**LCDP sign reversal Impact on Controllability**

The effects of the LCDP and Cn-dynamic variations on the lateral stability and the control feedback gains is better illustrated with an example. Let us consider a lateral vehicle model that is controlled by aileron and rudder inputs and its states consisting of: roll and yaw rates (p, r), roll attitude (), plus angle of sideslip (). This system is controlled by a (2x4) state-feedback matrix (KSpr1) and the roll angle is controlled by a command (cmd). This system is open-loop statically stable with a Dutch-roll resonance of 2 (rad/sec), Cn-dynamic>0, and it has a negative LCDP ratio, -0.334 . It is shown in Figure (1) responding to a cmd=1 (rad). The state-feedback matrix is also included in the figure.

A parameter of this system was modified which causes the LCDP to change sign. Figure (2) is almost an identical system with a different Cn\_dailer. The yawing moment due to aileron was changed from negative to positive value. The system is still stable with the same Dutch-roll resonance but the LCDP ratio is now +0.302, almost reversed from the previous system. This system is no longer stabilizable with the previous state-feedback matrix and a different one was designed in order to stabilize it. It responds satisfactorily to a cmd=1 (rad) with the new feedback matrix (KSpr2). Notice how the signs of most of the elements in this new matrix are reversed. This example, therefore, demonstrates that an unexpected reversal in the LCDP sign can have destabilizing effect on the vehicle, even though the vehicle was statically stable in both cases. The exact time of sign reversal is not known due to the uncertainties in the aero-dynamics so there is a transitioning period where we cannot rely on the aileron for control. A solution when the LCDP ratio is small and it transitions between positive and negative is to introduce some rudder control in roll which can increase the magnitude of the LCDP, either positive or negative, but not less than 0.02. An even better solution is to use RCS jets for roll control during this type of transitioning period.

LCDP ratio reversal can also be caused by a change in the sign of Cn-dynamic. This is when the vehicle transitions let's say from a statically stable to a statically unstable region where Cn-dynamic<0. This also requires a change in the state-feedback control law in order to avoid a lateral instability, as shown in Figure (3). In this example which is similar to Figure (1) the sign of Cn-dynamic was changed to negative by a modification in the aero coefficients Cn and Cl. The new state-feedback control law (KSpr3) which stabilizes the modified system and enables to respond to a cmd=1 (rad) is also significantly different from the original state-feedback matrix (KSpr1). Notice how some of the rudder gains are now reversed. Notice also how the () response is not monotonic as in the previous two cases but it first responds in the opposite direction and then it reverses. This is also an unreliable situation and one cannot rely on the aero-surfaces for lateral control during this type of transitioning period and, therefore, RCS is the only reliable solution during periods of uncertainty in the LCDP.