Study of Vortex Breakdown and Pitch up on a Compound Delta Wing

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DOI: 10.13111/2066-8201.2019.11.2.14

Received: 22 January 2019/ Accepted: 22 May 2019/ Published: June 2019

Abstract: *This paper discusses the calculation of mean pressure on a compound delta wing configuration and its variance to understand vortex breakdown and pitch up on the setup. The configuration of the compound delta wing being used was 50°-60°. The data was used to find the location of vortex breakdown and pitch up over the compound delta wing. It was done using calibration of different pressure ports on span and chord wise location of the wing. The pressure values were then converted to Coefficient of Pressure (Cp) for proper study and comparison.*

Key Words: *Compound* Delta ta *Wing, vortex breakdown, pitch up, Delta wing, Mean pressure*

1. INTRODUCTION

With the strive for faster speed and maneuverability, military air vehicles with variable configurations have clearly been the need of the day. The World today needs a fast fighter with good low-speed flight capabilities for combat. These requirements may be contradictory but this today is the main concern of any aeronautical engineer. Since the 1950's, most fighters had wings optimized for high speed.

Double Delta Wing configuration and Compound Delta Wing configuration are the first examples. Double Delta wing configuration, most common in practice is the one which has the first sweep angle greater than the second sweep in the aft portion of the wing.

Compound delta wings are another type of Delta wing configuration where the first sweep angle is lesser than the second sweep. The basic aerodynamic phenomenon of a delta wing includes the formation of leading edge vortices, their development, and subsequent breakdown.

As per Polhamus theory [1], the lift increases non-linearly with the angle of incidence. The leading edge vortices of the delta wing play a significant role in this enhanced lift. At low angles of attack, vortex-induced lift accounts for around 30% of the total lift but with

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increasing angle of attack, it contributes to the major portion of the lift. However, with increasing angle of attack, Delta wings and Double delta wings experience the problem of Vortex Breakdown.

For a double delta wing, vortices are formed on each of the sweeps. These vortices grow larger with increasing angle of attack and merge together at a particular angle. Interaction of these vortices creates complex flow field on the wing surface and even more increase in vortex lift with further increase in angle of attack.

This leads for undesired forces and moments to develop on the surface and hence causes a disturbance in the flight path.

Another major problem that is widely experienced in Double-Delta and Compound Delta wing is the Pitch-up [2]. It is defined as an abrupt change in the slope of the Cm-α curve such that it is greater than what it was before the pitch-up occurred. The pitch-up occurs at various angles depending on the configuration type and the angle of attack of the aircraft. It can occur as low as 5 degrees on a highly swept cranked wing and on an average it's around 12-15 degrees for a double delta wing [3].

Thus, the pitch-up is mostly associated with vortex breakdown [4], but it also involves outboard flow separation on the surface of the wing.

Vortex Breakdown, on the other hand, plays a crucial role in deciding the lift distribution in a delta wing configuration since leading edge vortices are responsible for creating lift on delta wing configurations [5].

A leading edge vortex on swept wing configuration is created when the flow separates at the leading edge and then reattached downstream on the surface, creating an area of low pressure above the leading edge of the upper surface. This, in turn, creates vortex-induced lift on the surface.

As the angle of attack is increased, the core of the main vortex moves inboard and vortex breakdown takes place on the trailing edge. This breakdown location subsequently moves upstream as the angle of attack is increased even further.

The scope of the study is to investigate the longitudinal aerodynamic characteristics and flow field associated with the compound delta wing. Light combat aircraft (TEJAS) developed by the ADA has a compound delta wing configuration with a forward sweep of 60 degree and rearward sweep of 50 degrees [6].

A previous experimental study conducted on a scaled model of TEJAS shows pitch up at a very less angle of incidence of 7°-10° which is further accompanied by a non-linear increase in lift. Previous CFD study done by ADA shows the formation of the vortex at the outboard portion of the wing and with an increase in angle of attack, vortex starts to spread on the second outboard sweep as well. At around 9 degrees, vortex starts spreading on the entire leading edge [7].

In this paper, we have focused on calculating the mean pressure measurement over different pressure ports and also on showing the variation of static pressure. Like stated previously, pitch up has been a major problem for TEJAS and no thorough study has yet been done on the compound delta wing type to know what factors affect the pitch up and how does it vary in spanwise and axial direction.

2. EXPERIMENT DETAILS

The compound delta wing model was manufactured in the Model shop section at Experimental Aerodynamics Division, National Aerospace Laboratory. Figure 1 shows the picture of an entire model with the setup.

Figure 1 - Entire Model of the Compound Delta Wing with setup

The model consists of an ogive cylinder body having a diameter of 36mm and length of 280mm. The ogive cone has an arc of radius 242.7mm. The diameter and length of the cylinder body are based on the diameter/size of the balance used. The wing is fixed to the body through pins at several locations. The wing geometry has the first sweep of 50° and the following sweep angle of 60°. The first sweep is provided at a 0.25chord location corresponding to the geometry of 60° sweep. The span of the wing geometry is kept at 186mm. The total area of the configuration is 17948.35 mm^2 and mean aerodynamic cord is located at 97.03 mm from the nose. The wing leading edge is located at a distance of 96.01 mm from the nose and the location of c/4 from the nose is 161.54 mm. The trailing edge sweep is 5° to the vertical and the cross section of the wing is rectangular having a thickness of 2mm with a beveled leading edge angle of 8.5°. The body and wing are made out of EN-24 material. The compound delta wing model was manufactured in the NAL Model shop. The selection of the location of pressure ports was done based on the requirement of our study which involved the study of the pressure readings at axial and longitudinal directions.

The mean pressure ports were marked along the wing axially in large numbers to study the formation of the vortex at each location of the wing as shown in Figure 2. An averaged or mean the study of these pressure readings would highlight how vortex develops and finally breaks down giving us a better knowledge of the pitch-up behavior.

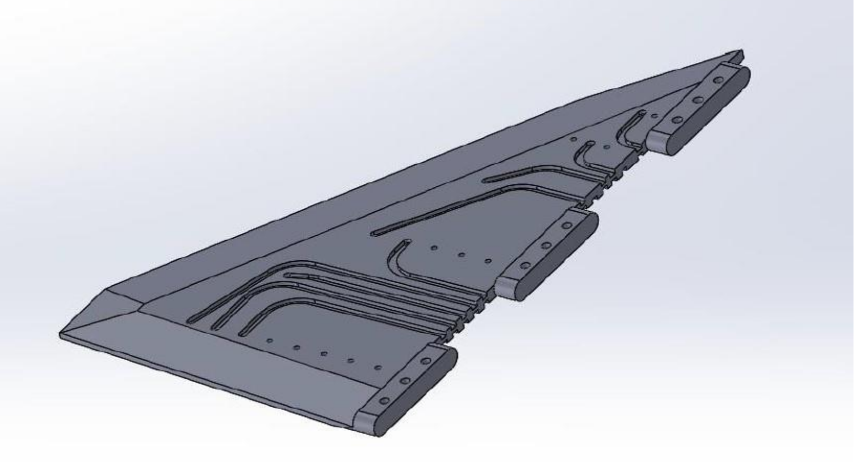

Figure 2 - Location of various pressure ports along the wing

For pressure readings, we manufactured two different wing sets, one with ports and one without it. The wing with a slot was specifically designed to accommodate 20 ports as shown in Figure 2.

The 0.3m transonic wind tunnel is intermittent, blow down type wind tunnel which can produce flow in the Mach number range of 0.2 to 4.0. Compressed air is stored at 10 bars in large reservoirs of about 283m^3 capacities.

To achieve the desired Mach number in the test section, compressed air is discharged through the tunnel circuit in a regulated way. Pressure regulating valve is needed to maintain a constant pressure in the settling chamber, which in turn ensures constant condition in the test section during blow down.

For Subsonic and Transonic Mach number from 0.3 to 1.2, a solid test section of 0.38m height and 0.3m width having slotted walls at the top and bottom, and solid walls at the side is used. For supersonic Mach numbers, nozzle blocks are designed and contoured to provide a desired supersonic Mach number in a 0.3m height ×0.3m width test section.

The 1 ft. The tunnel at present is equipped with nozzle blocks to generate free stream Mach number of 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.2, 2.5, 3.0, 3.5 and 4.0. Operating pressure of tunnel varies with Mach number and is about 1.79 bar (26psia) up to Mach number of 1.4 and 8.5 bars (125psia) at M=4.0.

Reynolds number capability of the tunnel based operating pressures ranges from 4 to 38 million per meter in the Mach number range of 0.2 to 4.0.

The instrumentation system consists of the pressure ports and pressure transducers for pressure measurements. Mean pressure ports were connected to the ESP Transducers.

ESP Pressure Scanners are miniature electronic differential pressure measurement units. The outputs of the sensors are electronically multiplexed through a single onboard instrumentation amplifier at rates up to 50,000 Hz. The scanner used is ESP-16

The number of pressure ports being used is clearly shown in Figure 2. In total, we used 20 pressure ports to capture the mean pressure data over a particular time interval.

The pressure ports were further connected to the transducer and ESP through which we gathered the mean pressure data.

3. RESULTS

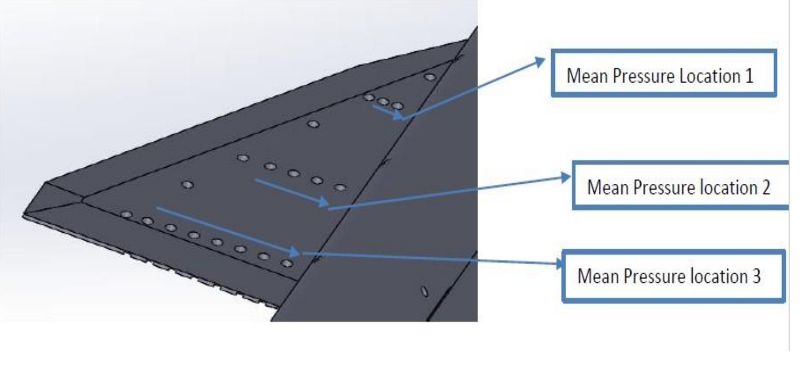

Figure 3 - Location of Mean Pressure ports along the wing

Figure 3 explains the different location of mean pressure ports along which the values were calculated. There are three columns namely Mean Pressure Location 1, 2 and 3 as shown in Figure 3 along which the different pressures were measured.

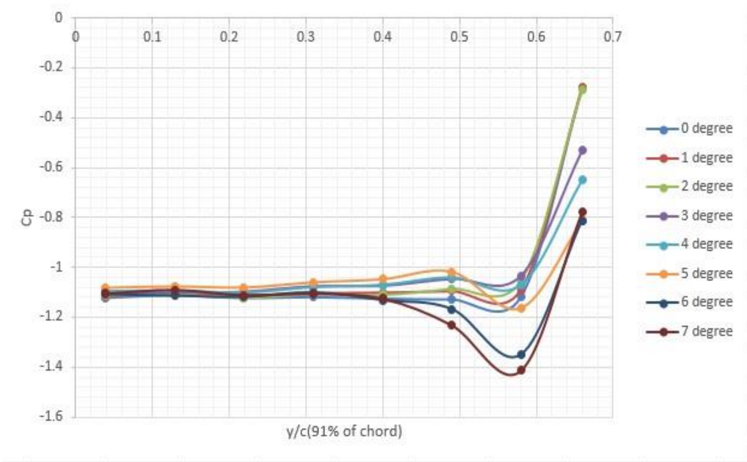

Figure 4 - Variation of Cp from 0-7 degrees at Mean Pressure Location 3 (91% of chord)

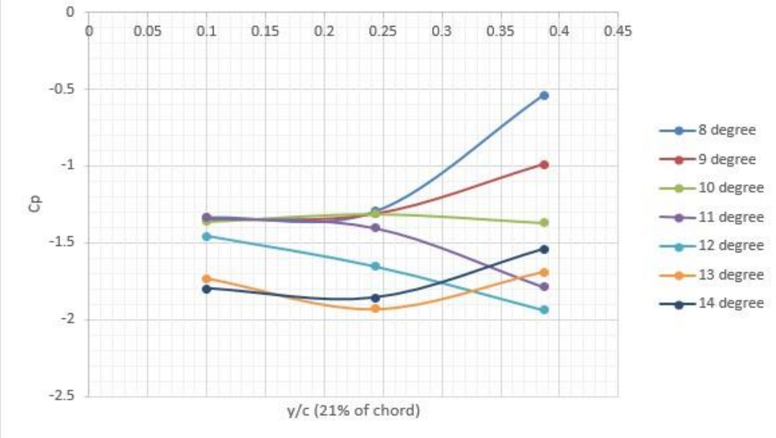

Figure 5 - Variation of Cp from 8-14 degrees at Mean Pressure Location 1 (21% of chord)

Figure 4 and 5 show the variation of Cp at the different spanwise location of the chord varying with the angle of attack.

The mean pressure location 3 corresponds to the location at 91% of a chord with 8 pressure ports in the spanwise direction.

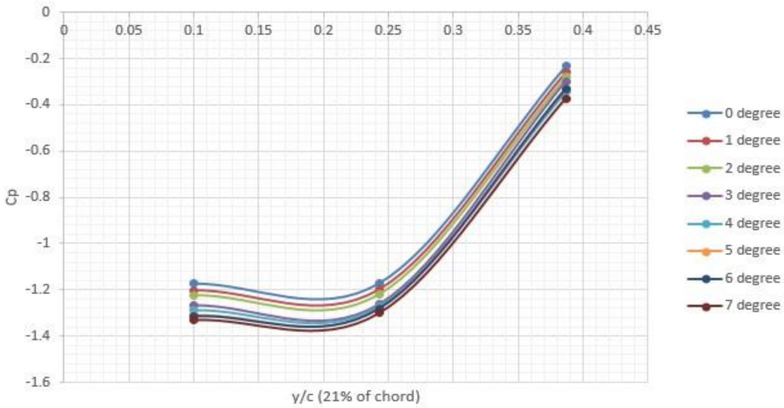

Figure 6 - Variation of Cp from 0-7 degrees at Mean Pressure Location 1 (21% of chord)

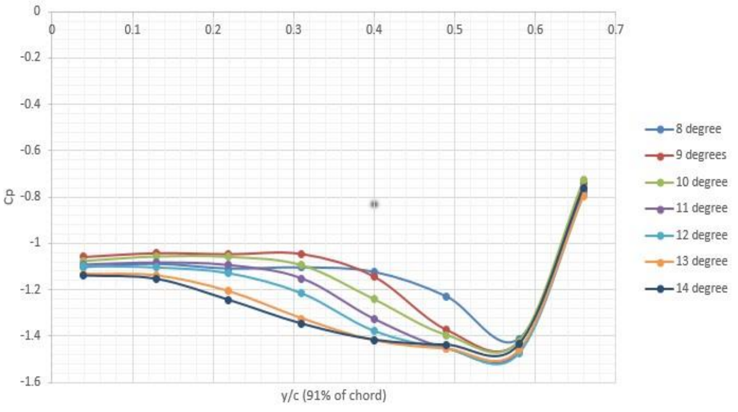

Figure 7 - Variation of Cp from 8-15 degrees at Mean Pressure Location 3 (91% of chord)

Figure 6 and 7 show the variation of Cp at Mean pressure location 1 (21% of chord) with angle varying from 0 to 7 degrees and Mean pressure location 3 (91% of chord) with angle varying from 8 to 14 degrees.

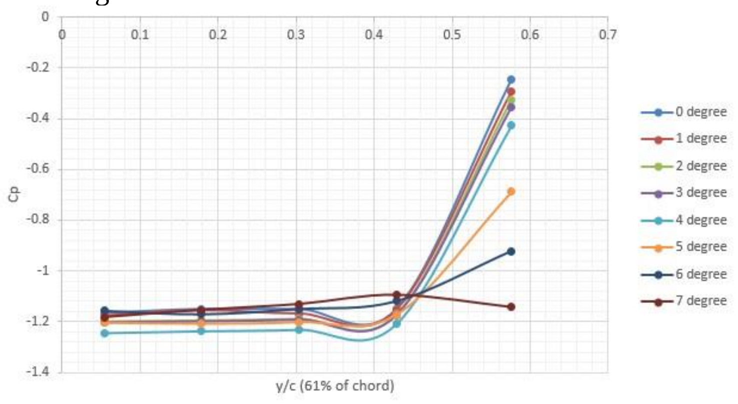

Figure 8 - Variation of Cp from 0-7 degrees at Mean Pressure Location 2 (61% of chord)

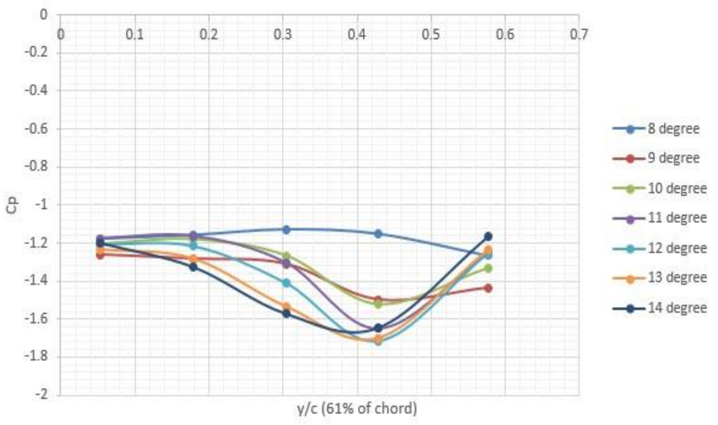

Figure 9 - Variation of Cp from 0-7 degrees at Mean Pressure Location 2 (61% of chord)

Figure 8 and 9 show the variation of Cp at the different spanwise location of the chord varying with the angle of attack.

4. CALCULATIONS

The mean values of pressure were calculated for various angles at a different position of the chord by converting the voltage output into pressure readings. In order to compare the pressure readings over various angles and chord, we converted it into a measurable format, Coefficient of Pressure (Cp). The formula used for the above was $Cp= (P-P_\infty)/q_\infty$. The value of Pressure and velocity were based on wind tunnel parameters as stated above.

5. CONCLUSIONS

Figure 3 and 4 show the variation of Cp (Coefficient of pressure) at 91% of a chord with the angle of attack varying from 0 to 15 degrees. Based on the plot, we can clearly see Cp showing a regular trend which stays constant up to 50% of chord followed by a slight peak when we go further down the span length for an angle up to 5 degrees.

The pressure values showing no significant change till 40% of a chord can be explained by the reason that the vortex core is formed near to the edges and hence the strength at smaller angles is not considerable.

The same reason is applicable to why the plot shows a peak at around 30% of the chord at higher angles of attack.

Degrees and further, the vortex strength increases considerably and hence its effect can be seen on the larger portion of the wing.

The other conclusion we can derive from the pressure reading is the onset of pitch up of the wing. The angle between 6 and 10 degrees shows a sudden peak in the value of Cp. This can be attributed to the onset of pitch up. The effect of pitch up stays strong up to an angle of 10 degrees and starts to become bleak as we increase the angle of attack even further from 12 to 15 degrees. The pressure readings also show a regular trend of abrupt decrease in pressure towards the last port. This can be attributed to the fact that vortex core lies away from this region and hence the strength decreases where the flow is uniform and vortex strength is less compared to its core.

Figure 5 and 6 show the variation of Cp at Mean pressure location 2 (61% of chord) with angle varying from 0 to 15 degrees. As the ports here is located at 61% of the chord, we can see the strength of the vortex increasing. The values of Cp at lower angles of attack namely 0-4 degrees shows a value of -1.2 in comparison to 1.0 at 91% chord location. Another important conclusion we can derive from the pressure readings is the fact that the point of the peak has moved to 30% of spanwise location in comparison to 50% as we saw in the previous case. The pitch up tendency starts to peak up late in this case and initiates around 9 degrees compared to 6 degrees at 91% of the chord.

The pitch up can be seen to be active up until 14 degrees. The delay in the pitch up angle at this chord length can be attributed to the fact that vortex had higher strength here and hence higher force was required to overcome it in the form of pitch up. Like in the previous case, this also shows a drop in the last pressure location and the reason remains the same; vortex core lying away from the pressure port at that span location.

Figure 7 and 8 show the spanwise distribution of the mean pressure with angle varying from 0 to 15 degrees. The spanwise pressure is measured at 30% of the chord length. Following the trend, we can see a higher value of Cp at all the angles compared to previous chord locations. The spanwise location at which the value of Cp starts to become evident is even lesser, in this case, i.e. 23% of spanwise location. This reveals the formation of vortex core near the leading edge and a potential flow formed at the middle.

6. LIST OF FIGURES

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