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Evaluating Aerodynamic Characteristics of Wind-Tunnel Models Produced by Selective Laser Sintering Method

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Abstract: - Traditional wind tunnel models are meticulously machined from metal in a process that can take several months. While very precise, the manufacturing process is too slow to assess a new design's feasibility quickly. Rapid prototyping (RP) technology makes this concurrent study of air vehicle concepts via computer simulation and in the wind tunnel possible. It produces a model in days or hours, depending upon model complexity. This paper discuses the application of RP in Vertical lander model production by using selective laser sintering for subsonic and transonic wind tunnel testing. An experimental study was undertaken comparing a rapid prototyping model constructed of SLS technologies using glass-reinforced nylon to that of a standard machined steel model. Testing covered the Mach range of Mach 0.3 to Mach 1.3 at an angle-of-attack range of -4° to +16° at zero sideslip. Results from this study show relatively good agreement between the two models. Finally It can be concluded that RP models show promise in preliminary aerodynamic development studies.

Key-Words: - Fabrication - Rapid prototyping - Wind tunnel model - Selective Laser Sintering - SLS

1 Introduction

Rapid prototyping technologies being developed for the space program have many uses in the commercial industry. Wind tunnel models, used to provide performance test, can be produced at lower cost than traditional methods [1]. Most wind tunnel models are CNC machined from aluminum (for low speed) and steel (for high speed) tunnels. The addition of pressure taps is particularly expensive and time consuming and requires skilled workers with considerable experience. Rapid Prototyping has also been referred to as solid free-form manufacturing computer automated manufacturing, and layered manufacturing. RP has obvious use as a vehicle for visualization. In addition, RP models can be used for testing, such as when an airfoil shape is put into a wind tunnel [2]. In some cases, the RP part can be the final part, but typically the RP material is not strong or accurate enough. In this study has been undertaken to determine the suitability of model constructed using SLS rapid prototyping method for use in wind tunnel testing. The study involved the construction of a Selective Laser Sintering model to replicate the geometry of a model (Fig. 1) already slated for testing in the Wind Tunnel. This study provided the necessary data to compare the aerodynamic characteristics of an SLS model to that of a standard steel machined model. The findings from this initial study indicated that the aerodynamic database obtained from SLS model showed good agreement with data obtained from the machined steel counterpart. This study was conducted to determine if certain criteria can be satisfactorily met in order to produce an adequate assessment of vehicle aerodynamic characteristics.

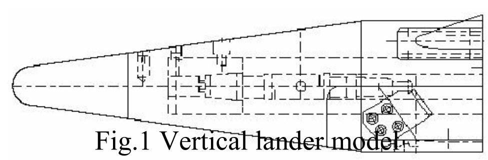

Fig.1 Vertical lander model

These pertinent questions or criteria were as follows: (1) Could SLS method be used to produce a detailed scale model within required dimensional tolerances? (2) Did the available SLS materials have the mechanical characteristics, strength, and elongation properties required to survive wind tunnel testing at

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subsonic and transonic speeds and still produce accurate data? (3) What are the costs and time requirements for the SLS method as compared to a standard machined metal model?

SLS model constructed were compared to a machined metal model. The RP process were Selective laser sintering (SLS) with glass reinforced nylon as a material. It can initially be stated that at the time of the study, machined metal models cannot be replaced by RP models for all required aspects of wind tunnel testing [3]. This study focused on a small aspect of wind tunnel testing determining the static stability aerodynamic characteristics of a vehicle relevant to preliminary vehicle configuration design.

2 Model Fabrication

A vertical lander configuration was chosen for the actual study. Vertical lander RP model was constructed using the Selective Laser Sintering method. Selective laser sintering uses a laser beam to selectively fuse powdered materials, such as nylon, elastomer, and metal, into a solid object. Parts are built upon a platform which sits just below the surface in a bin of the heat-fusible powder [4]. A laser traces the pattern of the first layer, sintering it together. The platform is lowered by the height of the next layer and powder is reapplied. This process continues until the part is complete Fig. 2 [5].

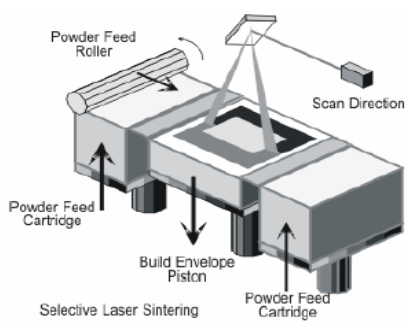

Fig.2 The selective laser sintering (SLS) process

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. 3) a preliminary computer aided design (CAD) file was available for RP model design and fabrication. This Geometry provided a basis for comparisons between RP model and machined metal model. The reference dimensions for this configuration were as follows:

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

X_{ref}=158.648 millimeter aft of nose

The model was constructed in two parts, a nose and a core body. A 19 millimeter hole was reamed through the center of the body for placement of the aluminum balance adapter [6]. The nose was attached to the core body with a removable knock pin (Fig. 4).

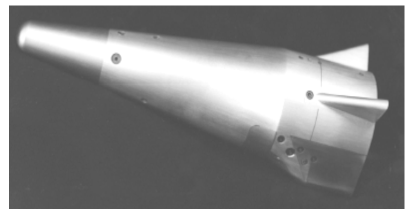

Fig.3 Vertical lander model configuration

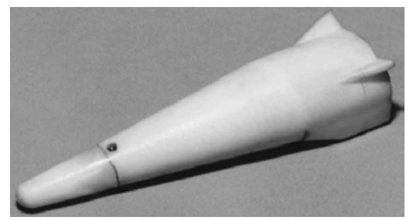

Fig.4 SLS Vertical lander model configuration

The rapid prototyping process and materials selected for the steel model and SLS were the SLS technologies using glass-reinforced nylon and steel 17- 4PH. The material properties of steel and SLS are shown in Table 1 and Table 2 [7].

Table 1 Material properties of steel.

Property	Steel 17-4PH
Yield Strength (Mpa)	1171
Tensile Strength (Mpa)	1309
Elongation (Percent)	6

Table 2 Material properties of SLS

Property	Unit	SLS
Tensile Strength	Mpa	48.91
Tensile Modulus	Mpa	2811.12
Elongation at Break	Percent	6
Flexural Modulus	Mpa	4306.25
Impact Strength	N	66.92

3 Test Models Selective Laser Sintering and steel

Wind tunnel is an intermittent blow down tunnel which operates by high-pressure air flowing from storage to either vacuum or atmosphere conditions. The transonic test section provides a Mach number range from 0.2 to 1.3. 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. Table 3 shown lists the relation between Mach number, dynamic pressure, and Reynolds number per meter [8].

Table 3 Wind Tunnel Operating Conditions

Mach Number	Reynolds Number	Dynamic Pressure
0.3	9.18×104/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
1.2	20.32	64.14

Testing was done over the Mach range of 0.3 to 1.2 at 5 selected numbers for the precursor study. These Mach numbers were 0.30, 0.80, 0.90, 1.05 and 1.2. Both Models were tested at angle-of-attack ranges from -4 degrees to +16 degrees at zero sideslip. The reference aerodynamic axis system and reference parameters for the precursor study are shown in Fig. 5 [9].

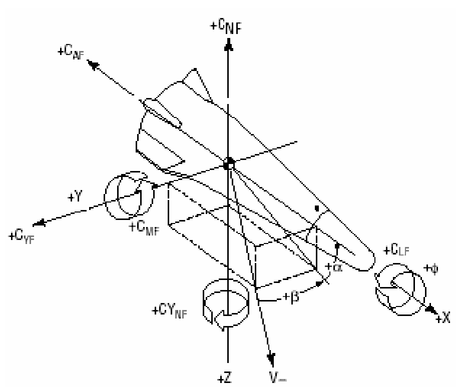

Fig.5 Vertical lander aerodynamic axis system

4 Test Results

For all phases of the baseline study coefficients of normal force, axial force, pitching moment, and lift over drag was determined. Only longitudinal data at mach 0.3, 0.8 and 1.05 are shown in this paper. The precursor study revealed that between Mach numbers of 0.3 to 1.2, the longitudinal aerodynamic data or data in the pitch plane showed approximately a 1-degree shift in the data between the SLS and steel model for the normal force (figs. 7, 11 and 15), and approximately a 3-degree data shift for the pitching moment (figs. 6, 10 and 14). Except for these shifts, the data trends for each model type were consistent with each other. The total axial force was slightly up for the SLS model than the steel model (figs. 8, 12 and 16). Part of the noted offset is due to the approximation for a weight tare correction. In general, it can be said that the longitudinal aerodynamic data for each model is within 5 percent. The greatest difference in the aerodynamic data between the models at Mach Numbers of 0.3 to 1.2 was in total axial force. It can be said that SLS model longitudinal aerodynamic data at subsonic and transonic Mach numbers showed a few divergence at higher angles-of attack when compared to the steel model data.

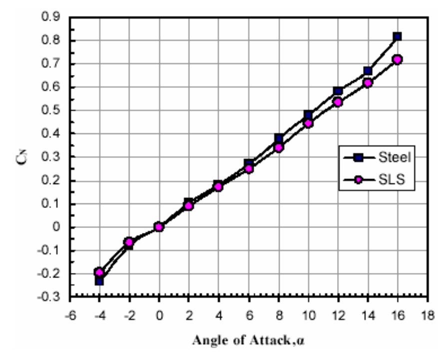

Fig.6 Comparison of pitching moment Coefficient at Mach 0.3

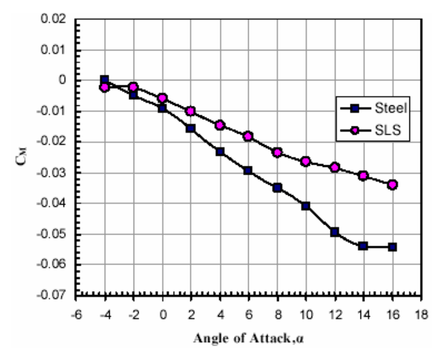

Fig.7 Comparison of normal Coefficient at Mach 0.3

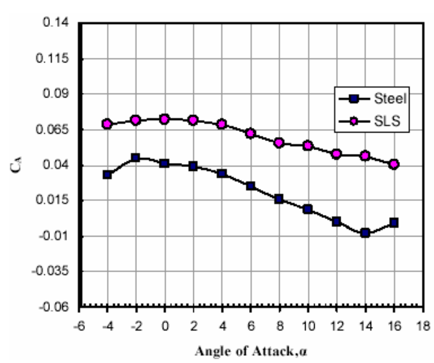

Fig.8 Comparison of axial force Coefficient at Mach 0.3.

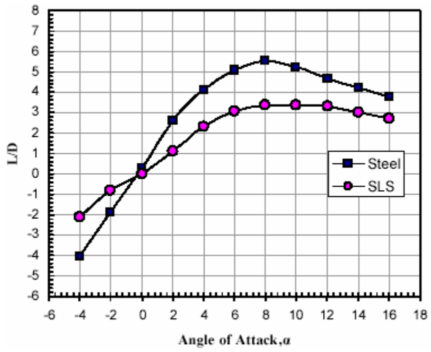

Fig.9 Comparison of lift over drag
At Mach 0.3.

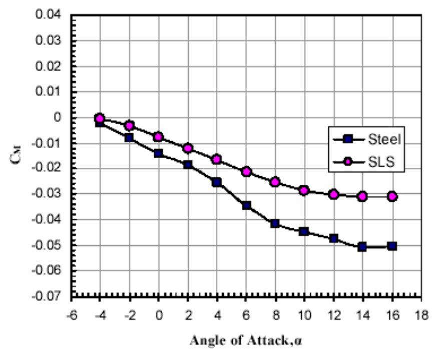

Fig.10 Comparison of pitching moment
Coefficient at Mach 0.8

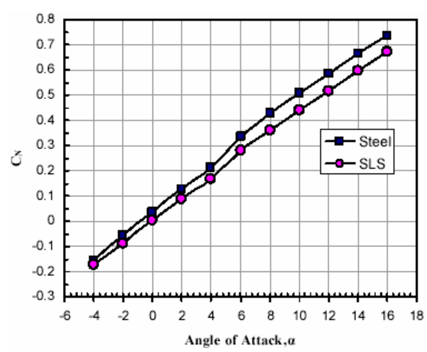

Fig.11 Comparison of normal
Coefficient at Mach 0.8

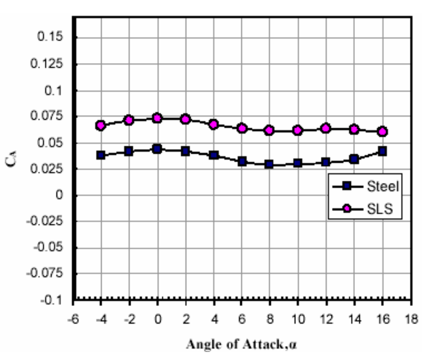

Fig.12 Comparison of axial force
Coefficient at Mach 0.8

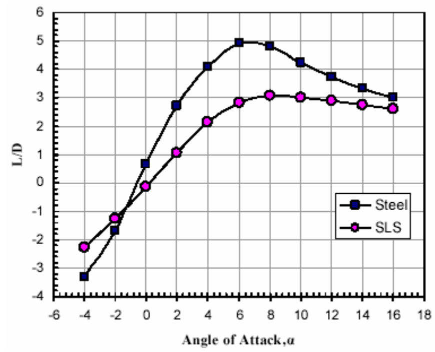

Fig.13 Comparison of lift over drag
At Mach 0.8.

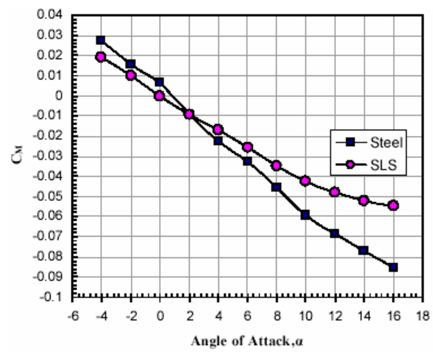

Fig.14 Comparison of pitching moment
Coefficient at Mach 1.05

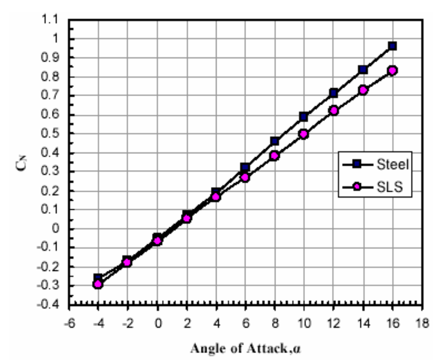

Fig.15 Comparison of normal
Coefficient at Mach 1.05

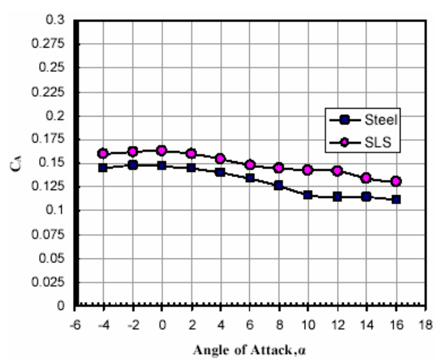

Fig.16 Comparison of axial force
Coefficient at Mach 1.05

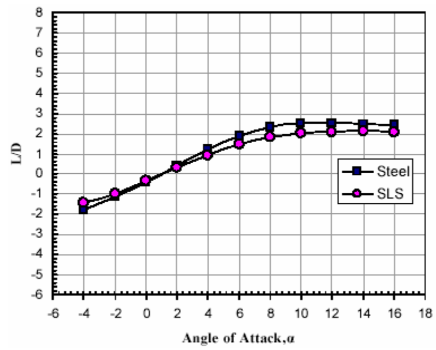

Fig.17 Comparison of lift over drag
At Mach 1.05

5 Data accuracy

The data accuracy resulting from test can be divided into two sources of error or uncertainty: the model and the data acquisition system [10]. 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 SLS model along with the roll of the balance adapter in the model. A comparison of model dimensions is shown in table 4.

Table 4.Vertical Lander Model Dimensions

Dimension	Steel	SLS
Length	228.625	228.512 mm
Width	63.602	63.420
Height	63.500	63.810

Other discrepancies in the RP model dimensions were that the flat sides of the base varied within 0.152 mm, 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 SLS model balance adapter was rolled in the model with respect to the metal model approximately 2 degrees. The SLS model balance adapter was rolled approximately 2.5 degrees starboard wing down. 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 roll on the normal force and side force aerodynamic coefficients is shown in table 5 if a C_N of 1.0 and a C_Y of 0.0 are assumed.

Table 5. 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)

Initially, due to time constraints, the weight tare of the metal model was used during testing for the RP model.

6 Time and cost

A study was done of rapid prototyping technologies and their ability to make components for wind tunnel models in a timely and cost effective manner. The cost and time requirements for the SLS model and the metal model are shown in table 6.

Table 6.Wind tunnel model time and cost summary

Model Cost &Time	SLS	Steel
RP Model	$500	
Conversion	400	
Balance Adapter	200	
Total Cost	1100	$12000
Time	3-4Weeks	3 ½ Months

The SLS model for this test cost about $1,100 and took between 3 and 4 weeks to construct, while the metal model cost about $12,000 and took 3 1/2 months to design and fabricate. It should be noted for the conversion of an RP model to wind tunnel model is $500—$100 for the balance adapter and $400 for parts and labor. Along with the standard 3 days for RP model fabrication, a wind tunnel model could be constructed in under a week.

7 Conclusions

Rapid prototyping method have been shown to be feasible in their limited direct application to wind tunnel testing for producing preliminary aerodynamic databases. Cost savings and model design/fabrication time reductions of over a factor of 4 have been realized for SLS technique as compared to current standard model design/fabrication practices. This makes wind tunnel testing more affordable for small programs with low budgets and for educational purposes. At this time, SLS method and materials can be used for only preliminary design studies and limited configurations due to the rapid prototyping material properties which allow bending of model components under high loading conditions (high angles-of-attack). It can be concluded from this study that wind tunnel models constructed using rapid prototyping Method and materials can be used in subsonic and transonic 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 difference in the aerodynamic data between the metal and SLS model aerodynamics is acceptable for this level of preliminary design or studies. The use of RP models will provide a rapid capability in the determination of the aerodynamic characteristics. However, at this time, replacing machined metal models with SLS models for detailed parametric aerodynamic and control surface effectiveness studies is not considered practical because of the high configuration fidelity required and the loads that deflected control surfaces must withstand. The current materials of SLS models may not provide the structural integrity necessary for survival of thin section parts such as tip fins and control surfaces. Consequently, while this test validated that SLS models can be used for obtaining preliminary aerodynamic databases, further investigations will be required to prove that SLS models are adequate for detailed parametric aerodynamic studies that require deflected control surfaces and delicate or fragile fins.

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