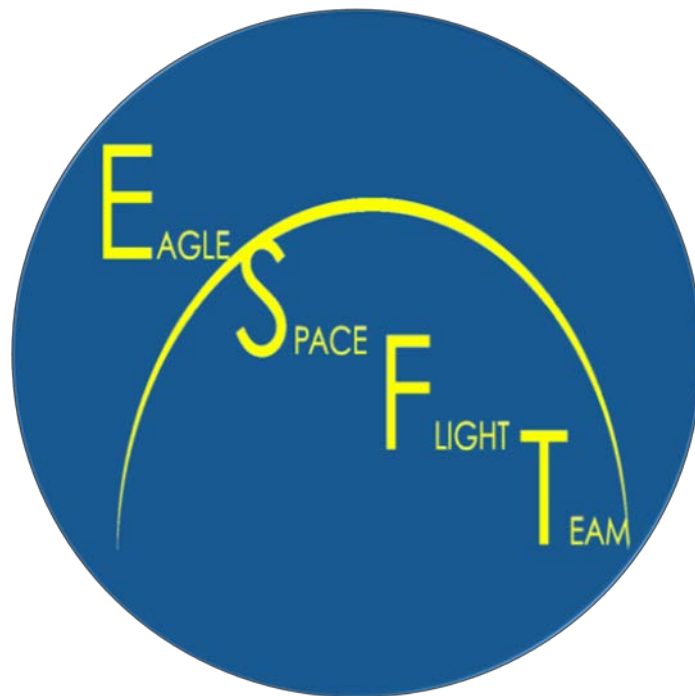


# Eagle Space Flight Team 54mm Propellant Mixing Procedure

Rev. 1 – 2/25/15



## **Introduction**

This document is a procedure for the mixing and processing of large (multiple pounds) batches of ammonium perchlorate composite propellant (APCP) for use in amateur rocket motors. Its purpose is to provide a means for the Propulsion Group of the Eagle Space Flight Team (ESFT) to safely produce a consistent, reliable solid rocket propellant for use on ESFT's rocket test flights leading up to and including an attempt at a suborbital spaceflight. This version of the document, specifically, is tailored to the mixing and processing of propellant for the 54mm - diameter motors we will use to perform a ballistic characterization of our propellant. These motors will each contain approximately 2lb of propellant, and each individual motor will be mixed as one batch of propellant.

## **Method**

For mixing the propellant, the team will use a 6qt KitchenAid mixer. Its powerful motor, sturdy construction, and reliability have made this particular mixer the standard in amateur rocketry circles. To avoid generating excess heat during mixing, the mixer is run at a moderate speed, just fast enough to prevent the thickness of the propellant from causing the motor to seize and burn out.

After mixing, the bowl of propellant will be fitted with an acrylic lid attached to a vacuum pump. The vacuum pump will then be used to pull a light vacuum on the contents of the mixing bowl. This will remove any air bubbles introduced into the propellant during mixing as well as any trapped gas from the curing process of the propellant's binder.

After vacuum processing, the propellant will be packed into cardboard casting tubes with an aluminum mandrel in the center. Each propellant grain will be cast individually, eliminating the need for any cutting or drilling of the propellant after curing.

## **Safety**

Safety of those working with propellant is the highest priority of any propellant manufacturing operation. During the entire propellant mixing process, all personnel will wear eye protection. Those working directly with propellant chemicals will wear nitrile gloves, and all personnel will wear dust masks during the measuring and incorporation of the dry components of the propellant. Those working directly with propellant will wear non-loose fitting clothing made of cotton or wool (**No synthetics!**), and long hair will be tied back.

In order to account for the extremely unlikely event of the propellant igniting during mixing, the mixer will not be located inside while it is running. Instead, it will be located a safe distance from the building on the end of an extension cord. The mixer's speed will be set with it powered off. It will then be switched on and off by inserting and removing the end of the extension cord plugged into a wall socket a safe distance away.

In order to keep dust to a minimum, dry propellant chemicals will be added with the mixer powered off and gently incorporated by hand until they are sufficiently wetted out to prevent any dust from being kicked up when the mixer is restarted. No team members will stand near the

mixer while it is switched on and off, and monitoring of the mixing process will take place with a Lexan blast shield between any personnel and the mixer.

During all mixing operations, one person will constantly man a chemical fire extinguisher (**No water-filled “pump cans”!**), and another will man the point where the extension cord plugs into a wall outlet. In the extremely unlikely event of the propellant igniting during mixing, all team members will move away from the mixer and the person manning the wall outlet will immediately power off the mixer. The mixer, which will be a safe distance from any structures or personnel, will then be allowed to burn until all propellant in the mixing bowl has been consumed. It is only at that time that the person with the fire extinguisher will attempt to put out any remaining fires fueled by parts of the mixer itself.

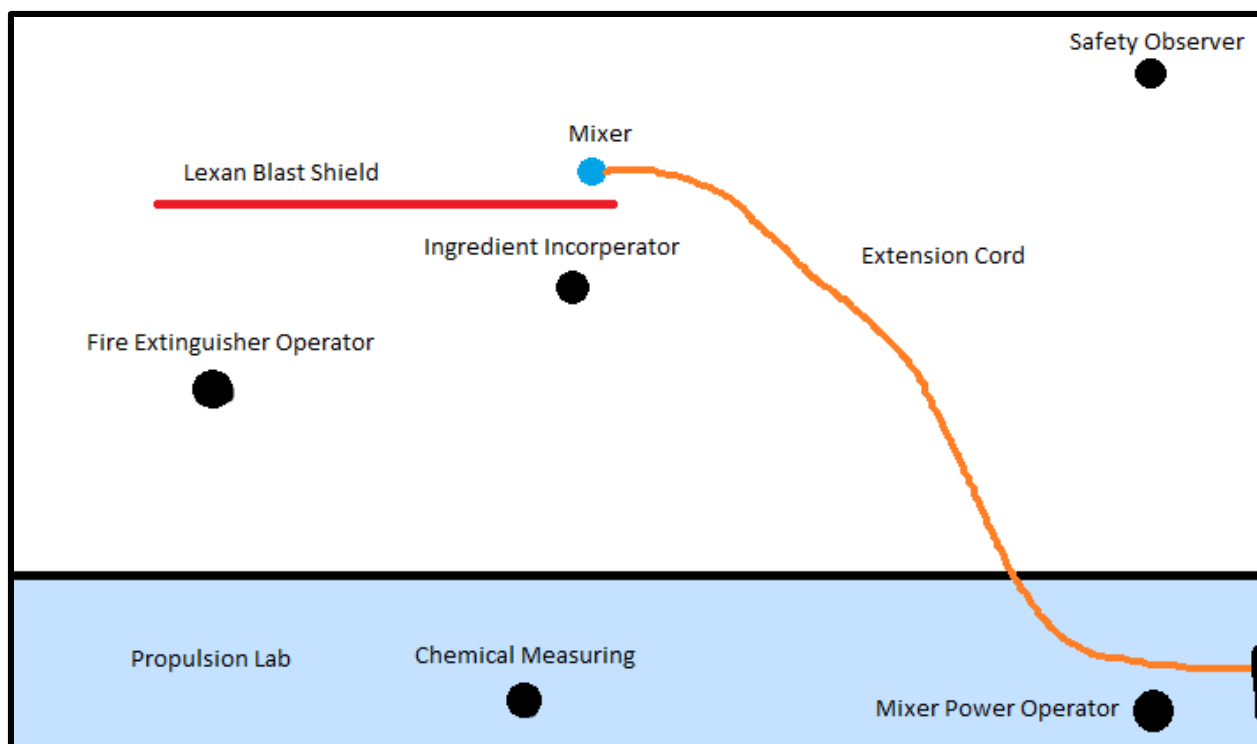
After mixing, vacuum processing, and packing of the propellant is complete, it will be allowed to cure in a fire cabinet designated for solid rocket propellant and other self-oxidizing materials. After the propellant has cured and the mandrel has been removed, the propellant will continue to be stored in the same cabinet until it is needed for static testing or flight. Mix sessions will be scheduled such that this storage interval is as short as is feasible.

## **Personnel**

The personnel present for any mixing session will be assigned to one of the following duties.

- Chemical Measuring: Weighs out precise amounts propellant chemicals into temporary containers before mixing starts. This makes the mixing operation itself run more smoothly.
- Ingredient Incorporation/Mix Observer: Adds propellant chemicals to mixing bowl one at a time in the order presented later in this document. Occasionally checks propellant during mixing to ensure that it is being mixed thoroughly enough to produce a consistent product.
- Mixer Power Operator: Mans the location where the mixer plugs into a wall outlet. Switches mixer on and off as needed during mixing and remains ready to switch off mixer in unlikely event of propellant ignition.
- Fire Extinguisher Operator: Stands ready with fire extinguisher. In unlikely event of propellant ignition, they will wait until propellant has been fully consumed before extinguishing remains of mixer.
- Safety Observer: Watches area surrounding mixing operation for safety hazards. Keeps unrelated personnel a safe distance away from mixing operation.

The setup for propellant mixing will be arranged similarly to the diagram on the next page.



In this setup, all personnel have either a blast shield, building wall, or sufficient offset distance between themselves and the mixer at all times. Sufficient offset distance is considered to be at least 30ft without a blast shield or wall.

## **Procedure**

### **Propellant Formula**

The propellant formula to be used by the team consists of the following components.

- 200μ Ammonium Perchlorate: The propellant's oxidizer
- 20μ Atomized Spherical Aluminum Powder: The propellant's fuel
- 5μ Oxamide: Burn rate suppressant.
- R-45M Hydroxyl-terminated Polybutadiene Resin (HTPB): The propellant's binder. Also serves as a fuel.
- Desmodur E744/MDI Isocyanate: Curative for the HTPB.
- Isodecyl Pelargonate (IDP): Plasticizer for the HTPB.
- Silicone Oil: Anti-foaming agent/surfactant.

Before mixing, all personnel working with propellant must read and familiarize themselves with the MSDSs for the propellant chemicals.

These chemicals are to be mixed in the following proportions, each percentage being a portion of the desired mass of propellant to be mixed.

- Ammonium Perchlorate: 72%
- Aluminum: 7%
- Oxamide: 3%
- HTPB: 14.08%
- E744/MDI: 2.12%
- IDP: 1.8%
- Silicone Oil: One drop per kilogram of propellant being mixed

## Equipment

The following equipment is needed for each propellant mix session.

- Safety glasses
- Dust masks
- Nitrile gloves
- Lexan blast shield
- Chemical fire extinguisher
- 6qt mixer fitted with paddle
- Mixing bowl corresponding to mixer
- Ice cream spade
- Extension cord, minimum length 30'
- Vacuum pump
- Plexiglas lid fitted to bowl with fitting for vacuum pump
- Core mandrel
- Casting tube caps
- Casting tube
- Metal or wood packing rod
- Mold release spray
- Paper towels
- Mineral spirits
- Metal "burn bucket"

## Procedure

### **Read through this procedure in its entirety before beginning to mix!**

The process of mixing propellant is both time sensitive and unforgiving of mistakes. It is imperative that all personnel know exactly what tasks to perform and exactly when to perform them.

Throughout this procedure, important safety notes will appear in boxes such as this one. Important procedural notes will appear bolded within the text.

1. Set up the mixer, extension cord, blast shield, and fire extinguisher as shown in the figure earlier in this document.

2. Cut casting tube to desired grain length. Spray coring rod and casting tube caps with mold release. Insert coring rod into bottom (non-vented) casting tube cap before sliding the casting tube over the core mandrel and seating it in the cap. **Do not get mold release on the inside of the casting tube.** A thorough bond between the propellant and the inside of the casting tube is imperative to proper motor operation.

The tube should fit snugly into the cap. If the casting tube fits loosely in the cap, wrap a few layers of masking tape around the bottom of the tube. If the casting tube will not fit, lightly sand the bottom of the tube.

**If not wearing them already, all personnel don safety glasses at this time. All personnel in the chemical measuring area don nitrile gloves and dust masks at this time.**

3. If you have not done so already, use the percentages in the propellant formula earlier in the document to calculate the mass of each component needed for the desired amount of propellant to be mixed. **Double and triple check your calculations before moving forward.**
4. Measure the ammonium perchlorate, aluminum, oxamide, curative, and plasticizer into **separate** disposable containers.

**Ammonium perchlorate and aluminum are never to be allowed to come into contact without the binder!**

The binder acts as a burn rate suppressant for the ammonium perchlorate/aluminum mixture and also increases the activation energy of the propellant. With the binder, this mixture will burn at approximately the same rate as office paper and requires a substantial energy input to ignite. Without the binder, the mixture is virtually identical to pyrotechnic flash powder, possessing a fast burn rate and sensitivity to friction and physical shock.

5. Measure out the HTPB resin. This ingredient can be measured directly into the mixing bowl. Next, add the plasticizer and silicone oil into the bowl. Do not stir the contents of the bowl at this time. The goal is to create a pool of plasticizer on top of the resin.
6. The aluminum is then added to the bowl by pouring it into the pool of plasticizer. When pouring in the aluminum, keep its container low over the surface of the liquid in order to keep dust to a minimum. Allow the plasticizer to soak into the aluminum until it is completely wetted out. Then, gently incorporate the aluminum into the mixture by hand using the ice cream spade. Do not move on to the next step until the aluminum powder is completely wetted out and evenly distributed within the HTPB. The container into which the aluminum was measured is then discarded in normal garbage.
7. The oxamide is then added to the bowl in the same manner as the aluminum, taking care with dust prevention. It is then incorporated into the mixture by hand. The container into which the oxamide was measured is then discarded into normal garbage.

**From this point on, all waste will be disposed of in the burn bucket.**

Waste which has not come into contact with ammonium perchlorate is safe to dispose of in normal garbage, but any oxidizer-contaminated waste must be disposed of in the burn bucket. This waste will be burned before disposal. The procedure for burning this waste is outlined later in this procedure.

8. Approximately one third of the ammonium perchlorate is added to the bowl at this time, employing the same dust prevention practices used with the other solid components. The ammonium perchlorate is then wetted out and incorporated into the mixture by hand as before.
9. Another third of the ammonium perchlorate is then added to the bowl and wetted out by hand.
10. The final third of the ammonium perchlorate is then added to the bowl and wetted out by hand. The bowl is then placed in the mixer which is then switched on and allowed to mix the propellant for ten minutes. During this process, the mixing is stopped every few minutes in order to scrape down the sides of the mixing bowl.
11. The mixer is then stopped and the E744/MDI is added to the bowl. The mixer is then restarted and allowed to mix the propellant for 10 minutes, stopping every few minutes to scrape down the sides of the bowl.
12. The bowl is then removed from the mixer. The vacuum lid is placed on the bowl and the vacuum pump is switched on and allowed to pull vacuum on the propellant for five minutes.
13. The pump is switched off and the lid is removed. The propellant is then pulled from the bowl, rolled into "clay snakes", and dropped into the casting tube. Occasionally, the packing rod is used to tamp down the propellant. With the packing rod, the goal is not to mash the propellant into the tube, but rather to ensure a well-packed, uniform propellant with no voids present in the grains.
14. Once the casting tube has been filled, the top (vented) casting tube cap is slid over the mandrel and seated on the top of the casting tube. If multiple grains are being cast, the next casting tube (already fitted with a non-vented bottom cap) is slid onto the mandrel and propellant packing proceeds as with the first grain.
15. Once all propellant is packed, the casting setup is placed in a fire cabinet and allowed to cure. This process will usually take a few days.
16. The mixing bowl, mixer paddle, ice cream spade, and packing rod are all thoroughly cleaned with paper towels and mineral spirits. These paper towels and any scrap propellant are disposed of in the burn bucket. **After cleanup is complete, no propellant residue whatsoever may remain on any tools or equipment.**

17. After cleanup is complete, the burn bucket is taken to a remote area away from combustible materials. Its contents are then ignited either electronically or using a fuse and allowed to burn completely. The ashes left over are then doused with water and disposed of in normal garbage.

**Firefighting measures must be in place when burning the contents of the burn bucket!**

This includes at least two people and at least one chemical fire extinguisher. Shovels and/or rakes are also useful for firefighting.

18. After three to five days, the propellant should be fully cured. The casting tube caps can now be removed and the core mandrels pulled out of the grains. The propellant is to be stored in a fire cabinet until use.