Stinson 108 Fuel Tank Selector Valve Replacement (STC No. SA00471SE) – The Ten Year Update

The original equipment fuel tank selector valve used in the Stinson 108 series aircraft can be prone to sticking without frequent maintenance. A thin film of grease is used to separate the tapered plug valve mechanism from the valve seat, preventing metal-to-metal galling of the all brass components. Eventually the film of grease dissolves and galling occurs, making the valve hard to actuate. Frequent disassembly and lubrication, typically on an annual basis, is required to keep this type of valve operating smoothly

In 1996, I set about finding a different fuel tank selector valve for my Stinson 108-2 that would reduce the need for frequent maintenance. The project took better than a year from the beginning through issuance of a single airframe Supplemental Type Certificate (STC). The FAA was originally approached about making the fuel selector change through the field approval process, but the FAA required an STC, working with the Seattle FAA Modification Engineering group. Considerable effort was spent over the fall and winter of 1996-97 to prepare supporting data for the project. Approximately 4 months passed from the first in depth meeting with FAA engineering personnel about this project until the STC was issued.

The Stinson 108 series airplanes were certified under Civil Air Regulations – Part 3 – Airplane Airworthiness – Normal, Utility, Acrobatic, and Restricted Purpose Categories, (also known as CAR 3) as shown in its Type Certificate Data Sheet, A767, on page 6. CAR 3 is the predecessor to Federal Aviation Regulations (FAR) Part 23.

When making a modification to an aircraft system or aeronautical product, the FAA expectation is for the system to meet the latest requirements of the FARs, except where the change is not significant, where it would be impractical, or where the change would not contribute materially to the level of safety of the changed product. The following CAR 3 and the newer FAR 23 regulations were pertinent to the change to the fuel system for replacement of the fuel selector valve. The applicable aspects of the regulations are reprinted at the end of this discussion for reference.

CAR 3	FAR 23
§ 3.429 (Fuel system) General	§ 23.951 (Fuel system) General
§ 3.433 Fuel flow rate	§ 23.955 Fuel flow
§ 3.434 Fuel flow rate for gravity feed systems	
§ 3.446 Fuel tank vents and carburetor vapor vents	§ 23.975 Fuel tank vents and carburetor vapor vents
§ 3.550 Fuel system lines, fittings, and accessories	§ 23.993 Fuel system lines and fittings
§ 3.551 Fuel valves	§ 23.995 Fuel valves and controls

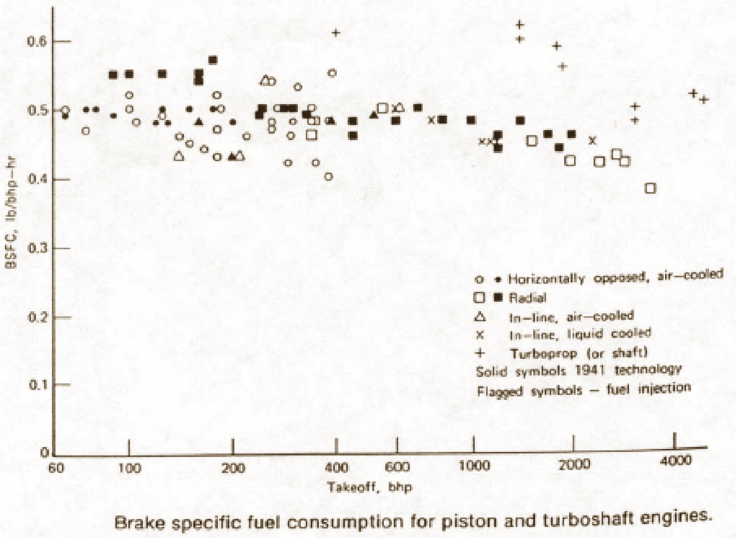
When considering the change to the fuel selector, the obvious first step was to determine what valves were available as possible replacement for the original equipment Imperial-Eastman valve. The candidate valve would need to meet the requirements of FAR § 23.995. The desire was to use a valve that was an FAA approved part already used on other aircraft to make the certification easier. A requirement in § 23.975 (a)(4) stipulates that “Airspaces of tanks with interconnected outlets must be interconnected.” This requirement eliminates the option of using valves with a “Both” position, such as is used in other aircraft, to feed fuel simultaneously from the LH and RH tanks without extensive changes to the Stinson fuel tank vent system. Other considerations in picking a new fuel selector were to find a valve that would mount to the airframe without modification of the structure, and minimizing changes to the fuel lines such that the requirements of § 23.993 would be meet through similarity of design. Finally, an attempt to find a valve that would have a negligible impact on fuel flow was highly desired.

Several different valves were considered, and they all had issues that needed to be resolved. One potential valve used in other aircraft, that was very similar to the original equipment Imperial-Eastman all brass valve, eliminated the metal galling by replacing the central valve core with a plug made of a polymer material. In discussions with Univair it was learned that plug failures had been seen in extreme cold temperatures with the polymer core valves used in Piper PA-18s. These discussions were also where I first became familiar with the Allen Aircraft Products family of fuel selectors. Univair sold an Allen valve kit as a replacement for the PA-18 that quoting the Univair catalog, “eliminates concerns of failure due to extreme cold.” The service experience was reported to be very favorable, with the Allen valve being a maintenance free product. The Allen valve was an ideal replacement for the Stinson 108 and 108-1 airframes that use ⅜ inch fuel lines as the internal valve sizing was nearly identical to the original equipment valve. In addition, the valve body would mount to the airframe without structural modifications. Unfortunately, Allen as well as the other valve brands considered for this project, did not have a valve available with as large an internal orifice as the original equipment valve used in the 108-2 and 108-3 fuel systems, which use ½ fuel lines.

In spite of the smaller orifice, the Allen 6S122 valve was chosen as the best candidate valve readily available for this project. The valve was an FAA approved part used on other certified aircraft, would be relatively easy to install in the Stinson fuel system, and had a proven track record as a maintenance free design. It was known that fuel flow would be adversely affected for the 108-2/-3 fuel system with the Allen valve, so the effort to certify a new fuel selector became much more complex. The certification activity fell into three main tasks, establishing the critical fuel flow requirement for the engine installation, establishing the critical attitude to demonstrate fuel flow, and performing the fuel flow test. The first two tasks would not have been necessary if the new fuel selector could have been shown to not affect fuel flow rate.

Establishing the minimum fuel flow was done per FAR § 23.955 (b) which requires that the fuel flow rate for gravity systems must be 150 percent of the takeoff fuel consumption of the engine. CAR 3 had the same requirement as today’s regulation plus a more stringent aspect that fuel flow rate shall be 1.2 pounds per hour for each takeoff horsepower, whichever is greater. For even the most “thirsty” horizontally opposed, air cooled engines of the post World War II era, the CAR 3 rule would require a 40% greater fuel flow rate than only meeting 150% of takeoff fuel consumption of today’s regulation. This was fortunate as it resulted in the Stinson fuel system being designed having excess capacity. For engines that are supported by the original manufacturer, the specific fuel consumption (SFC) data should be readily available. This was not the case for the Franklin 6A4-165-B3 engine. The Stinson Owner’s Operating Manual had limited fuel burn data quoted for the Franklin installation at 75 and 83 percent power settings that equated to a SFC of about 0.5 Lb per horsepower per hour. This value was in good agreement with data presented in the figure below. A survey of SFCs for similar technology engines was used to establish a likely somewhat conservative but defendable value of SFC used for this analysis.

Figure 1: Specific Fuel Consumption

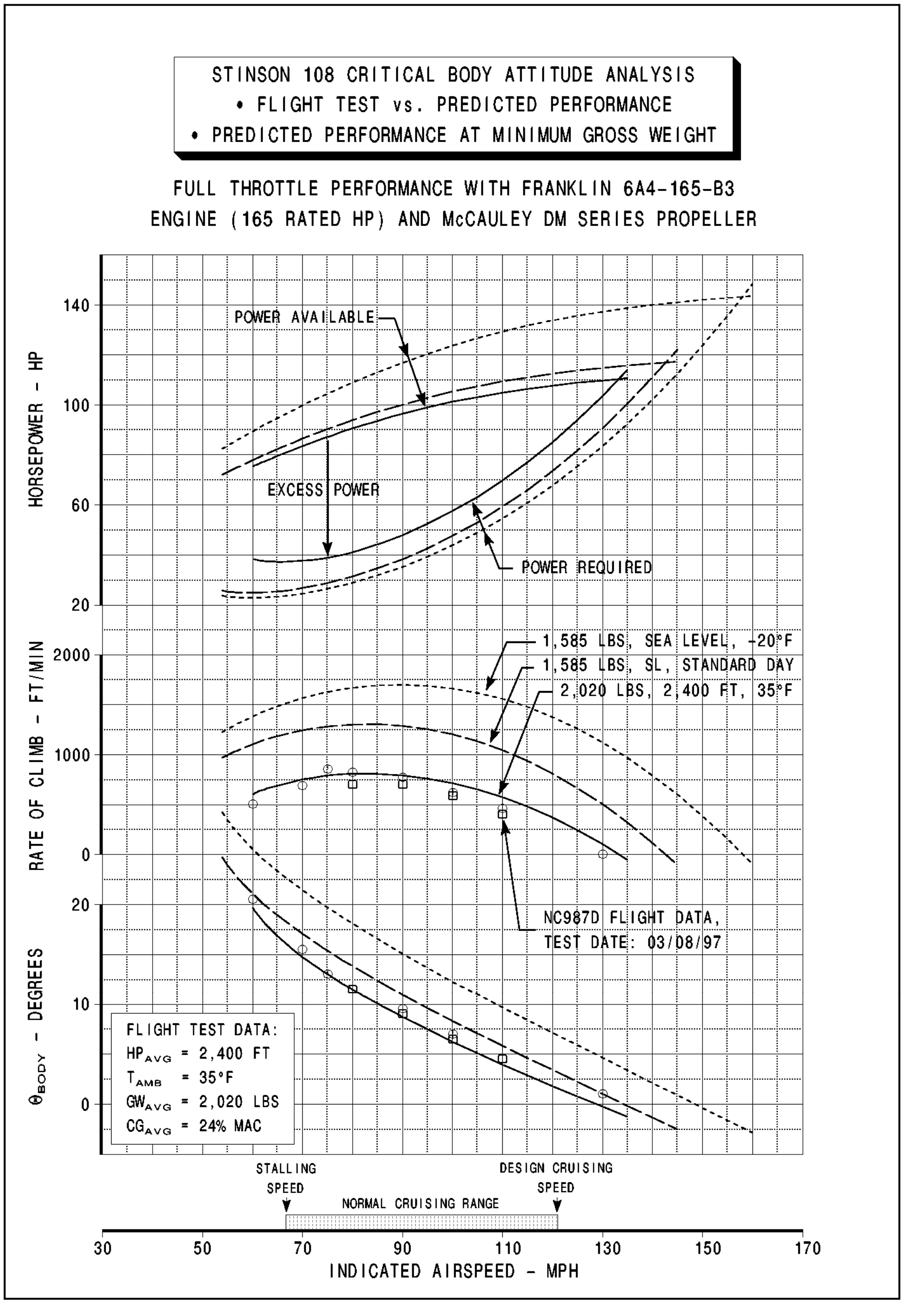


Brake specific fuel consumption for piston and turboshaft engines.

Reference: McCormick, B. W. “Aerodynamics, Aeronautics, and Flight Mechanics,” John Wiley & Sons, Inc., 1979.

The performance capability of the engine-airframe combination needed to be established per FAR § 23.955 (a) which requires that fuel flow must be shown in the attitude that is most critical with respect to fuel feed and quantity of unusable fuel. For the Franklin 165-Stinson 108 combination, analysis was used to predict the performance of the airplane. Critical performance relative to the fuel system occurs at very light gross weight and also cold temperature which increases the engine horsepower output and the overall airplane performance. The aerodynamic and propulsion system modeling developed for the analysis was later substantiated by a flight test demonstration to verify the validity of the analysis. Using this approach, one could perform the flight test under available conditions rather than having to configure the airplane to a critically light gross weight and search for suitably cold atmospheric conditions. The Stinson Owner's Operating Manual shows performance to -20°F which was impractical as well as undesirable to replicate using only a flight test demonstration and foregoing the analysis effort.

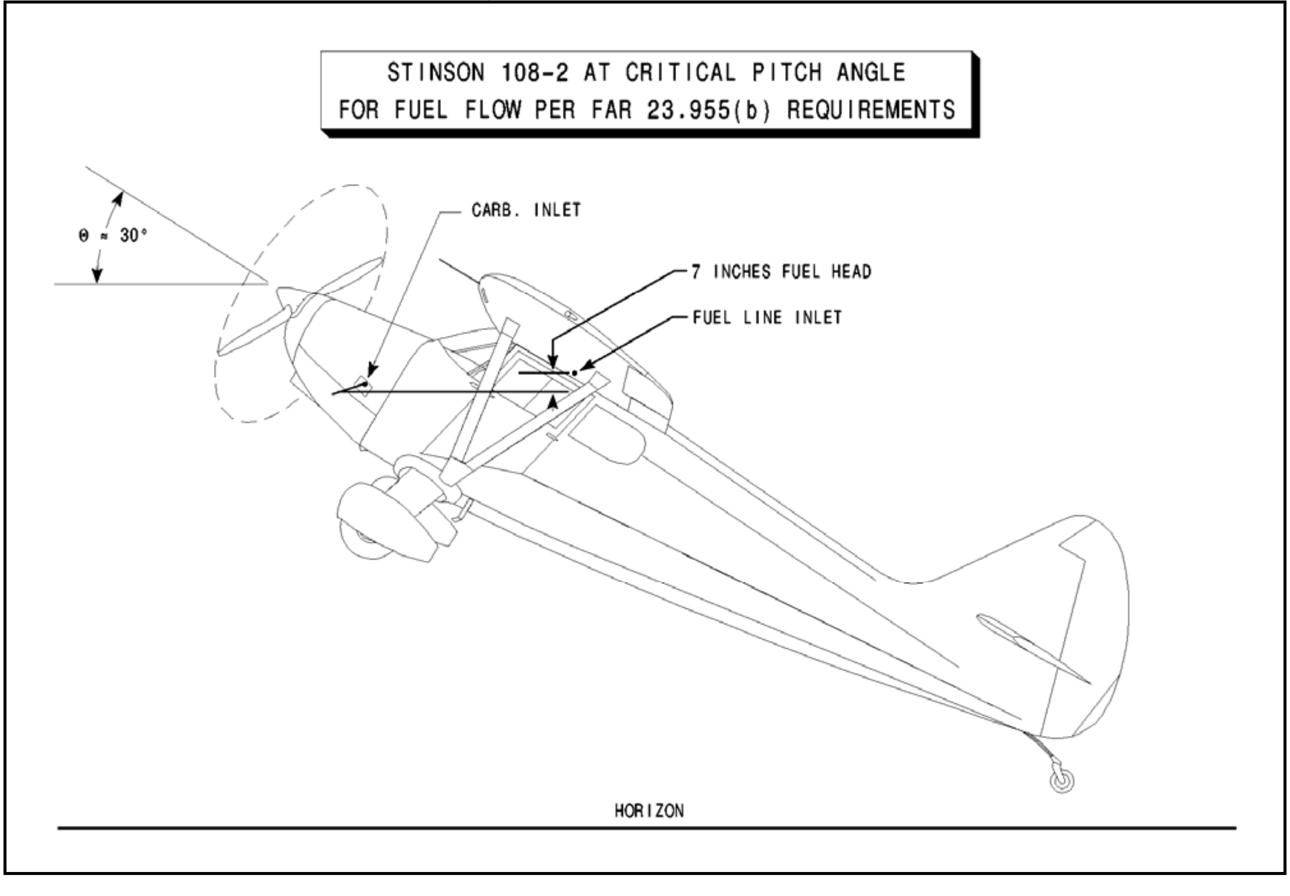
Figure 2: Performance Modeling Validation and Critical Performance



Development of a performance model for the airplane was an involved effort that took better than 6 months to complete, working many hours each week. The modeling required producing basic aerodynamic parameters including the key items of lift vs. angle-of-attack and a flaps retracted drag polar. A model of the propulsion system, i.e., the engine and propeller combination, was also needed. Contact with McCauley was successful in obtaining a partial propeller efficiency map to help with this aspect of the analysis. Engine performance was again difficult to locate for the Franklin, so extensive use of performance data from similar horsepower air cooled, horizontally opposed, and naturally aspirated engines was used. The above figure shows the demonstrated performance from the substantiation flight test and also the matching theoretical prediction for the average conditions during that flight. The highest pitch attitude attained was in excess of 20˚, flying at just above the stall speed. The test condition was similar to what could be expected during execution of a go-around and getting into a near departure stall situation. Also shown on the figure is the critical performance for the Stinson 108–Franklin engine combination. The gross weight used was the basic airframe empty weight plus additional weight for engine oil, VFR day minimum fuel reserves, a 170 Lb pilot, no passengers or cargo. Under these conditions, the critical pitch attitude of the airplane could get to near 30˚.

When these flight test data were presented to the FAA, the manager of the modification group commented that they would not have required showing the performance at any higher pitch attitude than that achievable at best angle of climb speed, which is consistent with the FAR requirements for demonstrating unusable fuel quantity. This would lower the critical pitch attitude by roughly 4˚ as the best angle of climb speed at these light weights occurs at about 60 mph indicated speed. I found the FAA position to be somewhat surprising considering full power departure stall recovery is usually demonstrated during a biennial flight review. The following figure shows the geometric relationship between the fuel tank outlet and carburetor in a 30˚ pitch attitude for your consideration and amusement. Note that the required fuel flow rate at critical pitch attitude must be achievable on a near empty tank, that is, with the unusable fuel quantity plus the additional fuel quantity necessary to demonstrate compliance. No credit is available for extra fuel in the tank.

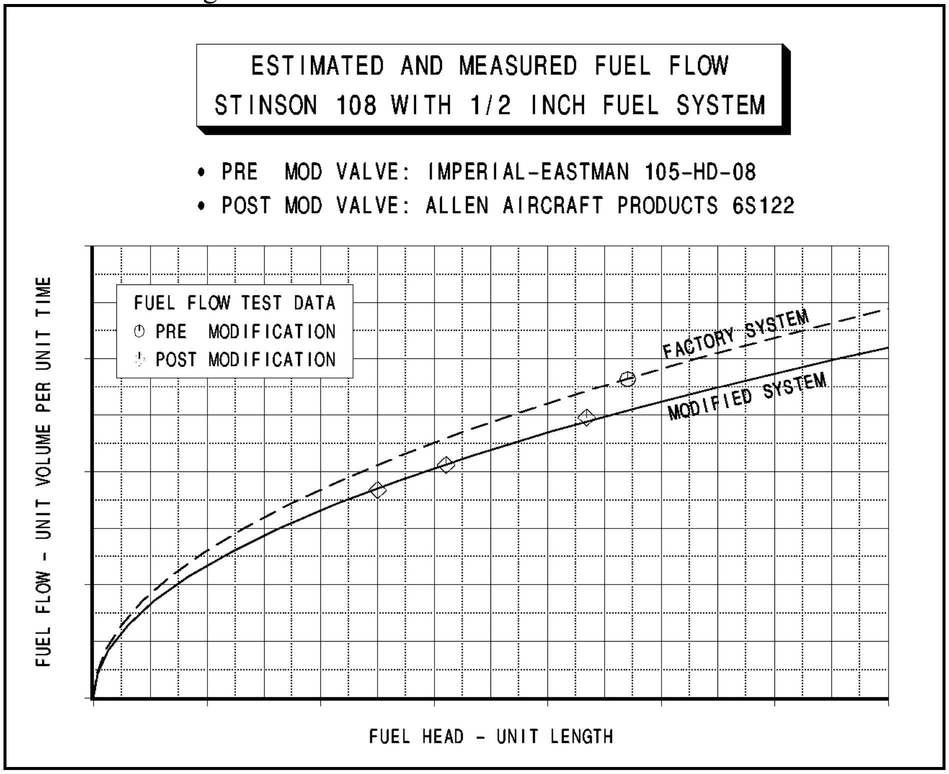
Figure 3: Critical Pitch Attitude



After the takeoff fuel consumption and critical attitude had been established, a fuel flow test was needed to show that the requirements would be met with the new fuel selector. Before committing to modify the stock fuel system, a preliminary fuel flow test was run with the Allen valve attached into the fuel system at the carburetor fuel line, leaving the original selector installed. The losses from two valves in the system would provide conservative results. The figure below shows the Stinson in the biggest ditch available at the local airport. The pitch attitude was about 22.5° which was slightly below the attitude at best angle of climb speed for the critical fuel scenario. Rather than finding a backhoe to create a deeper ditch or jacking the airplane to get to a higher pitch attitude, fuel flow data at three different fuel heads were used to produce a fuel system loss coefficient from which fuel flow as a function of any fuel head was developed.

Figure 4: Fuel Flow Test Set-Up at 22.5° Pitch Attitude

Figure 5: Estimated and Measured Fuel Flow Rate



Data provided by Allen for a valve-only flow test showed the 6S122 selector would pass 165 pounds (27.5 gallons) of fuel per hour with a 5-inch fuel head. Unfortunately a significant fuel flow reduction relative to the isolated valve capability occurs in the Stinson fuel system due to several factors including internal friction of the gasoline in the fuel lines, numerous bends and fittings, gascolator, etc. However, the fuel flow rate needed to meet FAR §23.955 with the Allen 6S122 valve was achieved with slight excess margin at the critical pitch attitude achievable just before reaching the stall speed. This margin is further increased by limiting the critical pitch attitude to the best angle of climb speed as was considered as an acceptable means of compliance to the FAA in 1997. Needless to say, the FAA found the supporting analysis and testing to be sufficient to issue a one airframe STC for this project. Univair as the Type Certificate holder for the Stinson 108 now sells this valve in conversion kits for the Stinson 108. Univair kit part number 9010078-38 is used with the ⅜ inch fuel lines and 9010078-12 is used with ½ inch fuel lines, the difference being in the fittings.

Epilogue:

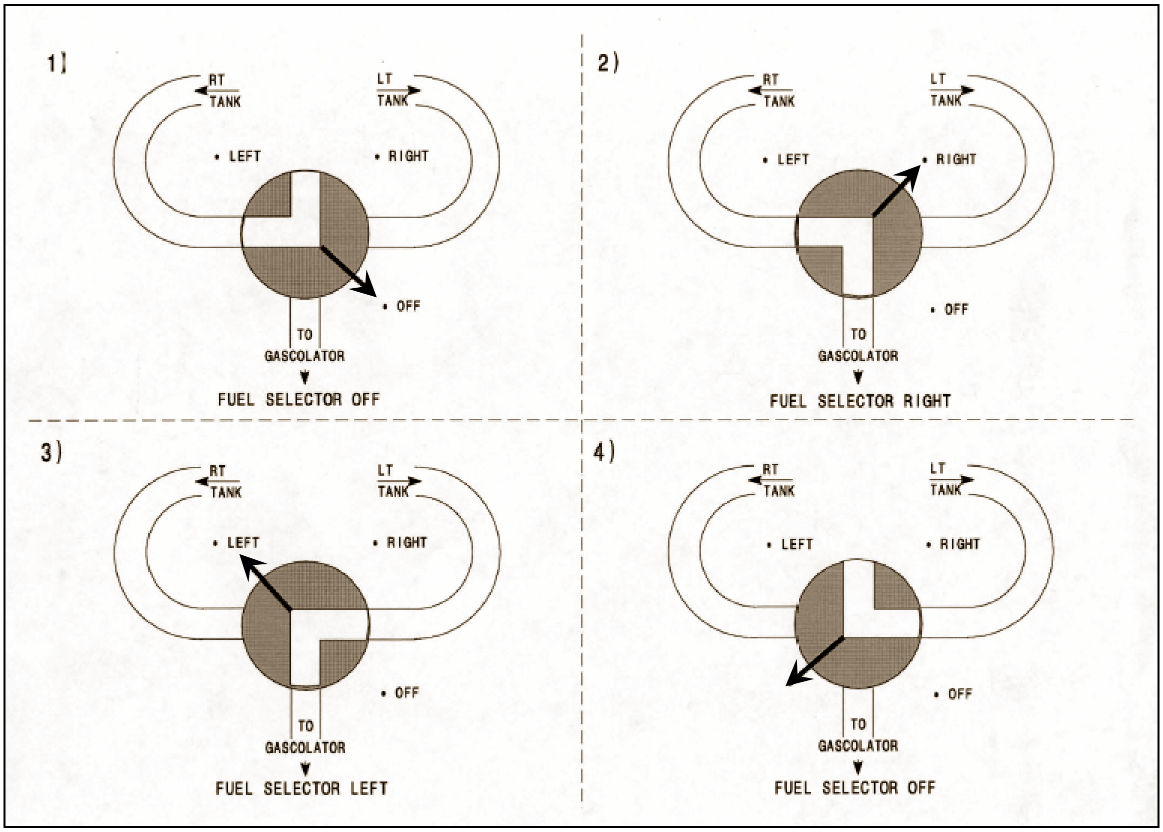
It is fair at this point to ask about the possibility of qualifying the modified Stinson fuel system for other engine options for the airframe. As there was excess fuel flow rate relative to the Franklin 6A4-165-B3 installation, and combined with potentially better SFC for other engines, it maybe possible. A very preliminary estimate of the performance of a Stinson 108 with the Univair Lycoming O-360 180HP engine installation can be deduced through inspection of the temperature effects on performance data shown above in Figure 2. The 15 extra rated horsepower (165HP vs. 180HP) would only yield about an 8-10 available horsepower increase as the propeller efficiency for a fixed pitch propeller installation is not that impressive when operating off-design. This horsepower increase is similar to the change shown at the lower speeds of interest due to temperature effects between standard day (59˚F) to -20˚F. Pitch attitudes just under 30˚ at the best angle of climb speed would be expected. Assuming the FAA still uses the pitch attitude at the best angle of climb speed for the critical fuel compliance, it would appear that an 180HP installation could be successfully certified.

Another common engine change has been to install engines as high as 220HP. This is where the use of a gravity feed fuel system is questionable. The 55 rated horsepower increase alone would result in very impressive climb performance. Add to this the additional available horsepower from the use of a constant speed propeller, which itself is more efficient plus it allows the engine to operate at near rated RPM, the best angle of climb speed pitch attitude would be over 30° for sea level standard day performance! Maximum rate of climb of near 2,500 Ft/Min appears achievable. Without specific geometry for the engine carburetor installation, at appears that the performance would exceed the capability of even the stock fuel system unless a fuel pump was used.

As you can see, considerable work would be needed to attempt to qualify any of these larger engines on the Stinson airframe with the new fuel selector. Following the precedence of this analysis, an available airframe would likely be needed to substantiate the performance model with the new engine installation. This is a major stumbling block that impedes Univair's ability to qualify other engine-airframe combinations as they don't have an airplane readily available that they can perform the tests with.

Fuel Tank Selector Valve Internal Arrangement:

The following diagrams show the internal valve arrangement for either the Imperial-Eastman or Allen Aircraft Products fuel selector valves used in the Stinson 108. The thick line represents the pointer position of the fuel selector handle at the lower instrument panel. Diagram 1 illustrates the "Off" position, with diagram 2 showing the "Right" fuel tank selected and diagram 3 showing the "Left" fuel tank selected. The original equipment Imperial-Eastman valves had a hard stop to prevent further valve actuation past the "Left" tank position in a counter-clockwise motion. Newer replacement Imperial-Eastman and the Allen fuel selectors do not have this stop so the valve will actuate through 360° of rotation. Diagram 4 is therefore another "Off" position for these valves. Further rotation in a CCW direction is not possible with the stock fuel quantity indicator as the tank selector handle will hit the toggle switch used to select which fuel level sender is being displayed on the fuel gage. This is an important feature as FAR § 23.995 (g)(2) states that that it must be impossible for the selector to pass through the "OFF" position when changing from one tank to another. While arguably Stinson's use of a fuel quantity indicator toggle switch is a poor aspect of the fuel system design, it does serve the purpose nicely of preventing valve rotation through an "Off" position.



Reference Federal Aviation Regulations:

CAR 3: § 3.429 General. The fuel system shall be constructed and arranged in a manner to assure the provision of fuel to each engine at a flow rate and pressure adequate for proper engine functioning under all normal conditions of operation, including all maneuvers and acrobatics for which the airplane is intended.

FAR 23: § 23.951 General. (a) Each fuel system must be constructed and arranged to ensure fuel flow at a rate and pressure established for proper engine and auxiliary power unit functioning under each likely operating condition, including any maneuver for which certification is requested and during which the engine or auxiliary power unit is permitted to be in operation.
(b) Each fuel system must . . .

CAR 3: § 3.433 Fuel flow rate. The ability of the fuel system to provide the required fuel flow rate and pressure shall be demonstrated when the airplane is in the attitude which represents the most adverse condition from the standpoint of fuel feed and quantity of unusable fuel in the tank. During this test fuel shall be delivered to the engine at the applicable flow rate (see §§ 3.434-3.436) and at a pressure not less than the minimum required for proper carburetor operation. A suitable mock-up of the system, in which the most adverse conditions are simulated, may be used for this purpose. The quantity of fuel in the tank being tested shall not exceed the amount established as the unusable fuel supply for the tank as determined by demonstration of compliance with the provisions of § 3.437 (see also §§ 3.440 and 3.672), plus whatever minimum quantity of fuel it may be necessary to add for the purpose of conducting the flow test. If a fuel flowmeter . . .

CAR 3: § 3.434 Fuel flow rate for gravity feed systems. The fuel flow rate for gravity systems (main and reserve supply) shall be 1.2 pounds per hour for each take-off horsepower or 150 percent of the actual take-off fuel consumption of the engine, whichever is greater.

FAR 23: § 23.955 Fuel flow.
(a) *General.* The ability of the fuel system to provide fuel at the rates specified in this section and at a pressure sufficient for proper engine operation must be shown in the attitude that is most critical with respect to fuel feed and quantity of unusable fuel. These conditions may be simulated in a suitable mockup. In addition—
(1) The quantity of fuel in the tank may not exceed the amount established as the unusable fuel supply for that tank under §23.959(a) plus that quantity necessary to show compliance with this section.
(2) If there is . . .
(3) If there is . . .
(4) The fuel flow . . .
(b) *Gravity systems.* The fuel flow rate for gravity systems (main and reserve supply) must be 150 percent of the takeoff fuel consumption of the engine.
(c) *Pump systems.* The fuel flow . . .

CAR 3: § 3.446 Fuel tank vents and carburetor vapor vents. (a) Fuel tanks shall be vented from the top portion of the expansion space. Vent outlets shall be so located and constructed as to minimize the possibility of their being obstructed by ice or other foreign matter. The vent shall be so constructed as to preclude the possibility of siphoning fuel during normal operation. The vent shall be of sufficient size to permit the rapid relief of excessive differences in pressure between the interior and exterior of the tank. Air spaces of tanks the outlets of which are interconnected shall also be interconnected. There shall be no . . .

FAR 23: § 23.975 Fuel tank vents and carburetor vapor vents.
(a) Each fuel tank must be vented from the top part of the expansion space. In addition—
(1) Each vent outlet must be located and constructed in a manner that minimizes the possibility of its being obstructed by ice or other foreign matter;
(2) Each vent must be constructed to prevent siphoning of fuel during normal operation;
(3) The venting capacity must allow the rapid relief of excessive differences of pressure between the interior and exterior of the tank;
(4) Airspaces of tanks with interconnected outlets must be interconnected;
(5) There may be no point . . .

CAR 3: § 3.550 Fuel system lines, fittings, and accessories. Fuel lines shall be installed and supported in a manner which will prevent excessive vibration and will be adequate to withstand loads due to fuel pressure and accelerated flight conditions. Lines which are connected to components of the airplane between which relative motion might exist shall incorporate provisions for flexibility. Flexible hose shall be of an acceptable type.

FAR 23: § 23.993 Fuel system lines and fittings.
(a) Each fuel line must be installed and supported to prevent excessive vibration and to withstand loads due to fuel pressure and accelerated flight conditions.
(b) Each fuel line connected to components of the airplane between which relative motion could exist must have provisions for flexibility.
(c) Each flexible connection in fuel lines that may be under pressure and subjected to axial loading must use flexible hose assemblies.
(d) Each flexible hose must be shown to be suitable for the particular application.
(e) No flexible hose that might be adversely affected by exposure to high temperatures may be used where excessive temperatures will exist during operation or after engine shutdown.

CAR 3: § 3.551 Fuel valves.
(a) Means shall be provided to permit the flight personnel to shut off rapidly the flow of fuel to any engine individually in flight. Valves provided for this purpose shall be located on the side of the fire wall most remote from the engine.
(b) Shut-off valves shall be so constructed as to make it possible for the flight personnel to reopen the valves rapidly after they have once been closed.
(c) Valves shall be provided with either positive stops or "feel" in the on and off positions and shall be supported in such a manner that loads resulting from their operation or from accelerated flight conditions are not transmitted to the lines connected to the valve. Valves shall be so installed that the effect of gravity and vibration will tend to turn their handles to the open rather than the closed position.

FAR 23: § 23.995 Fuel valves and controls.
(a) There must be a means to allow appropriate flight crew members to rapidly shut off, in flight, the fuel to each engine individually.
(b) No shutoff valve may be on the engine side of any firewall. In addition, there must be means to—
(1) Guard against inadvertent operation of each shutoff valve; and
(2) Allow appropriate flight crew members to reopen each valve rapidly after it has been closed.
(c) Each valve and fuel system control must be supported so that loads resulting from its operation or from accelerated flight conditions are not transmitted to the lines connected to the valve.
(d) Each valve and fuel system control must be installed so that gravity and vibration will not affect the selected position.
(e) Each fuel valve handle and its connections to the valve mechanism must have design features that minimize the possibility of incorrect installation.
(f) Each check valve must be constructed, or otherwise incorporate provisions, to preclude incorrect assembly or connection of the valve.
(g) Fuel tank selector valves must—
(1) Require a separate and distinct action to place the selector in the “OFF” position; and
(2) Have the tank selector positions located in such a manner that it is impossible for the selector to pass through the “OFF” position when changing from one tank to another.