Pitch Stabilization with Tailored Canard Compliance

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ABSTRACT

The aircraft design problem is an example of a highly integrated design, which calls for a multidisciplinary approach from the very beginning. With every generation of aircraft, it gets more difficult to make substantial improvements since so much already have been done to produce as efficient aircraft as possible. Next generation civil aircraft needs to take every possibility to increase efficiency. One potential area of improvement is to reduce drag due to the requirement of positive stability. The stability requirement is a result of safety regulations, and with the present state of the art, it is difficult to get a system certified that can artificially stabilize an aircraft. If this can be overcome, there are potential gains in drag, since all horizontal surfaces can be used for lift, and hence total planform area, and hence parasitic drag, can be reduced. Another advantage is that a wider cg range can be allowed.

In this paper we propose a configuration with dynamic load canards, suitable for business aircraft (biz jet and biz prop), as well as large next generation transport aircraft, with prop fans that have to be located in an aft position.

The approach used here is to look at control surface actuators and different means to utilize force control, possibly together with position control, to introduce compliance in proper positions of the system. As a side effect, excessive loads on control surfaces can also be avoided, which can translate into weight reduction. There is also scope to reduce gust sensitivity, for e.g. passenger comfort.

KEYWORDS: *Aircraft design, flight control, canard, force control*

1 INTRODUCTION

Looking at future aircraft concepts, one recurring concept is that of aft mounted prop fans. This is a problematic configuration from a cg point of view, since a lot of weight is located aft. Therefore, the distance between wing and tail becomes short, resulting in considerable trim drag, unless a canard is added. This is aggravated by the fact that the cg position is changing considerably between empty and fully loaded. One example of an aircraft using this three wing configuration is the Piaggio Avanti. In order to minimize drag the optimum lift distribution between the wing surfaces would result in an unstable configuration, Kendall [1] .

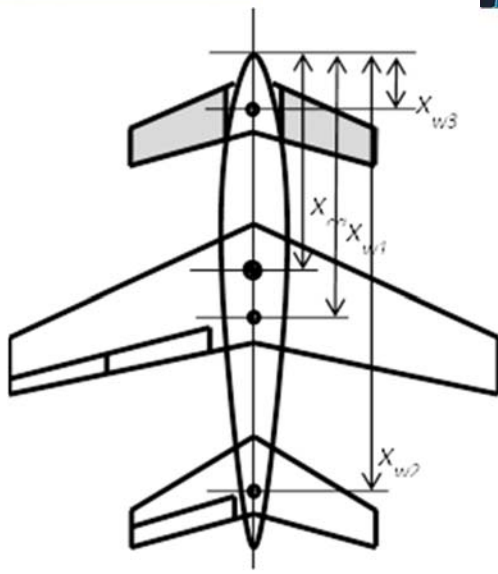

Figure 1. Three wing transport aircraft configuration

Here we will be looking at introducing a control system with compliance. By having a preloaded spring that transmits the force to the fuselage from the canard, a dynamic control surface is achieved. In the extreme case, with an infinite compliance, the wing would just float and would in principle, provide no contribution to the dynamic properties of the aircraft. With a preload of the spring it still provides the lift but not with the negative influence on stability. The stability characteristics of a compliant wing was derived in Krus 1997 [2], where it was demonstrated that introducing flexibility in wing in front of the cg has a stabilizing effect on an aircraft/bird without the need for sophisticated control systems. The free wing concept is an old concept, studied in Kapseong et al 2007 [3] that is also related to this. In the free wing concept, the wing can freely rotate and the angle of attack is controlled by control surfaces. This does, however, have the disadvantage that a wing with positive moment cannot be used, which means a less efficient profile has to be used.
An extension of this kind of control system is force controlled flight control actuators in general. In conventional flight control systems, actuators are position controlled. E.g. to have a actuators, where a force (or torque) is controlling the rotational speed of the aircraft, since the objective of flight control surfaces is to provide a control force. A hydraulic concept with force control using pressure control was suggested in Marganski 2011 [4]. Until now, it has had little use in aircraft, although manual control system can be argued to be like this. There are potential benefits in this approach, e.g. it is likely to produce less stress on the airframe, and effects such as rate limitations and actuator stall will be more benign. There is also scope to reduce gust sensitivity by simple means, for e.g. passenger comfort.

2 THE DYNAMIC TRIM CANARD

A hydraulic concept of a *dynamic trim canard* is shown in the picture as an example. It is essential that the solution is robust to ensure certification, e.g. implemented with passive control for civil aircraft. This system is nothing more than an adjustable spring, represented by the accumulator and thus need no active servo control. The valve is used for trim and can in principle be a manual valve that is actuated to change the lift distribution between the wings. In the example demonstrated here, a position feedback with low gain is used, but a pressure control could be used either instead, or in a combination with the position feedback.

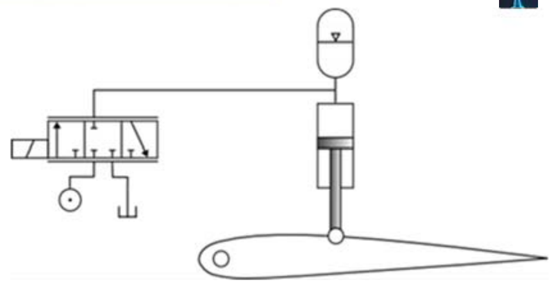

Figure 2. Hydraulic system for dynamic trim canard

3 FULL SYSTEM SIMULATION

Using simulation models of whole aircraft with subsystems, it is then possible to do design analysis, e.g. sensitivity analysis and trade of analysis, as well as design optimization. In recent decades, there has been a lot of development in methods and tools suitable for simulation of systems. One example is the Hopsan simulation package developed at Linköping University. This means for example that it is possible to model basic aircraft systems, such as hydraulic system, air system and fuel system, much more efficiently than before and that many systems can even be simulated in real time or faster than real time. E.g., subsystem models of actuation systems can be coupled to models of flight dynamics, propulsion, and flight control, to produce a more complete aircraft system model. This was demonstrated in Krus et al [5].

Using full system simulation the dynamic load trim canard concepts is simulated, and in this way evaluated. The flight dynamics model is based on a 6 degree of freedom rigid body model that is connected to an aerodynamic model. The aerodynamic model can have a different number of wings, with an arbitrary number of control surfaces, and a body with its characteristics. It is here based on a static version of the model presented in Jouannet et al. [6], although the unsteady effects can of course also be included.

The control surfaces are modeled with both a linear increase of lift force with deflection and the corresponding increase in induced drag. In this way, also the effect of trim drag on performance is automatically included. The system also includes a simple control system. The system is implemented in the Hopsan simulation package developed at Linköping University.

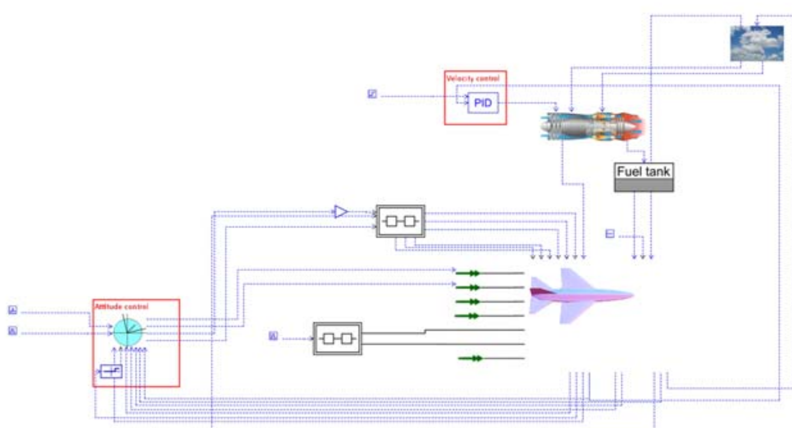

Figure 3. Full system simulation model.

Here the control system for the canard is modelled in detail with one cylinder per canard connected to a common accumulator and a single control valve. In this way, both canards will exert the same control force. There is a low gain feedback of the canard wing positions in order to trim them.

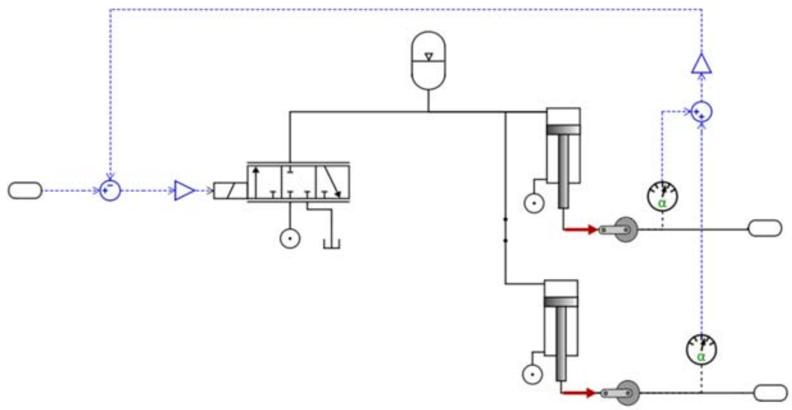

Figure 4. Hydraulic dynamic actuation subsystem

The simulated aircraft is based on a transport aircraft loosely modeled on the Embraer ERJ145 but with a canard. Empty weight is 111667 kg. To this, a fuel load of 4170 kg is added, and in addition, there is 4200 kg of payload. The canard is 5.1 m^2, which is 10% of the reference wing area (51.2 m^2). The aspect ratios are 8.128 for all the horizontal wing surfaces.
Simulation results are shown in the figures below. The speed is around 240 m/s and the altitude is around 10000m. The two piston attached to the canard have a piston area of 10^{-3} m^2. The moment arm for the piston is 0.1 m. The aerodynamic center of the canard is located 0.25 m behind the axis of rotation. I the simulated condition with the dynamic actuation system active the pressure in the actuator is around 15 MPa. The volume of the accumulator is 5 liters. This means that the whole system is very compact.
Three cases are simulated. One is the baseline without canard, Figure 5. One where the canard is fixed at a zero angle relative to the airframe, Figure 6, and one where the system with compliance is activated, Figure 7. In both cases the cg is 0.1 MAC in front of the neutral point, giving a stable aircraft for the case without canard.
Here a simple straightforward control system is used to simulate the pilot with only a proportional gain of pitch and a 0.1 sec time delay (reaction time of pilot. This value is taken from [7]). A step change in reference attitude is given. The result is rather oscillative with the fixed canard since the aircraft is in an unstable configuration with the added forward wing surface, and the resulting system becomes highly oscillative. Using the canard with compliance, this is much more damped. The result is also slower since the dynamic characteristics are like those of an aircraft with a high stability margin. In this case, the gain in the control system/pilot could be increased to have a more rapid response, but here the same gain is used for comparison, for all cases.

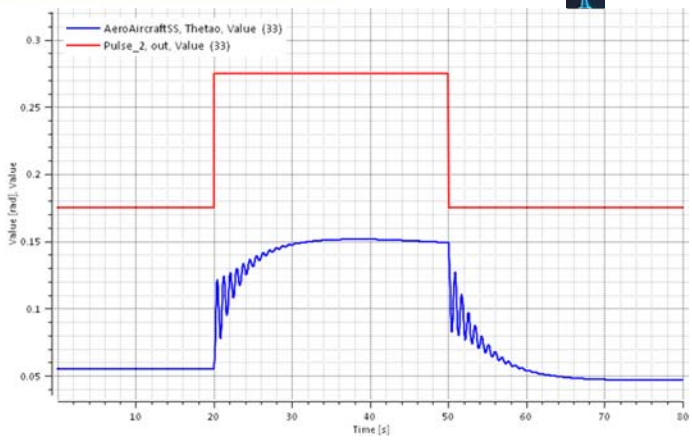

Figure 5. Aircraft attitude and reference attitude for the baseline case without canard.

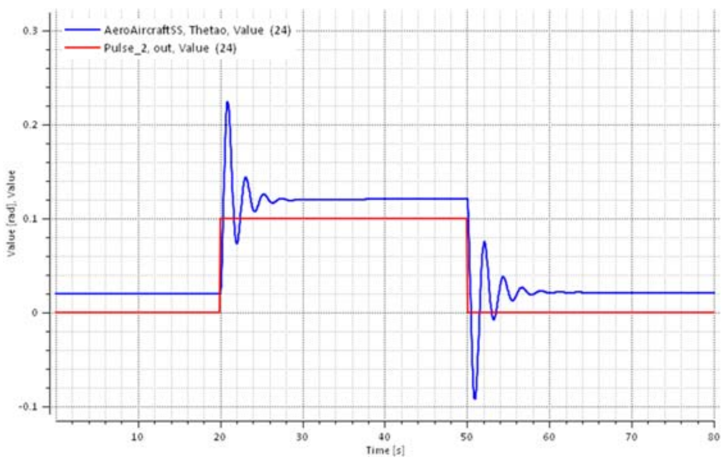

Figure 6. Aircraft attitude angle and reference attitude for the case with fixed canard.

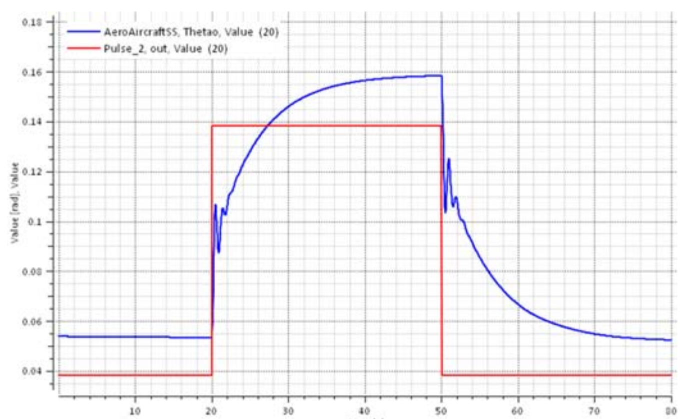

Figure 7. Aircraft attitude and reference attitude for the case with dynamic trim canard

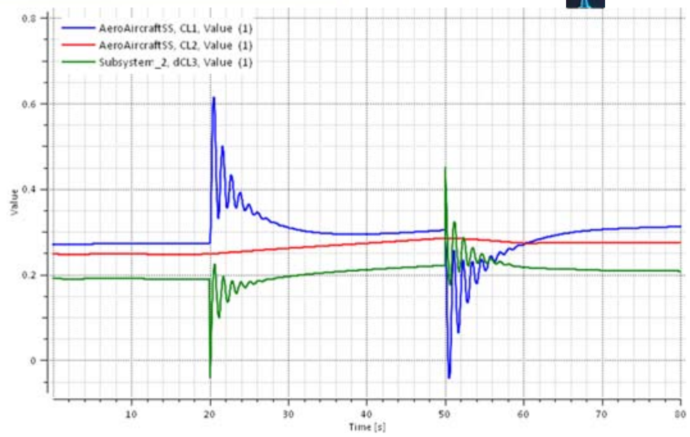

Figure 8. Lift coefficients for the three wing surfaces. The main wing and the canard are close since the canard is controlled to have zero angle relative the main wing.

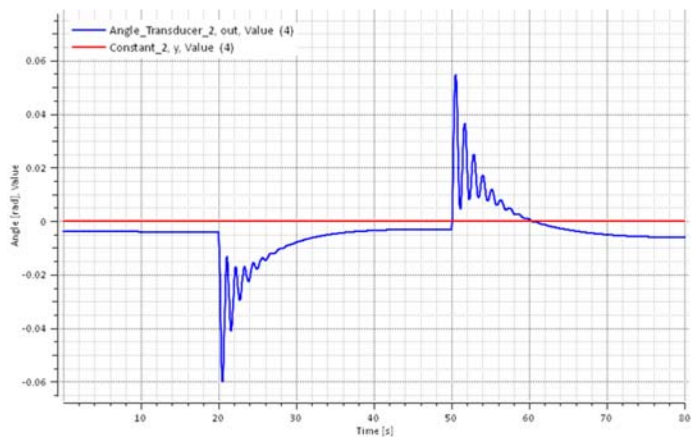

Figure 9. The canard position (relative the aircraft). Reference position is zero angle.

4 DISCUSSION

The simulation results shows that the dynamic trim canard works very well. The step response with the very simple controller used to represent the pilot is very benign in contrast to the case with a fixed canard. There are additional factors that should be further explored. E.g. the effect of introducing damping in the hydraulic system. Furthermore, the effect of cg of the canard in relation to the axis of rotation. Here these are set to coincide so that there will be no coupling between airframe movement and rotation of the canard. Furthermore, the distance between aerodynamic center of the canard and the rotation of axis is another critical variable.

With the simple scheme used here where there is a low gain control of the canard that puts it at a position to have the same CL as the main wing, an optimal lift distribution is obtained if the cg is at the same position as the wing center of pressure. A more advanced controller could take the loading of the tail into consideration to optimize the lift distribution between the wing surfaces to minimize drag at cruise.

5 CONCLUSIONS

Compliance in a control surface can occur naturally or artificially by different means. If this control surface is forward of the center of gravity, this will increase the longitudinal stability of the aircraft. In this way, a passive system can be obtained that should be much easier to certify than a system with an active control system. This makes it is possible to realize an aircraft that can fly in a geometrically unstable configuration and hence with greatly reduced trim-drag. A hydraulic system concept has been suggested, that can realize this functionality in a very compact form. The concept has been demonstrated through simulation. Force control as a complement to position control is also in general a concept that can have many advantages, e.g. for simplifying flight control systems, and should be the topic for further studies.

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