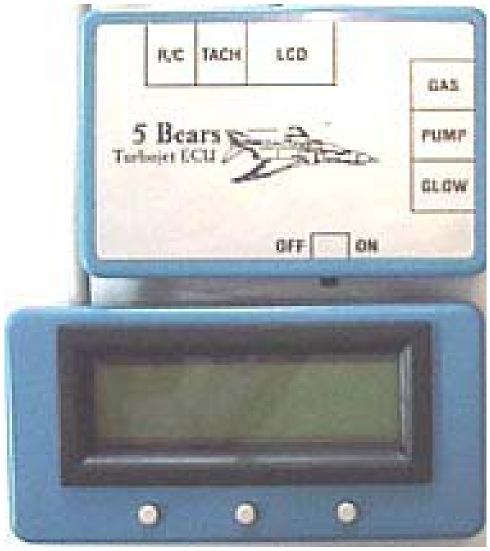
5 Bears
Turbojet ECU



User Manual

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Overview

The 5 Bears Turbojet ECU is a compact, high performance model jet turbine controller, with a wide range of parameters making it suitable for any number of model turbojets or turboprops. Rather than focus on any particular make of turbine, the 5BECU is designed to control almost any conceivable model. Important parameters are programmed by the pilot, rather than being hard-coded, or “fixed”. Starting is as simple as applying air to the inlet, or cycling the R/C transmitter's throttle stick from idle, to max, and back to idle.

The ECU can run three different turbines, stored as "Turbine Sets" within the onboard, non-volatile memory. This is very similar to the way a modern computer R/C transmitter can store parameters for several different models. Selection of the Turbine Number is a simple matter, and the ECU always defaults to the last flown turbine upon power-up, so if the pilot doesn't require this capability, its existence is transparent. Another use for the "Turbine Sets" is to have two (or more) different sets of parameters for the same turbine, and by selecting a particular set, performance can be optimized for a given circumstance, such as sport vs. competition flight, etc.

Inputs for the ECU consist of a type K thermocouple, R/C, tachometer probe, and an LCD display. Output signals control a fuel pump, gas solenoid valve (for starting propane/butane), glow plug, and starter motor. Starting is optimized for the popular electric starters, but the ECU also can be started using compressed air, as the display generates excellent cues for manual air application.

The ECU can be run with or without the LCD display attached... no features are disabled, and functionality is the same whether the LCD is attached or not. As the LCD is very small and light, most pilots will normally leave it attached to the ECU. Critical parameters and faults are logged in flight and can be viewed post-flight by attaching the LCD display.

The brain inside the ECU is a PIC16F876 processor, which can be software upgraded without removal of the chip. Please write or email me (kurt@5bears.com) for information on this process.

Dimensions

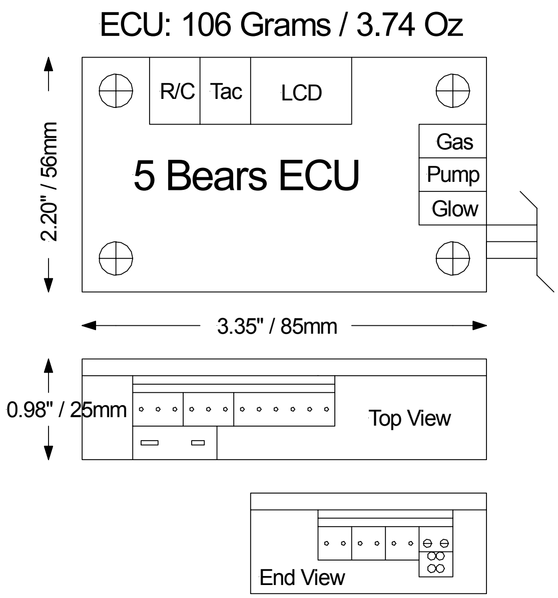


Fig. 1

The ECU is encased in a quality ABS plastic box, which is durable and fuel resistant. Connections to the Turbine and inputs are made with Molex "C-Grid" gold-plated connectors which are locking and keyed. The pins are a standard 0.100 inch spacing and will accept many R/C styled connectors. If this is done, you must respect the polarity of the connection.

High current cables are extra-flexible, stranded silicone. The battery cable comes standard with a Dean's "Ultra" male connector. R/C cables are available to fit Futaba "J", Airtronics, or Hitec/Jr. Other cables can be made to any specification.

Note: Damage to the ECU will result if the polarity of the battery cable is not respected. Be sure the red battery cable is attached to the positive pole of the battery, and the black cable attached to the negative pole!

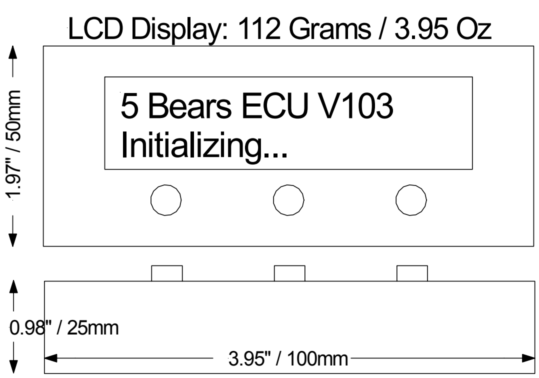


Fig. 2

The LCD Display is both light and compact. It does not need to be connected for any portion of the flight, including startup. It is needed, however, to program the ECU and to display post-flight data, and if desired, it may be connected permanently to display all of the normal turbine parameters.

Data input and manipulation is made using three tactile buttons below the LCD bezel.

ECU / Turbine Connections

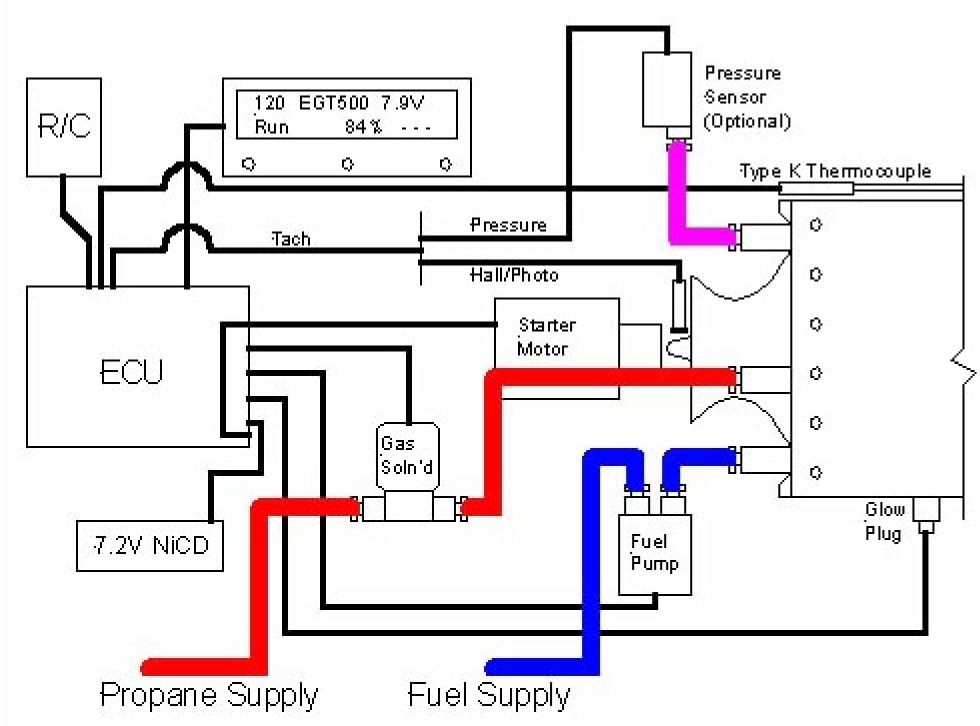


Fig. 3

Shown here is the general arrangement of the components necessary for successful ECU operation. A filtered fuel supply of the correct grade of fuel for your turbine is necessary. For starting, a propane or butane supply must be connected with the gas solenoid valve between the regulated gas supply and the turbine. This may be either an external or smaller internal bottle. When using an external bottle, I highly recommend the miniature QD (Quick Disconnect) couplers available from 5 Bears. Maximum pressure allowed into the gas solenoid is 100 PSI. A needle valve between the propane supply and the solenoid is desirable to control the flow. In practice, the regulator is fully opened, and the needle valve is used during propane burn to adjust the flow for an EGT of between 200 and 350 degrees Celsius. Once the correct flow is obtained, the needle valve is locked into this position. Subsequent starts then become consistent and effortless.

Tachometer input may be made via a Hall sensor, a more sensitive *magnetoresistive* sensor or photodiode; or, it may be achieved using an optional pressure transducer unit. Please see the *Tachometer Interface* section for more detail.

Use of a starter motor is optional. Using compressed air to start the turbine works very well, and requires *only* manual application of the air for success. Airstarts are generally cooler and faster than motor starts, and are recommended for the beginner.

The ECU is powered with an external, 7.2 or 8.4 V NiCd battery. Bench tests have shown a quality 1200 mAH NiCd to be adequate for 15 minute runs at various and typical throttle settings for an MW54 using a Speed 280 sized fuel pump. DO NOT use NiMH batteries if you are using an electric motor for starting. Instead, use NiCD batteries. NiMH batteries are fine when used for air starts.

One aspect of the fuel system critical for success is the avoidance of what I call an *overpumped* system. An overpumped system means that the fuel pump output is high enough to result in maximum RPM being achieved at very low pump settings. Microprocessor control of DC pumps uses a technique known as *Pulse Width Modulation* (PWM), with the entire pump range being digitally controlled by setting the value of a byte within the ECU. For example, the theoretical range of an 8-bit PWM pump is a value from 0 (off) to 255 (full power). PWM is widely used in electronic speed controllers for electric R/C flight. It is important to make use of the available PWM range within the ECU, and this cannot be done if the pump delivers enough fuel to achieve maximum RPM at a value of 45, for example.

To further clarify this situation, let's assume Turbine A idles reliably at 40,000 RPM and a Pump DC value of 35. The pilot increases the throttle, and the turbine accelerates to a maximum RPM of 110,000 at a pump setting of 50. This means that for each pump unit increase or decrease, the turbine is responding with over 7,000 RPM up or down! The ECU is forced in this case to accept a significantly lower RPM than the user intended, or worse, the ECU will hunt excessively trying to obtain both programmed idle and maximum RPM settings. As will be explained later, the fuel pump output is displayed on the LCD. During test runs, be sure that the pump output to produce programmed maximum RPM is at least 60 units above idle. For example, if the turbine starts and idles with a pump output of 40, we want the maximum RPM to be obtained with a pump output of at least 100. Numbers greater than 100 are fine, as long as the turbine is reaching maximum RPM somewhat below 255.

Many turbine/pump combinations will naturally work in this manner. Others (overpumped) will require either a different fuel pump, or more easily a modest fuel restrictor or needle valve installed in the fuel line on the *output* side of the pump. A simple fuel restrictor can be a brass diameter which is a snug fit inside the fuel line, perhaps 0.500" / 13mm in length, with a 0.0625" / 1.5mm hole drilled lengthwise. Increase or decrease the diameter of the through hole to suit. This will *not* alter acceleration or hurt the pump; rather, it will smooth throttle response and overall result in a happier, more stable turbine!

A more advanced and better way to correct overpumping is to place a "T" connector on the output side of the pump. One branch of the T goes naturally enough to the turbine. The other branch of the T goes through a fine needle valve and is returned to the fuel tank. In use, the needle valve is opened slightly, allowing a portion of the pumped fuel to be routed back into the fuel tank.

ECU Inputs

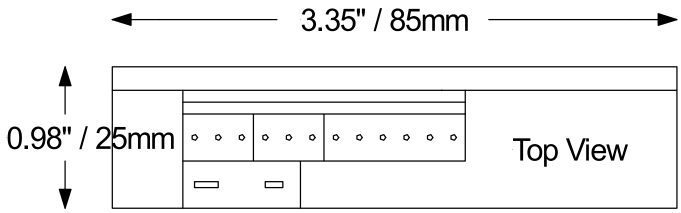


Fig. 4

The inputs for the ECU are located on the top edge of the case. Three C-grid connectors accept R/C, tachometer, and LCD Display inputs. The fourth connector is a standard miniature type-k thermocouple jack for the EGT probe.

Referencing the image, the input jacks, from left to right:

- R/C [Ground, +, Signal]
- Tach [Signal, Ground, +]
- LCD

R/C: The R/C input to the ECU is optically isolated, meaning that no portion of your R/C receiver is in contact with any high currents or potential damaging spikes. The throttle signal is fed directly to an integrated circuit containing a light emitting diode / phototransistor combination which provides isolation above 5000 V. The ECU makes use of your receiver's throttle channel for normal starting and operation.

Tachometer: The 5 Bears ECU has a "generic" tachometry interface which will allow any RPM sensing which delivers "pulses" of +5, -0 V to the ECU.

The pins for the tach consist of a signal pin, a ground pin, and a +5V supply for the external tachometer sensor. The 5V supply is *not current limited*; if the tachometer circuitry is not properly connected, damage to the ECU will result. The ECU tachometer interface has been designed with the greatest flexibility in mind, and will interface with most common systems.

Recommended sensors include photodiode, inductive pickup, Hall effect, and magnetoresistive sensors. The latter two are rugged, integrated circuits less than 1/4" across, and are pin interchangeable with each other. The magnetoresistive sensor is both more sensitive and more expensive than the Hall sensor. Both are sensitive to magnetic fields. When the magnet is within the Hall sensor's range, the Hall IC delivers a LOW signal to the ECU; otherwise, a HIGH signal is generated. The drawback to using a Hall sensor for tachometry is the requirement for a magnet or two to be mounted in a suitable location. My MW-54 has a custom spinner nut with a pair of internal rare-earth magnets, and performance has been 100% in all ranges. Other turbines have had pockets milled in the rear of the compressor wheel for the magnets. Whatever method you choose, be sure the magnets are perfectly balanced and absolutely secure. The HAL506 Hall IC has a theoretical top sensing speed of 10 KHz, which corresponds to 600,000 RPM!

LCD Display: The LCD display is a 2 line X 16 character, supertwist display, without backlighting. In normal operating mode, it continuously displays RPM, EGT, fuel pump output, Run/Fault mode description, percentage of throttle commanded, and three characters showing the state of the Starter, Ignition, and Gas (SIG) circuits. In addition, it has three momentary pushbuttons, which allows the user to enter and retrieve programming and logged data. The LCD gets its power from the ECU and carries no battery. Use of the LCD Display is optional. It is needed for programming and viewing of logged data, and for air starting the turbine.

EGT Probe: The ECU carries an industry-standard type K miniature female jack, mounted flush. The EGT interface shows excellent accuracy, with EGT being measured from ambient temperature to greater than 1000 degrees Celsius. Any *ungrounded* type K thermocouple can be used. If the type K thermocouple is *grounded,* the ECU will report this as an Open TC error; such probes are not suitable for use.

I recommend a fine a probe for quicker response, with .064" / 2.0mm being ideal. Larger probes often have a difficult time sensing the initial propane lightoff before RPM decays to zero during cranking.

Internally, the EGT circuitry features cold junction compensation, which means the EGT measurement will be accurate regardless of the temperature of the ECU itself. It also detects the condition of the thermocouple loop, and will take appropriate action if the thermocouple (or its connecting wires) fails in any way. The circuitry is also heavily filtered to prevent interference from the fuel pumps, R/C equipment, and other electrically "noisy" inputs and outputs.

ECU Outputs

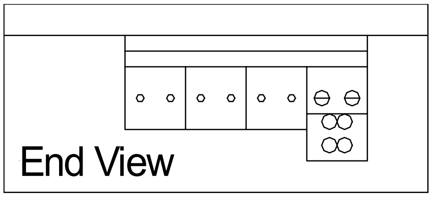


Fig.5

The outputs of the ECU are located on the right end of the case. There are 2-pin C-Grid locking connectors for gas solenoid actuation, fuel pump, and glow plug drive. Since the starter motor and the battery lines can carry upwards of 17 Amps momentary and 10 amps continuous, these were designed around heavy screw terminals inside the case.

Referencing Fig. 5, the output jacks are, from left to right: Gas solenoid output [+, -], Fuel Pump [+, -], Glow Plug [+, -], and 2 ea sets of cables for Battery In and Starter Motor connections.

Gas Solenoid: Pre-heating the fuel sticks and the combustion chamber with a flammable gas such as propane or butane starts the vast majority of model gas turbines. The ECU gas solenoid output allows the switching of this gas flow via software, allowing effortless, hands-free starts. I have tested several different gas solenoid valves; not all are suitable for propane. I recommend the purchase of the companion gas solenoid valve from 5 Bears, which has 2 pre-fitted 4mm "Festo" style push fittings and a check valve. If you want to use your own solenoid, be sure that it is capable of handling the pressure of the gas supply you wish to use. The solenoid valve *must* use a 5V coil for actuation.

Fuel Pump: The fuel pump is controlled by the ECU through this port, using 10-bit (1023 discrete steps) Pulse Width Modulation, or PWM output. A dedicated IC, controlled in turn by the ECU's microprocessor, drives the advanced MOSFET that energizes the pump. The circuitry is robust and very effective.

The ECU circuitry has been designed to power a Speed 280/300 style of fuel pump. However, it can handle any imaginable turbine pump based upon a small DC motor.

Glow Plug: A single glow plug can be attached here for starting purposes. The level of drive is set within the SETUP mode, and can range from cold, to incandescence, to a blown plug, so care must be taken in setting the drive. The positive lead is connected to the center post of the plug, and the ground lead is attached to any portion of the turbine provided that the path from the ground lead can reach the plug base. An ideal attachment point is underneath turbine mounting bolts.

Starter and Battery Cables: Out of the end of the ECU are two sets of power cables, one for battery input to the ECU, the other for powering your turbine's starter motor. The battery cable is identified by the red Dean's Ultra plug. The starter cable set is left unterminated for the connector of your choice. If desired, the ECU can be opened and the cables detached or replaced with cables of a custom length, as they are attached internally via a pair of quality terminal blocks. The cable is 22 gauge, ultra-limp stranded copper with a fuel-resistant silicone insulation. 22 gauge is more than adequate for these lines as their high amperage duty cycle is quite low. Normally, the battery cable will carry from 0.8 to 2.5 Amps with the pump running, and during start, they will conduct 10 amps with a Speed 300 starter motor, but only for the short time necessary to get the turbine started, and for post-run cooling "bursts" of the starter motor.

General Operation

This short description of the ECU's general operation is designed to orient you to the basic operation of the unit. It assumes that the ECU has been correctly programmed. See the programming section for a detailed description of this process.

To use the ECU, securely attach all external inputs and outputs to the ECU. Turn on the ECU with the slide switch on the bottom edge of the ECU case. The ECU will initialize and exercise its sensors, undergoing a BIT (Built-In-Test) check that must be passed before starting is authorized. If any of the required inputs fail the BIT check, the ECU will announce the fault and wait for the problem to be corrected. For example, if the thermocouple is faulty (or simply disconnected), an OPEN TC fault will be announced. Once all BIT checks are passed, READY will be announced, and the ECU is ready to start the turbine. To start, the throttle trim must first be fully up, (a closed throttle/trim low will prevent start and/or shut down the turbine if running), the throttle is advanced fully, priming the turbine, and the throttle retarded back to idle. Startup commences, with CRANK being annunciated. The starter motor spools the turbine slightly, and propane and glow plug drives are turned ON. Once propane lightoff is obtained, the starter re-engages, and start fuel ramping begins.

The ECU monitors EGT and RPM during start, and once RPM is near the pre-programmed Idle RPM value, the ECU shifts into an IDLE TRIM mode; the ECU allows the turbine to stabilize for a few seconds, then adjusts fuel minutely to obtain an accurate idle.

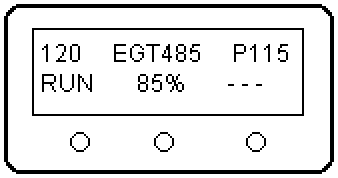
If this is the first run of this ECU/Turbine combination, the ECU announces MAX RUN. Max Run is designed to generate a high-throttle baseline for the fuel pump output. Fuel ramping when MAX RUN is annunciated is especially gentle. The ECU will remain in MAX RUN until you have commanded 100% throttle, and the turbine has reached its pre-programmed maximum RPM. The fuel pump output is saved to non-volatile EEPROM memory, and the turbine enters its normal RUN mode.

During RUN, the ECU monitors all inputs and keeps the turbine within safe parameters. It also records maximum RPM and EGT values, elapsed run time, and during shutdown, it records the spool-down time for bearing check between 18,000 and 2,000 RPM.

To shut the turbine down normally, the throttle must be in idle, and the throttle trim is then driven LOW. If the turbine is not at idle, it will be brought to idle for several seconds. Fuel is then cutoff, and the bearing timing and cool down cycle begins. If equipped with an electric starter, up to six brief "bursts" of the starter are used to cool the turbine to below 100 degrees C. If using an external air source for starting and cooling, allow the turbine to spin down to below 2,000 RPM before applying the cooling air, or the bearing spin down timing will not be accurate. After the turbine has cooled, recorded data may be read by pressing the ENTER button repeatedly. Another press of the ENTER button will display any faults the ECU recorded during flight.

The ECU power switch must be cycled to OFF, then ON again to run the turbine once more.

The LCD Display



The LCD Data Terminal is laid out as shown. There are three tactile buttons below the LCD bezel. The RIGHT button is the ENTER button. The left button DECREASES the value of the data during programming, and the middle button INCREASES the value of the data. See the programming section for more information on button functionality.

There are 2 lines of 16 characters each. The top line shows the current turbine RPM in thousands, the EGT, and the Pump output. Line two has an eight character run mode/fault enunciator, the commanded throttle setting as a percentage, and three characters showing the status of the **S**tarter motor, **I**gnition (Glow Plug) and **G**as (Propane). During start, the dashes are replaced with the appropriate characters when the given circuit is energized. For example, if line two of the LCD read

Crank 0% S - -

this indicates that the ECU has begun the starting process, and the starter motor has been turned ON. Other indications might include

Crank 0% -IG

indicating that the starter motor is de-energized, but the Ignition (glow) is ON, and the Gas (propane) is flowing in an attempt to achieve light off. To summarize: when the dashes (- - -) are replaced with SIG (**S**tarter, **I**gnition, **G**as) the given circuit is energized.

During normal turbine RUN, the display is updated roughly 3 to 4 times per second.

Programming the ECU

While the 5 Bears ECU was designed and primarily tested for the Wren MW-54 turbojet, it was also designed to run conceivably any turbojet available to the modeler. Unlike ECU's which are targeted for a single, specific turbine, with fixed RPM or EGT limits, the 5 Bears ECU has parameters which are "wide open", meaning that you, the end user, decide what parameters are suitable for your turbine. This makes it ideal for Kamps, KJ, and other experimental turbines, including those of your own design. *It also means that improper programming can result in destruction of the turbine, model, and/or injury or possibly death to you or bystanders!*

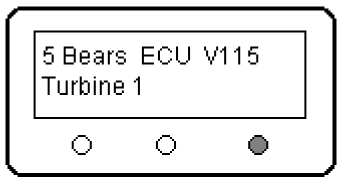
> I cannot overemphasize the necessity for proper, conservative programming of turbine parameters, especially RPM and EGT. Do **not** attempt to wring even one additional ounce of thrust out of a turbine design by exceeding the specified RPM and EGT parameters. Keep this hobby SAFE, have FUN, and do not risk turning what should be an exciting, rewarding hobby into a potential tragedy.
>
> To users with experimental turbines: start with extremely conservative parameters. If the calculated maximum RPM is 140,000, the turbine will run just fine during testing with a programmed maximum RPM of 120,000 while investigating running characteristics.
>
> The ECU is designed to keep the turbine within its programmed limits. Like any computerized device, its performance is defined by its input. It is a dumb device, and unable to decide that 155,000 RPM (entirely suitable for a properly built Wren MW-54) will **destroy** a Schreckling FD3 64.
>
> The user of this ECU **must** be **entirely familiar** with the general operation of his turbine, and know what parameters are necessary to keep the turbine and bystanders safe. If you are unfamiliar with operation of a turbojet, start with the designer of the turbine, and also investigate the Gas Turbine Builder's Association website at http://www.gtba.cnuce.cnr.it/

I realize the following list of programmable parameters seems large and complex, and in a sense it is. Many of these values I might have made as fixed, generic values inside the ECU code, but by making them variable to you, the user, performance is optimized for a wide variety of turbines. It might be tempting to attach the ECU, load a set of parameters, and go fly. I would like to discourage this practice, and instead encourage you to either bench run the turbine, or fix the aircraft in a firm cradle and become familiar with the ECU and turbine by running a couple of quarts of fuel through the turbine. This will allow you to become familiar with the ECU and determine programmable values that will work best for you.

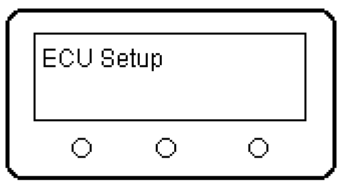
A quick note on setting idle RPM - Different turbines, even among the same type, have different idle characteristics. I would venture to say that the majority of model turbines have most of their "problems", such as roughness, high EGT, stalling, etc., at idle rather than mid and high throttle. Many model turbine operators seem to take a certain unwarranted pride in having an especially low idle RPM. Having flown USAF jet fighter aircraft and now transports like the MD-11 and B-777 for many happy years, may I make the following observations?

"Real" (meaning BIG) gas turbines used to move people and cargo usually have two separate idle settings programmed into their fuel control systems. The first is ground idle, and is the lower of the two values. Its purpose is to minimize thrust and fuel consumption during ground, or taxiing, operations, where long airport delays and the cost of brake components make this worthwhile. Inflight, when the throttles are retarded to idle, the engines trim to a higher RPM, called flight idle. A higher idle RPM is desirable from a safety and wear standpoint. Gas turbines at a low RPM have a high inertia, meaning that fuel additions tend to raise EGT rather than increase RPM, and fuel additions in this regime must be especially well programmed. Spool up can be frighteningly slow, and in an aborted landing, a slow spool up can be fatal. Therefore, I highly recommend as high an idle RPM setting as your model can tolerate. If your model is especially slick, you may need the lower thrust from an especially low RPM, but be prepared for slow spool up from this state. If you can use or add flight controls that are "draggy", like flaps or spoilers, this is an effective way to reduce the slickness of the airframe, allowing a higher idle setting. Remember that roughly 80% of a turbine's thrust comes from the final 40% of available RPM, so raising your programmed idle a small amount will have minimal impact upon the thrust the model “feels” when at idle.

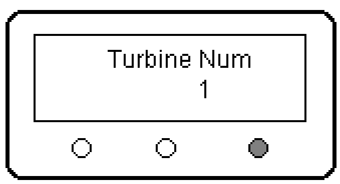
Now, on to programming the ECU!



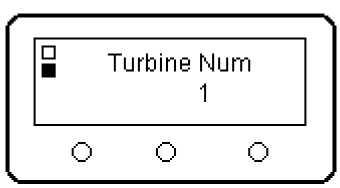
First, connect a battery and turn the power switch ON. While this screen is displayed, press and hold the Enter button, shown here as a dark button.



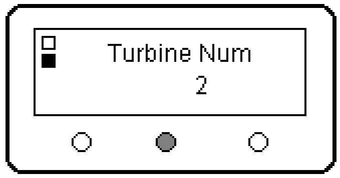
This shifts the ECU into its programming mode. The screen here is displayed briefly...



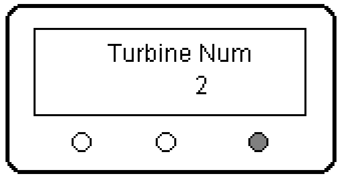
...followed by the opening page of the Setup mode. Each programmable data item is displayed as a separate page. Here, the page is telling us that the ECU is ready to program Turbine 1. The ECU can store complete data sets for 3 different turbines. Each turbine data set must be separately programmed. To change the Turbine Number, press the highlighted Enter button again.



The Enter button does two things with the ECU. First, it tells the ECU that you want to change the current data. After pressing Enter above, an animated widget appears, which consists of a small box that rapidly bounces up and down. This indicates that the displayed data may now be altered using the Increase (middle) and Decrease (left) buttons.



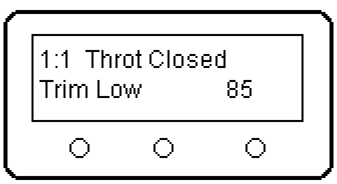
Pressing the Up button, shown here, changes the displayed Turbine Number from 1 to 2. Pressing and holding either the Up or Down buttons will rapidly scroll the value to the lower right. When you are happy with the data...



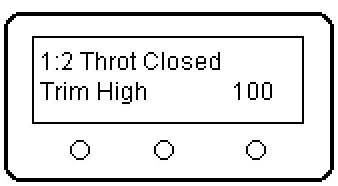
...pressing the Enter button once more stores the data into permanent memory, its second function. The animated widget disappears.

To summarize button functionality in Setup Mode: The Up and Down buttons page through the available data items. To change an item, press the Enter button. The display then animates with the widget, and the Up and Down buttons alter the data. Pressing Enter once more then stores the data. Whenever the widget is jumping, the Up and Down buttons change the displayed *data*. When no animation is present, the Up and Down buttons scroll through the data *pages.*

After the Turbine Number is selected, press the Up button. Page 1 is now displayed. Note the symbology in the upper left corner of the display - 1:1 The first digit indicates the Turbine Number being modified or viewed... the second indicates the data page number in question. For example, a 3:2 symbology indicates Turbine 3, Page 2.

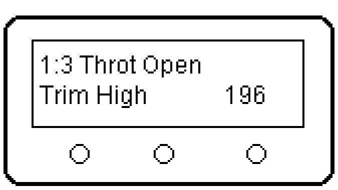


Page 1: Throttle Closed, Trim Low: Attach your R/C throttle cable to the R/C input port of the ECU, and turn on the transmitter and receiver. Press the Enter button to tell the ECU you want to alter the data. The animation widget appears. Now, movement of the throttle stick should change the number displayed. Once this is verified, close the throttle (stick fully aft), and run the throttle trim fully low. Press Enter once more to store the new value. Then, press the Up button to shift to page 2.



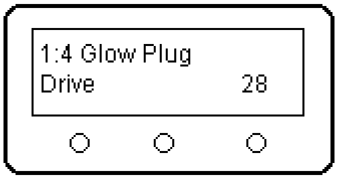
Page 2: Throttle Closed, Trim High: Again, press the Enter button to tell the ECU you wish to enter a new value. Be sure the R/C equipment is still properly attached and powered on. Close the throttle (stick fully aft), and run the throttle trim fully high. Press Enter once more to store the new value.

From this point on, I will describe each pages function rather than how to navigate using the buttons. You cannot hurt the ECU during programming. In the worst case, you will simply have to start over again by turning the ECU off, then on again. You also do not have to finish programming in one session... the ECU will retain all changes made, whether one page or sixteen.

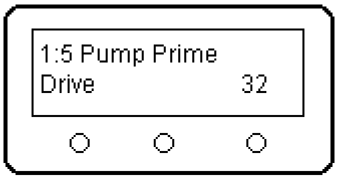


Page 3: Throttle Open, Trim High: Throttle fully open (forward) and throttle trim fully high. During flight, the throttle trim tab controls the turbine operation. If the trim is ever below mid-range and the throttle reduced to idle, the ECU will receive a shutdown signal, and initiate the shutdown procedure. Keeping the throttle trim high will allow the turbine to operate normally, from idle through max power.

Page 4: Glow Plug Drive: Plug the glow plug cable into the ECU. Attach the plug end into a loose glow plug of the same type you plan on using for ignition. Using an alligator clip or similar, attach the base of the glow plug to complete the circuit. Pressing enter will reinitialize the glow plug drive to 0. Pressing the Up button will start energizing the plug. Don't burn yourself! A typical plug will show a visible glow around 14, be quite bright around 30, and be probably burnt out much above 45. Increase the drive until the plug is glowing brightly, but not in danger of being burnt out. Press Enter to store the value and stop drive to the plug.

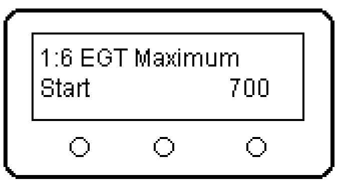


If you have ignition problems (no light off), try increasing the drive a unit or two until reliable ignition is realized.

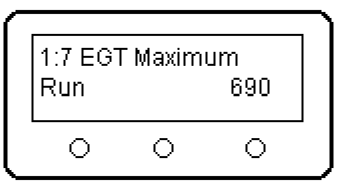


Page 5: Pump Prime Drive: Set up your turbine with a fuel supply and pump either in the model or in a position similar to the model on a test stand. Important considerations are the height of the fuel tank, pump, and turbine relative to each other. Press enter. The Pump Prime Drive reinitializes to 0. Pressing Increase will begin powering the pump.

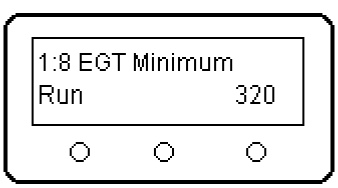
Continue to press increase until the fuel is *just moving* towards the turbine between the output port of the pump and the turbine fuel port. A buzzing or humming noise is common and harmless. If the fuel moves too quickly, press the Down button to reduce pump output. Press Enter to store the value and stop the pump.



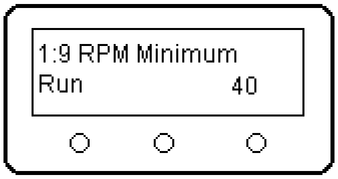
Page 6: EGT Maximum for Starting: The 5 Bears ECU allows two maximum EGT values, one for starting, the other for normal run operations. Press Enter, and use the Increase and Decrease buttons to change this value. The Max Start EGT increments by plus or minus 5 degrees Celsius. Press Enter once more to store the new value.



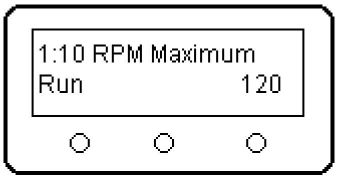
Page 7: EGT Maximum for Run: Press Enter and modify this value as desired, keeping the value at or below the turbine designer's stated maximum EGT. The Max Run increments by plus or minus 5 degrees Celsius. Press Enter once more to store the new value.



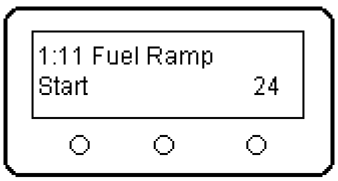
Page 8: EGT Minimum Run: This value determines the ECU's flameout detection threshold. During turbine deceleration profiles, fuel reductions become limited as this value is approached. If the EGT descends below this value, further fuel reductions are temporarily prohibited, and a *fault counter* begins to track how long the EGT remains below this value. If the EGT droop does not recover after a period of time, and the turbine's EGT continues to decay, the ECU will announce **FlameOut,** and the pump will be shut off. If, while below this value, the turbine's EGT begins to recover, the flameout out detection logic senses this trend and will delay shutdown. This value is critical for proper operation of your turbine, and must be set with caution and an understanding of what it does. The best way to set this is to bench-run your turbine with a lower value set, and experiment with some hard decelerations. Note the EGT during these decelerations, and if any flameouts do occur, take note of the EGT at that point. Set this value somewhat higher, retest the turbine, and be sure you have full authority with the throttle before risking the model in flight.



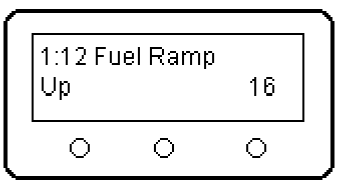
Page 9: RPM Minimum Run: This is your turbine's **idle** RPM. Enter the desired target in thousands. During start (and Run, when idle is commanded), the ECU will continually trim the pump output in an attempt to track this RPM. Please see my observations on Idle RPM earlier in this chapter. To summarize, a higher idle is preferable if your model can handle the thrust that such an idle will generate.



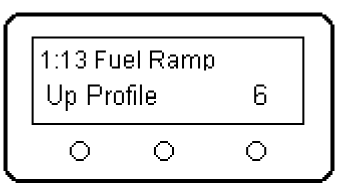
Page 10: RPM Maximum Run: Enter the absolute maximum RPM for the turbine. Derating your turbine for both safety and turbine longevity is a good idea. I personally limit my MW-54 (designer max. RPM of 160,000) to 154,000. The ECU does a good job in preventing overspeeds and aggressively reduces fuel flow upon overspeed detection, but a slight derate provides peace of mind and a bit of buffer in case of fuel injector or line failures, or other failures which can cause a sudden surge in fuel flow.



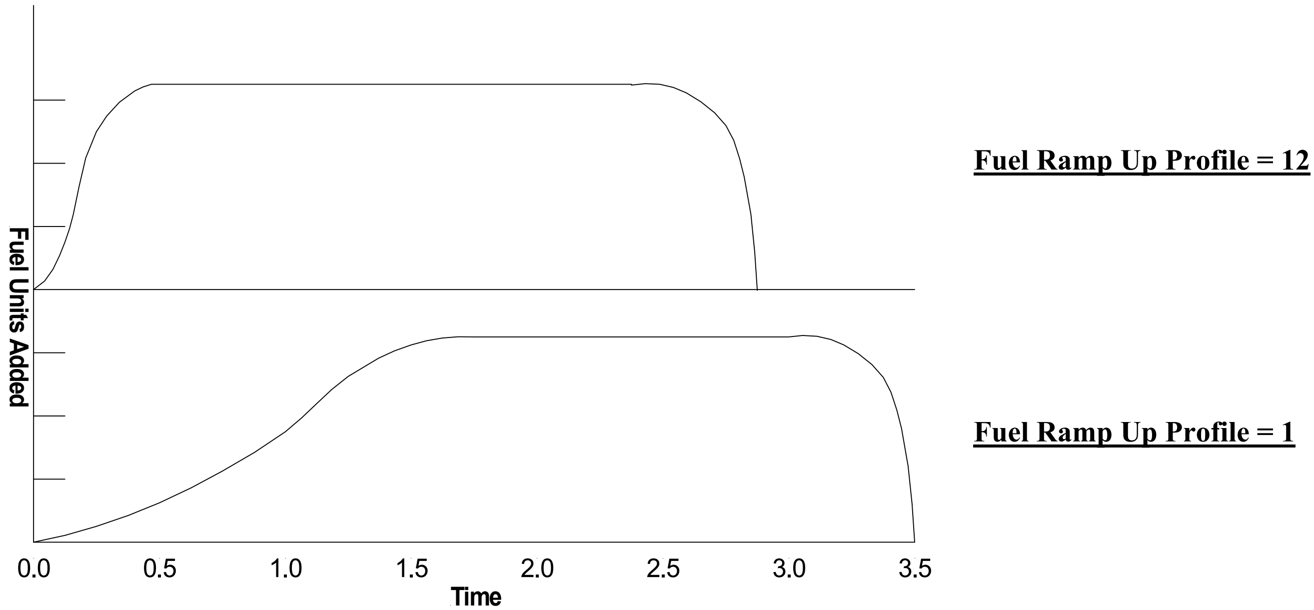
Page 11: Fuel Ramp Start determines how quickly fuel is added during the startup phase. A lower number results in faster, more aggressive fuel flow during startup. The ECU will automatically limit fuel flow as higher EGT's are generated during start, but it is impossible to avoid a hot start if fuel is injected too rapidly. This number will also vary due to fuel line plumbing and pump variations. The best way to determine a value that will work with your turbine is to initially try a higher number... if the turbine starts promptly, leave it alone. If the start seems especially protracted, reduce the number. A suggested number to begin with is 16.



Page 12: Fuel Ramp Up: Run Ramping, both upwards and downwards, is a complex process which determines throttle response. Any turbojet ECU faces formidable challenges in balancing crisp throttle response with turbine parameter limits, especially the EGT. For Fuel Ramp Up, a lower number results in faster, more aggressive increased throttle response in flight. The ECU will continually strive to keep parameters in limits, and will limit fuel additions if EGT climbs to higher levels, but if the ECU is constantly *limiting* fuel to prevent overtemps, the net result is *slower* throttle response. Optimum settings are often a matter of experimentation. Higher numbers will, at worst case, result in slower throttle response. The absolute fastest throttle response possible is when the EGT peaks during the ramp profile to approximately your maximum programmed run EGT minus 20 degrees. A suggested starting value for Fuel Ramp Up is 16. Below 12, the throttle response upwards becomes exponential, so use caution in this regime.



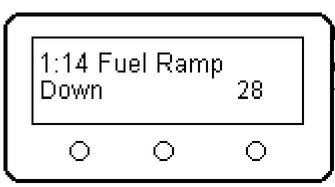
Page 13: Fuel Ramp Up Profile defines the shape of the fuel curve during accelerations. Accelerating a gas turbine from a stable RPM is a complex process when done in a manner that precludes EGT spiking, especially at low RPM. Some turbines require an initial, gentle fuel addition to force rotor acceleration without an EGT spike. Others are more tolerant of aggressive fueling. Allowable values here are from 1 to 12. Lower numbers force the ECU to be a bit gentler in the early stages of the profile. Higher numbers allow the ECU to be quite aggressive in accelerating the rotor from a static RPM. Please refer to the following graph for a detailed explanation of this baffling value!



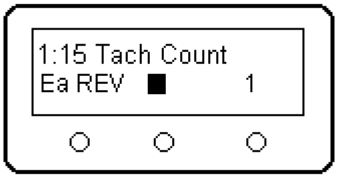
These curves roughly illustrate how fuel is delivered when accelerating from idle RPM to Max RPM. The vertical axis is the amount of fuel added as time passes to accelerate a turbine to max. The overall height of the curve is set with Pump Ramp Up. Pump Ramp Up defines how long the acceleration profile takes from a lower RPM to a higher RPM.

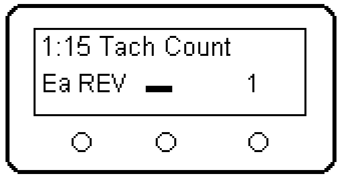
A simple way to view this effect is to note that with a lower number (bottom curve), the fuel required to accelerate the turbine to a given setting is <u>*back loaded,*</u> meaning the bulk of the fuel is delivered later in the profile. With a higher number (top curve), the fuel delivered is more evenly distributed across the time of the acceleration. Higher numbers create faster acceleration.

For initial tests, set this number at 3 or less. This value is one of three settings which can be changed during RUN by pressing the ENTER button to display the settings, the other two being Fuel Ramp Up, and Fuel Ramp Down. Try some modest accelerations from idle. If the turbine accelerates without running into the EGT limit defined by EGT Maximum Run, you may want to try a higher number. Optimum acceleration occurs with higher numbers, but *only if the ECU is not forced to limit fuel because of higher EGT values being generated.* If all of this seems baffling, the safest setting is 1.



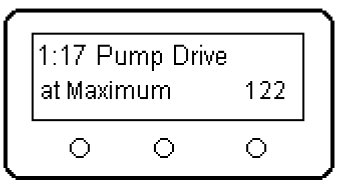
: The ramp profile when a lower throttle is commanded is also complex. The ECU will ut there are challenging factors that must be considered. The first is the thermal inertia probe made can instantaneously detect a lower temperature… there is a finite time lag Unfortunately, if the fire has gone out, the detection of the low EGT comes often too The second factor to consider is that different turbines tolerate reduced throttle bursts better than others, and there is no "magic" EGT number, such as 350 degrees, which will guarantee that the turbine will remain lit. **The best way to set this number is with experimental bench or static running**. Like Fuel Ramp Up, a *lower* number generates a *faster* response to your throttle commands. Start with 20, and try some sudden reduced throttle bursts from mid or high to idle. If the turbine does not reduce power quickly enough, try a lower number. Find the point where the turbine does not flame out, and you are happy with the response, then add 4 to the current value for safety. Fuel Ramp Down is closely tied to another SETUP page, EGT Minimum Run. Both combine to provide crisp downward throttle response with flameout protection. The fastest downward throttle response possible is when the EGT droops to no lower than your programmed EGT Minimum Run value + 20 degrees.





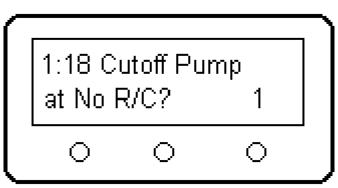
Page 15: Tachometer Count each Revolution: Some tachometers create 1 pulse per revolution of the turbine rotor, others additional pulses. Most Photo tach systems generate 2 pulses, while a Hall IC / magnet combination, or an inductive pickup, can create 1 or more pulses dependent upon magnet polarity and placement. On this page is displayed a tool to help you determine the number of pulses your tach system will generate. To the right of the REV text is a box, which expands upwards as the tach generates its “pulse”. To use the tool, rotate the turbine by hand in its normal direction, and halt rotation when the display transitions from the left illustration to the right illustration. Note the angular position of the rotor. A small spot of marker may help here. Continue to rotate the turbine wheel by hand through 360 degrees, and count the number of times the pulse box expands, as in the left illustration. Enter this number as your Tach Count ea REV. If the box does not transition, there is a fault in either the placement of the magnets or photodiode, the sensor itself has failed, or there is a problem with the ECU. *Do not run the turbine with a faulty tachometer!*

Page 16: Starter RPM Cutoff is the value that determines the RPM at which the starter motor is turned off during startup of the turbine. The value must be at least 5,000 RPM less than programmed Idle RPM.



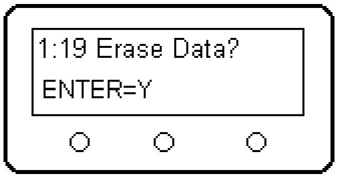
Page 17: Pump Drive at Max: During the first live running of the turbine/ECU combination, the turbine will undergo what is called a **Max Run**, a slow acceleration to the programmed Max RPM, to determine a valid pump output value at the “top end”. This value is automatically stored here for viewing by you. Subsequent flights will skip the Max Run as long as the ECU finds this value upon power up. It is dynamically modified during running of the turbine, and the value will change depending upon such factors as atmospheric pressure, fuel head pressure, and especially battery voltage. Being able to view the generated pump output number for max RPM is valuable to aid in trouble shooting.

Note that you cannot enter this value manually. It is set for you by the ECU. You can, however, enter a 0 to force the ECU to perform another Max Run during the next live turbine running. Reasons to do so might include drastic change in fuel line plumbing, addition of fuel restrictors or extra filters, or any time you want to recalibrate pump output. Note also that changing the Turbine’s Maximum RPM will automatically reset this value to “0”. It is also recommended that you perform another Max Run if you change the battery pack voltage from the previous run, although this is not essential to do.

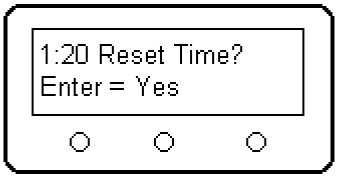


Page 18: Cutoff Pump At No R/C? This setting determines how the ECU will respond to the loss of a valid R/C throttle signal. Allowed settings are 1 or 0. If a 1 is entered here, the ECU *will shut off the pump and stop the turbine* if it detects an R/C failure. If a 0 is entered, the ECU will *bring the turbine to, and maintain, idle RPM.* It is your responsibility to program this setting so as to be in compliance with the rules governing turbine usage in your country. For example, in the U.K., the Gas Turbine Builder’s Association rules require the ECU to shut down the turbine with failure of R/C.

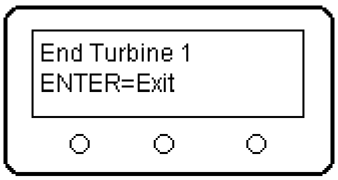
The ECU can detect loss of non-PCM equipped R/C signals. *If you are flying with PCM equipment, or have any sort of fail-safe radio, you* must *properly program the fail-safe to send the throttle channel the desired setting.* If you want the ECU to shut down the turbine, program the radio’s fail-safe to deliver a throttle low, trim low signal to the ECU. On the other hand, if you want the turbine to idle with loss of signal, have the fail-safe send to the ECU a throttle low, trim high signal.



Page 19: Erase Data? To erase all of the data for only the turbine being programmed, *press and hold* the ENTER button. The LCD display will show “Hold to Erase”. If you continue pressing the enter button for approximately 5 seconds, the data for the specific turbine set will be erased, and all values reset to 0. Releasing the button early will abort the erase procedure, and the data will be retained. If you erase data for Turbine 2, Turbines 1 and 3 will still retain their data.



Page 20: RESET TIME? The ECU will log all cumulative elapsed run time from start initiation to shutdown. This value will be displayed during the log view session. If you want to reset the elapsed time to zero, press and hold the enter button for 5 seconds. The time will be reset, and the ECU will reenter its normal program mode.



End Turbine 1: To exit the Setup mode, press Enter when you see this page. Either the Increase or Decrease buttons will continue to scroll through the data pages.

Once again, please remember that you cannot hurt the ECU during programming. Remember also that programming Pump Prime Drive and Glow Plug Drive are **live** in the sense that the appropriate circuits are energized. If you want to reset these values without energizing them, you may disconnect the appropriate cables from the ECU.

One last note on programming for your turbine – I have devoted many months to making the software inside the ECU as safe and as flexible as possible. Literally hundreds of revisions were tested both synthetically and live with my MW54 and Bill Blackburn’s KJ66. The reality and conclusion is this: the ECU will safely and effectively run your turbine, and will provide long service, but only if you, the user, take the time to work with these parameters by ground running of your pump, radio, and turbine. The only way an ECU can be considered “Plug and Play” is if the turbine, pump, and battery are precisely matched, and this defeats the purpose of an ECU such as this, which is designed for multiple turbines. DO NOT risk your model in flight without first becoming accustomed to the operation and programming of the ECU on the ground, and being satisfied that the values you have entered are safe, conservative, and effective!

Detailed Operation

This section will detail normal operation of the 5 Bears ECU. I will assume that you have programmed the ECU with some conservative values, and have essential equipment on hand. Think safety! Wear eye and ear protection, and always have a fire extinguisher ready.

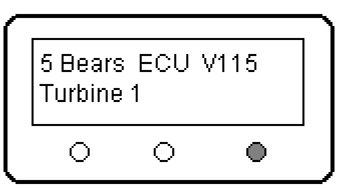
Preflight Preparation

Ensure all appropriate connections between the fuel system and the turbine are complete, and the fuel tank is filled with the correct fuel for your turbine. Fuel should be filtered, as a minimum, between both the external refueling supply, and also between your airplane's fuel system and the fuel pump inlet. Turbine pumps are spur gear pumps, which are positive displacement pumps capable of high pressure. They will have no problem pumping through normal R/C fuel filters.

ECU battery pack - Connect a 6 or 7-cell NiCd battery to the ECU. Absolute maximum battery voltage must not exceed 10 Volts. I recommend a 7-cell battery for autostarts using an electric starter motor such as the Speed-300. The capacity of the battery must be high enough to allow a start attempt or two, then power the turbine's fuel pump for the expected duration of the flight, with a comfortable margin of safety. Lengthy testing with my MW54 using an "Orbit" speed 280 pump has shown that a 1200 mAH pack is sufficient for 15 to 20 minutes of operation at typical flight power settings, with capacity to spare for both starting and cooling. I recommend battery packs with quality Sanyo cells for reliability.

Use a freshly charged battery for each flight! This is especially important for the very first live running of the turbine with the ECU, when pump settings are determined and stored for certain run settings. Don't risk your model for lack of an extra, freshly charged battery pack or two! If you plan on using multiple battery packs and swapping them out over an afternoon's flying, be sure they are of the same voltage and capacity, preferably several examples of the same brand and type of pack.

With the ECU power switch OFF, certain lines of the ECU remain hot, although current flow is negligible, well below 1 milliamp. For safety purposes, then, I recommend you disconnect the ECU battery when not in use.



Next, turn on the ECU - When you see this display, pressing Enter will shift the ECU into its programming mode. Since the ECU is programmed, simply wait for its built-in-test to complete. The last Turbine Number selected during programming will be the turbine in use. For example, if you loaded a set of data into Turbine 3, and exited Setup from that data set, then Turbine 3 will be the data set the ECU uses. If you want to use a different turbine set, press Enter, select the turbine number you want, and then Exit the setup. The ECU will reinitialize, displaying this screen, and then enter the flight mode.

BIT Check - During its BIT (Built-in-test) check, the ECU looks for inputs that will permit a start. It loads the turbine data from its non-volatile memory, and does a simple validation to be sure the data has no obvious inconsistencies. It also looks for the following valid signals:

- An operating R/C throttle channel signal
- Throttle at idle and throttle trim fully forward
- Thermocouple (EGT) probe plugged in and working

- EGT is below 100 degrees C
- Battery voltage is above 7.00 VDC

Once these requirements are met, the ECU announces READY, indicating that the ECU is prepared to start the turbine. Otherwise it will tell you of the problem and allow you to correct it. See the Faults section for detailed explanations of these pre-start problems.

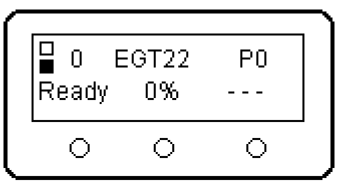
Once READY is annunciated, the EGT probe should show the current ambient temperature, which might be a bit higher on a hot day or if the probe is enclosed in a hot fuselage environment. The animated widget bounces up and down to let you know the ECU is operating and scanning its inputs. Throttle input should read 0%

A note on throttle position: It is possible to "trick" the ECU into the prestart *throttle low, trim high* state by having the throttle stick very slightly forward with the trim low. When start is initiated and the throttle retarded to idle with the trim in its *low* position, the turbine will be shutdown. Always remember to check and be sure the throttle stick is fully aft. In this state, the ECU will recognize the trim low condition and prohibit start.

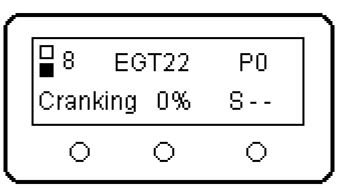
Turbine Startup

For the following examples of a normal startup and run of the ECU, I have programmed it for an Idle RPM of 40,000, a Max RPM of 110,000, and a Starter Cutoff of 30,000. The LCD shows what the ECU will display during the various phases of startup, run, and shutdown.

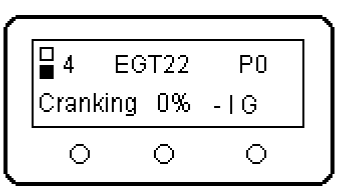
Electric Starter



Open the throttle (stick fully forward) and hold there for a few seconds. The turbine primes itself by briefly advancing the fuel, avoiding air bubbles and pump cavitation. Retard the throttle to idle when priming is completed. Start is now initiated.

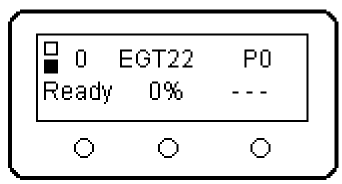


The electric starter has spun the turbine up to 8,000 RPM. Note the S— annunciation, telling you that the starter motor is energized, but neither **I**gnition nor **G**as are yet on. The starter motor will cut out after ¾ of a second of rotation

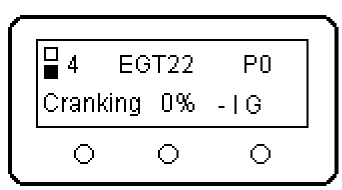


The starter motor has deenergized, and the turbine is decelerating. Ignition and Gas are both switched on in an attempt to obtain propane ignition.

Air Start

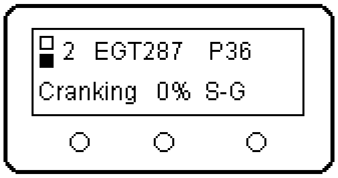


Leave the throttle in idle. Prime, if necessary, by pressing and holding the UP and DOWN buttons simultaneously. Release the buttons. Apply the air to the inlet of the turbine. The rotor should begin to spool up.



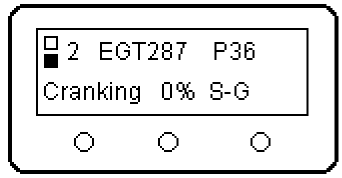
When the ECU senses 3,000 RPM or greater, it will turn on the ignition and the gas, and await propane lightoff. You should remove air when

If the RPM decays to zero without a lightoff, the starter motor will pulse the rotor again for another attempt. It will make 3 such attempts before aborting the start.



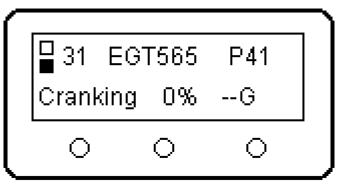
The propane is ignited! Note the EGT rise. Upon detection of successful ignition of the propane, the **I**gnition source is cutoff. **G**as remains on. The ECU re-engages the starter motor. Note the **S**tarter annunciation. The Pump is energized at Pump Prime + 3 units. Here, RPM = 2,000, EGT 287, Pump = 36.

the **SIG** annunciation reads **IG**, indicating **I**gnition and **G**as are ON. Annunciations here indicate 4,000 RPM, Ignition and gas are on, EGT = 22 degrees (no lightoff yet), and pump still at zero.



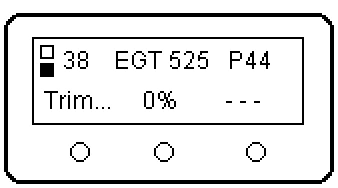
The propane is ignited! Note the EGT rise. Upon detection of successful ignition of the propane, the **I**gnition source is cutoff. **G**as remains on. The ECU Annunciates **S** to tell you to reapply start air. The Pump is energized at Pump Prime + 3 units. Here, RPM = 2,000, EGT 287, Pump = 36.

Note that the displays for both air and electric starts are almost identical. When you use an air source rather than a starter motor, all you are doing is replacing the electric motor with the air source. Typically, you will want to remove starting air when the RPM is at roughly idle RPM minus 4 or 6 thousand, or when you see **Trim…** annunciated, indicating that the ECU is entering its Idle Trim phase. From this point on, the displays (and actions) are identical for both electric and air starting.



As soon as the propane ignition is confirmed, the ECU begins a controlled introduction of the liquid fuel, and tracks EGT and RPM right up to idle. If electrically starting, the starter circuitry will cutoff when the RPM reaches the preprogrammed Starter Cutoff RPM. If air starting, remove the air at approximately Idle RPM minus 3 or 4 thousand. Overshoots (sometimes large) of idle RPM during air starts are common and no cause for concern. The turbine is now started!

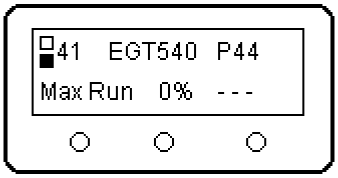
Idle Trim



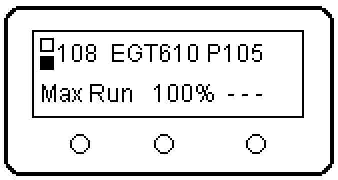
Upon reaching Idle RPM - 2000, the ECU enters its Idle Trim mode. Starter, Ignition, and Gas circuits are verified off, and the fuel pump controller enters a very fine 10-bit pump drive mode to trim the turbine to its programmed idle RPM. Acceptable values are programmed Idle RPM plus 3,000, minus 2,000. This allowable idle RPM "envelope" keeps the ECU from constantly hunting for a perfect Idle RPM and makes for a smooth, happy idle. Annunciations: RPM = 38, EGT = 525, Pump = 44. Trim operation underway, throttle at 0%, and SIG (Starter, Ignition, Gas) are all off. Do not manipulate the throttle at any point during the start phase! The turbine may be shut down at any point if desired by driving the throttle trim low. Idle trim usually takes around 7 to 10 seconds to accomplish.

Max Run

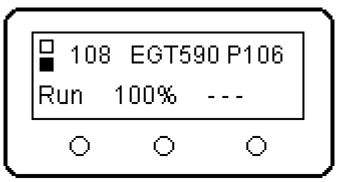
The Max Run only occurs if the ECU detects that this is the first live running of the turbine; or it finds a zero value on page 17 of SETUP; otherwise, it is skipped.



The Max Run is the only "hot" programming done for the ECU. Its purpose is to create a fuel pump mapping, telling the ECU what approximate pump drive level is required to allow the turbine to approach its programmed maximum RPM. This *must* be done at least once, and the model should *not* be flown until it is complete. Secure the model, stay clear of exhaust and rotational planes, and apply full throttle. *There will be no acceleration of the turbine until the throttle reaches 100%.*

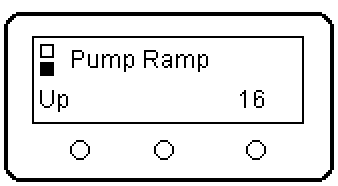


The ECU will command a gentle acceleration. As the turbine accelerates, it will sense your programmed Max RPM and halt acceleration at that point. During the Max Run, if you wish to halt acceleration, simply move the throttle to midrange. The turbine will stabilize at an intermediate RPM. If you wish to continue the Max Run, return the throttle to 100%. If, at any time you wish to idle the turbine, simply retard the throttle to idle, or 0%



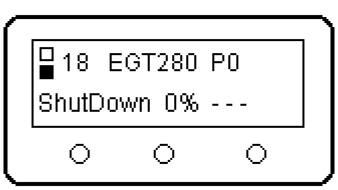
Once Max RPM is reached, the ECU will announce RUN and you will have full, normal control of your turbine. Time for the Max Run will vary, but is roughly 10 to 15 seconds. Full envelope protection is provided, and any faults encountered will be handled by the ECU. Now, retard the throttle and go fly! In the Run mode, any time either 0% or 100% throttle is commanded, the ECU trims the turbine to maintain the appropriate RPM.

Adjustment of Pump Ramps During Run



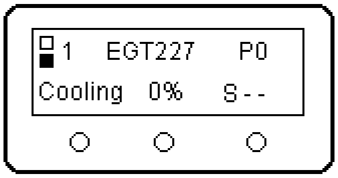
Any time Run is annunciated, three of the programmable values may be altered "live", while the turbine is running. These are the Pump Ramp Up, Pump Ramp Up Profile, and Pump Ramp Down values. To access these, press the enter button once. Pump Ramp Up is displayed, and the current value shown. Press the up or down buttons to adjust the value; pressing enter again will shift to the Pump Ramp Up Profile page. Adjust this value to your liking. One more press of Enter will display the current Pump Ramp Down setting, allowing adjustment and testing. The last press of ENTER returns the display to the normal RUN mode. During parameter adjustments, the ECU will continue to track all important turbine parameters, and will provide normal protection for the turbine. Changes to the values are immediately effective.

Normal Shutdown



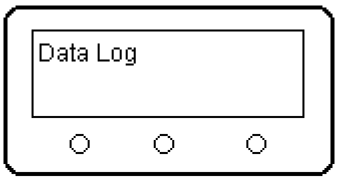
After your jet has landed, taxi back to the pad and shut the turbine down by reducing the throttle to idle and run the throttle trim fully aft. The ECU will hold idle for a few seconds, and it will then shutoff the fuel. Here, the ECU has detected the user Shutdown signal that is now annunciated on the LCD. The pump is off, and the RPM is in the process of decaying through 18,000. EGT from the still hot turbine is 280. Between 18,000 and 2,000 RPM, the time for the spool down (bearing check) is recorded.

Cooling

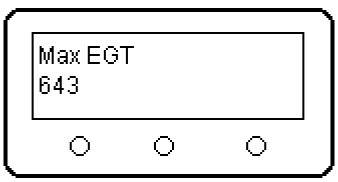


If equipped with a starter motor, the turbine will initiate self-cooling at 1,000 RPM. The starter motor will pulse briefly, spinning the rotor back up to ~ 7,000 RPM, while it tracks the EGT. Note the **S--** indicating the starter motor is energized. If you are using external air to start and cool your turbine, have it available for shutdown. For accurate timing of the bearing spin down check, wait until the RPM has decayed below 2,000 and Cooling is annunciated. Then, apply the air and allow EGT to cool to your desired target. For electric starter motor cooling, the cooling cycle is complete when the EGT is below 100 degrees Celsius, or six "squirts" of the turbine with the starting motor have been accomplished.

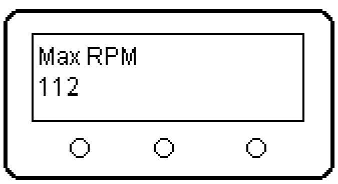
Data Log



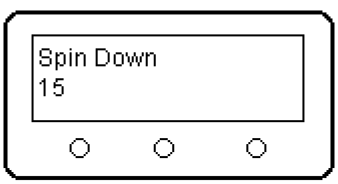
After the cooling cycle is complete, the ECU will display a screen similar to the **Normal Shutdown** LCD display shown above. Press the Enter button to view the data log. This screen is briefly displayed...



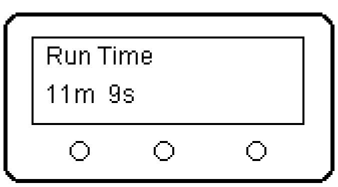
...and then the first data log page becomes visible. Pressing Enter repeatedly will page through the data. No modifications are permitted; the Up and Down buttons are inactive. The first page shows the Maximum EGT encountered during both startup and running of the turbine.



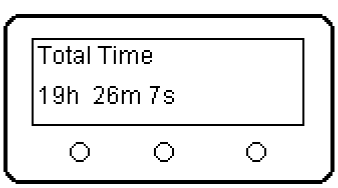
The second page of logged data is the Maximum RPM.



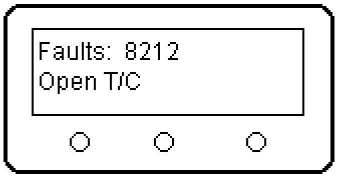
The third page shows the bearing spin-down timing value that the ECU recorded between 18,000 and 2,000 RPM. The actual time is not critical, and will vary widely between turbine types. New bearings should show consistent spin-down times for many runs. If the time suddenly decreases, it may be a sign of bearing wear. It is good practice to record both spin-down time and run time, shown next, in a log book.



The fourth page of the data log displays the Run time, from initiation of start to shutdown. The display format is in minutes and seconds.



The final log page is the elapsed, total time for the turbine. This cumulative includes *all* of the turbine sets. If you wish to track elapsed times for separate turbine sets, it must be done manually.



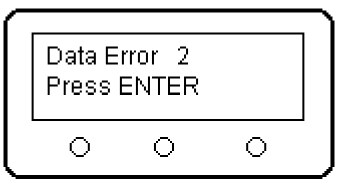
Finally, after all the logged data has been displayed, pressing Enter will reveal any faults encountered during the run. If there is any question as to the faults revealed, make a note of the number to the right of the Faults: annunciation, for reporting to me at 5 Bears Engineering. Here, the ECU has reported an Open T/C, or open thermocouple error. See the Errors section for more detail. Pressing Enter one last time will return you to the normal ShutDown display. The ECU must be reinitialized from this state by cycling the ECU power off, then on.

Errors and Faults

No one likes them, but they are unavoidable if you fly a turbine for any length of time. Even the finest turbines, sensors, fuel systems, and pumps, eventually succumb to wear. What we can do is minimize their impact, and recover our model free of damage.

There are two varieties of faults which the ECU deals with - the first are *data errors*, which are trappable errors in programming the ECU and are simple to correct, and *run faults*, potential problems which can crop up in flight and are far more serious in nature.

Data Errors: When the ECU is first powered, it retrieves the data needed to run the turbine from non-volatile memory. Non-volatile (EEPROM) memory is storage space on the processor that is retained when the battery power is removed. It is also where the data you create during programming is stored. The ECU then validates the data, checking for missing values and obvious inconsistencies. Any problems detected are displayed as a simple number rather than a text description. While not as user friendly, this saves memory space inside the ECU for more important coding!



What you will see: After power up, or when you have exited a programming session, the ECU has detected a data error. The screen here is displayed, informing you of the error, and prompting you to press the ENTER button. After looking up the error here in the manual, press the enter button, and the ECU will enter the programming mode, allowing you to correct the error.

Data Error 1 - Throttle signal values are not properly ordered.
The throttle channel of your receiver normally tells the throttle servo which position to assume by varying the width of the pulse. During programming, you are prompted to enter three values:

1. Throttle low, trim low
2. Throttle low, trim high
3. Throttle high, trim high

Depending upon the servo direction of your radio, the values of these signals may go from low to high, or high to low. The ECU can accommodate either direction, but the Throttle Low, Trim High signal value must be between the other two.

To Correct: Re-enter the three values, being sure you have the controls on your transmitter correctly positioned. See LCD Data Pages 1, 2, and 3 in the programming section.

Data Error 2 - Starter Cutoff value is too high.
The RPM value for starter motor cutoff must be at least 5,000 less than idle RPM.
To Correct: Enter a starter cutoff RPM value which is less than the programmed Idle RPM – 5,000.

Data Error 3 - Missing either Idle RPM or Max RPM values.
The ECU has found a value of 0 for either the Idle RPM setting or the Max RPM setting.
To Correct: Enter reasonable values for Idle RPM and Max RPM. The ECU does no validation beyond checking for a non-zero value! If you enter a ridiculous Max RPM of 3,000, and an idle RPM of 2,000, the ECU will accept this, with predictably poor results.

Data Error 4 - Idle RPM value is greater than Max RPM.
To Correct: Check your settings as above for Idle RPM and Max RPM, being sure that the Idle RPM is less than the Max RPM.

Data Error 5 - Missing Pump Prime Drive value.
A zero value has been found.
To Correct: Enter a value for the Pump Prime Drive.

Data Error 6 - Missing Glow Plug Drive value.
A zero value has been found.
To Correct: Enter a value for the Glow Plug Drive.

Data Error 7 - Missing Max EGT Start, Max EGT Run, or Min EGT Run.
The ECU has found a value of 0 for any of the above programmable settings.
To Correct: Enter appropriate values. Again, the ECU does no validation beyond checking for a non-zero value!

Data Error 8 - Starting Pump Ramp = 0
To Correct: Enter a value for Fuel Ramp Start.

Data Error 9 - Run Pump Ramp Up = 0
To Correct: Enter a value for Fuel Ramp Up.

Data Error 10 - Run Pump Ramp Down = 0
To Correct: Enter a value for Fuel Ramp Down.

Data Error 11 – Tach Count Each Rev = 0.
To Correct: Enter a value for Tachometer Count each Revolution setting.

Run Faults - With the exception of fuel ramping, no portion of the ECU coding process took as much time and thought as fault handling. Run Faults are those parameter errors and hardware failures which occur during otherwise normal operation of the turbine. Many of the other ECU's available to the turbine enthusiast have one solution for a run fault... shut down! The only problem with this is that your precious model now becomes a lead sled, especially the scale birds with high wing loading, making safe recovery very difficult indeed.

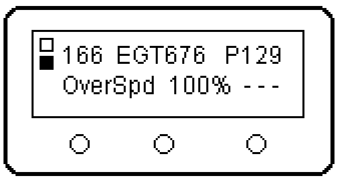
The 5 Bears ECU will shut the turbine down only as a very last resort. Most faults result in what is called a *Throttle Limit*, whereby the ECU limits available throttle movement, often with accompanying gentle fuel ramping. The faults must also be persistent and repetitive, meaning the fault must continue over a number of scanning cycles before it is identified as a true fault. For example, the ECU can determine the integrity of the thermocouple loop, and can tell when the loop fails, but it is identified as an Open TC only after several scans do in fact confirm this.

Most faults may be self-correcting. If the ECU identifies a problem and limits throttle movement, and the problem resolves itself (perhaps a sticky or intermittent pin contact), the ECU will restore full throttle authority to you.

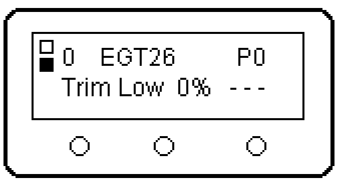
Additionally, the ECU can detect and handle multiple faults simultaneously, with the most serious being resolved before the less serious.

Faults are logged inflight, and may be viewed by pressing the Enter button after the turbine is shut down and cooled. Remember that pressing Enter post flight will display first the logged data; then, if there are any recorded faults, these are displayed next.

The detected faults fall into 3 categories, pre-start, startup, or flight faults, with some being detected in more than one of these situations. The ECU will prohibit startup with any pre-start faults detected. The usual cause of a prestart fault is a cable not being plugged in. The ECU is considered in flight if the ECU has started the turbine successfully. If, during actual flight, you notice either a limited throttle output from your turbine, or especially sluggish throttle response, it means that the ECU has detected a fault and has limited the turbine in some fashion**. Land the aircraft as soon as you notice this and investigate both logged faults and the turbine log for clues to the problem!**



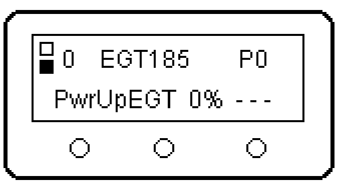
What you will see: If you have the LCD attached and are bench running, the lower line RUN mode is replaced with the fault detected. If there is more than one fault active, the most serious fault is displayed. Here, the ECU has detected a rather severe overspeed of 166,000 RPM. If the LCD display shows a fault, it is an indication that the ECU is, in fact, handling the fault.



Trim Low **Fault category: Prestart**

The ECU recognizes that the throttle trim tab is not fully forward.

Correction: Be sure the throttle stick is fully aft and run the throttle trim all the way forward.

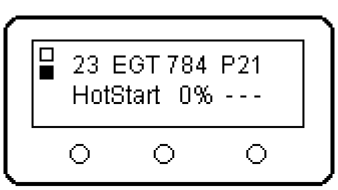


PwrUpEGT **Fault Category: Prestart**

Power Up EGT - The measured EGT is greater than 100 degrees Celsius when the ECU is turned on.

Correction: This fault can occur in two different circumstances... the normal occurrence is when the ECU power is cycled OFF/ON to reinitialize, and the turbine is still fairly hot from radiant thermal energy inside a closed fuselage. Wait until the EGT is less than 100 before starting the turbine... the ECU will inhibit start in any case with PwrUpEGT annunciated.

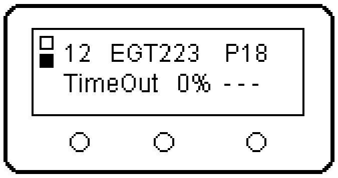
The other occurrence is more serious, and is the result of an inflight power interruption, or brownout, to the ECU. As soon as power to the ECU is interrupted, then restored, the ECU cannot tell if it is inflight or not, and simply starts its normal initialization process. Of course, if the model is inflight, the pump has already quit due to the brownout, and the model is now a glider. Thermal if you can! I stress this latter occurrence as a pitch for using fresh, high capacity, reliable NiCd batteries to power the ECU!



HotStart **Fault Category: Startup**

The ECU has detected that the EGT during startup has exceeded the programmed limit set with EGT Max for Starting.

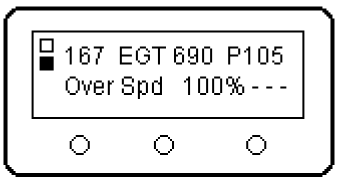
Correction: The ECU will abort the start and initiate cooling, if necessary. Most hot starts result from improper priming of the turbine. Any ECU has a difficult task in getting fuel to the turbine during startup in a smooth and proper manner if the fuel line is full of air! The pump must not be cavitating (trying to pump air) for cool, successful starts. Ideally, the fuel lines will be primed all the way to the turbine itself. Excess priming can result in a hot start as well, as the raw fuel dumped into the combustion chamber ignites.



Time Out **Fault Category: Startup**

A function that should have been accomplished has, for some reason, timed out.

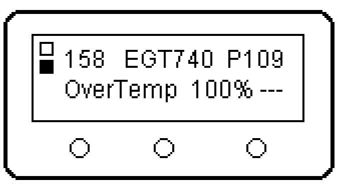
Correction: Time Outs occur during startup and are used to prevent the ECU from indefinitely trying to accomplish some function. When crank is annunciated, the ECU begins to track the time taken to achieve idle RPM. If excessive, the ECU aborts the start. One other occurrence of Time Out may happen during the Idle Trim mode, when the turbine is trimming its fuel pump output for a stable RPM. If the ECU times out during Idle Trim, the ECU will progress to the normal RUN mode if the noted RPM is above idle. If the RPM is well below idle, the ECU will abort. Timeouts are rare but needed, as it is very uncomfortable to watch a starter motor grind away indefinitely due to a blocked fuel line or cavitating pump!



Over Speed **Fault Category: Flight**

Over Speed - The turbine has exceeded the programmed limit set with RPM Maximum Run

Correction: The ECU handles an over speed in a very similar fashion to over temp (as both usually have their roots in excessive fuel flow) except it will shut the turbine down sooner than an overtemp, as an overspeed fault is quite urgent and must be corrected quickly. Upon the first detection of an over speed, the ECU will immediately begin a programmed fuel reduction to no lower than the last idle pump setting, or until the over speed is corrected. If several consecutive scans show a continuing over speed condition, the ECU will shut down the turbine. Experience has shown that the ECU's immediate fuel reduction normally solves the problem, and will allow normal operation subsequently.

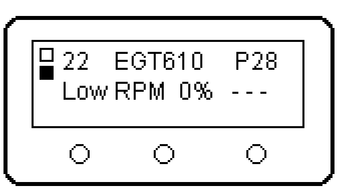


OverTemp **Fault Category: Flight**

The ECU has detected that the EGT during flight has exceeded the programmed limit set with EGT Max for Running.

Correction: Overtemps inflight can range from minor and temporary low RPM deviations to more serious circumstances, such as a turbine at near maximum RPM, where the stresses of an overtemp can be catastrophic. Upon the first detection of an overtemp, the ECU will immediately begin a programmed fuel reduction to no lower than idle, or until the overtemp is corrected. If several consecutive scans show a continuing overtemp condition, the ECU will shut down the turbine. Since the ECU scans at the rate of ~ 3 per second, this will take as long as 5 to 8 seconds to actually terminate the fuel pump's output. While this seems quite long, actual experience during testing has shown that the ECU's immediate action in reducing fuel will quickly fix this problem as long as the turbine is mechanically sound.

If the turbine has an internal malfunction like a blown fuel line or injector needle, the immediate fuel reduction may not solve the problem, and the turbine will probably be shut down. I chose this "delayed" action as opposed to an immediate, unconditional shutdown, as the vast majority of EGT excursions are not mechanical, and the problem will normally be resolved by the ECU. This, of course, will allow you to recover the model under power.



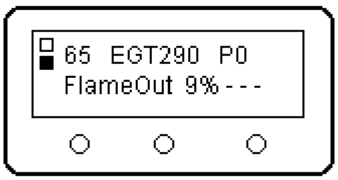
Low RPM **Fault Category: Flight**

Inflight, the ECU has detected a valid RPM reading less than programmed Idle RPM minus 5,000.

Correction: First, the ECU ensures that the Low RPM fault is not the result of a bad tachometer signal. If in fact the tachometer is operating, it begins adding fuel in a controlled fashion, attempting to restore the turbine to idle RPM.

A flame out fault will also trigger a Low RPM fault, but since there are other clues that a flame out has occurred, such as EGT, the flame out fault handling will take priority and properly shut off the fuel pump.

If the Low RPM fault occurs in addition to an Open T/C fault, the turbine will be shutdown... without a valid EGT measurement, Low RPM is the only indication of a flameout.



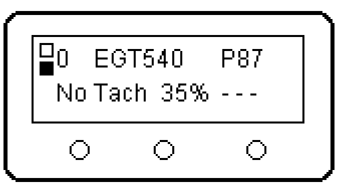
FlameOut **Fault Category: Startup / Flight**

The turbine has flamed out - there is no combustion of propane (startup) or kerosene (flight). During startup, while burning only propane, the ECU annunciates this fault if the EGT drops below a dynamically calculated propane lightoff temperature, which is close to ambient + 20 degrees C.

Inflight, flameout logic is considerably more complex. During deceleration profiles, your programmed **EGT Minimum RUN** value forms a baseline for fuel reduction. As the EGT droops towards this value, reduction of fuel becomes increasingly inhibited; below this EGT value, fuel reductions are *prohibited,* and the ECU then begins to track the trend of the EGT. If rising, further flameout logic is delayed, as this is an indication that the turbine is recovering. However, if the EGT continues to decay, after 20 scans the ECU will shut off the pump and announce FlameOut. A clue that this dreaded fault has taken place is a brief stream of unburnt fuel being ejected from the model as a white smoke.

Correction, Startup: The ECU will abort the start and initiate cooling, if necessary.

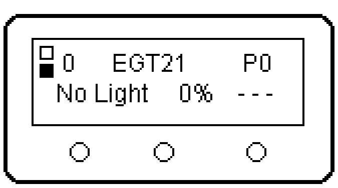
Correction, Flight: The ECU cannot correct a flameout, and all that remains for the ECU to do is shut down the fuel pump and initiate cooling. Your job is to recover the now powerless model.



No Tach **Fault category: Flight**

Either the RPM (tachometer) sensor has failed, or the turbine is in fact at 0 RPM. The ECU, due to rounding errors, considers anything less than 500 RPM to be 0 RPM.

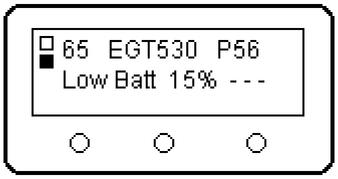
Correction: A No Tach fault usually means a failed tachometer, as a true flameout can be detected by examining EGT. If the ECU determines that the turbine is running fine (normal EGT), but the tachometer reads 0, the ECU will limit throttle movement to no greater than 40% throttle. Since the ECU cannot detect the RPM to trim for idle when so commanded by the pilot, it uses the last known pump setting for idle. Land as soon as possible.



No Light **Fault Category: Startup**

No Lightoff – During start, the RPM has decayed to zero with both glow and gas available.

Correction: During Motor Starts, the starter will automatically attempt another spoolup / spooldown cycle (seeking propane ignition) up to 3 times. If the propane is not ignited after the third attempt, the ECU will abort the start and present this fault. If airstarting, allowing the RPM to decay to 0 will also display this fault. To avoid it, if the propane hasn't ignited by 1,000 RPM, apply the air once more to spin the rotor back up, and then allow it to coast once more while awaiting ignition.



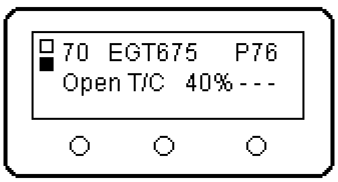
Low Batt   **Fault Category: Prestart / Startup / Flight**

Low Battery - The ECU has detected a weak battery. A battery voltage of less than 7.0 V. will inhibit starting. Inflight, a battery voltage below 6.6V will activate this fault.

Correction, Prestart: Replace the battery.

Correction, Startup: The ECU will abort the start and initiate cooling, if necessary.

Correction, Flight: The ECU limits the throttle to 50%. A typical "Speed" 280/300 fuel pump like the Orbit pump will draw about 0.8 ampere at 50% throttle, with significantly higher current above this. Again, land as soon as possible with an obvious throttle limit inflight.



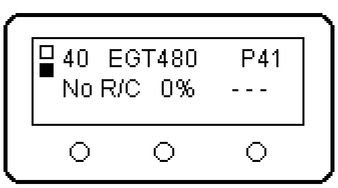
Open T/C   **Fault category: Prestart / Startup / Flight**

The EGT probe (Thermocouple) loop has failed; the circuit is not continuous and no valid EGT is available.

Correction, Prestart: Be sure the thermocouple is plugged into the ECU.

Correction, Startup: The ECU will abort the start. Since it cannot detect EGT, the ECU will not initiate its own cooling procedure.

Correction, Flight: The throttle command is limited to 60%. *The EGT is internally (and artificially) set to your programmed EGT Max Run minus 25 degrees*. This "tricks" the ECU into being especially gentle with fuel additions, keeping actual turbine temperature hopefully within parameters. If the Low RPM fault occurs in addition to an Open T/C fault, the turbine will be shutdown. Without a valid EGT measurement, Low RPM is the only indication of a flameout.



No R/C   **Fault category: Prestart / Startup / Flight**

The ECU cannot detect a valid throttle channel signal from your receiver. A valid throttle signal is defined as a set of pulses that falls within the range entered by you during throttle channel programming. With PPM (non-fail-safe) radios, loss of transmitter signal or interference can cause the receiver to output invalid signals. These are detected by the ECU. The ECU will maintain the last throttle setting and wait a very short (0.5 seconds) period of time. If the signal is restored, no action is taken. If the invalid signal continues, this fault will be triggered. With PCM radios (fail-safe equipped), by definition, the receiver verifies the quality of the signal, and if it is degraded, will output a throttle signal appropriate for your fail-safe setup. In this case, the ECU simply responds to the throttle signal… it cannot tell that the R/C receiver has entered fail-safe. The last possibility is total lack of a throttle signal from the receiver. This too will trigger this fault.

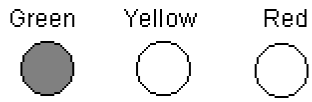
Correction, Prestart: Be sure your RC system is plugged in correctly, is turned on with a fresh battery, and the transmitter is on as well.

Correction, Startup: The ECU will abort the start and initiate cooling, if necessary.

Correction, Flight: It is very difficult to interpret exactly what is happening within the R/C system when throttle channel signal is absent or erratic. This fault will *only* be annunciated if the throttle signal pulses are outside the normal range as established during programming of the ECU. If your system is encountering interference, different signals may be generated by the receiver which may cause odd behavior. If the ECU has determined that the throttle channel signal is aberrant, it will wait for a very short period of time to see if the signal may be recovered. If not, it will display No R/C, and then either execute a shutdown of the turbine, or bring the turbine back to idle and hold it there. Which behavior to follow is determined by you during setup, page 18, *Cutoff Pump at No R/C?*

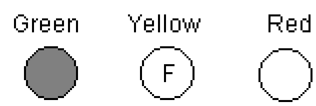
Interference, PCM (Fail-safe) Radios: You *must* follow the rules of the governing body for your flying location. If the rules require shutdown of a turbine with loss of R/C signal, then you must program your transmitter/receiver to deliver a *throttle low, trim low* condition for fail-safe actuation. This will shut the turbine down if in fact the model enters fail-safe.

The LED Module

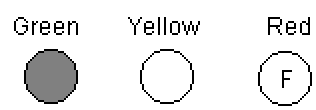


While the normal LCD display provides a wealth of information and is easy to use, I realize that many will want to fly without the extra bulk and weight onboard their jet. To make this possible, I have developed a small, lightweight LED module which is a direct, plug-in replacement for the LCD display. The LED module consists of three LED's (Light Emitting Diodes) mounted on a small board along with supporting components. The LED's are colored *Green, Amber*, and *Red*. Enough information is displayed to allow you to start and fly your turbine with confidence. One real benefit is the fact that the LED module is not integral with the ECU, but is connected with a length of cable. This allows the LED module to be positioned in a visible location, such as inside a canopy or beneath a likely access panel.

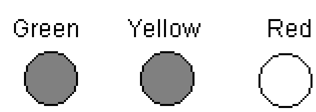
The LED board can be hot swapped with the LCD display at any time, ECU powered or not. Simply disconnect the LCD display and plug in the LED module. After a brief warmup, the Green LED will illuminate, as shown above. The lights may be either solid, or they may blink, depending upon ECU mode of operation, and/or fault. Especially important when air starting is the status of the yellow light, which is a cue to apply air. ***In a nutshell… when airstarting, if the yellow LED is flashing, apply the air. If it is solid, remove the air. If there is a fault, the RED LED will flash.***



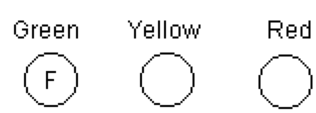
Prestart: Ready for crank. Green is illuminated. Yellow is flashing, telling you the turbine is ready to be started. Apply the air or cycle the throttle to initiate a motor start, if equipped.



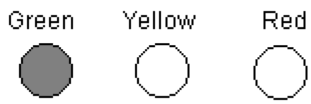
Prestart: **Fault is present; start inhibited.** Green is illuminated, but the Yellow LED is unlit. The Red LED flashes, telling you there is a fault inhibiting the start. Investigate connections; ensure your R/C is ON, the EGT probe is attached, and any other start inhibiting faults are taken care of. If you cannot tell what the problem is, simply attach the LCD display for detailed information.



Crank: The turbine is actively starting. Since the yellow LED is solid and not flashing, do not apply any air. The yellow LED will illuminate solidly during spooldown while awaiting propane ignition. When ignition is detected, the yellow LED will once again flash. Apply air if airstarting. As the turbine approaches idle, the yellow LED will again turn solid; this is your cue to remove the air source. During the Idle Trim phase of startup, the yellow LED will remain illuminated steady. Once Idle Trim is complete, only the green LED will be illuminated.



Max Run: If the turbine detects the need for a Max Run, the Green LED will flash. Apply 100% throttle. The turbine will slowly accelerate to maximum RPM. When the Max Run is complete (or if it is not needed)…

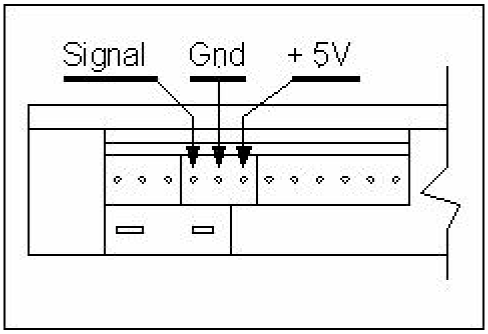


Run: … the ECU enters the normal run mode. During Run, if the ECU detects any faults, the Red LED will flash. Depending upon the fault, the turbine may or may not be shut down. If the Red LED is flashing after a flight, the ECU *has* in fact detected a fault. Connect the LCD display to examine the fault if desired.

There are some very simple rules of thumb for use of the LED module. The Green LED will always be either illuminated solidly or flashing; it is a sign that the ECU is powered and the LED module is operational. If the Yellow LED is flashing, apply air or initiate start. If it is solid, remove the air and let the ECU have control of the start. The yellow LED will go out after a successful start. *If, at any time, the ECU encounters a fault, the RED LED will flash.* All fault handling logic applies. Your turbine is protected, and steps will be taken by the ECU to ensure that all parameters stay within limits.

The Tachometer Interface

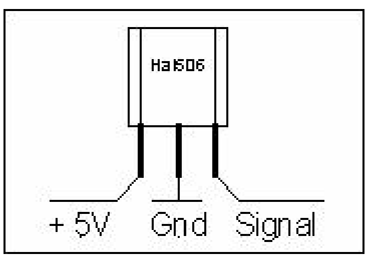
The 5 Bears ECU measures RPM by counting the number of "pulses" arriving on the tachometer signal line over a short period. A "pulse" simply means that the tachometer sensor has changed the voltage on the signal line from +5 to 0 volts. Without getting too technical, any device which can take the signal line, pulled "high" to 5V, back to ground, once or twice per revolution of the turbine rotor, will work fine. Two common techniques are shown below, with the correct wiring to interface with the ECU.



The Inputs port of the ECU is shown here. For a more detailed view, see the ECU Inputs section. The Tachometer input port consists of 3 pins, and the connector is keyed to avoid improper connection. The 3 pins consist of a +5 V source from the ECU, a ground pin, and the signal pin, much like a servo connector.

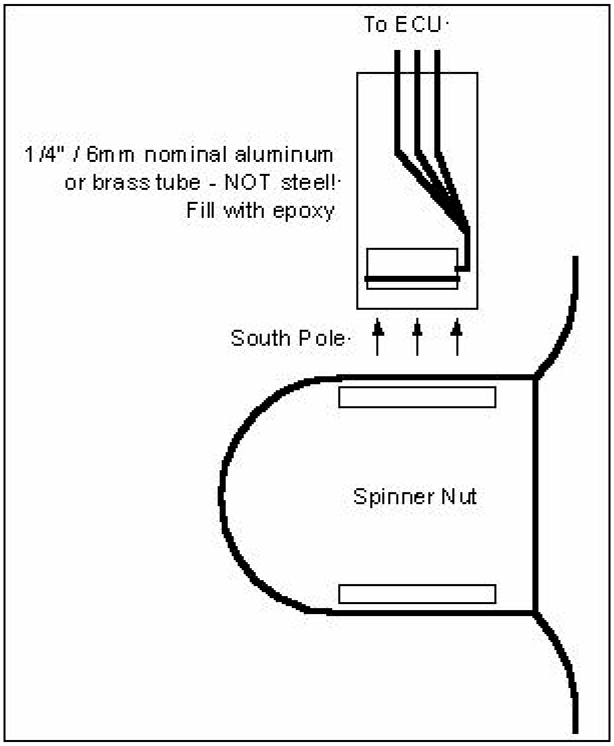
To make this port as useful as possible, the +5 V supply is not current limited, and if it is shorted directly to the ground pin, damage to the ECU will result.

My favorite interface uses a Hall Sensor and magnet combination. On my MW-54, this has proven to be 100% reliable and extremely accurate. The hall sensor I use is the HAL506. The pinout of this sensor (and all other hall IC's I have looked at) is shown here. The side of the IC with printing on it is the sensitive side, and has 2 bevels as well to identify it. Pin 1 is connected to the ECU's +5V pin, Pin 2 to ground, and Pin 3 to the ECU Signal pin. In use, the sensor is mounted in some fashion. The chip itself is rugged and is often used in automotive applications for anti-lock braking systems.



This hall sensor is available from 5 Bears, encased in a 0.25" / 6.35mm aluminum tube, complete with cable and plug for a direct connection to the ECU. It comes also with 2 rare earth magnets for your installation into the compressor spinner nut of your turbine. Please see www.5bears.com for more details

If you need a magnetic tachometer of greater sensitivity, 5 Bears also carries an excellent magnetoresistive sensor which can tolerate air gaps roughly twice that of the HAL506. It is pin compatible with the Hall IC, and may be used in its stead. It is more expensive, and it is "triggered" by either the North or South poles of the magnets, as opposed to the Hall IC which is sensitive only to a magnetic South pole.

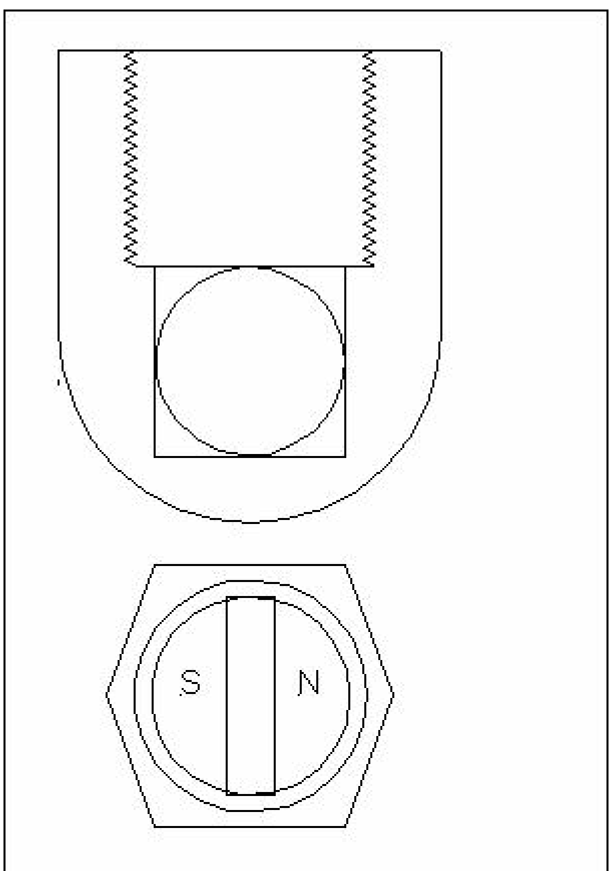


A typical positioning of the tachometer is shown here. After soldering the three wires to the chip (26 gauge servo wire works fine), the leads are bent and the wire routed up through a brass or aluminum tube. Don't use steel or any other ferrous metal, which would interfere with the magnetic signal! Fill the tube with epoxy, "potting" the sensor in place.

The tube is then clamped to either a starter motor mounting arm, or through the compressor inlet cone. A special spinner nut must me made containing a pair of small, rare earth magnets.

It is the South pole of the magnet which generates the signal to the hall IC. It is also desirable to have one South pole sweep by the hall IC, generating one pulse per revolution of the rotor. Since a pair of magnets is required for balance, one way to guarantee this is to introduce the pair of magnets together so they "stick". By definition, one of the faces is South, the other North. Separate the magnets and mark the faces with a marker or touch of paint. Mount the magnets so that both marked faces sweep by the hall sensor.

The HAL506 is very sensitive, and can tolerate an air gap between magnets and chip of probably 1/2" or 13mm. With a reasonably rigid setup, there is no reason the sensor cannot be mounted as close as 1/8" or 3mm. No external components are required to interface the hall chip to the ECU. Simply connect the wires as shown.



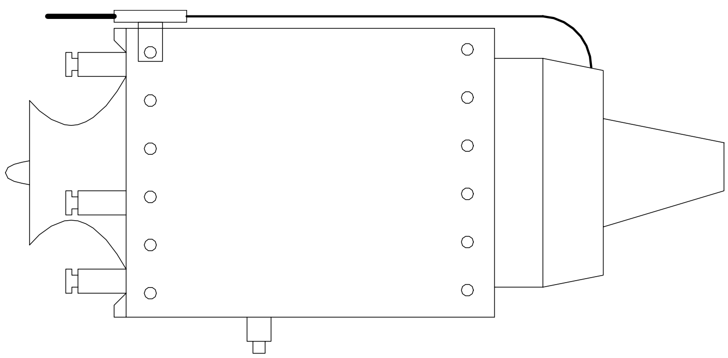
An alternative to the dual-magnet nut shown previously is this compressor nut created for a single, disk magnet. The magnet's diameter is measured, and the nut bored as deeply as possible with a diameter identical to the measurement. The magnet is then pressed into the bore; since the magnet disk has a thickness, the edges of the magnet will "swage" or form a channel for each edge and nicely self-center.

Epoxy or similar potting compound is added to the bore, being sure to fill all voids. Back in the lathe, the nut is centered, bored, and tapped for the appropriate thread.

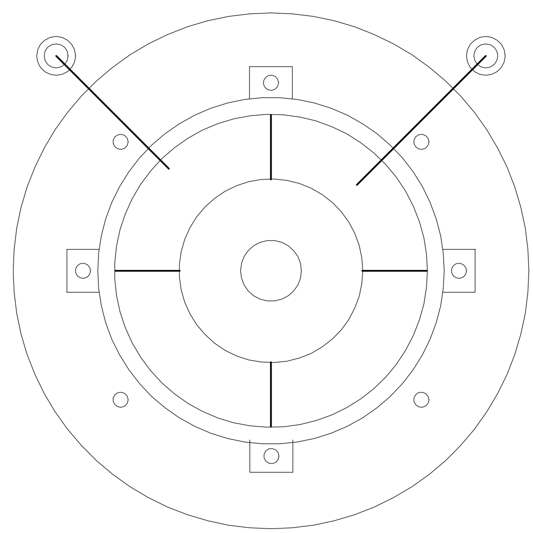
The nut *must* be made of aluminum. Steel will block the magnetic field and render the nut useless for a hall-effect tachometer system.

Installing an EGT Probe

While on the outside, a typical turbine EGT probe looks like a soft piece of wire, it is actually a precision device and should be mounted and treated with the care it deserves. An EGT probe is really a thermocouple loop, which is two dissimilar wires welded at the end to form a circuit. This is normally sheathed in a hollow tube of a heat-resistant alloy such as Inconel or stainless steel., and supported inside the sheathe with a ceramic matrix. For the ECU to properly detect the condition of this loop, the probe must be an *ungrounded* probe, meaning the loop itself must never make contact with the sheathe. If you bend the sheathe with a radius which is too small, you risk destroying the probe. Likewise, cutting the probe will destroy it, as will clamping it in such a manner that the sheathe is crushed.



The best way to mount the probe is shown here. The portion of the probe where the flexible wires are attached is known as the *junction.* If you purchased your probe from 5 Bears, this junction is a 0.25” / 6.35mm stainless tube and very suited to mounting with a sheet-metal clamp, which may be screwed onto the turbine using existing external case cap screws. Bend the working end of the probe around a suitable diameter to form the gentle radius, and guide the tip into, or just aft of, the outer exhaust cone.



How far to insert the probe into the gas stream? This can be tricky. Ideally, you want an *average* reading of the temperature of the exhaust gasses, rather than the absolute hottest reading. Likewise, you don’t want to fool yourself and risk damage to the turbine by inserting the probe in the coolest portion of the exhaust. Most turbines are best suited to probe positioning at the two o’clock position as shown in the right-most mounting here. Try a position which will place the tip of the probe, which is where the actual measurement occurs, roughly 0.125 / 3mm into the exhaust stream. Run the turbine, and note the EGT reading at a mid-throttle setting. If the EGT is very close to the published measurement of the turbine design, it is fine. If the measurement is excessive, try reducing the tip extension, as shown by the probe positioned here at 10 o’clock. You may be surprised by the change in reading as the extension of the tip is changed! The best method is to position the probe so that published values are obtained. This will allow the probe to measure the average temperature, and thus work done, by the turbine wheel. Likewise, longitudinal changes in tip position will produce dramatic variations in measured EGT. I have spent many weeks of testing, and despite this rather non-precise approach, this is the best way to set an EGT probe for correct use in these turbines.

Troubleshooting

Prestart

The EGT reads 0, or the EGT diminishes when it should increase!

Check the polarity of the thermocouple probe. Inside the male jack, there are terminals marked + and - . Normally, the yellow wire is positive (+), and the red wire is negative (-). If they are not connected properly, reverse them.

Starting

Ignition of the propane gas is inconsistent or non-existent.

Two things here – first, be sure the glow plug element has been tweaked out slightly from inside the body of the plug. This can be done with a good tweezers. Secondly, when you set **Page 4: Glow Plug Drive** during SETUP, be sure you are generating a healthy glow. Remember that there is a large amount of air flowing through the turbine during ignition, which can blow on the element and cool it significantly.

If ignition is still problematic, set the Glow Plug Dive to deliver a healthy glow, then detach the plug wire. Reinstall the glow plug. With the plug wire detached, increase the Glow Plug Drive an additional 2 or 3 units. Press enter to de-energize the plug cable, and reattach. Now, when you start, the glow plug will get additional current to overcome the cooling effect of the airflow!

I can hear the propane ignite, but the ECU spins down, reports 0 RPM, and aborts.

This happens when the propane ignition occurs at a low RPM and the RPM decays to zero before the hot gasses have raised the EGT probe high enough to indicate ignition. Heavy EGT probes have enough thermal inertia to prevent the probe from heating up quickly enough. This is far more common on a cool turbine than one run recently and still warm. There are several things you can try… first, be sure the glow plug element is sufficiently "tweaked" outwards so that it can ignite the propane easily, at a higher RPM. Secondly, try increasing the Glow Plug Drive in setup a unit or two. You can also increase the flow of propane, which will make a richer mixture that ignites easily. The ECU start logic cuts propane flow during start once the EGT has been raised to levels associated with kerosene burn, so you can freely use quite a bit of propane during start to get a good heating action on the fuel sticks without a risk of overtemping the turbine. The last and most troublesome resort is to replace the EGT probe with one of a finer diameter.

I obtain good propane lightoff, but the fuel seems to "hang" in the fuel line for a very long time, and the start sequence aborts with a Time Out fault.

Increase the Pump Prime Drive in SETUP a few units. Normal setting of the Pump Prime Drive is with a static turbine. As the turbine spools, it creates back pressure which inhibits fuel flow, and it may take time for the fuel pump output to increase sufficiently to overcome this back pressure.

During certain portions of the start sequence, the LCD display either flickers or goes out! It then comes back on in a few moments.

This happens due to a voltage sag. When the glow plug turns on, and especially when the starter motor is activated, the current demanded can be quite high, greater than 15 amps. As the current flows, the voltage that the ECU "sees" drops dramatically, to the point where the LCD can fade, flicker, or go out. This can be corrected by using quality NiCad batteries of sufficient capacity. If you are using electric starting, I cannot recommend more strongly the use of a 7-cell pack of at least 1200 mAH capacity. Look for Sanyo cells; these indicate a quality pack. The fellows who fly electric R/C are experts on this stuff, and accept nothing but the best in terms of cell quality and capacity. It makes no sense to launch a multi-thousand $$ turbine model whose very performance hinges upon a cheap battery pack. For U.S. flyers, try New Creations R/C at http://www.newcreations-rc.com These guys will set you up with the best batteries imaginable.

The fuel really races up the tubing and the turbine torches or overtemps.

Reduce the Pump Prime Drive a few units, perhaps 3. Increase the value of Fuel Ramp Start, which will slow the rate of starting fuel.

The fuel enters the turbine and I can hear the fuel ignite, but start acceleration is very slow.

Reduce the value of Pump Ramp Start. This will increase the rate of starting fuel.

I am using external air to start my turbine, and it starts successfully but it overshoots the programmed Idle RPM rather severely. The ECU enters Idle Trim mode, but the RPM doesn't reach idle before the ECU announces RUN.

Air starts provide a lot of power to the compressor wheel, and the turbine can really accelerate briskly. Once above idle RPM, the ECU enters its Idle Trim mode, where the fuel is very gently altered to track Idle. This is a timed function, and if the timing expires before the RPM is trimmed to idle, it will accept this and announce RUN. Trimming will continue, however, and if you leave the throttle at 0%, even in RUN, it will continue to trim the turbine. Trimming is a necessarily slow and gentle function, both at idle and max RPM; otherwise, the turbine may surge up and down hunting for the correct RPM due to the lag inherent in gas turbine RPM relative to fuel delivery changes.

Air starts work fine but motor starts seem to overtemp, and the start aborts.

Air starts are preferable, in my opinion, for ease of use and nice, cool starts. Motor starting can be really problematic. A lot rests upon the strength of the starter motor, the clutch assembly, and battery voltage. Be sure you are using a 7-cell (8.4V) battery pack if this occurs, with a decent capacity of 1200 mAH minimum. Try experimenting with Pump Ramp Start settings… some systems prefer aggressive fueling, others gentle fueling. A ball-raced starter motor helps a lot.

My turbine has started and run successfully many times, but today it torched with high EGT's and the pump output seems VERY high for a given RPM.

This is not an ECU function, but it happened to me and caused all sorts of grief, so I bring it up here so that it may help others.

Fuel tubing can soften with time. Most current model turbines use mixed fuel/oil, a portion of which is delivered to the bearings for lubrication. What is happening is that the fuel/oil mix in the lube line is *bypassing* the restrictor device, filling up the tunnel (causing huge drag to the rotor and bearings) and being ejected radially at the turbine wheel, causing the torching!

Replace the restrictor with one that will not allow fuel under pressure to bypass it under any circumstance.

Running

The turbine seems to hunt a lot at idle, rather than smoothly transitioning. The RPM fluctuates up and down across the programmed idle RPM.

Check the pump output in the upper right of the LCD. If the number is below 20, you are overpumped and each fuel change causes a large change in Idle RPM. Add an inline valve to the output side of the pump so that the pump output will read above 20 (preferably above 30) at idle RPM.

The turbine fluctuates at Max RPM, and either continues to fluctuate, or settles well below Max RPM.

Again, you are probably overpumped. For proper ECU functioning, there must be a sufficiently large range of operation of the pump across the RPM spectrum of idle to max. Ideally, we want at least 50 pump units between idle RPM and max RPM, and 150 is even better. This allows a much finer and precise control of the pump by the ECU. Add an inline valve to the output side of the pump, restricting its flow a bit. Reset Pump Drive at Max in SETUP to zero, and run the turbine. Note the pump output readings at both idle and max RPM's, and strive for the minimum 50 units of change in pump output. Note that the ECU considers any RPM within 3,000 of programmed Maximum to be acceptable.

After a successful run, the Log shows that the max RPM encountered exceeded my programmed value.

Overshoots of 1,000 to 3,000 are considered normal. During acceleration profiles, the turbine RPM *always* lags a bit, so it is very difficult to halt acceleration at exactly RPM Max. The ECU makes every attempt to limit the RPM, and when it is exceeded, it is very rapidly brought down to the correct value, or slightly below. If these minor overshoots are bothersome, note the value of your overshoot and subtract this number from your programmed RPM Max in SETUP. This is known as derating, and is a smart thing to do regardless.

My logged Max EGT exceeded my programmed value.

Like the RPM overshoots, EGT overshoots are transient and very quickly resolved. If the EGT *remained* at that peak value for more than a few seconds, the ECU would have shut down the turbine with an OverTemp fault. Again, if this is bothersome, derate your turbine's max EGT 10 or 20 degrees.

At low RPM, stable and at or slightly above idle, my turbine's EGT is high and the throttle does not respond.

The ECU will *never* allow fuel additions if the noted EGT is within 20 degrees of programmed max EGT. Moving the throttle will have no effect in this case. This is not an ECU problem, but rather a turbine issue. Your turbine is simply running hot. Try raising the idle RPM value to get the turbine into a “happier” regime, as the airflow may not be sufficient at low RPM. If this fails, you need to refer to the turbine’s designer to resolve the hot-running issue.

When chopping the throttle to idle, the turbine keeps flaming out!

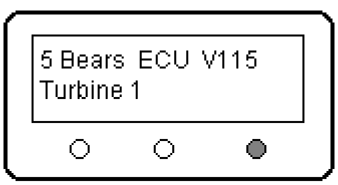
You must increase the value of **Pump Ramp Down** in SETUP. Flameouts can be unavoidable if fuel is reduced too quickly. It is *far* better to have a sluggish downward throttle response, than one too fast which results in flameouts. You can also raise the programmed **EGT Minimum Run** value in SETUP. The relationship between Pump Ramp Down and EGT Minimum Run is complex. Please review the Programming section for details.

Post Flight

I am using air to start and cool my turbine. The logged bearing spin down time is very large or inconsistent between runs.

Since you are using air to cool the turbine, you *must* wait until Cooling is annunciated before applying cooling air. Otherwise, you are keeping the rotor turning during the spin-down phase, and this cooling duration time is added to the normal time. Look for the Cooling annunciation, or wait until the RPM has dropped below 2,000 before applying cooling air.

I turned off my ECU before looking at the logged data. Is it still available?



Yes. Turn on the ECU. When you see this screen, press either the Up or Down buttons immediately. You will be shown the logged data and the faults encountered on the previous run. As soon as the next start is initiated, this data will be erased.

Frequently Asked Questions

When I program my throttle channel, a reduced throttle produces* larger *numbers than an advanced throttle. Is this OK?

The preferred mode of operation for the ECU is to have an advancing throttle produce larger numbers. The ECU will function normally, though, in either state. If you have a computer radio, simply select the throttle channel and reverse the direction. This should change the output of the channel so the pulse width (the "number") will increase with advancing throttle.

Can the ECU battery power my R/C system?

No. The ECU battery is totally isolated from your R/C system. For this reason, the ECU cannot measure the voltage of your receiver battery.

How can I use different receivers with the ECU without reprogramming?

If the receivers generate throttle pulse numbers within a unit or two of each other, no changes are necessary. For example, if you have a receiver in an F-86 Sabre model with pulse numbers of 85, 100, and 186, and a receiver in an F-16 with pulse numbers of 83, 97, and 188, this will work fine and there will be no noticeable difference when the ECU is moved from one model to another. The more elegant solution, if you want to move the ECU between 2 or more models, is to make use of the "Turbine Sets" feature, which allows up to 3 totally different sets of parameters to be stored within the ECU. When the ECU is moved from the F-86 to the F-16, simply switch the ECU from turbine set 1 to set 2.

My thermocouple (EGT probe) works fine until a portion of the sheath touches the turbine body or exhaust cone… then the ECU says* Open T/C *and no longer displays a temperature. What's going on?

You are trying to use a probe called a *grounded* probe. A grounded probe has electrical contact between the special thermocouple wire inside the sheathe with the sheath itself, and this generates the error you see because the minute signal from the thermocouple is traveling through the turbine frame, into the glow plug ground wire, and thus into the ECU. The 5 Bears ECU requires an *ungrounded* probe, where the thermocouple is isolated from the sheathe.

Can you bend a thermocouple sheathe?

Yes. Within reason, of course. Keep the radius relatively large and avoid kinking.

How long will a thermocouple last?

This depends upon several factors, such as operating temperature, sheathing, and importantly, the thickness of the junction/TC wires inside the sheathe. A smaller diameter probe will be more sensitive but will not last as long. A larger probe may not have the sensitivity for best performance. I recommend an ungrounded, inconel sheathed type K probe of 0.040" to 0.093" diameter.

Does the ECU ever need to be internally trimmed for a correct EGT reading?

No. There are no trimmer pots or any adjustable devices inside the ECU. The thermocouple section is very accurate and no adjustment is ever required.

How can I use case pressure in lieu of a true rotor tachometer with the ECU?

The use of case pressure will always be less accurate than a true tachometer sensor. I am working on a small module that will sample the case pressure, translate the pressure to an approximate RPM reading, and report the RPM to the ECU via a serial cable. This capability is programmed into the ECU, but the module is not yet available. Please see my web site at http://www.5bears.com for news. For now, the ECU requires a tachometer to operate.

How much heat will the ECU and LCD stand?

The ECU components are the most robust I could find in terms of temperature. The central processor is a more expensive, "industrially" rated chip, and the other components were selected with a severe environment in mind. The processor is rated for environments from –40 degrees C to +85 degrees C. I suggest the temperature of the ECU never exceed 80 degrees C to provide a margin of safety. This should never occur unless the ECU is badly positioned too close to the turbine. The best location is well forward of the turbine inlet area.

The LCD cannot tolerate higher temperatures. Like all supertwist displays, heat tends to temporarily darken the pixels in the display, and in severe cases can cause the LCD to be unreadable until it cools. If you detach the display after starting, keep it out of direct, hot sunlight if possible. Slip it into a shirt pocket or keep it shaded.

I need cables of special length for the LCD Display / starter motor / battery cables, etc.

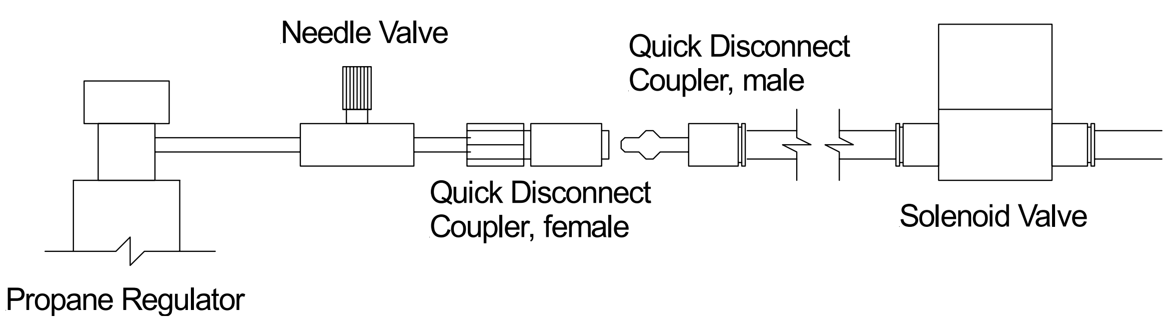
If you know when you order that you need longer cables, let me know and I will customize them for you. If you determine later that you have special requirements, I can build cables at a nominal cost. It is best to keep them as short as possible. Otherwise, they become prone to interference and signal loss problems.

How do I attach a propane source to the solenoid valve?

There are two methods to do this… The first method is to have an external propane bottle and connect it to the aircraft for each start. The propane bottle should be equipped with a regulator. This can be any of the common disposable bottle regulators that reduce the pressure to 50 PSI or less. A cheap, converted propane torch head cannot be used because it is not a true regulator device. If the regulator has a flexible hose coming from it in its original configuration, the hose can usually be detached and replaced with a festo-style fitting. This will work fine. Unregulated propane bottles will deliver a pressure of well over 150 PSI, and this is excessive for both the solenoid valve and the normal plastic lines used for turbine setups.

Between the regulator and the solenoid input port, it is best to insert an inline needle valve. Note that a needle valve is *not* a regulator, and can throttle the flow only if the output side is not blocked. Once the propane begins to flow, the needle valve can be adjusted for the correct propane delivery, and the adjustment screw locked in place.

On the model, the solenoid must be carried onboard. The output port of the solenoid valve is connected more or less permanently to the propane input of the turbine. The input side of the port terminates with a miniature Quick Disconnect coupler, which is your attachment point for the external bottle assembly.



Starting on the left, we have a propane bottle with a regulator. This is fed into an inline needle valve, which in turn is fed into a female Quick Disconnect coupler. This assembly is part of your flight line equipment and is external to the jet.

Inside the jet, we have a male QD coupler which mates with the female coupler body when we want to start the turbine. Normal plastic line attaches the male coupler with the input port of the solenoid. In use, the regulator is opened fully, and since the female QD coupler acts as a check valve, no propane flows. The QD couplers are connected, completing the circuit. The turbine is started, and during the propane-only burn, before fuel is introduced, the needle valve is set for the desired flow rate. At least on my MW54, a sustained propane burn during start of ~150 to 300 degrees C. works fine. Too much propane tends to create hot starts, while not enough propane tends to flame out or not heat the fuel sticks properly. Once you are happy with propane delivery, the needle valve is locked in place, and starting simply becomes a matter of opening the regulator fully, connecting the QD coupler, and initiating the start.

After the turbine is started, the ECU will automatically de-energize the solenoid. In this state, the solenoid acts as its own check valve, preventing the higher pressure inside the turbine from leaking out through the propane line. Disconnect the QD coupler and go fly!

The alternate method of starting is to have your own onboard supply of propane or butane. In this case the QD coupler may be omitted. Be sure that the pressure on the supply side of the solenoid does not exceed 100 PSI.

The whole MAX RUN mode is a bit confusing… why is it done, and why would I need to reset* Pump Drive at Max *to zero?

To provide good throttle response, the ECU needs to know two values relating to the pump. The first value is the pump setting that provides pump output corresponding to idle RPM. This value is easily determined by the ECU after a successful start. When 0% throttle is commanded (idle), the ECU smoothly sets the fuel pump to this setting. After the turbine stabilizes, it then gently trims this value to maintain Idle RPM. The second value is harder to determine – that value is the approximate pump output necessary to bring the turbine to its programmed maximum RPM. The only way to do this is with live running, as fuel systems, pumps, batteries, and the turbine itself, combine to make this impossible to determine otherwise.

Here is how MAX RUN works. The ECU first looks to see if it has a stored value called Pump Drive at Max, which you can see on page 15 of SETUP. This value, which will be somewhere between the Pump Prime Drive value and 255, is the last known pump output which produced Max RPM for the turbine. If there is a number there, the ECU knows that this is the pump output to use to generate Max RPM when 100% throttle is commanded. Since the ECU now knows the pump outputs corresponding to 0% and 100% throttle, any throttle command between these two will translate easily into a desired pump output, and the ECU computes the correct fuel ramping schedule to get there.

If the Pump Drive at Max value is 0, the ECU cannot determine the pump setting for maximum RPM. The only reasonable way to determine this setting is to schedule the fuel in an exceptionally gentle manner until Max RPM is sensed; once this occurs, the pump output is noted, stored, and the MAX RUN annunciation on the LCD is replaced with RUN.

If all of this seems especially complex, it can be simplified by following some general rules of thumb. If the turbine is being run for the first time, you will see MAX RUN on the LCD after a successful start. Simply command 100% throttle, and the turbine will slowly accelerate to its programmed Max RPM. Once this RPM value has been reached, the LCD will switch to RUN, telling you that the MAX RUN has been satisfied, and you can go fly.

Here are several reasons you would want to set Pump Drive at Max (page 15 of *setup*) to 0 to force another Max Run:

1. You have significantly altered the fuel system in some fashion

2. You are trying a new fuel pump

3. You want to test a new battery with more or less voltage, or a significant capacity change, say from 1100 mAh to 1800 mAh.

The danger in not resetting this value is that the ECU may overshoot your programmed Max RPM slightly. It *will* recognize this and retard the fuel, but optimal throttle response will be lost.

How do I connect the glow plug harness?

The hot wire of the glow plug cable terminates in a lug which is pressed directly to the central stem of the glow plug. If it seems loose, remove it and squeeze *gently* with a pliers, then reattach. The ground (black) wire may be attached to any portion of the turbine which is metallic and is in good contact with the glow plug base. The best place is the outer case of the turbine – especially under the turbine mount if the mount is in contact with the turbine's outer case.

What good are the 3 turbine sets? I don't understand them.

I personally use more than one set for the following reasons, even when the turbine is the same between sets. First, one set can be used for air starting, another for motor starts. These often require different Start EGT and Pump Ramp Start settings for best performance. Another case would be different voltage battery packs. Since a higher voltage pack can burn out a glow plug relative to a lower voltage pack at the same Glow Plug Drive setting, using a different turbine data set can allow different values. One other case might be sport vs. max performance flight. With daily sport flying, you may want to derate your turbine both with EGT and RPM to prolong the life of the turbine.

Is there any way to use the ECU to defuel my jet?

Yes. Plug in the LCD display. Detach the output of the pump from the turbine, and route this tube into a suitable receptacle. Simultaneously press and hold both the DOWN and UP buttons. This is also the normal means of priming your turbine for airstarting. The pump will run at a slow setting and transfer the fuel from your tank to the receptacle. When defueling is complete, release the buttons. The pump will stop.

Warranty / Liability Statement

The 5 Bears ECU has a 1-year warranty for mechanical/electronic functionality of the ECU, LCD display, and gas solenoid valve. This applies *only* if the ECU is connected and mounted in accordance with the procedures outlines in this manual. *In no case* is there any liability in the event of a crash or collision, or other damage consistent with abuse of any kind. Inputs and/or outputs improperly connected *will* cause damage, and are not covered. *No liability is assumed by 5 Bears Engineering for damage/injury to turbine power plants, people, vehicles, or anything else.* The user assumes all risk in this case.

Firmware updates are free for any original/subsequent owner of a 5 Bears ECU. User will provide postage in this case.

In all cases, I want you, the turbine enthusiast, to be happy with your ECU. I will work with you to your satisfaction to resolve troublesome issues, or I will refund your payment in full upon receipt of the ECU and accessories.

Fly Safe, have fun!!

Notes: