Refuel/Defuel SystemFunctional Design of a Civil Aircraft Configuration

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Abstract
In this paper a civil aircraft fuel system design with special focus on refuel and defuel system is considered and functional protocol design of the both refuel and defuel systems with layout design is presented. Refuel system of a commercial aircraft with about 150 passengers is designed byspecifying interfaces with relevant systems including fuel measurement, fuel management and tank venting as well as fuel transfer.Defuel subsystem functional protocol is designed as well. Some of the refuel pipelines and boost pumps were employed for defuel application. Sequence of tank refueling and defueling with their limits were discussed and also some relevant regulations (specially from Iranian Civil Aviation Derivatives)were used and their compliance were checked to make the design accurate.In a brief manner, tank refueling starts firstly from the wing tank. Fuel is delivered to the outer wing tank and when it reaches the full capacity, a spill pipe placed at the top of the outer wing tank transfer the fuel to the inner wing tank automatically. Inner wing tank is filled up when high level sensors becomes wet and fuel measurement and management systems involved. The design layout and protocols comply all of the refuel and defuel requirements like some other commercial aircraft design. Functional protocols algorithms which are required for management system design were completely determined for refuel and defuel systems.
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Introduction

Fuel system complexity include all type of air vehicle from small unmanned to large aircraft as well as fighter with high demand for reliability and redundancy. Due to high volume of liquid fuel stored in the tanks (approximately 50% of aircraft gross weight) and also fuel mass reduction during flight, center of gravity location variation becomes a very important issue in control and navigation regarding fuel system.In addition, this amount of fuel capacity requires high refueling rate capability specially in large civil aircraft for commercial transport applications which turnaround time is an operational factor.

The purpose of an aircraft fuel system is primarily to provide a reliable supplyof fuel to the engines. Without the motive power provided by them the aircraftis unable to sustain flight. Therefore the fuel system is an essential elementin the overall suite of systems required to assure safe flight [1]. Preventing fuel from splashing which may cause structural damage and CG variation as well as fuel tank ventilation during refuel/defuel and engine feed function are of major concerns in fuel system design procedure.From another point of view, fuel tank inerting systems must be designed based on state of the art regulations to render the space above the fuel safe from potential explosion. This system uses special purpose fiber bundles to strip and dispose of a large percentage of the oxygen molecules from incoming air resulting in the generation of a source of nitrogen-enriched air (NEA) [2].NEA output from the fiber bundles contains only a small percentage of oxygenand much less than what is required to sustain a fire or an explosion and therefore replacementof the ullage air with NEA will render a fuel tank inert and safe from potential explosion. Another concern regarding fuel tank safety is the solution of air in kerosene fuel. Kerosene fuelcan contain up to 14 % of air by volume at standard sea level conditions. Therefore as theaircraft climbs, this air, and more importantly the oxygen in the air, comes out of solution andcan serve as a potential ignition source that must be dealt with in any effective inerting systemsolution.

The stated concerns of fuel system are a few topics which must consider before making decision for fuel system conceptual design. Fuel system design is commonly done based on system requirements and regulations imposed by aviation associations. However, some research works were presented in literatures. Gavel et al. [3] studied matrix design methodologies for aircraft fuel systems, with theaim of shortening the system development time. The methods introduce automation early in thedevelopment process and increase understanding of how top requirements regarding theaircraft level impact low-level engineering parameters.Fluid simulation of fuel subsystems is of interests recently. Boroumand et al. [4] simulated engine fuel feed system design layout and calculated flow properties for a specific design. Also Ellstrom and Gavel [5]presented a simulation method for predicting pressure surges in aircraft fuel systems that is suitable for engineering purpose. Some other researches in design of fuel system were done by Asli et al. [6,7] and presented some aspect of civil aircraft fuel system conceptual design.

Refueling and defueling of an aircraft is usually done by a truck at airport trough the refueling coupling and pipelines. It must be done in a short period of time which requires high volume of flow rate in almost prior to every flight. Refueling can be done in two ways of pressure or gravity.In this paper refuel/defuel system early design considerations were presented. System description and classification as well as functional protocol were discussed as a major part of the whole design of a civil aircraft fuel system in conceptual phase. The fuel system consists of three separate tanks in each wing with a center tank bellow the fuselage.Fig. 1shows the fuel system layoutdesigned that is located in the aircraft CATIA model.

Refuel System

The fundamental need for pressure refueling of an aircraft is to provide a safe and quick aircraftturnaroundtime.Although not all airlines require a thirty minute turnaround time, there is normally acontracted refueling time the airlines have with the aircraft supplier. This contracted refuelingtime will always require pressure refueling.Typically the refueling system mustprovide: 1) fast refuel times, usually between 15 and 40 minutes depending upon the size and missionof the aircraft; 2) accurate loading of the required fuel quantity, often via an automated system on board theaircraft that allows the refuel operator to preset the total fuel load required at the refuelstation; this facility allows the airline to select a fuel load that matches the upcoming flightrequirements thus avoiding the operational penalty associated with carrying the extra weightof unneeded fuel; 3) accurate location of the fuel on board to ensure compliance with aircraft CG limits; 4) protection against overboard spillage of fuel out of the tank vent system; 5) protection against over-pressurizing of the tank structure (since the refuel source pressuresneeded (typically 35–55 psi) to provide fast fuel loading cannot be withstood by the aircrafttank structure) [2].The refuel system design was done based on tanks requirements and filling sequence is managed trough Fuel Quantity Indicating Computer (FQIC) and Fuel Level Sensing Control Unit (FLSCU). The designed refueling layout is depicted in Fig.2.

The functional protocol of the refuel system is based on the fueling priority and the mission, includes the FQIC, FLSCU, FQI and Refuel/Defuelas internal subsystems and the refuel bus as external systems. The functional protocol of the fuel system in the aircraft mission has two important features which are the regular method of refueling and the automotive system of operation. The regular method describes the sequence of refueling of the tanks in which the pressure refueling bus transfers the fuel to the outer tanks. As intercell valves remain open from the prior flight, specific quantity of fuel is transferred to the inner tanks. Since the level of fuel in inner tanks reaches to about 750 kg in the tank, intercell valves are closed and the outer cells are filled. When the outer tanks reach their maximum level, the fuel is transferred to the inner tanks via a spill pipe. As the fuel in the inner tanks reaches the maximum level, the center tank fueling begins. The automatic system covers the fuel system refueling operation and the security. Two main internal systems meeting the requirements of the automatic process are FLSCU and FQIC. The fuel distribution in the tanks during refueling operation is shown in Fig.3.

Also the functional protocol of refuel system can be presented as below. In this process, the position of refuel valve is sent to the FQIC. With starting the fueling form bus station, the cabin should give the permission for refueling. This is done by switching the delatch switch from the cabin. As this switch acts, the end annunciator light turns on. Then a command from FQIC opens the refuel valve and fuel is transferred by pressure to the outer tanks. If the refuel valve fails to open, a signal is sent to the FQIC to inform about the failure and the light test and dimming dims. The refuel process is stopped automatically. This leads to compliance of CAD 2508.979 (a) [8]. The refuel valves used in refueling are flap valves which prevents from backflow in the line. These valves provide the compliance of CAD 2508.979(a) as well. If the system works properly, the fuel transferred to the outer cell will be moved to the inner tank till it reaches about 750kg of fuel in the inner tank. The low level sensor in the inner tank is checked continuously via the FLSU and as the sensor becomes wet, the FLSCU sends a signal to the actuator of intercell valve to close the valve. If the intercell valve fails to close, a signal from the intercell valve is sent to the FQIC and informs the cabin or bus station. But in normal conditions, by closing the intercell valves, the fuel fills the outer tank. Since the outer tank is filled, the fuel is transferred to the inner tank by the spill pipe. When the fuel reaches to the high level in the inner tank a signal from the FLSCU closes the fuel inlet valve to the outer tank. Closing refuel valve in reaching high level in the tank provides the compliance of CAD 2508.979 (b) [8]. Then if the preselected fuel quantity is more than about 13tons, the refuel valve in the center tank line becomes open and the tank is filled up to the preselected amount. If the center tank is fully loaded, the refuel operation resumes while reaching the maximum level in the tank and as the high level sensor in the tank becomes wet the refuel process will be stopped automatically. The high level sensor's wet status is shown in the refuel panel for any tank which covers compliance of CAD 2508.979 (b). Also during this process, if any unbalance or paradox in fuel filling is occurred, the end annunciator dims. The whole functional protocol of the fuel system in refuel operation is presented in Fig. 4.

The refueling can be done by both or one of the fuel couplings (one in right wing and one in left wing). If one of the couplings is used in refueling process, the fuel transfers to both outer tanks and then by filling to the maximum level transfers to the both inner tanks via spill pipe and finally by opening the center tank refuel valve, the extra fuel fills the center tank. Another important issue during refuel process is on the ground while the fuel can enter in the manifold from any tank to the other if the crossfeed is open. This is very critical point when there is some unbalance in the tanks.

For compliance of the refueling process regulation regarding CAD 2508.975 (a) (3) (iii) [8], the vent lines are designed for the worst occasion in which sizing of the pipelines are adequate that the venting is effectively performed in emergency landing. In this occasion the aircraft should descent under 10000 feet from maximum cruise level.

The refueling can be done from out of the aircraft or from the cabin but the cabin have priority in managing the refuel process. When the refuel panel in the cabin is activated and controlled from the cabin, the outer panel orange light figure lights on. Also the fuel quantity in each tank and total fuel quantity is shown in the panel. The blue lights in the panel are on when the fuel in the tanks reaches to their maximum level in the tanks. This monitoring and maximum level restriction leads to compliance of CAD 2508.979 [8].

Emergency Refuel Mode

Refuel on battery; One of the emergencies the refuel process may meet is the problem regarding power supply. In this case in order to refuel the aircraft, refuel batteries are employed. These batteries can supply the power required for the refuel panel up to 20 minutes. If there is some fuel in the tanks, the refuel bus is stopped and then the refuel power is supplied by APU. In this case the tanks can even refuel to the maximum level if utilizing APU power from sufficient point of refueling. During refuel operation by battery the intercell valves are kept open to have the maximum fuel in the collector tanks (wing inner tanks). Because both FLSCU's and level sensors' power are out in this occasion. As there is a restriction in refueling, the fuel level does not reach the critical level. If the APU could come in the line during the process, their power can be supplied as well. Indeed battery power supplies the actuators' electricity, FQIC and Refuel panel's, only.

Sensors Malfunction; The other emergency may occur in a refuel process is a failure in the high level sensors and carelessness of the operators about it. In this case the fuel over flows to the surge tank and accordingly the refuel process abruptly stops via FLSCU. In order to prevent more structural damagesof the tanks, the extra fuel goes out of the aircraft via exit manifolds in the surge tanks. This process for the fuel system can be seen in theFig. 5. In this figure the dash line is the emergency line in stopping refuel process. The compliance of CAD 2508.975 (a) (2) and CAD 2508.979 (c) [8] are provided via this arrangement.

Defuel

Defueling the aircraft is usuallyneeded only for maintenance of the aircraft although defueling of an in-service aircraft may be required to reduce the amount of on-board fuel. Defueling is normally performed by suction applied at the aircraft's ground refueling adapter or by using on-board transfer and engine feed pumps to pump the fuel off the aircraft. Using aircraft pumps and defuel/transfer valve may lead to make the tanks more empty while suction defueling by the outer source can be done faster. Defueling is also a necessary function following an accident where the aircraft is damaged and fuel must be removed before it can be safely moved for repair. For this reason, consideration must be taken during the design phase regarding the location of the refuel/defuel points to allow access in the unlikely event of a wheels-up landing [2].

Defuel system designer must keep in mind the following factors:

- Allowed defuel time
- Operation with worldwide facilities
- Suction or pressure defueling or both
- defuel flow shutoff when empty (suction)
- Allowable remaining fuel
- Engine feed and transfer pumps powered for pressure defuel
- Final defuel through in-tank drain valves.

The functional protocol of fuel system in defuel process is likely to the refuel system and the same manifold used in refuel process is applicable in the defuel process as well. Also the indicators utilized in the refuel process are used in this state. In this design process the aircraft's defueling is based on using engine feed pumps. So that the pumps used in engine feed pump the fuel to the feed line and as the low pressure valve is open and the defuel/transfer valve has been opened via FQIC by selecting defuel process. Then the fuel comes to the refuel manifold from any tanks as the defuel mode is selected from the refuel/defuel panel.The total function of the fuel system in defueling process can be presented as in 0Fig. 6.

The defuel process can be done from one or both of the couplings. if only one coupling is used the crossfeed should be open from the cabin manually. Also the defuel process is usually selected manually from the refuel/defuel panel in the cabin or right side of the aircraft.

Any failure in the defuel valve is signaled to the FQIC and FQIC stops defueling process and end annunciator dims as well. This leads to compliance of CAD 2508.979 (c) [8].

Concluding Remarks

In this paper refuel system functional protocol design was firstly stated while related regulations were complied. Tanks fueling sequence was determined and the block diagram was depicted. Two emergency refueling containing lacks of power supply and sensoring problems were considered and the related functional protocols were designed. In addition, defueling procedures and related functions were designed using the same pipelines of refueling. The whole functional protocol design is based on CAD 2508 regulations. The refuel defuel system includes these types of components in aircraft configuration: pipeline, coupling, level sensors, fuel feeding pumps, valves, diffusers. These functions and interface determination are the main algorithms for designing the fuel management computers to control the refuel system.

Fig. 1:J150+ civil aircraft and the fuel system located in the model.

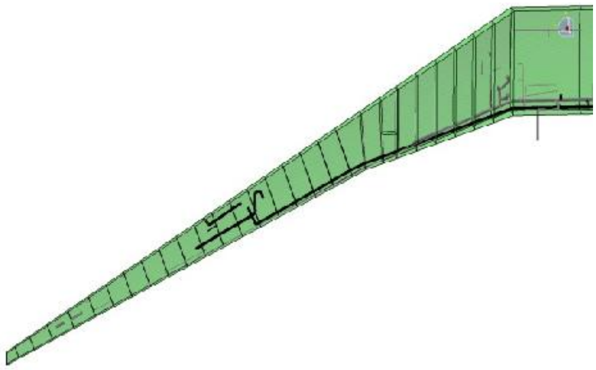

Fig.2: Engine feed block diagram (crossfeed valve is not shown).

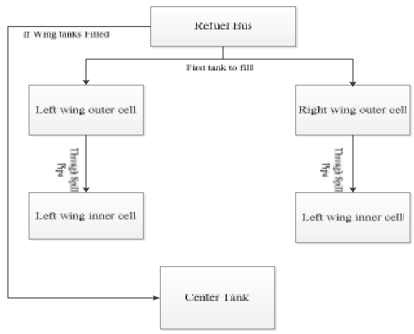

Fig.3: Refueling Sequence.

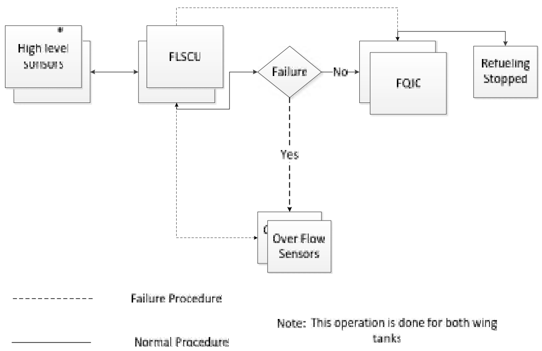

Fig.5: Functional protocol of the fuel system in over flow emergency.

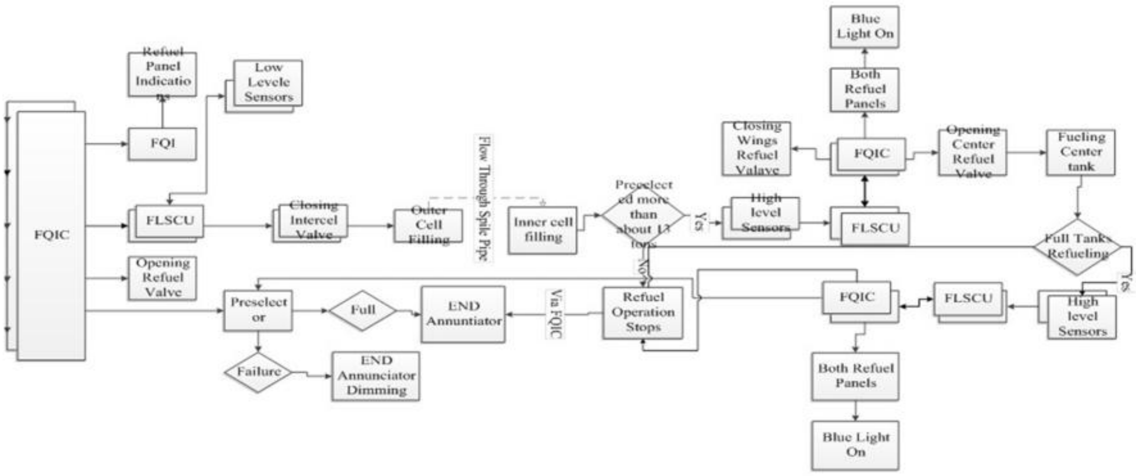

Fig. 4: Refuel Functional protocol in normal operation

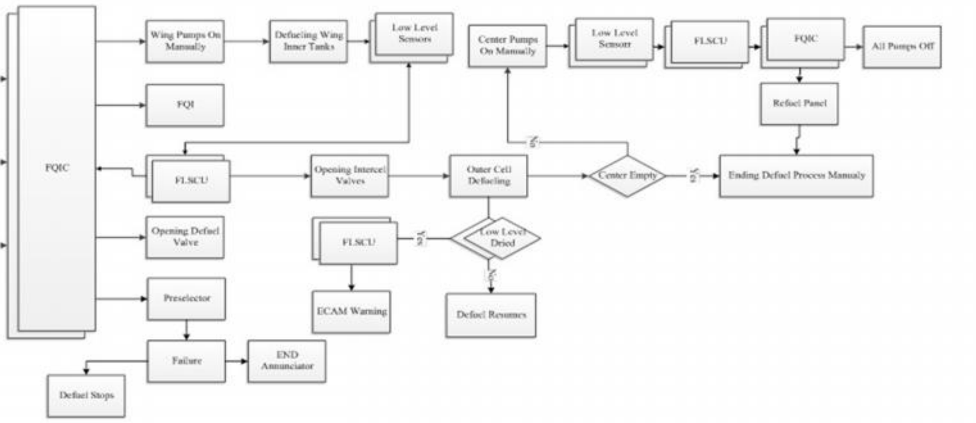

Fig. 6: Functional protocol of defueling operation

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