SLS Block 1C with four RS–25D core with small upper stage with one AJ10–190 engine. Payload to 51.6° 400 km orbit LEO = 50.5 t. 28 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	SLS1C4	SLS1C4O1
Aft Skirt Diameter (m)	5.156	5.156
Nozzle Diameter (m)	3.875	3.875
Sea Level Thrust at 0.2 s (N)	15,599,386	15,599,386
Vacuum Isp (m/s)	2,622.3	2,622.3
Total Mass (kg)	733,776	733,776
Usable Propellant (kg)	632,791	632,791
Residual Propellant (kg)	442	442
Burnout Mass (kg)	100,543	100,543
Action Time (s)	131.9	131.9

The simulations have no thrust bucket and reduced the thrust rating to 109%, as reported in [4].

Core Stage: 4xRS–25 Engines	SLS1C4	SLS1C4O1
Stage Diameter (m)	8.407	8.407
Nozzle Diameter (m)	2.304	2.304
Vacuum Isp (m/s)	4,436.5	4,436.5
Engine Thrust (N)	2,278,824	2,278,824
Engine Thrust Rating (%)	109	109
Thrust Bucket (%)	109	109
Total Mass (kg)	1,091,525	1,091,525
Usable Propellant (kg)	966,061	966,061
Reserve Propellant (kg)	8,210	8,210
Fuel Bias Propellant (kg)	1,678	1,678
Startup Propellant (kg)	7,439	7,439
Dry Mass (kg)	115,575	115,575
Interstage (kg)	5,346	5,346

At the end of the core burn, the core is separated. The upper stage and payload then ascend to apogee where the upper stage engine fires, circularising the orbit.

Parameters	SLS1C4	SLS1C4O1
Engine	–	AJ10–190
Number of engines	–	1
Nozzle Diameter (m)	–	1.168
Vacuum Isp (m/s)	–	3071.4
Engine Thrust (N)	–	26,689
Total Mass (kg)	–	2,361
Usable Propellant (kg)	–	1,524
Reserve Propellant (kg)	–	80
RCS Propellant (kg)	–	22
Dry Mass (kg)	–	735

Simulation results for SLS1C4O1 are shown in Figures 1–4. Figure 5 shows the ascent to apogee. To allow core to reach orbit, the maximum acceleration after booster separation is limited to 25 m/s^2. When maximum acceleration is reached all engines are incrementally reduced in thrust 1% at a time to a minimum of 65%. Engines are then shut down one at a time when the maximum acceleration is reached. Payload into a 400 km 51.6° orbit is 50.5 t, an increase of 21.8 t or 76% compared to direct insertion.

	SLS1C4	SLS1C4O1
Orbit (km)	400 ± 0.1	400 ± 0.1
Liftoff Thrust at 0.2 s (N)	38,623,742	38,623,742
Liftoff Mass (kg)	2,593,115	2,617,294
Liftoff Acceleration (m/s^2)	14.90	14.77
MaxQ (Pa)	26,701	26,520
Maximum Acceleration (m/s^2)	25.50	25.01
Spacecraft (kg)	28,692	50,510
Remaining Propellant (kg)	0	0
Total Payload (kg)	28,692	50,510
Total Delta–V (m/s)	10,071	9,623

[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.

Figure 1: Altitude versus time for SLS Block 1C

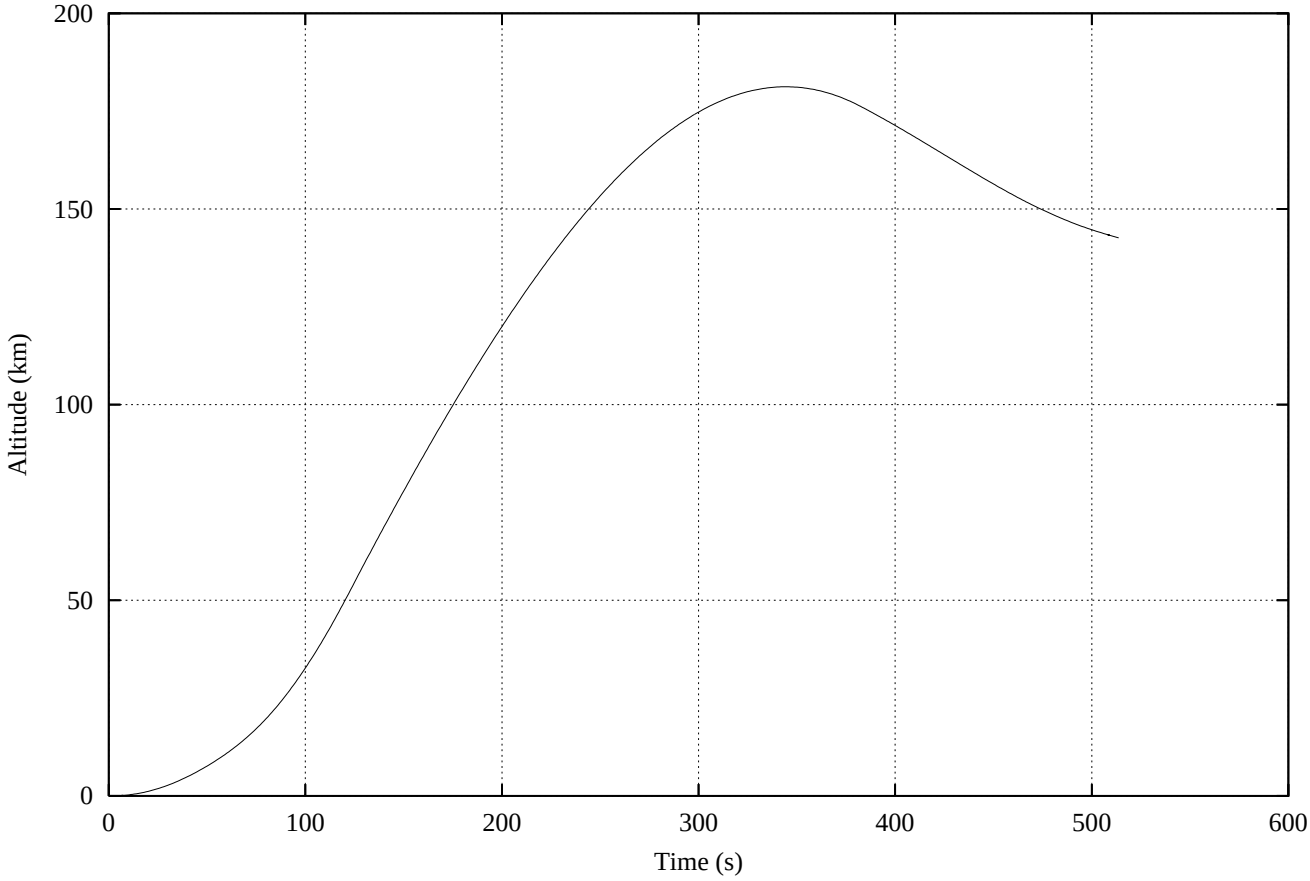

Figure 2: Speed versus time for SLS Block 1C

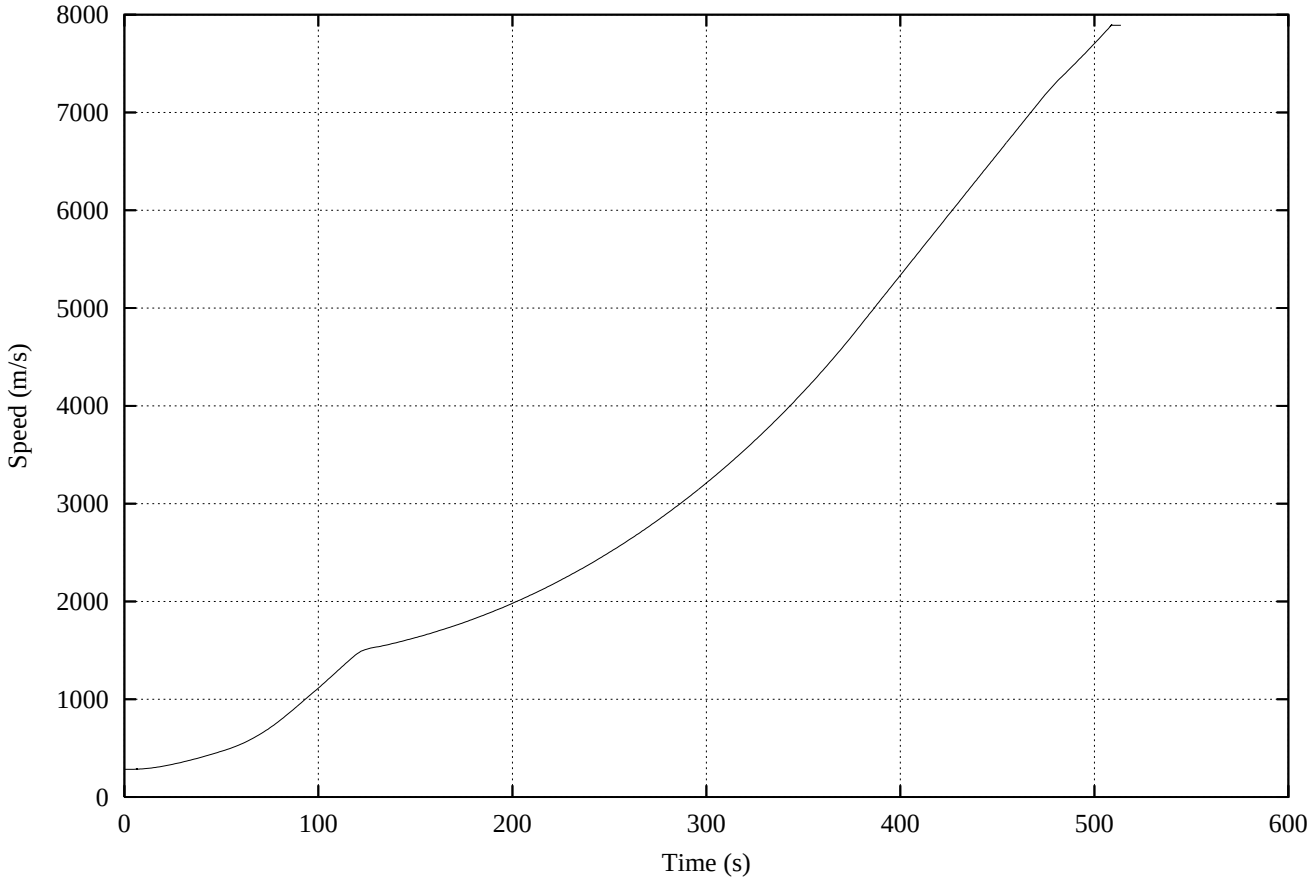

Figure 3: Acceleration versus time for SLS Block 1C

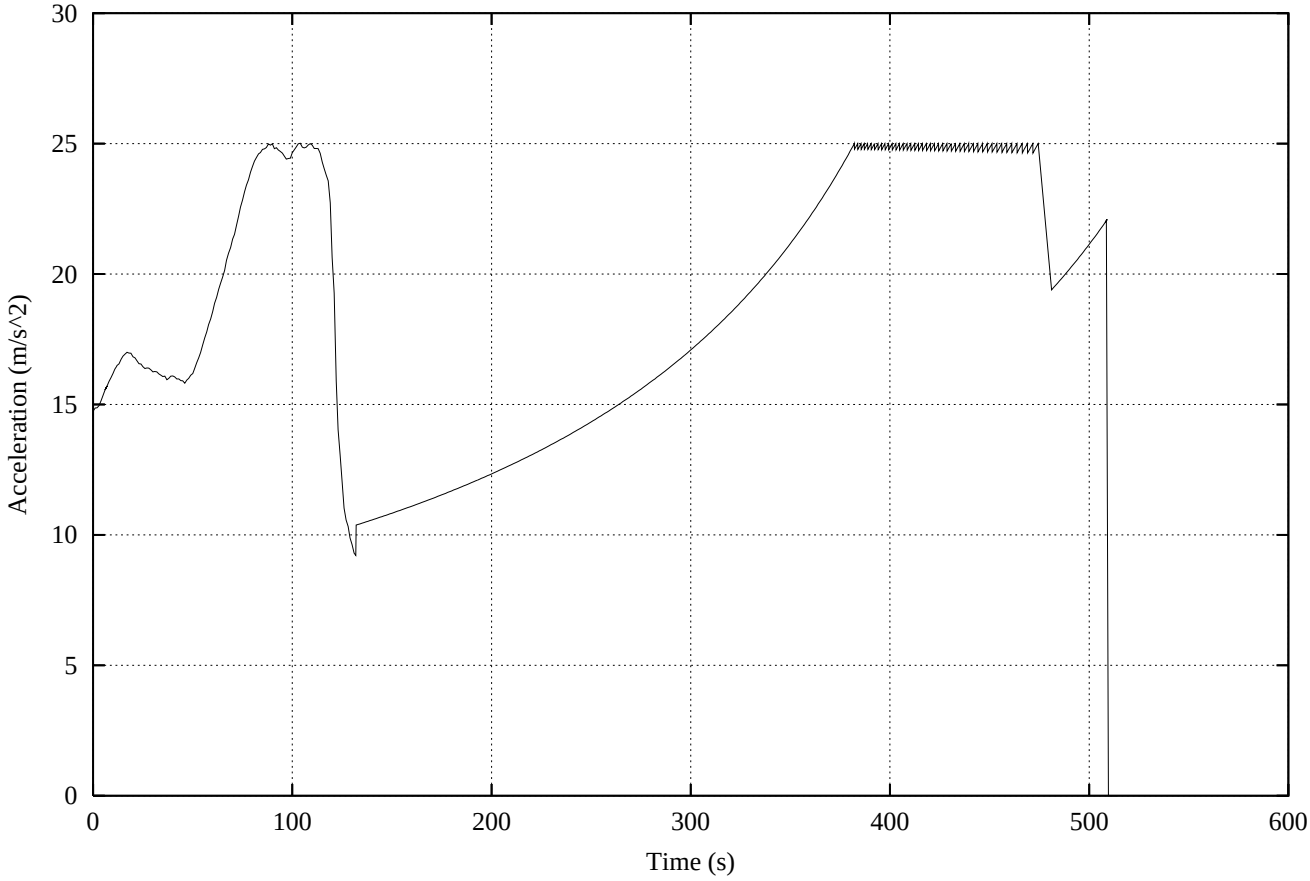

Figure 4: Dynamic pressure versus time for SLS Block 1C

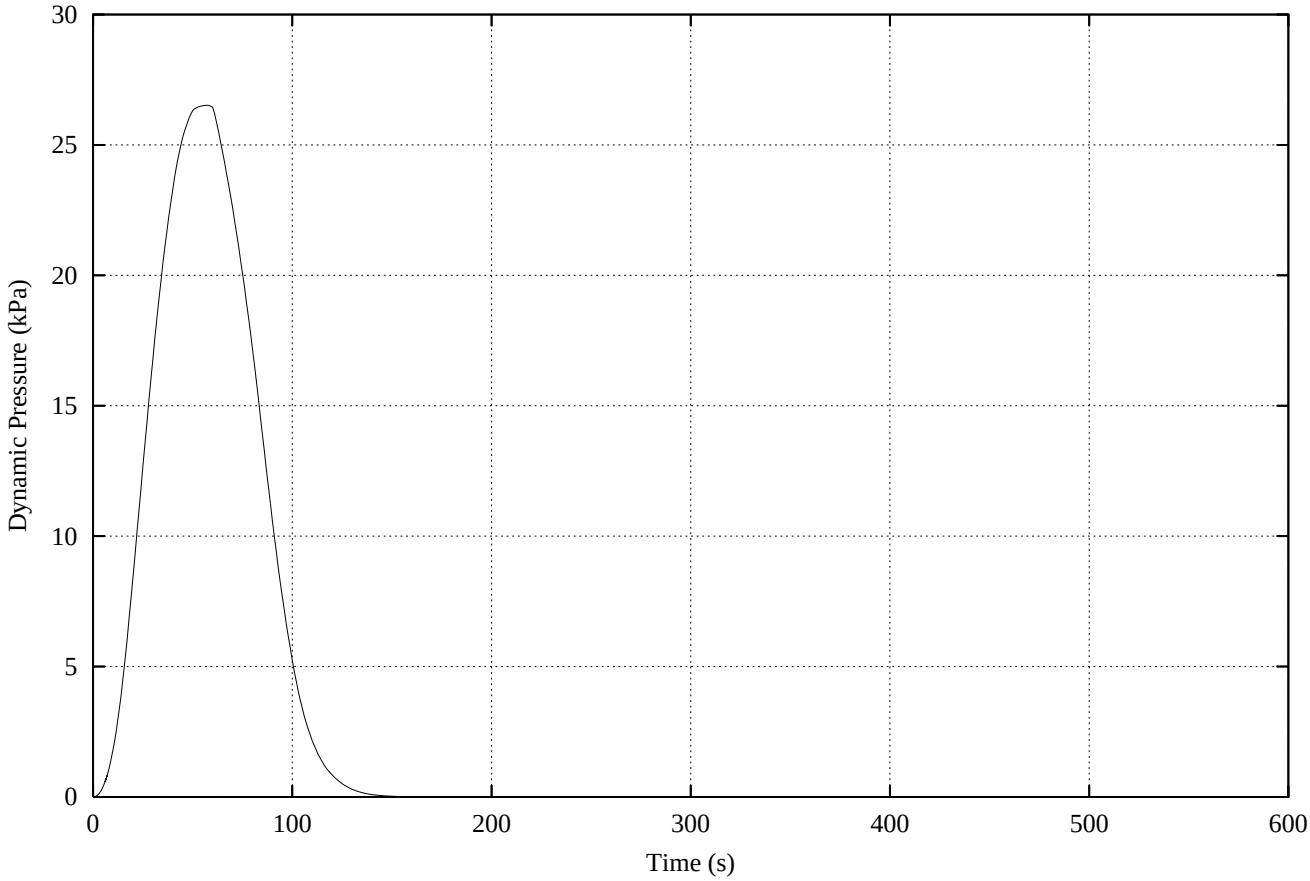

Figure 5: Altitude versus time for SLS Block 1C