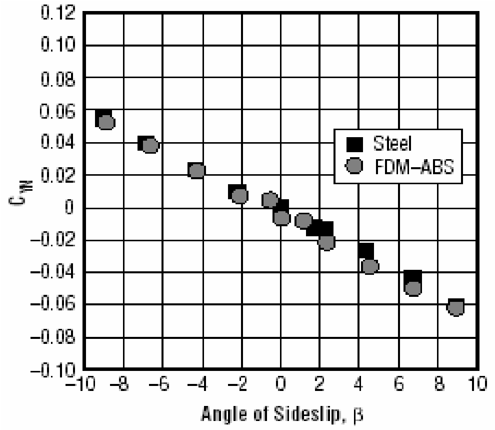

Fig.8 .Comparison of Yawing Moment Coefficient at Mach 1.25

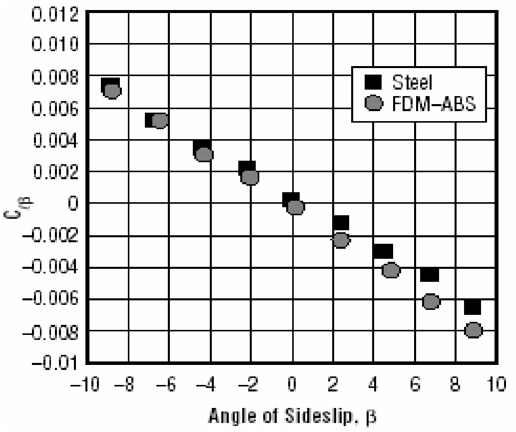

Fig.9 .Comparison of Rolling Side Moment Coefficient at Mach 1.25

7 Influences Surface Finish Models

The effects of surface finish and grit on the aerodynamic characteristics of the models were determined. The FDM models did not have as smooth a finish, as did the steel model, so runs were made to determine if the difference in these surface finishes would affect the aerodynamic characteristics .A rough surface finish was simulated on the steel model by covering the full model in a layer of silicon carbide particles called "grit." This grit would "rough" up the surface. The effect of grit on the model was also determined. Grit is used to trip the boundary layer over the model to simulate a higher Reynolds number than the actual wind tunnel Reynolds number. Number 100 silicon carbide particles, or grit, were applied on model. Number 100 grit has a nominal spherical particle diameter of 0.15 mm [10]. The effect of these changes is shown in figures 10 through 12. In these graphs it can be seen that surface finish does have little effect on the aerodynamic characteristics.

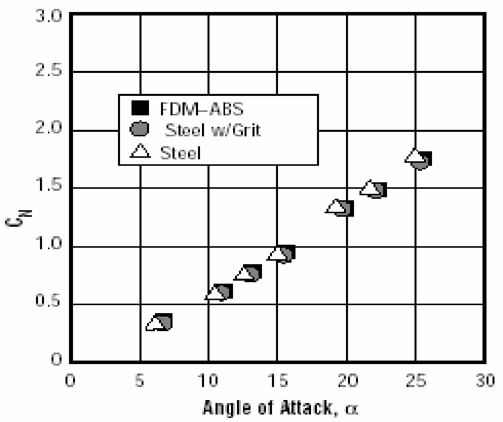

Fig.10. Comparison of Normal Force Coefficient at Mach 1.05

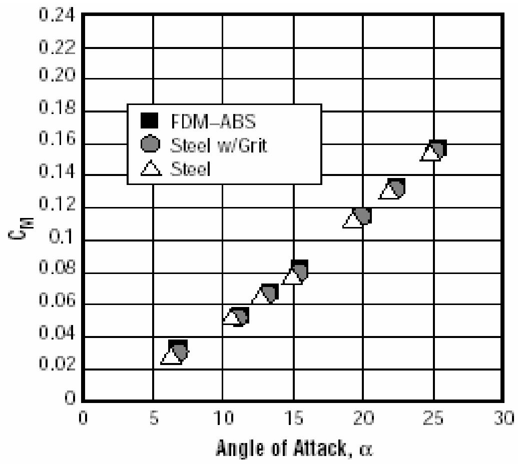

Fig.11 .Comparison of Pitching Momen Coefficient at Mach 1.05

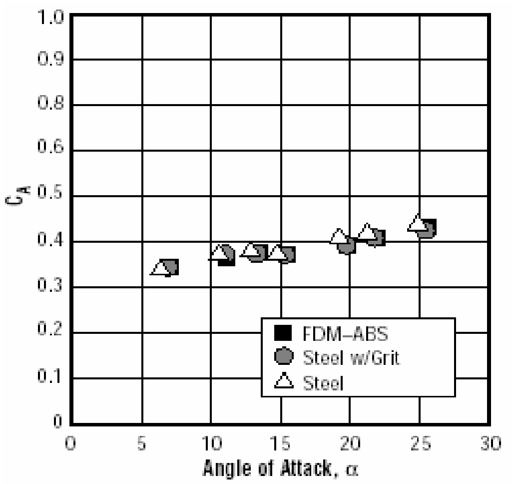

Fig.12 .Comparison of Total Axial Force Coefficient at Mach 1.05

8 Cost and Time

The cost and time requirements for the FDM model and the steel model are shown in table 4. The FDM model for this test cost about $1100 and took between 1 and 2 weeks to construct, while the steel model cost about $16,000 and took 3 1/2 months to design and fabricate.

Table 4.Wind tunnel model time and cost summary

Model Cost &Time	FDM-ABS	Steel
RP Model	$500	
Conversion	500	
Balance Adapter	100	
Total Cost	1100	$16000
Time	1-2 Weeks	3 ½ Months

9 Accuracy

The data accuracy resulting from the test can be divided into two sources of error or uncertainty:
(1) the model, and (2) the data acquisition system. Each of these factors will be considered. First, the dimensions of the two models must be considered. Difficulty arose in the interface between the nose and core body for the FDM model along with the roll of the balance adapter in the model. A comparison of model dimensions is shown in table5.

Table 5.Vertical Lander Model Dimensions

Dimension	Steel	FDM
Length	228.625	228.777 mm
Width	63.602	63.302
Height	63.500	63.906

Other discrepancies in the FDM model dimensions were that the flat sides of the base varied within 0.13 millimeter, and the diameter at the nose junction did not vary linearly due to smoothing the model for a good fit between the nose and core body. The FDM model balance adapter was rolled in the model with respect to the steel model approximately 2.5 degrees. The FDM model balance adapter was rolled approximately 2 degrees starboard wing down, while the metal model balance adapter was rolled approximately 0.5-degree port wing down, resulting in a difference of approximately 2.5 degrees between the two models. This resulted in a small error in all the coefficients, since the model was installed in the tunnel level. The effect of the balance adapter rolls on the normal force and side force aerodynamic coefficients are shown in table 6 if a C_N = 1.0 and a C_Y = 0.0 are assumed.

Table 6. Effect of Balance Adapter Roll on Aerodynamic Coefficients

Roll Angle	C_N	C_Y
0.5°	0.9999	0.0087
1.0°	0.9998	0.0175
1.5°	0.9997	0.0262
2.0°	0.9994	0.0349
2.5°	0.9990	0.0436 (Factor of C_N)

10 Conclusions

It can be concluded from this precursor test that wind tunnel models constructed using rapid prototyping methods and materials can be used in wind tunnel testing for initial baseline aerodynamic database development. The accuracy of the data is lower than that of a metal model due to surface finish and dimensional tolerances, but is quite accurate for this level of testing. The fewer than 5 percent change in the aerodynamic data between the metal and RP model aerodynamics is acceptable for this level of preliminary design or phase studies. The use of RP models will provide a rapid capability in the determination of the aerodynamic characteristics of preliminary designs different Mach range. This range covers the transonic regime, a regime in which analytical and empirical capabilities sometimes fall short.

For future works, some of the machined metal model parts can be replaced with those of Rapid Prototyping parts and current experiments and evaluations can be done on these models with combined parts.

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