Modelling and simulation of the fuel transfers for CoG position control in an Aircraft

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Abstract: - Fuel transfers are used in aircrafts for the control of the COG position. This is essential for stability and operational performance. This paper deals with the modelling and simulation of the fuel transfers in a generic airplane. The model is established using Simulink, for an easy adaptation to specific airplane cases. Simulations are useful to study COG control strategies, and operational reactions to certain contingencies. The paper focus on the COG control in the aeronautical technical context, keeping it inside a region of interest.

Key-Words: - Avionics, Aircraft Fuel System, Fuel Distribution Control, Aircraft stability, CoG Control

1 Introduction

Aircrafts use fuel for several purposes. It is not only to keep the engines running. As a fluid, the fuel can be moved to optimise the COG position, or used for engine cooling. There is a specific on-board control system in charge of fuel management.

This paper describes part of an European Community Research Project, denoted “Smartfuel”. The objective of this project is to develop a new fuel management system, based on the use of a fieldbus and smart components. The consortium for the project is formed by four companies providing fuel system components, two companies making aircrafts and which can be users of the new system, and three universities providing scientific support.

The purpose of this paper is to present a new simulation environment, for the study of fuel management operations and control, focusing on the optimisation of the COG position. The simulation is based on a computer model of the fuel management system.

Experts in aircraft development, partners of the research project, gave us the required data for modelling. There are some books with chapters on aircraft subsystems, including fuel management systems [1][2]. Other books and articles deal with the effect of the COG on the aircraft performance. [3-6].

The order to follow in this paper is first to describe the research objectives and the fuel system, then to present a computer model of the system, then to use the model for simulation purposes, focusing on the COG position control. Finally some conclusions are drawn.

2 Objectives of the Research

The engineers of aircraft fuel management systems, partners of the project, asked for a new simulation environment. Part of the needs is connected with new fuel components and new fuel control strategies, for aircraft performance improvements. Another part is related with “what-if” studies. For instance what to do when a flight is reconfigured, or when an aircraft balancing problem appears. In these cases, some of the functions should be assumed by the on-board control, and other by the humans and/or the external flight support environment (from airports, etc.).

Simulations are based on models. Consequently, once simulation requirements have been established, the first efforts should be driven to develop an adequate model of the fuel management system. The model should operate according with the logic of the on-board control system, and should offer information of the variables of interest: fuel quantity and distribution among tanks, COG position, and status of the components.

For evident stability reasons, the COG position must be kept into a zone. This position is also important for fuel consumption along the flight.

Thus, the objectives of the research are to develop a model, and to make a simulation environment for control and operation studies, with main focus on COG position.

A generic airplane will be considered. The model should be easily modifiable, to be able to consider more specific airplane cases.

3 The Fuel Management System

Figure 1 shows a schematic of a fuel management system of a generic airplane. There are three fuel tanks in each wing, and one trim tank at the tail.

There are sensors to gauge the fuel quantity in each tank. The figure $ shows only one sensor per tank. This is a simplified view of the system. In reality, as many as 60 fuel gauge sensors can be used in a tank, due to the geometry of the tank inside the wing. However, data concentrators are used, so a set of sensors can be seen as “one” sensor.

The fuel characteristics do change along the flight, so measurements should be corrected in real time.

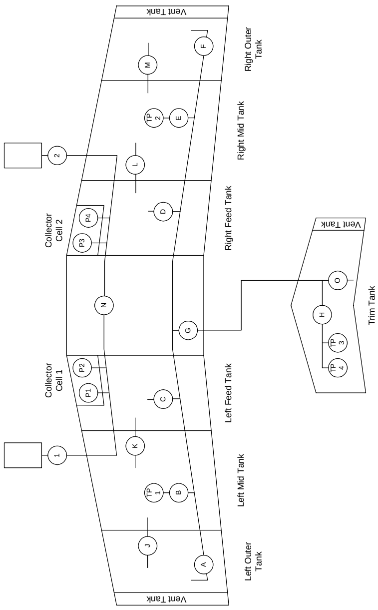

fig.1, schematic of the fuel system in a generic airplane

On/off valves are used to control the fuel transfers between tanks. Since the wings are inclined, simple gravity transfers can be done. Notice that the system has also pumps. The pumps ensure certain functions, not only transfers; for instance, engine cooling.

Notice that the system embodies some fuel path redundancies, to guarantee engine supply even when there are component failures.

Transfers between wings can be done. Likewise, transfers from and to the tail tank can be done. This later function is important to obtain a good airplane trim angle. The airplane drag depends on this angle, and should be optimised to reach longer distances.

An important operation of the fuel management system is refuelling. It should be fast and safe.

4 Model of the Fuel Management System

From the control point of view, the fuel management system is a hybrid control system. There is a combination of continuous variables, such fuel quantity, and discrete variables, due to the use of on/off valves and pumps.

The computer model of the fuel management system will be developed using Matlab-Simulink. It offers several important advantages for the project. It can be easily edited, so both component characteristics and interactions can be modified, to consider specific airplanes.

Simulink uses icons to represent abstract components. For instance a DC motor can be represented with an icon corresponding to the transfer function of the motor. The icons are drag into an editing window, and can be connected with arrows following the cascade of causes and effects. Models are similar to block diagrams.

There are several steps in the model development. First, modelling of components using Simulink icons. Second, connection of components. The logic of the system (the system intelligence) is expressed in part by the components, which can be of logical nature, and in part by the interconnection structure.

4.1 Models of Components

Tanks are modelled in a simple way. Figure 2 shows the Simulink model, and figure 3 shows this model as an icon.

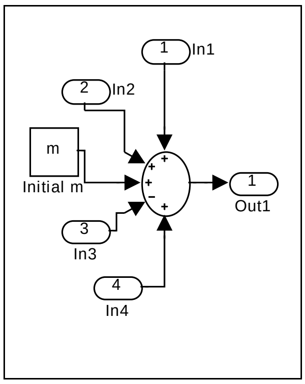

fig.2, Tank model

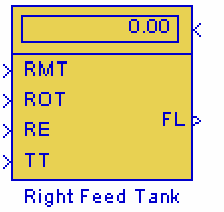

fig.3, Icon for the right feed tank

The engine is modelled as depicted in figure 4. Figure 5 is the icon for this model

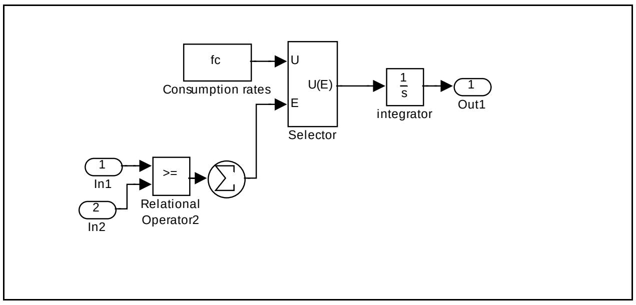

fig.4, Engine model

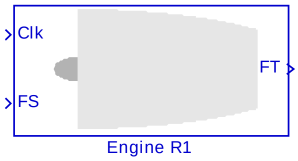

fig.5, Engine icon

Notice that the engine model includes some logic to represent different consume rates along the flight.

Each pump has a different model since the particular logic is embodied in the model. For instance figure 6 shows the model for the pump linking the middle tank with the aft tank. Figure 7 shows the icon for this model.

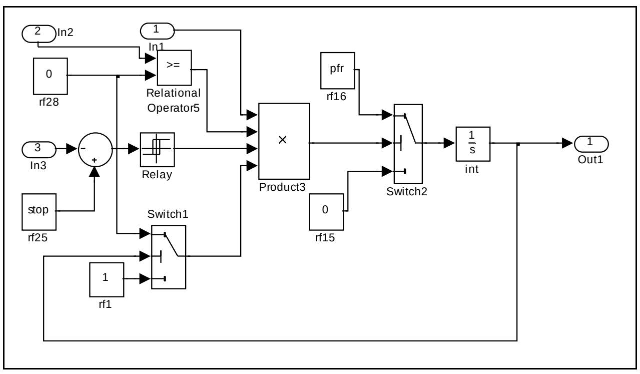

fig.6, Model of the middle to aft tank pump

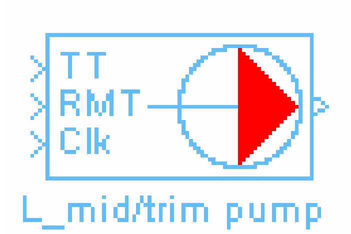

fig.7, Icon for the middle to aft tank pump

The aft to fed tank valve is modelled as depicted in figure 8. This valve is very important to control the CoG position. So, its logic is fairly complex. Figure 9 shows the icon for this valve.

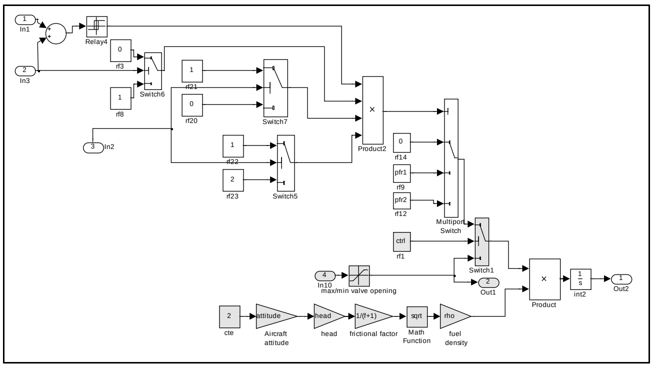

fig.8, Model of the aft to fed tank valve.

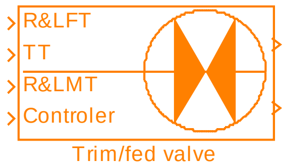

fig.9, Valve icon

The grey symbols in figure 8 represent a positional valve. Conventional valves are on/off, however the opening of positional valves can be controlled in a range from closed to open. Figure 10 shows the model of the controller associated with the aft to fed tank valve. Figure 11 shows the icon of the controller.

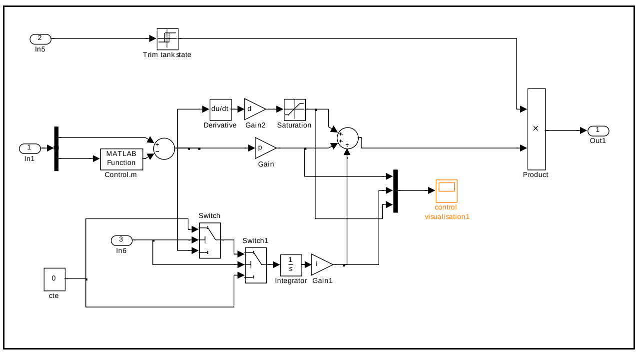

fig.10, Model of the controller.

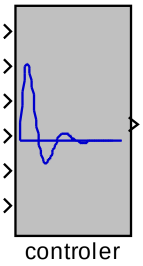

fig.11, Controller icon

Some Matlab code has been developed as Simulink function for the estimation of the CoG position. Figure 12 shows the icon for the CoG position estimator.

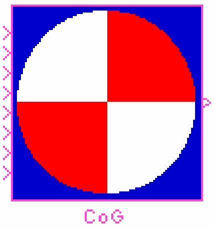

fig.12, CoG position estimator

4.2 Model of the Fuel Management System

Once the models of the components have been developed, their icons can be interconected to build a complete model of the fuel management system. Figure 13 shows a general view of the Simulink model.

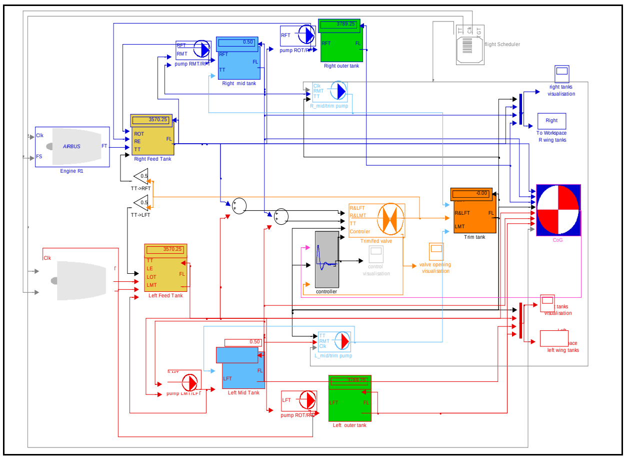

fig.13, Complete model of fuel management system.

Each icon can be edited to change its parameters. For instance a tank can be edited to have 14000 kg of fuel at the beginning of flight. Also the number of tank can be modified, etc.

5 Control of the COG Position

The simulation environment depicted in figure 13 is used to study the control of the CoG position along a typical flight.

Figure 14 shows the tanks weight evolution along the different phases of a typical flight.

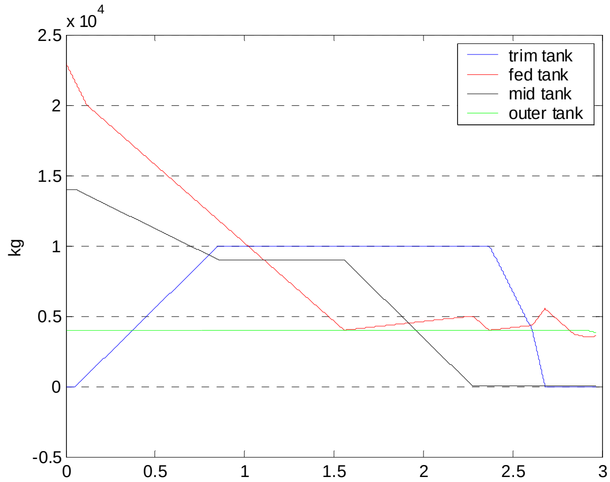

fig.14, Tank weight evolution during a typical flight

Along the flight there are several transfers, to ensure engine supply and a good COG position.

Here is a brief description of the fuel system work during the main phases of the flight:

- During the take off, the engines consumption is the highest, this corresponds to the line coming downwards from the top right of figure 14. This is the content of the fed tank. During this short period no fuel transfer take place among the tanks
- Once the aircraft has reached a predetermined flight level, transfer form mid tanks to aft tank takes place. The content of the aft tank increases as shown by the line coming upwards from the bottom left of the figure. The line starting from near 1.5 and coming downwards is the content of the mid tank. The transfer continues during the cruise until the aft tank reaches a weight of 10000 kg. As can be seen also in figure 14
- Later during the flight when the fed tank reach a minimum level (4000 kg) fuel is transferred from the mid to the fed tanks.
- Notice that before landing there is a line coming downwards from 10000 kg to 0 kg. This is the content of the aft tank. The line has two parts. The first part describes the controlled transfer of fuel from the aft to the fed tanks to assure that CoG is always inside its security region. The second part happens just before landing. It is necessary to transfer the remaining fuel in the aft tank as fast as possible to the fed tanks. No

fuel should remain in the aft tank during landing.

Fuel consumption and transfers cause a motion of the COG. It is important to keep the COG inside a zone.

In the airplane engineering context, this problem is analyzed using a special graphical representation. The CoG position is expressed as a percentage of the Mean Aerodynamic chord (MAC).

Depending on the specific aerodynamics of each aircraft, the CoG should not surpass certain limits which are also expressed as a percentage of the MAC. These limits depend also on the total aircraft weight and thus, they change during the flight as fuel is consumed.

… In consequence, a key experiment to be done in the simulation environment is to reproduce a complete flight and see the evolution of the COG position. Figure 15 shows the results.

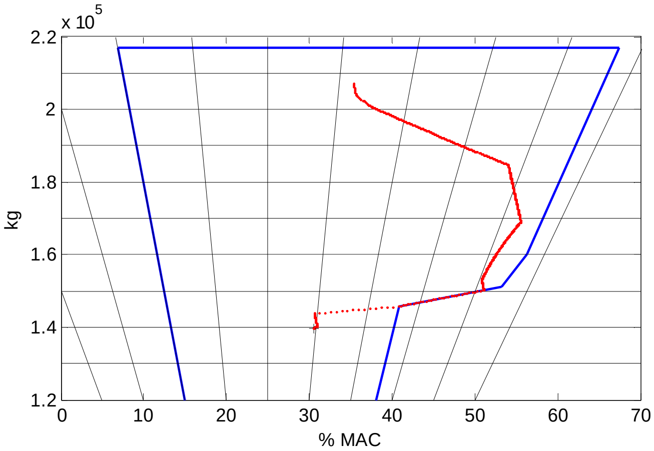

Figure 15 Evolution of the CoG during a typical flight.

In figure 15 the CoG limits are represented by an external perimeter formed with straight stretches. The CoG evolution is a curve that is always inside the perimeter (as should be).

7 Conclusion

In this paper a new control-oriented model of the fuel management system of a generic airplane has been developed. With the model several simulations can be applied, for the study of COG control strategies with new components, and for the "what-if" analysis of operational contingencies. The model is developed with Simulink, so it can be easily modified to study specific airplane cases.

Simulations have been run under the supervision of aircraft makers, and they showed good agreement with the observed behaviours on real flights. From the many remarks the experts made, it seems that the simulation environment is of clear professional interest.

In the future, a friendly human interface will be developed, for experiment specifications. Also, certain specific airplane cases will be studied, and the simulation system will be improved.

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