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Lecture 05c
Wind Tunnel Data Analysis and Testing Considerations

The YouTube video entitled ‘Wind Tunnel Data Analysis and Testing Considerations’ that covers this lecture is located at https://youtu.be/Nt4Ab2YdiLA.

Outline

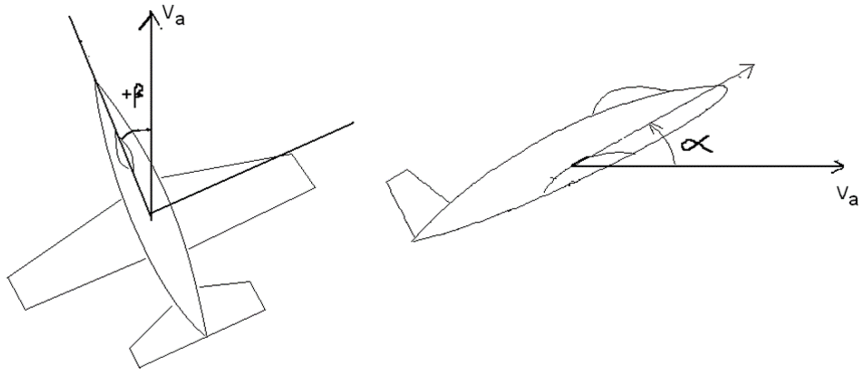
-Wind Tunnel Data Analysis
- -Coefficient of Lift: C_L
- -Coefficient of Drag: C_D
- -Coefficient of Sideforce: C_Y
- -Coefficient of Pitching Moment: C_M
- -Coefficient of Rolling Moment: C_R or C_l
- -Coefficient of Yawing Moment C_N

-Considerations for a Wind Tunnel Test
- -Model Construction
- -Wind Tunnel Test Design

Wind Tunnel Data Analysis

What Should Wind Tunnel Data Plots Look Like?

Once we obtained the corrected data from the wind tunnel, we should examine the plots to ensure that they are reasonable. For our situation, we recall that a positive α is defined when the wind hits the underside of the aircraft and a positive β is defined when air hits the right side of the aircraft.



For ease of analysis, let us assume an aircraft which is symmetrical about the body $x\,z$ plane.

Let us first consider plots of the various force/moment coefficients vs. α. The most intuitive axes to analyze the coefficients in are the wind axis (similar to what a wind tunnel balance would measure).

Coefficient of Lift: C_L

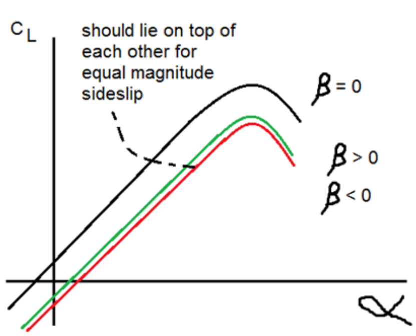
Dependence on α: At a given β, we know that typically, the lift will increase as angle of attack increases until the wing stalls. When this occurs, the lift should decrease. The aircraft is typically optimized such that the lift is maximum at zero β. At non-zero values of β, we expect the lift to decrease.

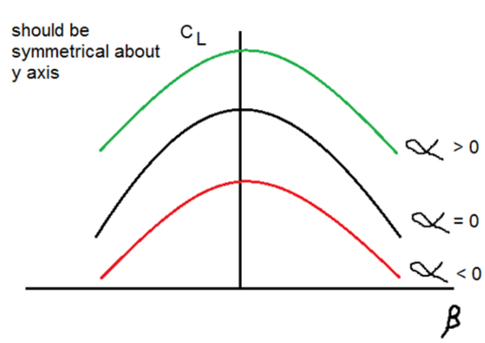
If the wing is symmetrical, we would likely see $C_L(\alpha = 0) \approx 0$ but if it is chambered, then we typically see $C_L(\alpha = 0) > 0$.

The slope of the lift curve slope in the linear region is sometimes referred to as $\partial C_L / \partial \alpha$ but to be accurate, we see that this partial is actually a function of α, β, and potentially other parameters as well. We will talk about this in more detail when we discuss linearizing the aircraft about an operating point using numerical techniques (see video entitled 'Numerically Linearizing a Dynamic System' https://youtu.be/1VmeijdM1qs)

<Stalling joke>

Dependence on β: At a given α, as β increases or decreases, we expect the lift to decrease. Since the aircraft is symmetrical, we expect that at both positive and negative β values, we expect the lift to decrease. As discussed previously, as α increases, lift should increase until we reach stall.





Note that depending on the desired flight envelope, we might want to increase the range of α. For example, if this was a highly maneuverable aircraft, you might need to acquire data at α larger range for example past stall or even at large negative angles of attack (you can even have reverse stall at large negative α).

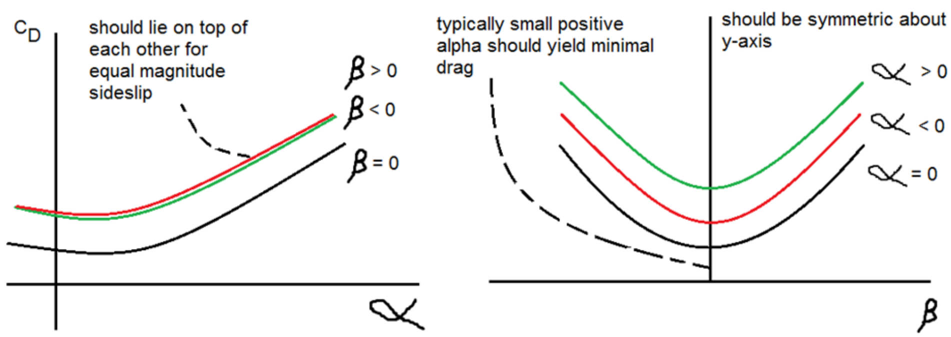
Dependence on control surfaces deflections: Deflecting a control surface such as flaps would likely increase the lift curve but at the penalty of increased drag (we will investigate this later).

In a similar fashion, deflecting the elevator might have a similar but much reduced effect on C_L (its effect is likely manifested in pitching moment that we will also investigate later).

Coefficient of Drag: C_D

Dependence on α: At a given β, as α increases, we anticipate that the drag will increase. The drag will likely be designed to be minimum when the aircraft is at its trimmed angle of attack. The aircraft will be optimized for minimal drag when $\beta = 0$, therefore, at both positive and negative β values, we expect drag to increase.

Dependence on β: At a given α, as β varies, we expect the drag to increase. The drag should be minimal at the trimmed angle of attack. Furthermore, the data should be symmetric about the y-axis.

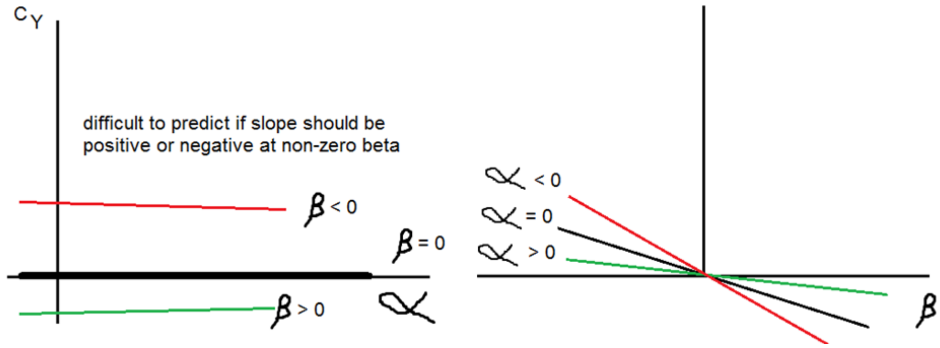


Dependence on control surfaces deflections: As discussed earlier, most control surface deflections will tend to increase drag (with the exception of a throttle correction if you are doing powered testing).

Coefficient of Sideforce: C_Y

Dependence on α: If the aircraft is symmetric about the body $x\,z$ plane, then at $\beta = 0$, the sideforce should be zero at all α. At a non-zero β, as the aircraft is pitched up and down, it is hard to determine if C_Y should increase or decrease.

Dependence on β: From the geometry, if the aircraft is at a positive β, we should expect that a force pushing it towards the left wingtip (negative β). As the angle of attack deviates from 0, it is difficult to predict how this will affect the sideforce.



Dependence on control surfaces deflections: The rudder will have a tendency to change the curve

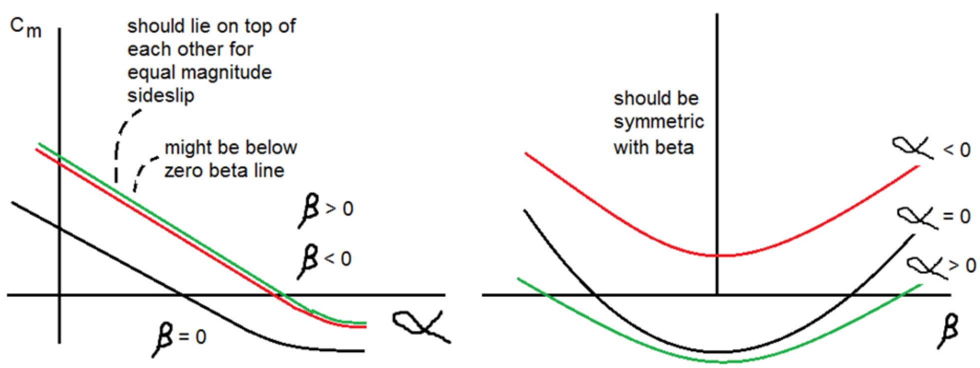
Coefficient of Pitching Moment: C_M

Dependence on α: The trim angle of attack is where the $C_{M,cg} = 0$. If there are no moments due to propulsion, we expect the aircraft to be trimmed at the angle of attack where $C_{M,cg}$ is zero (not the case for the RCAM model because the engines cause a moment).

If the aircraft is stable, we should expect C_M to decrease as α increases for longitudinal stability.

Note that the slope of the curve ($\partial C_M / \partial \alpha$) is important for longitudinal stability (talk about classic example). Further note that you may need to be careful about which moment center you are plotting. Just because the data coming from the wind tunnel does not have a negative slope does not mean the overall vehicle is unstable as it may be displaying pitching moment about the BMC rather than the desired MMC.

Dependence on β: It is difficult to predict if pitching should increase or decrease with β. However, we know that it should be symmetric with β.



Dependence on control surfaces deflections: Note that things like underslung engines may have the potential to influence the pitching moment. This leads to the concept of powered wind tunnel testing.

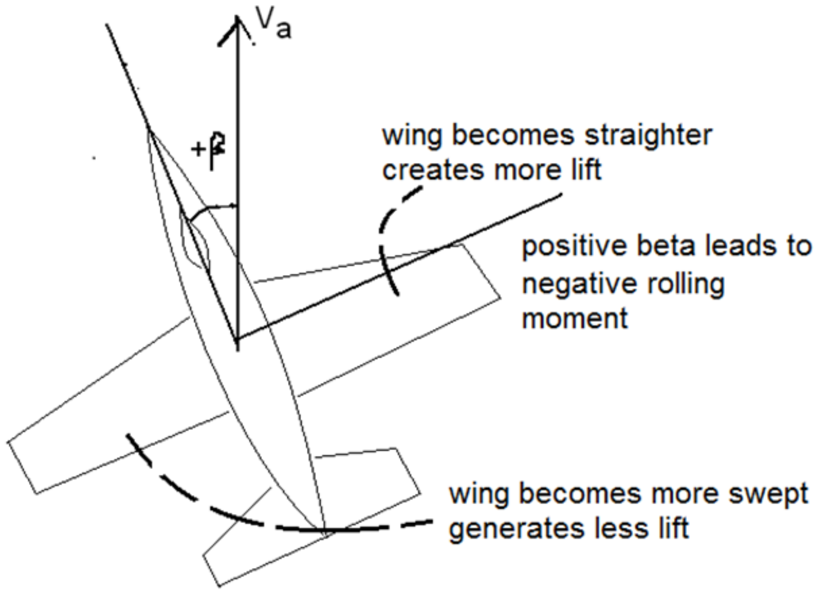
This is a good time to discuss experimentally determining $\partial C_M / \partial \delta_s$ (draw curve). Note that this is typically a function of α, β, and possibly other parameters but for the most part, we simply take the value at the trim α.

The elevator will likely have a large effect on C_M. Flaps may also influence this plot. Engines may also influence the plot.

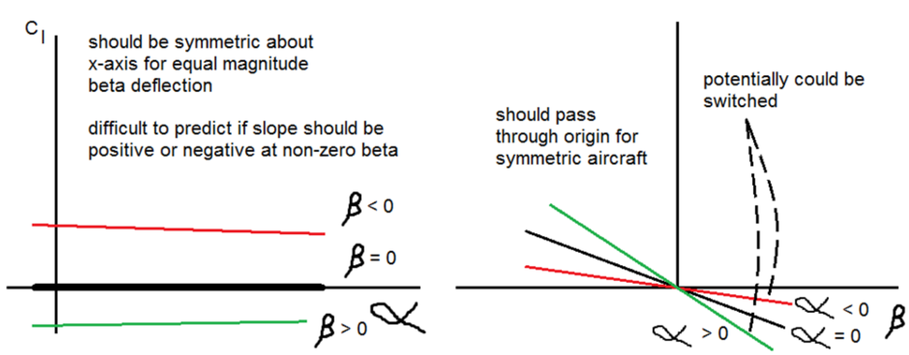
Coefficient of Rolling Moment: C_R or C_l

Dependence on α: If the aircraft is symmetric about the body $x\,z$ plane, then at $\beta = 0$, the rolling moment should be zero at all α. At a non-zero β, as the aircraft is pitched up and down, it is hard to determine if C_l should increase or decrease.

Dependence on β: For a swept wing configuration, we see that at a non-zero sideslip angle, one of the wings will become closer to a straight wing while the other becomes even more swept. The wing which is closer to a straight wing will tend to generate more lift whereas the other will generate less left. This causes the plane to roll. It is difficult to predict how this effect changes with angle of attack. As the angle of attack increase, both wings generate more lift so it is difficult to tell if the rolling moment will be more or less as α increases. Note that this does not imply stability (or lack thereof) in the roll direction.



So the plots should be similar to that shown below

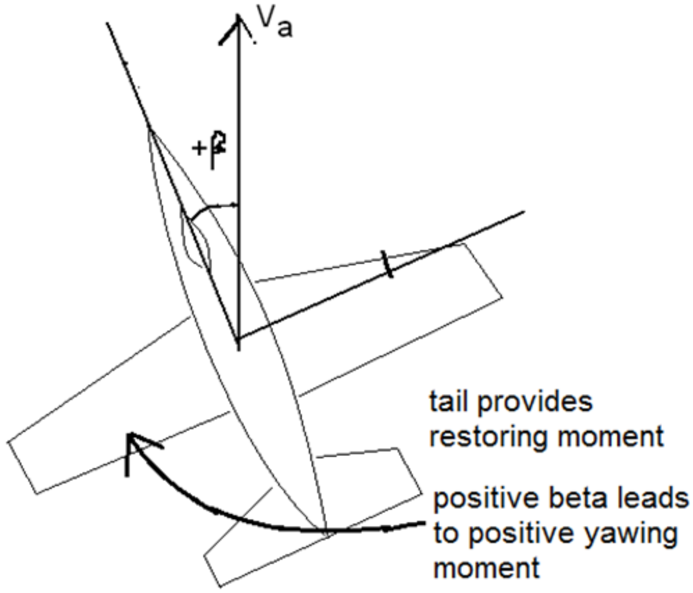


Dependence on control surface deflections: Ailerons will likely influence these plots but note that other control surfaces may have indirect influence on rolling moment. For example, a rudder deflection might introduce rolling moments.

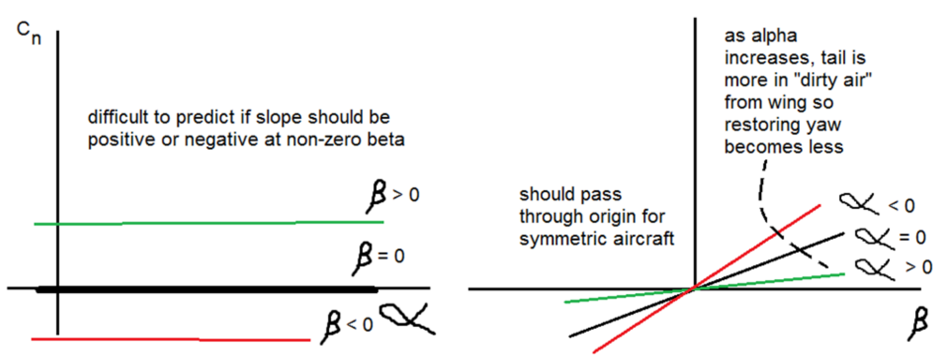
Coefficient of Yawing Moment C_N

Dependence on α: If the aircraft is symmetric about the body $x\,z$ plane, then at $\beta = 0$, the yawing moment should be zero at all α. At a non-zero β, as the aircraft is pitched up and down, it is hard to determine if C_n should increase or decrease.

Dependence on β: In a stable configuration, as the aircraft is yawed at a sideslip angle, the vertical stabilizer should provide a restoring force. So a positive β should lead to a positive yawing moment. As the angle of attack increases, the tail becomes more entrenched in the downwash of the wing and therefore becomes less effective. We expect the restoring force to become less powerful as α increases.



So the plots should be



Dependence on control surface deflections: Rudder deflections will likely shift the C_N vs. β curve up or down depending on the sign convention of δ_R.

Considerations for a Wind Tunnel Test

Model Construction

-Do you build the model to accommodate inverted testing and image strut/fairing setup?
-Do you build it with a removable tail for a generating lift sets? Should the tail be able to move to different incidence angles to experimentally measure $\partial C_M / \partial \delta_s$?
-Should the model have deflecting control surfaces? Should these be motorized or require stopping wind to do a model change?
-Where can you mount an accelerometer to measure angle of attack or do you want it calibrated via an inclinometer?
-What about powered testing?
-Do you add pressure ports and tubing to accommodate pressure testing?

Wind Tunnel Test Design

-What ranges of α, β, q, etc. do you want to test at? Are you covering the appropriate flight envelope? Should the α flag by non-linear (ie more fine data points near stall)?
-Which configurations are critical to obtain lift sets and strut and interference tares for?
-Which model changes are significant enough to warrant a new weight tare?
-Do you spend the extra time to perform flow visualization? This has the potential to jam up pressure ports. Flow vis can be messy and may require taping off the balance and/or pressure ports. This means you cannot collect force and moment data while you are performing flow visualization. Are you willing to sacrifice data acquisition time to perform flow viz?
-If you have a non-standard model, which of these corrections are needed? Where can you cut out runs to save time? Which runs are ground plane runs?
-What order of runs can minimize the number of model changes and DFMC (Down For Model Change)? (current rates are $500/hr for occupancy at UWAL, F1 can be $40k/day)
-How often do you calibrate and check for pressure system if doing pressure testing?
-Can the wind tunnel support the flight envelope you desire? For example can it support a big enough model or obtain the proper Re or Mach number? Do you need to go to a specialized facility such as F1 to reach appropriate ranges of the envelope?