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# Half Model Testing for Canard of a Hybrid Buoyant Aircraft

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***Abstract*****—**Due to the interference effects, the intrinsic aerodynamic parameters obtained from the individual component testing are always fundamentally different than those obtained for complete model testing. Consideration and limitation for such testing need to be taken into account in any design work related to the component buildup method. In this paper, the scaled model of a straight rectangular canard of a hybrid buoyant aircraft is tested at 50 m/s in IIUM-LSWT (Low Speed Wind Tunnel). Model and its attachment with the balance are kept rigid to have results free from the aeroelastic distortion. Based on the velocity profile of the test section's floor; the height of the model is kept equal to the corresponding boundary layer displacement. Balance measurements provide valuable but limited information of overall aerodynamic behavior of the model. Zero lift coefficient is obtained at -2.2° and the corresponding drag coefficient was found to be less than that at zero angle of attack. As a part of the validation of low fidelity tool, plot of lift coefficient plot was verified by the experimental data and except the value of zero lift coefficients, the overall trend has under predicted the lift coefficient. Based on this comparative study, a correction factor of 1.36 is proposed for lift curve slope obtained from the panel method.

***Keywords*****—**Wind tunnel testing, boundary layer displacement, lift curve slope, canard, aerodynamics.

## I. INTRODUCTION

ONE way of determining the accuracy of any analytical technique is to compare data so obtained with that from a scaled down model testing in wind tunnel at comparable Reynolds number [1]. To achieve the same Reynolds number as of the real application, the kinematic viscosity or velocity has to be altered. In most wind-tunnels air at atmospheric pressure is used, and the only option left is to increase the velocity. Often it is not possible to increase much the velocity, so the results from wind-tunnel experiments are not available at the required full scaled Reynolds number. Moreover, in wind tunnel testing, the drawback is that small scale models are often not full scale ditto. This is due to the scaling issues as some minute geometric parameters are washed out [2]. One of the prospective solutions of above mentioned issues is to go for half model testing (HMT). However, HMT is also not free from the problems. The merits and de-merits of both testing methods are briefly shown in Table I.

TABLE I
COMPARISON OF HALF AND FULL MODEL TESTING

| S. No. | Parameters | Half Model | Full Model |
|---|---|---|---|
| a | Operating envelop of Reynolds number | Increases | Limited due to size of geometry |
| b | Capturing the effect of change in wing shape | Aero data will improve for twist; either aerodynamic or geometric | Data quality is less in comparison with half model |
| c | Model's structural rigidity/strength or stiffness | Improves | Limited due to allowable space of test section |
| d | Sting-support interference effects | Absent | Have a major effect |
| e | Minor changes in model build | Many uncertainties will arise | Restricted uncertainties |
| f | Sidewall effects | Wall's boundary layer and high alpha issues | Not have high impact on results |
| g | Penalty in drag | Increment in drag due to undesirable flow at junction | Incorporation of drag due to additional components |
| j | Manufacturing cost | Less | Quite high |

If we attach the wing's model with the external strut then there will be additional interferences due to strut. Also, the presence of strut does affect the flow, especially in the area which is located at its attachment. In the present study, a scaled model of canard, consisting of NACA 65(3)-218 airfoil of a hybrid buoyant aircraft is tested in IIUM-LSWT. Its geometric parameters are selected such that the exposed span and its corresponding chord are modeled by ignoring the side wall effects of the tunnel floor. Therefore, the results so obtained from the wind tunnel should not be multiplied by two as it is there for half model testing. Brief details of the configuration are given in Section II for quick reference.

XFLR, an open source code, especially for wing design has been used in the past for a good comparative study of the analytical results with those obtained from the experimental testing of a model manufactured by using the rapid prototype [16]. A good comparison of lift curve slope is obtained in this study. Authors are of the point of view that although the model was geometrically similar but it can have different aeroelastic deformations for a given combination of Reynolds number. A good numerical simulation can rule out the effect of such deformations. Hence the evidence of the success of such comparison would be useful in assessing the data quality of the model manufactured by using rapid prototyping technique. It was perhaps the motivation to use a rigid model,

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which is tightly connected with the base plate at the tunnel floor.

## II. CONFIGURATION DETAILS

The pictorial view of the configuration is shown in Fig. 1. It contains two vertical stabilizers mounted on either side of horizontal tail, which will give better ground maneuverability of aircraft on runway, especially during taxi and take-off. Moreover, one of the unique features of the configuration is that the horizontal surface is more efficiently loaded because the vertical tails act as winglets. Horizontal tail is at some incidence angle so that positive pitching moment at zero angle of attack can be generated. This incidence decreases the overall lift which is compensated by the lift produced by the canard. The configuration contains wings similar to sailplane's wings; resulting in less induced drag from the wings and hence high glide ratio can be achieved [3].

In HB vehicle, partial lift requirement is fulfilled by the aerostatic force. Since the wings are of the reduced span and have less area owing to body lift; therefore it will result into reduced drag and weight. Additional aerodynamic lift is generated by the hull from the beginning of ground roll in take-off segment [4]. This feature of hybrid lifting hull is beneficial to meet the additional lift requirement in takeoff and perhaps will also save the additional weight requirement due to flaps.

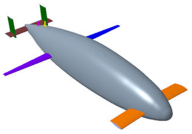


Fig. 1 Pictorial view of hybrid buoyant aircraft

## III. GEOMETRY

The dimensions of the scaled down model of canard along with the dimensions of the test section are shown in Fig. 2. The model's span is 1 m and its chord is 0.25 m. In this way the scaled down factor is just 7.68. The exposed span of the hull is 7.68 m, which corresponds to the aspect ratio of the exposed surface that is equal to 4. The airfoil used for defining the aerodynamic contour of canard surface is NACA 65(3)-218 [5].

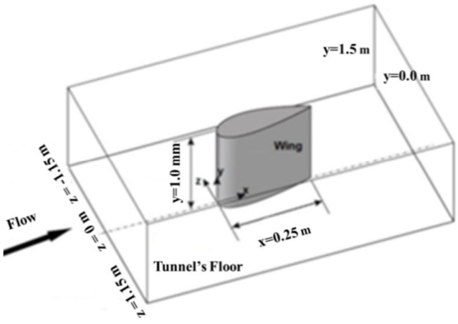


Fig. 2 Geometric details of the scaled down model in test section

## IV. EXPERIMENTAL SETUP

Static tests have been conducted in the IIUM wind-tunnel to obtain the aerodynamic response of the canard. Complete three dimensional model is mounted using a "plate mount" system which permits attachment of the model with the balance and is shown in Fig. 3. By installing a level plate, it is possible to test the model of larger scale, for which higher Reynolds numbers can be achieved. The actual Reynold's number is $3.64 \times 10^6$ (based on the mean geometric chord of the canard) and its corresponding value for sub scaled model is $8.54 \times 10^5$.

Techniques for full/half wing model for sidewall effects seem to be lacking. All that is done so far in order to minimize such effects as much as possible, by displacing the model base from the sidewall by a small distance [6]. This provides some allowance for the inward displacement of the model. However, this change does not ensure zero interference due to the inherent interaction between the model and the wall boundary layer. A number of experimental and numerical studies [7]-[13] are conducted to understand the flow topology, especially the formation of the horseshoe vortex system. However, there is no universal school of thought to define either the gap or the boundary layer suction techniques. Conducting balance measurements on wings require a minimum gap between the wing and tunnel floor to prevent the transfer of unwanted loads to the balance. Kuppa & Marchman [14] observed that a gap as small as 0.1 mm can still influence half wing measurements. Pope [10] also suggests that a small gap of the order of 0.5 % of the span may be allowed which could be a few millimeters wide for a wing with a span of the order of 1 m. Therefore, as per Pope's recommendations [10]; for one meter wing span of model of canard, the gap between the model and tunnel's floor should be equal to 5 mm. However, to the best of authors' knowledge there is no experimental evidence to support this fact. Since most of the references of experimental studies have defined some gap, therefore the absence of a gap may prevent any meaningful balance data being collected. Hence it was decided to first conduct experiments with a gap equal to the boundary layer displacement at 50 m/s.

Fig. 3 Half model tested in IIUM-LSWT

In the present work; boundary layer displacement is estimated by using the velocity profile, which was measured using boundary layer rake for 50 m/s. The rake consists of one static pressure port at the top and twenty total pressure probes, so that the dynamic pressure profiles which determine velocity profiles can be derived. Velocity profiles are then normalized with the boundary layer rake tip velocity, to force and the same is shown below as Fig. 4.

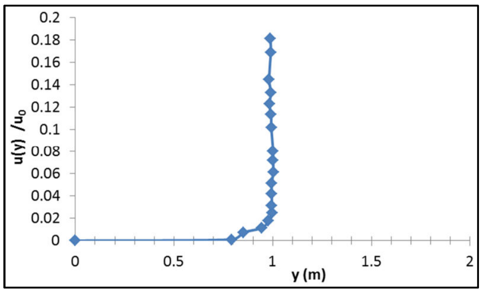


Fig. 4 Variation in $^{u(y)}/_{u_o}$ with respect to $y(x)$

In this figure the x-axis is the distance of the boundary layer point from the wall (*y)* and vertical axis is normalized by the corresponding measured value of the axial velocity; normalized by the maximum velocity i.e. 50 m/s. This dimensionless velocity profile shows that the velocity gradient is steeper in higher velocity regime. Boundary layer displacement $\delta^*$ is then calculated by using (1), taken from [15] and after integration, its value comes out to be equal to 1.5 mm. No adjustment for the boundary layer thickness i.e. 0.99U was carried out as actual velocity profile is now available.

$$\delta^* = \int_0^\infty \left(1 - \frac{u(y)}{u_0}\right) dy \qquad (1)$$

The six axis balance is used to measure the aerodynamic forces for defined range of the incidence angle i.e. ± $20^0$ with increment of only one degree to get a smooth slope of the curve. Trends of variation of $C_D$ and $C_L$ w.r.t angle of attack (α) are shown below in Figs. 5 and 6 respectively:

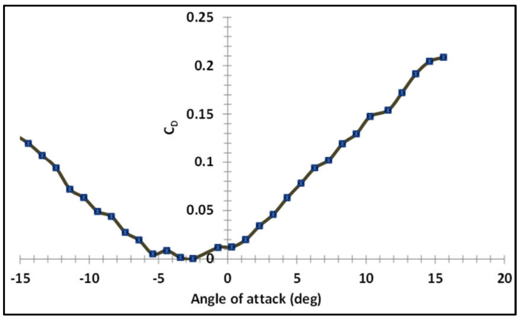


Fig. 5 Variation in $C_D$ with respect to $\alpha$

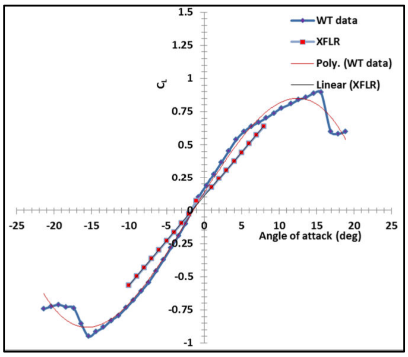
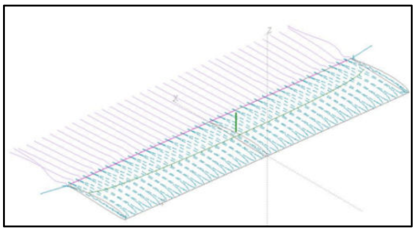


Fig. 6 Variation in $C_L$ with respect to $\alpha$

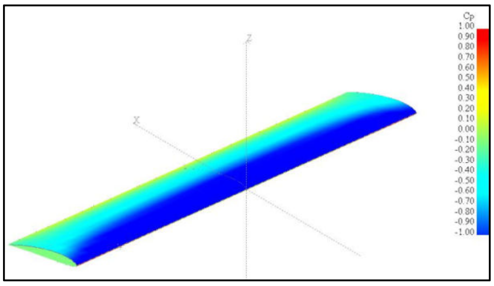
In order to compare the experimental results with the panel method; XFLR software [16] is selected. For the geometry under discussion; coordinates of NACA 65(3)-21 airfoil are first defined and batch analysis is carried out for a long range of Reynolds number in XFLR. Geometry of the wing is then defined for the required chord and span of the wing, similar to that of the sub scale model tested in the wind tunnel. VLM method is selected and lift polar is then obtained at desired velocity of 50 m/s. This method is based on the hypothesis that a lifting wing can be replaced:

> "*By a lifting line and that the incremental vortices shed along the span trail behind the wing in straight lines in the direction of the freestream velocity. The strength of these trailing vortices is proportional to the rate of change of the lift along the span".* [17].

The results so obtained for the $C_L$ for the defined range of $\alpha$ are then overlapped with the experimental results. Streamline plot and the coefficient of pressure are also plotted and the same is shown as Figs. 7 (a) and (b) respectively.



(a) Plot of streamlines



(b) Contours of coefficient of pressure

Fig. 7 Flow visualization by using panel method

In experiments, it is clear that the $C_{L_\alpha}$ (per degree) is high in comparison with those obtained by using the panel method. Its experimental value is 0.0913 and analytical value is 0.0617. Based on these results; it is proposed to apply a correction factor of 1.36 to the analytical value. Moreover, the value of $C_{L_\alpha}$ obtained by using (2) is 0.09 (/deg). $C_{L_\alpha}$ value predicted by using the above mentioned relationship is perhaps same as that predicted by the experiment. It is important to note that (2) will provide the value of $C_{L_\alpha}$ in per radian and for the purpose of comparison of results, that digit has to be then converted into per degree.

$$C_{L_\alpha} = \frac{2\pi A_R}{2+\sqrt{4+A_R}} \tag{2}$$

Irrespective of the difference between the true Reynolds number and that achievable in the wind tunnel, the results of $C_{L_\alpha}$ obtained from this study will be helpful for applying the $C_{L_\alpha}$ with correction factor for the aerodynamic and stability analysis of a canard based model of a HB vehicle. Moreover, the effect of the interaction between the model and the sidewall boundary layers for the model is unknown, which may affect the quality of the comparison between predictions and measurements for this configuration. In this regard, future work will include the study of the effect of the gap/standoff height, like keeping it equal to the boundary thickness where the local velocity is 0.9 times the free steam velocity and look into the overall behavior of the aerodynamic coefficients.

## V.CONCLUSION

Wind tunnel testing was carried out to assess the aerodynamic characteristics of canard of a hybrid buoyant aircraft. In comparison with the experimental data; VLM code underestimates the lift coefficient. This loss of lift increases with incidence, resulting in a reduced lift curve slope. A correction factor is proposed for accurate prediction of the same by using VLM. The comparative study confirms the existence of the relationship of standoff height to be equal to the boundary layer displacement.

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