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Shrox Plan: “Bisix”

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Deciding Which Nose Cone Shape To Use For A High-Altitude Rocket

By Vicente Alvero and Hans Olaf Toft

Background

The Sugar Shot to Space (SStS) rocket has a design goal of reaching at least 100km in altitude, using a low performance sugar-nitrate propellant in a single stage rocket. In order to achieve this goal, it will be important to keep the drag loss at a minimum. Two strategies are being applied in this respect:

1. Dual phase rocket motor
2. Minimum drag airframe

The dual phase motor splits the burn into two parts, divided by a coasting phase. This allows the rocket to save half of its propellant until it has passed through the denser part of the atmosphere.

The minimum drag airframe will improve the rockets altitude performance by keeping the energy loss in form of aerodynamic drag at a minimum. The overall shape of the rocket consists of a nose cone and a cylindrical rocket body and one set of fins. The dimensions of the cylindrical body are determined primarily by motor design restrictions and are as such outside the scope of this report. The dimensions of the fins are to be determined according to stability requirements, and are also outside the scope of this report. The purpose of this report is to investigate the impact of shape and fineness ratio of the nose cone on the performance of the rocket, when it follows a trajectory profile that is reasonably realistic.

Dual phase configuration		
Run ID number	dph47	
Configuration	dual-phs.	
SIM code	SOAR	
Metric or Imperial	M	
Cd function code	cdo=0.4	
Phase Delay (sec.)	16.5	sec
Vehicle OD	25.5	cm
Motor total impulse	257850	N-s
Motor burn time (each ph.)	8.7	sec
Motor average thrust	29638	N
1st charge grain mass	202	kg
2nd charge grain mass	202	kg
Vehicle dead mass	88.0	kg
Vehicle liftoff mass	492	kg
Propellant mass fraction	0.822	
Meet 14 CFR Ch.3 crit?	No	
Max. altitude	107694	m.
Max. velocity	1542	m/s
Max. mach no.	5.2	
Max. acceleration	240	m/s/s
Min. Acceleration	-63	m/s/s
Burnout altitude, 1st phase	1946	m
Burnout altitude, 2nd phase	16843	m

Image 1A: Performance predictions of the DPH47 rocket.

Vehicle (Single dual-burn motor + vehicle ancillary items)

Fins	5	lb	
Nosecone	8	lb	
Payload	15	lb	
Fairings	8	lb	
Recovery systems	15	lb	
Other	12	lb	
Total	63	lb	Vehicle ancillary mass
	28.6	kg	
Vehicle diameter	10	in.	Max
Vehicle dead mass	193	lb	Complete empty vehicle
	87.6	kg	
Vehicle gross mass	1085	lb	Vehicle + 2 propellant charges
	492	kg	
2nd burn gross mass	639	lbm	Vehicle + 1 propellant charge
	290	kg	
Frontal area	78.5	in²	Based on uniform diameter
Ballistic coefficient	13.8	lbm/in²	Gross vehicle mass / frontal area
Over limit			14 CFR Section 401.5 limit <12 lb/in²

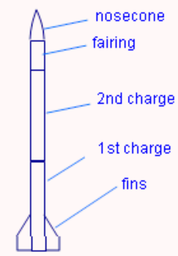

Image 1B: Additional specification of the DPH47.

Conditions

This investigation is based on Richard Nakka's DPH47 configuration as detailed in Image 1A and 1B.

Design Tools

This investigation is based on the "Aerolab" drag and stability software and the "Launch" trajectory simulation software, both by Hans Olaf Toft.

"Aerolab" is used to calculate the coefficient of drag in the entire Mach range of relevance for the SStS for the configuration candidates of the airframe. The calculated drag coefficients are fed into the trajectory calculator, and the output is collected into a spread sheet for comparison. The trajectory simulator is being tricked to handle the dual phase configuration by adding a zero weight first stage and a dummy stage separation.

Although the overall purpose of this study is to set up a realistic scenario, some things are not known at this early stage. This affects the drag model in two ways:

1. Base drag reduction during powered flight is ignored as there is (yet) little knowledge of the nozzle dimensions.

2. The dimensions and number of fins are not yet

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known. Furthermore, fin canting has been suggested but not (yet) specified, so the drag contribution from the fins has to be guesstimated. All the candidate configurations are being analysed with the same set of dummy fins that are assumed to provide a reasonable first order approximation of the fins impact on the trajectory profile.

The base configuration, featuring a 3:1 conical nose cone is shown below in Image 2A.

Candidate configurations are being generated using all the nose shapes currently implemented in Aerolab:

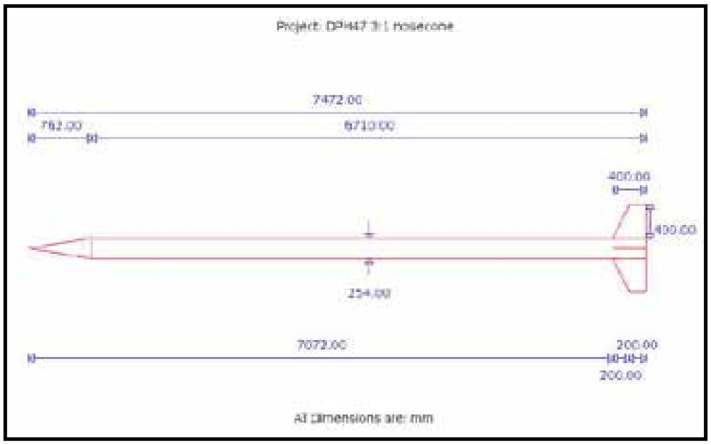

Image 2A: Configuration of the DPH47.

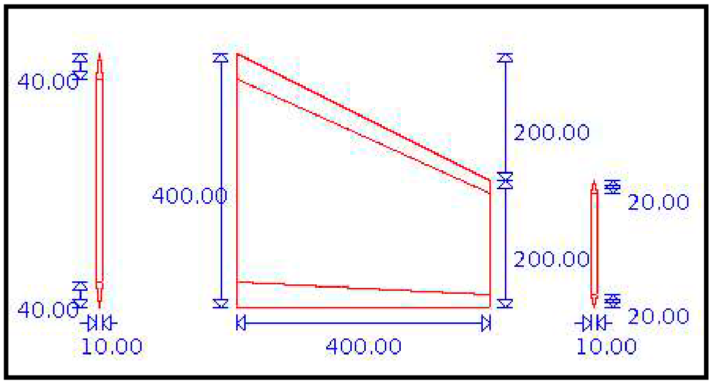

Image 2B: Fin planform

- Conical
- Tangent Ogive
- Parabolic
- Elliptical
- ½ Power
- ¾ Power (also known as "hypersonic optimum")

Configurations are being generated with nose fineness ratios of 2:1, 3:1…,7:1 for all shapes. A trajectory simulation of the DPH47 configuration is being run for all combinations of shape and fineness ratio. The trajectory simulator calculates – among other things – the altitude and drag loss (in Newton seconds) versus time.

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Trajectory profile

The main highlights of the trajectory when using the standard drag model from Launch is:

1st phase burnout	8.70s	2232m	558m/s
2nd phase ignition	16.50s	5882m	401m/s
2nd phase burnout	25.20s	13664m	1638m/s
Apogee	164.75s	107689m	257m/s

The drag varies mostly with the Mach number, so one wants to check out the variation in Mach number as seen in Image 3.

One notable feature of this chart is that the Mach number stays constant between approximately 60 and 70km. This is not because the rocket travels at constant speed, but rather that the Mach velocity decreases with altitude at the same rate as the rocket speed decreases. This is however a curiosity, as the air drag is neglible at that altitude.

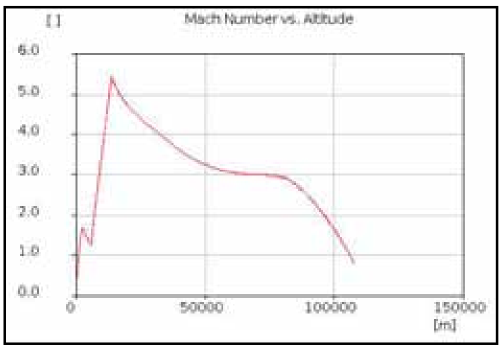

Image 3: Speed of the rocket versus altitude

Different nose shapes are known to be optimal at different Mach ranges, so in order to select the best nose shape, it would be advisable to look at the velocity distribution as seen in Image 4.

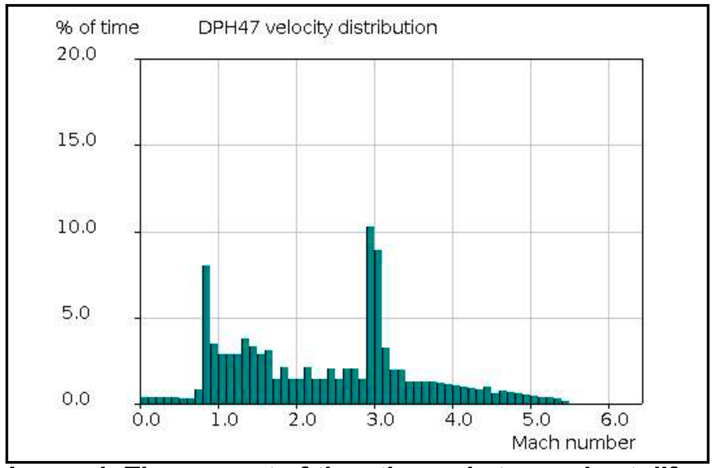

Image 4: The amount of time the rocket spends at different flight speeds.

Again, the Mach 3 peak is clearly visible. Even ignoring this, the rocket will spend approximately 50% of the travelling time at Mach 1.5+, where the hypersonic optimum

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shape has minimum wave drag for any given fineness ratio. For comparison, the same rocket spends approximately 35% of the travelling time at transsonic speeds, where the hypersonic optimum shape is not the optimal choice.

Simulation results

The simulation results are listed below.

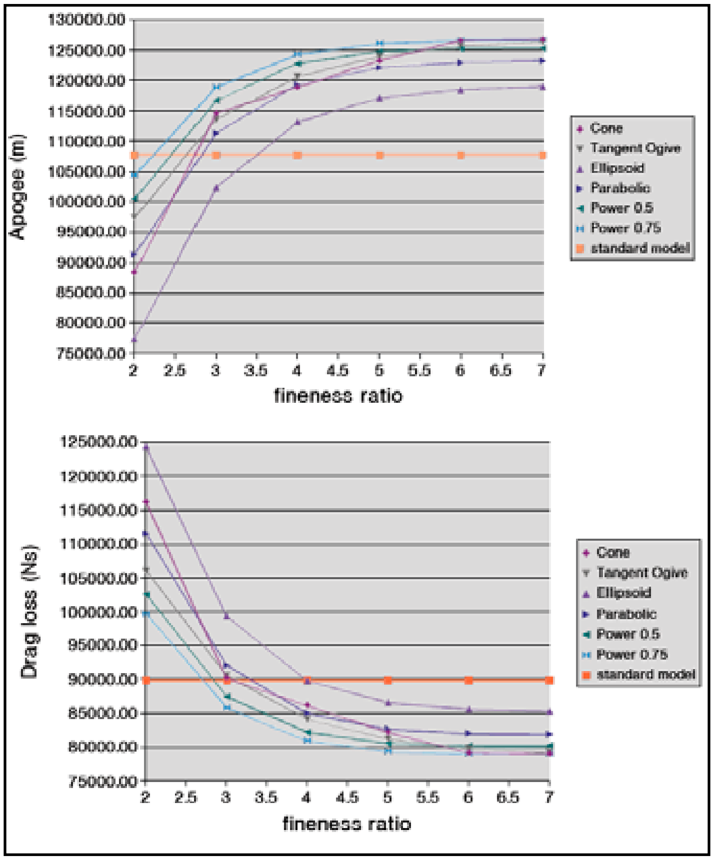

Image 5: The performance predictions of different nose cone shapes at different length-to-diameter ratios.

The main conclusions are

- For any given fineness ratio, the hypersonic optimum shape has the least drag loss. The difference in drag loss between conical and hypersonic optimum shapes decreases however for increasing fineness ratio, and at 7:1 it has nearly vanished.
- For any given shape, altitude increases with increasing fineness ratio. However, the benefits of increasing fineness ratio beyond 5:1 are small.
- For fineness ratios up to 6:1, the hypersonic optimum shape yields the highest apogee - but for increasing fineness ratios, the conical shape gets increasingly closer in performance, and at 7:1 fineness ratio, the conical shape yields the highest apogee, although only by a very small margin.

The wave drag contribution decreases at higher fineness ratios, so skin friction becomes more important, and it becomes less important what shape has the least high Mach number wave drag.

Not surprisingly, the elliptical shape has poorer performance than the other shapes, but except from that, and perhaps the parabolic shape, the difference in apogee between the other shapes is so small for the higher fineness ratios, that other criteria may be taken into account when selecting the shape. A 5:1 fineness ratio may be chosen over 7:1 for practical reasons. The hypersonic optimum shape may be chosen for performance, but the penalty for choosing a conical shape is neglible, and it would have the advantage of simplicity. Also there are the thermal considerations. In general, the aerodynamic heating increases with the equivalent nose vertex angle, so a conical nose would be expected to have higher temperature at the base than the hypersonic optimum but lower temperture at the tip. However, the temperature rise also depends on the lo-

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cal heat capacity, and the tip of a hypersonic optimum nose can have a larger heat capacity so it may still have the lowest skin temperature overall. A blunted cone could be a reasonable way of approximating the hypersonic optimum shape while keeping the simplicity of a cone.

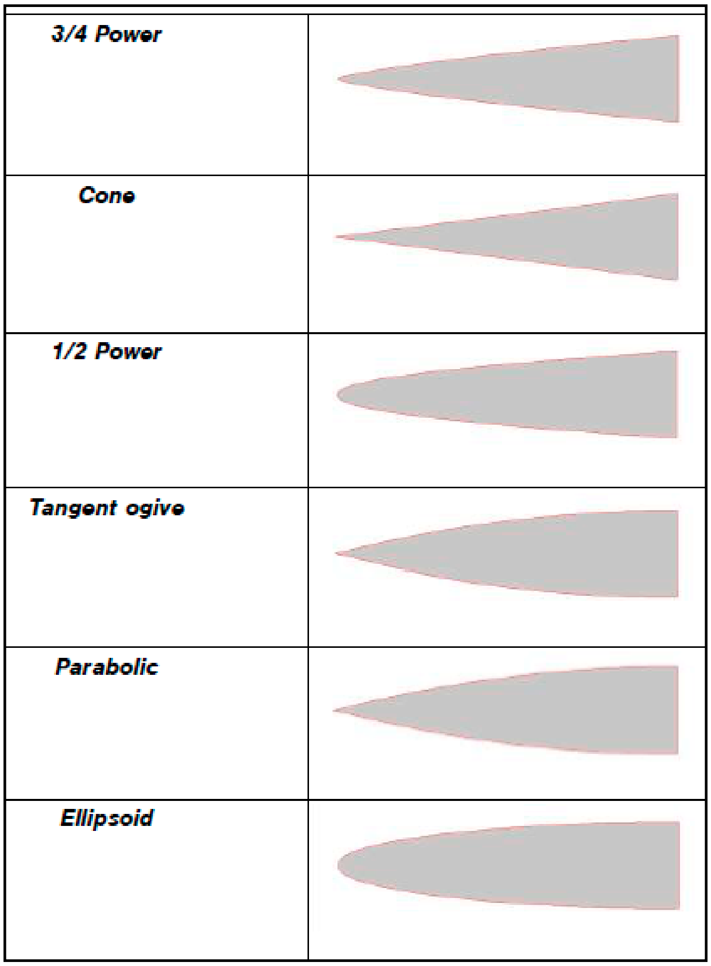


Image 6: Shapes of the nose cones simulated.

The estimated wave drag coefficient of the different nose shapes can be seen in Image 7 for comparison. Fineness ratio is 5:1.

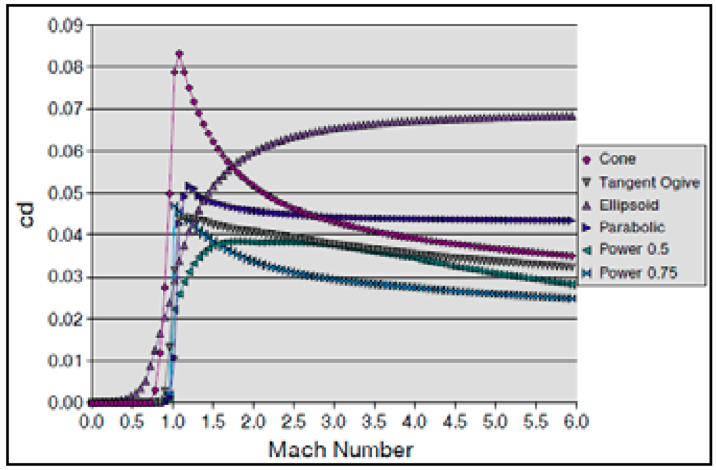


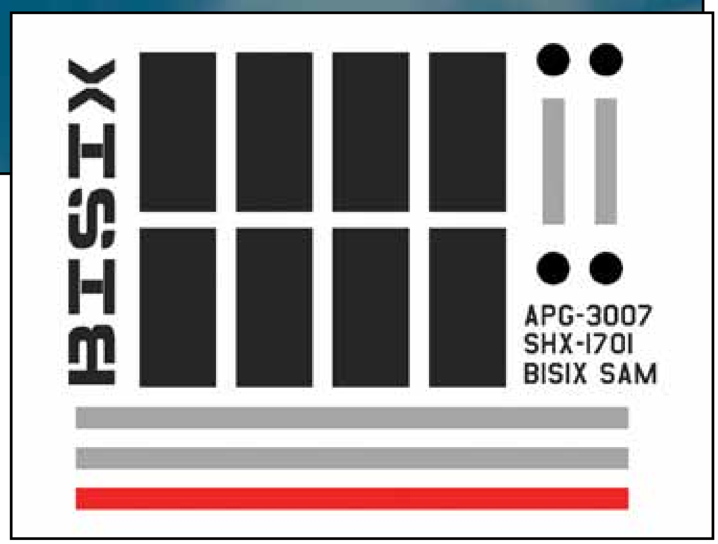
Image 7: Wave drag coefficient for different nose cone shapes (fineness ratio is 5:1).

About the Author:

Vicente Alvero Zambrano is a Student of physical science and lives in Santa Marta de los Barros (Badajoz- Spain). His goal in model rocketry is to make space more accessible. He also enjoys cycling, robotics, electronics, chemistry, physics, and geology.

Shrox Plan: The "Bisix"

By Shrox



Download the RockSim file (which includes the parts list) and the decal file at: www.ApogeeRockets.com/Downloads/Bisix.zip