SLS Block 1C with optimised Second Stage and six RS–25D engines. Payload to 200 km LEO = 133.0 t. 7 Dec. 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 | 1C4J2.2 | 1C5J2 | 1C6J2 |
|---|---:|---:|---:|---:|
| 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]. 1C6J2 adds two additional RS–25D engines (mass obtained from [5]).

| Core Stage: RS–25 Engines | Boeing | 1C4J2.2 | 1C5J2 | 1C6J2 |
|---|---:|---:|---:|---:|
| 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 | 2,278,824 | 2,278,824 | 2,278,824 |
| Engine Thrust Rating (%) | 110 | 109 | 109 | 109 |
| Thrust Bucket (%) | 65 | 109 | 109 | 109 |
| Number of Engines | 4 | 4 | 5 | 6 |
| Total Mass (kg) | 1,098,963 | 1,098,963 | 1,102,512 | 1,106,061 |
| Usable Propellant (kg) | 966,061 | 966,061 | 963,800 | 961,556 |
| Reserve Propellant (kg) | 8,210 | 8,210 | 8,191 | 8,156 |
| Fuel Bias Propellant (kg) | 1,678 | 1,678 | 2,098 | 2,517 |
| Startup Propellant (kg) | 7,439 | 7,439 | 9,299 | 11,159 |
| Dry Mass (kg) | 115,575 | 115,575 | 119,124 | 122,673 |

For 1C4J2.2, 1C5J2 and 1C6J2, 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: 2xJ–2X Engines | Boeing | 1C4J2.2 | 1C5J2 | 1C6J2 |
|---|---|---|---|---|
| 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 | 147,516 | 204,711 | 217,933 |
| Usable Propellant (kg) | 206,022 | 125,292 | 176,718 | 188,621 |
| Reserve Propellant (kg) | 3,765 | 2,114 | 2,977 | 3,177 |
| Startup Propellant (kg) | 771 | 771 | 771 | 771 |
| Shutdown Propellant (kg) | 408 | 0 | 0 | 0 |
| RCS Propellant (kg) | 136 | 102 | 134 | 143 |
| Dry Mass (kg) | 26,399 | 19,005 | 23,738 | 24,802 |
| Ullage Motors Propellant (kg) | – | 115 | 192 | 218 |
| Ullage Motors Dry Mass (kg) | – | 117 | 181 | 201 |
| Ullage Motors Action Time (s) | – | 3.87 | 3.87 | 3.87 |
| Ullage Motors Thrust (N) | – | 65,032 | 108,332 | 122,736 |
| Ullage Motors Offset Angle (°) | – | 30 | 30 | 30 |
| Interstage Mass (kg) | 7,394 | 5,944 | 7,822 | 9,257 |

The addition of two RS–25D engines to the core allows a reduction of the delta–V from 9859 to 9233 m/s as well as an increase in the upper stage mass from 147.5 t to 217.9 t, a 48% increase. Payload mass is increased by 30.3 t or 22.8% from 102.8 t to 133.0 t. The LAS/SAJ jettison time was obtained from [6]. Simulation results for 1C6J2 are shown in Figures 1–4.

| | Boeing | 1C4J2.2 | 1C5J2 | 1C6J2 |
|---|---|---|---|---|
| Orbit (km) | $166.7 \pm 74.1$ | $200 \pm 0.4$ | $200 \pm 0.2$ | $200 \pm 0.2$ |
| Liftoff Thrust at 0.2 s (N) | 35,537,732 | 38,623,742 | 40,479,985 | 43,336,228 |
| Liftoff Mass (kg) | 2,909,196 | 2,823,613 | 2,905,302 | 2,930,991 |
| Liftoff Acceleration (m/s$^2$) | 12.22 | 13.69 | 13.94 | 14.45 |
| MaxQ (Pa) | 39,700 | 21,877 | 24,291 | 27,765 |
| Maximum Acceleration (m/s$^2$) | 20.59 | 23.80 | 24.39 | 27.14 |
| 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 | 102,762 | 123,689 | 133,032 |
| Remaining Propellant (kg) | 31,535 | 0 | 0 | 0 |
| Total Payload (kg) | 128,445 | 102,762 | 123,689 | 133,032 |
| Total Delta–V (m/s) | 10,403 | 9,905 | 9,508 | 9,234 |

[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

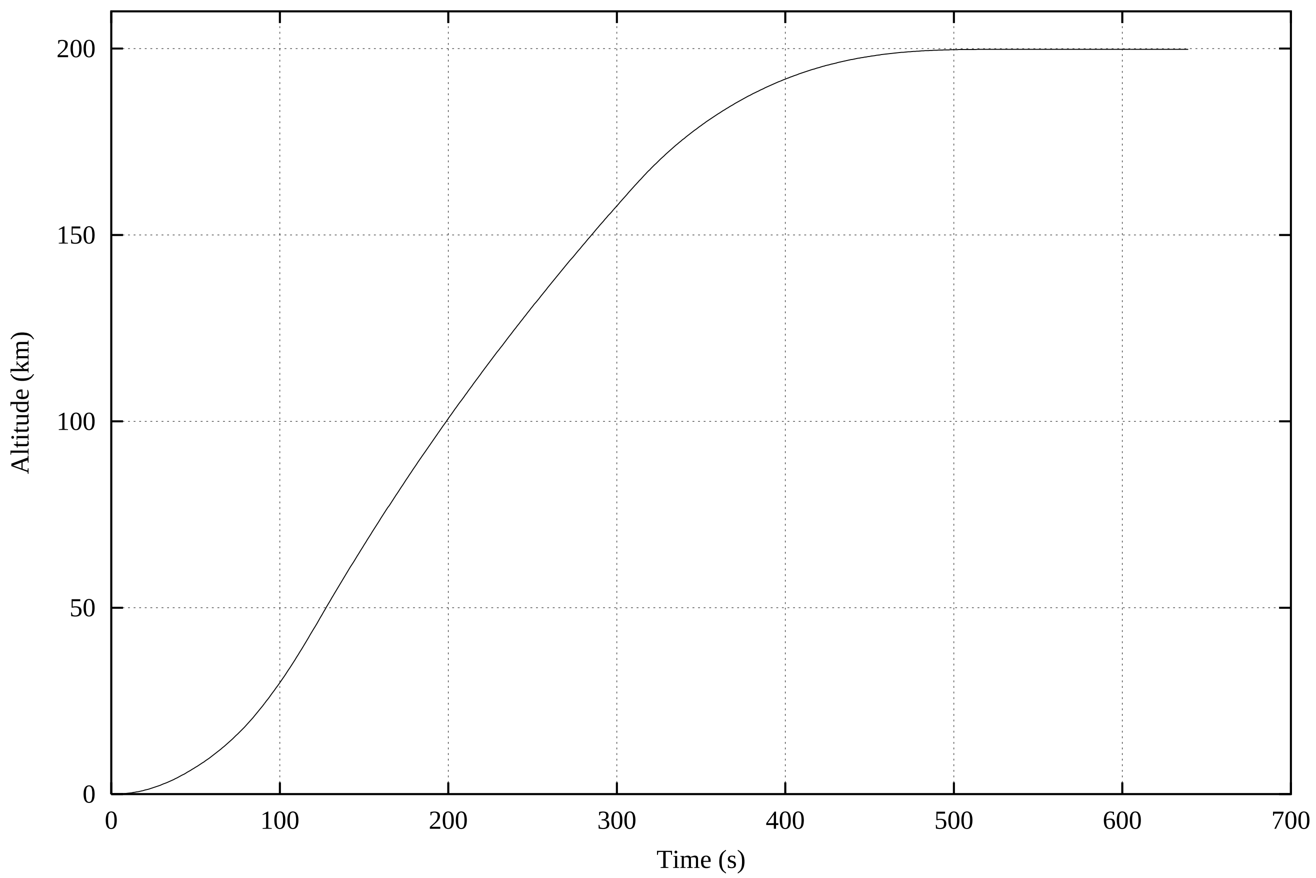


Figure 2: Speed versus time for SLS Block 1C

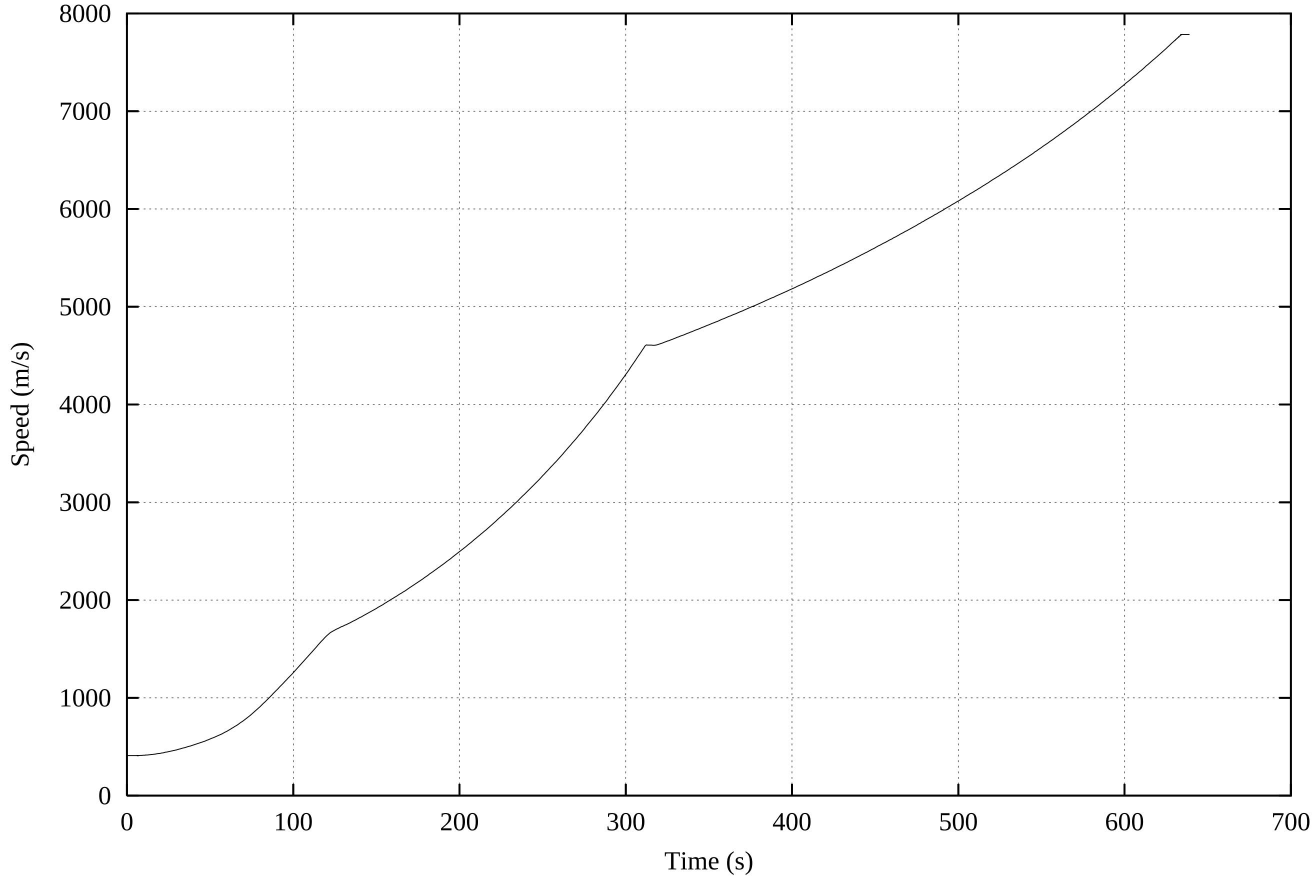

Figure 3: Acceleration versus time for SLS Block 1C

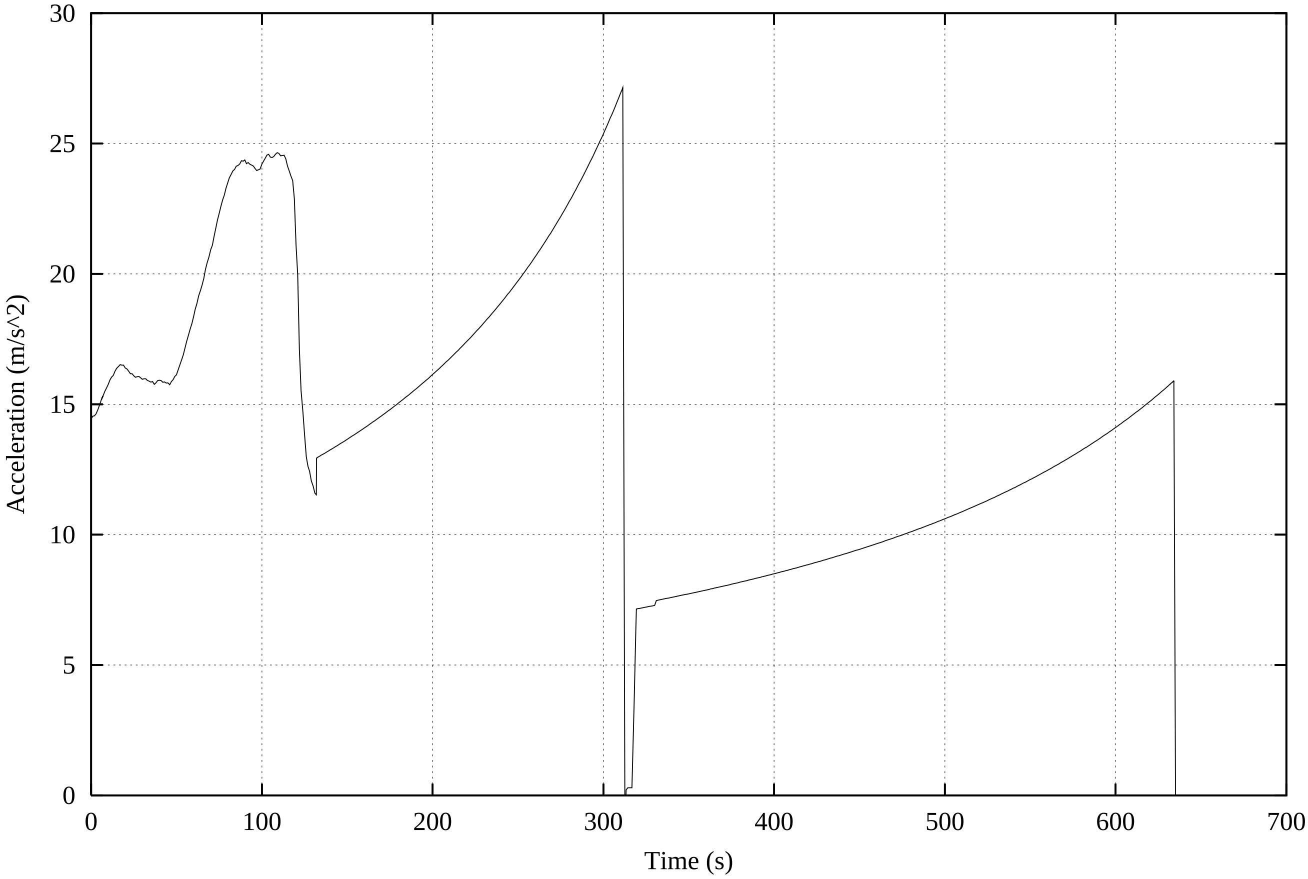


Figure 4: Dynamic pressure versus time for SLS Block 1C