



Propellant Development Team

Proposed Investigations

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### Introduction

This document describes several propellant-related investigations that are proposed to be conducted in support of the **Sugar Shot to Space** project. The purpose of these investigations is to facilitate selection and testing of a large-scale propellant production method required for this project. The investigations also relate to potential enhancement of propellant performance, reliability and safety.

**1. Inert propellant** – It is expected that “inert propellant” will be used to test the various casting methods, including casting of the full-scale grain segments. This would constitute both a safety and a cost saving measure. The inert propellant that had previously been developed uses salt (sodium chloride) instead of potassium nitrate (see <http://www.nakka-rocketry.net/inert.html> ). The problem with salt is that it does not behave quite the same as potassium nitrate, and the resulting propellant tends to caramelize (when used with dextrose) or does not become fluid (with sorbitol). Prior testing of inert KNSB made with salt indicated that the resulting slurry is “pastelike”, even when heated well beyond normal casting temperature (175°C.), and as such, is not castable.

The challenge that lies ahead is to come up with a substitute “inert” material for the potassium nitrate that does not exhibit this behaviour, and in fact, behaves as similarly to potassium nitrate as possible. The key to success might be (as described on the reference web page) a material that has a similar “specific heat capacity”. This property determines how much heat energy a material needs to absorb to raise its temperature. There are numerous web pages that list the specific heat capacity of various chemicals, such as: <http://webbook.nist.gov/chemistry/>  
Other factors may be responsible, however.  
Obviously, a prospective material must be safe to use and reasonably available and inexpensive.

**2. Effect on performance of KNSB blending** – This could be very important to determine if we end up using a “traditional” casting method. Intuitively, the better the KNSB is blended, the better, and more consistent, the performance will be. But how much blending is needed as a minimum to get the performance & consistency we need, taking into account practical limitations & safety considerations?

Experimentation will likely involve test firing a small motor with KNSB propellant prepared with various degrees of blending.

Also included in this investigation would be the approach whereby propellant is prepared by first melting the sorbitol, then blending in the potassium nitrate.

For each batch of propellant prepared, the potassium nitrate should be ground to an identical particle size (best to prepare one batch of potassium nitrate, enough for all batches, to guarantee particle size is the same for all).

**3. Addition of an opacifier** – This should be seriously considered to reduce internal heating of the propellant grain during combustion. Since KNSB is relatively translucent, IR heat transmission could pose a problem for large grains such as those needed for our purpose. Burn rate could be enhanced beyond that expected. As well, it is possible that the odd “triangular thrust” nature of KNSB (often referred to as “flushing”) could be a consequence, at least to some extent, of its translucency. Experimentation would involve the addition of a small amount of an opacifying agent (e.g. carbon, charcoal) and conducting static firings of a small motor with a BATES grain to determine the effect on performance, burn time, and thrust curve shape. Further investigation would be needed if an opacifier is found to be beneficial and is considered as a contender for our project. Such investigation would include measurement of burn rate as a function of pressure, and the consequence of overheating during casting.

**4. Modification of O/F ratio** – It may be worthwhile to consider small modifications to the 65/35 O/F ratio of standard KNSB. For example, a ratio of 65.5/34.5 or 66/34 might be considered if the performance gain is sufficient to justify the additional propellant characterization that would be needed if such a formulation were to be adopted. Investigation could include GUIPEP runs to determine theoretical gains followed by small motor static testing, if justified, to determine actual gains.

As an alternative to static motor testing, “ballistic bomb” measurements would indicate any increase in characteristic velocity ( $c^*$ ).

If such modification proves promising, additional investigations would then be warranted, such as determination of casting characteristics (e.g. slurry temperature, viscosity, etc.) and eventually measurement of burn rate as a function of pressure.

**5. Experimenting with KNSB alloys** – the alloying of sorbitol with other sugars such as sucrose or dextrose might be a promising solution to a number of drawbacks with KNSB. Limited experimentation has suggested that an alloy of sorbitol and sucrose cures a lot faster than basic KNSB. This could be an important advantage for our huge grains, especially considering the large number of grain segments needed. The odd “triangular” thrust curve of KNSB might be alleviated to some degree, which again would be a big advantage. Other factors such as greater burn rate of alloyed propellant could be an advantage, as well.

The following aspects of KNSB alloys are proposed to be investigated:

**5a. Melting of KNSB alloys** – This experimentation would be relatively simple, with the intent being to compare the melting temperature and slurry characteristics of various KNSB alloys.

**5b. Hygroscopicity of KNSB alloys** – This experimentation would also be relatively simple, with the intent being to compare the resistance of various KNSB alloys to moisture absorption in the open air. It is important to know if the known resistance of KNSB to moisture absorption is compromised. Experimentation would involve casting specimens of various degrees of alloying, and exposing them to various levels of humidity (e.g. 60%, 70%, 80%, etc.). Control samples would also be prepared of standard KNSB for comparison.

**5c. Cure time of KNSB alloys** – This experimentation would involve casting a number of KNSB samples with varying amount of alloying agent, and measuring the time duration for the propellant to “cure”. Of course, it would be necessary to come up with a criterion for the cured condition for the basis of comparison.

**5d. Thermal stability of KNSB alloys**- Melted KNSB is considered to have a more or less unlimited pot life, which is a great advantage of this propellant, especially for our application. If alloys of KNSB are to be considered, it is necessary to know if the pot life is significantly reduced. Proposed experimentation would involve melting the mixture and maintaining it at a prescribed temperature (i.e. typical casting temperature of 130°C.) for an extended time period, and observing changes to its physical state. This would be repeated for compositions of varying degrees of alloying.

**5e. Performance of KNSB alloys**- This would probably represent the most ambitious study relating to KNSB alloys. It is necessary to determine if there is a performance advantage (or degradation) over standard KNSB. Test firings would be conducted utilizing a small motor using BATES grain. Various KNSB alloys would be compared to basic KNSB with regard to specific impulse, burn time and shape of the thrust curve.

**5f. Overheating experiment**- This would be performed only if a KNSB alloy is selected as a possible contender for our project. Experimentation would involve overheating a mixture of the alloyed propellant in order to determine how sensitive it is to inadvertent overheating during the casting operation. This is important to know from an overall safety perspective. Overheating experiments have been performed in the past on the three basic sugar propellants, for example: <http://members.aol.com/riccnakk/sorb.html#Overheating>

**5g. Burn rate at elevated pressure** - This would be performed only if a KNSB alloy is selected as a possible contender for our project. Measurements of burn rate at elevated pressure, over a suitably large pressure range, would need to be performed using a strand burner apparatus. This would allow for determination of

burn rate exponent and burn rate coefficient data, which is essential for motor internal ballistics design.

**Suggested KNSB based alloys for consideration:**

Designation	Alloying sugar	Ratio ( potassium nitrate/sorbitol/other )			
KNSBSU	sucrose	65/30/5	65/25/10	65/20/15	65/15/20
KNSBDX	dextrose	65/30/5	65/25/10	65/20/15	65/15/20

**6. Potassium nitrate solutions and liquid phase sorbitol** – In the document *Summary of Proposed Propellant Casting Schemes* ([http://www.sugarshot.org/downloads/ssts\\_propellant\\_schemes.pdf](http://www.sugarshot.org/downloads/ssts_propellant_schemes.pdf)), the Krech Method and the Krech/Nakka Method both attempt to take advantage of the liquid phase form of the propellant constituents to aid grain production and to enhance safety. Experience with these proposed techniques is virtually non-existent, and as such, it is not currently known whether or not such methods are feasible. The only similar method that has been tried by rocketry experimentalists in the past is the “water method” whereby the constituents are dissolved in water which is then boiled off.

If either of these methods is deemed to be worthy of further investigation, then it will be necessary to conduct experiments to determine:

**6a. Solubility of potassium nitrate in hot water.** This represents the determination of how much potassium nitrate can be dissolved in hot water (e.g. grams KNO<sub>3</sub>/ 100 grams H<sub>2</sub>O). Experimentation would involve the addition of potassium nitrate to hot water, in increasing amounts, until the limit of solubility is reached. Concurrent to this would be the measurement of boiling point at the various levels of concentration. The data obtained would be compared to the published value of 338.5 g KNO<sub>3</sub> in 100 gram water with boiling point of 115° C.

This information would be pertinent to both the Krech Method and the Krech/Nakka method.

**6b. Solubility of sorbitol in hot water.** This represents the determination of how much sorbitol can be dissolved in hot water (e.g. grams sorbitol/ 100 grams H<sub>2</sub>O). Experimentation would involve the addition of sorbitol to hot water, in increasing amounts, until the limit of solubility is reached. Concurrent to this would be the measurement of boiling point at the various levels of concentration.

This information would be pertinent only to the Krech Method.

**6c. Liquid phase sorbitol/KNO<sub>3</sub>/H<sub>2</sub>O mixture.** Pertaining to the Krech/Nakka Method, this investigation would determine how effectively

molten sorbitol would blend with concentrated  $\text{KNO}_3/\text{H}_2\text{O}$ . Experimentation would involve combining these liquids, and noting how well the resulting mixture blends, changes in viscosity, and other observations. Follow up investigation would involve “drying” of the resulting solution with vacuum and noting the time required for all moisture to be driven off. This would be determined by measuring the change in mass of the solution. The addition of heat would be required during this evaporation process, which is endothermic (absorbs heat). The viscosity of the final product would also be noted.

**6d. Propellant characterization.** Since the propellant that results from these methods is more homogeneous than that produced by the conventional mix & melt method, it is expected that the burn rate characteristics would be different. Performance may be affected in other ways, as well. If propellant production by either of these methods is deemed to be practical and worthy of consideration for our project, it would be necessary to fully characterize the propellant. This would involve the determination of burn rate characteristics at elevated pressure, and measurement of specific impulse by small motor static testing.

**6e. Other investigations.** If propellant production by either of these methods is deemed to be practical and worthy of consideration for our project, further investigations may be needed. Such investigations could include small-scale “continuous casting” of an actual propellant grain to determine how much time is required for casting of a grain, as well as determination of possible pitfalls.

Overheating experiments would also have to be conducted to determine if propellant produced by this method has increased sensitivity to accidental ignition during production.

If alloyed KNSB is deemed to be worthwhile of consideration, certain investigations described above would need to be repeated or modified to suit.

**6f.  $\text{KNO}_3$  crystal size.** With conventional mix & melt casting, the oxidizer particle size is controlled by the milling operation. With the solution methods, the oxidizer particle size is determined by crystal growth during processing. It is important to know what factors affect crystal size (e.g. evaporation, cooling rate, stirring, other) and whether crystal size can be readily controlled for consistent propellant performance, especially burn rate. Experimentation is needed to study the effect of cooling rate and evaporation rate on oxidizer crystal size.

**7. Mechanical strength of propellant** – Tentative measurements of certain key mechanical properties of KNSB propellant have already been undertaken (see <http://members.aol.com/riccnakk/sorb.html#Mechanical> ). More precise measurements should be taken, as this data is important for structural analysis of our rocket motor, to ensure safe and reliable operation during static testing and under flight conditions. This is

especially important if the propellant formulation is modified (e.g. O/F ratio, opacifiers, etc.) or if the production method is non-conventional.

**8. Grain shrinkage during cooling** – As KNSB propellant cools after being cast, it naturally tends to shrink in volume. The degree of shrinkage, and the consequence of shrinkage, needs to be investigated. Possible results of shrinkage are reduced grain length, increased core diameter, and disbonding at the propellant/casting liner interface. The consequence of the latter is potentially serious, and means needs to be developed by which the potential for disbonding is eliminated. Two suggested means are curing the grain under pressure (mechanical, hydraulic or pneumatic) and application of a bonding agent (e.g. epoxy adhesive) to the casting liner inside surfaces prior to casting. Other possible consequences of grain shrinkage should be considered, as well.

**9. Effects of storage** – Although it is expected that the propellant grains will be cast as close to usage date as possible, certain delays may be inevitable. As such, it is important to know the effects of “long term” storage, especially on grains of large mass such as those needed for our rocket motor. Possible effects are dimensional changes, hygroscopic deterioration, slumping, microstructure changes or chemical changes. Other possible consequences of grain storage should be investigated, as well.

**10. Consequence of accidental ignition** – Regardless of how much effort is put into designing and implementing a “safe” propellant production process, the very nature of rocket propellant makes the production of it inherently risky. The inadvertent ignition of a sizeable batch of propellant can have serious consequences both to personnel and to equipment. As such, it must be assumed that such an event **will occur** during the manufacturing process, and safeguards must be built into the process to minimize consequential harm. What exactly happens when a sizeable batch of propellant is ignited is the goal of this particular investigation. Experimentation would involve the preparation and safe & remote ignition of a sizeable:

- 1) batch of well-blended powdered propellant mixture at room temperature
- 2) batch of molten propellant slurry at typical casting temperature

Results would be suitably videotaped to allow approximate measurement of combustion time and fireball size. **Extreme care must be exercised in the implementation of these experiments!**