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Modeling of Control Circuit of Aircraft fuel system

***Abstract**. The proposal of fuel system for a particular airliner is a highly complex process, where all design requirements for the entire fuel system as well as individual components contained therein must be satisfied. And, it is also to show compliance with standards and regulations that determine the size parameters of the system. Nowadays at the design of these systems are increasingly being used tools of simulation software. With these tools it is possible to verify the properties a highly-complex nonlinear systems such as that aircraft fuel system.*

***Streszczenie.** W artykule przedstawiono projekt system paliwowego dla samolotu pasażerskiego, w którego modelowaniu wykorzystano oprogramowanie Matlab-Simulink. Założenia teoretyczne i badania symulacyjne obejmował wszelkie przepisy dotyczące jakości i wymiarów poszczególnych elementów, jak i całego systemu. (**Modelowanie układu sterującego dla systemu paliwowego w samolocie**).*

Keywords: Aircraft fuel management system, Fuel pump, Fuel valve, Fuel tank.
Słowa kluczowe: system zarządzania paliwem w samolocie, pompa paliwowa, wtrysk paliwa, tankowanie paliwa.

Introduction

Structurally and functionally, an aircraft fuel management system is a fairly complex device, the task of which is to ensure fuel delivery from the tanks of the aircraft to the combustion chamber of the engine. It is the type of the aircraft that determines the tasks the system is to perform in flight, i.e. the requirements for structural properties of individual elements and their parameters. Our design and subsequent verification in a simulation environment will be focused on the fuel system for small aircraft carrier with a gross weight of 8,618 kg, subject to certification according to JAR-23, FAR-23 and under-regulation RTCA/DO-160, RTCA/DO-178, RTCA/DO- 254, FAR PART 21 [6].

Usually this type of planes has 4-6 internal tanks and 2-3 engines. In our case, the aircraft has two engines and four internal tanks, which are located in the wings. The tanks are interconnected so as to enable, in case of any failure, fuel delivery from one part of the aircraft to another part, thereby eliminating a significant shift in the center of gravity and the possible loss of control of the airplane [1, 2]. When designing a fuel system, it is appropriate to verify system functionality and its features in a suitable simulation software. Currently, there are specialized programs developed for the design of the systems used by major airlines. In our case, we employed the Matlab – Simulink software, which has been developed for the design and simulation of various industrial systems [5]. This software was chosen for the design and simulation of our proposed fuel system of a small-size airliner [9].

General information

The primary task of the aircraft fuel system design is to propose fuel delivery in the fuel tanks available. Currently, two systems of pumping and consumption of fuel are in use. The "sequential" one is designed for large transport aircraft, when fuel is not used form the tanks immediately, but by a pre-programmed schedule, and the "direct" system, where fuel is consumed directly from the aircraft tanks [8]. This fuel system is primarily designed for small transport aircraft with fewer tanks. Both systems must be designed so as to operate almost automatically during the entire flight and to avoid posing additional burden for the aircrew. Management system and pumping fuel cooperates with other aircraft systems. The co-operating systems include:

- Flight Management System (FMS)
- Flight Warning Computer (FWC)
- Display Management Computer (DMC)
- Overhead Fuel Panel (OFP)
- Inertial Navigation System (INS)
- Engine Master Switches
- Landing Gear Status - Weight-On-Wheels (WOW)

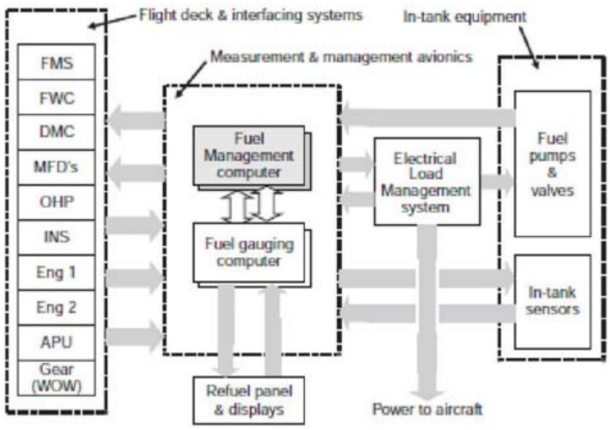

Fig.1. Management of sequential fuel delivery

Fuel systems also collaborate with the management system of power sources on board the aircraft. In case of loss of electricity supply or decrease in voltage or current, systems react immediately by switching over to backup power source, or backup fuel pump [3, 4].

Description of proposal for fuel system of small aircraft

The fuel system proposed by us will consist of 4 fuel tanks, four valves, which will also fulfill the of anti-fire function. The system will consist of 8 fuel pumps, 4 main, 2 backup and 2 for emergency delivery of fuel between the wings. The drive for aircraft will be provided by two turbo-propeller engines. The aircraft cabin will have a 2 member crew, with minimum load requirement in terms of fuel control. Delivery of fuel will be controlled automatically, with manual control of pumping to be performed only in emergency situations, in case when one of the pumps fails.

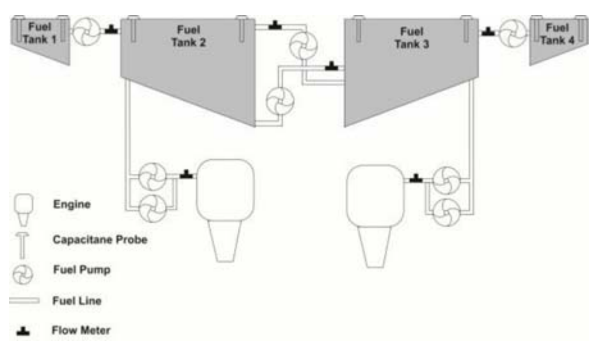

Fig.2. Block Model of aircraft fuel system

The entire fuel system design will include 4 fuel tanks, two integral wing-tanks with the capacity of 525 kg of aviation fuel and two wingtip tanks with the capacity of 350 kg of fuel. Total weight of fuel carried on the aircraft will be 1,750 kg. For sensing the amount of fuel in the tanks of the aircraft, capacitive sensors will be used, two in each fuel tank. For sensing fuel consumption, turbine sensors of fuel quantity will be used, 2 pieces for each wing. The fuel system will also include shut-off valves, connecting valves and fire protection valves [7].

Simulation of pumping and fuel consumption

The entire fuel system design was then compiled in the program Matlab-Simulink as shown in Figure 4, where is the entire fuel system in a subsystem with the output data of fuel flow inside tanks of wing and end-wing tanks of aircraft.

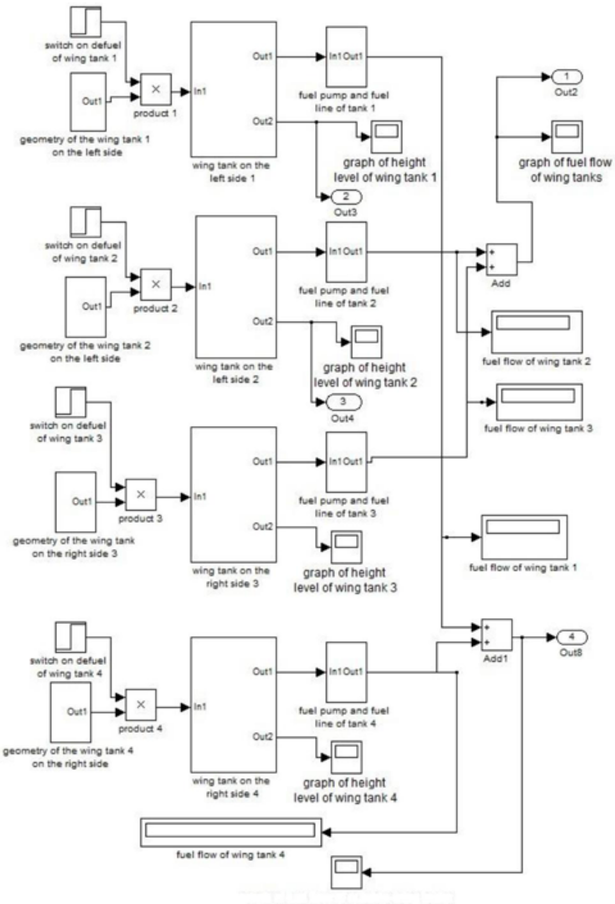

Fig.3. Model of simulation up to blocks

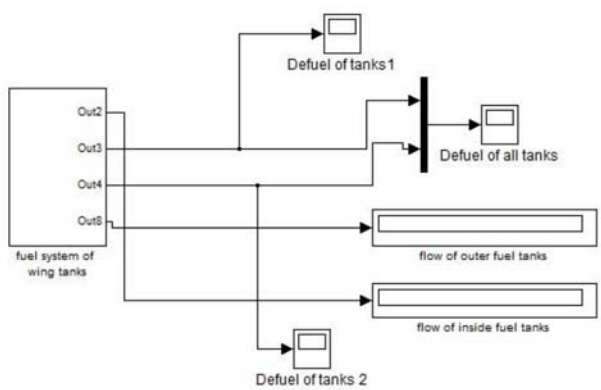

Fig.4. View the status of control system of pumping

You still need to define as correctly as possible the parameters of the tank and armatures in the fuel system due to the accuracy of results, as any change in bend, shape or size of armatures can cause large variations in them. If testing is focused only on the actual fuel flow through fuel lines and through the armatures, then fuel tank dimensions and shapes bear no such significance. However, when the entire fuel system and its behavior and of interaction between elements is examined, then great attention to be paid to precise definition of the tank parameters.

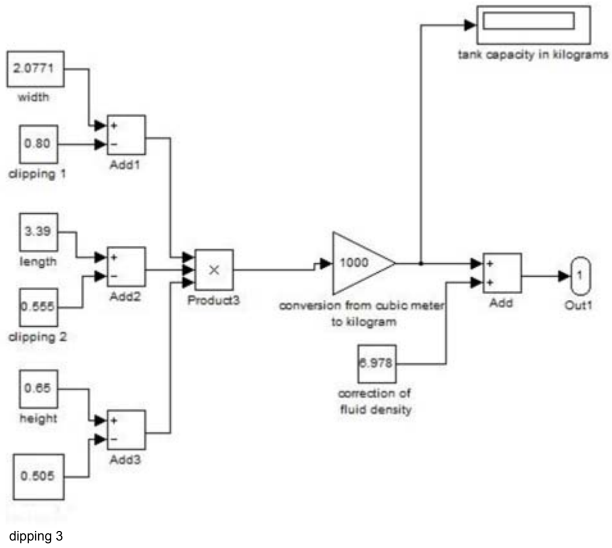

Fig.5. Geometry of Fuel Tank Aircraft

For the simulation the liquid Hyjet-4A was used as “fuel”, with viscosity 1 and temperature of 22.72°C. For fuel line a fixed - rigid metal pipes were chosen, as it is in real fuel systems. The length of pipes has been set for the same length of 500 mm between the internal wing tanks and wing-tip tanks, and 7,200mm between the integral wing tanks and the engines, the inner diameter of pipes were 10 mm and a the geometry factor was of 64 which determines the shape of the pipe, consequently, the pipe was of circular cross-section.

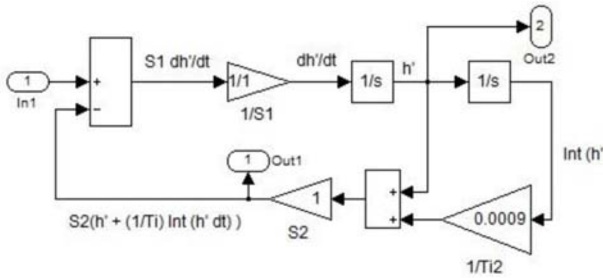

Fig.6. Parameters of Fuel Tank Aircraft

For fuel pump, an axial pump with electric motor drive was chosen. The reference angular velocity of the pump was set to a value 1770rpm and the correction factor to 0.8. The values of the approximation coefficients were as follows: first = 326.8 Pa.nfkg"^{1}, second = 3.104x104 Pa.s.kg"^{1}, third = 1.097x107 Pa.s^{2}.kg-^{1}.m-^{3}, fourth = 2.13 Pa.s^{2}.kg x105"^{1}.m-^{3}. The torque of the fuel pump drive shaft was 0.1 N.m torque.

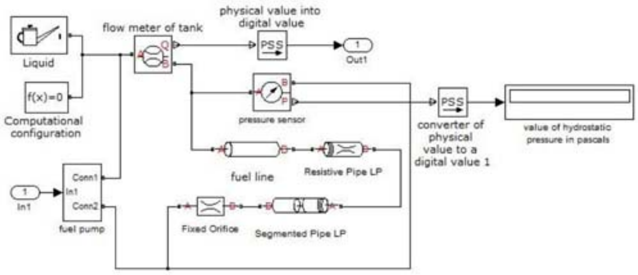

Fig.7. Diagram of Fuel pump and fuel line

Fig. 9 illustrates pumping of fuel from the wing-tip fuel tanks, showing how the pumping control circuit turns on the pump and fuel is gradually depleted from tank No. 1.

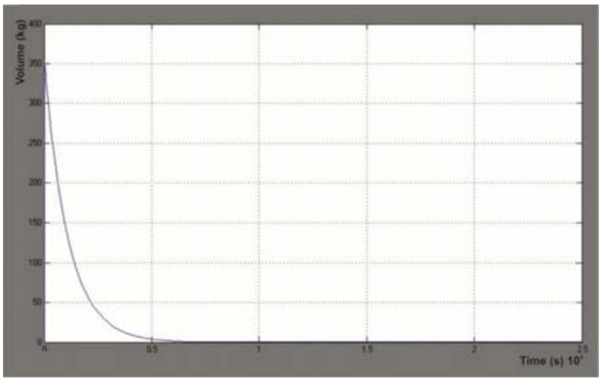

Fig.8. Depletion of fuel from tank 1

After having depleted tank No. 1, fuel pump No. 2 is switched on, starting the gradual depletion of the internal wing-tank No. 2.

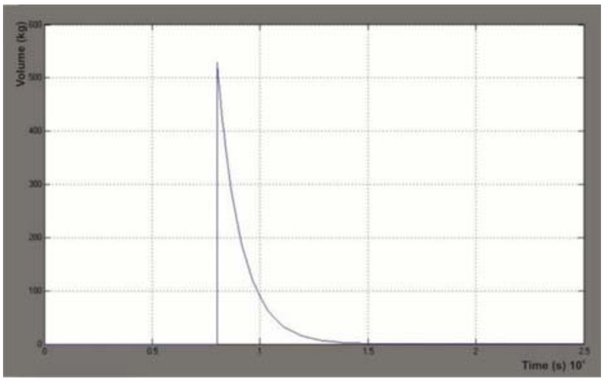

Fig.9. Depletion of fuel from tank 2

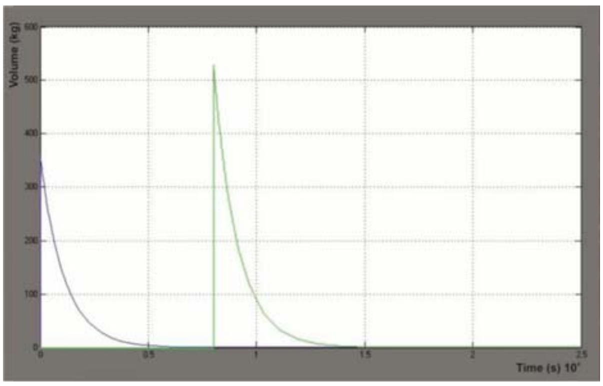

Fig. 10. Depletion of outers and inners fuel tanks of aircraft

Figure 10 shows how, after having emptied the wing-tip fuel tanks, fuel pump is switched on starting to fuel delivery from internal wing-tanks.

Depletion of both the wing-tip and internal fuel tanks is similar. Pumping from the internal wing-tanks starts at the moment when the fuel amount in the wing-tip tanks reaches the so-called minimum value. In real fuel systems, tanks are equipped with sensors fuel level indicating the minimum amount of fuel remaining.

Results of simulations

Fuel flow is measured behind each fuel tank. Since pumps are identical for the entire aircraft, and the same fuel line is used as it is common with most aircraft, in this respect, the fuel flow measured in the fuel lines is equal for all the tanks. Similarly, fuel pressure in the lines was also equal, see Table 1.

Tab.1. Fuel Flow from tanks of aircraft and pressure of fuel in fuel pipe

Fuel tank	Fuel Flow(m^3/s)	Pressure in fuel pipe (Pa)
Right Inner Tank	$1,2110\times10^{-4}$	5049163,7240
Left Inner Tank	$1,2110\times10^{-4}$	5049163,7240
Right Outer Tank	$1,2110\times10^{-4}$	5049163,7240
Left Outer Tank	$1,2110\times10^{-4}$	5049163,7240
Inner Tanks (total)	$2,4220\times10^{-4}$	5049163,7240
Outer Tanks (total)	$2,4220\times10^{-4}$	5049163,7240

Simulated values were taken into account for aircraft with Mach number 0.26, the air temperature of 22.72°C, speed of sound 314.8m/s aircraft speed 87.5m/s, 1265 km flight range of aircraft, the flight time of 12571.43 seconds.

The aircraft flight range was calculated using the equation for steady linear motion. Substituting values into the equation, the flight ranges for the individual types of tanks are obtained:

a, Left and right end-wing fuel tank:

$$s = \frac{V.v}{Q} = \frac{0,350.87,5}{0,0001210} = 253,09 \text{ km} \tag{1}$$

b, Left and right inside-wing fuel tank:

$$s = \frac{V.v}{Q} = \frac{0,525.87,5}{0,0001210} = 379,64 \text{ km} \tag{2}$$

Sum of the individual tanks we get a value of flight range of aircraft and namely 1265.46 km. The sum of the ranges for the individual tanks provides the value of total aircraft flight range of aircraft, namely 1265.46 km.

Conclusion

Modeling of fuel delivery is very important, because using these simulations help determine the functionality and the characteristics of the system. It also enables detection of any shortcomings in the fuel delivery management. Modeling a simple fuel system, used for small commercial aircraft, is easier, because such systems contain both lower number of fuel tanks and the less tasks to be performed during a flight, if compared to those systems used on large transport aircraft. However, in both cases the primary and main task is to control fuel delivery from the tanks to ensure a steady flow of fuel into the engines, until all the fuel tanks of the aircraft turn depleted. Unbalanced depletion of fuel tanks can result in changing the CG point, which can potentially lead to loss of control over the aircraft. In this regard, it is necessary to pay close attention to this system so that fuel delivery and depletion be as continuous as possible throughout the flight to ensure flight safety. In our case of modeling and simulation we were able to design a fuel system for a small airliner, which allows it fly at a range of 1265.46 km. It is considered sufficient for small regional airliners powered by turbo-propeller engines. At this range, at a speed of 87.5 m/s, the aircraft flight endurance is in excess of 4 hours.

REFERENCES

[1] Bréda, R. – Čižmár, J. – Soták, M. – Beňo V.: Letecké prístroje, Vysokoškolská učebnica, Technická Univerzita Košice, Letecká Fakulta, 2011, ISBN: 987-80-553-0626-1.

[2] Čižmár, J. - Trubač, M.: Přístrojové vybavení. skriptum. 1. Brno: Akademické nakladatelství CERM, s.r.o., Brno, 2006, 230 s. ISBN: 80-7204-445-1.

[3] Langton, R. - Clark, Ch. - Hewitt, M. - Richards, L.: Aircraft Fuel Systems , Wiley, 2009. ISBN: 978-0-470-05708-7

[4] Adamčík, F. – Adamčík, F. jr: Spacecrafts electrical power systems,. Acta Avionica 2010. ISSN 1335-9479. – Roč. 12, č. 20 (2010), S. 76-78.

[5] Sotak, M.: Determining stochastic parameters using an unified method. In: Acta Electrotechnica et Informatica. - ISSN 1335-8243, Vol. 9, No. 2 (2009), p. 59-63.

[6] FAR/JAR 25. *Airworthiness Standards: Transport Category Airplanes.* Part 25 of “Code of Federal Regulations, Requirements — large aeroplane” for the Joint Aviation Authorities.

[7] Totten, G.: Fuels and Lubricants Handbook: Technology, Properties, Performance, and Testing. ASTM, USA. 2003. ISBN: 0-8031-2096-6

[8] Madarász, L.- Főző, L - Andoga, R - Bučko, M.: Základy Automatického Riadenia, Elfa, s.r.o, Slovakia, 2010. ISBN: 978-80-8086-162-9

[9] Noskievič, P.: Modelovaní a Identifikace Systémů, Montanex a.s., Ostrava,1999. ISBN: 80-7225-030-2

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