SLS Block 1C with ATK Advanced Boosters, Core with 5xRS–25D engines and 2xJ–2X optimised upper stage. Payload to 200 km LEO = 140.2 t. 30 Nov. 2013. Author: Steven S. Pietrobon, PhD.

The RSRMV thrust curve obtained from [1]. There is a discrepancy in that Loaded Mass minus Burnout Mass in [1] is 650,743 kg compared to 633,233 kg in [2] and 628,701 kg in [3]. Therefore, we have adjusted the propellant mass and impulse in [1] to match the values in [2].

The propellant mass and dry mass of ATK's Advanced Boosters (AB) were obtained from [4]. The vacuum Isp was assumed to be same as for the Titan IV Solid Rocket Motor Upgrade (SRMU), which also uses HTPB propellant [1]. The RSRMV thrust curve was adjusted so that the peak vacuum thrust is 20.0 MN [4] and has the same impulse given by the Isp multiplied by the propellant mass. This resulted in a burn time of 137.2 s, compared to the 110 s reported in [4]. The same skirt and nozzle diameters as the RSRMV was assumed. The thrust curve is shown in Figure 1.

Boosters	1C4J2.2	2C4J2	4C4J2	4C5J2
Booster Name	RSRMV	Pyrios	ATK AB	ATK AB
Number of Boosters	2	2	2	2
Engine Name	–	F–1B	–	–
Number of Engines per Booster	1	2	1	1
Aft Skirt Diameter (m)	5.156	9.340	5.156	5.156
Booster Diameter (m)	3.711	5.486	3.708	3.708
Nozzle Diameter (m)	3.875	3.185	3.875	3.875
Sea Level Thrust at 0.2 s (N)	15,599,386	8,029,040	18,027,271	18,027,271
Maximum Vacuum Thrust (N)	17,866,606	8,836,221	20,016,997	20,016,997
Vacuum Isp (m/s)	2,622.3	2,932.7	2,756.6	2,756.6
Total Mass (kg)	733,776	942,030	777,004	777,004
Startup Propellant (kg)	0	17,940	0	0
Usable Propellant (kg)	632,791	787,311	679,920	679,920
Residual/Reserve Propellant (kg)	442	12,789	469	469
Burnout/Dry Mass (kg)	100,543	123,990	96,615	96,615
Action Time (s)	131.9	131.8	130.2	130.2

The simulations have no thrust bucket and reduced the thrust rating to 109%, as reported in [5].

Core Stage: 4xRS–25 Engines	1C4J2.2	2C4J2	4C4J2	4C5J2
Stage Diameter (m)	8.407	8.407	8.407	8.407
Nozzle Diameter (m)	2.304	2.304	2.304	2.304
Vacuum Isp (m/s)	4,436.5	4,436.5	4,436.5	4,436.5
Engine Thrust (N)	2,278,824	2,278,824	2,278,824	2,278,824
Engine Thrust Rating (%)	109	109	109	109
Thrust Bucket (%)	109	109	109	109
Total Mass (kg)	1,091,525	1,091,525	1,091,525	1,102,512
Usable Propellant (kg)	966,061	966,061	966,061	963,800
Reserve Propellant (kg)	8,210	8,210	8,210	8,191
Fuel Bias Propellant (kg)	1,678	1,678	1,678	2,098
Startup Propellant (kg)	7,439	7,439	7,439	9,299
Dry Mass (kg)	115,575	115,575	115,575	119,124

The size of the upper stage was optimised to maximise payload delivered into a 200 km orbit. The interstage mass was adjusted according to total maximum weight carried by the core. Ullage motors were added to ensure propellant settling, similar to that used by the Saturn V.

Upper Stage:	1C4J2.2	2C4J2	4C4J2	4C5J2
Engines	J–2X	J–2X	J–2X	J–2X
Number of Engines	2	2	2	2
Stage Diameter (m)	8.407	8.407	8.407	8.407
Nozzle Diameter (m)	3.048	3.048	3.048	3.048
Vacuum Isp (m/s)	4,275.7	4,275.7	4,275.7	4,275.7
Single Engine Thrust (N)	1,281,088	1,281,088	1,281,088	1,281,088
Single Engine Mass (kg)	2,472	2,472	2,472	2,472
Total Mass (kg)	147,516	156,359	172,544	202,336
Usable Propellant (kg)	125,292	133,184	147,751	174,542
Reserve Propellant (kg)	2,114	2,247	2,491	2,940
Startup Propellant (kg)	771	771	771	771
Residual Propellant (kg)	0	0	0	0
RCS Propellant (kg)	102	116	120	139
Dry Mass (kg)	19,005	19,748	21,103	23,542
Ullage Motors Propellant (kg)	115	148	156	208
Ullage Motors Dry Mass (kg)	117	145	152	194
Ullage Motors Action Time (s)	3.87	3.87	3.87	3.87
Ullage Motors Thrust (N)	65,032	83,178	87,998	117,254
Ullage Motors Offset Angle (°)	30	30	30	30
Interstage Mass (kg)	5,944	8,910	7,226	8,691

The LAS/SAJ jettison time was obtained from [6]. Simulation results for 4C5J2 are shown in Figures 2–5. The additional RS–25D engine allows for an increase of payload of 18.7 t or 15.4% from 121.5 t to 140.2 t.

	1C4J2.2	2C4J2	4C4J2	4C5J2
Orbit (km)	200 ± 0.4	200 ± 0.4	200 ± 0.4	200 ± 0.4
Liftoff Thrust at 0.2 s (N)	38,623,742	39,541,132	43,479,514	45,335,756
Liftoff Mass (kg)	2,823,613	3,242,240	2,955,068	3,006,757
Liftoff Acceleration (m/s^2)	13.69	12.20	14.72	15.09
MaxQ (Pa)	21,877	28,287	25,492	28,636
Maximum Acceleration (m/s^2)	23.80	31.65	23.41	24.63
LAS/SAJ Jettison Time (s)	330	330	330	330
Launch Abort System (kg)	7,394	7,394	7,394	7,394
Orion Jettisoned Adaptors (kg)	920	920	920	920
Other Spacecraft (kg)	102,762	128,953	121,452	140,195
Remaining Propellant (kg)	0	0	0	0
Total Payload (kg)	102,762	128,953	121,452	140,195
Total Delta–V (m/s)	9,905	9,689	9,735	9,332

[1] Alliant Techsystems Inc., “ATK space propulsion products catalog,” Aug. 2012.

[2] B. Donahue and J. Bridges, “The Space Launch System capabilities for enabling crewed Lunar and Mars exploration,” *63rd Int. Astronautical Congress*, Naples, Italy, IAC–12–D2.8.7, Oct. 2012.

[3] P. Phillips, “Ground systems development and operations,” NASA, July 2012.

[4] D. Sauvageau and A. Corliss, “Advanced booster for NASA Space Launch System,” *63rd Int. Astronautical Congress*, Naples, Italy, IAC–12–D2.8.6, Oct. 2012.

[5] M. Davidson, “RS–25: The Clark Kent of engines for the Space Launch System,” 13 Sep. 2013. http://www.nasa.gov/exploration/systems/sls/rs25–engine–powers–sls.html

[6] S. Creech, J. Holladay and D. Jones, “SLS dual use upper stage (DUUS) opportunities,” NASA, Apr. 2013.

Figure 1: Vacuum thrust versus time for ATK AB

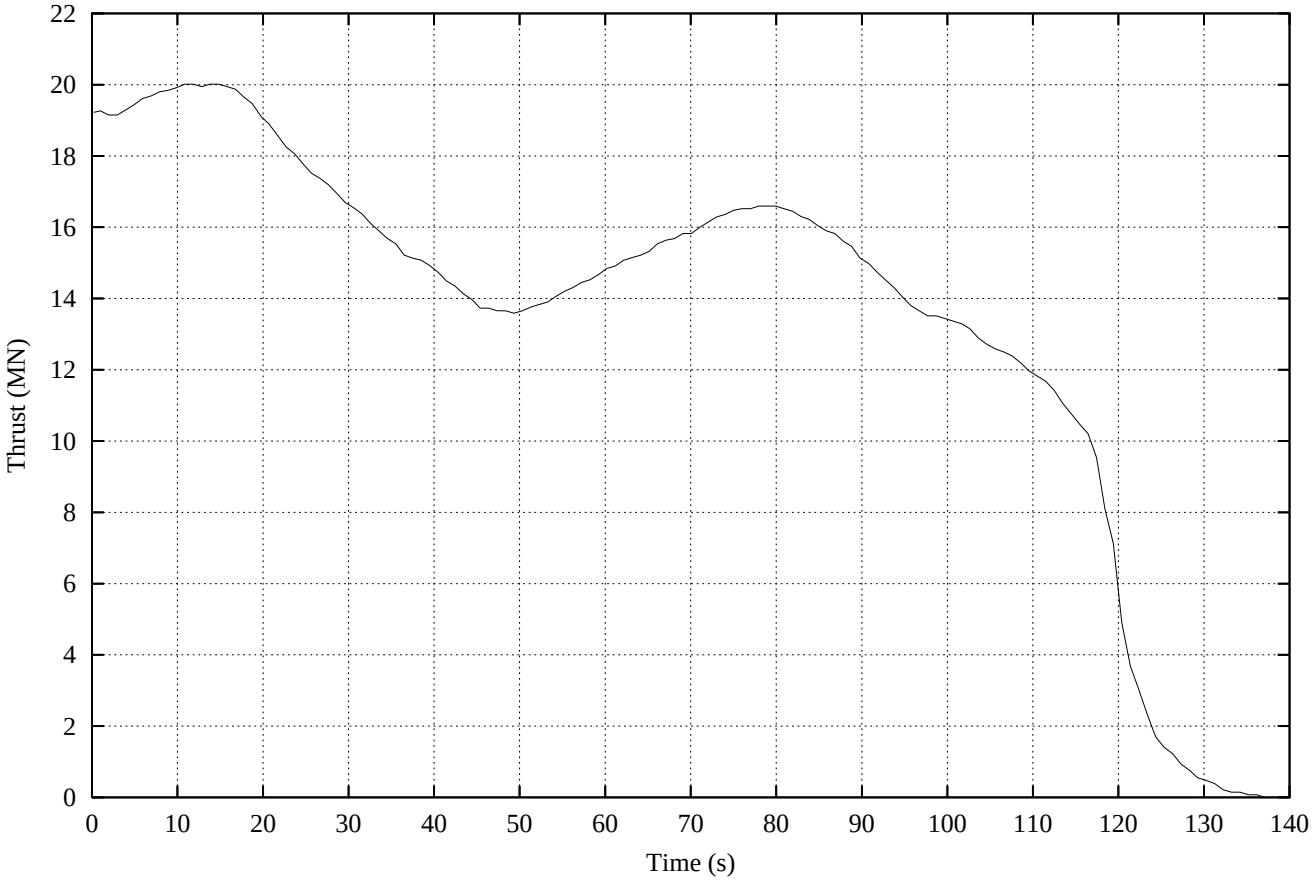

Figure 2: Altitude versus time for SLS Block 1C

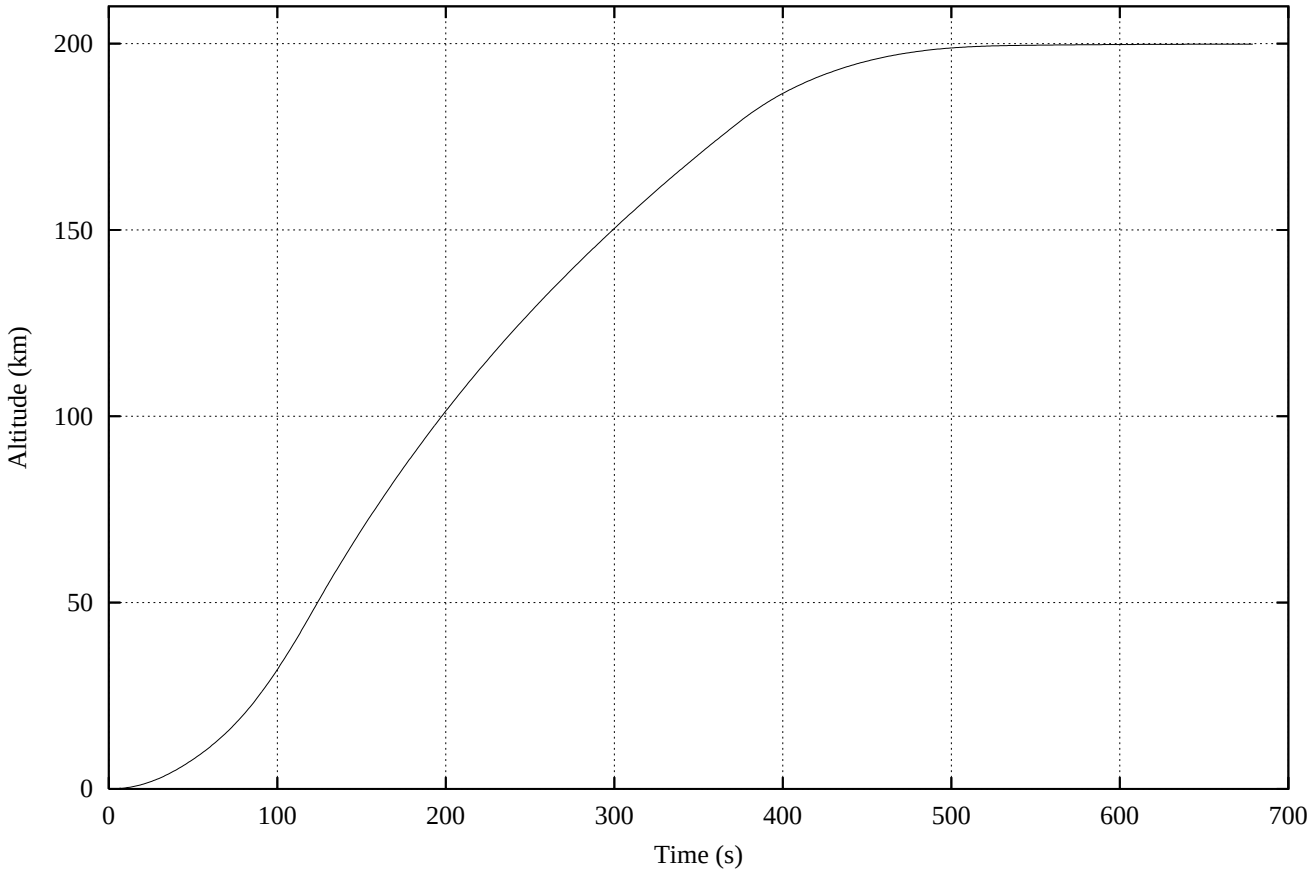

Figure 3: Speed versus time for SLS Block 1C

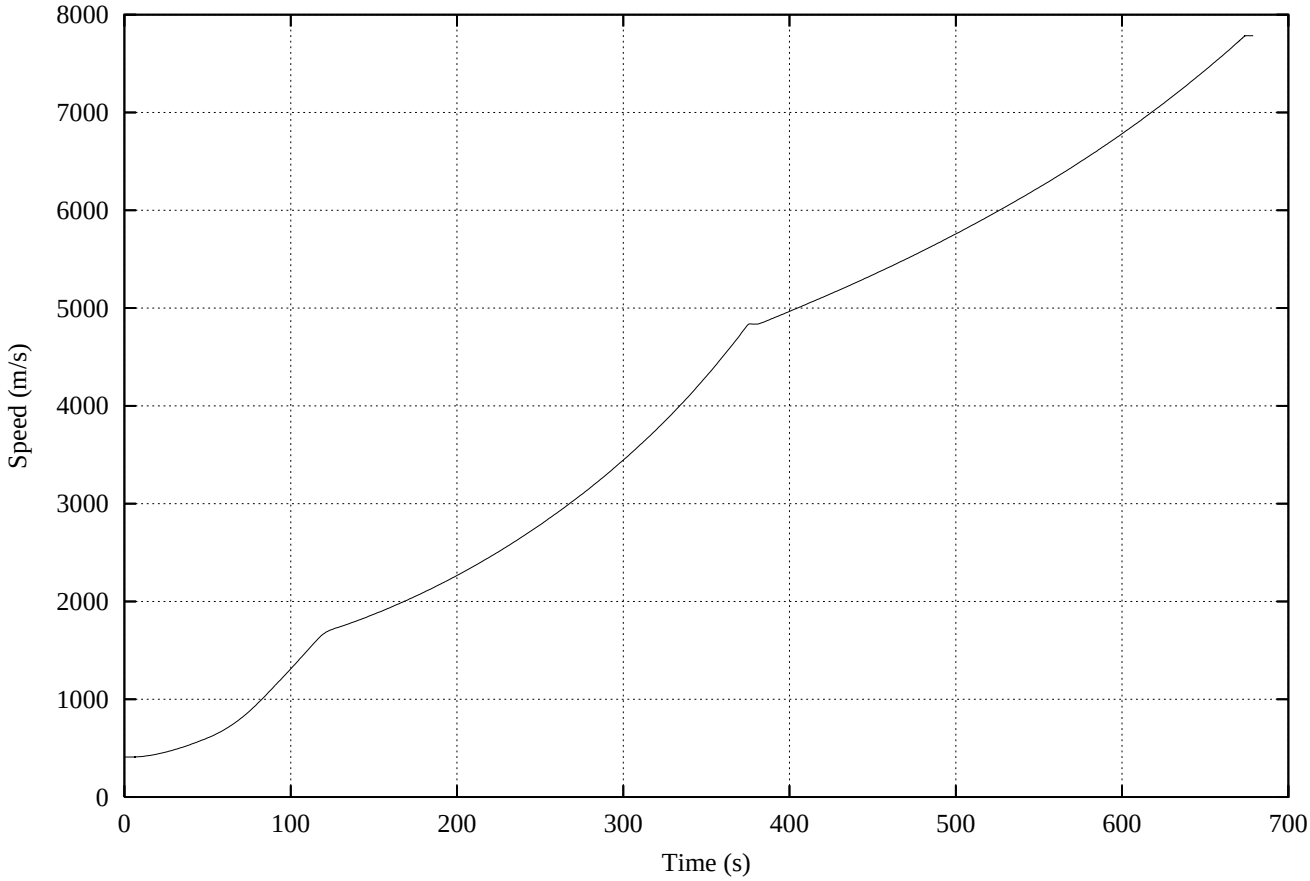

Figure 4: Acceleration versus time for SLS Block 1C

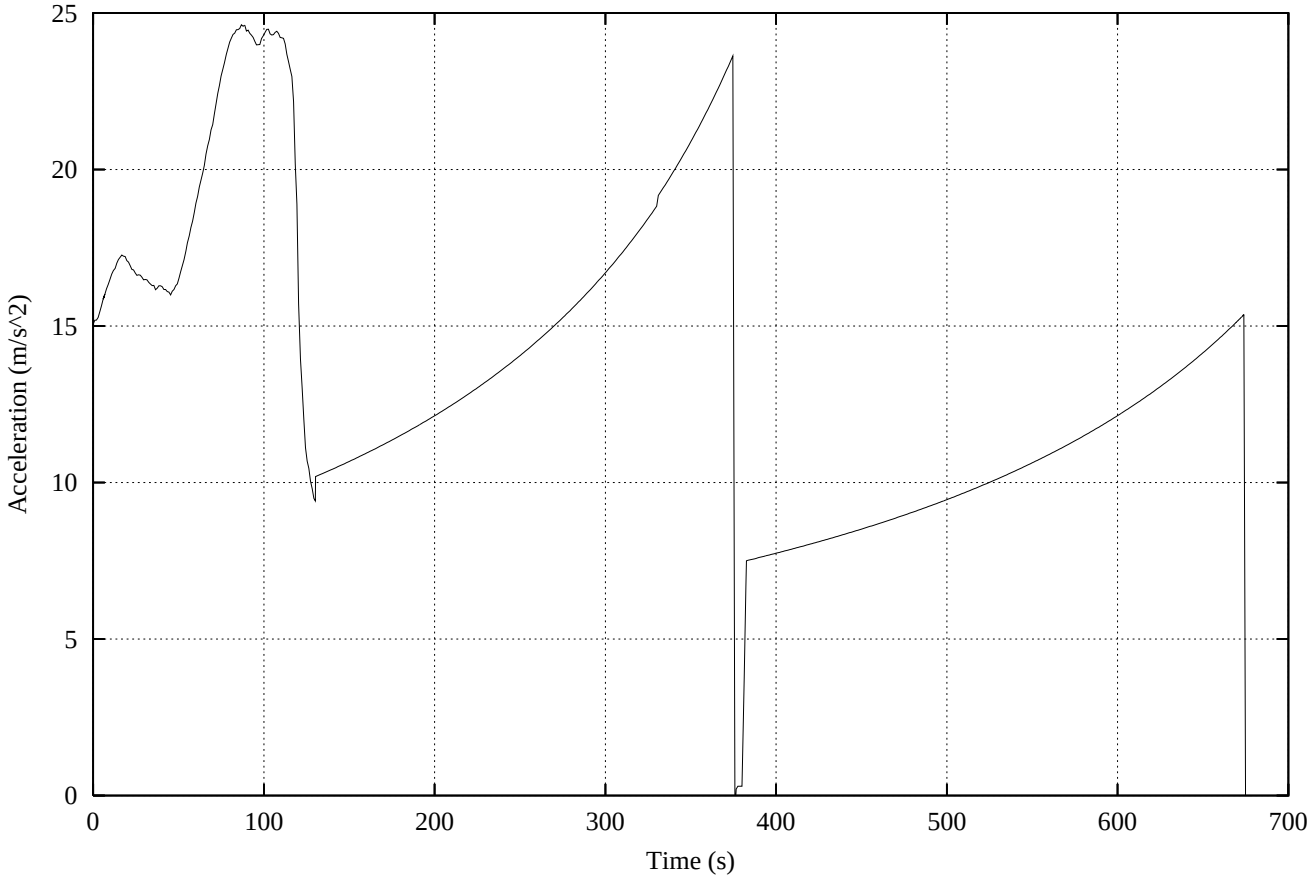

Figure 5: Dynamic pressure versus time for SLS Block 1C