PEAK OF FLIGHT

NEWSLETTER

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Cover Photo: The DynaStar Rip-Roar rocket kit. Get it now at: www.ApogeeRockets.com/Rocket_Kits/Skill_Level_3_Kits/Rip-Roar_Rocket_Kit

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Improved Designs for the D Super-Roc Altitude Contest

By Chris Flanigan

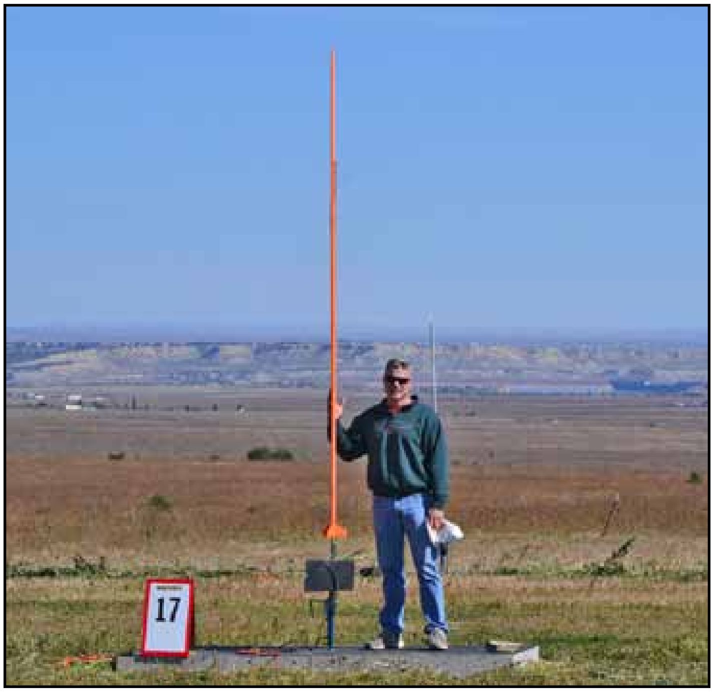

Figure 1: Super-rocs are long rockets that test the builder's ability to create structurally sound models that still fly high.

Introduction

Super-Roc is a very unique competition event. The models are usually very tall, often taller than the contestant!

When super-roc models fly successfully, they're elegant and amazing. The Estes "Mean Machine" and similar tall models are very popular at sport launches. However, super-roc models sometimes fail during flight, often in spectacular and entertaining ways. The primary failure mode is "kinking" or buckling of the airframe during boost. Another failure mode is aerodynamic instability, even when standard stability checks (such as the Barrowman method) indicate substantial margin.

Recent R&D work by the author[1] has developed new methods to predict the behavior of super-roc models. The methods account for how the flexibility of a superroc airframe affects the model's structural and aerodynamic stability.

D SuperRoc Altitude will be one of the events at NARAM56 (http://naram56.org). This will be an excellent opportunity to use the new techniques to develop higher performance super-roc designs with better confidence that the models will fly successfully.

Analysis of Flexible Rockets

What makes a Super-Roc model different from other model rockets? The obvious feature is that super-roc models are much longer than typical model rockets. However, the most important feature of a competition super-roc model is that the airframe is usually very flexible. This is quite different than a typical model rocket where the airframe is essentially rigid.

To analyze super-roc models, we must use "aeroelas-

Figure 2: Too much flexing can cause the tubes to buckle and the rocket to fail.

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1 *"Modal Aeroelastic Analysis of Super-Roc Vehicles,"* NARAM53 R&D report, 2011.

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ticity" methods. Aeroelastic analysis simply means that the analysis includes both aerodynamic terms and elastic airframe effects, including the interaction between these terms. The same methods are used in the aerospace industry to assess the aeroelastic performance (flutter and divergence) of commercial jet liners, high speed military aircraft, and missiles.

Aeroelastic effects are crucial for super-roc models. At high speeds, the forward end of the model starts bending more. This multiplies the aerodynamic force on the nose cone. In addition, the aft end of the model will bend, reducing the effectiveness of the fins. If the model is too flexible, these two effects can lead to structural buckling or aerodynamic instability. As you can see in Figure 2, having too much flexibility can cause the model to buckle.

Aeroelastic analysis of a model rocket can be performed using a computer program called "FlexRoc". This program is available as a free download from the "ContestRoc" Yahoo Group[2]. The FlexRoc program performs a simplified aeroelastic analysis including aerodynamic normal forces on the nose cone, transitions, and fins. Elastic and mass effects are defined using a Rocksim-like definition of the body tubes and other components of the model. Output from the FlexRoc program is shown in Figure 3. When the frequency of the rotation mode drops to zero, that is the velocity at which the vehicle will buckle or go unstable. Additional information about Super-Roc aeroelastic analysis and the FlexRoc program will appear in an upcoming issue of *Sport Rocketry* magazine.

2 http://groups.yahoo.com/neo/groups/contestRoc/conversations/messages

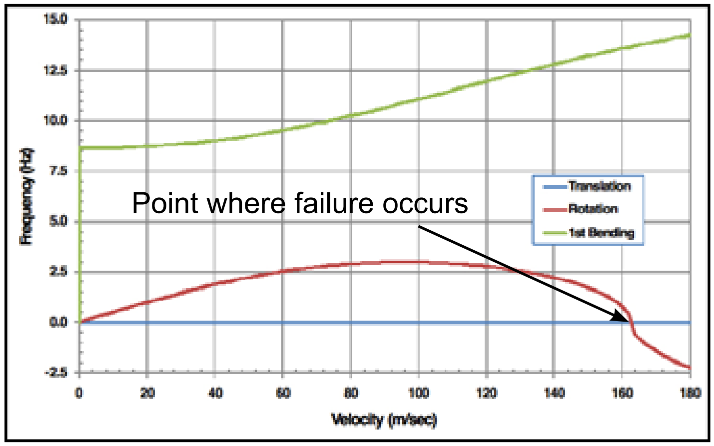

Figure 3. FlexRoc predicts the velocity at which a flexible model will buckle or become unstable.

Body Tube Stiffness

The key requirement for a super-roc model is that the body is sufficiently stiff such that the failure velocity is above the model's maximum flight velocity. Typically, a model is assembled from standard paper body tubes joined with couplers. This construction approach is light but is limited to the stiffness of paper.

Various methods have been used to increase the body stiffness. "Blackshaft" tubes (paper tubes impregnated with

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phenolic resin) were an excellent option due to their higher stiffness and low weight. However, blackshaft tubes are no longer generally available. One current approach for higher stiffness is to double the tube thickness. This can be easily done using nesting body tubes such as the BT-20 (18mm diameter) and TT-20 tubes, which is a telescoping tube that fits snugly over the BT-20 size tube. Another option is to use a standard tube (such as a BT-20 or BT-50) plus full length coupler stock. These approaches provide much greater stiffness, but the resulting tube is also much heavier so the rocket will not fly as high.

There are other reinforcement approaches for standard paper body tubes. Some people have applied tape or glass-reinforced tape to the outer surface of the tubes. Another option would be to add a layer of fiberglass to the outer surface of a paper body tube. A more advanced approach would be to use lightweight thin-walled fiberglass tube construction using materials and methods typically used for international (FAI) competition model.

The author has performed some testing to determine the stiffness of typical body tubes including the BT-5, BT-20, and BT-50. The test results can be used to calculate the "elastic modulus" or stiffness of the tube material. This is an important number required in a FlexRoc analysis. Based on current results, the best values for elastic modulus are as follows:

T-5 tube: elastic modulus = 510,000 lb/in^2
T-20 tube: elastic modulus = 545,000 lb/in^2
T-50 tube: elastic modulus = 370,000 lb/in^2

Additional testing is in progress and will be published as an R&D report at NARAM-56.

An important safety requirement for super-roc components is that they must not be a safety hazard. Excessively stiff/strong components such as wood dowels or composite arrow shafts are not permitted.

Super-Roc Altitude Model Design

A competition super-roc altitude model is fundamentally an altitude model. For example, adding excessive weight to make the airframe stiff will result in a low altitude and non-competitive score.

As with most competition models, the design of a competition super-roc model is a trade-off between many factors including propulsion, weight, drag, stiffness, and stability. Finding the right balance is the challenge for a winning design.

D-engine Super-Roc Altitude will be flown at NARAM-56 (and probably at several local and regional contests prior to NARAM). The following sections describe some considerations for a competitive D SRA design.

Propulsion

The design of a D SRA model starts with motor selection. Two readily available single-use D motors are the Estes D12 and the Aerotech D10 which are available from Apogee Components (www.ApogeeRockets.com/Rocket_Motors). The D10 motor might initially be perceived as the better selection due to its smaller diameter (18mm vs. 24mm), lighter weight (28 grams vs. 45 grams), and slightly higher total impulse (18.3 N-sec vs. 17.0 N-sec)[3]. However, the average thrust of a D10 is surprisingly higher than a D12 (14.8 Newtons vs. 10.2 Newtons). The ideal optimum thrust for a motor is 2X the gravity force on the model[4]. The mass of a typical D SR-A model will be 150 to

3 Engine properties from NAR Standards and Testing data (http://www.nar.org/SandT/NARenglist.shtml)
4 Milkie, Thomas, "The Ideal Model Rocket Engine Thrust Curve," *Journal of the MIT Rocket Society,* January, 1974.

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200 grams (including motor), so the ideal optimum thrust is 3 to 4 Newtons. Therefore, a D12 is closer to the optimum average thrust than a D10[5]. The higher average thrust and smaller diameter of a D10 will result in higher boost velocity, requiring a stiffer (and heavier) body. There are definitely tradeoffs to consider!

There are other propulsion options that could be considered. The Aerotech D9 reloadable motor might be of interest, but the mass of the reloadable motor casing must be considered. Other options include the Quest D5 (www.ApogeeRockets.com/Rocket_Motors/Quest_Motors) single use motor and the Aerotech D2.3 reloadable motor[6]. However, both of these motors are plugged for use by RC gliders. Some other mechanism would have to be provided to activate and deploy the recovery system, with associated mass and reliability concerns.

Drag Considerations

There are three significant contributors to drag of a model rocket: 1) pressure drag, 2) skin friction drag, and 3) base drag. For a typical super-roc model, skin friction drag is by far the largest factor, accounting for 90% or greater of the total drag.

There are several methods to control skin friction drag. Laminar flow has much lower drag than turbulent flow. Attached flow has much lower drag than separated flow. A smooth surface has lower drag than a rough surface. However, smooth and painted surfaces usually are achieved using filling material, and this adds weight to the model. The tradeoff between lower drag and higher weight must be assessed.

5 The Apogee D3 motor would be ideal for D Super-Roc models. However, this motor is no longer in production or NAR contest certified.
6 Contest certification is pending.

The other way to control skin friction drag is to reduce the wetted surface area of the model. This can be achieved by using a minimum diameter design. The forward end of the model can be made smaller by using smaller diameter body tubes. However, the tubes can't be made too small or otherwise the airframe will be too flexible and will buckle.

Fins also contribute to drag. Fins should be smooth and as small as possible. However, making the fins too small will lead to aeroelastic problems. The effect of fin size on the aeroelastic behavior of the model is included in a FlexRoc analysis.

A final consideration for drag is to not have items that contribute parasitic drag. In particular, items like launch lugs should be avoided if possible. Alternate methods such as pop lugs or tower launchers are preferred. Tim Van Milligan swears by the use of a high-power rail launcher because of its long length and stiffness. This requires the use of "Fly-Away Rail Guides" that are described in *Peak-of-Flight Newsletters 247* and 243 (www.ApogeeRockets.com/education/downloads/newsletter247.pdf).

Full Length or Short?

A big question for super-roc models is whether to go with a full length model or a shorter model. The objective is to maximize the super-roc score (length in cm multiplied by altitude in meters). A full length model maximizes the length factor, but a shorter model will go higher. Which factor is more important?

Simulations using Rocksim and similar programs generally show that full length models achieve higher scores than shorter models. However, an R&D project by Jay Calvert[7] showed that long models might have higher drag

7 Jay Calvert, *"The Relationship between Super-Roc Length and Drag Coefficient: Rocksim Erroneously Suggests That Size Matters"*, NARAM-47 R&D report, 2005.

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than predicted by standard methods. Jay built and flew a D Super-Roc model (all BT50) at five different lengths (three flights at each length). As shown in Figure 4, there was generally good agreement between predicted and actual flight altitudes. However, the correlation was better for shorter models than for longer models. When the data is converted to super-roc scores, there was significant difference between predicted and flight results. As shown in Figure 5, the super-roc scores from flight data of long models were significantly lower than from simulation predictions.

Note that Jay's model was made from BT-50 for all sections. It's not known if similar results would be obtained for

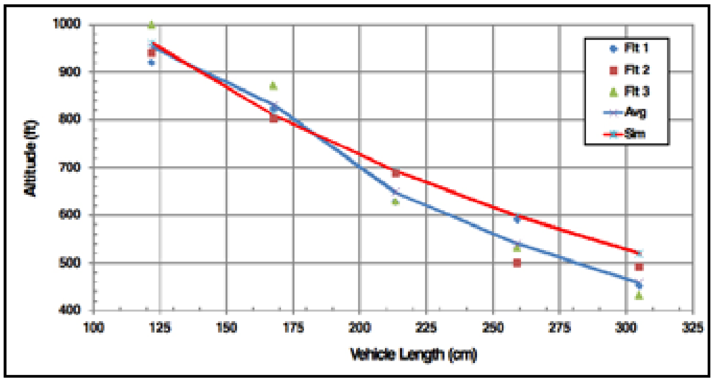

Figure 4. Flight data versus simulation predictions for five D Super-Roc models by Jay Calvert.

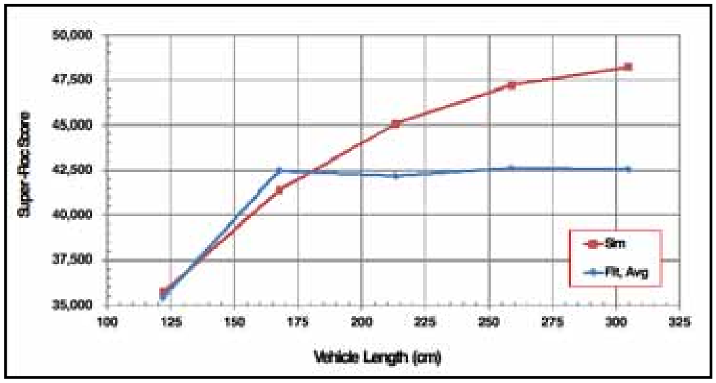

Figure 5. Flight data indicated that long super-roc modesl may have scores lower than predicted.

other designs or flight configurations. If anybody is looking for an R&D project for NARAM56, a great topic would be to obtain flight data for more super-roc models and compare to analyze predictions. Pending additional flight data, the issue of a full length model vs. a shorter model is still open.

Mass Matters

Mass is important for altitude models. A model rocket takes the total impulse of the motor and converts it to potential energy (altitude) and drag losses. For the available "D" motors, it's very likely that mass of a super-roc model will significantly exceed the optimum mass. Therefore, it's

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important to keep the model as light as possible. Using light materials for fins, couplers, and other parts will contribute to higher altitude.

Construction Tips

The final design topic is construction methods. It's very important that a super-roc model is straight as well as having high stiffness. All couplers should be snug and well aligned. The "shoulder" of the model (for the recovery device) should be fairly long with tight tolerances to minimize any rattles. Some great techniques for building accurate couplers for super-roc models are provided in issue 245 of the Apogee *"Peak of Flight"* newsletter[8].

D SRA Model #1

Let's look at a couple of actual D Super-Roc altitude models for which flight data is available. The first model, shown in Figure 6, was a full length model including 24" of BT-5, 33" of BT-20, and 54" of BT-50. Powered by a D12 motor, the maximum predicted velocity was 98 m/sec. This model was constructed and flown by Tim Van Milligan. The model kinked during boost.

The FlexRoc results for D SRA model #1 are shown in Figure 7. Using the latest results for the stiffness of paper tubes, the failure velocity of the model is predicted to be 107 m/sec. The predicted failure velocity slightly exceeds the maximum velocity. However, remember that the predicted failure velocity is based on an ideal model with no additional flexibility from joints or shoulder. In the aerospace industry, standard practice for aeroelastic analysis is to show stable results including a 15% margin on velocity. As shown in Figure 7, D SRA model #1 does not satisfy this requirement. This may indicate that 15% is a prudent margin to include in FlexRoc analysis results.

8 "Rocket Plan: The "Kink" Superroc Rocket", Apogee Peak of Flight newletter, Issue 245, October 6, 2009. www.ApogeeRockets.com/education/downloads/newsletter245.pdf

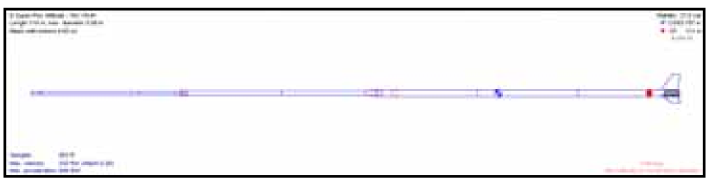

Figure 6. The first D Super-Roc model kinked during flight.

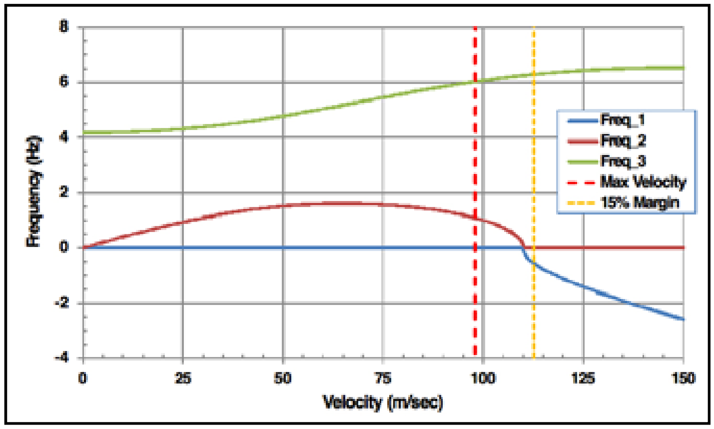

Figure 7. The predicted failure velocity of D SRA model #1 did not satisfy a 15% margin.

D SRA Model #2

The second model, shown in Figure 8, was also full length model. Tube lengths were selected based on

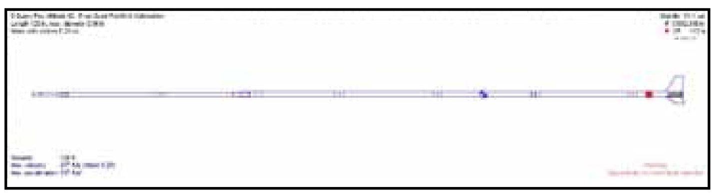

Figure 8. The second D Super-Roc model boosted successfully.

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some preliminary results from FlexRoc. The tube lengths were 4” of T-5, 33” of T-20, and 81” of T-50. This model was also constructed and flown by Tim Van Milligan and is shown in Figure 1 on page 2. The model boosted successfully! See the video at: https://www.youtube.com/watch?v=RW2dGfGoHCA The altitude on this flight was 229 m.

The FlexRoc results for D SRA model #2 are shown in Figure 9. The failure velocity of the model was predicted to be 97 m/sec. The maximum predicted flight velocity was 82 m/sec. Therefore, the predicted capability of D SRA model #2 slightly exceeded the expected maximum velocity plus 15% margin.

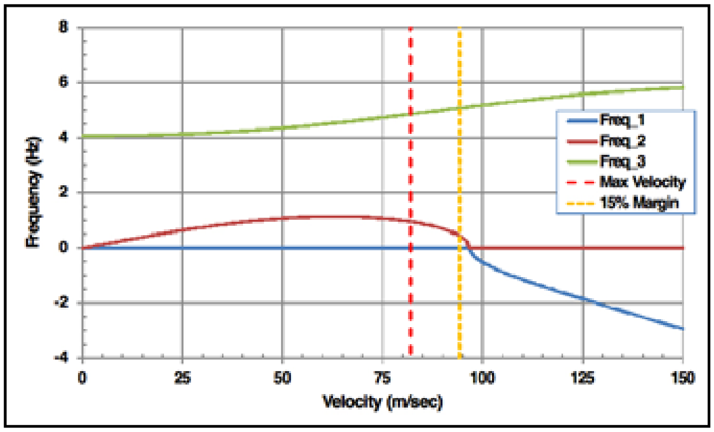

Figure 9. The predicted failure velocity of D SRA model #2 exceeded the max velocity plus 15% margin.

Candidate Designs for NARAM-56

Based on FlexRoc simulations, two candidate designs for D Super-Roc Altitude are presented. Both models are based on using D12 motors.

Candidate design #1 is a straightforward two-section model. The bottom section is BT-50, and the upper section is BT-20. In particular:

BT-50 = 62” long
BT-20 = 25” long
Fin: 2.5” root chord, 1.25” tip chord, 2.0” span

This model, shown in Figure 10, is not a maximum length model (length = 227 cm). FlexRoc predicts that this model will have a super-roc score of approximately 76,500 with an aeroelastic margin of approximately 20%.

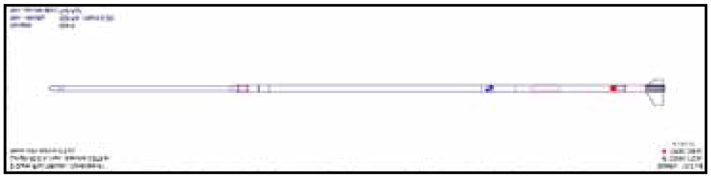

Figure 10. Candidate model #1 has a T-50 base section and a T-20 upper section.

Candidate design #2 is somewhat more complex. It has three sections: T-50 base section, T-20 mid-section, and T-5 forward section. In particular:

T-50 = 54” long
T-20 = 20” long
T-5 = 10” long
Fin: 2.5” root chord, 1.25” tip chord, 2.25” span

This model, shown in Figure 11, is also not a maximum length model (length = 221 cm). FlexRoc predicts that this model will have a super-roc score of approximately 77,600 with an aeroelastic margin of approximately 20%.

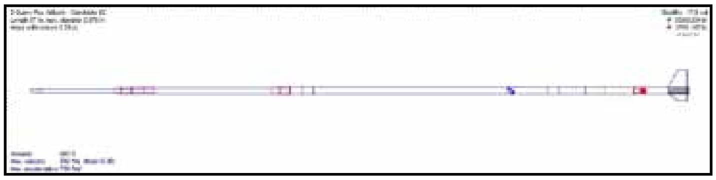

Figure 11. Candidate model #2 has three sections (T-50, T-20, and T-5).

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These candidate models have not yet been constructed or flown. If you build one and fly it, I'd be really interested to hear how it goes!

Summary

Super-roc is a very challenging event in which flexible body effects are very important. The FlexRoc program provides a method to predict the aeroelastic performance of super-roc models. This should help improve the design of super-roc models for NARAM-56.

Please contact me at ccflanigan@alum.mit.edu if you have any questions about super-roc analysis using FlexRoc.

About The Author

Chris Flanigan started flying model rockets in 1968. During his college years, he was a member of the MIT Rocket Society and supported publication of the "MIT Journal" and "MIT Competition Handbook." He has been very active in national and international model rocketry completion. He was the C Division national champion in 2011 and 2012. He has been on five USA international teams teams (including the 2014 team) and will be competing in the S4A (boost glider) and S7 (scale) events at the 2014 World Spacemodeling Championships in Bulgaria. He is also a mentor for the TARC program. In his "day job", Chris is a co-founder of Quartus Engineering and works on structural, dynamic, and aeroelastic design and analysis of aircraft, spacecraft, missiles, and other aerospace systems.