SLS Block 1C with optimised Second Stage, five RS–25D engines on core and one J–2X engine on upper stage. Payload to 200 km LEO = 118.2 t. 8 Dec. 2013. Author Steven S. Pietrobon, PhD.

RSRMV thrust curve obtained from page 56 of [2]. There is a discrepancy in that Loaded Mass minus Burnout Mass in [2] is 650,743 kg compared to 633,233 kg in [1] and 628,701 kg in [3]. Therefore, we have adjusted the propellant mass and impulse in [2] to match the values in [1].

Boosters: RSRMV 2x5–Segment	1C4J2.2	1C5J2	1C5J3	1C5J1
Aft Skirt Diameter (m)	5.156	5.156	5.156	5.156
Nozzle Diameter (m)	3.875	3.875	3.875	3.875
Sea Level Thrust at 0.2 s (N)	15,599,386	15,599,386	15,599,386	15,599,386
Vacuum Isp (m/s)	2,622.3	2,622.3	2,622.3	2,622.3
Total Mass (kg)	733,776	733,776	733,776	733,776
Usable Propellant (kg)	632,791	632,791	632,791	632,791
Residual Propellant (kg)	442	442	442	442
Burnout Mass (kg)	100,543	100,543	100,543	100,543
Action Time (s)	131.9	131.9	131.9	131.9

At 110% thrust, the burn duration of the core is 466 s. However, the curves in Figure 9 of [1] show a duration of 505 s. The longer burn can be explained by having a 65% thrust bucket during the booster phase. The simulation in 1C4J2.2 eliminated the thrust bucket and reduced the thrust rating to 109%, as reported in [4]. 1C5J2 adds an additional RS–25D engine (mass obtained from [5]).

Core Stage: RS–25 Engines	1C4J2.2	1C5J2	1C5J3	1C5J1
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
Number of Engines	4	5	5	5
Total Mass (kg)	1,098,963	1,102,512	1,102,512	1,102,512
Usable Propellant (kg)	966,061	963,800	963,800	963,800
Reserve Propellant (kg)	8,210	8,191	8,191	8,191
Fuel Bias Propellant (kg)	1,678	2,098	2,098	2,098
Startup Propellant (kg)	7,439	9,299	9,299	9,299
Dry Mass (kg)	115,575	119,124	119,124	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	1C5J2	1C5J3	1C5J1
Engine	J–2X	J–2X	J–2X	J–2X
Number of Engines	2	2	3	1
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
Engine Thrust (N)	1,281,088	1,281,088	1,281,088	1,281,088
Total Mass (kg)	147,516	204,711	269,148	121,108
Usable Propellant (kg)	125,292	176,718	232,285	104,184
Reserve Propellant (kg)	2,114	2,977	3,915	1,754
Startup Propellant (kg)	771	771	1,157	386
Shutdown Propellant (kg)	0	0	0	0
RCS Propellant (kg)	102	134	159	97
Dry Mass (kg)	19,005	23,738	31,126	14,472
Ullage Motors Propellant (kg)	115	192	267	106
Ullage Motors Dry Mass (kg)	117	181	239	109
Ullage Motors Action Time (s)	3.87	3.87	3.87	3.87
Ullage Motors Thrust (N)	65,032	108,332	150,618	59,794
Ullage Motors Offset Angle (°)	30	30	30	30
Interstage Mass (kg)	5,944	7,822	8,852	6,884

With one J–2X engine for the upper stage this resulted in a decrease of the delta–V from 9508 to 9321 m/s and a decrease in the upper stage mass from 204.7 t to 121.1 t, a 41% decrease. Payload mass decreased by 5.4 t or 4.4% from 123.7 t to 118.2 t. The LAS/SAJ jettison time was obtained from [6]. Simulation results for 1C5J3 are shown in Figures 1–4.

	1C4J2.2	1C5J2	1C5J3	1C5J1
Orbit (km)	200 ± 0.4	200 ± 0.2	200 ± 0.4	200 ± 0.4
Liftoff Thrust at 0.2 s (N)	38,623,742	40,479,985	40,479,985	40,479,985
Liftoff Mass (kg)	2,823,613	2,905,302	2,969,302	2,815,302
Liftoff Acceleration (m/s^2)	13.69	13.94	13.64	14.39
MaxQ (Pa)	21,877	24,291	22,589	22,589
Maximum Acceleration (m/s^2)	23.80	24.39	24.41	30.21
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	123,689	122,223	118,230
Remaining Propellant (kg)	0	0	0	0
Total Payload (kg)	102,762	123,689	122,223	118,230
Total Delta–V (m/s)	9,905	9,508	9,672	9,321

[1] 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.

[2] Alliant Techsystems Inc., "ATK space propulsion products catalog," Aug. 2012.

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

[4] 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

[5] R. Ryan, "Lesson in system engineering – The SSME weight growth history," NASA, Aug. 2008.

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

Figure 1: Altitude versus time for SLS Block 1C

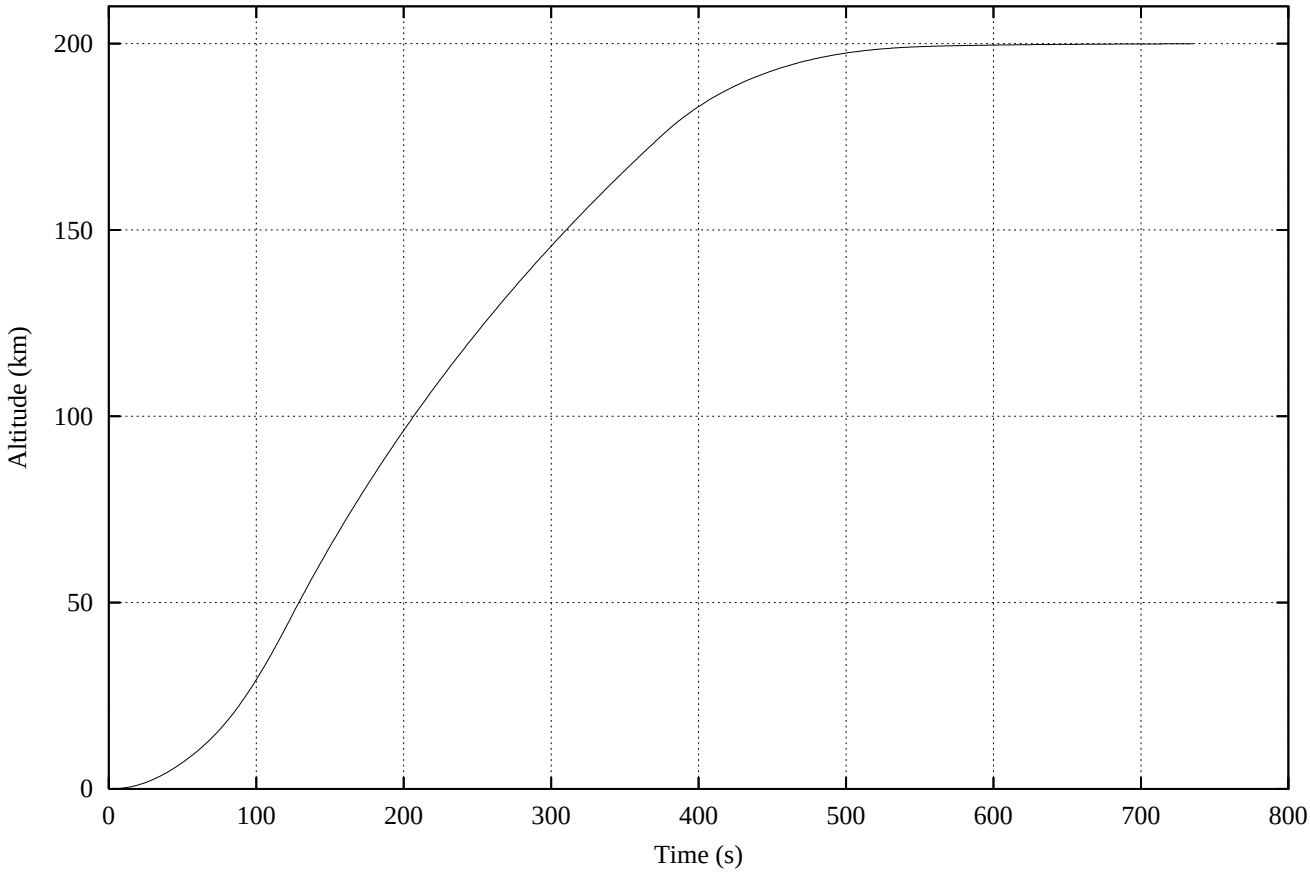

Figure 2: Speed versus time for SLS Block 1C

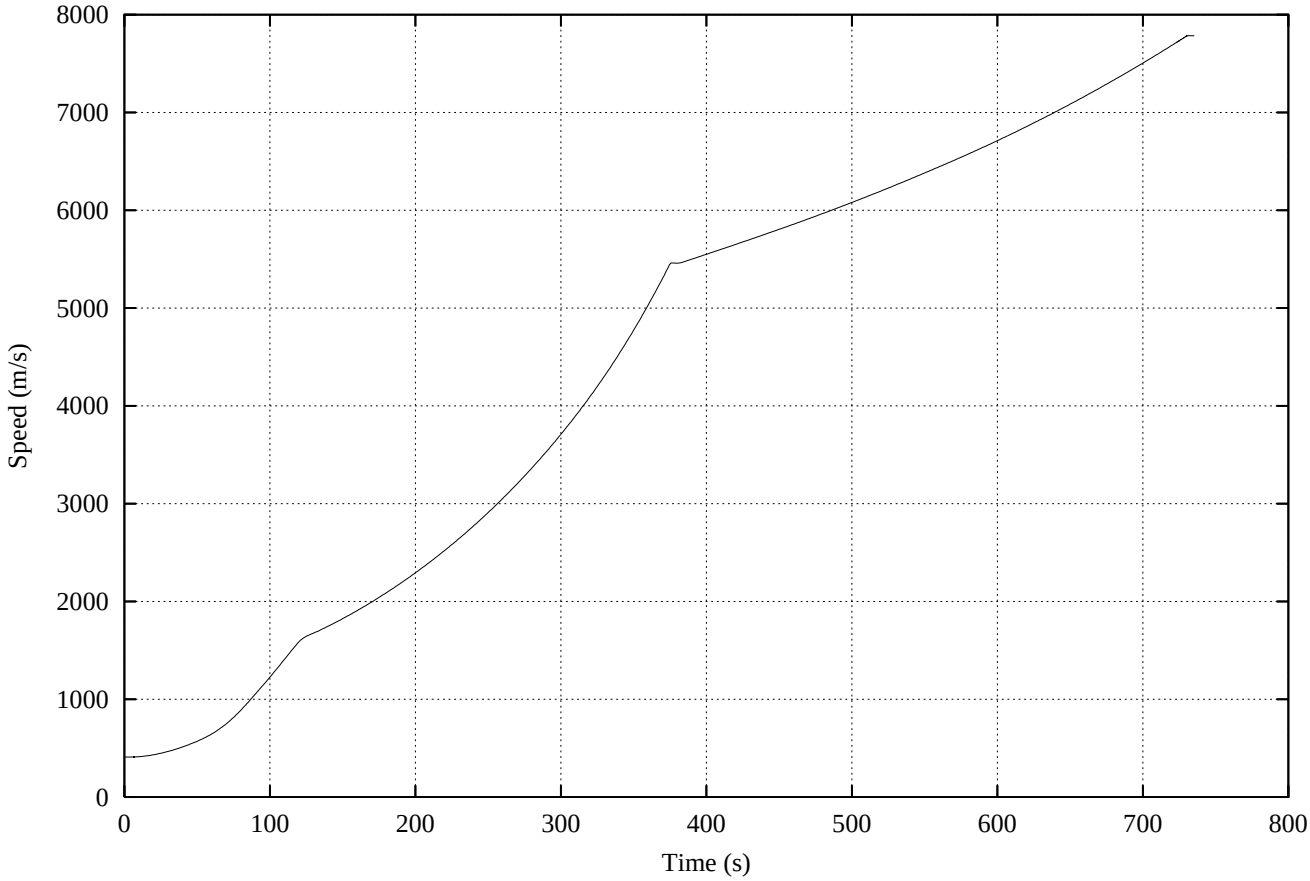

Figure 3: Acceleration versus time for SLS Block 1C

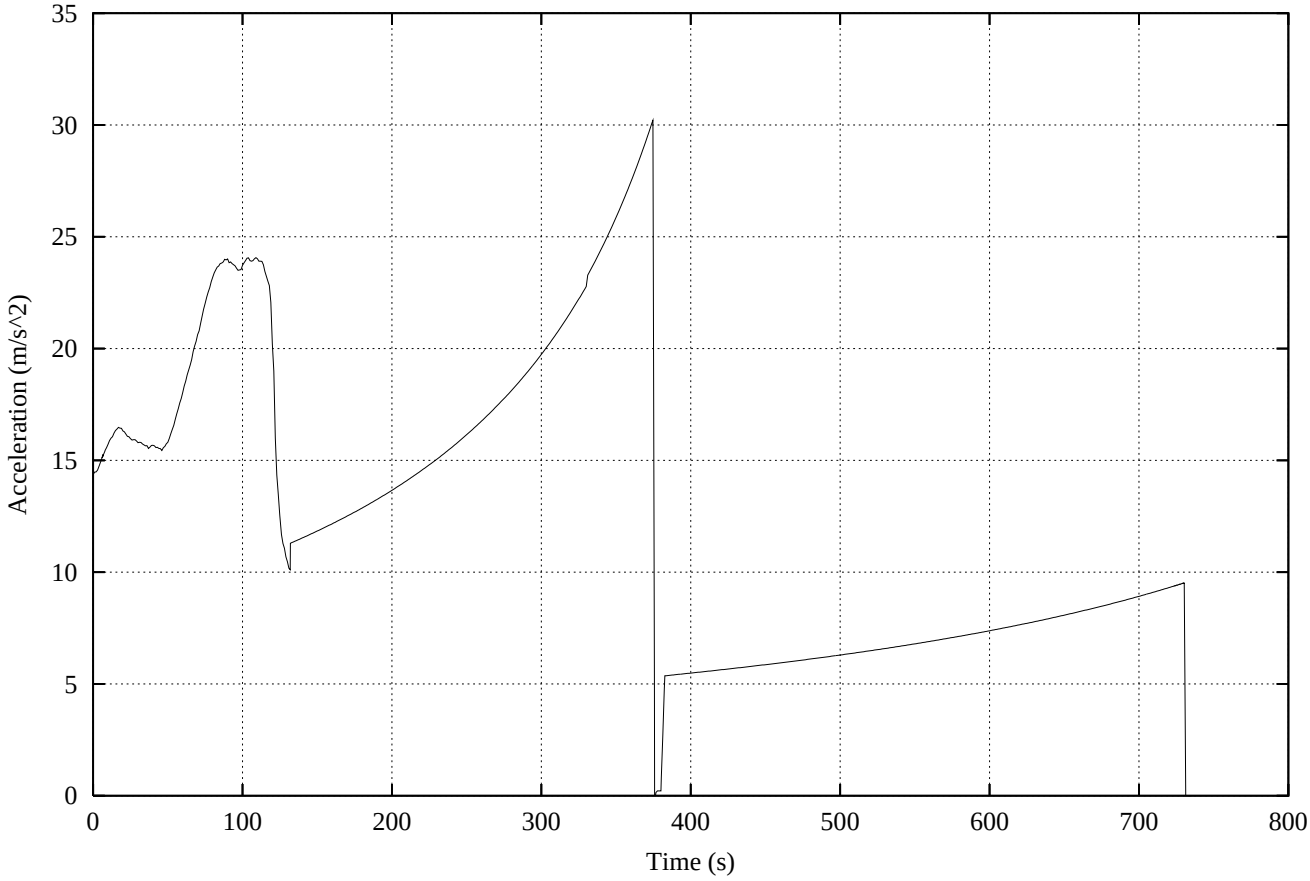

Figure 4: Dynamic pressure versus time for SLS Block 1C