S1 Analysis for 2016 World Championships

Matt Steele
NAR 22961

Summary

- I analyzed a number of key performance parameters for the S1B and S1A events in order to assist in designing and building the best possible model for the 2016 World Championships, and then reviewed the flight results.
- This report highlights key performance parameters for S1 model designs, advancing the state of the art of the hobby.

What is S1?

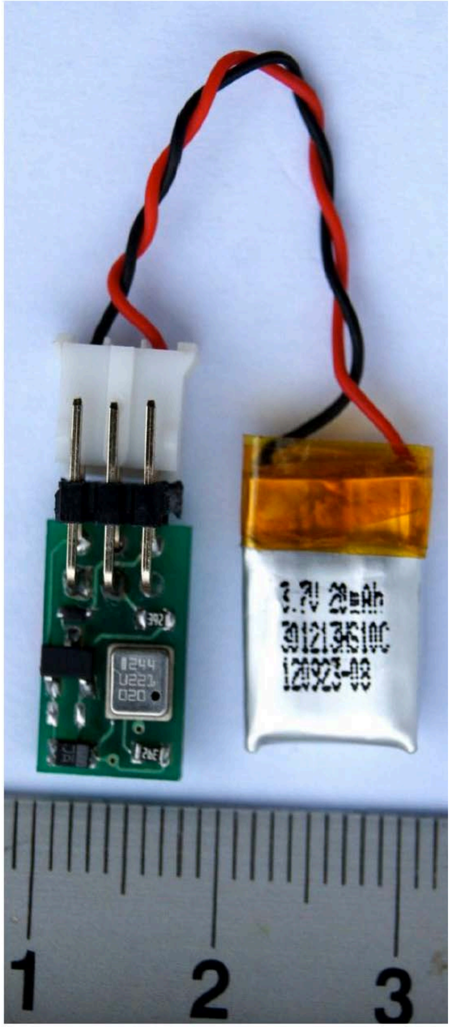
- The S1B and S1A events are the “pure” altitude events at the World Spacemodeling Championships.
- Seniors fly S1B (A motors staged to A motors)
- Juniors fly S1A (1/2A motors staged to 1/2A motors).
- Models must be 500mm long, at least 250mm must be 40mm in diameter, and upper stages must be at least 18mm in diameter.
- Adrel altimeters record the altitude data and results are downloaded upon return of the model.

USA S1B Models

USA S1A Models

Typical S1 Models


Adrel Altimeters



Adrel Altimeter Specifications

Method of altitude measurement:	measurement of pressure changes
Measuring Range	-500.... 9000 m
Resolution	0.2 m
Accuracy:	0,5 % (accuracy of measuring the difference of altitude)
Measurement triggering:	Set in the range of 0 – 200 m
Dimensions:	7,9 x 19,3 x 4,9 mm (with connector)
Weight:	0,6 g (without battery)
Recommended battery:	LiPo 20mAh – weight 0,8g
Battery life	for LiPo 20mAh – 3 hours
Serial number:	Unique entered permanently
Number of contestant:	Input form computer
Connection with computer:	USB

Overview

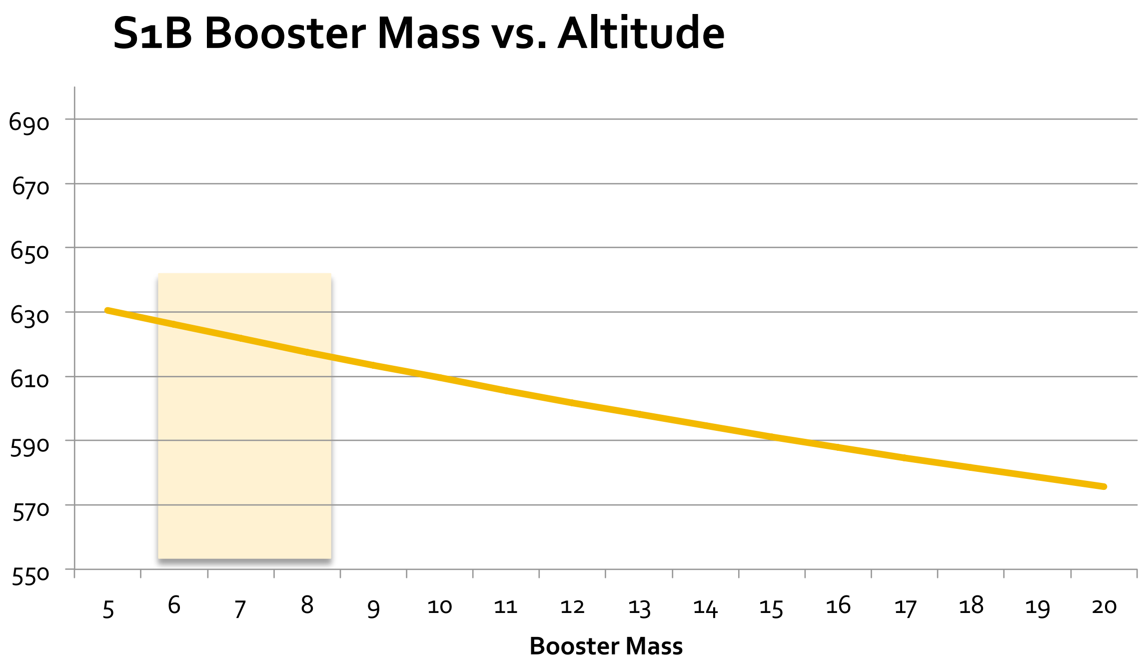
- I took a look at a number of key parameters for the S1B and S1A events, in order to assist in designing and building the best possible model.
- I used Chris Flanigan's spreadsheet performance model as the basis for the analyses. These values were then checked in RockSim 9.

S1B Parametric Analysis

- First, I looked at S1B to determine what design parameters are important to concentrate on.
- I used an A3-0 staged to an A1-7 as the baseline motors.
- Analysis was conducted without piston effects, since those are difficult to quantify and add uncertainty.
  - All results should be factored for lack of piston effects.

S1B Booster Mass vs. Altitude

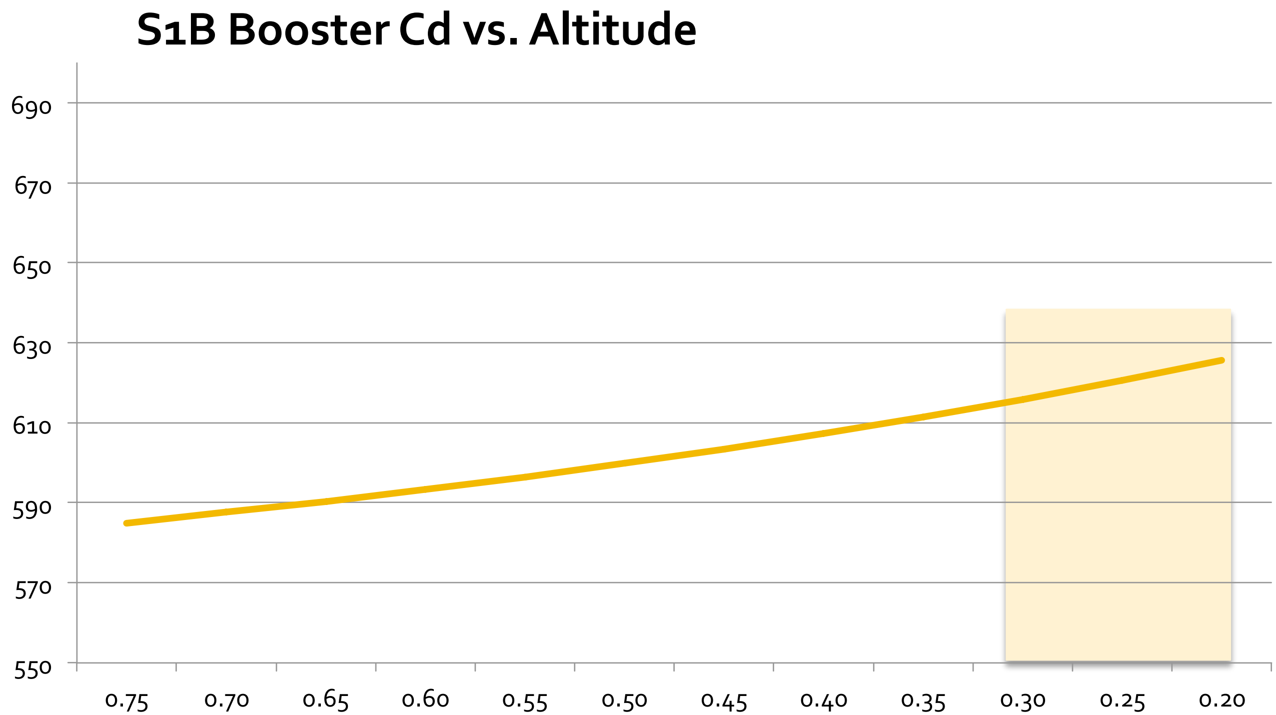
- I first looked at booster mass as a function of altitude.
- As expected, the lower the mass, the better the performance.



Booster Mass (g)	Altitude (m)
5	630.6
6	626.2
7	621.8
8	617.6
9	613.5
10	609.5
11	605.6
12	601.8
13	598.2
14	594.6
15	591.2
16	587.9
17	584.7
18	581.6
19	578.6
20	575.7

S1B Booster Cd vs. Altitude

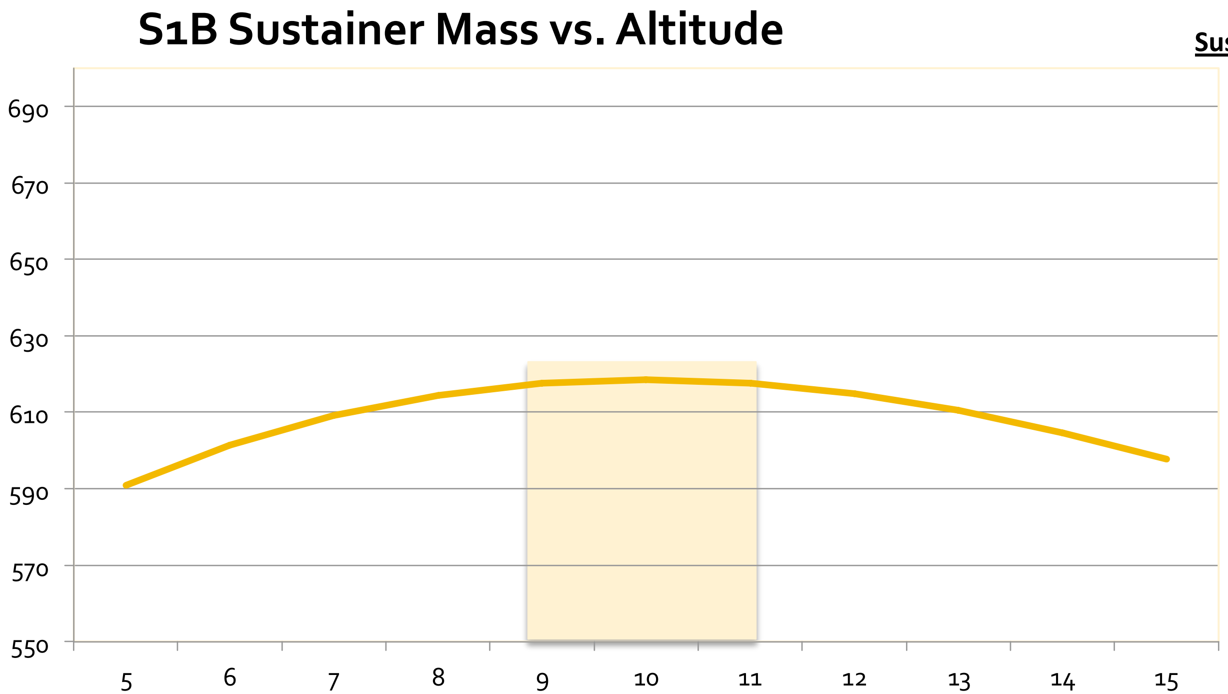
- As expected, the lower the Cd, the better the performance.
- However, the chart before shows that mass reduction is more important than Cd reduction – so adding a tail cone at the expense of extra mass is counterproductive.



Booster CD	Altitude (m)
0.75	584.9
0.70	587.6
0.65	590.4
0.60	593.4
0.55	596.5
0.50	599.9
0.45	603.5
0.40	607.3
0.35	611.4
0.30	615.8
0.25	620.6
0.20	625.7

S1B Sustainer Mass vs. Altitude

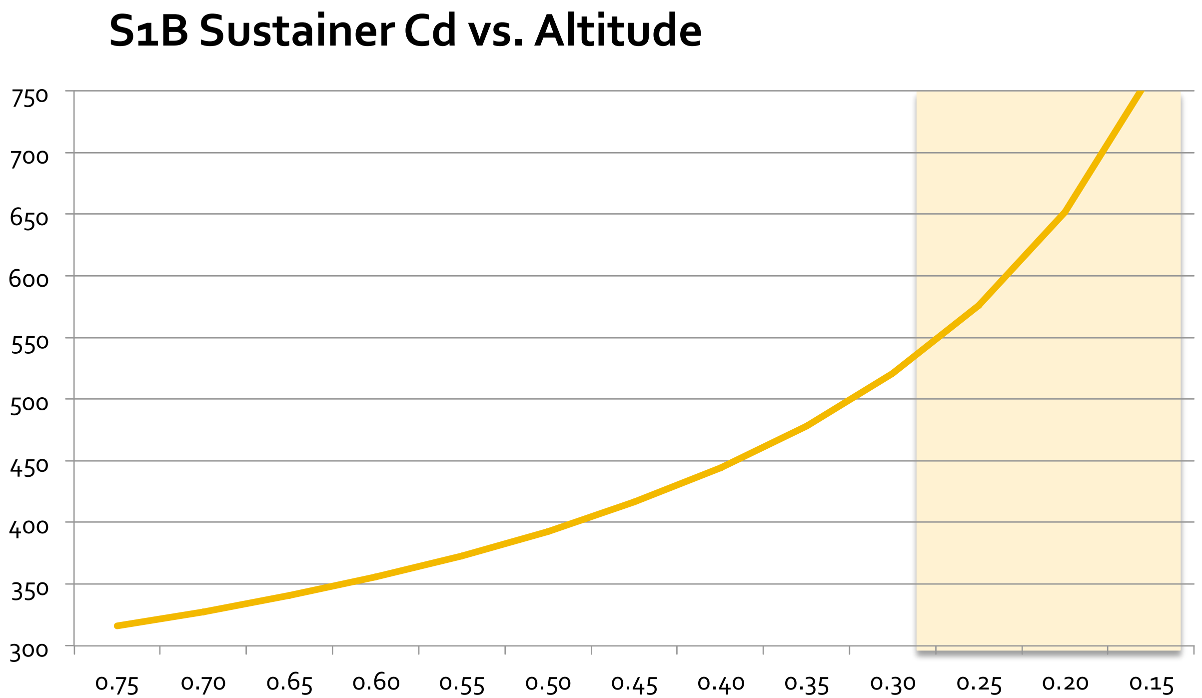
- Assuming a reasonably light (8 gram) booster and sustainer with a Cd of 0.281 (per Chris Flanigan flight results), I next looked at optimum sustainer mass.
- As expected, there is a optimum sustainer mass – the model needs to weigh between 9-11 grams (without the engine, but with the 1.4 gram altimeter).



Sustainer Mass (g)	Altitude (m)
5	590.9
6	601.4
7	609.2
8	614.5
9	617.6
10	618.5
11	617.6
12	614.8
13	610.5
14	604.7
15	597.7

S1B Sustainer Cd vs. Altitude

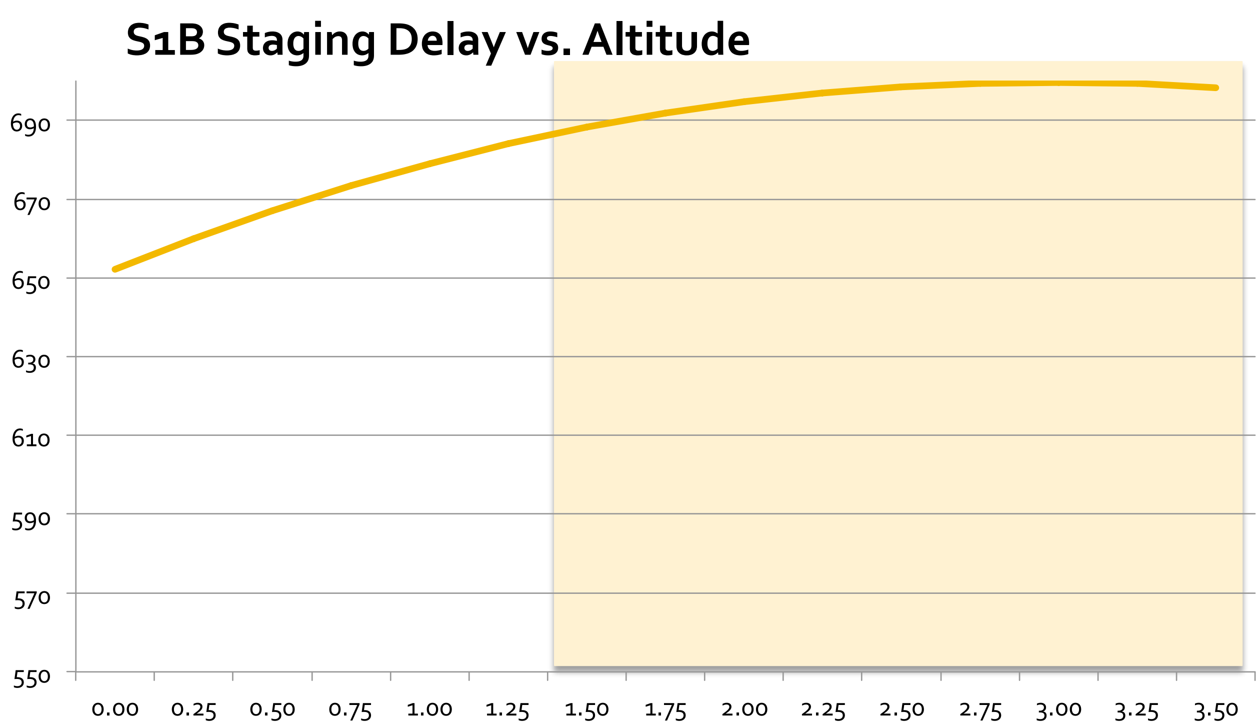
- Assuming an sustainer optimum mass of 10 grams, I then looked at the effect of Cd on the sustainer.
- This is the largest factor in determining altitude – having a smooth, drag free sustainer is the key to winning.



Sustainer CD	Altitude (m)
0.75	315.9
0.70	327.6
0.65	340.8
0.60	355.8
0.55	372.9
0.50	392.7
0.45	416.5
0.40	443.9
0.35	477.9
0.30	520.6
0.25	576.1
0.20	652.1
0.15	763.9

S1B Sustainer Staging Delay

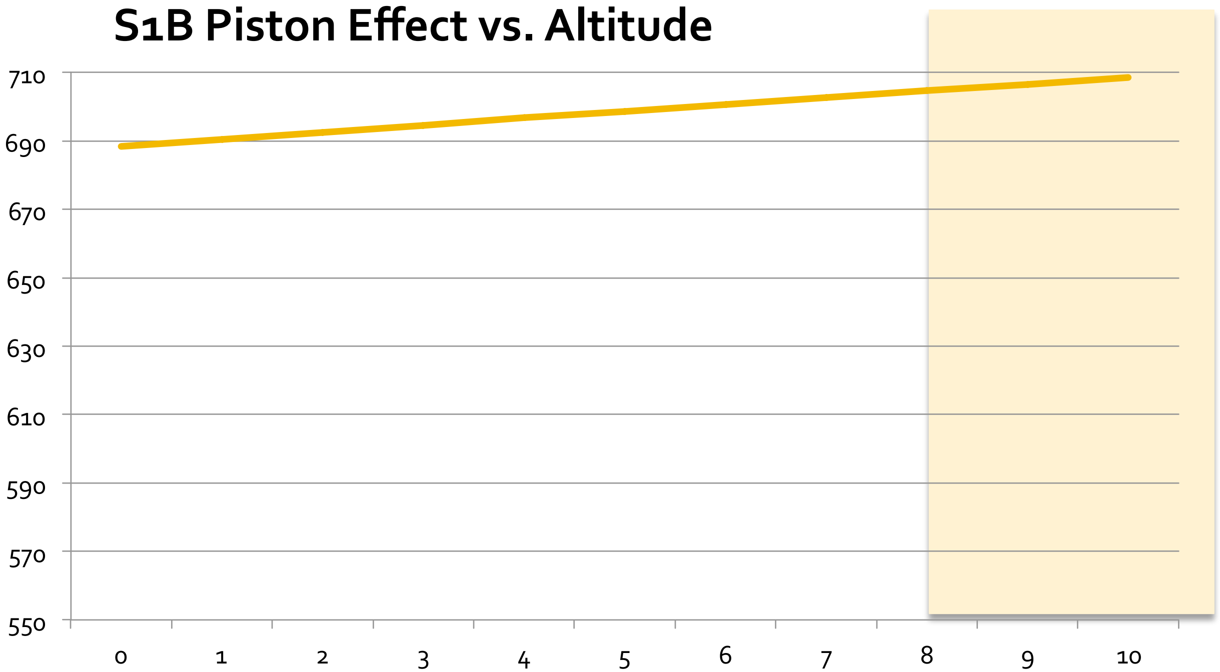
- The optimum staging delay in the simulation was a range between 1.5 and 3 sec.
- Due to the "real life" considerations of wind and tipoff, it appears that targeting a 1.5 second delay may have a payoff, though going for a 3 second delay might work in calm conditions.



Staging Delay (sec)	Altitude (m)
0.00	652.1
0.25	660.0
0.50	667.1
0.75	673.5
1.00	679.1
1.25	684.1
1.50	688.3
1.75	691.8
2.00	694.7
2.25	696.9
2.50	698.5
2.75	699.5
3.00	699.7
3.25	699.4
3.50	698.4

S1B Piston Effect

- The effect of a piston is linear – the better your piston is, the better the results.
- One of the challenges is to figure out what a representative value is for the net effect a piston – my model is pretty simplistic for this analysis.
- I stopped at 10m/sec, but Mitiuriev indicates that 20 m/sec are possible.



Piston Effect (m/sec)	Altitude
0	688.3
1	690.4
2	692.5
3	694.6
4	696.7
5	698.7
6	700.7
7	702.7
8	704.7
9	706.6
10	708.5

Analysis-based S1B Design Considerations

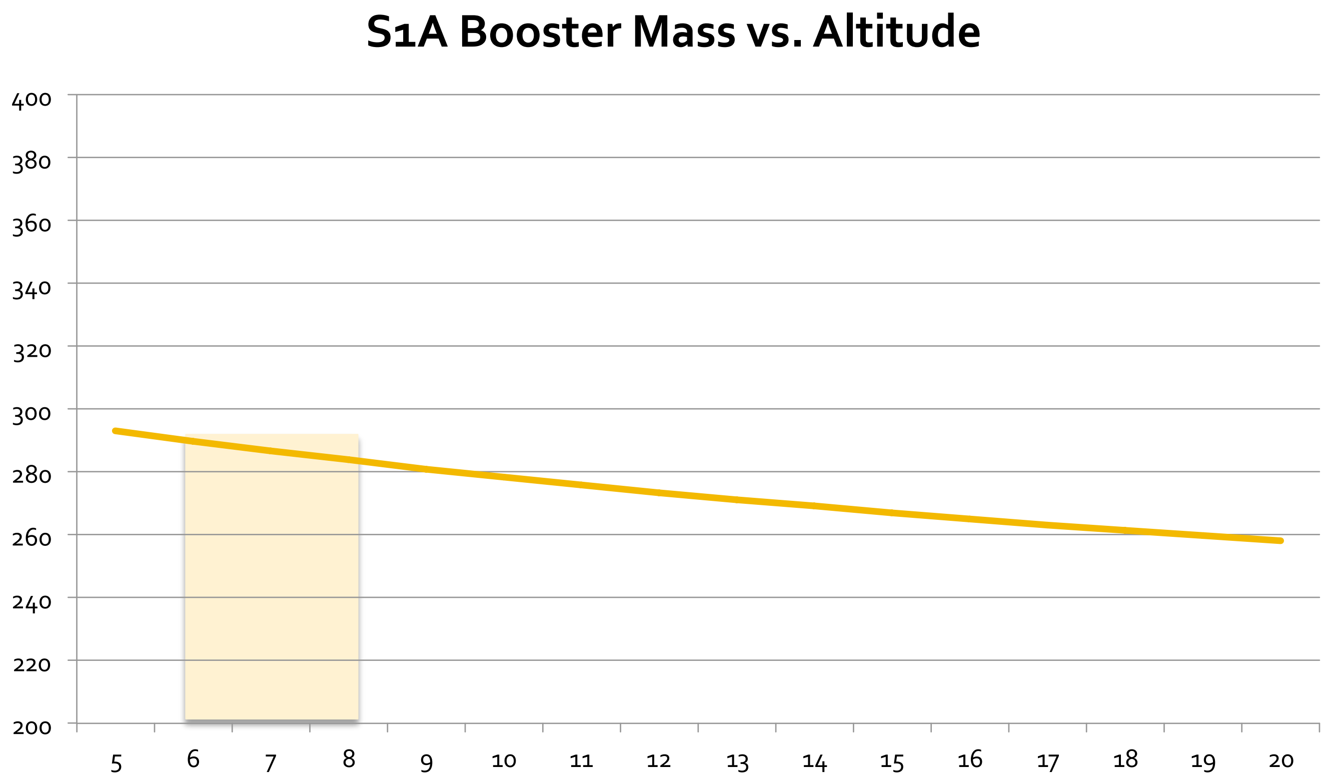
- Try and target these parameters:
  - Booster – 6 to 8 grams or less
  - Sustainer – 9 to 11 grams
- Make the sustainer as drag free as possible:
  - Rear ejection to eliminate nose/body joint
  - Best possible finish
- Minimize booster mass as much as possible:
  - Tailcone probably not worth the effort
- Use a delay in staging:
  - This needs to be tested extensively
- Use a good piston

S1A Parametric Analysis

- Next, I looked at S1A to determine what design parameters are important to concentrate on.
- I started with an 1/2A3-0T staged to a 1/2A1-6.

S1A Booster Mass vs. Altitude

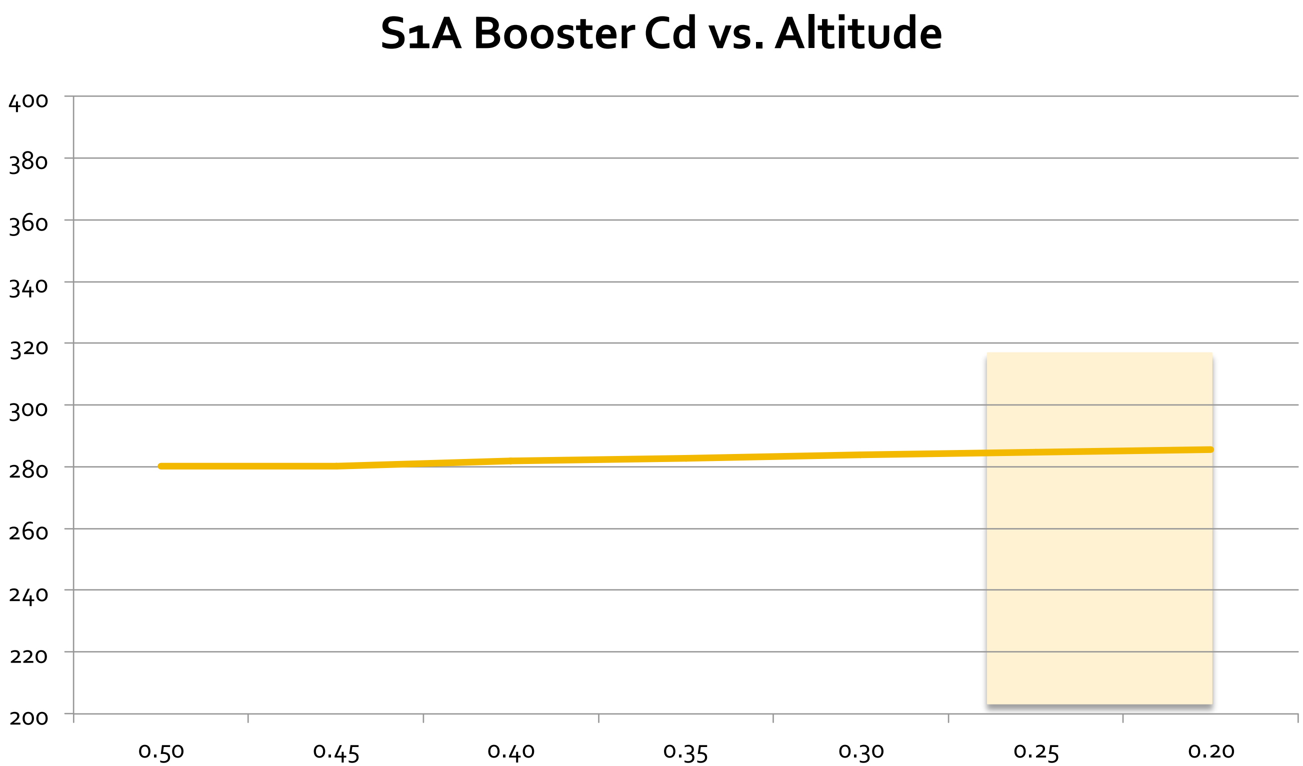
- I first looked at booster mass as a function of altitude.
- As expected, the lower the mass, the better the performance.



Booster Mass (g)	Altitude (m)
5	293
6	289.8
7	286.7
8	283.8
9	281.0
10	278.4
11	275.9
12	273.5
13	271.2
14	269.1
15	267.0
16	265.1
17	263.2
18	261.4
19	259.7
20	258.1

S1A Booster Cd vs. Altitude

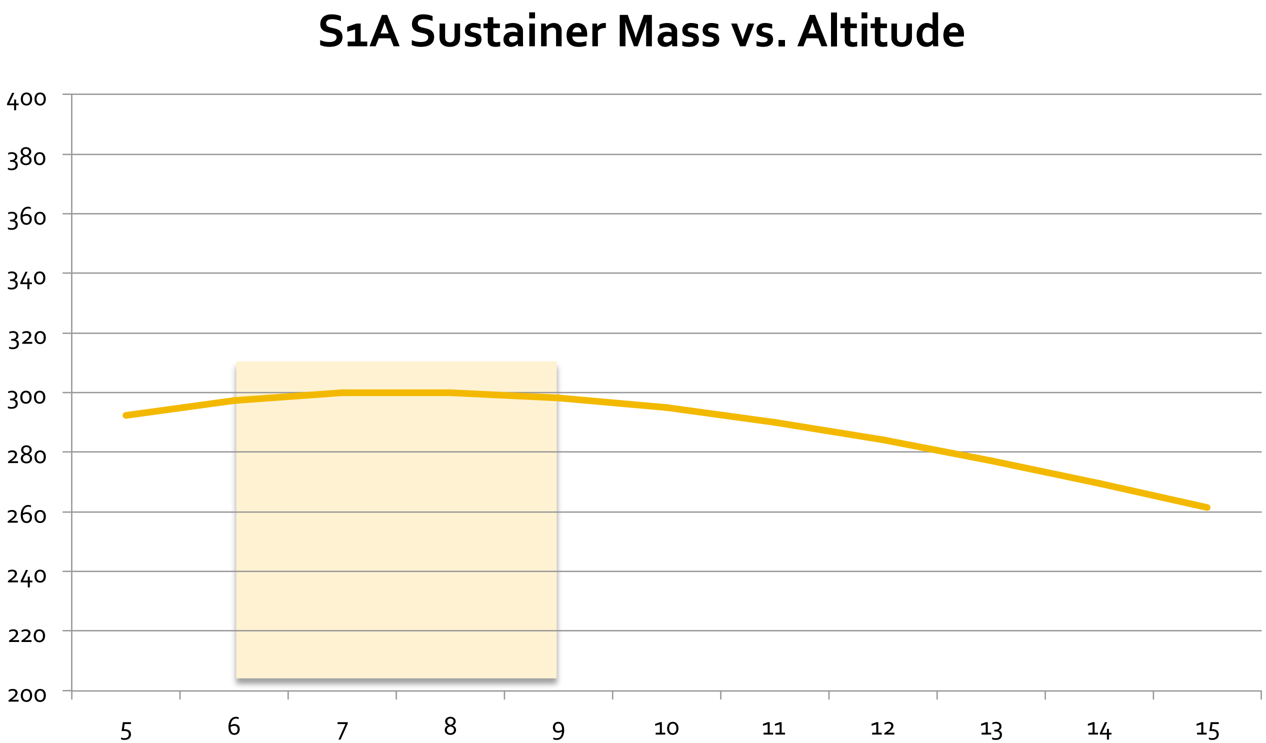
- The is no real effect in changing the Cd for the booster.
- However, the chart before shows that mass reduction is more important than Cd reduction – so adding a tail cone at the expense of extra mass is especially counterproductive.



Booster CD	Altitude (m)
0.50	280.2
0.45	280.1
0.40	281.9
0.35	282.8
0.30	283.8
0.25	284.7
0.20	285.7

S1A Sustainer Mass vs. Altitude

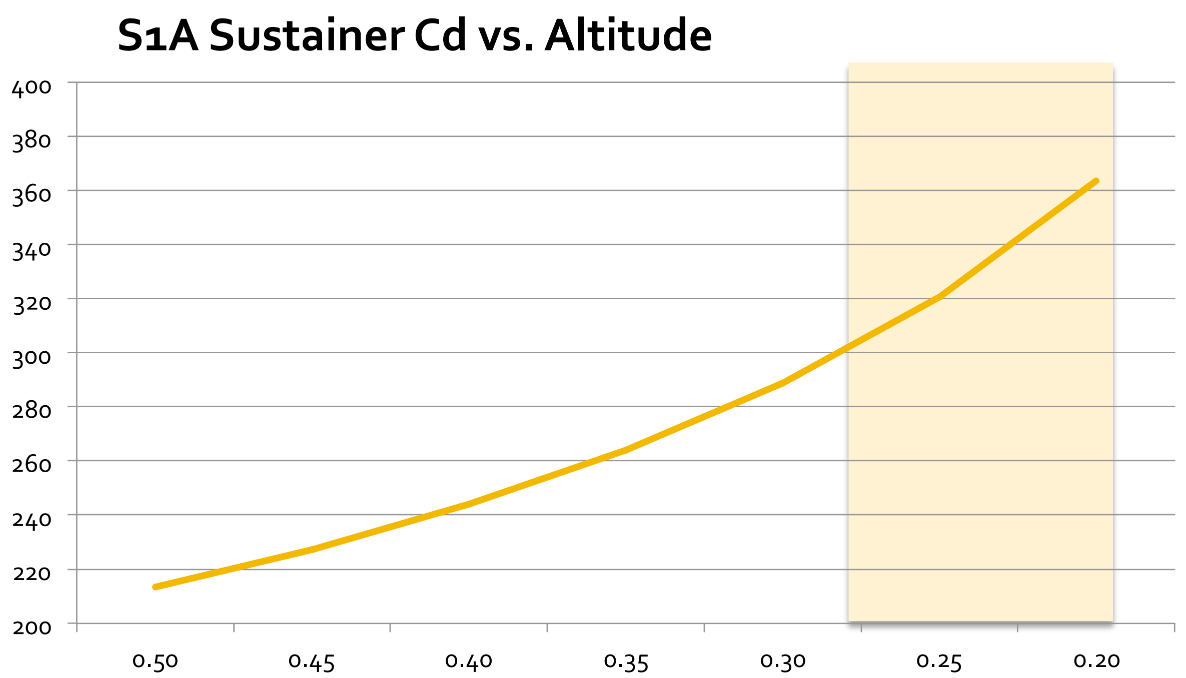
- Assuming a reasonably light (8 gram) booster and sustainer with a Cd of 0.281 (per Flanigan), I next looked at optimum sustainer mass.
- As expected, there is a optimum sustainer mass – the model needs to weigh 8 grams (without the engine , but with 1.4 gram altimeter).
- This makes S1A more difficult than S1B!



Sustainer Mass (g)	Altitude (m)
5	292.4
6	297.4
7	299.9
8	300.1
9	298.3
10	294.9
11	290.0
12	284.1
13	277.2
14	269.6
15	261.5

S1A Sustainer Cd vs. Altitude

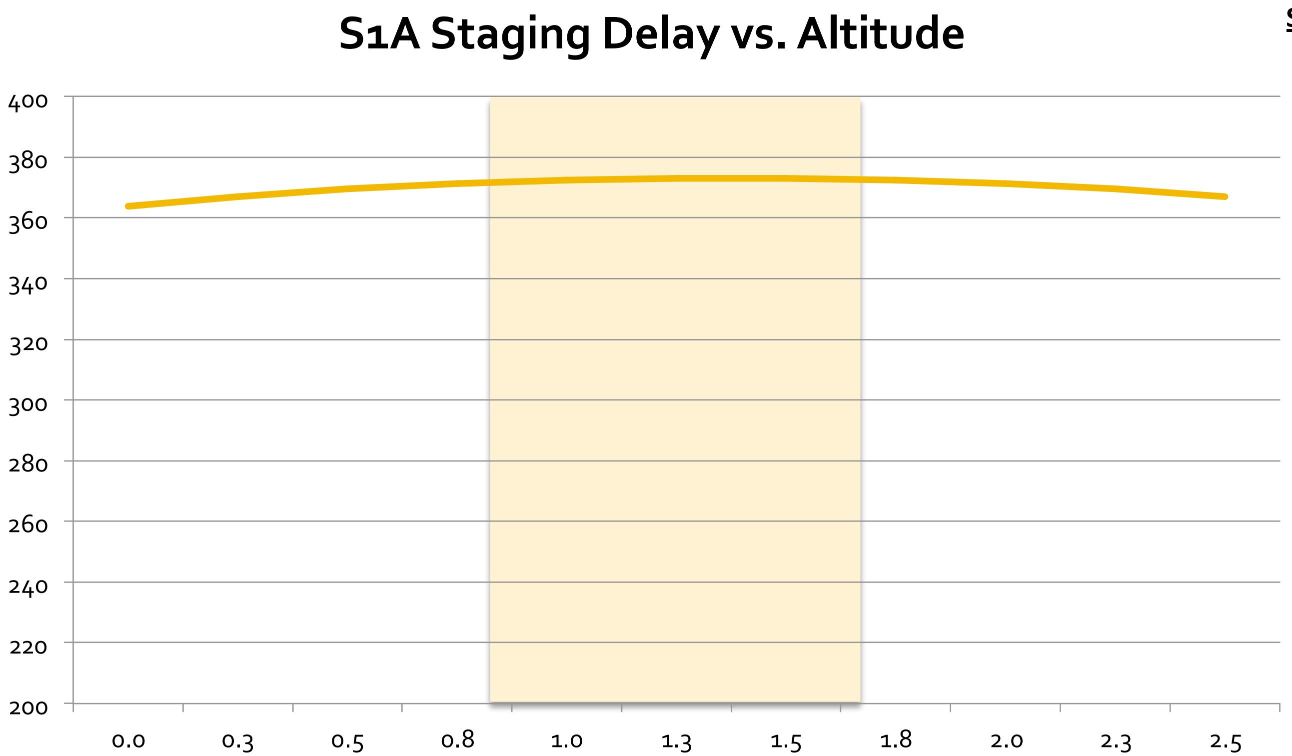
- Assuming an sustainer optimum mass of 8 grams, I then looked at the effect of Cd on the sustainer.
- This is the largest factor in determining altitude – having a smooth, drag free sustainer is the key to winning.



Sustainer CD	Altitude (m)
0.50	213.3
0.45	227.3
0.40	243.9
0.35	264.0
0.30	288.9
0.25	320.9
0.20	363.8

S1A Sustainer Staging Delay

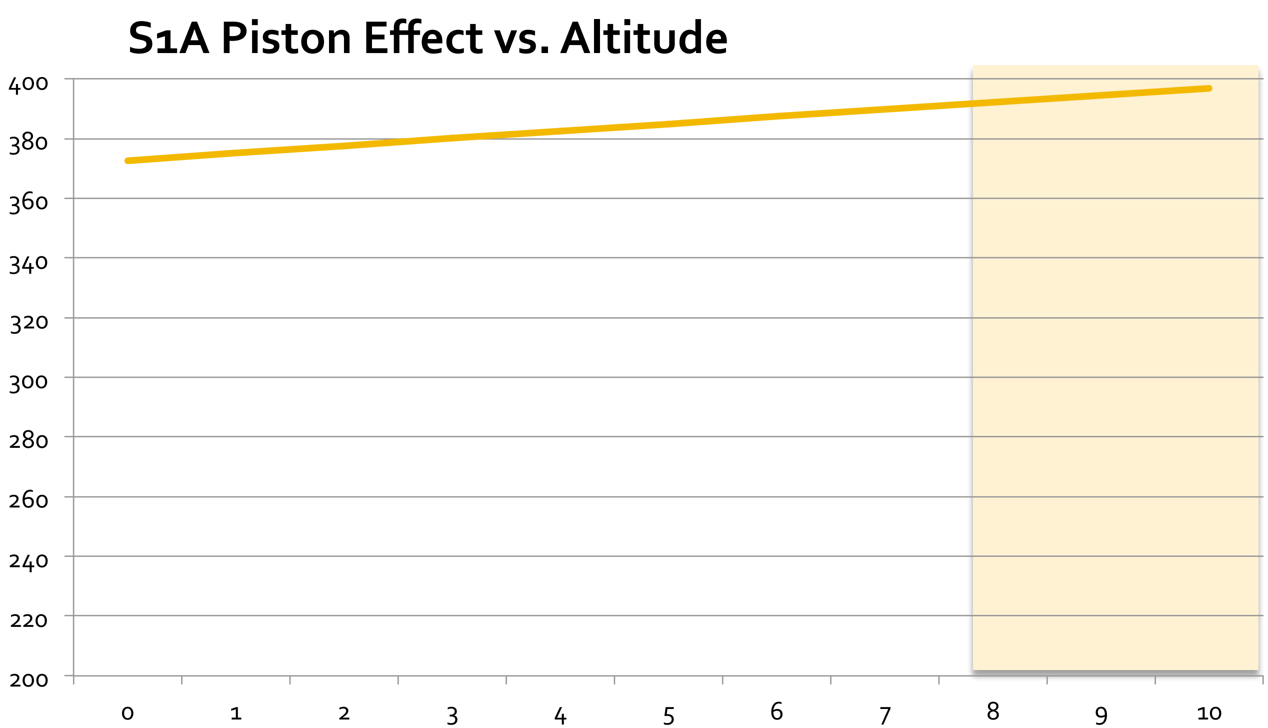
- The optimum staging delay in the simulation was a range between 1 and 2 sec.
- For these models, this is likely not worth the hassle, unless the piston adds a significantly to the booster velocities.



Staging Delay (sec)	Altitude (m)
0.00	363.8
0.25	367.0
0.50	369.5
0.75	371.4
1.00	372.6
1.25	373.2
1.50	373.2
1.75	372.6
2.00	371.3
2.25	369.5
2.50	366.9

S1A Piston Effect

- The effect of a piston is linear – the better your piston is, the better the results.



Piston Effect (m/sec)	Altitude
0	372.6
1	375.2
2	377.7
3	380.2
4	382.6
5	385.0
6	387.4
7	389.8
8	392.2
9	394.5
10	396.8

Analysis-based S1A Design Considerations

- Try and target these parameters:
  - Booster – 6 to 8 grams or less
  - Sustainer – 6 to 9 grams
- Make the sustainer as drag free as possible:
  - Rear ejection to eliminate nose/body joint
  - Best possible finish
- Minimize booster mass as much as possible:
  - Tailcone probably not worth the effort
- Use a delay in staging
  - This needs to be tested extensively
- Use a good piston

2016 WSMC Flight Results

2016 S1B Results

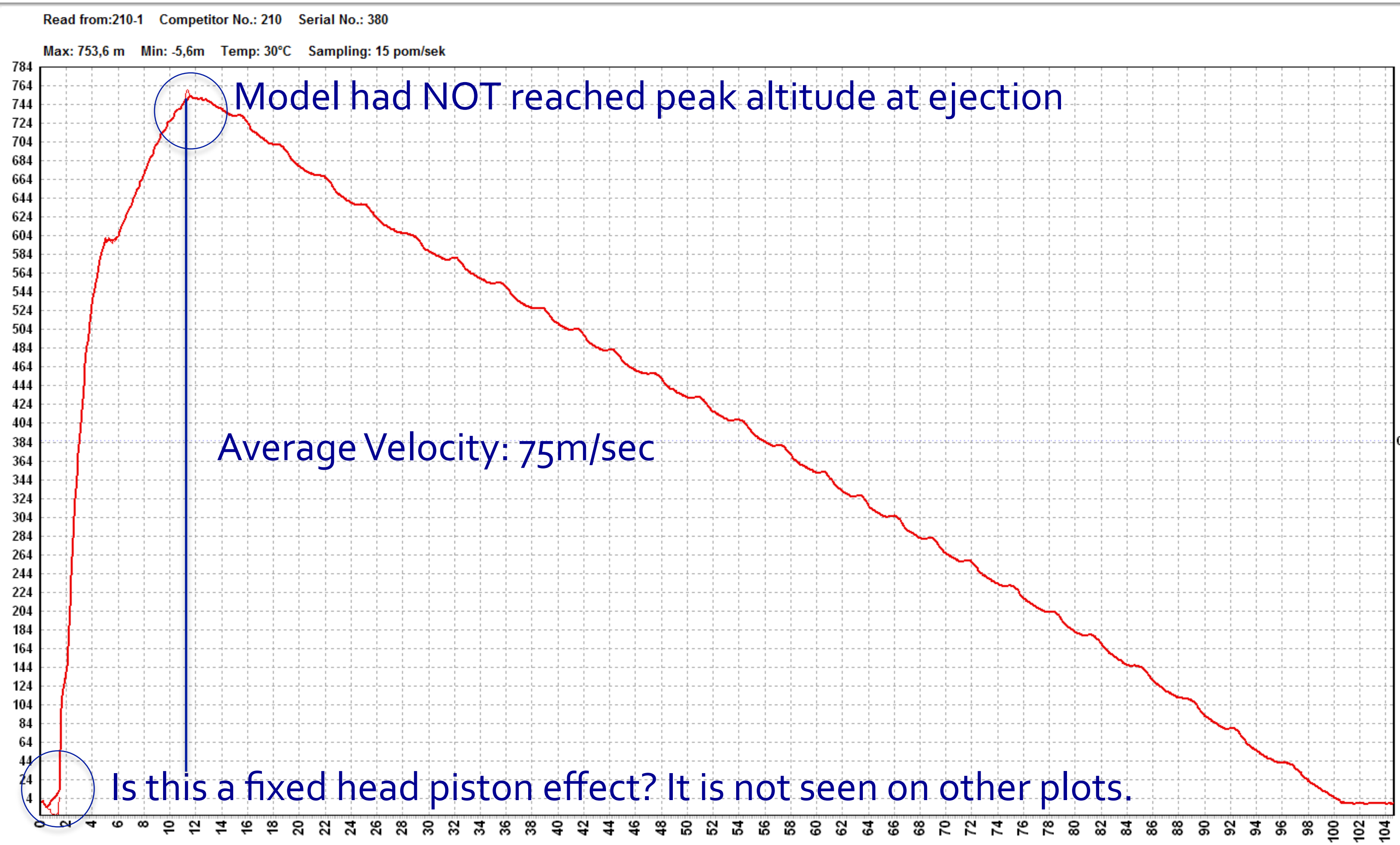
- World Champion: Dr. Bob Kreutz, USA – 753m
- Silver Medal: Kiril Protskeno, UKR – 690m
- Bronze Medal: Marian Gres, SVK – 656m
- 11th: Matt Steele, USA - 592m
- 15th: Steve Kristal, USA- 555m

- Teams:
  - Gold: Ukraine - 1968
  - Silver: USA - 1900
  - Bronze: Slovakia - 1887

2016 S1B Model Masses

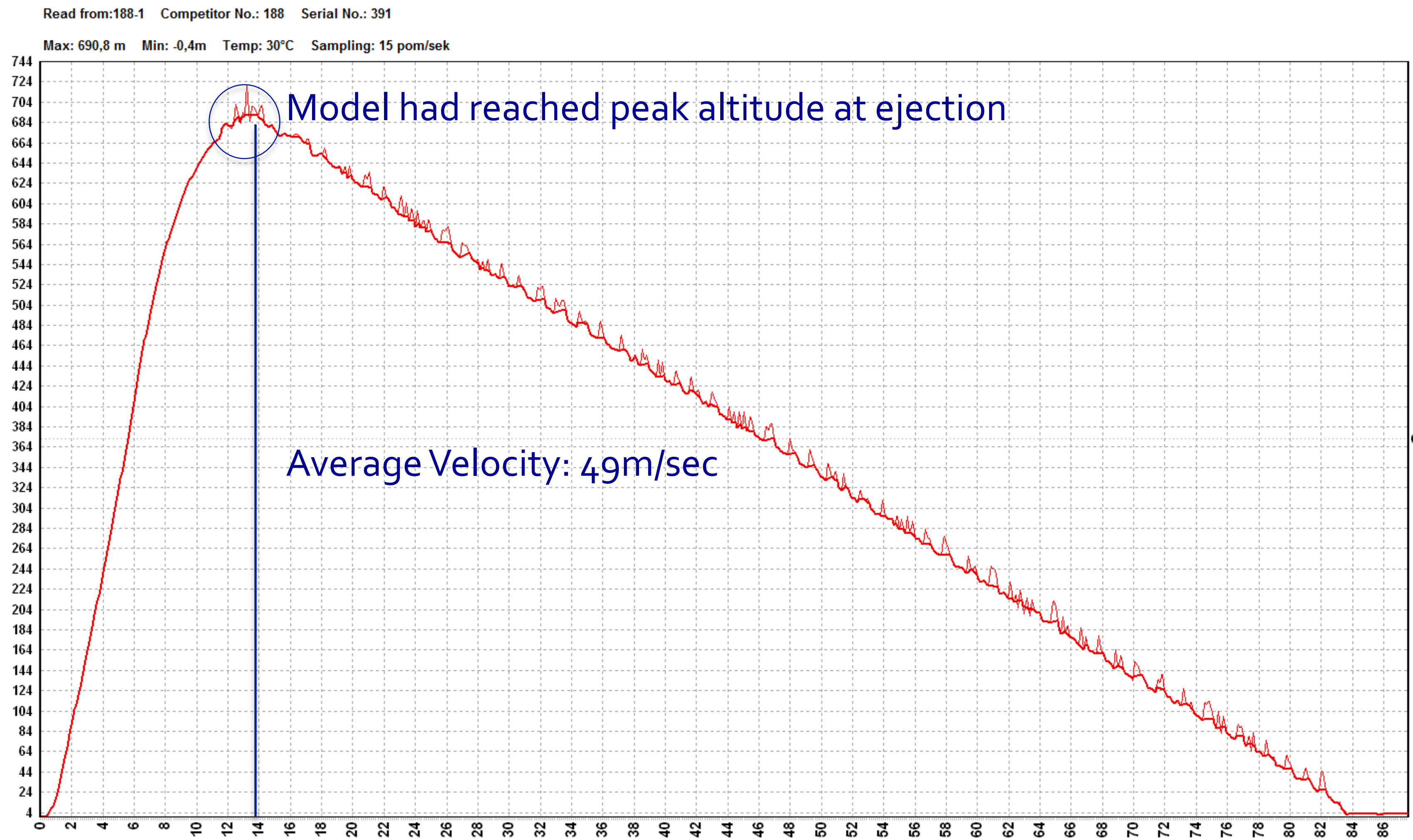
Modeler/Model	Booster Mass (g) Less engine	Sustainer Mass (g) Less engine with 1.4 g altimeter
Kreutz Model 1	9.5	8.7
Steele Model 1	7.9	9.6
Steele Model 2	8.6	9.9
Kristal Model 1	10.7	9.6

Gold Medal S1B Flight
Dr. Bob Kreutz – 753.6m

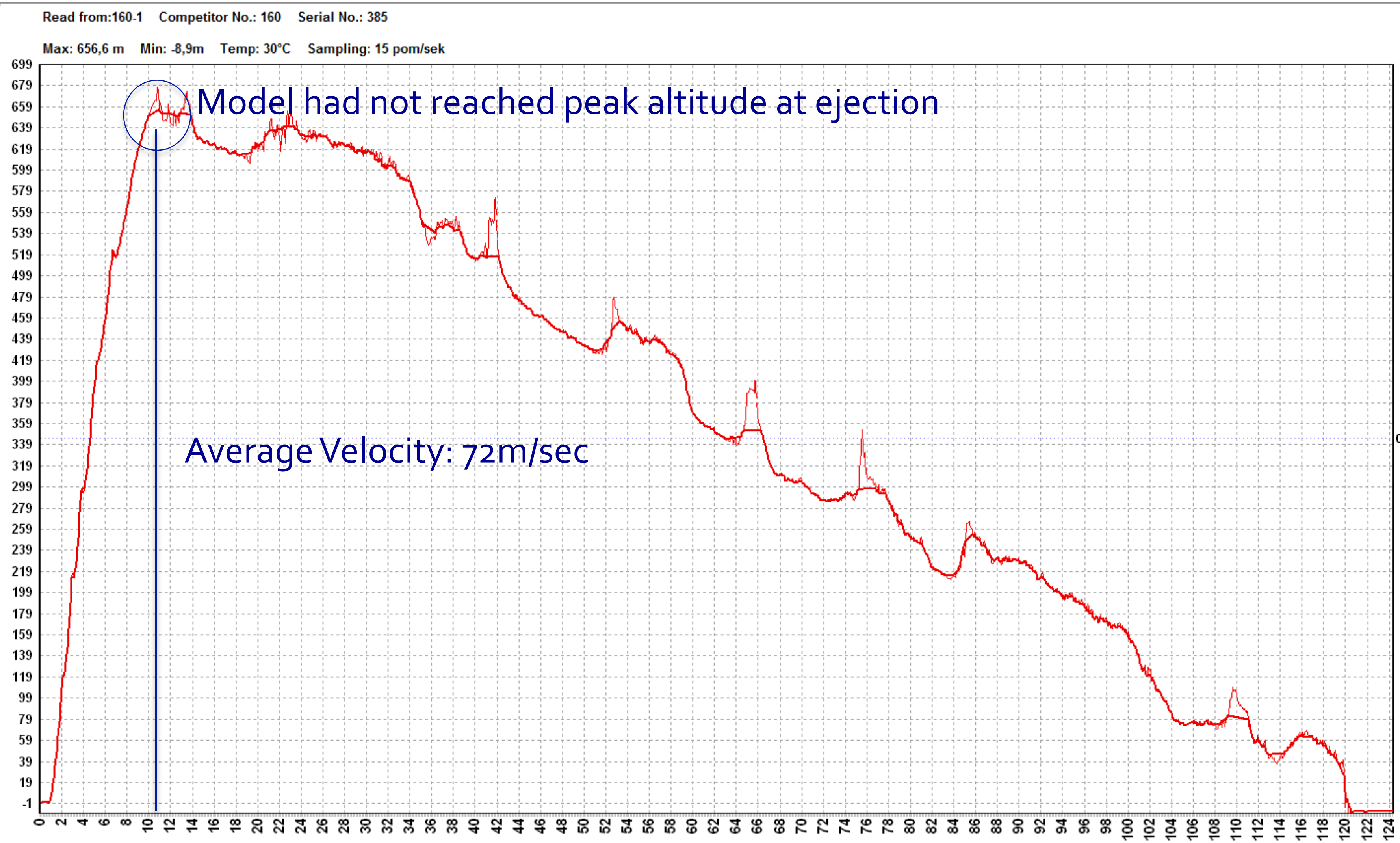


Dr. Bob Kreutz S1B Gold Medal

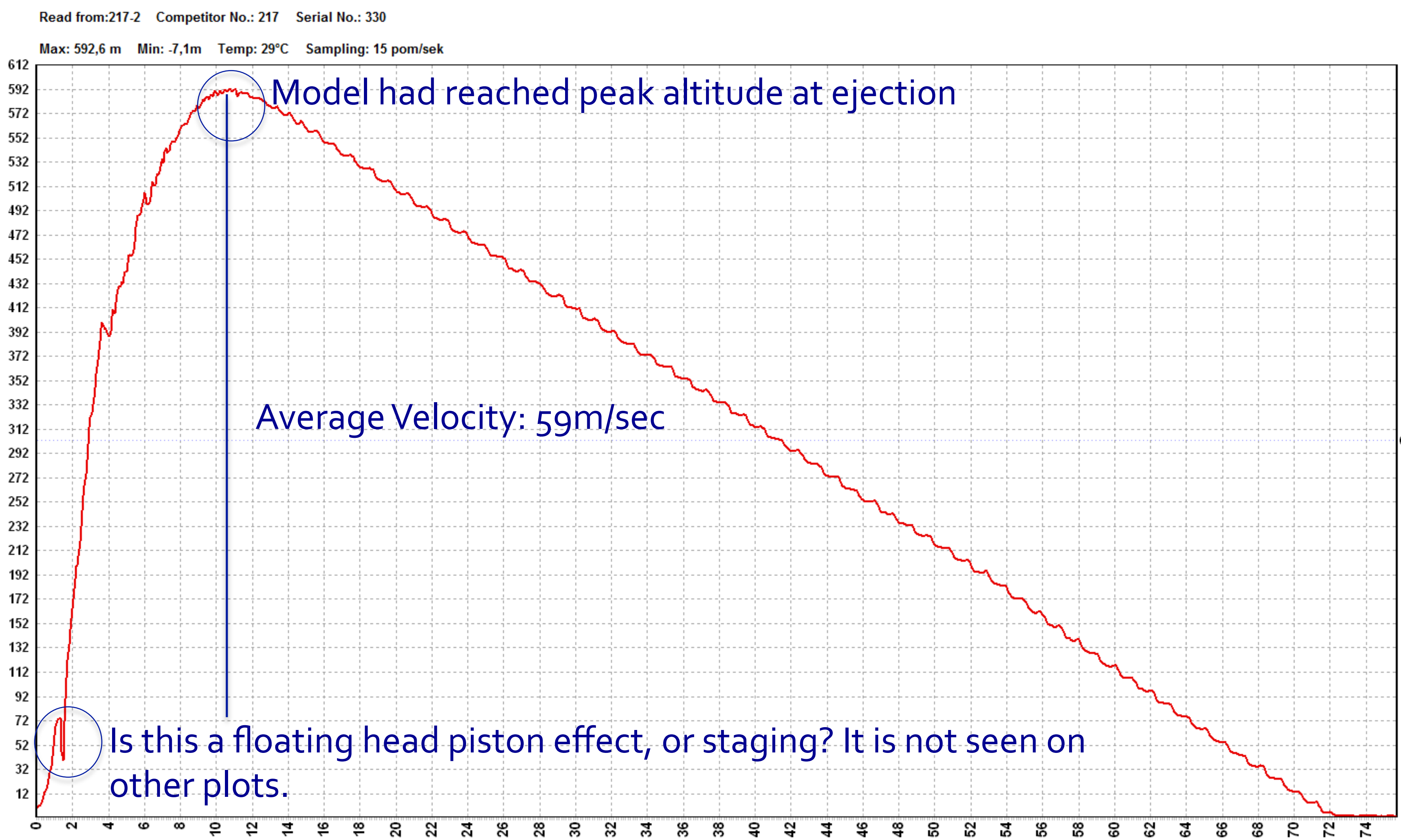
Silver Medal S1B Flight – 690.8m



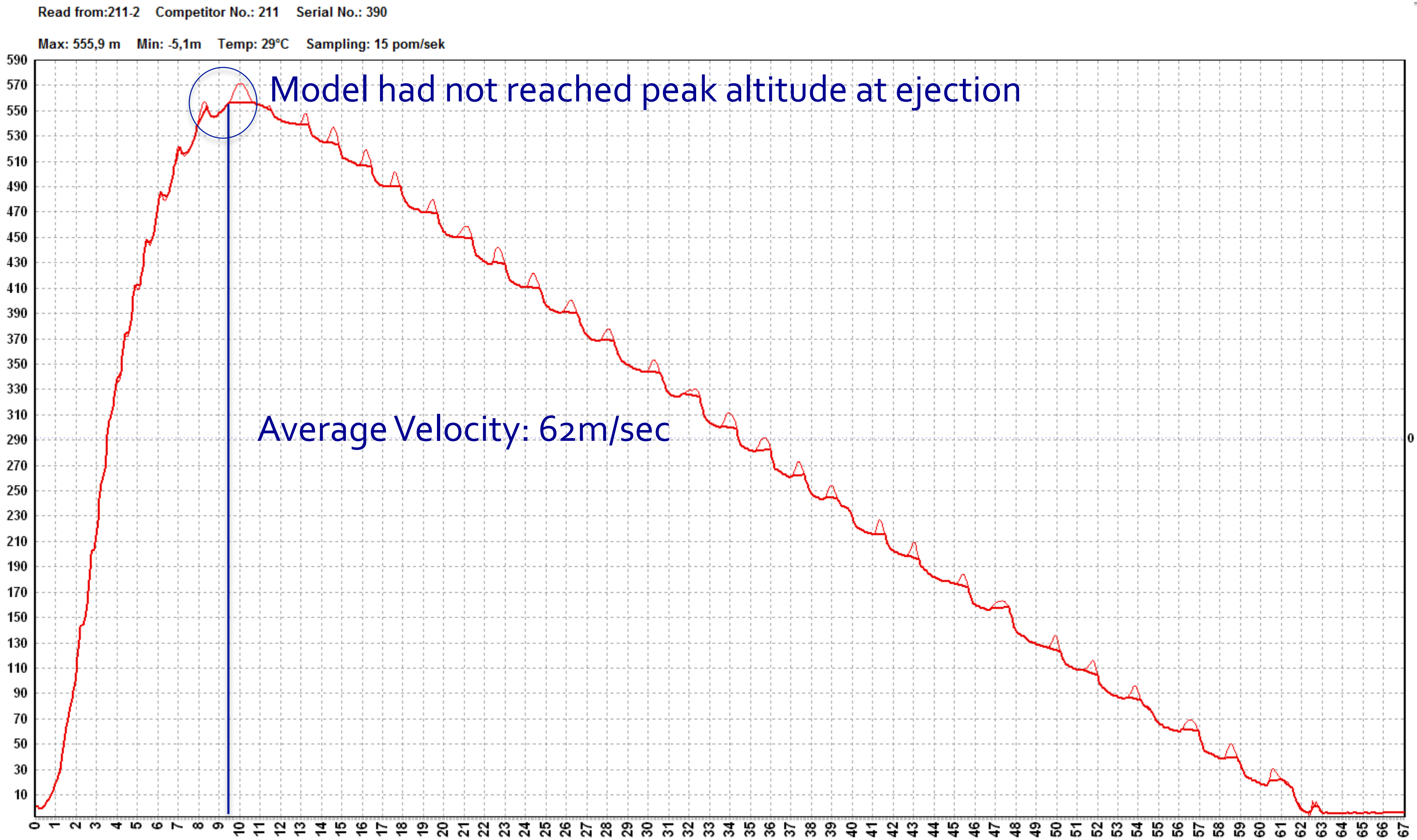
Bronze Medal S1B Flight – 656.6m



Steele Best S1B Flight – 592.6m



Kristal Best S1B Flight – 555.9m



S1B Team Medals

2016 S1A Results

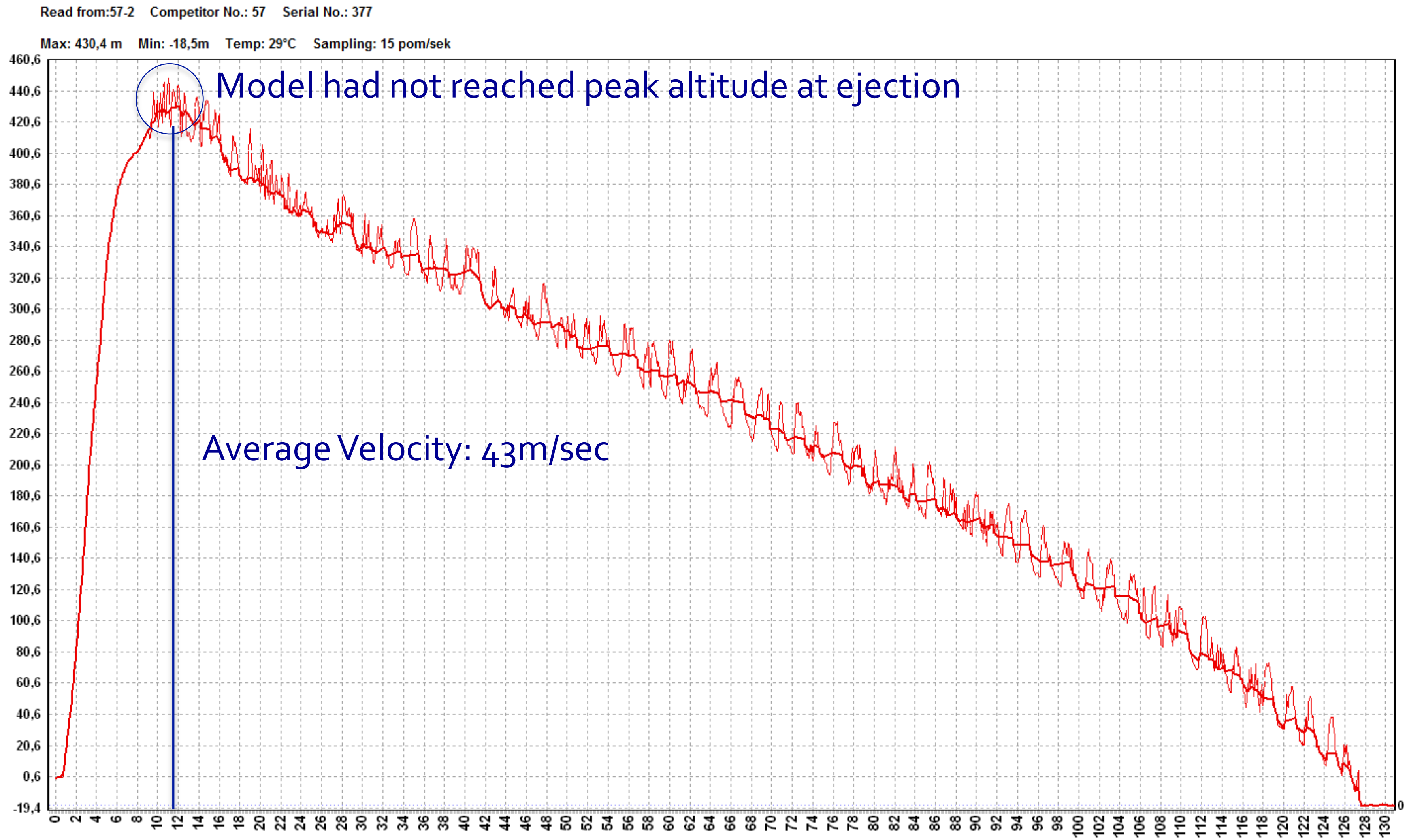
- World Champion: Mikal Zitnan, SVK – 430m
- Silver Medal: Ashley Van Milligan, USA – 394m
- Bronze Medal: Denis Galko, SVK – 384m
- 4th: Allison Van Milligan, USA 368m
- 13th: Rachel Nowak, USA 309m

- Teams:
  - Gold: Slovakia - 1169
  - Silver: USA - 1071
  - Bronze: Poland- 1032

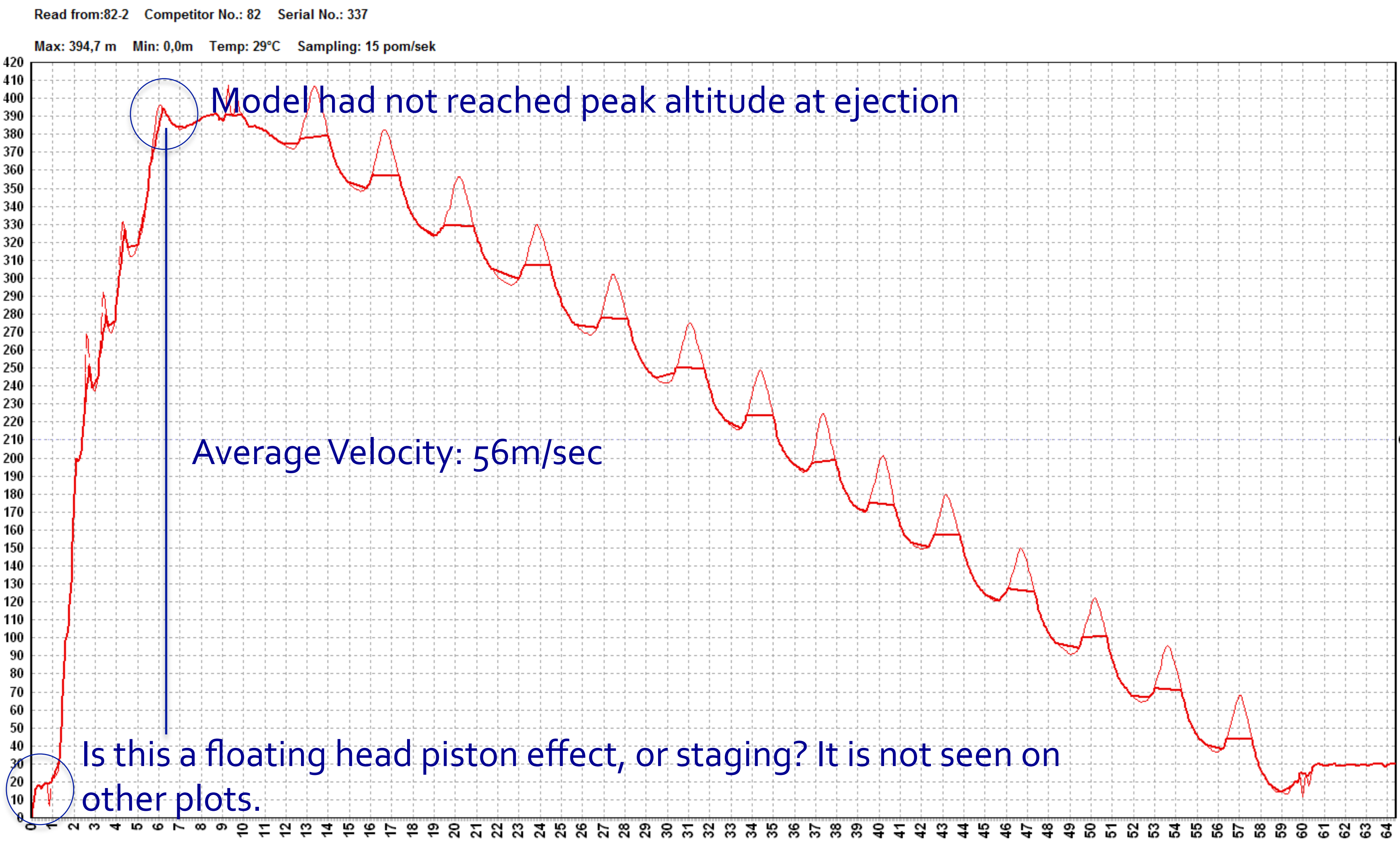
2016 S1A Model Masses

Modeler/Model	Booster Mass (g) Less engine	Sustainer Mass (g) Less engine with 1.4 g altimeter
Van Milligan Model 1	8.2	6.4
Van Milligan Model 2	8.6	6.4

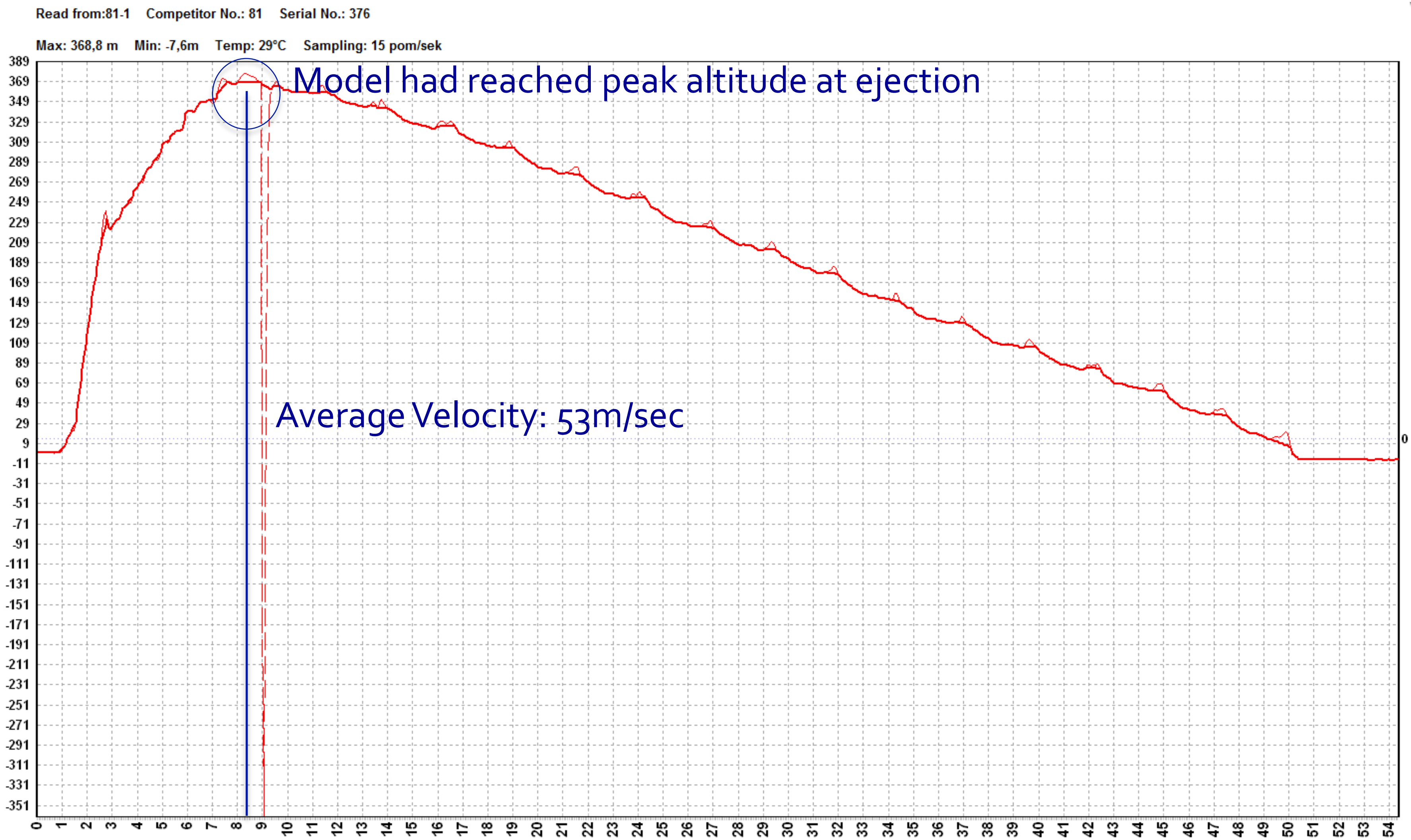
Gold Medal S1B Flight – 430.4m



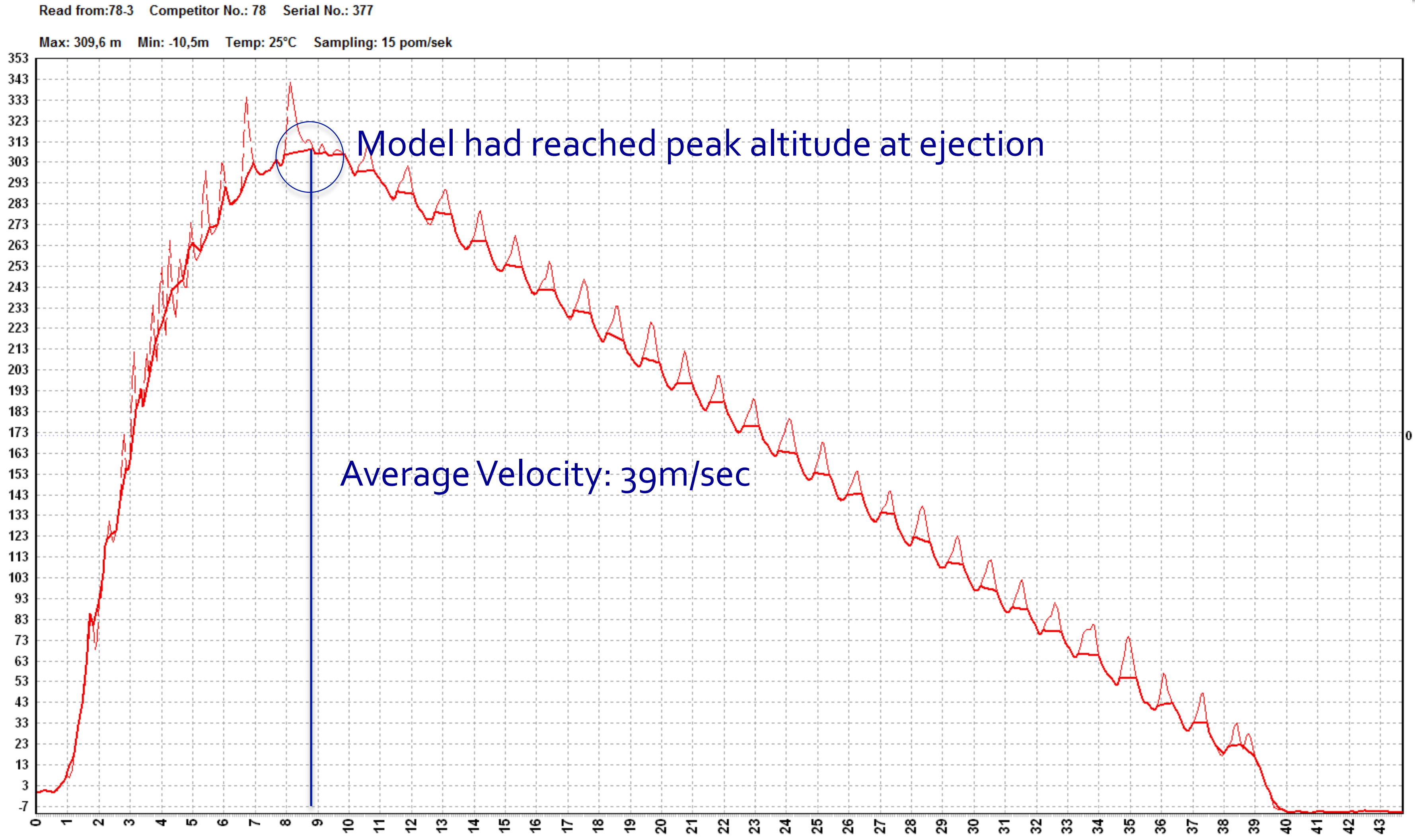
Silver Medal S1A Flight – Ashley Van Milligan – 394.7m



Allison Van Milligan Best S1A Flight 368.8m



Rachel Nowak Best S1A Flight – 309.6m



S1A Team Medals

Flight-based S1 Average Velocity Observations

- Average velocity could be a function of:
  - Motor Burn Times, i.e., a sustainer with an A0.5-7 should have a lower average velocity (and theoretically, less drag) and one powered by an A1-7;
  - Model mass, i.e., heavier models will have lower velocities than lighter models for the same engine;
  - Low Drag Airframes, i.e., a low drag airframe with fly faster than a high drag airframe with the same engine;
  - Higher Piston Efficiency, i.e., the piston contributes more velocity the the model at separation. If the drag from the higher velocity can be overcome, the piston can lead to higher overall overall altitude.
- US Team used identical motors for their top flights – Zenit A3/A1 – but had different masses and used different pistons.
- It's not clear from the data which approach gives better results.

Flight-based S1 Design Observations

- The analysis results understated the maximum performance of the models.
- This points to a need to refine the analysis tools.
- The flight results indicate that some combination of the following factors is not properly modeled:
  - The piston contribution to the model's velocity and resultant altitude;
  - The drag coefficients used in the simulation are too high.
- Refinement of these tools will likely point to different optimum masses.
- Flying longer delay motors may capture additional altitude, especially on exceptional flights.

S1B Future Work

- Update analysis to reflect 2018 performance.
- Model A0.5-7 sustainer engines to determine if performance is increased (flight data said no).
- Determine if a sustainer boat tail increases performance.
- Determine best piston modeling approach:
  - Determine "real" piston velocity increases
  - Re-run delayed staging with "real" numbers

Project Cost

- The cost to do the analysis was minimal:
  - Excel Spreadsheet and suitable computer (no cost, assumed to already have)
  - Rocksim 9.0: $123.60 (already had)
  - Models: $250 each (ROM estimate, based on hours required to fabricate)
  - Scales and measuring tools: $50 (already had)
  - Trip to Europe to gather data and compete: $2,000

Equipment & Facilities Used

- Mac Power Book Computer
- Lviv, Ukraine flying field
- 2 Models with shipping case
- 1 Piston Launcher with 3 piston tubes
- 1 Adrel Altimeter

Related R&D Reports

- *A Study of Optimal Time Delays Between Staging*, Alan Bates, USAFA Proceedings 73.
- *Optimum Delayed Staging*, Thomas Kuechler, MR Aug 75.
- *The Effect of Delayed Staging on a Multi-Staged Model Rocket's Performance*, Thomas Kuechler, MR Jan 73.
- *Some Notes on Delayed Staging*, Jay Apt, MR Feb 74.
- *Optimum Delayed Staging*, Thomas Kuechler, MR Aug 75.
- Delayed Staging vs Altitude, Chris Taylor, NARAM 40 R&D, 1998.

Publishing Rights

- Permission is granted to publish this paper in NAR publications.