Fuel Delivery Problems and Solutions

Ross Hoag

rosshoag@Power4flight.com

Power4Flight
202 Wasco Loop, Suite 104
Hood River, OR 97031
541-436-4299

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I. The Fuel Delivery Problem

From our experience fuel delivery is the single biggest cause of engine related failures in UAVs powered by internal combustion engines. Almost all UAV programs, carbureted or fuel injected, have suffered from the effects of an inadequate fuel delivery system (many unknowingly still do). While simple in concept the vast majority of implementations we have seen over the years fall short of meeting one or more of the basic requirements for reliable operation.

Almost all UAV development programs have gone through episodes of “mysterious” in-flight engine failures. Many of these engines are recovered and put on the test bench where they start and run perfectly. Typically the problem is related to an inadequate fuel delivery (pump/pickup/header) system and in many of those instances the root of the problem is the fuel pump itself. Most small volume fuel pumps on the market today were not deigned to be self-priming with a high compression ratio. Continuously pumping air until the main pickup or clunk is re-immersed in fuel without vapor locking is a hard requirement for a UAV fuel pump, regardless of the application (carbureted or fuel injected). If your fuel pump doesn’t meet this requirement you must guarantee that, in every phase of flight and in every orientation encountered, the fuel pickup or clunk will never ingest any air (must be continuously immersed in fuel). This is all but impossible to ensure in the UAS application, thus your pump MUST be self-priming. Not understanding and meeting this simple requirement has and continues to cause the loss of countless vehicles and expensive payloads.

The other common issue with fuel delivery is improperly designed header tank systems, which are used on many carbureted engines. While simple in concept, many implementations fall short of actually addressing the problems they were intended to solve and end up introducing obscure failure modes which lie undetected until just the right set of conditions are met.

II. Fuel Delivery - Carbureted Systems

Historically, this has been one of the primary causes of engine related issues in most UAS programs. A proper fuel delivery system for carbureted engines consists of:

- **Main Fuel Tank:** The main tank has a pickup whose output goes to the scavenge pump then onto the header tank. It also has a return input that comes from the header tank overflow and a vent line.

- **Fuel Pump and Filter:** A recirculating pump that continuously pumps fuel from the main tank into a small header tank, which when full overflows back into the main tank. This recirculating system keeps the header tank full and purged of air in normal operation. There is also typically a high quality fuel filter on the input side between the main tank and the scavenge pump.

- **Small Header Tank:** The header tank has one input and two outputs. The input comes from the main tank via the scavenge pump described above. One output provides the overflow path back to the main tank; the other output goes to the carburetor. The header tank carburetor feed line is typically flexible and fitted with a heavy clunk to keep it at the bottom of the header tank, thus allowing it to move with the fuel as vehicle orientation changes so it doesn't ingest any air. Fuel is drawn from the header tank by the carburetor's internal diaphragm pump.

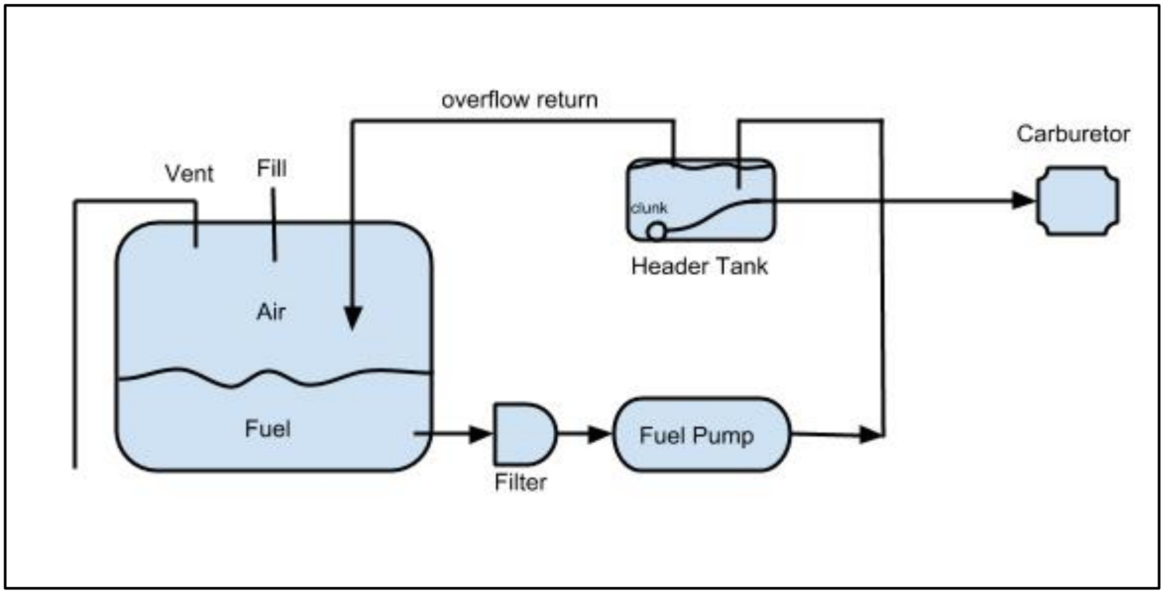

Figure 1 - Fuel Delivery System (Carbureted)

In normal operation the header tank is kept full and purged of all air - full and over flowing back into the main tank by the scavenge pump, which pumps at a higher rate then the engine can use at wide open throttle. If the vehicle encounters turbulence or experiences large pitch and/or roll transients the main tank scavenge pickup will likely ingest air as the fuel moves to other parts of the tank. When this happens the scavenge pump will stop pumping fuel to the header tank. The header tank, which is full and purged of air, will provide an air free fuel reservoir to allow the system to coast through the transients. Typically these transients are short lived so the system quickly recovers - main tank clunk is re-immersed with fuel, begins pumping fuel, and refills the header, purging it of any air that may have accumulated while the system was air locked. This all works flawlessly as long as the main scavenge pump is self-priming and will not vapor lock!

There are a few common mistakes that can render this simple and effective fuel delivery system inoperable. The first is assuming that the carburetors internal diaphragm pump can draw fuel through a restrictive filter and/or draw fuel from a negative head at its input, which most of them cannot do. To compensate for this fundamental weakness one must keep the header tank on or above the same level as the carburetor, to the extent possible, and not add substantial filter restriction at the pickup/clunk in the header tank. The second common mistake is assuming that any fuel compatible pump will suffice for the scavenge portion of the system. The scavenge pump has to overcome two things: first it must be self-priming (able to pump air and pull fuel up to itself through any fuel filter restriction without vapor locking); it also must be able to run dry for long periods without destroying itself. Most fuel pumps on the market today are not capable of meeting these two requirements so end up failing: causing either unrecoverable vapor lock situations in flight or burning themselves out or becoming worn and unable to self prime after long periods of running dry when the tank is empty. The second failure mode typically occurs during ground test or preflight of the vehicle. Generally only tight tolerance positive displacement piston pumps will meet the demanding UAS requirements. Gerotor pumps made for automotive applications are the most common off-the-shelf solution available to most integrators. Many of these pumps were designed to be mounted inside the tank (immersed in fuel) to address the self-priming and dry run issues outlined above. Remember, in the automotive case it's a pretty good assumption that the fuel will be at the bottom of the tank as they operate in a fairly benign 1g environment. This is unlike the UAS situation, where one cannot assume a 1g environment (the fuel may move to the top of the tank and the air to the bottom in turbulent conditions). Many of the pumps advertised and available today for UAS specific applications do not specify if they are self-priming. If they do specify self-priming capability they typically do not specify what level of negative head they can overcome at the input and still maintain that capability. This is an important concept and one that every system developer should pay attention to. The only way to know what margin you have is to test the system. Unfortunately most developers don't do this and don't actually know the limits and shortcomings of their particular fuel delivery system.

III. Fuel Delivery - Injected Systems

A common technique for fuel rail pressure regulation in injected systems is to use a mechanical bypass regulator that holds a constant pressure and bleeds excess fuel flow back into the main tank. This runs independent of the ECU and requires a high flow scavenge pump which runs continuously. Unfortunately, the system dissipates more power than is actually needed to develop the required head and flow required by the engine, is typically large and bulky, needlessly heavy, and offers poor regulation when ingesting air.

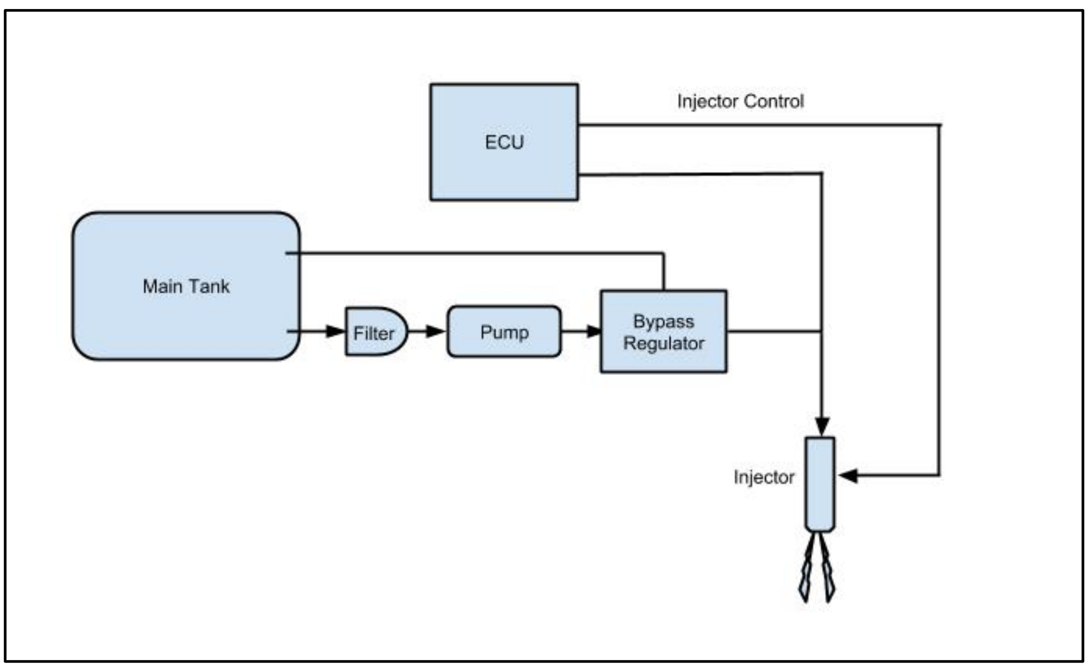

Figure 2 - Bypass Regulated Fuel Delivery System

A better approach is to use a deadheaded fuel delivery system as found in modern automotive applications as shown below.

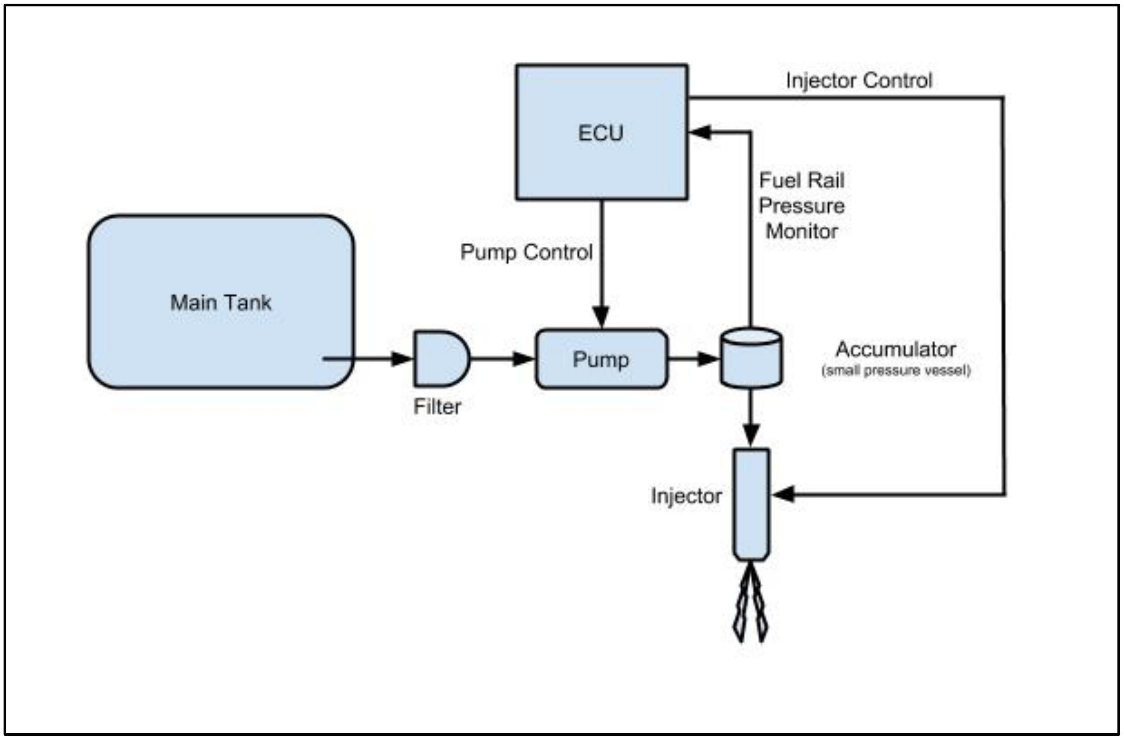

Figure 3 - Fuel Delivery System (Injected)

A deadheaded system is simple with a minimum of parts and plumbing. The basic setup includes:

- **Main Fuel Tank**: The tank has a pickup that feeds the fuel filter followed by a high-pressure pump, typically 3 bar for gasoline or 5-10 bar for heavy fuel applications. The tank also has a fill port and vent.
- **Fuel Pump and Filter:** A high-pressure/high-flow piston pump and filter with minimal flow restriction.
- **Accumulator:** The accumulator is typically part of the fuel pump assembly and acts as a mechanical low-pass filter between the pump and ECU/Injector.
- **Injector:** Typically a miniature automotive injector with a custom nozzle whose spray pattern is optimized for the flow rate of the specific application.

The required accumulator is tiny (about the size of the end of your thumb for a 25-100cc engine). At Power4Flight we use the Currawong ECU, it has an internal solid-state pressure sensor that monitors the fuel rail pressure and modulates the pump to keep the pressure within a specified pressure window. This means the pump does not need to run continuously as in the bypass system, which reduces power consumption and pump wear. Since it’s measuring the fuel rail pressure it can also adjust the injector modulation to account for the small changes seen as the pump is modulated and the accumulator expands and contacts. This removes the requirement for any external mechanical regulator and fuel bypass system. This system also has another benefit in that if any air is ingested it pumps it directly into the high-pressure rail (typically at 3 bar) where it is compressed and dissolves into the fuel due to the volume reduction when at 3 bar. This type of system can ingest air for long periods of time before fuel regulation is lost and the engine begins to lose power.

Take a look at the referenced video, it's surprising at how effective the deadheaded fuel rail system is at dealing with ingested air. This only works if you have a pump capable of actually pumping and compressing air at high pressure! This is a simple test that you should run on your existing fuel delivery system to see if it's actually up to this task. The deadheaded system is very simple, low power, is small, lightweight and requires minimal plumbing.

IV. The Power4Flight Solution

To solve the outlined fuel pump issues Power4Flight offers pumps that were purpose built for the demanding UAS application by Currawong Engineering. The Currawong range of miniature fuel pumps provide high-pressure and high flow rate with very low power requirements in a compact all-aluminum body design.

- **Pressure: 4bar**
- **Flow: Models from 35 g/min - 120g/min @ 4 bar, 15V**
- **Current/Power: 80-90 ma @4 bar, 15V/ 1.35 Watts**
- **Voltage: 8-20 volts**
- **Weight: 65g/2.29oz**

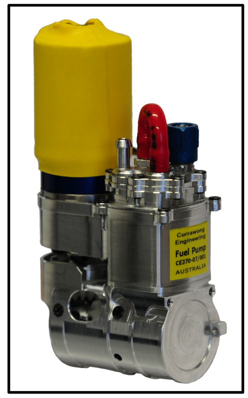

Figure 4 - Mini Fuel Pump

The Currawong miniature fuel pump is also a great choice for low-pressure high-volume scavenge pump applications typical in carbureted systems as outlined above. The pumps are rated for greater than 700 hours of continuous operation, based on an endurance test of 1,500 hours. In practice, we have EFI customers with over 1,000 hours on individual airframes with the pumps and EFI systems still functioning and meeting specification.

In addition to the miniature family of pumps Currawong also offers a higher-pressure model called the Triplex, which was built to address heavy fuel applications. It can operate up to 10 bar, has a CAN interface and can be used to directly meter and report fuel flow and total fuel delivered. The Triplex pump is a three piston extension of the miniature pump series.

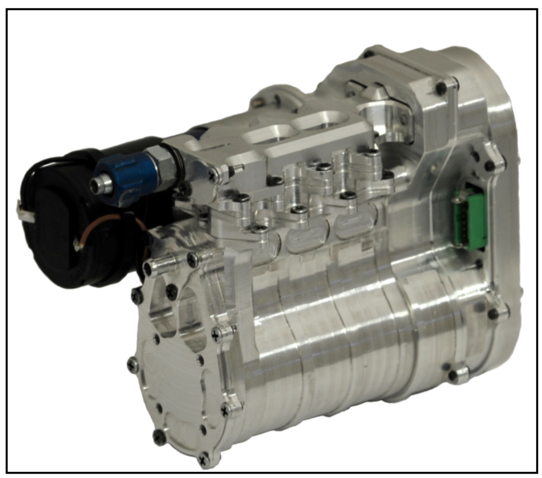

Figure 5 - Triplex Pump

V. Conclusion

Developing reliable and repeatable powertrain solutions is one of the last hard problems in UAS. It requires a specific set of skills, equipment and expertise and a team with actual UAS experience to ensure success in a timely and cost effective manner. In addition, developers need the proper components, ones specifically designed for and proven in the demanding UAS environment.

Power4Flight has assembled a team with the required skills and experience, built up the required infrastructure and teamed with the leading component and core engine suppliers to offer the most reliable, affordable and durable products to meet your complete powertrain needs.

Contact:

Ross Hoag
Power4flgiht
202 Wasco Loop, Suite 104
Hood River OR 97031
(541) 399-3176 cell
(541) 436-4299 office
rosshoag@Power4Flight.com
http://www.Power4Flight.com

Gavin Brett
Currawong Engineering
Currawong Engineering Pty Ltd
1/84 Browns Road
Kingston Tasmania, AUSTRALIA 7050
+61 3 6229 1973 Office
gavin@currawongeng.com
www.currawongeng.com