SLS Block II with ATK Advanced Boosters, 5xRS–25E engines, 2xJ–2X optimised upper stage and heavy Core. Payload to 200 km LEO = 144.1 t. 24 Aug. 2014. 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	4C5J2	4C5J2.2
Booster Name	ATK AB	ATK AB
Number of Boosters	2	2
Engine Name	–	–
Number of Engines per Booster	1	1
Aft Skirt Diameter (m)	5.156	5.156
Booster Diameter (m)	3.708	3.708
Nozzle Diameter (m)	3.875	3.875
Sea Level Thrust at 0.2 s (N)	18,027,271	18,027,271
Maximum Vacuum Thrust (N)	20,016,997	20,016,997
Vacuum Isp (m/s)	2,756.6	2,756.6
Total Mass (kg)	777,004	777,004
Startup Propellant (kg)	0	0
Usable Propellant (kg)	679,920	679,920
Residual/Reserve Propellant (kg)	469	469
Burnout/Dry Mass (kg)	96,615	96,615
Action Time (s)	130.2	130.2

The core values have been updated according to [5] and other sources with RS–25E engines. The dry mass of the heavy core in [2] is used with four RS–25D engines replaced with five RS–25E engines.

Core Stage	4C5J2	4C5J2.2
Stage Diameter (m)	8.407	8.407
Additional Area (m^2)	0.235	2.377
Engines	RS–25D	RS–25E
Number of Engines	5	5
Nozzle Diameter (m)	2.304	2.304
Vacuum Isp (m/s)	4,436.5	4,420.8
Engine Thrust (N)	2,278,824	2,320,637
Engine Thrust Rating (%)	109	111
Total Mass at Liftoff (kg)	1,102,512	1,090,012
Dry Mass (kg)	119,124	119,895
Usable Propellant (kg)	963,800	962,035
Reserve Propellant (kg)	8,191	7,984
Fuel Bias Propellant (kg)	2,098	2,098
Startup Propellant (kg)	9,299	10,546

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	4C5J2	4C5J2.2
Stage Diameter (m)	8.407	8.407
Engines	J–2X	J–2X
Number of Engines	2	2
Nozzle Diameter (m)	3.048	3.048
Vacuum Isp (m/s)	4,275.7	4,393.4
Single Engine Thrust (N)	1,281,088	1,307,777
Total Mass (kg)	202,336	206,215
Usable Propellant (kg)	174,542	178,029
Reserve/Residual Propellant (kg)	2,940	2,999
Startup Propellant (kg)	771	771
RCS Propellant (kg)	139	142
Dry Mass (kg)	23,542	23,856
Ullage Motors Propellant (kg)	208	217
Ullage Motors Dry Mass (kg)	194	201
Ullage Motors Action Time (s)	3.87	3.87
Ullage Motors Thrust (N)	117,254	122,315
Ullage Motors Offset Angle (°)	30	30
Interstage Mass (kg)	8,691	8,899

The LAS/SAJ jettison time was obtained from [6]. Simulation results for 4C5J2.2 are shown in Figures 2–5. The increase in core thrust and increase of upper stage Isp and thrust allows for an increase of payload of 3,913 kg or 2.8% from 140.2 t to 144.1 t compared to SLS4C5J2.

	4C5J2	4C5J2.2
Orbit (km)	200 ± 0.4	200 ± 0.1
Liftoff Thrust at 0.2 s (N)	45,335,756	45,545,898
Liftoff Mass (kg)	3,006,757	3,013,556
Liftoff Acceleration (m/s^2)	15.09	15.12
MaxQ (Pa)	28,636	28,795
Maximum Acceleration (m/s^2)	24.63	24.72
LAS/SAJ Jettison Time (s)	330	330
Launch Abort System (kg)	7,394	7,394
Orion Jettisoned Adaptors (kg)	920	920
Total Payload (kg)	140,195	144,108
Total Delta–V (m/s)	9,332	9,320

[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] B. Donahue and S. Sigmon, "The Space Launch System capabilities with a new large upper stage," *AIAA Space Conf. and Exhib.*, San Diego, CA, USA, Sep. 2013.

[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

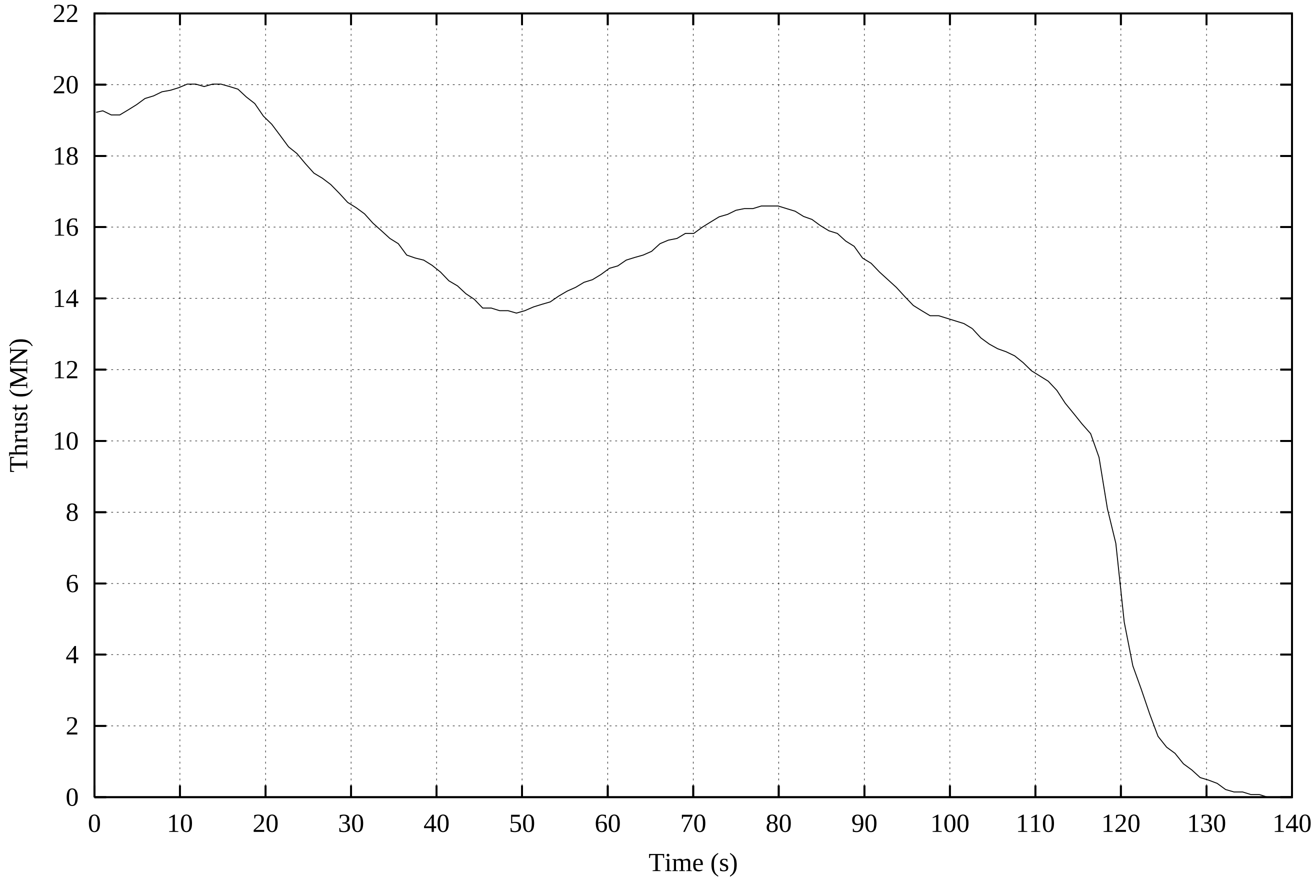

Figure 2: Altitude versus time for SLS Block II

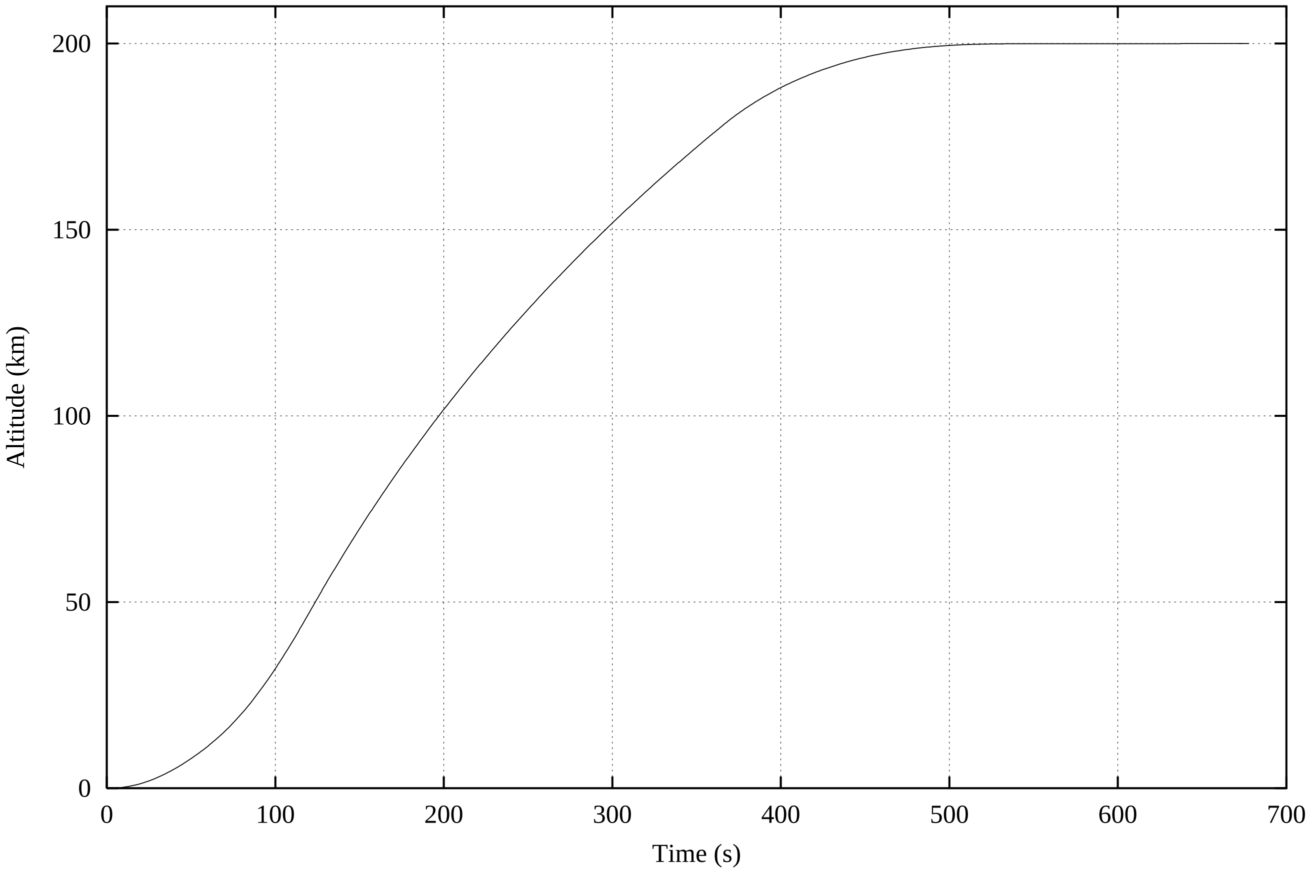

Figure 3: Speed versus time for SLS Block II

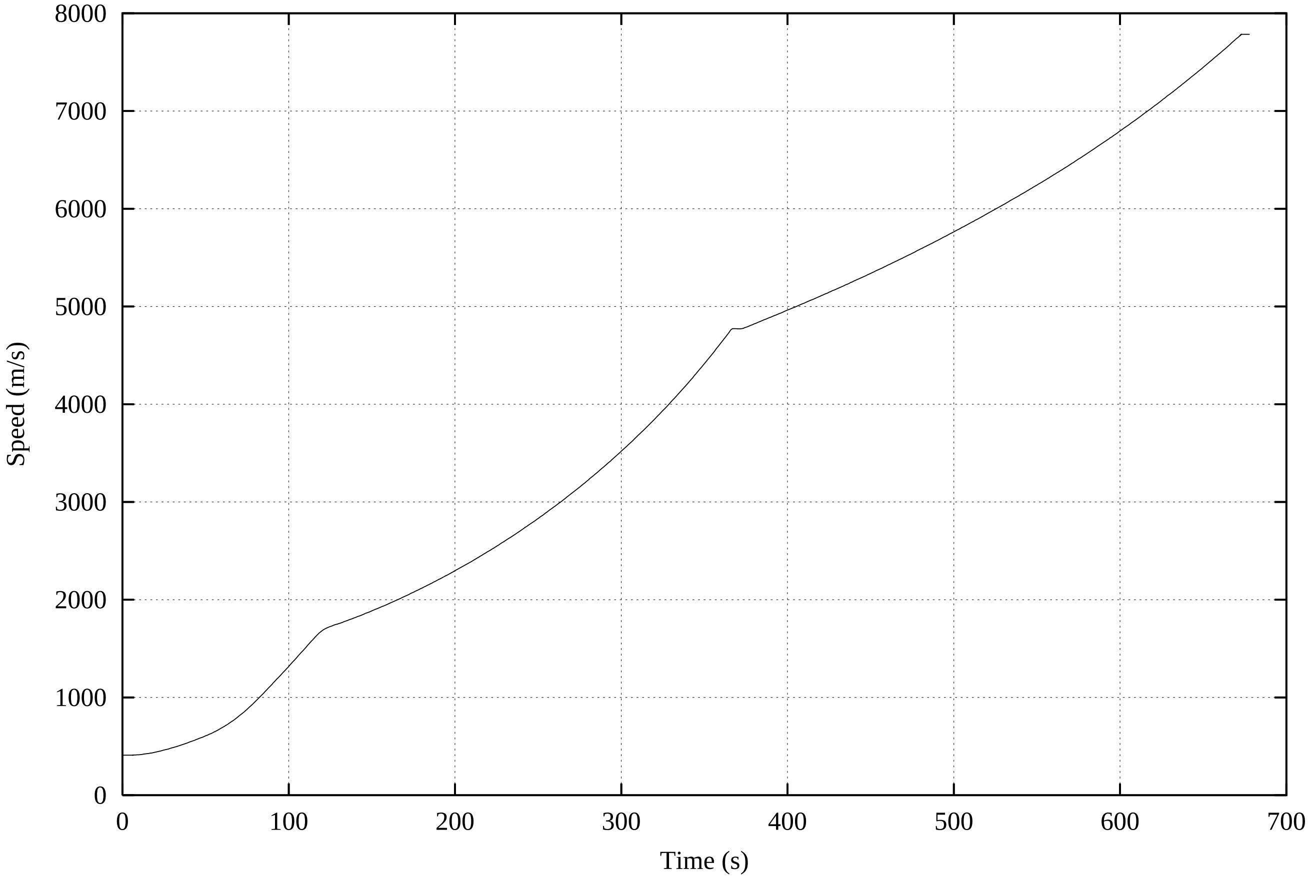

Figure 4: Acceleration versus time for SLS Block II

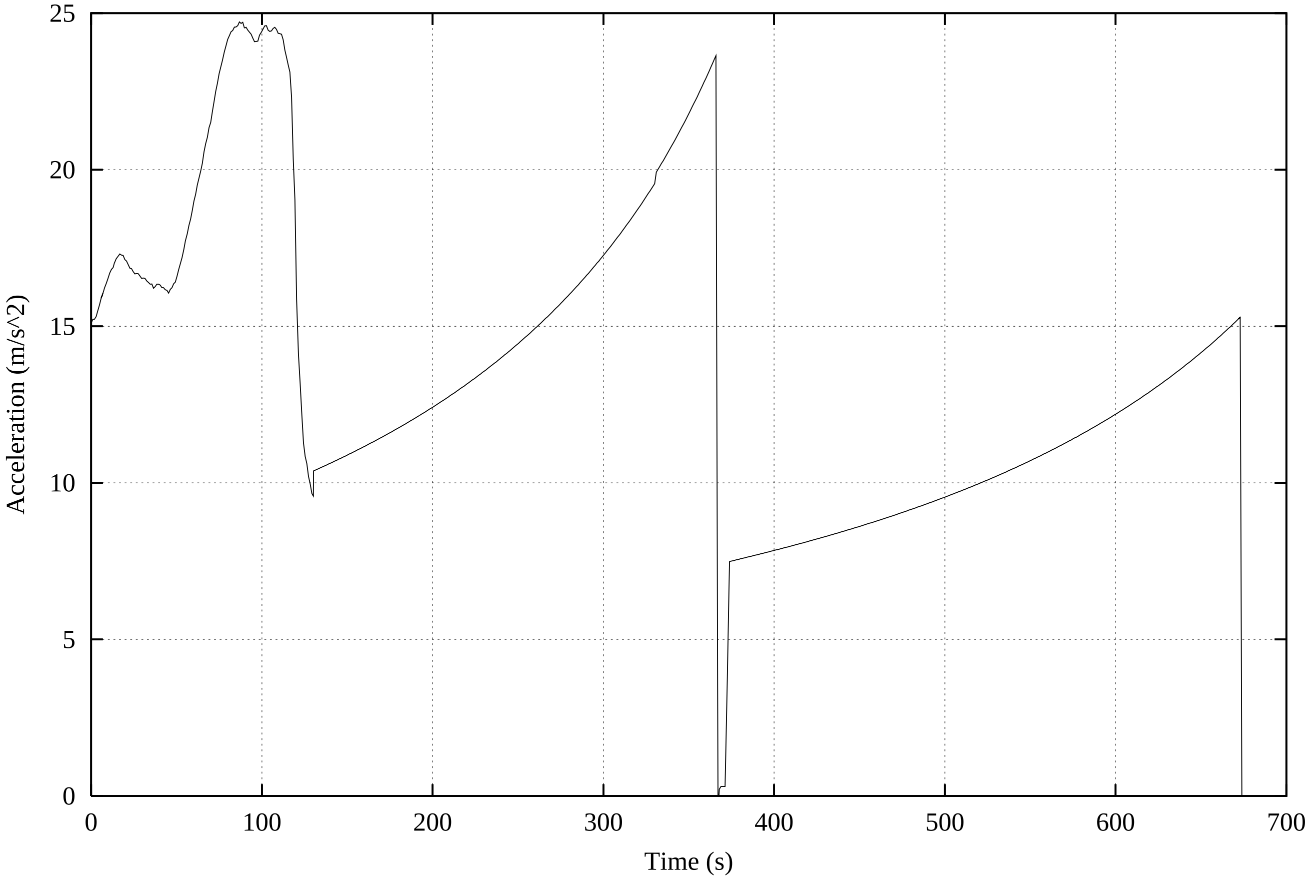

Figure 5: Dynamic pressure versus time for SLS Block II