SLS Block 1C with optimised upper stage. Payload to 200 km LEO = 102.8 t. 17 Nov. 2013. Author Steven S. Pietrobon, PhD. Boeing data obtained from [1].

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	Boeing	1C4J2.0	1C4J2.1	1C4J2.2
Aft Skirt Diameter (m)	–	5.156	5.156	5.156
Nozzle Diameter (m)	–	3.875	3.875	3.875
Sea Level Thrust at 0.2 s (N)	14,014,567	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)	632,716	632,791	632,791	632,791
Residual Propellant (kg)	517	442	442	442
Burnout Mass (kg)	100,543	100,543	100,543	100,543
Action Time (s)	128.4	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] for RS–25D engines.

Core Stage: 4xRS–25 Engines	Boeing	1C4J2.0	1C4J2.1	1C4J2.2
Stage Diameter (m)	8.407	8.407	8.407	8.407
Nozzle Diameter (m)	–	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)	2,299,730	2,299,730	2,299,730	2,299,730
Engine Thrust Rating (%)	110	110	110	109
Thrust Bucket (%)	65	110	65	109
Total Mass (kg)	1,091,525	1,091,525	1,091,525	1,091,525
Usable Propellant (kg)	966,061	966,061	966,061	966,061
Reserve Propellant (kg)	8,210	8,210	8,210	8,210
Fuel Bias Propellant (kg)	1,678	1,678	1,678	1,678
Startup Propellant (kg)	7,439	7,439	7,439	7,439
Dry Mass (kg)	115,575	115,575	115,575	115,575

For the upper stage, the only difference is that we have included the shutdown propellant into the usable propellant, in order to simplify the simulation. For 1C4J2.2, 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 in 1C4J2.0. Ullage motors were added to ensure propellant settling, similar to that used by the Saturn V.

Upper Stage: 2xJ–2X Engines	Boeing	1C4J2.0	1C4J2.1	1C4J2.2
Stage Diameter (m)	8.407	8.407	8.407	8.407
Nozzle Diameter (m)	–	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)	237,501	237,501	237,501	147,516
Usable Propellant (kg)	206,022	206,430	206,430	125,292
Reserve Propellant (kg)	3,765	3,765	3,765	2,114
Startup Propellant (kg)	771	771	771	771
Shutdown Propellant (kg)	408	0	0	0
RCS Propellant (kg)	136	136	136	102
Dry Mass (kg)	26,399	26,399	26,399	19,005
Ullage Motors Propellant (kg)	–	–	–	115
Ullage Motors Dry Mass (kg)	–	–	–	117
Ullage Motors Action Time (s)	–	–	–	3.87
Ullage Motors Thrust (N)	–	–	–	65,032
Ullage Motors Offset Angle (°)	–	–	–	30
Interstage Mass (kg)	7,394	7,394	7,394	5,944

Our simulations in 1C4J2.1 show that the thrust bucket and oversized upper stage results in large gravity losses, which reduce performance to only 72.1 t. The LAS/SAJ jettison time was obtained from [5]. Simulation results for 1C4J2.2 are shown in Figures 1–4.

	Boeing	1C4J2.0	1C4J2.1	1C4J2.2
Orbit (km)	166.7 ± 74.1	200 ± 0.3	200 ± 0.3	200 ± 0.4
Liftoff Thrust at 0.2 s (N)	35,537,732	38,707,369	38,707,369	38,623,742
Liftoff Mass (kg)	2,909,196	2,909,196	2,884,424	2,823,613
Liftoff Acceleration (m/s^2)	12.22	13.31	13.43	13.69
MaxQ (Pa)	39,700	20,857	16,139	21,877
Maximum Acceleration (m/s^2)	20.59	20.79	25.01	23.80
LAS/SAJ Jettison Time (s)	–	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)	96,910	96,910	72,138	102,762
Remaining Propellant (kg)	31,535	812	3	0
Total Payload (kg)	128,445	97,722	72,141	102,762
Total Delta–V (m/s)	10,403	10,350	11,215	9,905

[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] 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

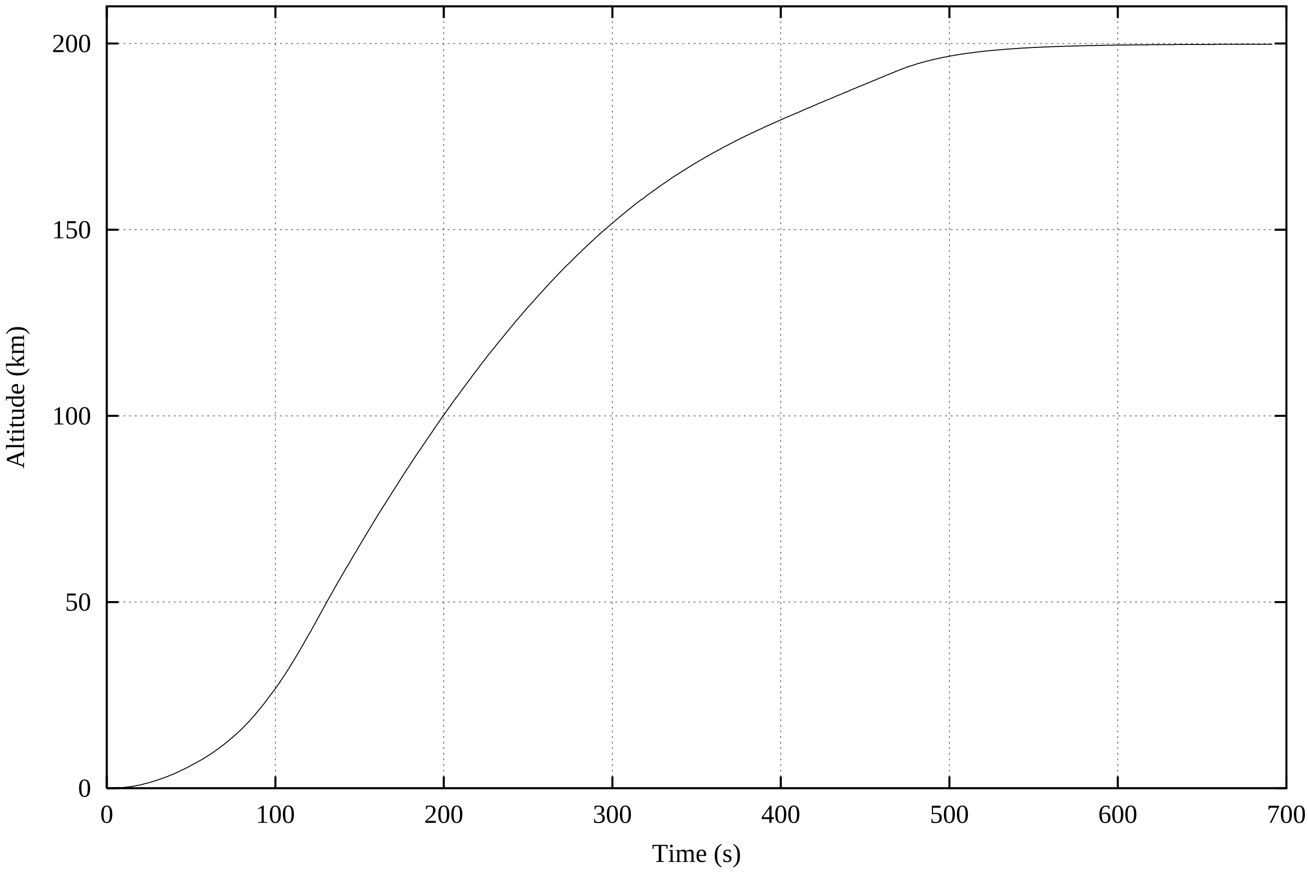

Figure 2: Speed versus time for SLS Block 1C

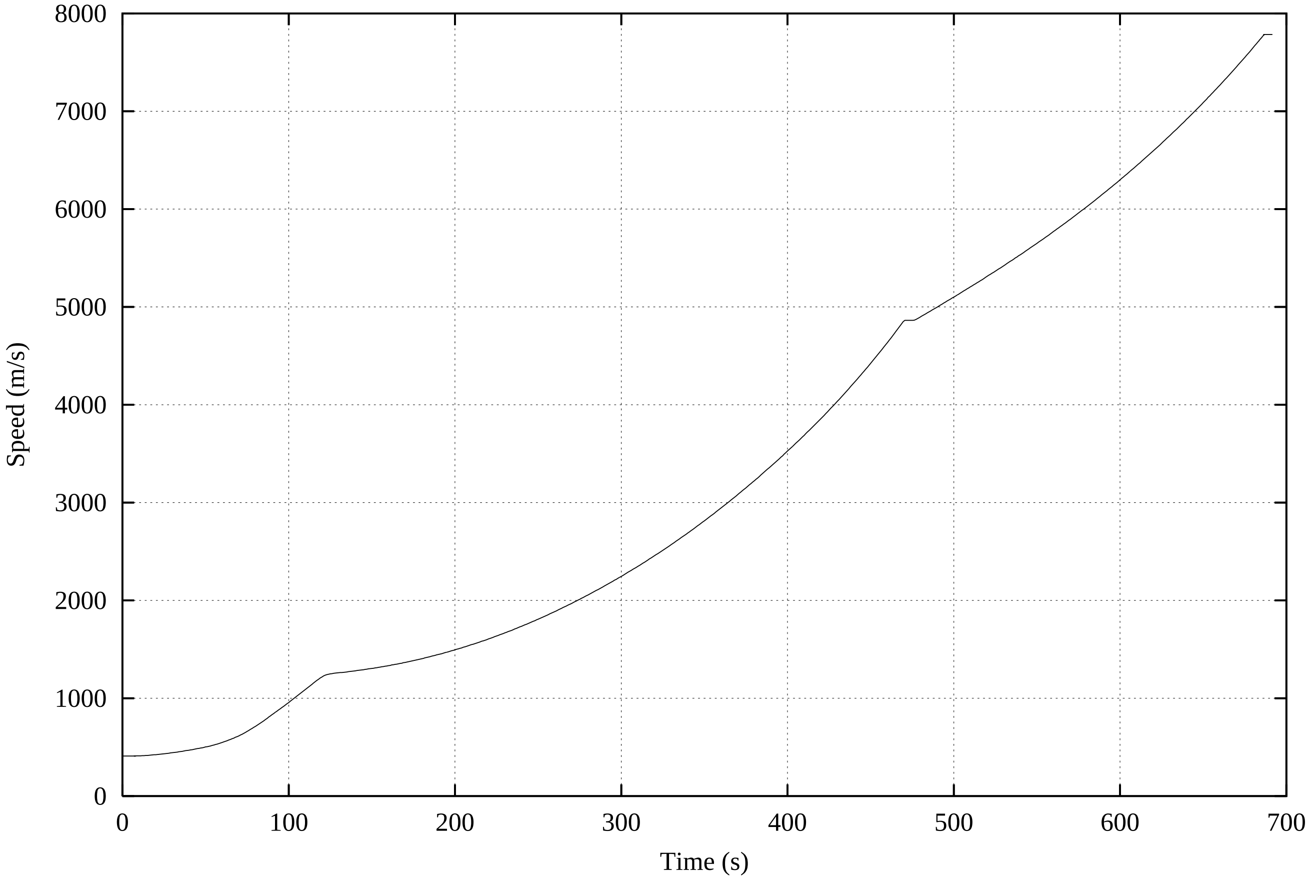

Figure 3: Acceleration versus time for SLS Block 1C

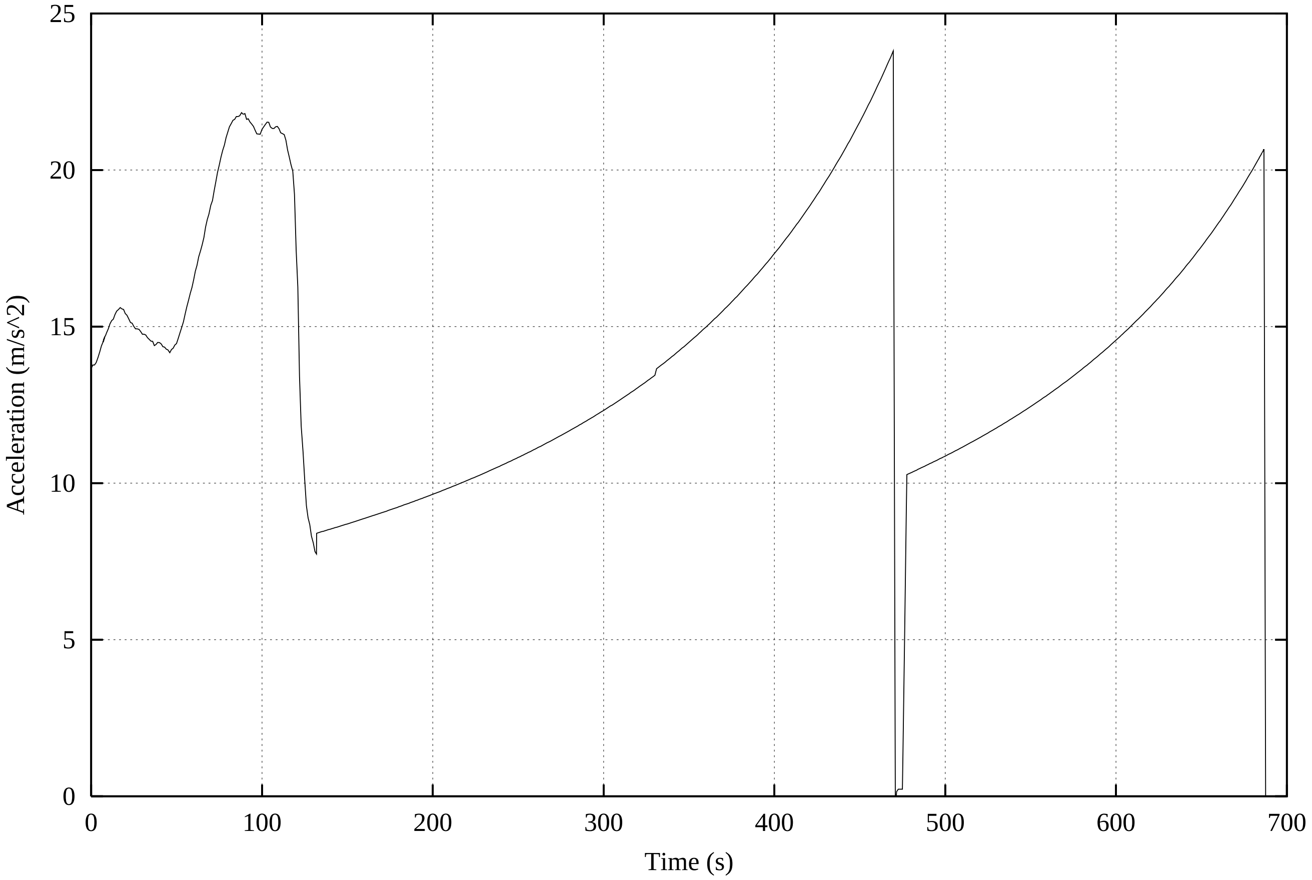

Figure 4: Dynamic pressure versus time for SLS Block 1C