Static Stability Analysis of Canard Configured Predator

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The original Predator Drone is redesigned with a canard instead of an inverted V-tail. Assumptions used in the analysis and requirements for the redesign are specified. Both the old and new Predators are discussed. The static stability analysis for both aircraft is presented and contrasted. Requirements are shown to be met. A dynamic stability analysis for the new predator is also presented along with it's predicted handling qualities.

Nomenclature

S_w	=	Main Wing Area	V_{min}	=	Minimum Airspeed
W	=	Weight	V_{cruise}	=	Cruise Airspeed
b_w	=	Wing Span	V_{max}	=	Max Airspeed
ζ	=	Damping Ratio			

I. Introduction

The RQ-1 Predator drone is one of the older military drones that is well known by the public. It was developed in the mid 90's and has been used extensively. The purpose of this paper is to explore the effects of a canard configuration on the Predator and perform a full static stability analysis for both the old and new designs. Certain parameters will remain constant for both aircraft (Table I) that will allow for a meaningful comparison. The analysis presented here uses a program called Wings, by Dr. Phillips, to determine aerodynamic coefficients and derivatives. An airplane is defined in a .wings text file that Wings can read and evaluate.

S_w	=	$121.5\ ft^2$	V_{min}	=	$100\ ft/s$
W	=	$2100\ lbf$	V_{cruise}	=	$135\ ft/s$
b_w	=	$48.6\ ft$	V_{max}	=	$200\ ft/s$

Table 1. Constant Parameters between the old and new designs

A. Assumptions

For this analysis the propeller was assumed to have no affect on the aerodynamic coefficients or derivatives and compressibility was neglected. Sufficient thrust was assumed to be available for all operating conditions. The destabilizing affects of the fuselage also weren't accounted for while the drag on the fuselage was roughly included.

B. Requirements

For this redesign, Predator's main wing could not be modified except in mounting angle, position, and sweep. The canard span could not be larger then 40% of the main wing span, have more then 20 degrees of sweep or have a taper ratio greater then 1. During the standard operating airspeeds of 100 ft/s to 200 ft/s no lifting surface could exceed a lift coefficient of 1.9 and the lift on the main wing could never exceed that of the canard. Also, the static margin had to be between 5% to 20% and the yaw stability derivative maintained positive. The new airplane was required to trim at it's cruise speed of 135 ft/s with zero degree angle of attack ($\pm$ 0.25 deg).

Some of the other variables that could be modified in the redesign were moving the center of gravity location, axial location of fuselage, canard geometry, canard airfoil, canard location, and adding winglets to the main wing. Altering the canard's vertical offset could also be considered.

II. Design Changes

In this section the changes that were made to the original Predator and why they were made are examined. A more detailed comparison with plots will follow in Section III with more detail.

A. Original Aircraft

The original Predator as shown in (Figure 1) was provided in a .wings format. A simple trimming analysis was done to find the axial center of gravity (CG) location that would yield 5% static margin for the cruise speed of 135 ft/s at sea level. It was found that when the CG was located 1.0642 ft behind the main wing (or at 14.0642 ft in the .wings coordinate system) the criteria above was met.

Figure 1. Predator Drone with standard inverted V-tail

B. New Aircraft

The first change to the original aircraft was to remove the inverted V-tail and vertical stabilizer then place a canard on the nose of the aircraft. To achieve a stable canard configuration the main wing was moved back and the CG was moved between the two lifting surfaces. Pitch stability was relatively easy to attain with these simple changes but the yaw stability was much more difficult.
To increase the yaw stability the main wing was swept back significantly and winglets were add as can be seen in Figure 2. Sweeping the wing shifted the main wing's center of pressure (CP) more aft of the CG. This helped in yaw stability but it wasn't enough. To increase yaw stability large winglets were added. The winglets extend above and below the main wing to increase their effectiveness.
A slight amount of sweep was also added to the canard to help with yaw stability. Sweeping the canard moved it's CP closer to the CG and lessened the destabilizing affect of the canard in yaw and pitch. The

canard was also moved up above the wing to minimized the negative affect of it's trailing vortices on the main wing.
Anhedral was added to the canard because it looks awesome.

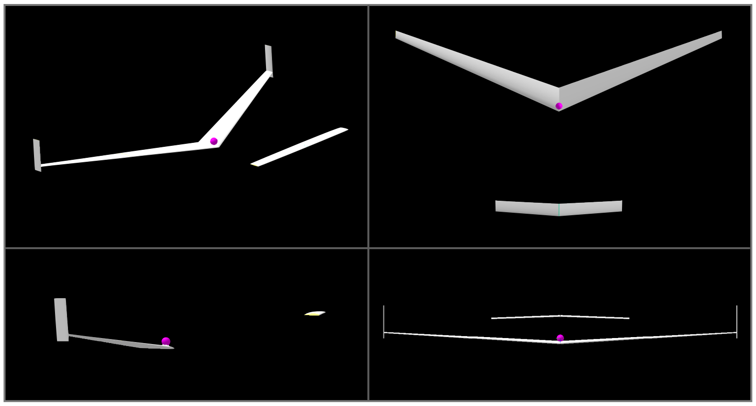

Figure 2. Predator with canard configuration

III. Static Stability Comparison

A more detailed comparison of the static stability for the two aircraft will now be presented through a variety of plots. First, the static stability characteristics over the standard operating airspeeds will be addressed followed by the pitching stability. The plots will show that the new aircraft meets all the new design requirements and that the old aircraft is stable but does not meet the new requirements.

A. Standard Operating Airspeeds

The new Predator was designed to trim with a near zero degree angle of attack and little elevator deflection at 135 ft/s. From Figure 3 we can see that this design criteria was met as it shows the angle of attack and the elevator deflection for steady level flight as a function of airspeed. At 135 ft/s the angle of attack is -0.113° and the elevator deflection is -0.265°. To met this requirement the mounting angles of the main wing and canard were set at 4.3° and 7.0°, respectively. Figure 3 also shows that the old Predator was not design with this constraint at the this airspeed.

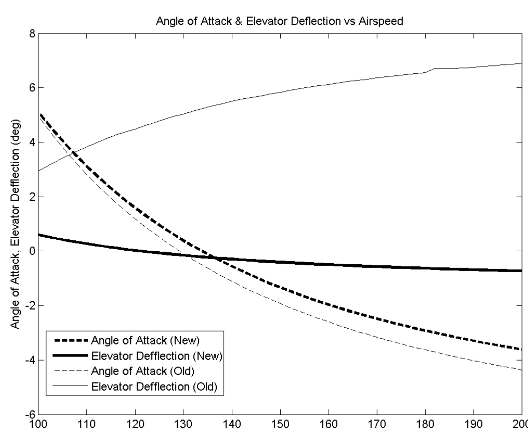

Figure 3.

For time and static stability of a canard configured aircraft the lift coefficient on the canard mush always be greater then that of the the main wing. Figure 4 is useful for seeing that this characteristic is met for all design airspeeds. The original Predator's more conventional configuration with stabilizing surfaces on the tail does not have to have a higher lift coefficient on it's longitudinal stabilizer and can actually be stable and trim at a specific airspeed with no lift on the tail.

Because the canard is always producing lift and because of the added winglets, the over all drag on the new Predator is more then that of the old (Figure 5).

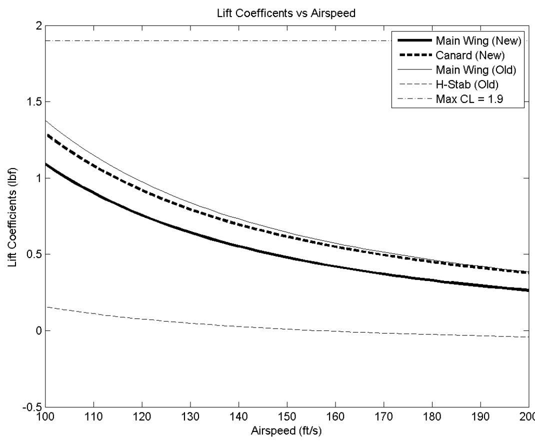

Figure 4.

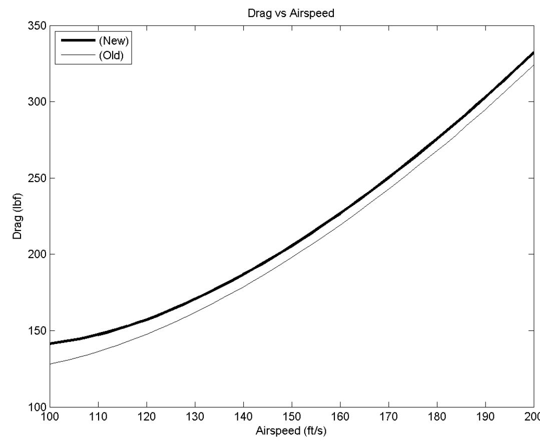

Figure 5.

Static margin is an important parameter to keep track of during the design of an aircraft. For the new aircraft the static margin varies between 10.8% and 9.1% (Figure 6). This is well within the limits of 5% to 20%The old aircraft has an over all higher static margin for the same airspeed range. The lack of a nice curve for the static margin of the old airplane is most likely due to numerical problems within Wings. The sharp discontinuities are hardly a representation of reality yet the fact that all values are positive for the points to a stable aircraft.

The yaw stability of the new Predator increases with airspeed from 0.0175 to 0.0559 (Figure 7). The increase is related to the large, outboard winglets that also increase in effectiveness as the air moves faster. This figure shows similar numerical problems with the old Predator to the last plot. Again, all the values are positive and point to a stable aircraft in yaw.

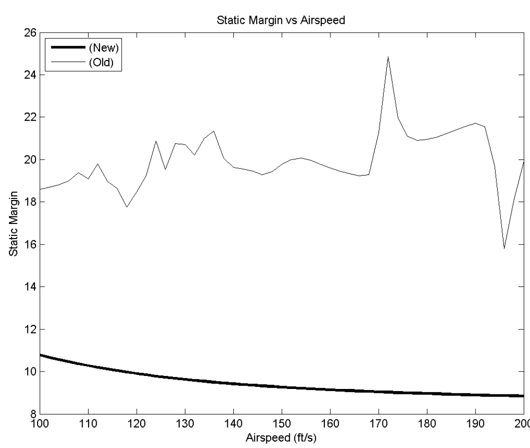

Figure 6.

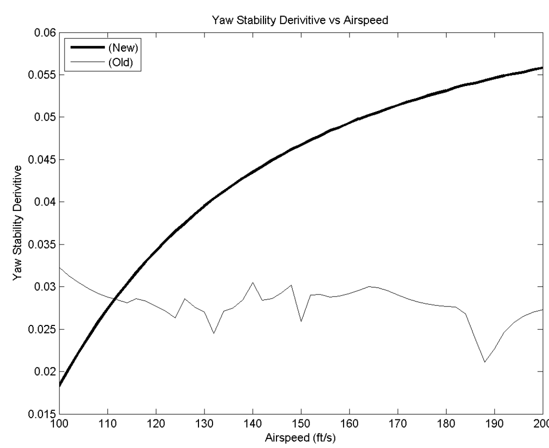

Figure 7.

B. Pitch Stability

Figure 8 shows the pitching moment as a function of angle of attack for three different airspeeds. To create these plots the airplanes were trimmed for level flight at the respective airspeed, then forced to different alphas while keeping everything else constant. The range of alphas is from positive to negative stall assuming stall happens at a lift coefficient of 1.9. The new predator has much more tail volume (due to both increased surface area and it's distance from CG) which causes the larger magnitude restoring moments. It is easy to see here that both aircraft are very stable.

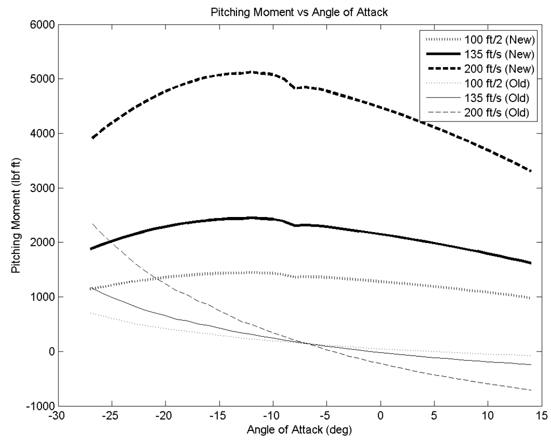

Figure 8.

The negative slop on the lines for the old Predator are good for unconditional stability. The new predator does have a region of positive slope with a positive value for the pitching moment which points to conditional stability. Well that maybe be a little worrisome for certain aircraft, the large magnitudes of the restoring moment make it not so much of a worry for the redesigned Predator.

IV. Dynamic Stability of New Predator

Now that static stability is proven, the dynamic stability will be explored. Using the nondimensional linearized 6 degrees of freedom (DOF) equations of motion (Phillips pg 932) and small disturbance theory, each homogeneous dynamic mode is found. All gyroscopic effects are assumed to be zero. The five most common modes that will be discussed in more detail are the Short-Period, Phugoid, Dutch Roll, Roll, and Spiral. We will find that the new Predator for category B flight phases has mostly level one handling qualities during it's normal range of airspeeds.

A. Short Period Mode

The short period mode for most conventional configured aircraft oscillates very quickly and can hardly be noticed by passengers except for a single bump. In contrast to that, the canard configured Predator has so much damping that there is no oscillation for this mode. This unusually high damping is because the CG sits forward of the main wing. When there is a pitch disturbance the huge main wings add significantly to the pitch damping.

For level 1 handling qualities the damping ratio must be $0.3 < \zeta < 2.0$ while the CAP must be $0.085 < CAP < 3.6$. The damping ratio meet the level 1 requirements (Figure 9) but at about 175 ft/s the aircraft has level 2 handling qualities because the CAP becomes to large (Figure 10). This is likely due to the fact that the greater air speeds increase the destabilizing affect of the canard.

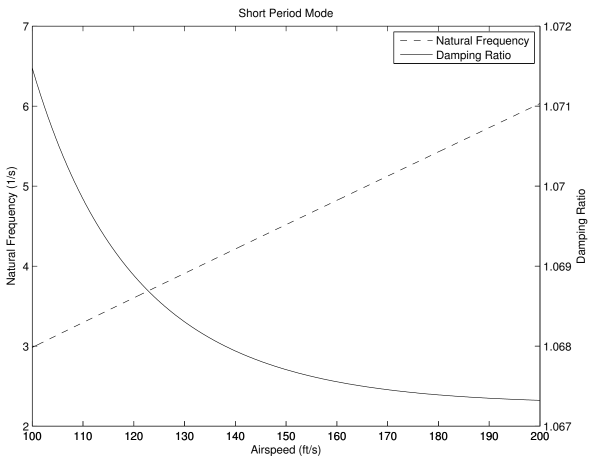

Figure 9.

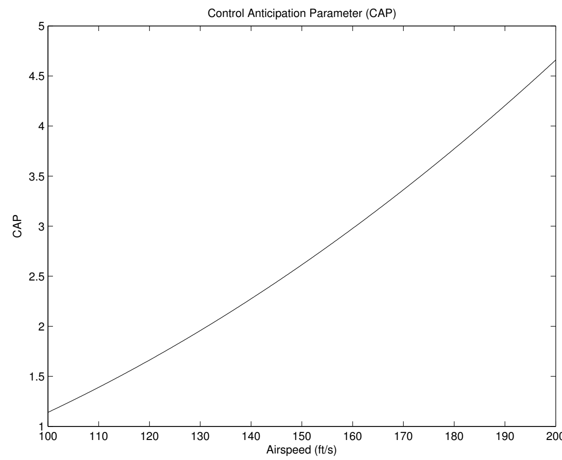

Figure 10.

B. Phugoid (Long Period) Mode

For the new Predator the Phugoid mode is oscillatory and convergent. To meet level one handling qualities the damping ratio must be $\zeta > 0.04$. The aircraft has level one handling qualities for required airspeeds as shown in Figure 11.

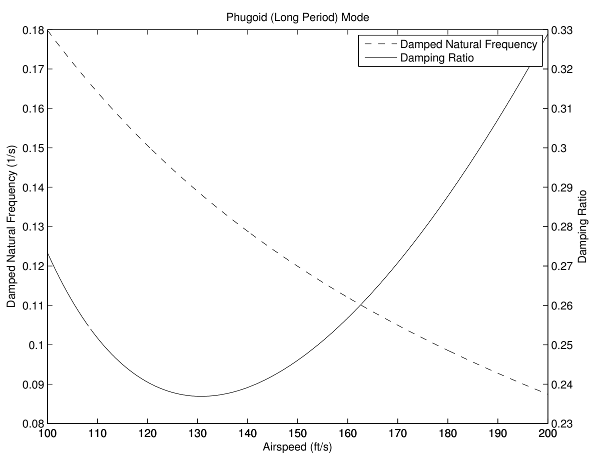

Figure 11.

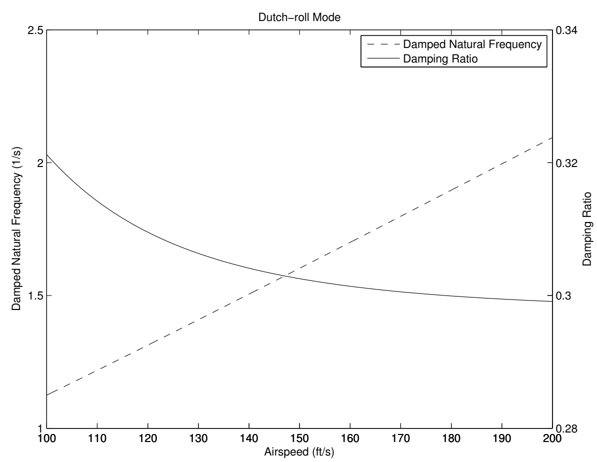

Figure 12.

C. Dutch Roll Mode

The Dutch Roll mode is also oscillatory and convergent. Figure 12 shows that level one handling is achieved by having a $\zeta > 0.08$ for all airspeeds. The large winglets contribute substantially to the high dutch roll damping.

D. Roll Mode

The roll mode is usually so fast that pilots don't totally realized that it exists. For the new Predator it is no different. The 63% time constant must be $\tau < 1.4$ for level one handling qualities and the new aircraft doesn't even exceed 0.16 (Figure 13).

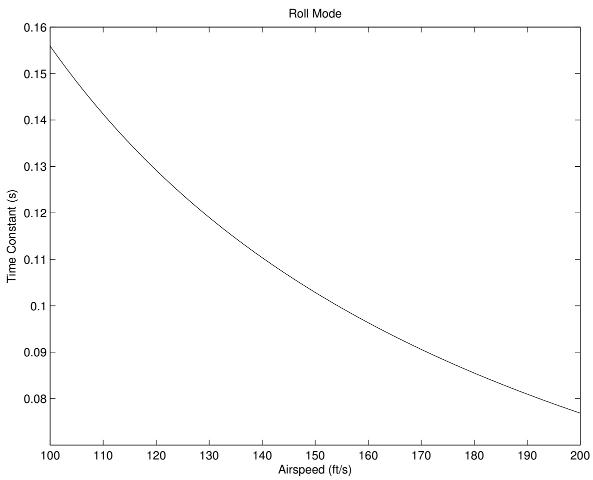

Figure 13.

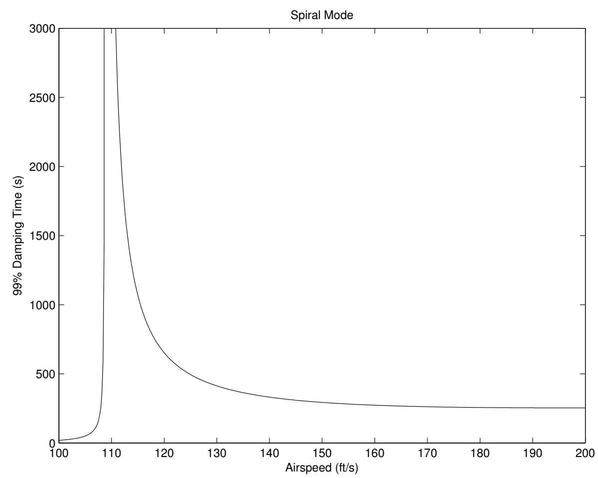

Figure 14.

E. Spiral Mode

The new Predator has a convergent spiral mode that approaches divergence at airspeeds between about 105 ft/s and 120 ft/s (Figure 14). Level one handling is achieved because the mode is convergent for all airspeeds. If it were to go slightly divergent the doubling time would be very large and the spiral mode still wouldn't be an issue.

F. Handling Quality Summary

Over all the new Predator is dynamically stable and has excellent handling qualities. Table 2 shows a summary of the handling.

Mode	V = 100 ft/s	V = 135 ft/s	V = 200 ft/s
Short Period	1	1	2
Phugoid	1	1	1
Dutch-Roll	1	1	1
Roll	1	1	1
Spiral	1	1	1

Table 2. Handling qualities the new Predator

V. Conclusion

As shown above, the canard configured Predator meets all the requirements for the redesign. While it isn't necessarily better then the original, the new plane is statically stable in pitch and yaw for airspeeds between 100 and 200 ft/s. For dynamics stability the new Predator is also stable and has great handling qualities of mostly level one. It is recommended by the author/designer that refining the design and doing a more detailed analysis of this configuration is worth the time and effort.