Wind Tunnel Model - Fabrication Challenges

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Abstract - Wind tunnel testing of scaled down model of flight vehicles is a must to generate aerodynamic data. Maintaining geometrical similarity between wind tunnel model and prototype is of prime importance during fabrication of such wind tunnel models. This not only requires accurate NC tool path generation for aerodynamic profile but also execution of the same through a wide variety of precise CNC machines selecting optimum cutting parameters. It was required to machine a wind tunnel model in Defence Research & Development Laboratory, Hyderabad using its existing fabrication facilities. Fabrication of different components of such a wind tunnel model and complexities associated with it has been presented in this paper.

Keywords - *Wind tunnel model, prototype, aerodynamic, fabrication, CNC*

I. INTRODUCTION

Designing of aerospace components are becoming more challenging day by day. Wind tunnel testing on scaled down model of flight vehicles is necessary to validate the aerodynamic data predicted by these analytical and computational techniques. This is the reason that the testing of wind tunnel model is still an integral part of development phase of any new aerospace system. The two-simulation parameters that govern the wind tunnel test are geometric similarity and dynamic similarity. Dynamic similarity means the flow parameters like Mach number; Reynolds number should be same as those in actual flight. From fabrication point of view, it is necessary to maintain geometric similarity (i.e. the model should be geometrically similar to the prototype) and hence, it is required to machine complex geometries with stringent dimensional tolerances and high quality of surface finish. To meet all these requirements, proper tooling should be selected and the components should be efficiently machined by optimum cutting parameters. In the present paper, the complexities involved in machining of wind tunnel model assembly components have been discussed in detail.

II. MODEL DESCRIPTION

The design of a wind tunnel model is a combination and tradeoff of several requirements such as cross section area of the available and economical wind tunnel, actual size and shape of the missile to be evaluated, actual performance (speed, Mach number) of the air vehicle, similarity parameters, Reynolds number, materials and production process of the model and more. This model of version as shown in Fig. 1, scaled at 1:7, consists of 4 body sections viz. Nose Section, Section-II, Mid Section or Balance Section and Wing & Tail section. The model also consist wire tunnels which are splitted into three parts and screwed on to section II, III and IV to simulate the actual flight situation. The Wings are located on section-IV at four orthogonal positions. The Tail panels with zero control deflection can be fixed in line with Wings.

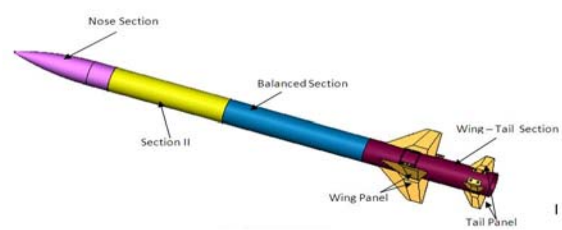

Fig. 1: CAD Model

III. MATERIAL SELECTION

The material selection is based on the strength and stiffness needed to resist the wind forces in the tunnel and also the durability. In this model the nose section and section –II are made of aluminum alloy 2014 for their light weight & higher strength to weight ratio. Maraging steel of 250 grade has been selected in the balance section and the wing-tail section for their higher strength. 17-4PH steel is used for Wings and Tail panels. Maraging steel 250 grade here used in solutionised condition with hardness of 48-52 HRc and 17-4PH steel used in H1025 condition with hardness of 35-42HRc to achieve the UTS of 1758MPa and 1172MPa respectively.

IV. CRITICALITIES IN MANUFACTURING

The main consideration in determining the overall model architecture is the limitation on maximum part size, which did not allow fabrication of the whole span as one piece. All this led to a configuration that consisted different parts as described earlier. Due to the different parts configuration it is mandatory to have about 'zero' mismatch between the all sections. The scale down model required higher geometrical and dimensional accuracy in the order of 10micron with good surface finish in the order of N6 as compared to the actual prototype hardware.

The process and the sequences are selected keeping assembly requirements, the type of material used, heat treatment requirement and geometrical & dimensional tolerances to be achieved. As the model is 1:7 scaled down, so the accuracy requires 7 times more compared to actual prototype. This needs proper material selection to achieve required geometrical and dimensional accuracies without any distortion during machining as well as assembly. To keep in mind, the above requirements different type of materials having higher strength is selected for sections, wings and tail panels. Finish machining is planned after heat treatment to achieve better surface finish and geometrical accuracies. To achieve model build repeatability and Interchangeability dowel holes are planned in each joint. Joint configuration in sections are planned in such a way so that all the fastening and positional holes can be transferred from one section to another to avoid any mismatch and correct fitment. The manufacturing tolerances have been chosen in maximum material condition and the section has been planned to machine separately to get near zero mis- match in assembly.

Nose cone (as shown in Fig. 2) is the front part of the model has a D/L ratio of 1:4 approximately. It has an aero dynamical (ogive) profile to reduce the air drag. It consist a cylindrical body merged with an ogive profile terminated gradually to match with the radius of the nose tip requires machining of whole part in a single machining setup. After creating programme correctness is verified with dimensions and co-ordinates given in drawing. A special thread mandrel is designed to minimize the deflection and vibration during machining. Turning, step turning and outer profile machining is carried out in the same set-up to ensure co-axiality of the features.

Fig. 2: Nose Cone

Section-II (as shown in Fig. 3) requires correct matching between the two sides by sections. Due to aluminum material and thin wall with more length it is very difficult to control the ovality of the Outer diameter. A special mandrel with locating diameter is developed to ensure the correct dimensions and control the ovality for matching with the Nose Cone.

Fig.3: Section-II

Section-III (as shown in Fig. 4) which is also called as balanced section accommodates sting-type strain-gauge to measure forces in terms of strain. Criticalities involves is accurate matching the main balance interface with balanced section to support the sting-type strain-gauge. Accuracy of the strain gauge deflection depends on the proper fitment between the main body and the strain gauge to reduce deflection losses due to air gap. This requires accuracy between the interfaces is in the order of 5µm**,** honing process has been selected to achieve it. Process involves machining of pre honing bore of diameter 38mm with 20µm tolerance over a length of 185mm. Due to concentricity and higher tolerance value it is very essential to machine the bore from one end only. The maximum permissible tolerance on taper is 50µm. A special carbide boring bar has been used to machine this bore to avoid vibration and chattering mark over the machined surface. This bore has been finished as per pre-honing requirements and later the final honing and interfacing with balance has been done. Another criticality of this section is drilling and boring two flat bottom holes with angular accuracy of +/-3'. These drilling of holes are carried out in Jig boring machine by holding the job in rotary table having rotation accuracy of one second and tilting accuracy of one minute with a special set-up (as shown in Fig. 5).

Fig.4: Section-III

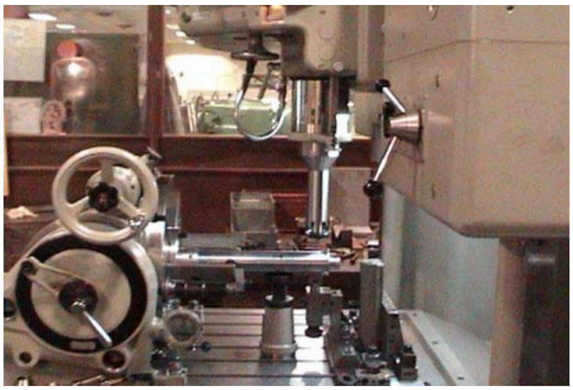

Fig. 5: Machining set-up for Section-III

Section IV (as shown in Fig. 6) also called wing-tail section, having slots to accommodate wings and tail panels. The criticalities involve maintaining orthogonality during machining of wing as well as tail mounting slots within 5minutes in-order to fulfill the assembly requirements. It also requires the zero mismatches (same line of sight) between the wing and tail slots. The machining of dowels holes for positioning & orthogonality is planned in Jig-boring, but the machining of radial slots for mounting tail panels is carried out in Electric Discharge Machining and orthogonality is achieved by taking the reference of pre drilled dowel holes.

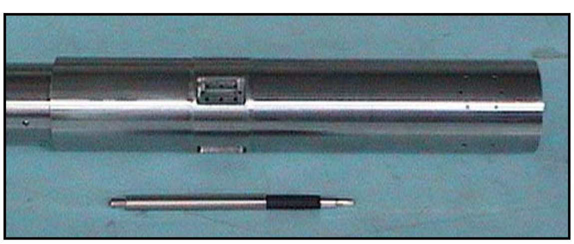

Fig. 6: Section-IV

The wing & tail panels having bi-directional angular profile are configured as separate bodies and made for different deflection angles to simulate the actual flight condition. Wing Panels are responsible to generate necessary lift for the vehicles during flight. Both the wings and the wings base had been integrated as a single body to avoid assembly inaccuracies.

Tail panel are responsible for direction control of vehicle. It can change its orientation depending on flight requirements. Tails and tail base is made as two single pieces (shown in Fig. 7) welded together using fixture as shown in Fig. 8 to ease manufacturability and to reduce material wastage. To machine such angular surfaces, the component is required to be tilted at different calculated angles, which was accomplished by universal sine table. For a single angle sine table different setting is required for machining different angles e.g. leading edge angle, trailing edge angle, roots to tip angle. An extra material is planned on the tip side to provide the support and reference plane for grinding of angular planes as shown in Fig. 9 and 10. To reduce the deflection/ distortion in wing and tail panels, balance machining with proper fixturing is carried out.

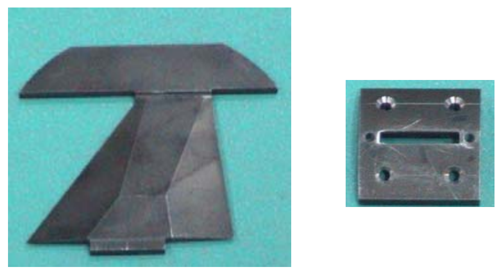

Fig. 7: Tail panel and Tail Base

Fig. 8: Welding Fixture for Tail panel with Tail base

Fig. 9: Tail Panel Assembly

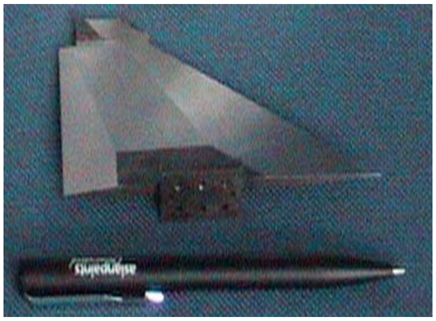

Fig. 10: Wing panel

V. CONCLUSION

Wind Tunnel Model of 1:7 Scale was fully developed (shown in Fig. 11) in DRDL and has been Tested at NAL Bangalore. CMM (Co-ordinate Measuring Machine) has been used for inspection overall dimensions and checking of balance axis shift as well as the orthogonality and the canting of the wing and tail panels. The inspection report results are directly proportional to the profile form tolerances and surface finish and dimensions as per the design requirements. The process for model manufacturing is established successfully. Proper assembly sequence was established to obtain required fitment. Part simplification approach is used has resulted in reducing the lead time and machining cost.

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Fig. 11: MODEL Assembly.

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