JOURNAL OF AIRCRAFT
Vol. 46, No. 3, May–June 2009

Influence of Layer Thickness on the Design of Rapid-Prototyped Models

C. Aghanajafi*
Khajeh-Nasier Toosi University of Technology, 19569-83911 Tehran, Iran
and
S. Daneshmand† and A. Ahmadi Nadooshan‡
Islamic Azad University, 81597-16778 Isfahan, Iran

DOI: 10.2514/1.39702

Today, engineers are aiming for performance, quality, and repeatability, to be reached in a very short delivery time. Rapid-prototyping techniques are applied to concept design and modeling. A typical aircraft development program usually needs at least four to five wind-tunnel models to adequately test the aerodynamics of a new airframe. The models are generally made of steel or aluminum. The models can require months to be manufactured. The dimensional accuracy, surface finish, and strength of such all-metal models have a distinguished history of providing high-fidelity aerodynamics data for both subsonic and supersonic aircraft. However, the fabrication of all-metal wind-tunnel models is very expensive and time-consuming. This paper describes the effects of layer-thickness models on aerodynamic coefficients to construct wind-tunnel-testing models produced with rapid prototyping. These models were fabricated from SOMOS NanoTool by stereolithography. The layer thickness for each model was 0.025, 0.05, and 0.1 mm. Testing covered the Mach range of Mach 0.10 to 0.40. Results from this study show that layer thickness does have an effect on aerodynamic characteristics. The layer thickness is more effective on the aerodynamic characteristics when Mach number is decreased and has the most effect on the aerodynamic characteristics of axial force.

Nomenclature

α = angle of attack
C_A = axial force coefficient
C_M = pitching moment coefficient
C_N = normal force coefficient
L/D = lift over drag ratio

I. Introduction

WIND-TUNNEL models for testing are manufactured to very high specification. The models can be assembled and dismantled with great accuracy and repeatability. High ambient pressure and very low temperatures within the tunnel can place extra demands on the models, both in terms of model strength and model shape. The resulting models tend to feature a minimal number of component parts, made of solid metal. Most wind-tunnel models are fabricated of all-metal components using computer numerical control milling machines [1]. The dimensional accuracy, surface finish, and strength of such all-metal models have a distinguished history of providing high-fidelity aerodynamics data for both subsonic and supersonic aircraft and rocket designs. However, the fabrication of all-metal wind-tunnel models is very expensive and time-consuming. A typical aircraft development program usually needs at least four to five wind-tunnel models to adequately test the aerodynamics of a new airframe. The models can require months to manufacture and are often made by small high-technology companies that specialize in wind-tunnel model manufacture [2].

For several years, rapid-prototyping (RP) materials and methods have been considered as a potential source of improvements to conventional wind-tunnel models [3]. RP technologies being developed for the space program have many uses in the commercial industry. When a concept is in the selling stage, a plastic model can be produced to serve as a visual aid. Wind-tunnel models, used to provide performance tests, can be produced at lower cost than traditional methods [4]. There are many different rapid-prototyping technologies available today, but not every machine is applicable for every need. For example, many problems in fluid dynamics are solved through complicated mathematical software. However, there is no substitute for actual wind-tunnel testing. An aeronautical component built and tested in the computer can be made into a three-dimensional solid test object through rapid prototyping [5]. RP parts can generally be made much more rapidly and less expensively than conventional machined parts. RP manufacturing is a field of high technology concerning the generation of three-dimensional solids using particles or layers of mostly polymeric materials [6].

Two of the most popular RP techniques include stereolithography (STL) and fused deposition modeling. Both techniques build solid objects layer by layer based on data from a CAD software program [7]. Significant use of RP components in high-load wind-tunnel tests has not occurred, however, because of problems with material strength and fabrication tolerances. The current plastic materials of RP models do not provide the structural integrity necessary for the survival of wind-tunnel models, especially for thin section parts such as tip fins and flaps. There is therefore a need for novel wind-tunnel model design techniques that overcome some of the difficulties and deficiencies involving the use of RP components [8]. The layer thickness is an important parameter in model fabrication, because in the rapid-prototyping method, each model is produced by many thin layers. Product quality is often associated with a smooth surface, which is usually expensive to make [9]. Each process can be expected to produce roughness values within a given range. In this spirit, a study has been undertaken to determine the suitability of models constructed using stereolithography with various layer thicknesses for wind-tunnel testing. Surface roughness is an important parameter in wind-tunnel-testing models fabrication [10].

In this study, the effects of layer thickness on the aerodynamic characteristics are determined and surface roughness for wind-

Received 11 July 2008; revision received 22 January 2009; accepted for publication 23 January 2009. Copyright © 2009 by the American Institute of Aeronautics and Astronautics, Inc. All rights reserved. Copies of this paper may be made for personal or internal use, on condition that the copier pay the $10.00 per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923; include the code 0021-8669/09 $10.00 in correspondence with the CCC.

*Associate Professor, Department of Mechanical Engineering.
†Majlesi Branch, Department of Mechanical Engineering; saeed_daneshmand@yahoo.com.
‡Majlesi Branch, Department of Mechanical Engineering; afshin_ahmadina@yahoo.com.

tunnel-testing models is evaluated. Three models constructed using three layer thicknesses and the aerodynamic characteristics are determined and compared with each other. The first model is produced with a fine smooth-surface finish. The second and third models are produced with surface finishes of noticeable distributed roughness as well as low chordwise ridges, due to resin overcure in building layer interfaces. Wind-tunnel tests were performed to assess the effects of surface finish on aerodynamic performance. A rocket configuration was chosen for the actual study. Three models are prepared and produced at various conditions for testing in a wind tunnel and determining the aerodynamics coefficients. These models were fabricated from SOMOS NanoTool by stereolithography. The layer thicknesses for each model were 0.025, 0.050, and 0.100 mm. The wind tunnel is an intermittent blowdown tunnel, which operates by high-pressure air flowing from storage to atmosphere conditions. Testing was done over the Mach range of 0.10 to 0.40. All models were tested at angle-of-attack ranges from -4 to $+10$ deg at zero sideslip. Coefficients of normal force, axial force, pitching moment, and lift over drag are shown at each of these Mach numbers.

II. Rapid Prototyping and Stereolithography

Rapid prototyping or layered manufacturing is a fabrication method in which artifacts are constructed layer upon layer by depositing material under computer control. It is widely used for the rapid fabrication of physical prototypes of functional parts, patterns for molds, medical prototypes such as implants and bones, and wind-tunnel models for aerospace [11]. Rapid prototyping is quickly becoming a valuable key for efficient and concurrent engineering. Through different techniques, engineers and designers are now able to bring a new product from concept modeling to part testing in a matter of weeks or months. In some instances, actual part production may even be possible in a very short time. Rapid prototyping has indeed simplified the task of describing a concept to design teams, illustrating details to engineering groups, specifying parts to purchasing departments, and selling the product to customers [12]. The first step in rapid prototyping is to develop a computer model with any CAD model or professional engineer. The volume of this model is then meshed or broken into small elements. Each element is described by the x, y, and z coordinates of the end points and the outward normal. The file containing all these information about the mesh elements is known as the STL file. This file format is readable by most prototyping machines. Having prepared the STL file, there are different technologies available to build rapid-prototyping models. But the following steps are common to all rapid-prototyping methods. The STL file is exported to the software that comes with the rapid-prototyping machine. Support structures are built to hold the part above the plate and they are needed to prop any overhanging part. The fabrication process starts with several layers of latticelike support, and then the machine builds the object layer by layer. When a layer is built, the platform goes down in the vertical direction and another layer is built on the top of the previous layer (Fig. 1). Stereolithography is one of the technologies used in rapid prototyping. Stereolithography creates a tangible three-dimensional object from a CAD drawing by directing ultraviolet laser radiation onto a vat of polymer resin. After being cured in an ultraviolet oven, each piece is then hand-polished and finished to specifications. The end product is an exact model of the three-dimensional drawing, giving designers, engineers, manufacturers, sales managers, marketing directors, and prospective customers the opportunity to handle the new part of the product. In this way, design iterations can be made quickly and inexpensively, guaranteeing companies the best product in the shortest time possible [13]. The flowchart in Fig. 2 shows the different steps that are involved in a stereolithography process. The advantages of rapid prototyping are 1) money savings, 2) quick product testing, 3) fast design improvement, 4) time savings, 5) fast error elimination from the design, and 6) rapid manufacture.

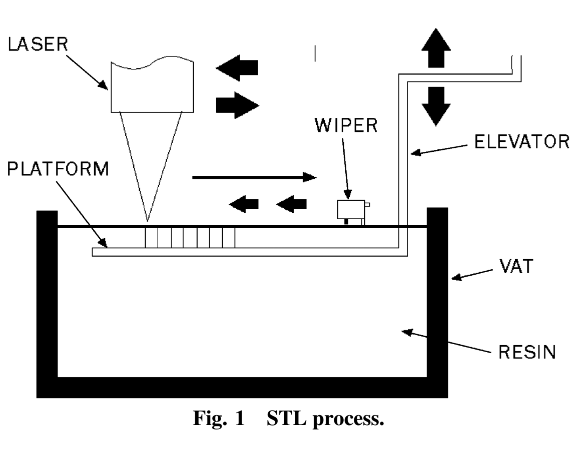

Fig. 1 STL process.

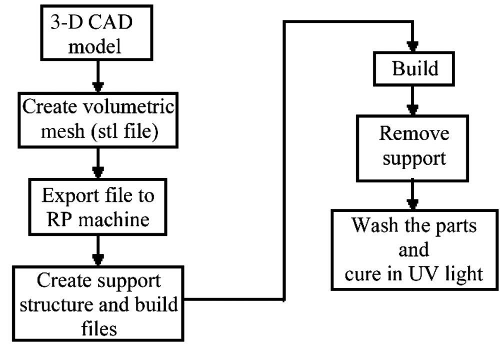

Fig. 2 Building parts in a stereolithography machine.

III. Material Properties

The advent of new rapid-prototyping manufacturing techniques and materials could provide a means to reduce the cost associated with the acquisition of a wind-tunnel model, provided that the data obtained with the rapid-prototype model were of sufficient fidelity to justify their use [14]. The rapid-prototyping process and material selected for the baseline study were the STL by three-dimensional systems using NanoTool. NanoTool produces strong, stiff, high-temperature-resistant composite parts on conventional stereolithography machines. It exhibits superior sidewall quality, along with excellent detail resolution as compared with other composite stereolithography materials. NanoTool's smooth-surface quality and high initial modulus make it an excellent resin for metal plating, a growing application that saves time and money as an alternative to fully metal prototypes. It is also ideal for creating strong, stiff parts that need to resist high temperatures, including wind-tunnel models for aerospace and automotive applications. A third major application area is rapid tooling for injection molding. The material properties of NanoTool[§] are shown in Tables 1 and 2.

IV. Wind Tunnel Model

The geometry used for the precursor study was that of a rocket concept. The rocket was a generic cone followed by a bread-loaf-shaped base with three fins, or fairings, on the base's surface (Fig. 3). Because this model was being fabricated in a RP format, a preliminary CAD file was available for RP model design and fabrication. Three models were fabricated; the layer thicknesses were 0.100, 0.050, and 0.025 mm. The reference dimensions for this configuration are shown in Table 3 and a cross section of the model is shown in Fig. 4.

V. Wind Tunnel

A wind tunnel $0.6 \times 0.6 \times 1$ m in size and with a maximum tunnel speed of 150 m/s is shown in Fig. 5. This will be used for characterizing the power plant at different wind-tunnel speeds. This

[§]Data available online at http://www.Matweb.com/ [retrieved 13 April 2008].

Table 1 Material properties of Somos NanoTool (metric)

American Society for Testing and Materials method	Description	SOMOS NanoTool UV postcure
D638M	Tensile strength	61.7–78.0 MPa
D638M	Tensile modulus	11,000–11,400 MPa
D638M	Elongation at break	0.7–1.0%
D638M	Poisson's ratio	0.34–0.38
D790M	Flexural strength	79–121 MPa
D790M	Flexural modulus	10,200–10,800 MPa
D256A	Izod impact-notched	0.12–0.15 J/m
D2240	Hardness (shore D)	94
D570-98	Water absorption	0.23%

Table 2 Thermal and electrical properties (metric)

American Society for Testing and Materials method	Description[a]	Somos NanoTool UV postcure
E831-00	C. T. E. −40–0°C	25.3–26.0 μm/m · °C
E831-00	C. T. E. 0–50°C	30.4–32.4 μm/m · °C
E831-00	C. T. E. 50–100°C	75.9–87.4 μm/m · °C
E831-00	C. T. E. 100–150°C	90.0–95.7 μm/m · °C
D150-98	Dielectric constant 60 Hz	4.0
D150-98	Dielectric constant 1 KHz	3.9
D150-98	Dielectric constant 1 MHz	3.6
D149-97a	Dielectric strength	15.6–16.8 kV/mm
E1545-00	Glass transition temperature	57–62°C
D648-98c	HDT at 0.46 MPa	225°C
D648-98c	HDT at 1.82 MPa	85–90°C

[a]C.T.E. is the coefficient of thermal expansion, and HDT is the heat distortion temperature.

wind tunnel will also be used for the measurement of aerodynamic characteristics of the aircraft. For small load measurements, a torque sensor is used, and the arm of the torque sensor works as a mechanical amplifier. The transonic wind tunnel is an intermittent blowdown tunnel, which operates by high-pressure air flowing from storage to atmosphere conditions. The transonic test section provides a Mach number range from 0.10 to 0.40. Each Mach number above 0.5 requires a specific set of two-dimensional contoured nozzle blocks. The tunnel flow is established and controlled with a servo-actuated gate valve. The air then passes through the test section that contains the nozzle blocks and test region. Downstream of the test section is a hydraulically controlled pitch sector that provides the capability of testing angles of attack ranging from −5 to +10 deg during each run. The diffuser section has a movable floor and ceiling panels, which are the primary means of control. Table 4 shows the wind-tunnel test-section characteristics. A six-hole probe or a wake rake can be used to determine the wake characteristics of a test subject. Pilot probes are used to measure velocity gradients and to calculate drag through integration. Pressure ports can be used on a test subject to determine the forces on specific parts of a model or

Table 3 Reference dimensions (metric)

Description	Dimension	Unit
Reference area	85	mm
Reference length	210	mm
Moment reference point	160	mm aft of nose

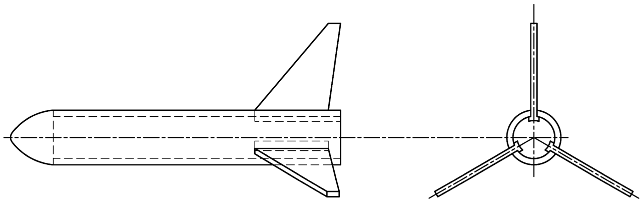

Fig. 4 Cross section of the model.

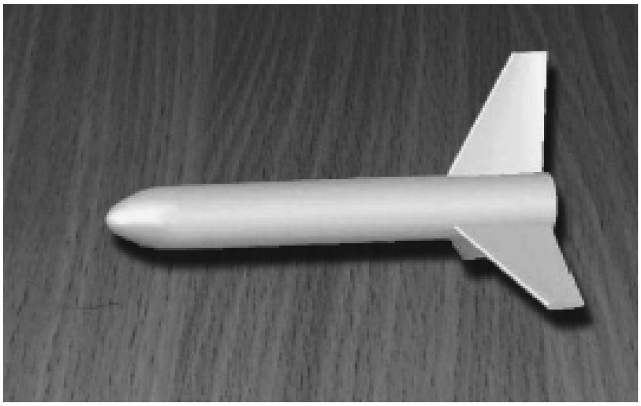

Fig. 3 Model tested.

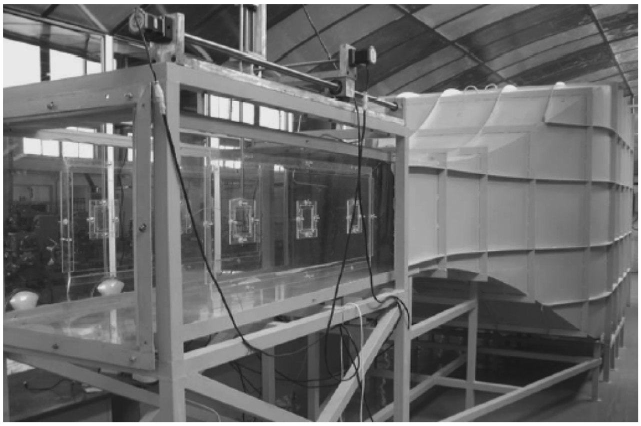

Fig. 5 Wind tunnel.

Table 4 Wind-tunnel test-section characteristics

Maximum speed, m/s	150
Minimum speed, m/s	2
Mach number range	0–0.5

how forces are distributed across a model. A boundary-layer mouse can also be employed to determine the boundary-layer characteristics. Long force and moment data refer to the three forces (lift, drag, and side forces) and three moments (roll, pitch, and yaw moments) that the wind applies to the test subject. Force and moment data are usually measured by the external balance or by an internal balance.

VI. Test Parameters

The model configuration and reference aerodynamic axis system are shown in Fig. 6 [15]. This configuration would indicate possible deflections in the wings or tail due to loads; whether the manufacturing accuracy of the airfoil sections would adversely affect the aerodynamic data that resulted during testing; and whether the model would be able to withstand the starting, stopping, and operating loads in a wind tunnel [16]. The configuration was chosen to test the ability of the RP process to produce accurate airfoil sections and to determine the material-property effects related to the bending of the wing and tail under loading. The effects of layer thickness and surface roughness on the aerodynamic characteristics of the models were determined. The layer thicknesses for each model were 0.100, 0.050, and 0.025 mm. The various RP models were compared to determine which, if any, of these models would be best suited to produce a wind-tunnel model. Testing was done over the Mach range of 0.10 to 0.40 at 4 selected numbers. These Mach numbers were 0.10, 0.20, 0.30, and 0.40. All models were tested at angle-of-attack ranges from -4 to $+10$ deg at zero sideslip.

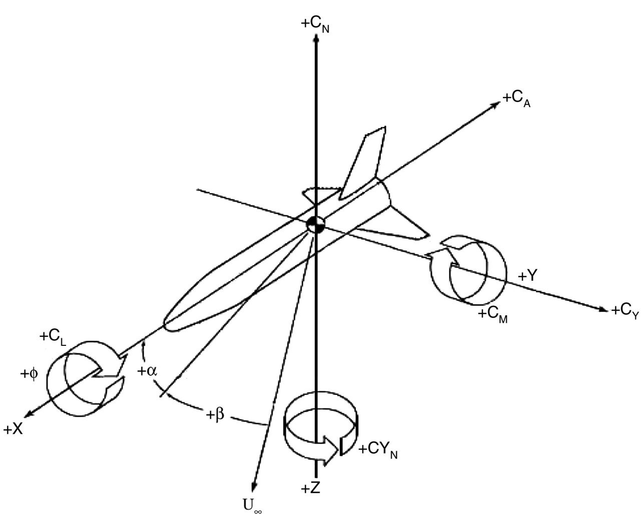

Fig. 6 Model configuration and reference aerodynamic axis system.

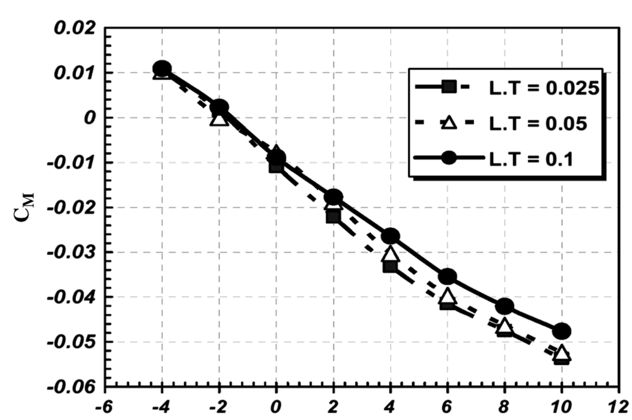

Fig. 7 Comparison of pitching moment coefficient at Mach 0.1 (LT denotes layer thickness).

VII. Result

The RP models did not have as smooth a finish as did the metal model, and so runs were made to determine if the difference in these surface finishes would affect the aerodynamic characteristics. A surface roughness was simulated on the models by various layer thicknesses. Testing was done over the Mach range of 0.10 to 0.40 at 4 selected numbers. Coefficients of normal force, axial force,

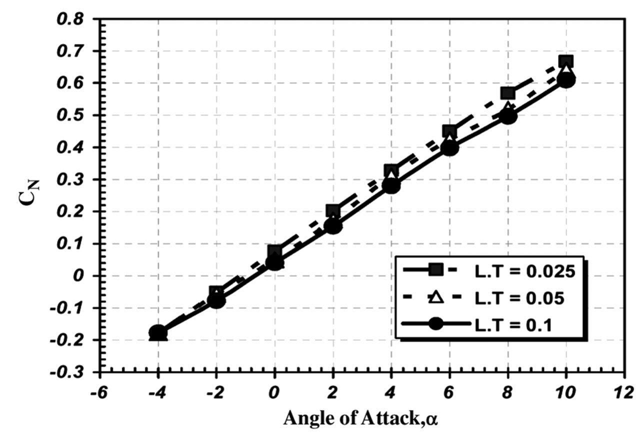

Fig. 8 Comparison of normal force coefficient at Mach 0.1.

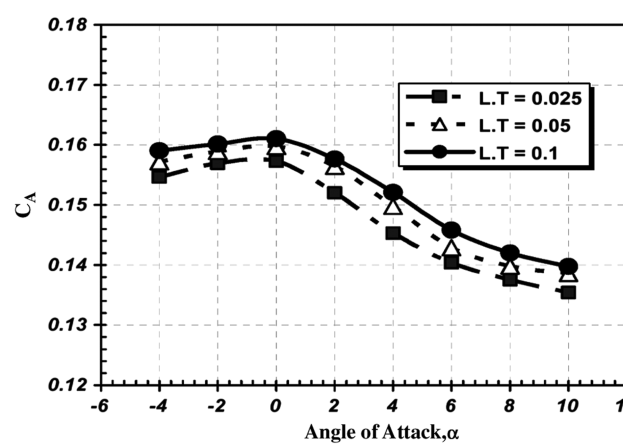

Fig. 9 Comparison of total axial force coefficient at Mach 0.1.

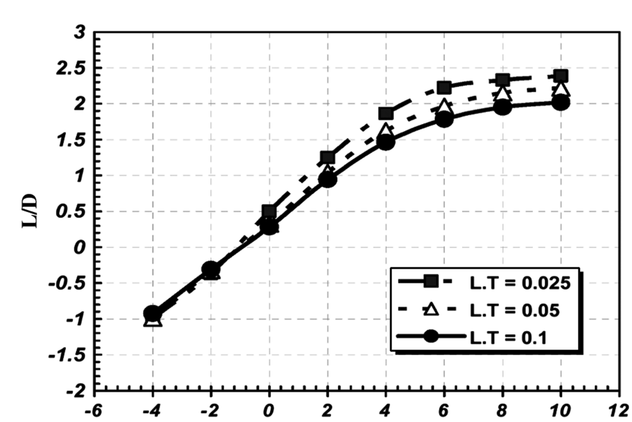

Fig. 10 Comparison of lift over drag at Mach 0.1.

pitching moment, and lift over drag are shown at each of these Mach numbers. The study showed that between Mach numbers of 0.10 to 0.40, the longitudinal aerodynamic data showed good agreement between the STL models up to about a 10 deg angle of attack, when it started to diverge due to assumed STL model surface bending under higher loading (Figs. 7–20). The greatest difference in the aerodynamic data between the models at Mach numbers of 0.10 to 0.40 was in total axial force (Figs. 9, 13, 17, and 21). The study revealed that between Mach numbers of 0.10 to 0.40, the longitudinal aerodynamic data or data in the pitch plane showed approximately a 2 deg shift in the data between the model with a layer thickness 0.025 mm and other models for the pitching moment (Figs. 7, 11, 15, and 19), and between Mach numbers of 0.10 to 0.40, all the models showed good agreement in normal force (Figs. 8, 12, 16, and 20). Between three models (0.025, 0.050, and 0.100 mm) only a small shift in the data was noticed at lift over drag (Figs. 10, 14, 18, and 22). Note that longitudinal aerodynamic data at subsonic Mach numbers showed a slight divergence at higher angles of attack when compared with different layer thicknesses.

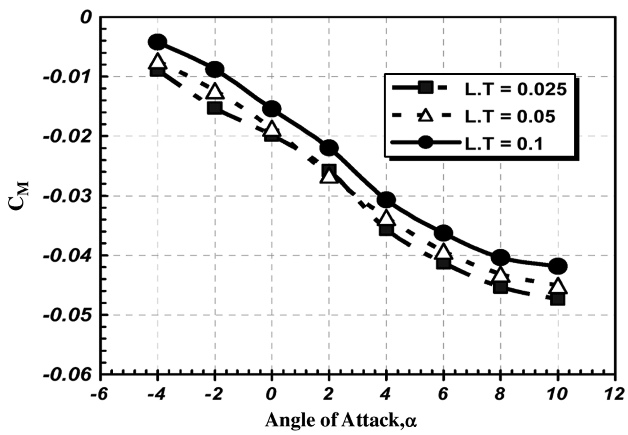

Fig. 11 Comparison of pitching moment coefficient at Mach 0.2.

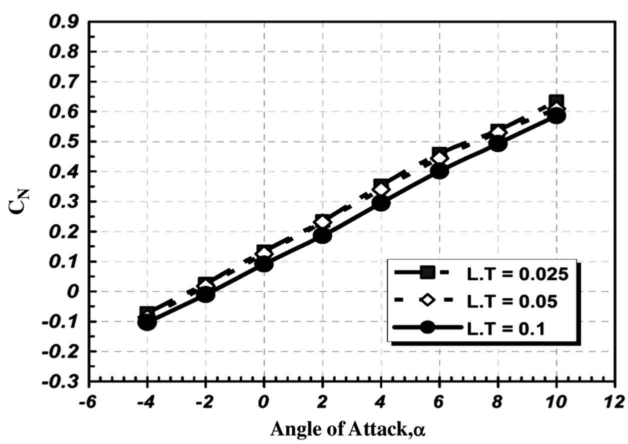

Fig. 12 Comparison of normal force coefficient at Mach 0.2.

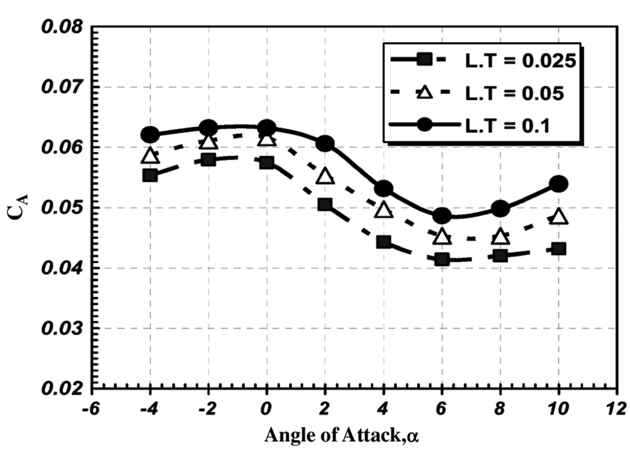

Fig. 13 Comparison of total axial force coefficient at Mach 0.2.

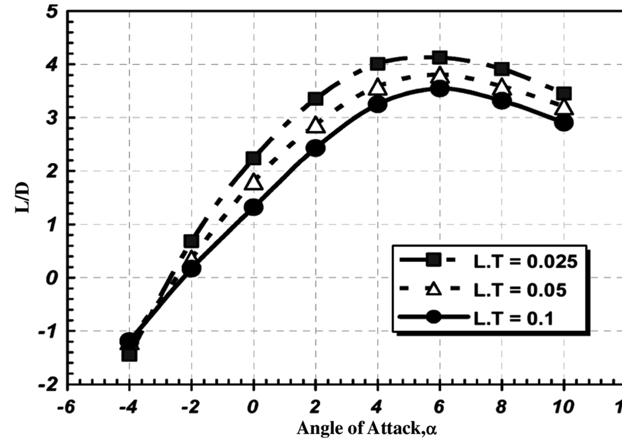

Fig. 14 Comparison of lift over drag at Mach 0.2.

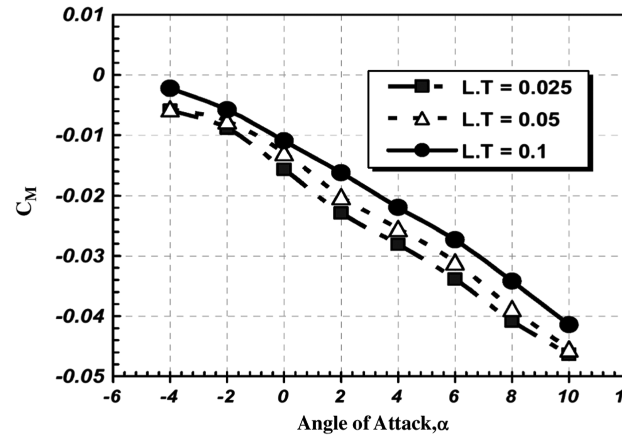

Fig. 15 Comparison of pitching moment coefficient at Mach 0.3.

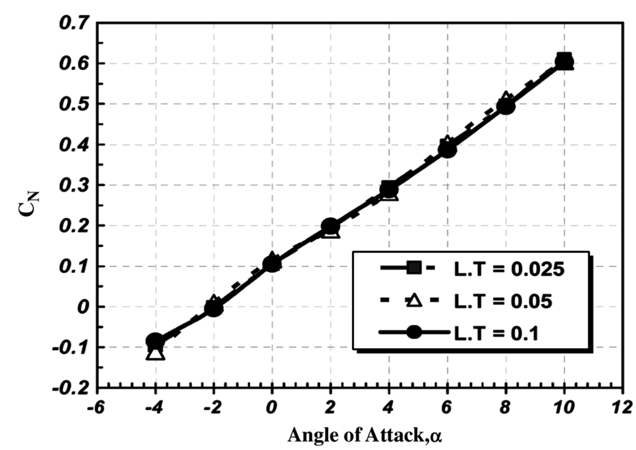

Fig. 16 Comparison of normal force coefficient at Mach 0.3.

VIII. Data Accuracy

The data accuracy resulting from the precursor test can be divided into two sources of error or uncertainty: the dimension of the models

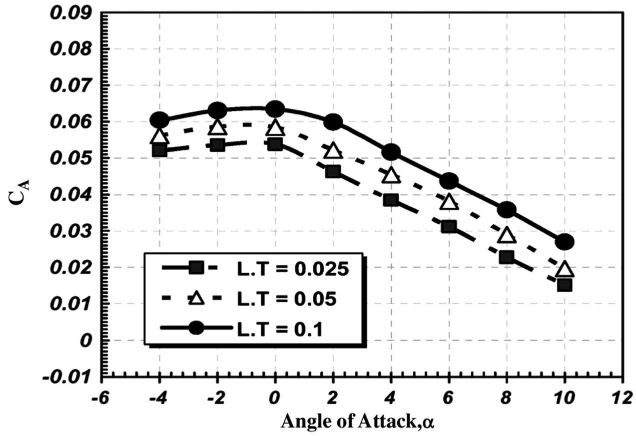

Fig. 17 Comparison of total axial force coefficient at Mach 0.3.

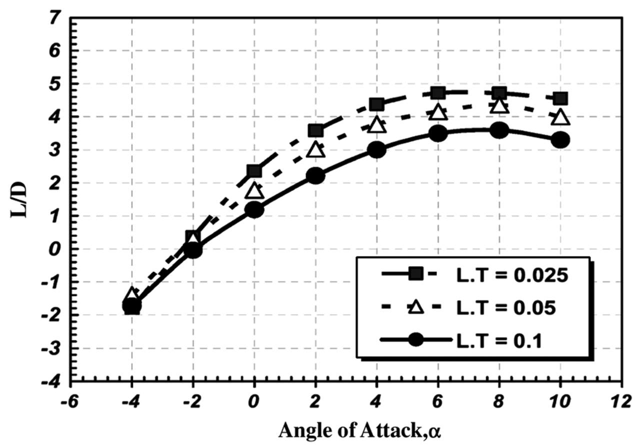

Fig. 18 Comparison of lift over drag at Mach 0.3.

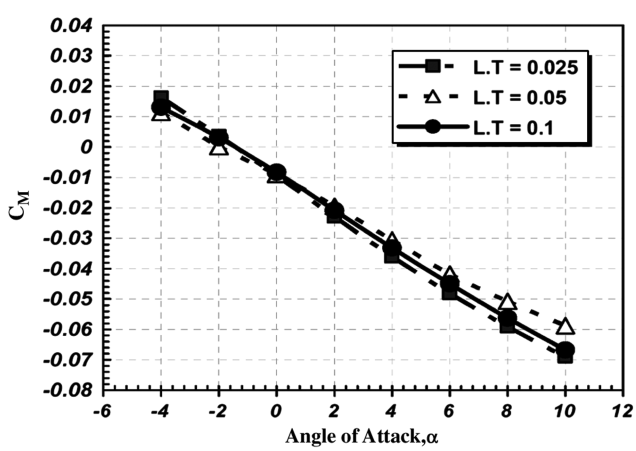

Fig. 19 Comparison of pitching moment coefficient at Mach 0.4.

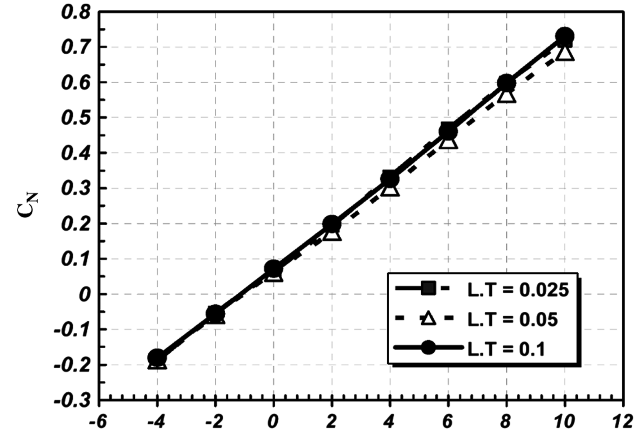

Fig. 20 Comparison of normal force coefficient at Mach 0.4.

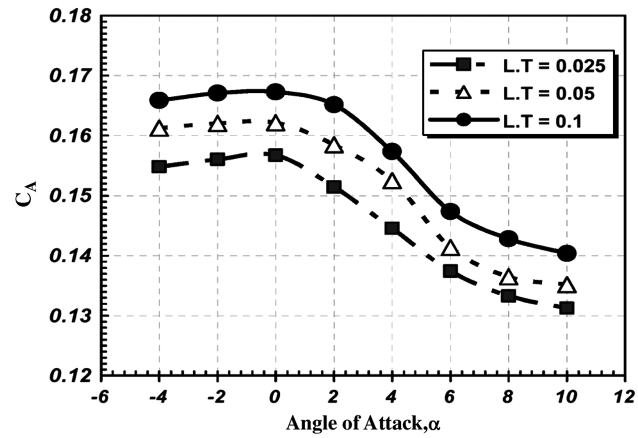

Fig. 21 Comparison of total axial force coefficient at Mach 0.4.

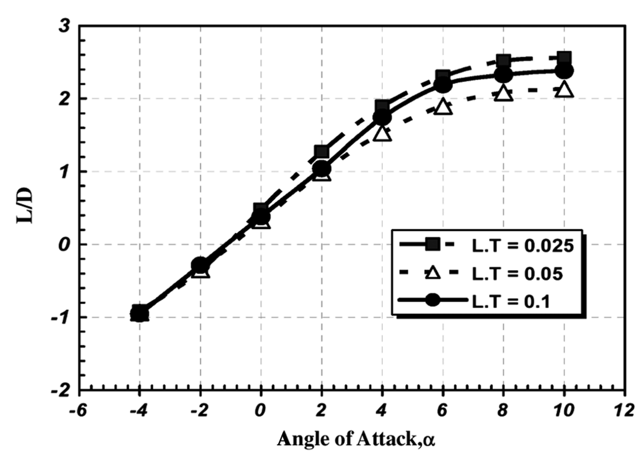

Fig. 22 Comparison of lift over drag at Mach 0.4.

and the data acquisition system. Each of these factors will be considered [17]. The dimensions of the three models must be considered. A comparison of model dimensions is shown in Table 5. The dimensions of models must be compared with the CAD model. The contours of the models used in this test were measured at two wing sections, vehicle stations, tail sections, and the x–y and x–z planes. Two sectional cuts were made on each wing, left and right; two on the body; two on the vertical tail; and one cut in the x–y and x–z planes. This shows a representation of the maximum discrepancy in model dimensions relative to the baseline CAD model used to construct all the models at each given station. The standard model tolerance is 0.1 mm.

IX. Conclusions

Rapid-prototyping materials and methods have been considered as a potential source of improvement to conventional wind-tunnel models. It is clear that the increased use of RP components in wind-tunnel models could dramatically reduce the cost and time associated with wind-tunnel model fabrication. The aerodynamic data show some small discrepancies between the three model types. In these graphs, it can be seen that layer thickness does have an effect on the

Table 5 Model dimensions compared with the CAD model

Dimensions	Model with 0.025 mm LT	Model with 0.050 mm LT	Model with 0.1 mm LT
Wing L1	0.065	0.085	0.118
Wing L2	0.073	0.093	0.123
Wing R1	0.063	0.095	0.110
Wing R2	0.065	0.100	0.108
Body 1	0.060	0.083	0.120
Body 2	0.055	0.078	0.119
Tail 1	0.059	0.085	0.101
Tail 2	0.050	0.091	0.131
x–y plane	0.053	0.079	0.109
x–z plane	0.062	0.075	0.123

aerodynamic characteristics up to high speeds, where the effect is less drastic than at lower Mach numbers. The application of surface roughness had little effect on the aerodynamic characteristics except for axial force and its derivative coefficients. In general, the longitudinal aerodynamic data for each model are within 4%. The wind-tunnel models constructed with any layer thickness are used in subsonic and transonic wind-tunnel testing for initial baseline aerodynamic database development. At transonic Mach numbers, the majority of the configurations started diverging at about an 8 to 10 deg angle of attack, due to the higher loads encountered by the models. The accuracy of the data is lower for models that have less surface roughness, but is quite accurate for this level of testing. Discrepancies of less than 3% in the aerodynamic data between the models are acceptable for this level of preliminary design or phase studies. Using models with high layer thickness will provide a rapid capability in determining the aerodynamic characteristics of preliminary design over a large Mach range. This range covers the transonic regime, a regime in which analytical and empirical capabilities sometimes fall short. The cost and time for models that are constructed with high layer thickness is less than models with low layer thickness.

References

[1] Gibson, T. M., U.S. Patent Application for “Wind Tunnel Testing,” Docket No. P- 7127942, filed 31 Oct. 2006.

[2] Springer, A., Cooper, K., “Application of Rapid Prototyping Methods to High Speed Wind Tunnel Testing,” *Proceedings of the 86th Semiannual Meeting Supersonic Tunnel Association*, AIAA, Reston, VA, Oct. 1996.

[3] Karalekas, D., and Antoniou, K., “Composite Rapid Prototyping Overcoming the Drawback of Poor Mechanical Properties,” *Journal of Materials Processing Technology*, Vol. 153–154, Nov. 2004, pp. 526–530.
doi:10.1016/j.jmatprotec.2004.04.019

[4] Hildebrand, R. J., and Eidson, R. C., “Development of a Low Cost, Rapid Prototype Lambda Wing-Body Wind Tunnel Model,” 21st AIAA Applied Aerodynamics Conference, Orlando, FL, AIAA Paper 2003-3818, 23–26 June 2003.

[5] Chuck, R., and Thomson, V., “A Comparison of Rapid Prototyping Techniques Used for Wind Tunnel Model Fabrication,” *Rapid Prototyping Journal*, Vol. 4, No. 4, 1998, pp. 185–196.
doi:10.1108/13552549810239030

[6] Trowmans, G., Winpenny, D., “Rapid Manufacturing,” *4th European Conference on Rapid Prototyping & Manufacturing*, Univ. of Nottingham, Belgirate, Italy, 2002, pp. 653–670.

[7] Bocking, C., Jacobson, D. M., Sangha, S. P. S., Dickens, P. M., and Soar, R., “The Production of Large Rapid Prototype Tools Using Layer Manufacturing Technology,” *Journal of Technology*, Vol. 14, No. 2, 1997, pp. 110–114.

[8] Heisler, R. R., and Ratliff, C. L., U.S. Patent Application for a “Rapid Prototype Wind Tunnel Model and Method of Making Same,” Docket No. P- 6796171, filed 31 May 2004.

[9] Daneshmand, S., Adelnia, R., and Aghanajafi, C., “The Effect of Layer Thickness on Aerodynamic Characteristics of Wind Tunnel RP Models,” *Journal of Fluid Science and Technology*, Vol. 3, No. 1, 2008, pp. 22–30.
doi:10.1299/jfst.3.22

[10] Daneshmand, S., Dehghani, A. R., and Aghanajafi, C., “Investigation of Surface Roughness on Aerodynamics Properties,” *Journal of Aircraft*, Vol. 44, No. 5, Sept.–Oct. 2007, pp. 1630–1634.
doi:10.2514/1.28030

[11] Cho, I. L., Choi, K., and Song, Y., “Development of a New Type Rapid Prototyping System,” *International Journal of Machine Tools and Manufacture*, Vol. 40, No. 12, 2000, pp. 1813–1829.
doi:10.1016/S0890-6955(99)00086-3

[12] Upcraft, S., and Fletcher, R., “The Rapid Prototyping Technologies,” *Assembly Automation*, Vol. 23, No. 4, 2003, pp. 3308–3318.

[13] Onuh, S. O., “Rapid Prototyping Integrated Systems,” *Rapid Prototyping Journal*, Vol. 7, No. 4, 2001, pp. 220–225.
doi:10.1108/EUM0000000005896

[14] Williams, R. E., Komaragiri, S. N., Melton, V. L., and Bishu, R. R., “Investigation of the Effect of Various Build Methods on the Performance of Rapid Prototyping ,” *Journal of Materials Processing Technology*, Vol. 61, Nos. 1–2, 1996, pp. 173–178.
doi:10.1016/0924-0136(96)02483-1

[15] Springer, A., “Evaluating Aerodynamic Characteristics of Wind-Tunnel Models Produced by Rapid Prototyping Methods,” *Journal of Spacecraft and Rockets*, Vol. 35, No. 6, 1998, pp. 755–759.
doi:10.2514/2.3412

[16] Springer, A., Cooper, K., and Roberts, F., “Application of Rapid Prototyping Models to Transonic Wind Tunnel Testing,” 35th AIAA Aerospace Sciences Meeting, AIAA Paper 97-0988, Jan. 1997.

[17] Springer, A., Cooper, K., “Comparing the Aerodynamic Characteristics of Wind Tunnel Models Produced by Rapid Prototyping and Conventional Methods,” 15th AIAA Applied Aerodynamics Conference, AIAA Paper 97-2222, June 1997.