Aviation Throttle Body Injection – an update

One goal of this article is to provide some information on both Rotec and Ellison TBI systems including some of the commonalities and differences in these units. Another is to speculate on where we currently stand in industry in terms of purchasing and maintaining these systems. It would also be beneficial to develop or strengthen the user community for those who are interested in self maintaining their TBI systems within the boundaries of safe practices and the limitations of our capacity due to availability of equipment and accurate understanding of how these systems need to be set up.

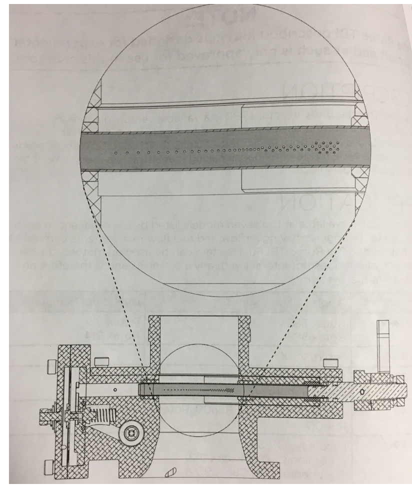
Ellison TBI's were invented, manufactured and marketed by Ben Ellison in Seattle area who retired and eventually sold the business to Steve Glover, in Southern California. Glover is currently overhauling units and working towards manufacturing new units. Rotec is in Australia and along with TBI's they manufacture a series of small radial aircraft engines.

The best description for these units is they are pressure regulated variable venturi throttle body multiport spray injection. They somewhat mix technologies from several different fuel-metering systems. Like Bendix pressure carburetors they use a diaphragm with air at inlet impact pressure on one side and fuel at venturi pressure on the other to regulate fuel pressure to a semi-constant that is not affected by changes in inlet pressure, without the use of a float. Like a Mikuni or Bing slide carburetor they use a slide throttle valve (versus butterfly) to emulate a variable diameter venturi that approximates a constant pressure delta (impact to venturi) across the full range of throttle opening. Because engine load will also affect MAP and RPM, fuel pressure and air pressure will vary but as a ratio they are held fairly constant as the throttle moves. Where the Mikuni or Bing change fuel flow by moving a tapered needle in a jet, the TBI's maintain controlled air/fuel ratios during throttle changes by opening, or closing a series of tiny fuel ports in the metering tube running through the center of the throttle slide.

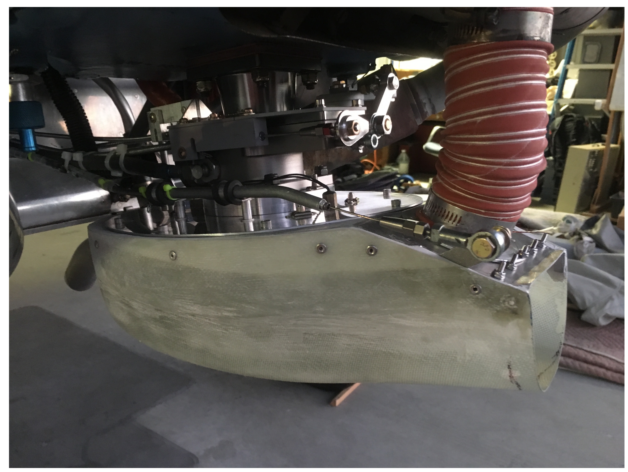
Having mentioned a constant ratio of fuel to air it must be pointed out that this is not actually desirable for air cooled engines because they often produce more heat than they can reject during certain phases of engine operation. In general we use the evaporation from extra fuel to lower both inlet and subsequently lower combustion temperatures when the engine produces too much heat for the cooling available. So we run it rich, typically during high power settings and in some cases at idle settings (because the cooling is so poor). Meanwhile, during cruise periods where heating is low, cooling is high and economy is desired we will want to lean the ratio of air to fuel. So any fuel metering system must be able to somewhat autonomously provide these modified ratios depending on what power setting is being used. The Ellison and Rotec TBI's do this by uncovering a series of asymmetrically spaced fuel ports as the throttle is opened. While this valve mechanism is very different it is the same principle used on a Bing or Mikuni carb, when the fuel-metering pin valve is moved by the slide throttle. The Mikuni/Bing pin is cut at differing tapers throughout its length. Unlike the Bing or Mikuni the other thing the Ellison/Rotec units can do to alter the ratio, in this case manually, by changing the orientation of the fuel ports within the surrounding airstream. By facing them into the impact air the increased fuel rail pressure will close the fuel regulator some and produce less flow. Alternately, facing them at 90 degrees to the airflow, at the apex of the venturi siphoning action will open the fuel regulator some increasing flow.

Because of this design, changes in atmospheric pressure will have a similar affect on both fuel and air pressure such that the need to adjust mixture for changes in altitude is quite a bit less than many other fuel metering systems.

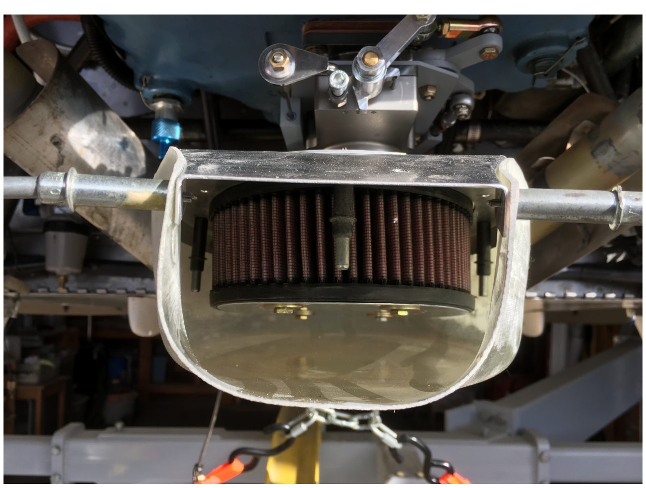
This image from the Rotec manual shows the basic arrangement of the regulator, slide throttle and fuel spray/mixture tube with fuel ports arranged to increase flow appropriately as the throttle opens.



The conversion process of an RV-6 with a Lycoming O-360 engine from a Marvel/Schebler MA4-5 float carburetor to the Rotec MKII 48.4/5 TBI was fairly straight forward, very much on a par with the installation of an Ellison TBI. Both require some rigging modifications because the action of the throttle and mixture control are not on the same axis and one is linear while the other rotates along an arc. Ben Ellison was very adamant that the throttle action must be oriented so that its slide motion was at 90 degrees from the crankshaft axis. The RV-6 exhaust does not leave much room in this area so the throttle slides forward to open. At this early point in operational testing the only difference I've noted is when leaning to extreme lean of peak the hottest cylinders tend to be one and three, which are on the side away from the direction the spray bar emits fuel in this installation. This may be why Ellison was emphatic about installation orientation. The Rotec also provides a button on the fuel regulator, which can be pushed in flight with the addition of a lever and cable. This opens the regulator thereby priming the engine. They claim it can be used to run the engine at full throttle but when I tried it there was way too much fuel, even at full power. It does prime very nicely and I should add the engine will not start unless primed., cold or hot Starter cranking speed does not produce enough venturi flow to get the fuel regulator to open. While I haven't tested it, the engine easily starts with a little prime so I'm reasonably sure it will also hand prop easily. But you will need enough battery power to run a boost pump for a bit.



Performance of both units seems to be very good, both allow one to control mixture to lean of peak quite well during lower power settings. Both were installed with identical air box systems, modified from the Vans FAB vertical air box kit. Both Rotec and Ellison call for a large plenum with stable high-pressure air available to the inlet with little turbulence. I did greatly increase the volume of the air box relative to the Vans original design, which is strongly recommended by both Ellison and Rotec.



The one idiom of the Rotec that I have not yet worked out is higher EGT's in the last 3/8" of throttle opening. This is the one place where fuel enrichment is critical, however… "high" is a very relative term with respect to EGT's. What is too high? This is not well spelled out and can change due to many variables. I found that this engine tends to peak EGT's at about 1450f during cruise with the float carb and therefore I concluded that going above 1480f was undesirable and much above 1500f was probably bad. I openly confess there is no science to this but I know that the Marvel/Schebler never went much above 1350f at full throttle and the Rotec will easily go higher than 1550f at the same power setting. While there is no science defining what is too high, clearly by comparison to the MA4-5 Carb (and inherently Lycoming in its choice of this model carb) it's running leaner than was intended, but only in that last bit of throttle opening. Rotec's manual also claims the unit can open too much depending on the engine so one needs to be sure MAP and RPM keep going up, and a throttle stop is put in place where they stop. Well, on this engine MAP and RPM increase throughout the full range of throttle travel.

Since mixture adjustability at all other power settings seems to be just fine I'm generally convinced the fuel ports on the extreme open throttle end need to be opened up a small amount, for this installation. For those who are wondering if the air box design might be a factor due to high ram air, when I close off the ram air thereby opening heated air the EGT's do drop a little as expected, but the "too high" behavior is essentially the same. I also opened up the idle fuel screw some to enrichen things. The manual says it comes from the factory at 1 3/4 turns from closed however I found it at about 1/8 turns from closed. Using the mixture cut off/RPM rise technique to determine idle fuel ratio doesn't work that well on this kind of TBI because the mixture doesn't exactly shut the fuel off. It is running fairly rich at idle though with it set at 1.75 turns as evidenced by loping and a significant rise when I go full lean at 1000 RPM. As I sort out the high power issue I intend to reset the idle fuel back to leaner.

After I spend more time tweaking things I'll update this section.

Physically the two units are similar. The Rotec is about one inch shorter from top to bottom flange. Both flanges are dimensionally the same, although the Rotec is dimensionally smaller in other ways. The Ellison uses a ball end clip that screws onto the end of a 10/32 threaded throttle cable. The Rotec uses two provided spacers that also accept a 10/32 threaded shaft. But the travel distance here may be offset by an inch or more because the Ellison ball end adaptor is no longer necessary. The mixture rotates similarly and can be indexed to similar positions. Like the Ellison, this is limited by interference with the throttle shaft. However, it should be noted that the shaft rotates in the opposite direction in terms of going lean to rich, or rich to lean. (To update: it turns out that Rotec will modify direction of rotation during the ordering process, but this will require a phone call.)

The Rotec manual seems to be more comprehensive than that provided by Ellison. They also sell rebuild kits… wherein a couple of things need to be said about other internal differences. The Ellison uses a Grose-Jet fuel inlet valve that instead of being a needle has two balls (one glass and one steel) stacked within a brass seat and a spring-loaded lever that is pushed on by the impact air diaphragm. The Rotec just uses a spring-loaded valve that directly rests against the diaphragm. I'm not sure either is better. Rotec recently made a change to their system to improve the valve by bonding the seal ring to the valve stem.

One thing I did not like about the Rotec is the threads cut for the bolt holes on the air box side flange were kind of torn up. They were cut too fast and tore some in production. Their manual also claimed lock washers were on all the screws, which apparently no longer get used. However, one aspect of the Ellison that I've never liked is the heavy reliance on retaining parts by staking dents into the body. This might work marginally, but one can only stake so many dents before the body is no longer serviceable. Since these major parts are currently not available this limits the serviceability of these units.

Ellison was never willing to sell parts for these units, in part for good reason. While they are inherently simple they can be easily misassembled and set up so badly as to be unsafe. So the question at this point is, is there anything Ellison owners can do to ensure continued safe and reliable operation and do this within our capabilities and resources?

I do think that there is some work owners can do on a periodic interval that is within the capacity of many homebuilders and the equipment available to them that could increase service life between overhauls. However, like Bendix pressure carburetors, full overhauls of these units must be done by the current manufacturer, Ellison Inc. under Steve Glover.

I'd like to suggest a users group might be able to compile a basic parts list of what I call class A parts that one can use to clean up and inspect their units. Having said this let's talk about what it means to overhaul or rebuild something. Ultimately several things occur during an overhaul. Everything gets cleaned and inspected. Class A parts are discarded and replaced, no questions asked. All other parts are reused, replaced, or restored to serviceable condition and reused. The system is then reassembled and adjusted or setup to some potentially exacting specifications. It is this latter part that I would argue most of us are not well equipped to accomplish. However, with respect to cleaning things up and replacing all O-rings, top plate seals and the diaphragm there are many of us who could accomplish this without too much difficulty.

Anytime the fuel regulator valves, springs and levers (all with staked screws) need to be removed the unit must be readjusted and set up with bench testing. But one could easily remove the diaphragm plate, clean/rinse out any debris, and replace the diaphragm and gasket without affecting the regulator valves. The same can be said for removing the top plate where one can easily clean out the gunk around the throttle slide and replace the few O-rings therein. However, removal of any other staked in, or riveted parts, removing the throttle shaft from the slide (lots of locktite) or replacing any of the three Bal-Seal rings on the mixture and throttle shafts are all things that need appropriate equipment, materials and post-assembly adjustments.

Not only are we not equipped to replace these parts and make these adjustments, sourcing some of these parts seems to be problematic. I have found most of the other O-rings, roll pins, screws and retention internal push rings. I also think a users group could compile a list of known wear issues to look for whenever anyone choses to clean and inspect their units. Anybody doing such an inspection should have clear criteria to determine when it should instead be returned to Ellison for a full overhaul.

In my recent visit to Steve's shop it is clear he is gearing up both to produce more new units and to increase their overhaul operations. Now, having typed all this, existing Ellison users as well as those new to the TBI idea might also consider the option of converting to the Rotec, which is clearly a viable option. The conversion should be fairly easy. For some they'll need to build an adaptor to fill in the missing one inch, and for others this is not a factor. While Rotec is in Oz, they have a knowledgeable rep in Florida who has been helpful. They do claim their units are warrantied and their forum seems to reflect an interest in serving their clients well.

Here is a link to a number of images reflecting the installation I did. Also there are some images of an Ellison EFS-4-5 disassembled.
www.miravim.org/4RE

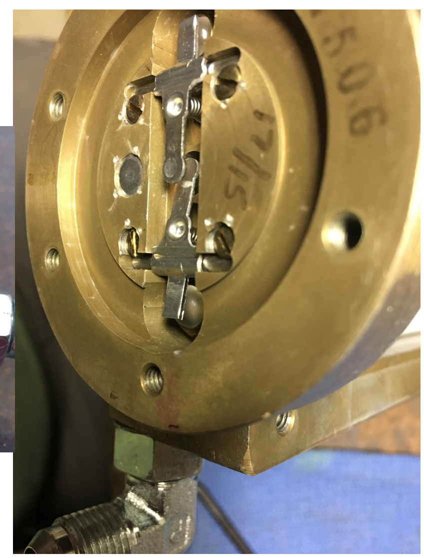
Ellison is now in Southern California owned by Steve Glover and he can be reached at info@ellison-fluid-systems.com http://ellison-fluid-systems.com/index.htm

Rotec just recently completely upgraded their website with the introduction of their new MKII product line. The earlier units had the fuel regulator separated from the TBI. The new ones have them integrated just like the Ellison units.
https://www.rotecaerosport.com/tbi

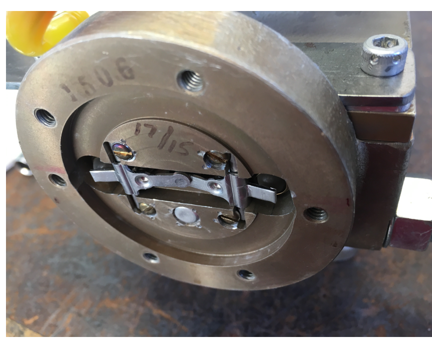
Brian Kelly is their Florida rep… radialconversions@gmail.com

Additional Notes:
Grose-Jets were originally made by D&G Valve Manufacturing and is no longer in business. However, LLP Manufacturing in NY seems to still be making them. Several of the Ellison units have been having these valves jam open (while running), and in one case jam closed (while shut off). This does not appear to be caused by wear because in one case they were brand new. So, at this point it is not clear if wear, substandard manufacturing or contamination is causing this. The pictures below show this behavior being replicated for both valves. A general guess would be contamination as the likely culprit. Filtration recommendations by both Ellison and Rotec must be followed.

This shows the inner valve jammed open.



And this shows outer valve jammed, thereby jamming both open.

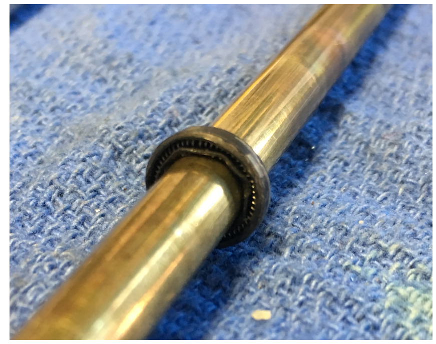


Most of the class A parts are reasonably priced, but the square PTFE .125" bar is not cheap. PTEF is generally not cheap anyways. The Bal Seal seals are also pricy. The Grose-Jet valves have yet to be identified. #07-415 or sometimes sold as #415 seems to be close but it has an unthreaded segment that needs to be gone and the inlet port is smaller. So it is not clear if these could be modified because the lower steel ball may be sized to the diameter of the inlet hole.

Ellison EFS-4-5 Parts

O-rings

2 - AS568-008	Top plate small seals, AS568-009 might also work
2 - N2.00X12.5 metric	Inlet fittings, or AS568-112
1 - AS568-156	Top plate main (square shaped groove, AS568-157 might also work)



Screws – (Aircraft Spruce may sell these if you call)
6 - AN500 A8-8 8/32 x 1/2" Drilled head fillister head screws
6 - MS24677-24 Drilled head cap screw 10/24 x 5/8" (Two may be MS24677-25 10/24 x 3/4" for throttle bracket)

Roll Pins
2 - 1/16" x 7/8" Mix tube
1 - 1/16" x 1/2" Slide/throttle shaft
1 – .100" x 3/4" (possibly longer) Mix lever stop

Diaphragm and gasket
Winderosa LP07402 – diaphragm kit for Tillotson DG1HD, the full repair kit also includes a 155A-23 lever and 32-79 pin and a bunch of stuff you won't need. Winderosa 451466

<u>The following parts require special tooling and post installation adjustments.</u>
Lock ring and seals for mixture and throttle shaft seals
2 - Daemar P/N TI-0044-PA, TI - Toothed Internal Stainless Steel "Push on" Ring 7/16" x 1/4" (www.rotorclip.com seems to offer them under the P/N TI-44SS, not sure about retail sales, https://www.huyett.com/Products/Fasteners/Retaining-Rings/Push-On-Rings/TI-044-SS?searchText=TI-44)
3 – For mixture and throttle shaft seals, they are a plastic V lip seal with spring 3/8" x 1/4" OD/ID, made by Bal Seals, Inc. https://www.mcmaster.com/#13125k75/=1b66ry8 McMaster Carr has them under the PN 13125K75 spring loaded seal, $22 ea
An AS568-010 O-ring might also work but probably won't last as long.

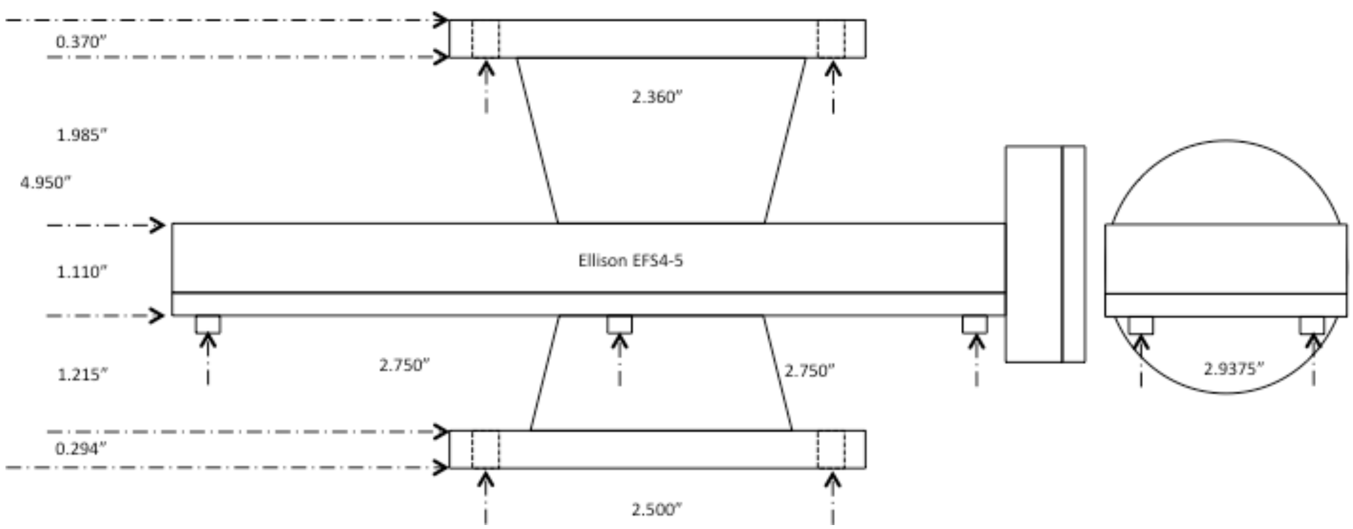
Fuel inlet valve (2 in the EFS 4/5, 1 in the other Ellison units)
2 – Grose-Jet, similar to #415 common to some Tillotson carburetors, but the #415 is slightly longer and its inlet port is smaller.
Dimensions .500" open length, .451" closed length, 5/16 hex, threads 5/16-32, inlet port .125", six outlet ports centered on each the hex flat .075".
2 – Seat gasket 16B-199, often comes packaged with seat/Grose-Jet.
2 – Tillotson levers 155A-23
2 – lever pins, Tillotson 013406, or 32-79
4 – retention screws, brass, pan head, slotted, 3-48 x 3/16"

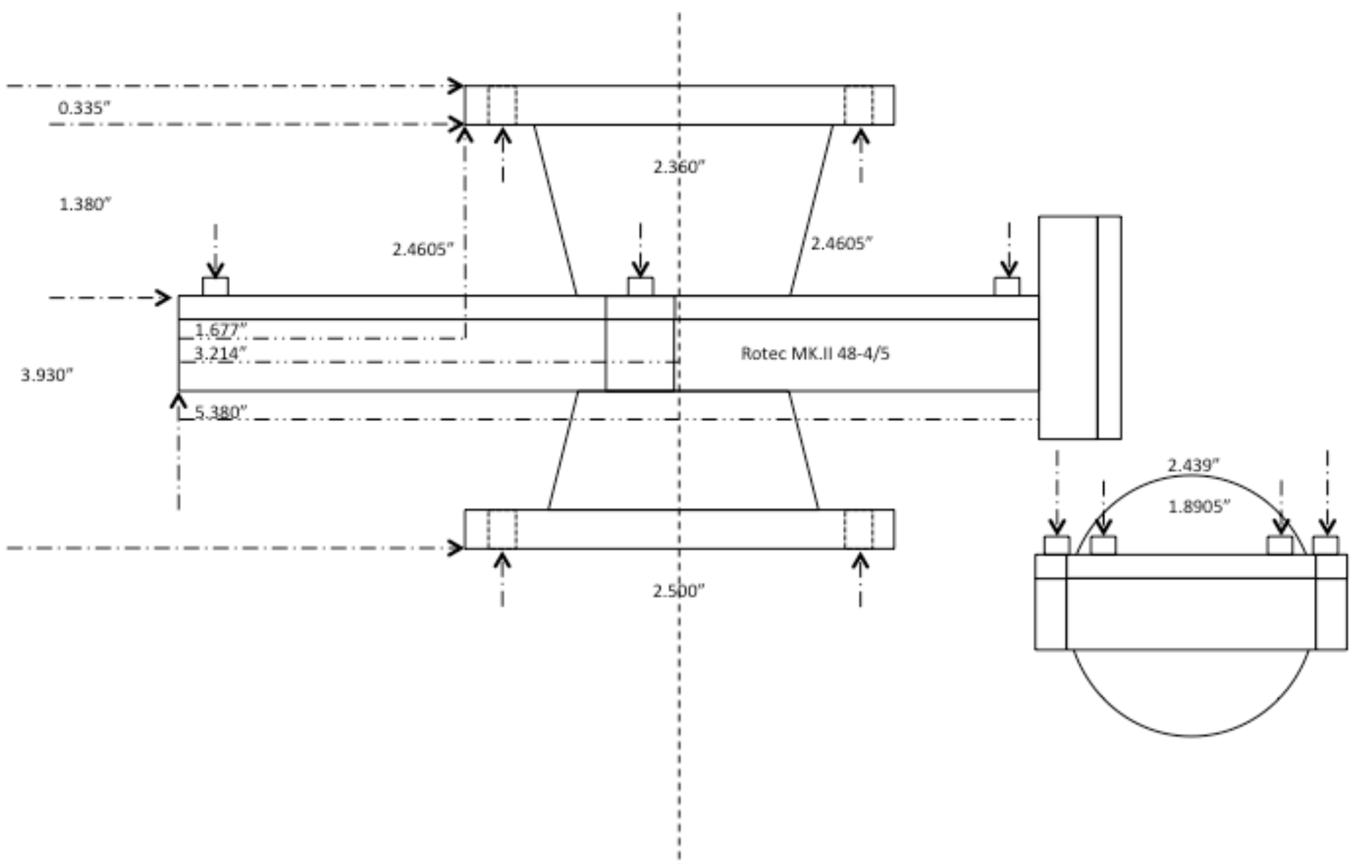
Teflon/PTFE Parts (McMaster-Carr sells these PTFE parts by the foot.)
4 - .125 x .125 x 2.375"apprx. square bar
1 – 3" x 6" x .040" sheet, trimmed to fit
4 – AN426-3 rivets, length to fit (apprx. ½")

If anybody ever figures out what model number of Grose-Jet is used and a source, or has any other questions feel free to drop a note to: wnorth@sdccd.edu or johnhickman@roadrunner.com

Additional measurements not shown on the installation diagrams for Ellison and Rotec.

These are for general comparison only. Although the top and bottom flanges are respectively the same the units are quite different dimensionally. The Ellison is 4.95” tall and the Rotec is 3.93” tall. I have not weighed them but I suspect the Ellison is somewhat heavier.





CHT/EGT/MAP/RPM data from the Rotec MKII 48.4/5 Lyc. O-360, Jan 2018