Quick Guide to Patrick Carroll's
AeroTech 54/1280 RMS Hybrid Revival Project

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During the mid 1990s, under pressure from the BATF, sport rocketeers started looking toward hybrid rocket technology to bypass the stiff regulations being placed on APCP-based propellants. One of the leaders on the commercial front was *AeroTech.* In 1995 AeroTech introduced the RMS 54/1280 Hybrid rocket motor followed a bit later by a second 98/5120 version (Figures 1 and 2).

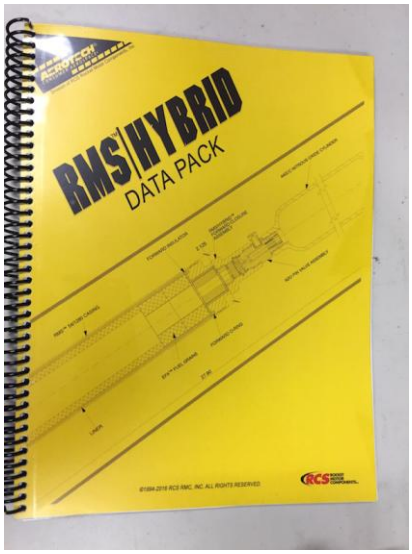
Figure 1. Nameplate for the AeroTech 54/1280 RMS Hybrid instruction manual.

These motors are unique among high power hybrids because they use pre-filled N_2O flight tanks that are refillable at home and require no special ground support equipment (GSE) at the pad! This is in contrast to conventional sport hybrids that use a N_2O supply bottle actually at the pad. The loading of the flight tank is controlled remotely by a solenoid valve thus allowing the flight tank to be filled right at launch time. As long as the rocket sits on the pad additional N_2O is simply vented. While this may be cool-looking like larger liquid rockets, it is a complicated, wasteful and environmentally unfriendly practice. Nitrous oxide is at least 250 times (some sources report over 300 times) more effective of a greenhouse gas than is carbon dioxide! And, nitrous is very stable in the lower atmosphere, typically residing over 100 years. To put this into perspective, by my best estimate, venting only 100 grams of N_2O is the greenhouse equivalent to the amount of CO_2 emitted by driving an average American gasoline automobile 75 to 100 miles! (26 mpg with each gallon generating 20 pounds of CO_2)

Sadly, these superbly-made motors were manufactured only until 2001. They are no longer available for sale and have become coveted objects by their owners (Figure 2 top)! In 2022 Patrick Carroll started working on ways to revive this long out-of-production motor trying to use mostly off-the-shelf parts. By the time he was done, only one small component (the injector plate) needed to be made completely from scratch; all other parts could be used as-is or with a few modifications! Patrick began his efforts with two critical items still available from AeroTech/Rocket Motor Components (RCS):

The first item is not a piece of hardware at all…rather a document that contains all the plans, specifications, materials and original sources for the motor that AeroTech has bundled into a hard copy manual:

RMS/Hybrid Data Pack (rocketmotorparts.com)



And the second item is the forward closure, a critical part for this motor that AeroTech still has in stock as described a bit later on.

Using his experience as a professional aircraft mechanic and dedicated rocketry enthusiast Patrick worked on gathering together, and modifying as needed, all the components necessary to assemble one of these motors. He demonstrated the results of his efforts by successfully flying a 54 mm revival hybrid motor at the 2023 Balls launch in the Black Rock Desert of Nevada (Figure 3). He details his whole journey on his web site/blog at:

https://pcarroll2525.com/high-power-rocketry/

Understandably, Patrick's revival project is fairly involved working through a number of detours, optional approaches, and possible modifications all the way up to his 98 mm version.

To streamline the process, I have created this concise guide to show interested flyers how to assemble a nearly original version of the 54 mm motor like the one I made based on all of Patrick's hard work (Figure 2 middle).

Figure 2. An original AeroTech 54/1280 RMS Hybrid (top), a standard 54/1280 Revival Hybrid derived from Patrick Carroll's work (middle), and an "I" class 54/852 Revival Hybrid with a 380 cc flight tank (bottom).

Figure 3. Patrick Carroll celebrates the successful flight of his "Lust for Thrust" rocket flown on the first burn of his AeroTech hybrid revival project using a sorbitol-based fuel grain.

Here are the major subsystems/hardware components that go into the revival hybrid:

1. Flight oxidizer tank
2. A master flight tank valve (manually actuated or pin actuated)
3. Forward closure & miscellaneous small parts (also houses component #s 4, 5, and 6)

4. Injector plate w/multiple jets and flight tank valve depressor pin
5. Pyrovalve (consists of a “burst disk”, pyrovalve element, O-ring and backup washer)
6. Pre-heater grain
7. Case/solid fuel container/combustion chamber
8. Rear closure
9. Nozzle
10. N_2O supply tank and filler hose/valve ground support equipment (GSE)

We will begin by sourcing key hardware components off-the-shelf that can be used with no modifications needed then discuss those parts that require work (note the sources, availability and prices listed were current as of the original 7/1/24 version of this guide).

The Forward Closure:

The key piece of hardware that makes this project possible without a lot of complex machining is the “forward closure” (Figure 4). This closure not only connects the combustion chamber to the oxidizer tank but it also houses many of the crucial subsystems needed to make the hybrid operate. Fortunately this part is still available from Rocket Motor Components (RCS):

[54mm RMS-Hybrid Forward Closure (rocketmotorparts.com)]

Figure 4a, b and c. Various views of the forward closure for a 54mm AeroTech hybrid.

Obtain this part to start your revival hybrid build (note the 98 mm version forward closure is no longer available).

Small Hardware Parts for the Forward Closure:

A few additional items are needed when assembling the internal parts within the forward closure (these are all available from large hardware suppliers like *McMaster Carr*) (Figure 5).

Figure 5. Small parts for the forward closure.

1) An internal stainless steel snap ring (11/16” diameter x 0.035” thick) which secures the injector plate and all other components beneath (upper right) (McMaster Carr # 91580A175).
2) A pyrovalve backup stainless steel washer (5/8” OD x .380” ID x .060” thick) to help support the black powder pyrovalve pellet. One of these washers was included in each factory reload kit however they should be reusable. Exact replacements may be hard to find (upper left) (McMaster Carr # 97022A541 shims should work) but thinner versions can be used by stacking two together.
3) A dash 017 Buna-N O-ring to seal the circumference of the injector plate (lower left) (McMaster Carr # 9452K71).
4) A “jam screw” (3/4”-16 x 3/8”) used to secure all the pyrovalve parts plus the injector plate and press them together to form a pressure-tight seal (lower right) (McMaster Carr # 91301A200).

Case and Rear Closure:

The combustion chamber/solid fuel container is a standard AeroTech 54/1280 motor casing (also *Dr. Rocket* and *Rouse-Tech* equivalents work fine). It is usable off-the-shelf and needs no modification, just swap the hybrid forward closure for the standard solid propellant closure. It will be a bit more economical to buy just the rear closure and the motor case (Figure 6) but more versatile to buy the complete motor so you can use it with solid propellant reload kits as well:

[AeroTech RMS-54/1280 Complete Motor Hardware Set (w/ Forward Seal Disc – AeroTech/Quest Division, RCS Rocket Motor Components, Inc (aerotech-rocketry.com)]

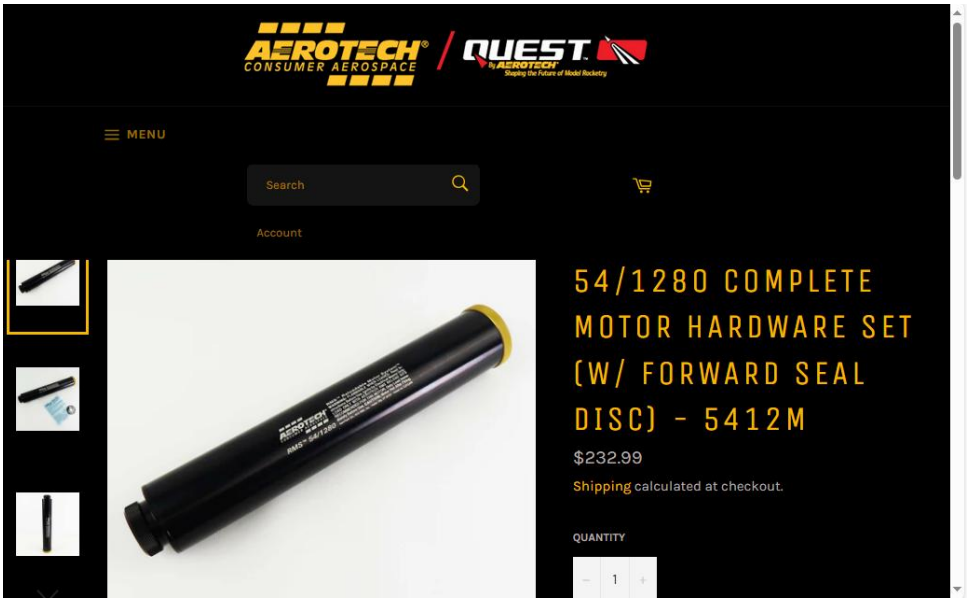
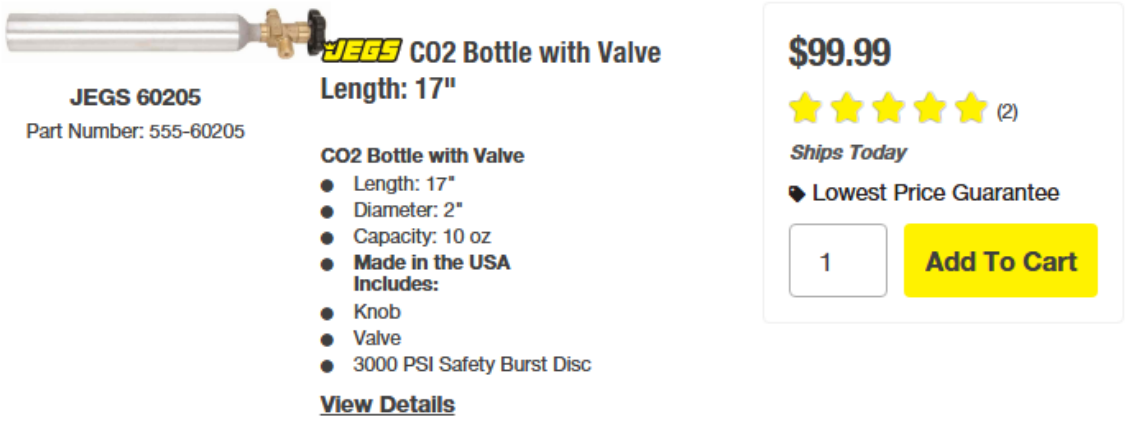


Figure 6. An AeroTech 54/1280 case and rear closure.

Flight Tank:

The next major component needed is the nitrous oxide flight tank. Thanks to the paintball and the performance automotive industries there are a number of options available. The key things to look for are the 2" tank diameter and the 5/8-18 UNF outlet thread. CO_2 rated tanks will work just fine for N_2O. CO_2 paintball guns operate at around 800 to 850 psi very similar to the pressure inside a nitrous flight tank(see Appendix A) but any motor part potentially coming in contact with N_2O must be scrupulously cleaned to remove all traces of manufacturing contaminants (see Appendix B and C). I have used the following two tanks:

555-60205 - JEGS High Performance



This *JEGS* product (also sold by *Autometer*) appears to be the very same bottle that was supplied with the original AeroTech 54/1280 RMS Hybrid motor which is actually made by *Catalina Cylinders* (Figure 7)! It is specified as holding 440 cc volume which is enough nitrous for "J" class performance (see Appendix D). You will not need the JEGS included valve assembly.

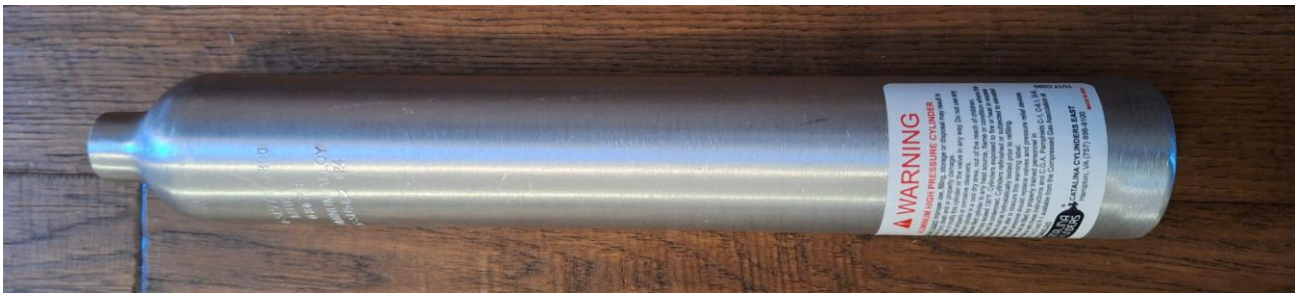


Figure 7. Catalina Cylinders 440 cc flight tank, same as the AeroTech original.

And, I have also used the *TUXING* Pcp 380 cc tank (Figure 8) available on Amazon:

[Amazon.com: TUXING Pcp Paintball Aluminum Air Tank, High Pressure Air Tank 0.38L 23Ci Capacity,for Paintball or PCP Air Guns (empty bottle) 5/8-18UNF,Red : Sports & Outdoors]

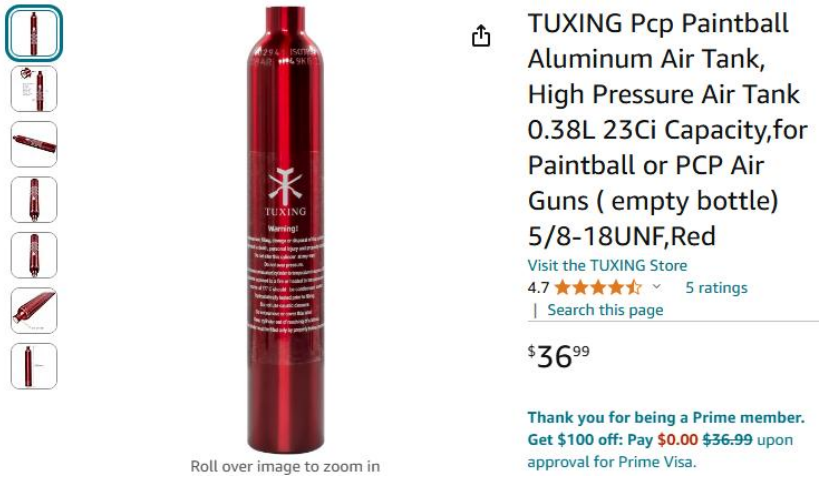


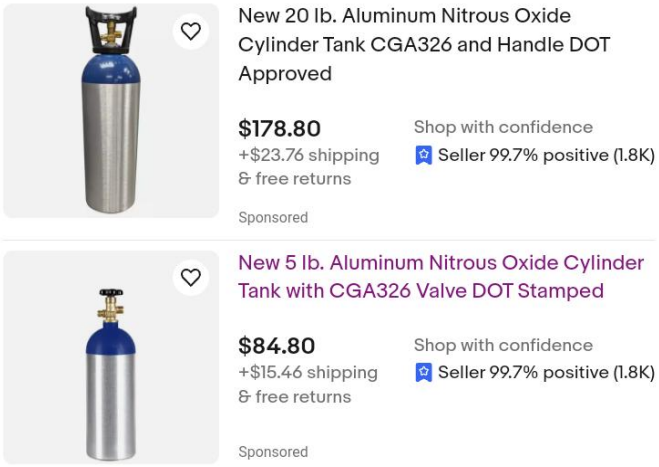
Figure 8. Tuxing 380 cc flight tank.

This tank is very nicely made and has a capacity of 380 cc. Both tanks are tapped for 5/8”-18 UNF threads which will work without modification for the tank-side threads of the Interstate Pneumatics pin valve described later. The thrust curves shown in Appendix E and the top figure of Appendix F were derived from burns using this tank. Recently, I put together an “I” class version of this motor using an AeroTech 54/852 case paired to a Tuxing 380 cc flight tank (Figure 2 bottom). And shown in Appendix E during an interesting static test burning poplar wood fuel.

Ground Support - Supply Tank and Fill Line Assembly:

You will need a professional grade storage bottle to hold your nitrous supply. These are beefy bottles, like welding tanks, capable of withstanding very high pressures. Ten to 20 pound capacity bottles are probably most convenient for rocketry and will hold enough nitrous for several flights (299 grams of nitrous for a typical flight is about 2/3 pound).

Commonly, big nitrous suppliers rent/lease larger bottles (typically 40 lbs); and thus, they will only exchange empty bottles and will not refill a private bottle! Check local 4x4/speed shops and welding equipment/ compressed gas dealers to see how this works in your area. I personally own a 10 lb bottle and have it filled at a local speed shop. If you can refill a privately owned bottle here are some purchase option examples from eBay:

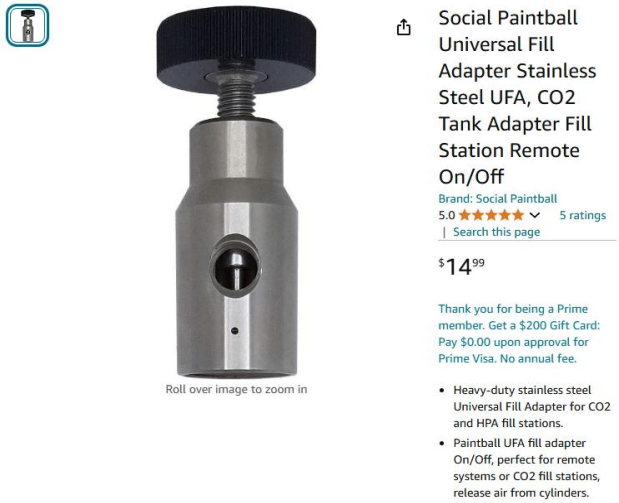


and you can also try [Gas Cylinder Source | Cylinders, Valves and Parts]

To connect the supply tank to the flight tank for filling, you will use a NOS compatible (**N**itrous **O**xide **S**ystem by *Holley*) stainless steel jacketed hose with AN4 fittings on the ends (Figure 9a). These types of hoses can be found on numerous auto supply sites (two feet long works fine). You will also need some couplers/adapters to go from the hose to the fill adapter (1/8" NPT male to AN4 male fitting) and also the valve on your supply tank (AN4 tank nut). Connection from the hose to the flight tank, along with filling control, is achieved using a UFA paintball fill adapter. *Social Paintball* brand is a good one that works with both possible valve pin extension modifications as discussed in the detail papers (Figure 9b).

Figure 9a (left). Filler hose and 9b (right). UFA adapter for opening the pin valve during filling.

[Amazon.com : Social Paintball Universal Fill Adapter Stainless Steel UFA, CO2 Tank Adapter Fill Station Remote On/Off : Sports & Outdoors]



To fill with nitrous at home, the flight tank is first chilled in a refrigerator or freezer; or, when in the field, an iced jug or cooler works beautifully (Figure 10 shows an easy-to-use setup).

Figure 10. A safe and convenient way to fill a flight tank with nitrous when in the field. The flight tank is chilled with an ice bath contained in an insulated jug while the supply bottle remains at air temperature. Open the pin valve, tare the digital balance to 0, then gently crack the supply bottle open and let the needed nitrous flow in slowly. Close all valves and carefully disassemble the components in the proper order!

The supply tank is then connected to the flight tank using the hose and adapter described above. Once connected, the knob on the adapter is turned in to depress the pin valve. The supply tank is then slowly opened to begin filling. A digital balance is used to monitor the weight of the tank as filling proceeds. According to AeroTech, the 440 cc tank should be filled with no more than 299 grams of N_2O. And thus the 380 cc tank proportionally less at 258 grams. Once filled, the supply tank is turned off and the knob on the fill adapter is backed out closing the pin valve. It is now safe to disconnect the fill system components. Store pre-filled tanks in cool locations (e.g. transport to a launch in an ice chest) prior to flight.

We will now look at those parts that need some modification to be used with the revival hybrid or need to be outright made from scratch. The machining involved reshapes some of the features/dimensions of the pin valve and makes the entire injector plate. Fortunately these procedures are fairly easily done by any knowledgeable machinist or machine shop.

Flight Tank Valve:

There are two basic ways by which the flight tank can be closed after refilling (as described earlier) to allow for storage, transport and subsequent reattachment to the forward closure; and also, to open the flow of nitrous from the tank to the forward closure thus "arming" the motor for launch. The first way is a manually actuated ball valve and the other way is a pin valve automatically actuated when the tank is screwed onto the forward closure. Patrick originally chose to use a ball valve (but has now switched to an agricultural style connector shown in Figure 11) while I chose to use the original AeroTech approach of using a pin valve keeping as close to the original as possible (Figure 12).

Figure 11. Ag connector.

Figure 12. Pin valve.

While either approach works well, I will cover only the pin valve here; but you can find out more details about the other methods by visiting Patrick's website.

Unfortunately, the original AeroTech pin valve is no longer available. The closest match I have been able to find comes from *Interstate Pneumatics*; and that valve is their model number WRCO2-PV available through Amazon:

Amazon.com: Interstate Pneumatics WRCO2-PV Brass Pin Valve for CO2 Paintball Tank : Sports & Outdoors

Click image to open expanded view

Interstate Pneumatics WRCO2-PV Brass Pin Valve for CO2 Paintball Tank

Brand: Interstate Pneumatics

4.3 ★★★★½ 33 ratings

$15.50

Thank you for being a Prime member. Get $100 off: Pay $0.00 ~~$15.50~~ upon approval for Prime Visa.

Material	Brass
Brand	Interstate Pneumatics
Exterior Finish	Brass
Manufacturer	American General Tools
UPC	791674000631

There are a few modifications (Figure 13) that must be done to make this valve useable with the AeroTech hybrid including:

- Re-shaping the forward closure-side threads from 1/2" G-14 TPI of the pin valve to 13/16" 14 TPI threads used by AeroTech
- Turning the pin down to 0.063" diameter or replacing the pin with the equivalent length 1/16" stainless steel rod
- Drilling the outlet port to 5/32" diameter
- Drilling the jam screw port to 0.190" diameter

Figure 13. Modifications to the Interstate Pneumatics pin valve.

This is the most involved machining that needs to be done for this project. I have written very detailed directions on how to make these modifications. These instructions can be found on Patrick’s web site under the sub heading of Additional AeroTech Hybrid Projects:

Additional Aerotech Hybrid Projects – Patrick Carroll (pcarroll2525.com)

or request a copy from me directly by e-mail to be sure you are getting the latest version:

nmrockets@yahoo.com

So far, the stock Interstate Pneumatics polyurethane pin valve seal has been successful both in holding pressure when filled with nitrous (some fills holding four weeks with no significant leakage); and, in functioning well during the motor burn. I have not been so fortunate with replacement pin seals I have tried. In previous versions of this Quick Guide, I had recommended *Captain O-ring* CO_2 Pin Valve Seals as replacements. Unfortunately, I encountered some problems when using these seals; like having the washer slip off its mount during arming, jamming in the outlet port thus aborting ignition and leaving a full flight tank of nitrous to bleed off! After a more careful review of these Captain O-ring seals, I found this washer yields an OD of .270” compared to 0.235” for the stock Interstate Pneumatics seals! This apparently allows the seal to act like a piston and it can slip down the pin and block the port.

Next, I located the seals AeroTech used in the original RMS Hybrid (made by Seastrom Mfg.). AeroTech chose PTFE over polyurethane and they are noticeably harder than the stock Interstate Pneumatics version. These PTFE washers measure 0.250" OD, 0.090" ID by 0.095" thick. Unfortunately, these appear to leak when directly substituted for the Interstate originals. Recently I have been working with off-the-shelf Viton^{tm} washers (McMaster Carr # 1170N15) with good results. Please read the detailed pin valve modification paper (Version 9) for more details as I keep researching this issue. In the mean time, make your original Interstate Pneumatics seal last as long as possible.

Figure 14. Pin valve O-rings and pin seal washer.

Injector Plate and Pin Valve Depressor:

The original injector plates are no longer available and must be custom made. Also, the original injector plate is a bit complicated (Figure 15). Arranged symmetrically around the base of the central depressor pin (this presses against the valve pin during motor assembly thus opening the flight tank) are 8 holes. Half of the holes are drilled through (with the actual 1/16" orifice size) and also partially drilled and tapped 3-48 for set screws. Every other hole is blind-drilled and also tapped for 3-48 set screws.

The idea is that set-screws can be used to block off unwanted injector jets to adjust the thrust characteristics and the blind holes can be used to store extra set-screws (as shown in the photos below). Thus, the possible configurations of the original AeroTech injector plate are:

2 jets open = J145 performance with standard paper grains
3 jets open = J170 performance with standard paper grains
3 jets open is also used with both the J260 EXF and J390 TURBO APCP enhanced grains
4 jets open = J210 performance with standard paper grains

Figure 15a (left) and b (right). Original AeroTech injector plates.

This injector plate makes a good CNC project as demonstrated by Jordan Slavish's work shown on Patrick's web site! However, my approach is much simpler and involves only basic lathe and drill press work to make serviceable injector plates. Optionally, a milling machine with a rotary table attachment will do a great job of precisely locating and drilling the orifice jet holes (Figure 16). If you intend to use the Interstate Pneumatics pin valve, the easiest way to make up the extra needed 0.070" pin length is to add that dimension to the length of the depressor pin while making this injector plate. A minor inconvenience of this "fixed injector" approach is that the various plates must be switched out to change jet configurations. However, manipulating tiny 3-48 set screws deep in the forward closure is not much fun either, especially in the field!

Figure 16. Dexter's 2, 3 and 4 jet revival hybrid injector plates.

My set of detailed directions can be found on Patrick's web site under the sub heading of Additional AeroTech Hybrid Projects:

Additional Aerotech Hybrid Projects – Patrick Carroll (pcarroll2525.com)

or request a copy from me directly by e-mail to be sure you are getting the latest version:

nmrockets@yahoo.com

We have secured all of the re-usable hardware parts so now we need to find consumable items like the nozzle, O-rings, washers, the pyro element, burst disk etc. Here is the list of these items as supplied in a typical paper grain based AeroTech RMS Hybrid reload kit (Figure 17):

Figure 17. An original AeroTech 54/1280 RMS Hybrid paper grain reload kit.

1 glass/phenolic hybrid nozzle drilled to match the power rating and the number of open jets
1 cardboard liner tube 1.985" OD x 1.875" ID x 10.35" long
1 Forward paper fuel grain 1.87" OD x .875" ID x 2.00" long
1 Aft paper fuel grain1.87" OD x 1.375" ID x 7.94" long
2 Fuel grain O-rings 2" OD x 1/8" thick
1 Pyrovalve O-ring 5/8" OD x 3/32" thick
1 Pyrovalve element 5/8" OD x 1/4" thick pressed black powder pellet
1 Pyrovalve Teflon separator disk (i.e. a burst disk) 5/8" OD x .010" thick
1 Pyrovalve backup washer 5/8" OD x .380" ID x .060" thick stainless steel
1 Forward insulator 1.990" OD x 1/16" phenolic washer
1 N_2O Pre-heater forward insulator 1 1/8" OD x .5" ID x 1/16" fiber washer
1 N_2O Pre-heater insulator 1 1/8" OD x 1' long phenolic tube

1 N_2O Pre-heater charge 1” OD x .375” ID x 1” long Blue Thunder grain
1 Nozzle cap 1 1/4” red caplug
1 Igniter guide tube 1/4" OD x 13 3/8” long Mylar tube
1 FirstFire igniter w/ 24” leads

The Nozzle:

[54mm Nozzle, 0.313" Throat (rocketmotorparts.com)]

This nozzle is still available through the RCS web store. Like most AeroTech reload kits, the ones supplied for the RMS hybrid use glass/ phenolic nozzles. The basic AeroTech hybrid nozzle is manufactured in one throat diameter which is 0.313”. When shipped as part of a reload kit the throats were subsequently drilled out to match the nominal power rating of the reload kit:

0.313” = J145 performance with standard paper grains
0.375” = J170 performance with standard paper grains
0.438” = J210 performance with standard paper grains
0.438” = J260 performance with EXF White Lightning enhanced grains
0.500” = J390 performance with TURBO White Lightning enhanced grains

While these nozzles are intended to be single use I am trying out a method to re-use them with graphite throat inserts (Figure 18). Initial static test results are encouraging with only around 1/64" throat erosion off the diameter during a full 4 second burn!

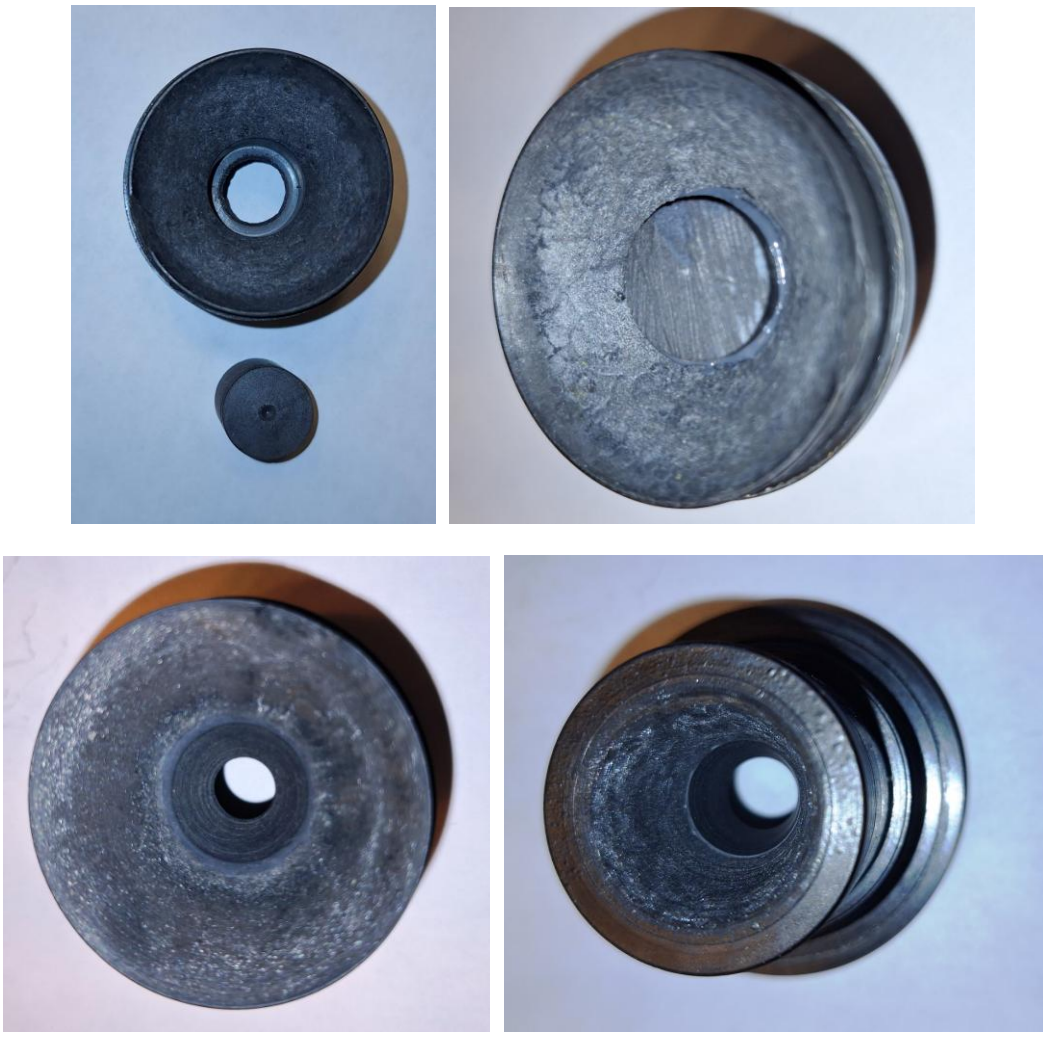


Figure 18 a, b, c, d. Dexter's graphite throated hybrid nozzles.

Motor Liner Tube:

TheAeroTech reload kits came with an orange glassine covered cardboard liner tube that measured 1.985" OD x 1.875" ID x 10.35" long (Figures 17 and 23). The closest substitute is the phenolic liner tube for 54/1280 motors from AeroTech (which I have found to be reusable):

Phenolic Motor Liner, RMS-54/1280 (rocketmotorparts.com)

O-rings:

In addition to the O-rings mentioned earlier, two different O-ring sizes are needed for use in the combustion chamber of this motor (Figure 19). Two of the 2” OD Buna-N O-rings to seal the rear and forward closures (these are dash 224 size):

Buna-N O-ring, 2" O.D. (rocketmotorparts.com)

And one 5/8” OD Buna-N O-ring is needed to seal the Teflon separator disk and block the flow of nitrous prior to ignition (these are dash 111 size):

Buna-N O-ring, 5/8" O.D. (rocketmotorparts.com)

Figure 19. O-rings for the combustion chamber and pyrovalve along with a jar of Krytox oxygen-safe lubricant.

Insulator Washers and Tubes:

Two different sizes of phenolic or fiber washers are needed, one larger 1.990” OD phenolic washer for the forward end of the fuel grain (Figure 20);

[Washer, 1.990" (rocketmotorparts.com)]

and one smaller fiber washer for the forward end of the pre-heater grain.

The “official” RMS Hybrid washer that matches the 1.125” OD of the pre-heater insulator tube is no longer available from AeroTech but I have found the slightly smaller one that fits inside the 1.00"ID of the pre-heater insulator tube seems to work satisfactorily (Figure 20).

Washer, 1.000" (rocketmotorparts.com)

Alternatively, you can sand the OD of 38 mm washers. Stacking several together with a bolt and nut for an axle will facilitate sanding several at once. I am beginning to double these up out of an abundance of caution since a single washer is entirely consumed during a typical burn.

And you need a short 1” long insulator tube for the pre-heater grain. I started out cutting a foot long section of 29 mm fiberglass motor tube into appropriate lengths (Figure 20).

29mm X 12.000" Long Fiberglass Casing (rocketmotorparts.com)

But given the issue shown in Figure 22, it may be better to use a paper liner tube which would incinerate more easily. In that vein, have found out that my cardboard mini-hybrid 29 mm motor adapter tubes (see www.micronitrorocketry.com) can be cut and lightly sanded to make these and are more economical than the fiberglass version. You also may be able to modify the AeroTech delay liners:

[Delay Insulator, 54mm (rocketmotorparts.com)]

But I have found these need to be sanded heavily in the ID to work with 29 mm Blue Thunder pre-heater grains.

Figure 20. Insulative washers and tubular pre-heater liner.

Since the large phenolic washer typically burns out in its center, I have had situations where the pre-heater insulator tube has dropped into the motor core during the burn (as seen in Figure 22). So recently,I have started using an aluminum washer (Figure 21) as a bulkhead inserted at the forward end of the fuel grain to serve as a positive stop for the pre-heater tube. This washer is a modified Mc Master Carr # 93286A156 that I turned down to 2” OD (note that # 93286A155 is 2” stock OD and therefore should work without modification). To use this washer requires shortening the fuel grain and the liner by about 0.1”. This washer is reusable.

Figure 21. Aluminum washer bulkhead placed at the forward end of the fuel grain and just behind the 1.99” phenolic washer to serve as a positive retainer for the pre-heater tube.

Figure 22. A fiberglass pre-heater liner that dropped out of place and fell into the core of the fuel grain during early flight. This caused a noticeable pop in the sound of the burn but no other ill effects were noticed.

Fuel Grains:

One of the beauties of hybrid rocket motors is the ability to experiment with fuels so the world opens up here to your creativity. For example Patrick has made both sorbitol-based and paraffin-based grains and I have made a PVC and HDPE pipe-based grain. I am including the dimensions for the standard two-section kraft paper reload grains that were supplied by AeroTech for the J-145 (2 jet), J170 (3 jet) and J210 (4 jet) flight configurations:

1 Forward paper fuel grain 1.87” OD x .875” ID x 2.00” long
1 Aft paper fuel grain1.87” OD x 1.375” ID x 7.94” long

These grains are pictured in Figure 23 along with an original orange cardboard liner tube. Note that the core port is “stepped” a ways back from the front to promote turbulence and improve fuel/oxidizer mixing. It is fairly easy to replicate these grains by rolling and gluing tubes made of contractor/builder (brown kraft) paper from your local home store; or even easier, make grains incorporating scrounged cardboard mailing tubes, carpet roll cores etc. Interestingly, the OD of shipping tubes used for 38 mm *Cesaroni* reloads is exactly the same OD as AeroTech 54 mm fuel grains! AeroTech 38 mm reload tubes are the same size too if you peel the yellow paper wrap off of the cardboard. In any case, simply select the tubes you have available, modify the outer diameters as needed by gluing on wraps of contractors paper. Next nest and cement as many tubes inside each other to adjust the ID as necessary. Finally trim the resulting blank to length. I have stockpiled left-over cardboard tubes and can put together a paper grain in short order!

Figure 23. Original paper fuel grains and liner tube.

If you really get into flying these hybrids you can order large quantities of custom made cardboard tubes from suppliers like Yazoo Mills that will help reduce the cost per flight of fuel.

Pyrotechnics and Associated Parts:

Lastly we will look at the various pyrotechnics that are used in this motor. One downside of this motor is the need for a small amount of pyrotechcnics; unlike *HyperTEK*, for example, which doesn't use any. None-the-less AeroTech came up with an ingenious way to do three important hybrid motor functions during ignition virtually simultaneously:

1) Start the flow of N_2O
2) Decompose the N_2O into free nitrogen and oxygen
3) Ignite the fuel grain in the oxygen rich environment

Step 1 is implemented by blocking the injector jets with a thin sheet of Teflon sealed with an O-ring and this presses against a pellet of black powder (the "**pyrovalve element"**). Upon firing of the "**electric squib igniter"** the BP burns and melts the Teflon separator sheet (i.e. a burst disk) and this allows the self-pressurized nitrous to flow through the injectors. Teflon is available in 0.010" sheets (e.g. McMaster Carr # 8569K18) that can easily be punched with a 5/8" craft circle punch (Figure 24).

Figure 24. Craft styled circle punch along with three 5/8" diameter Teflon separator disks.

For example:

Dress My Craft - Circle Punch - 0.625 Inches (scrapbook.com)

Sitting just below the pyrovalve element is a 1" long cylinder of 29 mm Blue Thunder APCP propellant called the "**pre-heater grain**". This is ignited by the combination of the electric squib igniter and the burning BP pyrovalve element. Once the pre-heater starts burning there is enough heat and spark generated to accomplish step 2 (decompose the nitrous) and subsequently, step 3, (ignite the paper fuel grain in this oxygen rich environment).

The pyrovalve element was a specialty-supplied pellet of pressed black powder and is no longer made. We will fall back to the method that Gary Rosenfield used when he was developing the original motor. He cut slugs 1/4" thick by 5/8" in diameter from *Estes* 18 mm paper and BP motors (Figure 25). These can be made reasonably safely by careful cutting with a fine tooth woodworkers draw saw or hacksaw along with a plastic miter box (Figure 26) or a hobby saw and aluminum miter box. Whatever method you choose be absolutely sure it is non-sparking! The paper exterior is then peeled back to achieve the proper 5/8" OD.

Figure 25. "Pyrovalve element" made from an Estes 18 mm motor.

Figure 26. A draw saw and plastic miter box being used to cut "pyrovalve elements".

The pre-heater grain is likewise made by cutting 1” long slugs from longer AT 29mm Blue Thunder propellant sticks and then drilling out a 3/8” or 7/16” port (Figure 28):

[29mm Blue Thunder™ Propellant Grain (rocketmotorparts.com)]

Finally an effective electric squib igniter can be made from a low current e-match with at least 24” long leads, the head of which is epoxied into a 1 1/4” long section of soda straw. The straw is then filled with Black Powder or *Pyrodex* etc. and the open top of the straw is closed off with a bit of wadding and taped shut (Figures 27 and 28).

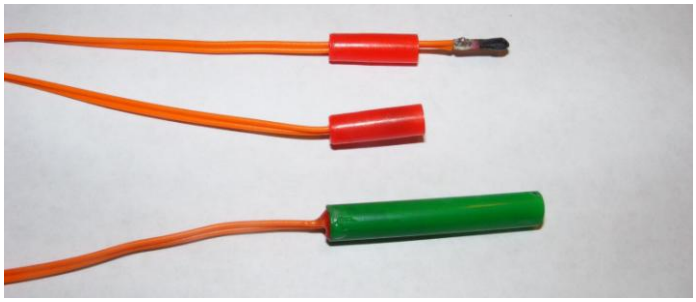


Figure 27a (top) Making an e-match based BP or Pyrodex powered squib igniter and 27b(bottom) a completed squib igniter running through a soda straw guide.

An igniter guide tube inserted up the core of the fuel grain in the combustion chamber helps place the igniter head inside the pre-heater grain and against the pyrovalve element.
I simply tape together a couple of soda straws and cut the resulting tube to 13 3/8” length to make these (Figure 27b). The usual red caplugs can be purchased or a reasonable substitute cap can be made from cut up plastic aspirin (or similar) bottles and lined with cardboard to fit the nozzle OD. Drill a small hole in the bottom of this cap for passage of the wires. Once in place over the end of the nozzle, this cap supports the guide tube and holds the igniter up against the pyrovalve element.

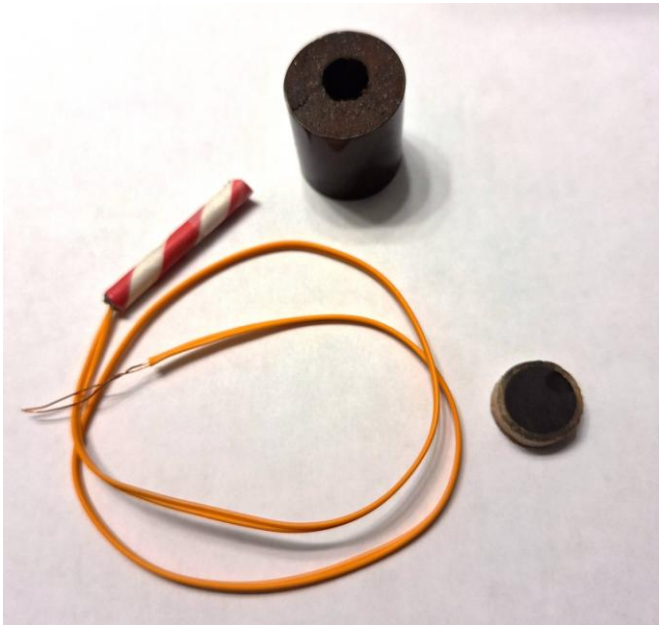


Figure 28. Pyrotechnic components for the Revival Hybrid.

Tools and Accessories:

1) A pair of small straight tip (about 0.047”) snap ring pliers to remove and replace the injector plate
2) A 3/8” “Allen wrench” hex key to remove and replace the pyrovalve jam screw
3) Krytox oxygen safe lubricant for all O-rings exposed to N_2O (Figure 18)
4) A 24 mm open-end wrench or an equivalent adjustable wrench to remove and replace the flight tank valve.
5) A digital balance with at least 1 gram precision to weigh flight tanks while filling
6) An ice chest to keep the nitrous tank cool during transport or for refilling in the field
7) Substantial gloves and quality eye/face protection!

Loading and Assembling the Motor:

When you have finished collecting all the components for your motor, refer to the *RMS /Hybrid 54/1280 Assembly and Operation Instruction Manual* to learn how to properly and safely load, assemble and fire it. I can e-mail you a pdf copy of my manual if you have difficulty locating one.

Related Readings:

Lathe-based Pin Valve Modifications for Patrick Carroll's AeroTech RMS 54/1280 Hybrid Revival Project V.9 (2026) Leland R. Dexter. 21 pp. Available for download from the links listed in the above text; or, to be sure of getting the latest version, request a copy directly from me by e-mail shown in the title block.

Making Simple "Fixed Jet" Injector Plates for Patrick Carroll's AeroTech RMS 54/1280 Hybrid Revival Project V.3 (2024) Leland R. Dexter. 12 pp. Available for download from the links listed in the above text; or, to be sure of getting the latest version, request a copy directly from me by e-mail shown in the title block.

Re-building and Re-furbishing AeroTech Phenolic/glass Nozzles for use with Patrick Carroll's AeroTech RMS 54/1280 Hybrid Revival Project V.4 (2026) Leland R. Dexter. 11 pp. Available for download from the links listed in the above text; or, to be sure of getting the latest version, request a copy directly from me by e-mail shown in the title block.

RMS /Hybrid 54/1280 Assembly and Operation Instruction Manual, Version 2.0 (1998) AeroTech Corp, Cedar City, UT, 40 pp. (this is the manual provided with the original motor and I can e-mail a scanned pdf copy of mine).

Additional Notes to the RMS /Hybrid 54/1280 Assembly and Operation Instruction Manual for the Revival Hybrid (2026) Leland R. Dexter. 6 pp. Available for download from the links listed in the above text; or, to be sure of getting the latest version, request a copy directly from me by e-mail shown in the title block.

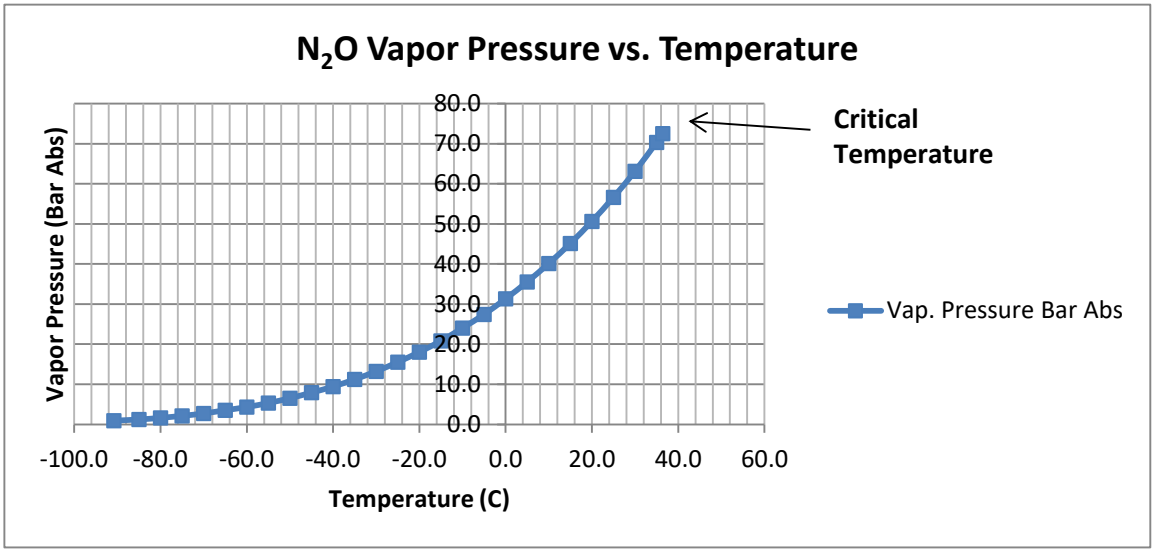
RMS /Hybrid Data Pack, (1998) AeroTech Corp, Cedar City, UT, 121 pp. (note: if you purchase the full data pack you will get the instruction manual listed above included with it).

Hybrid Safety, Richard M. Newlands (2019) self published in conjunction with the Aspirespace Rocket Engineering Society and available for download from (www.aspirespace.org.uk), 80 pp. A worthwhile reference for anyone using hybrid motors.

APPENDIX A

Temperature vs. Pressure for N_2O Tanks

	T (F)	P (psi)		
	-30	167		
	-20	203		
	-10	240		
	0	283		
	10	335		
	20	387		
	32	460		
	40	520		
	50	590		
	60	675		
	70	760		
	80	865		
	85	950		
	97	1069		
Note 97° F is Critical Temperature for N_2O				
Source: www.nitroussupply.com				



APPENDIX B

Basic N_2O Safety Issues

Overall nitrous oxide is one of the safest oxidizing compounds used in amateur rocketry. But, because we are using N_2O across a phase boundary, and not that far from its "critical point", it can have some quirky behavior that has led to fatal explosions. Also, the pure gas produces a "euphoric high" and deadens pain response as seen in its widespread use in medical applications (aka laughing gas). I am presenting a few important points regarding safe handling of nitrous oxide particularly with respect to rocketry applications. The following points have been distilled from Richard Newlands excellent publication on "Hybrid Safety". Those who are safety minded should read this paper:

http://aspirespace.org.uk/downloads/Hybrid%20safety.pdf

- Explosion/combustion concerns
  - Nitrous oxide has never been known to combust or explode while in the liquid state (but rapid expansion has lead to flash boiling providing more vapor).
  - Gaseous nitrous oxide does show quirky behavior that has lead to serious explosions.
    - BLEVE (a so-called **B**oiling **L**iquid **E**xpanding **V**apor **E**xplosion) Rapid leaking decompression of the flight tank has caused the nitrous to flash boil (part of the cause of the 2007 multi-fatality accident at Scaled Composites at Mojave California).
    - Small amounts of overheated vapor ignited by even a tiny spark, or blowback from the combustion chamber or overheated accessories can cause rapid dissociation (also a factor in the Scaled Composites accident and the primary cause of the fatal 2016 Airgas explosion at Cantonment Florida). This dissociation is exactly what we want to happen in our combustion chamber to liberate oxygen for burning; but we don't want it to happen further up in our plumbing!
    - Avoid rapid pressure change situations during filling (adiabatic compression aka "water hammer effects") and insure your N_2O systems are operating well below critical temperature (97^oF or 36.1^oC). Be aware of how fast your rocket will gain temperature as it sits on the pad before launch (quite often tens of degrees above air temperature as the sun heats the airframe).

I use a small *Bluetooth*-based temperature sensor taped to the top of my flight tank on hot and sunny days. I also keep an insulated jug of ice water at hand in case it becomes necessary to cool a flight tank.

    - Ask your LCO for an expedited launch on hot days.

- Medical concerns:
    - Nitrous oxide should not be handled in poorly ventilated areas and you would certainly not want to have a 10 pound leaking supply bottle riding in your car to a launch!
    - Note that racing grade N_2O is "denatured" by the addition of SO_2 to discourage inhaling this substance.
- Material concerns
    - Petroleum-based O-ring lubricants will combust in the presence of N_2O. Be sure to use only oxygen-safe lubricants like Krytox.
    - Copper along with its oxides and alloys are known to be catalytic for decomposition of nitrous oxide under extreme conditions (very high temperatures); and mixed opinion exists over the use of brass fittings with N_2O. But brass components, like injectors and tank valves, have been used for decades in commercial hobby and amateur rocketry with no known problems.
    - Silicone soaked in nitrous oxide has been shown to produce a shock sensitive explosive material. I have never seen any problems with silicone O-rings used in amateur hybrid combustion chambers as the contact time with the nitrous is very short.

APPENDIX C

Cleaning Parts that Contact N_2O

Following manufacturing or modification, parts may be contaminated with various petroleum-based products like cutting oils. It is important to thoroughly clean any components that may be exposed to nitrous oxide. This is a three step process:

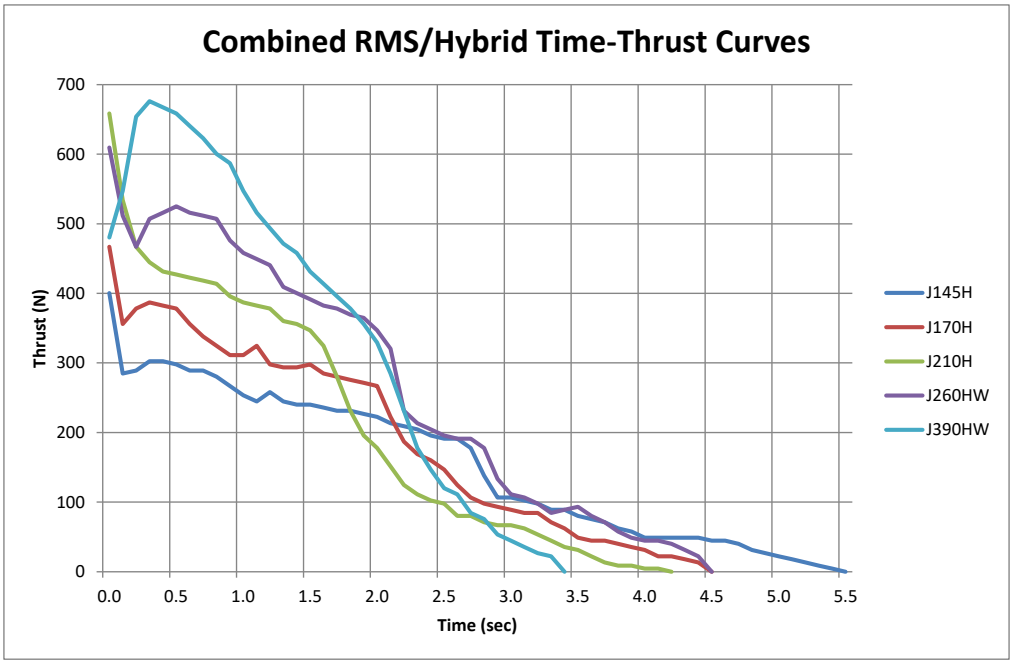
1. Acetone bath
2. Isoproponal (aka isopropyl) alcohol 99% pure bath
3. Chlorinated brake cleaner bath

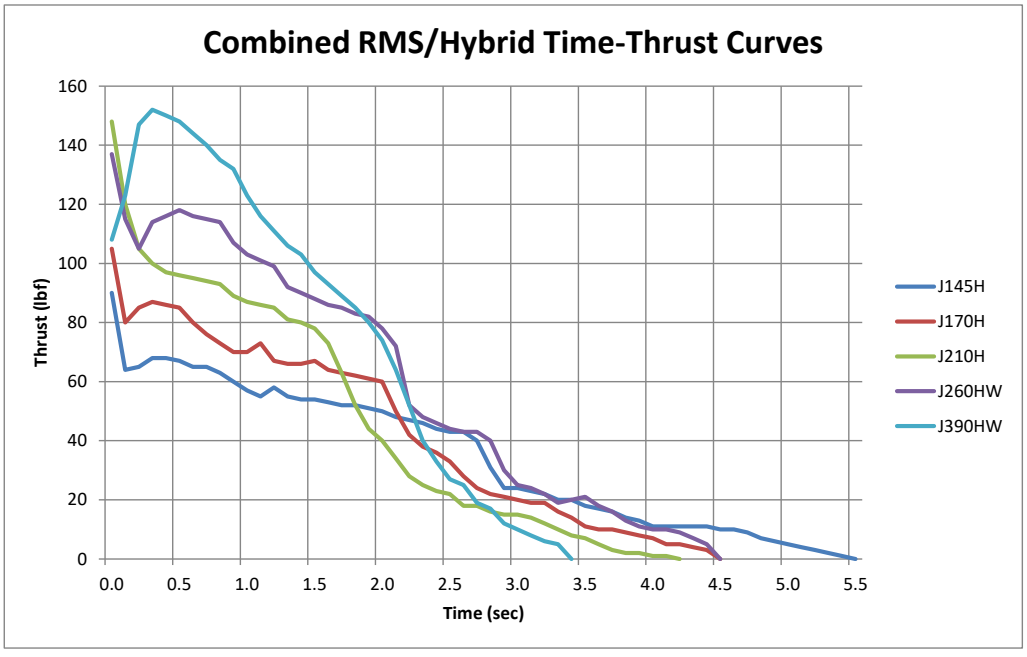
These solvents are harsh so handle with care and avoid breathing fumes.

APPENDIX D

Thrust Curves Derived from AeroTech Data

For burns using 299 grams of N_2O

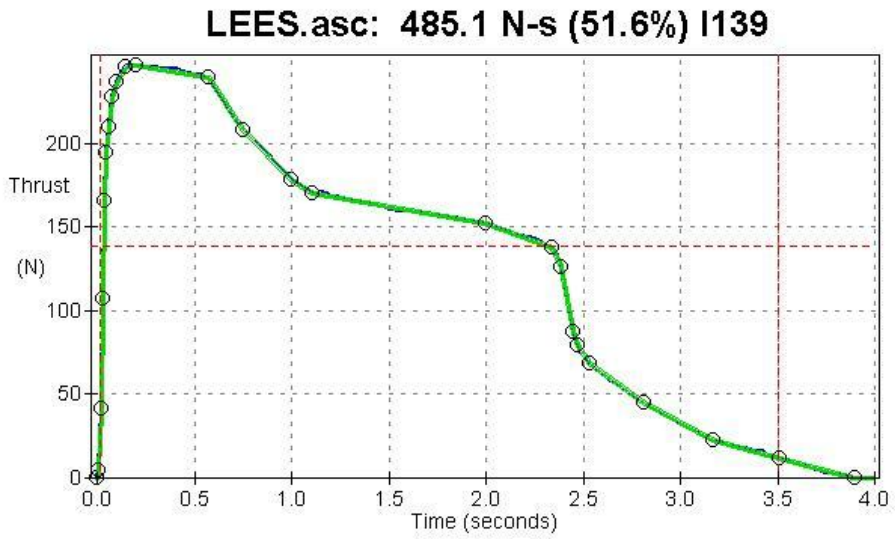




APPENDIX E

Example Thrust Curve Derived from Dexter's Test Stand Data

From a static test using an 852 Ns case, 2 jet injector, poplar wood grain and 255 grams of N_2O. Peak thrust 247 N, Average thrust = 139N, Total impulse = 485 Ns



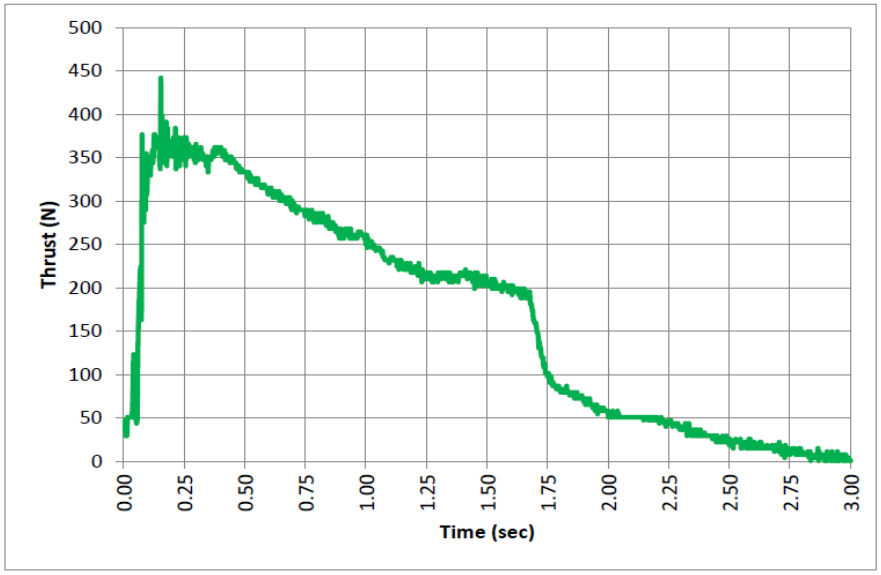
Peak = 246.99, Avg = 139.0, Isp = 157, Burn time = 3.49

Created using ThrustCurveTool, www.ThrustGear.com

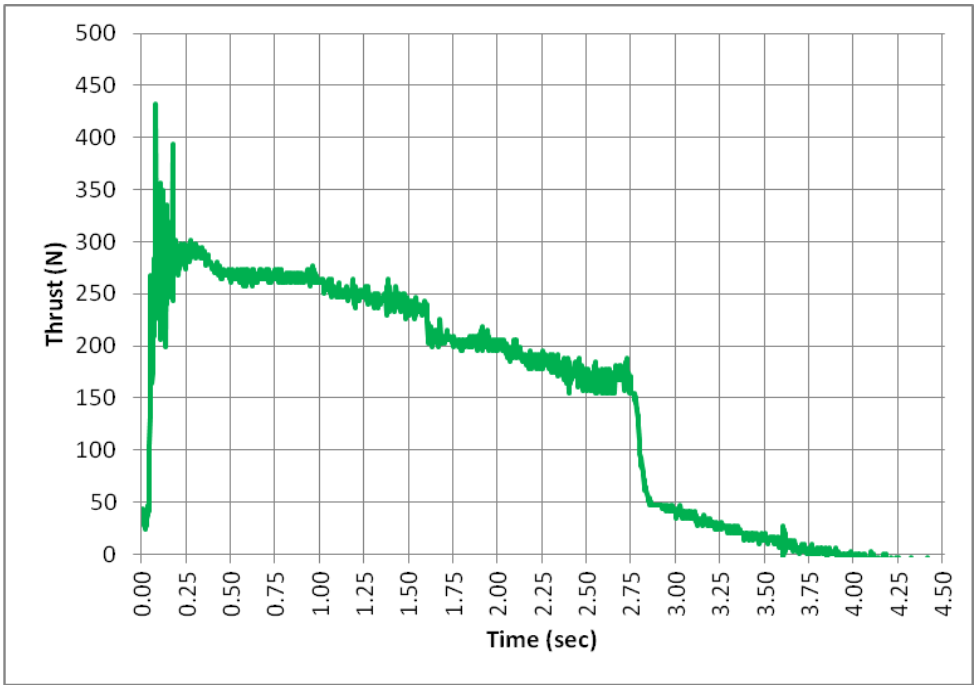
APPENDIX F

Example Thrust Curves Derived from Featherweight Raven 3 Flight Data

From a flight using a 1280 Ns case, 3 jet injector, paper grain and 250 grams of N_2O
Peak thrust 438 N (a spike), Average thrust = 167 N, Total impulse = 502 Ns



From a flight using a 2 jet injector, sorbitol-PVC multi-grain and 300 grams of N_2O
Peak thrust 432 N (a spike), Average thrust = 145 N, Total impulse = 649 Ns



APPENDIX G

Saving Money When Flying Revival AeroTech RMS Hybrids

One of the benefits of making the effort to assemble this motor is the ability to save substantial money over the long haul. Back in 2016, I was hoping just to be able to find consumables to allow me to even fly this motor! Since discovering Patrick's work and making a few of these motors myself, I have now actually found ways to save quite a bit of money with consumables (50% to 66%) compared to flying equivalent APCP reloadable motors. To illustrate this, I will list the components I use for a typical J-class Revival hybrid flight these days, along with their associated costs. The example shown here uses paper grains but other materials could keep costs low also (see Appendix E). A note on the glass/phenolic nozzle, each burn typically ablates the nozzle throat diameter by a bit less than 0.1". While not necessarily optimal for best thrust, it may be possible to reuse the burned nozzle from a 2-jet flight for a subsequent 3-jet flight etc. This should allow a new $36.50 nozzle to be used for two or three flights reducing the cost to as low as $12.25 each flight. This neglects the substantial additional savings possible from using the graphite throat rebuild described earlier!

2/3 pound nitrous oxide = $7 to $9
1 glass/phenolic hybrid nozzle x 3 re-uses by increasing jet count each burn = $12.25 per flight.
1 cardboard liner tube (actually now a reusable phenolic liner tube) = $3 per flight
1 Forward paper fuel grain (scrounged paper/cardboard tubes) = $2 for glue & extra paper
1 Aft paper fuel grain (scrounged paper/cardboard tubes) = $2 for glue & extra paper
2 Fuel grain O-rings = $3 (McMaster-Carr)
1 Pyrovalve O-ring = 5 cents (McMaster-Carr)
1 Pyrovalve element = $1.50 (cut from Estes C6 BP motors, 12 disks from a 3 motor pack)
1 Pyrovalve Teflon separator disk – under 10 cents each from McMaster-Carr
1 Pyrovalve backup washer = $0 (reusable from initial motor assembly)
1 Forward insulator phenolic washer = $1.25 from AeroTech/RCS
2 N_2O Pre-heater forward insulator fiber washers = 2 x 50 cents from AeroTech/RCS
1 N_2O Pre-heater insulator 1 1/8" OD x 1' long paper tube = 60 cents from AeroTech/RCS
1 N_2O Pre-heater grain cut from 12.5"x 29mm Blue Thunder = $1.25 from AeroTech/RCS
1 Nozzle cap = 0 (I use cut up empty aspirin bottles)
1 igniter w/ 24" leads and guide tube = $1 (e-match, BP, soda straws)

TOTAL = $36 Compare this to a typical J-class APCP propellant reload kit at about $100!