Longitudinal & Lateral Directional Short Course

Flight One – Effects of longitudinal stability and control characteristics on handling qualities

Background:

In this flight training exercise we will examine how longitudinal handling qualities are affected by three important variables that are inherent in a given aircraft design. They are:

- Static longitudinal stability
- Dynamic longitudinal stability
- Elevator control effectiveness

As you will recall from your classroom briefings, longitudinal stability is responsible for the frequency response to a disturbance, which can be caused by the atmosphere or an elevator control input. It may be described by two longitudinal oscillatory modes of motion:

- A Long term response (Phugoid), which is a slow or low frequency oscillation, occurring at a relatively constant angle of attack with altitude and speed variations. This response largely affects the ability to trim for a steady state flight condition.
- A short term response where a higher frequency oscillation occurs at a relatively constant speed and altitude, but with a change in angle of attack. This response is associated with maneuvering the aircraft to accomplish a closed loop task, such as an instrument approach procedure.

If static stability is positive;

- The long and short period responses will either be convergent or neutral (oscillations) depending on dynamic stability

If neutral;

- The long period will no longer be oscillatory and short period pitch responses will decay to a pitch rate response proportional to the amount of elevator input;

If slightly negative (Equivalent of moving CG behind the stick fixed neutral point);

- In the long period, elevator stick position will reverse, i.e., as speed increases a pull will be required on the elevator followed by a push, and as speed decreases, a push will be required followed by a pull
- The short period responses will result in a continuous divergence from the trim state.

If more negative (Equivalent of moving CG behind the stick free neutral point);

- In the long period, elevator forces will reverse, i.e., as speed increases a pull force will be required on the elevator, and as speed decreases, a push force will be required
- In the short period responses will result in a continuous divergence from the trim state.

Static longitudinal stability is responsible for the types of responses we have just presented, but the ability of the pilot to control these responses in terms of a flight task depend to a large degree on how well they are damped. Pitch rate damping can be expressed as a "damping ratio", which is related to the number of oscillations that occur about the trim point. Damping ratio can be very strong, where oscillations damp out in a cycle or less, or it can be quite weak, where it takes several cycles before oscillations are arrested. In the long period, damping ratio depends on the Lift/Drag (L/D) ratio, and in the short period mode, it depends on the combined resisting moments generated by the rotation of the tail (M_q) and the rate of angle of attack change ($M_{\dot{\alpha}}$).

With respect to aircraft handling;

- When damping ratio is high, any oscillatory response is quickly damped, generally within a cycle or two. A high damping ratio provides good predictability, and the pilot tends to capture a desired pitch attitude quickly with little chance of overshooting or "bobbling". The down side is that for large amplitude tracking tasks, very strong pitch damping will affect the control response and slow the rate at which the pilot can perform a task.
- As damping becomes weaker, there is less resistance to control response, but the chances of overshooting a pitch target and "bobbling" during target capture increases.

Elevator effectiveness is the pitching moment generated for a given amount of elevator deflection. Aside from the design of the horizontal tail, perceived elevator effectiveness can be varied by changing the gearing ratio (stick or column movement for a given amount of elevator deflection). The higher the gearing ratio, the less "sensitive" the aircraft feels to elevator input, and vice-versa. But, elevator effectiveness can also be varied by aerodynamic factors occurring inflight such as structural damage, a control jam, or ice accumulation on the leading edges or in the gap between the horizontal tail and elevator.

In this training element, we will demonstrate how variations in static longitudinal stability, pitch damping, and elevator effectiveness affect the handling characteristics of an aircraft. The baseline aircraft, from which we will provide these variations, will be the "middle of the envelope Navion". Using the VSS, we will examine how variations in stability and control parameters individually affect aircraft handling qualities. In the last flight training exercise, the EP will perform a handling evaluation of a simulated aircraft with an ice contaminated tail plane. This simulation is based on real flight test data and illustrates the combined effects of tail plane icing on stability, control effectiveness, and damping ratio.

Demonstration of static stability variations on short and long period response characteristics with fixed pitch damping and elevator effectiveness.

Objectives: The objective of this training exercise is to show how CG location affects the control response and motion characteristics of the long and short period modes. This will be accomplished with fixed nominal damping and elevator effectiveness for the baseline Navion.

Discussion: There have been a number of aircraft accidents over the years due to a center of gravity location that was out of the normal flight envelope limit. Generally, when this happens it is because cargo shifted in the aircraft, or more likely that the aircraft was improperly loaded with either passengers or cargo or both. Accidents during take-off have occurred for this reason because the pilot was suddenly confronted with a control response that was entirely unusual, and one from which he or she was never trained to recover. During flight, this aft CG problem can result if cargo shifts due to turbulence, or if the fuel is burned such that it causes an out of CG condition.

The out of the envelope CG in these scenarios effectively changes the longitudinal static stability (M_α) of the aircraft, resulting in response and damping characteristic that can be quite unusual. In this demonstration, we will begin with a baseline Navion configuration, which will provide essentially nominal "good" flying characteristics. However, as we change VSS settings to represent various stability conditions, these characteristics will change quite dramatically.

Strong Positive (forward CG limit) - easy to trim, pitch response is quicker, takes longer for pitching motions to damp out, control response seems less predictable, and pitch attitude captures are more difficult than those in the baseline (mid-CG) condition. If in turbulence, note that pitching motions from turbulence more pronounced than those in the baseline configuration

Weak Positive (CG at the aft limit) – more difficult to trim, pitch response seems more sluggish and less damped, turbulence causes more of a vertical acceleration response with less pitching motion than the baseline aircraft

Neutral (CG at neutral point) – cannot trim the aircraft for a flight condition due to lack of speed stability, elevator inputs result in a pitch rate response that is damped, there is no tendency for the aircraft to return to its initial condition when disturbed by flight control inputs or turbulence

Negative (CG between neutral and maneuver points) – cannot trim the aircraft and any disturbance causes an angle of attack and corresponding divergence from the flight path, control is possible but requires considerable shaping of inputs to arrest and stop divergent pitching motion, very difficult or impossible to perform any precision pitch task

The SP will set up the conditions for each observation, demonstrate the techniques to excite each mode, instruct the EP in the performance of the test procedure, and point out important observations that should be made.

VSS configurations: Stability derivative settings for M_α to represent the following center of CG: Baseline (middle of the envelope), Strong Positive (forward limit), Weak Positive (aft limit), Neutral (neutral point), Negative (CG between neutral point and maneuver point)

Flight condition: 100 KIAS, minimum altitude 1000 ft AGL

Task: From a trimmed condition of flight with the VSS off, the SP will demonstrate the pitch input tasks that the EP will perform when in VSS mode. The maneuver to excite the long period mode is a standard flight certification “long-stab”, which is a slow positive or negative pitch input to reduce or increase airspeed 10 knots followed by a slow return of the control column to the trim position, then releasing the control column and noting the free response characteristics. The maneuver to identify short period characteristics will consist of constant airspeed pitch doublet followed by releasing the control column and noting the free response characteristics.

Observations: The following observations will be made by the EP during the execution of each flight maneuver

- Trim state; ease of trimming for level flight, speed stability
- Control response; frequency response (quick, sluggish), overshooting tendency, precision
- Free response; oscillatory but convergent, oscillatory but weakly convergent, no oscillations, divergent
- Frequency of the oscillations and damping characteristics; number of overshoots and time to damp

Evaluation of variations in pitch rate damping on a pitch capture task with positive static stability and baseline Navion elevator effectiveness

Objective: The objective of this element of training is to demonstrate and have the EP evaluate the effect of pitch damping on a pitch capture tasks. The following discussion points explain what the EP will be looking for when performing the test procedure.

Discussion: In the preceding training exercise, we looked at the effect of only longitudinal static stability on aircraft pitching motion. We will build upon this and take a look at how pitch damping alone affects longitudinal handling qualities.

Here, we are concerned with how well a pilot can perform a closed loop flight task that requires maneuvering the aircraft, and therefore our focus is on the short period response mode. Pitch rate damping (M_q) and angle of attack damping ($M_{\dot{\alpha}}$) together comprise the total damping on short period response. The manner in which this response is damped is critical because a properly damped response defines the degree of precision a pilot is able to achieve for certain maneuvering tasks. This is especially true for flight conditions in rough air, turbulence, and wind shear where pitch tracking and pitch capture tasks affected by disturbances that excite the short period aside from the pilot's control inputs. For example, when certifying a transport category aircraft for Category II operations, several successful approaches must be manually flown using the flight director in 15 knot crosswinds. When wind speeds are that high, there are usually gusts, turbulence and wind shear, all of which can disturb the aircraft, especially in the pitch axis. At jet speeds the pilot must be able to control pitch within a degree or two in order to reach decision height at minimums (100ft AGL) and within the allowable certification error for the entire approach. Here, good pitch damping is critical to not only provide predictable response characteristics when tracking the guidance, but also needed to damp the responses due to the turbulent atmospheric conditions. In a second example, consider a tactical aircraft, where the requirements are more stringent. A head up display gun sight typically has a 6 milliradian (mr) diameter "snapshot reticle" with a 2 mr pipper. The pilot must maneuver the aircraft to keep the pipper within the reticle when tracking a target. Since there are 17.45 mr per degree, tracking accuracy in all axes must be on the order of a half a degree – and at speeds exceeding 500 knots in maneuvering flight. Very good pitch damping is mandatory if one expects to achieve a firing solution.

In this demonstration, we will use baseline Navion static stability and elevator control effectiveness, and provide three pitch damping evaluation cases; strong (damping ratio 0.7, medium (damping ratio 0.4 – 0.5), and low (damping ratio ≈ 0.2). When pitch rate damping is strong, pitch tracking and capture can be accomplished with little or no bobbling. When it is medium, there will likely be a tendency for some bobbling, especially when tracking, and more so as the task is flown more aggressively. When damping is low significant effort is required by the pilot to minimize pitch bobbles while tracking and especially when attempting to capture the pitch target.

VSS configurations: Stability derivative settings for $M\alpha$ will represent the Navion baseline (middle of the envelope) CG. Elevator effectiveness, $M_{\delta e}$ will be set to nominal Navion, and three damping ratios will be used to program the pitch rate damping derivative, $M_{\dot{\theta}}$.
Flight condition: 100 KIAS, PFLF, Minimum Altitude 1000 ft AGL

Task: The EP will perform a series of pitch capture tasks in each VSS configuration that begins with trimming and stabilizing in the initial condition. Once trimmed with PFLF, the SP will direct a series of pitch tracking maneuvers starting with a slow +/- 2 deg alternation, and increasing incrementally to +/- 10 deg. At some point in the exercise, the SP will ask the EP to capture a +/5 deg pitch target and stabilize. The series is then repeated more aggressively, i.e., at a faster rate and a compressed time for capture stabilization. The task will be performed either with reference to the attitude indicator, a good horizon reference, or a gun sight that provides the same approximate variation in the pitch tracking envelope. If conditions are turbulent at certain altitudes, we will take advantage of this to demonstrate the effects of good pitch rate damping on pitch tracking and capture tasks.

Observations:

The EP will note the precision of meeting the pitch capture requirements for each tested configuration, and will indicate how the level of effort changes for meeting the capture criteria at each test condition. The EP will observe the number of oscillations that occur to stabilize the attitude reference or external reference symbol on the pitch target during capture tasks. The EP will also comment on the difference between gross and fine acquisition of the pitch targets.

Evaluation of variations in elevator effectiveness on a pitch tracking and capture task with fixed positive static stability and pitch rate damping

Objective: The objective of this training element is to demonstrate how changes in elevator gearing affect the pilot's control gain and precision when performing a pitch tracking and capture task.

Discussion: Elevator effectiveness is essentially the pitching moment generated by elevator deflection. It can be affected by changing the gearing ratio of the control system, by a control jam, ice (aerodynamic) contamination of the horizontal tail, or possibly a structural or hydraulic failure. Examples follow for each of the three circumstances just mentioned.

1.) Gearing ratio changes the ratio of control column movement per degree of elevator deflection, which affects the perception of control effectiveness, response frequency, and stick force per g (Fs/g). Low gearing makes the aircraft feel very responsive, with light stick force. High gearing ratio makes the airplane feel more sluggish with high Fs/g. The latter case is good for a fighter or aerobatic airplane, and the former is good for a transport category aircraft where smoothness is appreciated by the passengers. Gearing ratio is a design choice that can have a large effect on handling qualities.

2.) A control jam in large transport aircraft under FAR 25 is considered a probable failure. Therefore, the certification rules require that there be redundant control paths provided for primary flight controls (usually ailerons and elevator). In the event of a jam in the elevator system, the jammed side can then be decoupled, allowing safe flight to a landing. Decoupling the elevators can reduce elevator effectiveness on the order of one-half. Additionally, depending on the jam angle, pitch damping can also be affected to some extent depending on the jam angle of the decoupled side. Therefore, a handling qualities assessment must be accomplished to demonstrate that an average pilot can safely complete the approach and landing task with this reduced level of elevator control effectiveness.

3.) Inflight icing can also result in a substantial loss of elevator control effectiveness if the horizontal tail becomes contaminated in flight. Failure of an ice protection system is certainly probable, and testing must be done to show safe flight to landing with a specified amount of ice contamination or what is called the "critical ice shape" on the horizontal tail. Horizontal tail ice can affect reduce static longitudinal stability, pitch damping, and especially elevator control effectiveness. Therefore, as in the previous case, safe flight to a landing must be demonstrated with the critical ice shape defined for this failure.

The three examples above illustrate why reduced elevator control effectiveness is such an important training aspect. In this training exercise, we will use the same pitch tracking and capture tasks as performed in the previous cases. We will begin with a VSS configuration of the basic Navion, and will then repeat the evaluation tasks by reducing elevator control effectiveness 50 % and then 25 %. We will also increase elevator control effectiveness by 25% to show the effects of gearing. Although the VSS uses a very simple spring bungee type of elevator force system, these configurations will also demonstrate how the change in elevator control effectiveness affects the pilot's perception of Fs/g and short period response.

<u>VSS configuration</u>: For this demonstration, M_α and $M_{\dot\theta}$ will represent the baseline middle of the envelope Navion, and will remain fixed for the duration of the test. Four elevator control effectiveness training configurations will be flown: Baseline Navion, 50% $M_{\delta e}$, 25% $M_{\delta e}$, and a 125% $M_{\delta e}$.

<u>Flight condition</u>: 100 KIAS, PFLF, Minimum Altitude 1000 ft AGL

<u>Task</u>: The EP will perform a series of pitch capture tasks in each VSS configuration that begins with trimming and stabilizing in the initial condition. Once trimmed with PFLF, the SP will direct a series of pitch capture maneuvers starting with a slow +/- 2 deg alternation, and increasing incrementally to +/- 10 deg. The series is then repeated more aggressively.

Observations: When elevator control effectiveness is decreased, there is a noticeable lag in pitch response, and as maneuvering requirements increase, the pilot has to do more control shaping to get the necessary response. The increased workload has a significant effect on handling qualities in order to try and meet the performance criteria of the task. With reduced elevator control effectiveness, the pilot will also perceive that the Fs/g is greater and that the short period response is slower. The converse will be the case for the higher elevator control effectiveness. For each condition, the EP will note that problems associated with the elevator control effectiveness are affected as the level of aggressiveness increases.

Longitudinal With Icing Option

Approach and missed approach handling evaluation task with an ice contaminated aircraft

Objective: The objective of this training exercise is to provide the EP with an opportunity to evaluate the combined effects of the three stability and control variables that we introduced in preceding sections of this syllabus; static stability, damping ratio, and elevator control effectiveness. Our goal is to illustrate how these three variables interact when performing a coupled pilot task during the critical phases of an approach and missed procedure. The intent is to tie together all that was covered in the previous training exercises.

Discussion: Several years ago, NASA employed its icing research aircraft in a rigorous investigation of tail plane icing. The investigation provided a great deal of the knowledge we have today about the effects of horizontal tail ice contamination. The configurations that NASA tested have provided us with the unique opportunity to program the VSRA with some of the more critical test configurations that they tested. For our evaluation, we will simulate an approach configuration of the NASA icing research aircraft where the ice shape they tested reduced static stability by 64%, elevator effectiveness by 73%, and pitch damping by 66%. Before starting the evaluation exercise, you will have a brief opportunity to get familiar with the handling characteristics of this configuration. The SP will then fly the aircraft to the point at which the approach procedure will commence.

You will fly the approach heads down with a vision obscuring device, and when reaching approach minimums, you will execute a go around and transition to a visual circling approach and line up with the landing runway. This maneuver will allow you make a handling assessment associated with both an IMC and VMC flight task.

Immediately after landing, the EP will evaluate the approach and missed approach procedure and provide HQR's via the Cooper-Harper rating system. You will find this to be a very intensive training exercise, in which you will be asked to comment on stability, damping, and control effectiveness during the post flight debriefing.

VSS configuration: The SP will set the required stability derivatives, which include M_α, $M_{\dot\theta}$ and $M_{\delta e}$.

Flight condition: 100 KIAS, minimum altitude 400 ft AGL.

Observations: Going back to the previous training exercise, you can anticipate the following to occur:

- It will be difficult to trim the aircraft and to keep it in trim, especially if you allow speed to vary much. The aircraft is weakly stable, and therefore the short period response will seem very low.
- Damping ratio is also weak, and as a result you may find it difficult to track the glide path indicator with precision. Additionally you will find that when you excite the short period, the resulting oscillations will take longer to damp, and you may have to do considerable control shaping to arrest any oscillations. Turbulence will aggravate the situation even more.
- Lastly, and most important, the reduction in control effectiveness will result in considerable delay before your input takes effect, and worse, you will find that you have to be ready to adjust your control strategy to prevent gross overshoots in pitch attitude control.

Flight Two – Effects of lateral –directional stability and control characteristics on handling qualities

Background: The lateral and directional handling characteristics of an aircraft cannot be adequately described without considering the coupling effects of those axes. For example, sideslip can generate a yawing and rolling moment, and a roll control input can generate a rolling and yawing moment. All one has to do is look back at the list of stability derivatives in Table 1 and it will be quite apparent how much coupling there is between both axes. As a result, it is a bit more difficult to isolate responses in one axis, without taking into account the coupling effects occurring from the other.

With this in mind, we will approach this second flight by examining the following important characteristics of a given aircraft design that directly affect handling qualities. They are:

- Static lateral and directional stability
- Dynamic lateral and directional stability
    - The roll mode and adverse yaw
    - The spiral mode
    - The "Dutch Roll" mode

Static *directional stability*, N_β is weakly affected by the location of the CG; however it is mostly dependent on the aerodynamic design of the airframe such as the size of the vertical stabilizer and rudder and the length of the tail arm from the CG. It can also be affected by airframe features that cause significant yawing moments ahead of the CG. In general, yawing moments ahead of the CG have a destabilizing effect, especially at high sideslip angles.

Like M_α, positive directional static stability tends to make the aircraft weathervane back to its initial trim condition when disturbed in the yaw axis. If static directional stability is decreased, the tendency to return to the trim condition also weakens. When reduced to zero (neutral static stability), any disturbance in the yaw axis will decay to a first order response. If rudder for example is applied in this condition, the aircraft will respond with a yaw rate that is proportional to the rate and amplitude of the rudder input. When static directional stability becomes negative, any yaw axis disturbance will result in a divergence unless arrested by the pilot with a rudder input. To assess directional static stability you will perform a steady heading sideslip at each of the VSS configurations. In the process of doing this maneuver you may notice coupling between the yaw and roll axes that results in oscillations (Dutch Roll mode) as you try to coordinate inputs to both the yaw and roll axis to null out any heading variation.

Lateral static stability is also called "dihedral effect" and quantified by the stability derivative L_β, which is the rolling moment due to sideslip. If a right sideslip (positive) produces a left rolling moment (negative), or if a left sideslip (negative) produces a right rolling moment (positive) that is considered positive lateral static stability. From a handling qualities standpoint, it is not good to have too strong a dihedral effect because it can cause excessive roll with only a small yaw disturbance, seriously affecting the performance of any precise lateral tracking task, such as instrument approaches, or crosswind takeoffs and landings. Lateral static stability can also be neutral, wherein there is little or no roll caused by sideslip, or negative, if the aircraft rolls towards the sideslip.

The *roll mode* is the principle means for making lateral-directional changes to the flight path. The two primary variables that affect this mode are aileron effectiveness ($L_{\delta a}$), and roll damping (L_p). To illustrate, if a pilot were to make a rapid aileron step input, the response would be an accelerated roll rate due based upon the level of aileron control effectiveness. The roll rate acceleration would eventually decay in time to a steady state roll based upon the level of roll damping. The time it takes for the roll rate to reach 63% of the steady state roll rate is known as the roll mode time constant. The level of roll damping determines the length of the time constant. A small L_p will increase the time constant because mathematically, the time constant is equal to the inverse of L_p. This means that the roll rate will build up slower for a given control input and aileron effectiveness. If the roll damping term is large, the time constant will be smaller and the buildup of roll rate will be faster for the same aileron input.

When performing certain lateral-directional tasks, pilots learn to alter their control strategy at times in order to meet task performance requirements. For example, when certifying an aircraft for Category II instrument approach procedures, pilots find that when having to meet the 15 knot crosswind requirement where there are significant gusts and turbulence, they sometimes have to change their control strategy to successfully meet the certification performance requirements. This is also referred to as "control shaping". Essentially, the pilots will ramp up their gain by making relatively fast and large roll inputs to increase the rate of roll acceleration, but must develop a sense for when to take out the input to avoid over-controlling. A properly designed aircraft will provide the right balance between roll control effectiveness and roll damping. The result provides a predictable response characteristic that minimizes pilot workload, which results in good handling qualities.

Yaw due to roll is also an important factor affecting lateral-directional performance. For example, if an aileron input causes the aircraft to yaw away from the direction of the roll input we say the aircraft displays an *adverse yaw* characteristic. If the aircraft yaws in the direction of the roll input, it displays a *proverse yaw* characteristic, which can be extremely annoying because rudder application opposite the roll direction may be required. Adverse yaw was inherent in a number of the 50's and 60's generation fighter aircraft. Generally the cause was due to the large amount of drag due to lift on the down aileron side at high angle of attack when maneuvering. Fighter pilots in that generation had to learn how to coordinate rudder and sometimes not to use aileron at all when rolling at very high angles of attack. In a dogfight, losing control is not a good thing!

The *spiral mode* is perhaps the least significant of the lateral modes. It is usually a weak stable or neutral in most aircraft, and is primarily due to sideslip effect on the yawing and rolling moments. In most cases, it is characterized by a slow roll response after the aircraft is established in a steady banked turn. If the mode is stable, the aircraft will tend to roll back to wings level. If neutral, it will remain in the established bank, and if negative, the roll will diverge and increase. If the mode is slightly unstable, it is easily controlled by the pilot's inputs because of its long time constant.

The Dutch Roll mode is often referred to as the "nuisance mode" because it represents a coupled yaw/roll oscillatory motion, which if not well damped, can have a very negative effect on lateral-directional handling qualities. It may also be divergent for some aircraft, such as the Boeing 727, which requires two operable yaw dampers for dispatch. The Dutch Roll is usually excited by a sideslip resulting from a yawing motion. The yawing motion is usually the result of adverse yaw, wherein a roll input to the controls in one direction results in yaw in the opposite direction. The opposite yawing moment generates a sideslip or β that results in a rolling moment opposite to that which is being commanded. The characteristics of the resulting oscillatory response, which may be either damped, neutral, or divergent is governed primarily by the interaction of the three variables (stability derivatives), which we will examine in this training exercise. The only way to stop this motion manually (assuming no yaw damper) is for the pilot to make anti-roll inputs that oppose the yaw direction in sequence with the Dutch Roll frequency. If for example the aircraft is rolling right and yawing left, the pilot must make a left roll input with feet on the floor and hold the input until the Dutch roll reverses, then make another opposing roll input. If the pilot times the anti – roll inputs properly, the Dutch Roll oscillation will be damped within a few cycles. For example, B-727 and Lear 20 series pilots practice the yaw damper "abnormal" procedure.

There are three variables that are primarily responsible for Dutch Roll characteristics. They are; the static directional stability (N_β), yaw damping due to yaw rate (N_r), and the absolute value of the ratio of the rolling moment due to sideslip (also known as "dihedral effect" L_β) to static directional stability (N_β). The absolute value of that ratio is (approximately) numerically equivalent to the ratio of the degree of roll that is generated per degree of sideslip. This is more commonly referred to in the flight test world as the "ϕ/β" ratio.

The frequency of the Dutch Roll oscillation is dependent upon the static directional stability derivative, N_β. Strong positive directional static stability results in a high frequency Dutch Roll oscillation, much like M_α in the case of longitudinal short period response. The number of oscillations to damp the Dutch Roll is primarily affected by the yaw damping derivative, N_r. Since yaw damping effect from β rate is very small, only the yaw damping from yaw rate is considered in the total yaw damping effect. The ϕ/β ratio, which defines the proportion of the roll and yaw components characterizing the Dutch Roll motion, is important to the level of "annoyance" the pilot must contend with when making lateral inputs. When ϕ/β is high, small β excursions (possibly from adverse yaw) result in substantial rolling effects, and this can degrade lateral handling qualities. When it is low, there is very little roll as a result of β excursions, and lateral control input becomes almost a pure rolling motion. ϕ/β ratio on the order of 2 or less seems to provide good flying qualities, but higher values tend to degrade roll response. However, the final result on lateral- directional handling must consider the combination of the three variables rather than the singular effect of each alone.

Demonstration of positive, neutral, and negative lateral and directional static stability

Objectives: The objective of this training element is to demonstrate the characteristics of high, medium, low, neutral, and negative static lateral-directional stability. This demonstration will show how the level of static directional stability affects frequency response in the yaw axis, and how the level of lateral static stability affects roll response to sideslip. The damping and control effectiveness derivatives will be fixed at the basic Navion settings for this demonstration.

Discussion: As we discussed earlier, lateral –directional static stability is responsible for the characteristics of the response to control inputs, and/or to atmospheric disturbances. Directional static stability, N_β determines the frequency of the response, and the damping ratio is responsible for the number of overshooting oscillations and the time required for damping them out. Lateral static stability, L_β, which is also known as "dihedral effect", is the rolling moment generated with sideslip. Lateral static stability in large part is also responsible for the yaw/roll characteristics of the Dutch Roll mode. We will look at that aspect in a later flight task.

For this demonstration, we will only investigate each of these terms individually while keeping the basic Navion settings for damping and control effectiveness fixed. We will perform the directional static stability demonstration first, beginning with the VSS settings for the basic Navion. You will find that the basic aircraft demonstrates good static lateral-directional stability and good damping characteristics. The SP will point these out when you begin this demonstration. We will then alter the VSS settings to vary the static stability terms. Here is a brief review of what to expect in this demonstration. We begin with directional static stability:

- When static directional stability N_β is high (strong positive), the response frequency is also high. The VSRA does not have reversible control systems or control force feedback, but if it did, you would note that rudder forces would be higher to induce a sideslip because of strong positive directional stability. When rudder is released, more oscillations will occur before the yaw rate damped when compared to the baseline condition
- As N_β is reduced below the baseline (weak positive), response frequency is lower than the baseline and the oscillations are well damped with fewer oscillations in yaw than the previous case.
- When N_β is neutral, a rudder input elicits a yaw rate response proportionate to the input.
- When N_β is negative (weak negative), response is characterized by a divergence in sideslip, and yaw angle visibly increases. The only way to stop the divergence is by applying opposite rudder.