Simply Serious

By John Morris

Historically, Fuel management has been one of the leading causes of incidents/accidents in general aviation. From underestimating range versus burn rate to fuel tank management pilots sometimes still do not understand their fuel systems. Complexities of the fuel system can/will cause misunderstandings. How can we correct these misunderstandings? Answer- simplify.

Pilatus designed what I consider to be about as simple a fuel system as any general aviation pilot will come across. First of course is the fact that there is only one engine to manage. Second is that the fuel is contained in integral wing tanks (no bladders-less maintenance or faults). Third, the tanks are "managed" by a motive flow / auto-balance system that normally requires no electro-mechanical influence, aka boost pumps. Finally, NO pilot input regarding fuel tank cross-feed or selection of different tanks. From a pilots perspective the previous line dealing with not changing tanks / cross feeding solves one of the major issues regarding fuel mismanagement.

Why am I writing about the PC12 fuel system if it is so simple? Because it is simple we may not take it seriously.

Looking at Figure 1, which is a copy of the fuel system page from the PC12 POH (all variants are the same), other than addition of the other identical wing/components, it is a simple system with few moving [check valves] or mechanical [boost pump] components from the wing to the Low Pressure Engine Driven Pump. What is not shown but will be mentioned often is the auto-fuel balancing device. It gets its inputs from the fuel capacitance probes in each wing (4) for balancing [fuel symmetry] purposes and low fuel indications. It needs to be noted that these same inputs are displayed in the cockpit as the analogue fuel quantity indications.

Reviewing the Fuel System. The engine has two mechanically driven boost pumps, High Pressure and Low Pressure. The High Pressure pump serves the Fuel Control Unit (FCU) for the engine while the Engine Driven Low Pressure pump [EDP] has two functions. One is to supply fuel to the High Pressure pump via the Fuel/Oil Heat exchanger. The second function is to supply a (fuel) motive flow back to the wings in order to facilitate fuel transfer and delivery back, via their respective motive ejector pumps, to the EDP.

Using an analogy, Motive flow is like using your garden hose with an attachment at the end consisting of a jar of lawn fertilizer. Once you start the water flow the fertilizer will be drawn into the water stream, by suction, at a mixture rate based on the opening in the fertilizer jar and the water pressure at the hose end. The water hose is the motive flow line and the attachment is the motive ejector pumps. See Figure 2 for the input/ output pressures and fuel flow (gallons per hour-GPH) for the EDP, the motive flow ejector pump, known as the delivery jet pump and the boost pump (both located in the inboard-collector tank).

There are two motive flow ejector pumps located in each wing but I am only dealing with the delivery jet pump, located in the inboard (collector) tank, which supplies the input pressure/fuel flow to the EDP. As indicated by Figure 2, the motive input pressure to the delivery jet pump is reduced to an output pressure of 5 psi while the output fuel flow is increased. It should be noted that the other motive pump, located in the outboard wing (main tank), is used to transfer fuel to the collector tank along with one-way flapper valves using wing dihedral for natural fuel transfer towards the inner wing tank.

Also in each collector tank is one fuel booster pump (see Fig. 2). The pumps are used for the engine start sequence and for auto/manual fuel balancing or low pressure issues. Normal setting of the boost pumps is AUTO. Once the EDP is operating the booster pumps are not in use. But they are quite important.

So in a normal flight the motive fuel system will continuously move fuel from both wings, including excess returned fuel from the Fuel Control Unit and Air Separator, to the single fuel feed line leading to the EDP.

Figure 2

	INPUT/OUTPUT (PSI)	INPUT/OUTPUT (GPH)
EDP	5.0 PSI / 43.5 PSI	87 GPH/ 208 GPH
DELIVERY JET PUMP	43.5 PSI / 5.0 PSI	53 GPH / 87 GPH
BOOSTER PUMP	OUTPUT - 31 PSI	OUTPUT - 91 GPH

When the fuel does not maintain natural balance we have managing assistance from the auto-balancing system. Monitoring the fuel quantity probes/indicators, the auto-balance system will activate the boost pump (when the pump has been selected to the AUTO position) of the higher indicating fuel quantity. The system will activate at a minimum difference of two Liquid Crystal Displays (LCD's) after a 60 second delay. The two LCD's equate to approximately 10.5 US Gallons. By design the auto-balancing system will function up to a six LCD difference, or approximately 40 US gallons. Normal re-balance (2 LCD's), in a steady-state environment, should occur in 3-5 minutes at which time the activated boost pump will be shut off automatically. *If there is a failure of one of the fuel probes this will cause an inaccurate quantity indication that may cause that wings quantity indications to fault OFF which will shut down the auto-balance function.

So how does the auto-balance system accomplish the re-balance? When either or both boost pumps, located in the collector tanks, are in use the out-going fuel pressure is greater than the normal motive pressure causing the boost pumps to move the fuel to the EDP. In a single boost pump operation the boost pump output pressure will close a check valve in the delivery jet pump causing the boost pump to be the only source of fuel from that collector tank. And since the boost output pressure is greater than the other wing's delivery jet pump it will also close that check valve. Therefore the sole source of fuel being delivered to the EDP is from the one operating boost pump and collector tank.

Normal engine fuel consumption at cruise is approximately 59 GPH or 1 gallon per minute. By the numbers given in Fig. 2 you can see that the EDP output is over 200 GPH so the engine consumes nearly 1/3 of the output fuel and the remaining is returned to both wing tanks via a single return line. This basically corresponds to the estimated re-balance time for a two LCD difference of 3-5 minutes since 3-5 gallons would be consumed and the remainder will be sent back to the tanks, which can decrease the re-balance time depending on condition of flight attitude.

Since the pilot has nothing to do with these operations but observe what's the problem? Seems pretty simple.

Just observing is too simple. The pilot has to watch and possibly do something.

The pilot has a responsibility to know this system and its limitations. The only limitations are: use of approved fuels, use of an approved anti-icing additive for all flight operations in ambient temperatures below 0°C, and maximum fuel imbalance (takeoff) of 3 LCD's, 26.4 US Gals.

Normal checklist pre-start of the engine requires checking each boost pump, manual ON-then AUTO after, for audible operation – not indicated [the NG check is to observe the CAS for Fuel Pressure Low indication-OFF instead of audible]. The reason for the pre-start checks of the boost pumps is due to the fact that the PC12 fleet boost pump (green) indicators only **indicate** that the auto-balance / pilot or the start sequence, has instructed the boost pumps to operate. The pilot only knows actual boost pump operation by the pre-start individual check or in-flight when the pilot visually confirms after auto-balance or pilot activation of a boost pump, a fuel quantity (level) change in a short duration of time or in the case of low fuel pressure (next paragraph) the caution extinguishes.

The fuel system also has a low-pressure sensor that will automatically activate both boost pumps, when set to AUTO, in the event of fuel filter contamination or failure of the EDP. When this sensor activates the CAWS / CAS will annunciate a FUEL PRESS / Fuel Low Pressure caution and audible tone. By design this system activates when the pressure drops below 2 psi and shuts off when pressure is greater than 3.5 psi (after a 10 second delay). By procedure if this continuously occurs in-flight the pilot is instructed to select both boost pumps to ON from AUTO to stop the cycling of the system while probably initiating a descent for a possible landing due to some form of fuel contamination.

Not written down but should be a normal operating procedure for the pilot is: while flying, does the auto-balance activate? Regularly? Same wing-pump? Almost every flight? An answer of yes to most of these questions means you don't get it! This is a simple system and unless you are flying in circles nature / gravity should basically keep the system balanced. Little to no activation of the auto-balance system should be the norm. If you have not brought these indications up with maintenance, well?

I have encountered many pilots over the years that, after prodding them, mentioned that they had noticed on multiple occasions the fuel system out of balance followed by the auto-balance system activating / successfully re-balancing the fuel. Asked them if they thought it "a little" unusual? Answer usually was No. Simple?

If we start out balanced we should end that way, right? There is just not that much to the system. But sometimes flight conditions might cause an imbalance, such as a continuous cross wind or maneuvering in the same direction. Then the auto-balance system should activate. But is every flight like what I just mentioned? This is where the pilot comes back into the picture. In flight we should be aware of the fuel state for multiple reasons. Two or three LCD's difference should get the pilot's attention just because the system is out of balance. If the system has not activated then the pilot needs to refer to the appropriate emergency procedure.

But what if the system has activated, as indicated by the appropriate boost pump indication, but the imbalance is not correcting? Or the fuel pressure sensor has activated both pumps but now the fuel quantity is starting to un-balance? These scenarios are the reason for the pre-engine start checks of the boost pumps since in flight we cannot determine if the selected boost pump (either by the auto system or pilot) is actually working.

Manual activation of one or both of the boost pumps requires the pilots' attention for the duration of the manual pump operations. As with other potential issues the pilot needs to promptly refer to the emergency procedures. In the particular case of continuing imbalance Pilatus has included in the latest revision to all POH's to consider burning off excess fuel until no more than 5 LCD's difference prior to landing.

Bottom line is the fuel system *is* simple but the pilot has to take it seriously due to what may appear as a minor but automatically corrected issue. Occasional activation of the auto-balance system is ok, not almost every flight. And are you sure that both boost pumps are operational?

"A safe pilot is always learning"

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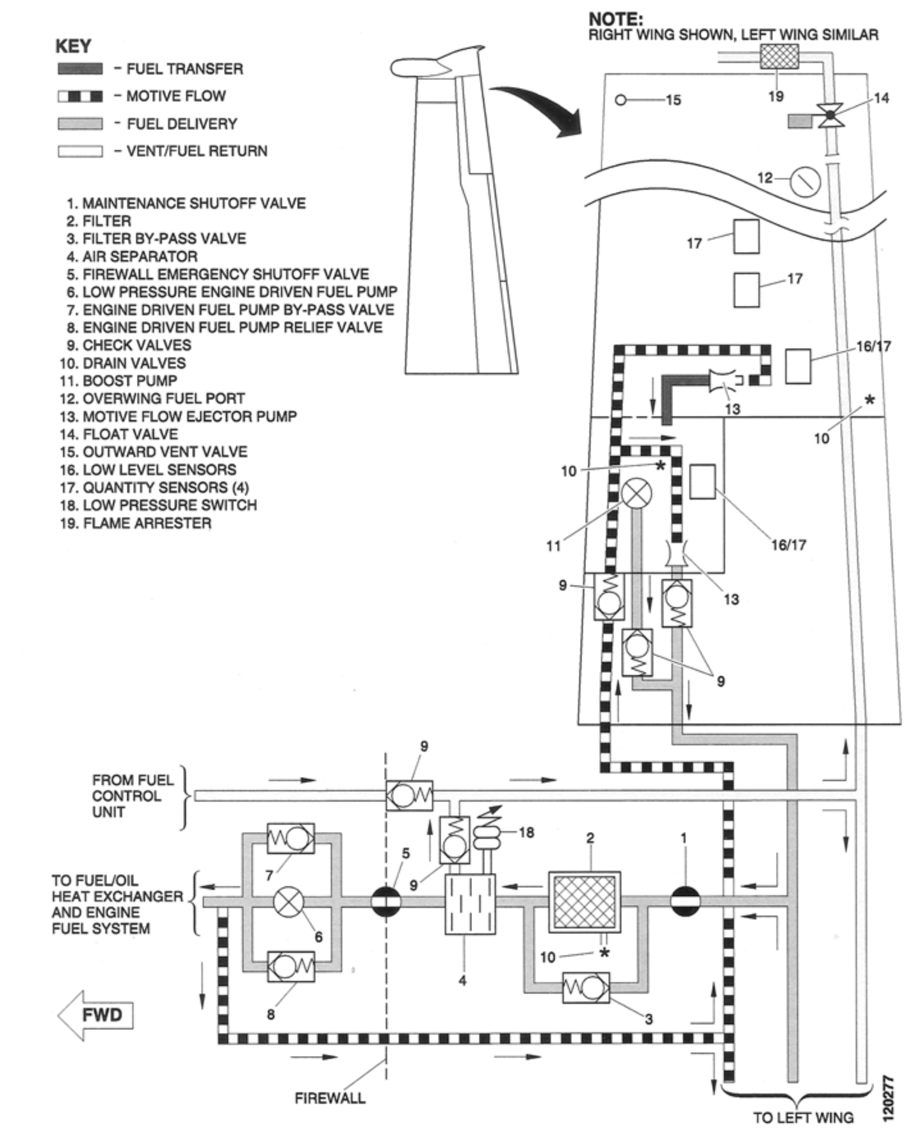
Author's note:

This article was written after reading the actual NTSB facts collected regarding the March 22, 2009 Butte, Montana PC12 crash. At the time of this writing the NTSB had not released a final conclusion but it strongly suggests a fuel imbalance possibly caused the deviation to Butte followed by loss of control due to the imbalance.

It is terrible to learn from an accident that causes loss of life but it is one of the greatest tools for further understanding and education. The investigative work of the NTSB is sometimes amazing in its scope and depth. As I always end my articles with the phrase "a safe pilot is always learning" I will use what information is available from this and any other resource to increase my knowledge and understanding to keep others and myself safe while enjoying the world of aviation and the PC12.

Figure 1


NOTE:
RIGHT WING SHOWN, LEFT WING SIMILAR
KEY
- FUEL TRANSFER
- MOTIVE FLOW
- FUEL DELIVERY
- VENT/FUEL RETURN
1. MAINTENANCE SHUTOFF VALVE
2. FILTER
3. FILTER BY-PASS VALVE
4. AIR SEPARATOR
5. FIREWALL EMERGENCY SHUTOFF VALVE
6. LOW PRESSURE ENGINE DRIVEN FUEL PUMP
7. ENGINE DRIVEN FUEL PUMP BY-PASS VALVE
8. ENGINE DRIVEN FUEL PUMP RELIEF VALVE
9. CHECK VALVES
10. DRAIN VALVES
11. BOOST PUMP
12. OVERWING FUEL PORT
13. MOTIVE FLOW EJECTOR PUMP
14. FLOAT VALVE
15. OUTWARD VENT VALVE
16. LOW LEVEL SENSORS
17. QUANTITY SENSORS (4)
18. LOW PRESSURE SWITCH
19. FLAME ARRESTER
FROM FUEL CONTROL UNIT
TO FUEL/OIL HEAT EXCHANGER AND ENGINE FUEL SYSTEM
FWD
FIREWALL
TO LEFT WING
120277