Technical Note II: An Automatic Pilot to Make *Perfect Horizontal Loops* Varying only *Gflyup* through the Horizontal Loop

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Summary

In this paper I define an automatic pilot to make perfect horizontal curves and horizontal loops in particular, that is a circumferences, making the centripetal acceleration, *Gflyup*, to vary through the loop and maintaining a constant motor impulse. I prove that this automatic pilot could be implemented easily in the flight computer of an F16, F15, F18, or in any other aircraft with a |*GoffSetRate*| > 0.9 g/s. In the near future I will study alternative approaches varying only the engine impulse and varying simultaneously *Gflyup* and the engine impulse.

Introduction

In a preliminary study with horizontal loops with constant centripetal acceleration, *Gflyup*, and constant engine impulse, through the loop [1], with a simplified model of the F16 [2], I obtained the following result, making >> v_through_h_curve(9, [400 450 500 550 600 650], 3000, 360, 50, 0) in matlab environment I got

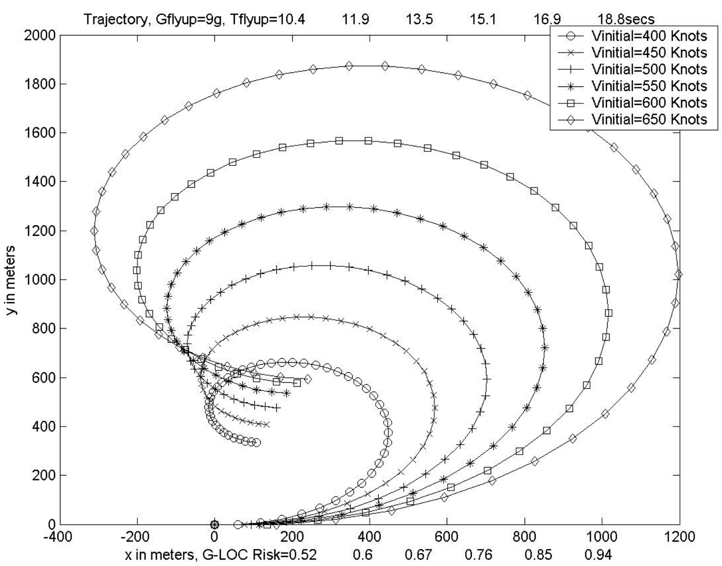

Figure 1- *Spiral Like Horizontal Loops* from [1] that result from a constant *Gflyup*.

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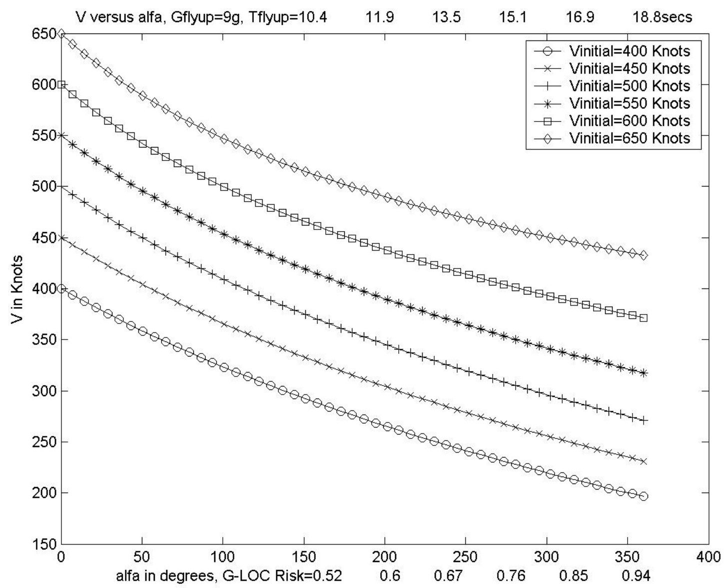

Figure 2- Speed versus α for *Spiral Horizontal Loops* of figure 1 from [1].

As we see in figure 2, speed decreases almost linearly with α, the angle of the trajectory, consequence of the brutal increase of the induced drag that is not compensated by an augmentation of the engine impulse, and since the centripetal acceleration *Gflyup* is constant through the radius of curvature *R(α)* through the horizontal loop, given by

$$R(\alpha)= V(\alpha)^2 / \text{Gflyup} \quad (1)$$

will decrease through the horizontal loop, which produce spiral like curves shown in figure 1, for different initial speeds and engine impulse adjusted to maintain that initial speed in level and straight flight.

In [1] I also answered the question of what must be the minimum initial speed such that at the end of the horizontal loop the speed doesn't go under the minimum flight speed, which for the F16 is about 200 Knots. Since to have a constant radius of curvature we must reduce Gflyup through the loop, which implies a lower average induced drag through the horizontal loop, the results obtained in [1] are also valid for perfect horizontal loops.

Auto Pilot for Perfect Horizontal Loops Varying only *Gflyup*

The solution to our problem is obvious, since we can rewrite (1) as

$$\text{Gflyup}(\alpha)= V(\alpha)^2 / \text{Rloop} \quad (2)$$

where *Rloop* is given by

$$\text{Rloop}= \text{Vinitial}^2 / \text{Gflyup}(0) \quad (3)$$

(2) Can be interpreted as the definition of an automatic pilot that would command *Gflyup* through the loop, resulting in a circumference of radius *Rloop* given by (3). Here there are the results of some simulations implemented with the F16 simplified model in Matlab®: making >> v_through_h_curve_p(9, [400 450 500 550 600 650], 3000, 360, 50, 0) we have

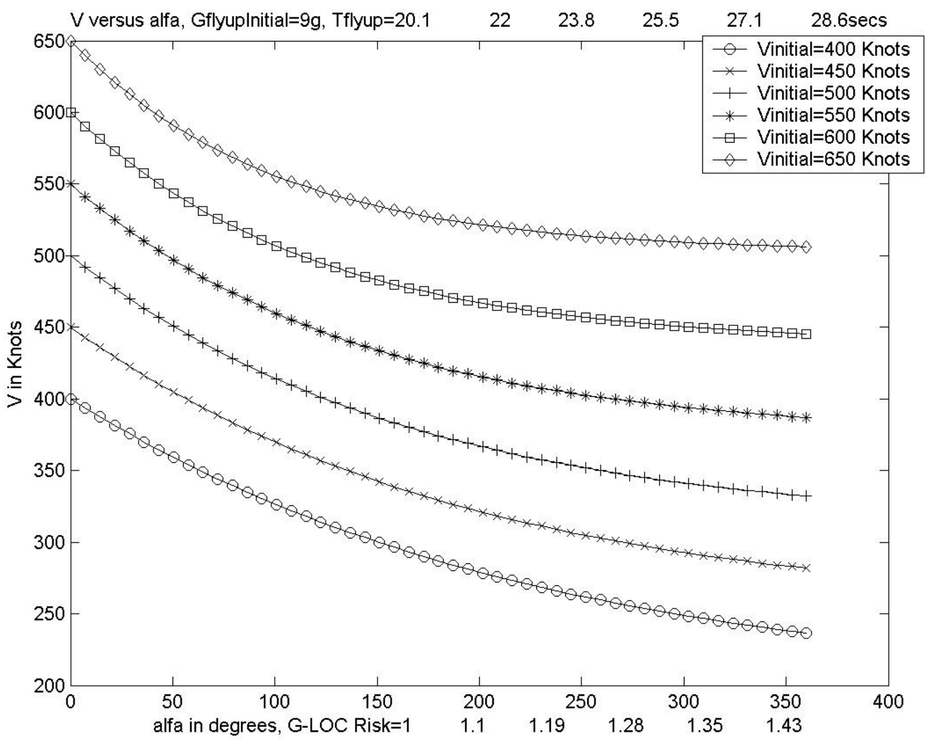

Figure 3- Variation of speed through the perfect loop for various initial speeds.

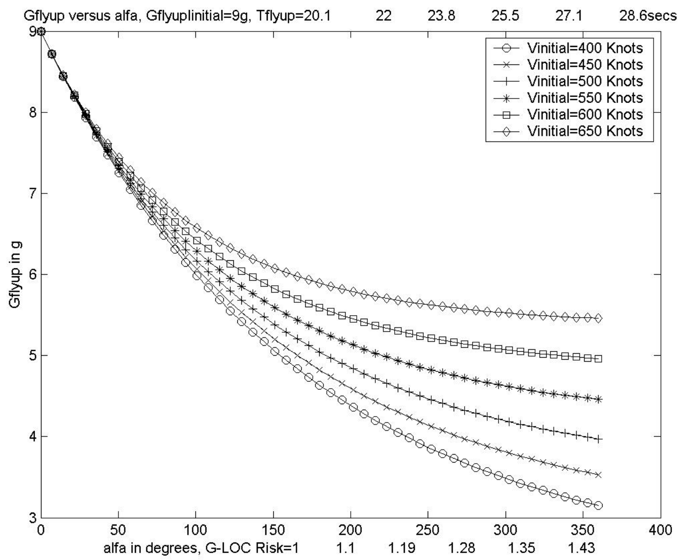

Figure 4- Variation of *Gflyup* through the perfect loop for various initial speeds.

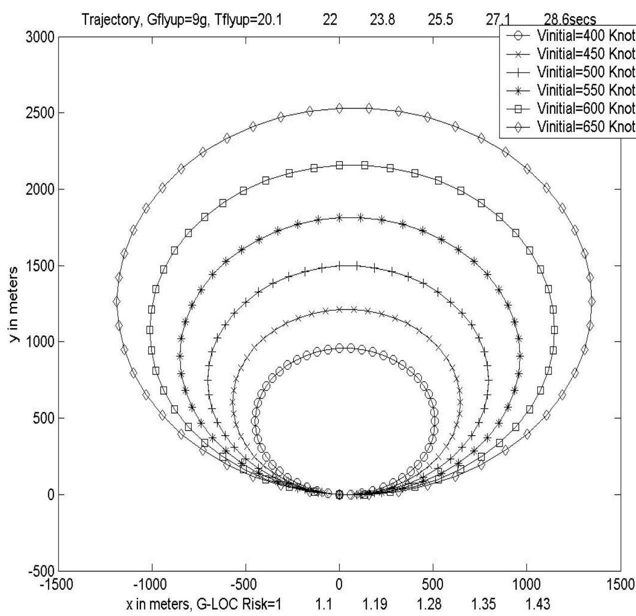

Figure 5- Resultant trajectories, circumferences, for various initial speeds.

Analysis of the Viability of the Auto Pilot to Make Perfect Loops

Since the F16 passes from *Gflyup*=9g to *Gflyup*=0g in about 0.5s, that is it has a *GoffSetRate*=-20g/s, it seems that will be possible to implement this automatic pilot in the F16 or in any other aircraft with a similar *GoffSetRate*. In mathematical terms the viability of our automatic pilot for perfect horizontal loops will be

$$\left|\left(\frac{dGflyup}{dt}\right)\right|_{\max} < \left|GoffSetRate\right| \quad (4)$$

We will see that d*Gflyup*/dt, that is the *instantaneous GoffSetRate,* is maximum for α~??º. Next I will verify if (4) is true for the F16, simulating the more unfavourable situation, that is minimum initial speed that would imply a minimum loop time (why?) and maximum initial *Gflyup*, say (450Knots, 9g), that would imply a minimum *Tloop* and a maximum *ΔGflyup*, maximizing the first term of (4).

(4) being true translates in, during all the horizontal loop, the next condition be always true

$$|Gflyup(i)-Gflyup(i-1)| < |GoffSetRate|\,\Delta t(i-1) \quad (5)$$

Making >>v_through_a_p_h_loop_gti(9, 450, 1000, 5000), we have

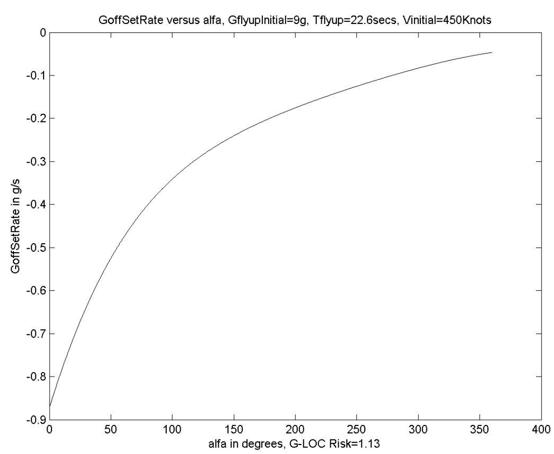

Figure 6- Variation of instantaneous GoffSetRate through the perfect horizontal loop with the most unfavourable initial *Gflyup*=9g and *Vinitial*=450 knots.

Since *GoffSetRateMax*~ -0.9g/s, our automatic pilot can be implemented in any aircraft with a |*GoffSetRate*|>0.9g/s, which include many aerobatic low power aircrafts with a propeller engine.

Conclusions and Future Work

I showed that makes sense to try to make a circumference like horizontal loop, since horizontal loops with constant *Gflyup* result in more average induced drag.

The implementation of the perfect horizontal loops automatic pilot results in a very simple mathematical formula which could be easily implemented in the flight computer, without any computation time problems, that is, to compute the new *Gflyup*($t+\Delta t$) in a time less than Δt. Nevertheless the flight computer must also *estimate* $V(t+\Delta t)$ in a time less than Δt, which means that we must implement a simplified model in the flight computer.

I'm planning to study other versions of the automatic pilot where I will maintain a constant radius trying to maintain constant the speed through the loop varying the engine impulse. Finally I will study another version where I will combine the variation of *Gflyup* and engine impulse trying to reduce the minimum *GoffSetRate* necessary to implement the perfect horizontal loops automatic pilot.

Reference

1 Barahona da Fonseca, J. (2003): *Incursões dum Engenheiro Electrotécnico na Aero Mil II: do Modelo Estático para o Modelo Dinâmico*, work submitted to Fernandes Costa 2003 Award (written in Portuguese), www.inst-informatica.pt/v20/produtos/premio_fern_costa/default.htm.

2 Stevens, B. L. and Lewis, F. L. (2003): *Aircraft Control and Simulation*, John Wiley & Sons, 2nd Edition.