SLS Block II with ATK Advanced Boosters, 2xJ–2X optimised upper stage and heavy core. Payload to 200 km LEO = 124.8 t. 23 Aug. 2014. Author: Steven S. Pietrobon, PhD.

The propellant mass and dry mass of ATK's Advanced Boosters (AB) were obtained from [1]. The vacuum Isp was assumed to be same as for the Titan IV Solid Rocket Motor Upgrade (SRMU), which also uses HTPB propellant [2]. The RSRMV thrust curve was adjusted so that the peak vacuum thrust is 20.0 MN [1] 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 [1]. The same skirt and nozzle diameters as the RSRMV was assumed. The thrust curve is shown in Figure 1.

Boosters	4C4J2.1	4C4J2.2
Booster Name	ATK AB	ATK AB
Engine Name	–	–
Number of Engines per Booster	1	1
Aft Skirt/Nacelle Diameter (m)	5.288	5.288
Booster Diameter (m)	3.710	3.710
Additional Area (m^2)	–0.038	–0.038
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 [3] and other sources with RS–25E engines. The dry mass of the heavy core in [4] is used.

Core Stage:	4C4J2.1	4C4J2.2
Stage Diameter (m)	8.407	8.407
Additional Area (m^2)	2.073	2.073
Engines	RS–25E	RS–25E
Number of Engines	4	4
Nozzle Diameter (m)	2.304	2.304
Vacuum Isp (m/s)	4,420.8	4,420.8
Engine Thrust (N)	2,320,637	2,320,637
Engine Thrust Rating (%)	111	111
Total Mass at Liftoff (kg)	1,074,908	1,089,801
Dry Mass (kg)	100,682	115,575
Usable Propellant (kg)	964,564	964,564
Reserve Propellant (kg)	7,984	7,984
Fuel Bias Propellant (kg)	1,678	1,678
Startup Propellant (kg)	8,437	8,437

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:	4C4J2.1	4C4J2.2
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)	4,393.4	4,393.4
Single Engine Thrust (N)	1,307,777	1,307,777
Total Mass (kg)	180,077	190,763
Usable Propellant (kg)	154,511	164,147
Reserve/Residual Propellant (kg)	2,604	2,766
Startup Propellant (kg)	771	771
RCS Propellant (kg)	127	128
Dry Mass (kg)	21,724	22,603
Ullage Motors Propellant (kg)	174	178
Ullage Motors Dry Mass (kg)	166	170
Ullage Motors Action Time (s)	3.87	3.87
Ullage Motors Thrust (N)	98,146	100,515
Ullage Motors Offset Angle (°)	30	30
Interstage Mass (kg)	7,638	7,657

The LAS/SAJ jettison time was obtained from [5]. Simulation results for 4C4J2.2 are shown in Figures 2–5. The increase in core mass results in a decrease of 6,705 kg or 5.1% of the payload from 131.5 t to 124.8 t.

	4C4J2.1	4C4J2.2
Orbit (km)	200 ± 0.2	200 ± 0.1
Liftoff Thrust at 0.2 s (N)	43,647,627	43,647,627
Liftoff Mass (kg)	2,956,452	2,975,345
Liftoff Acceleration (m/s^2)	14.77	14.68
MaxQ (Pa)	25,562	25,134
Maximum Acceleration (m/s^2)	23.54	23.28
LAS/SAJ Jettison Time (s)	330	330
Launch Abort System (kg)	7,394	7,394
Orion Jettisoned Adaptors (kg)	920	920
Total Payload (kg)	131,507	124,802
Total Delta–V (m/s)	9,708	9,787

[1] 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.

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

[3] 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.

[4] 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.

[5] 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

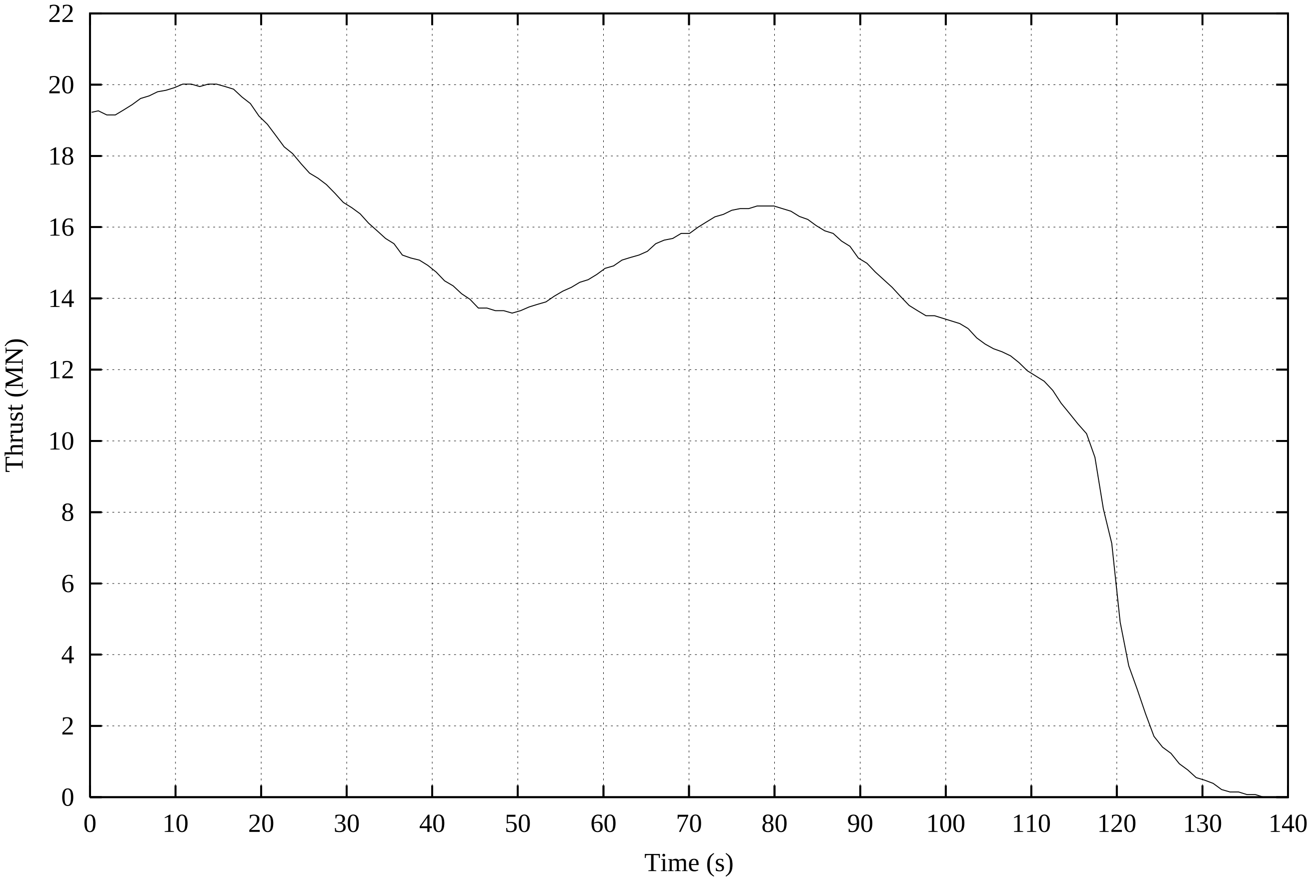

Figure 2: Altitude versus time for SLS Block II

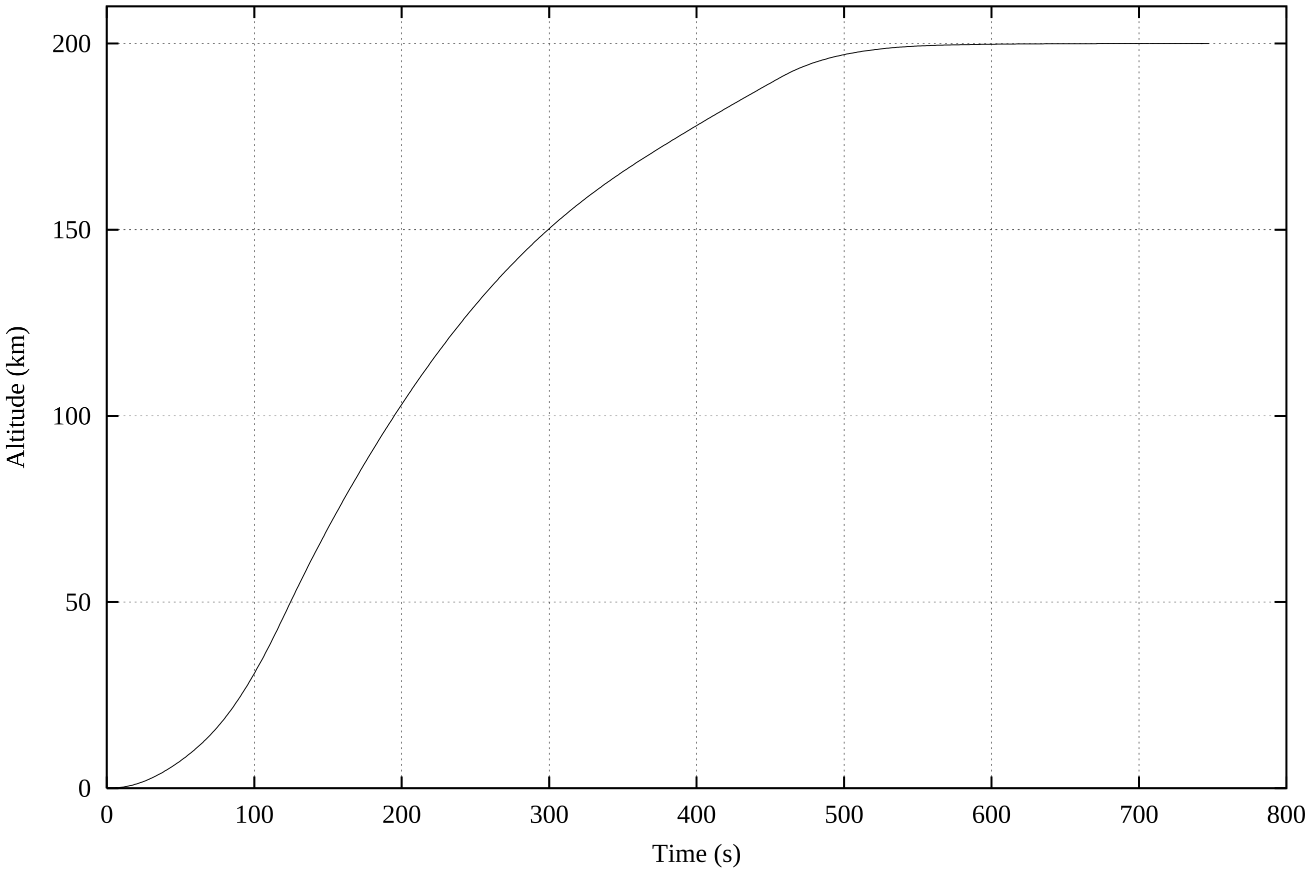

Figure 3: Speed versus time for SLS Block II

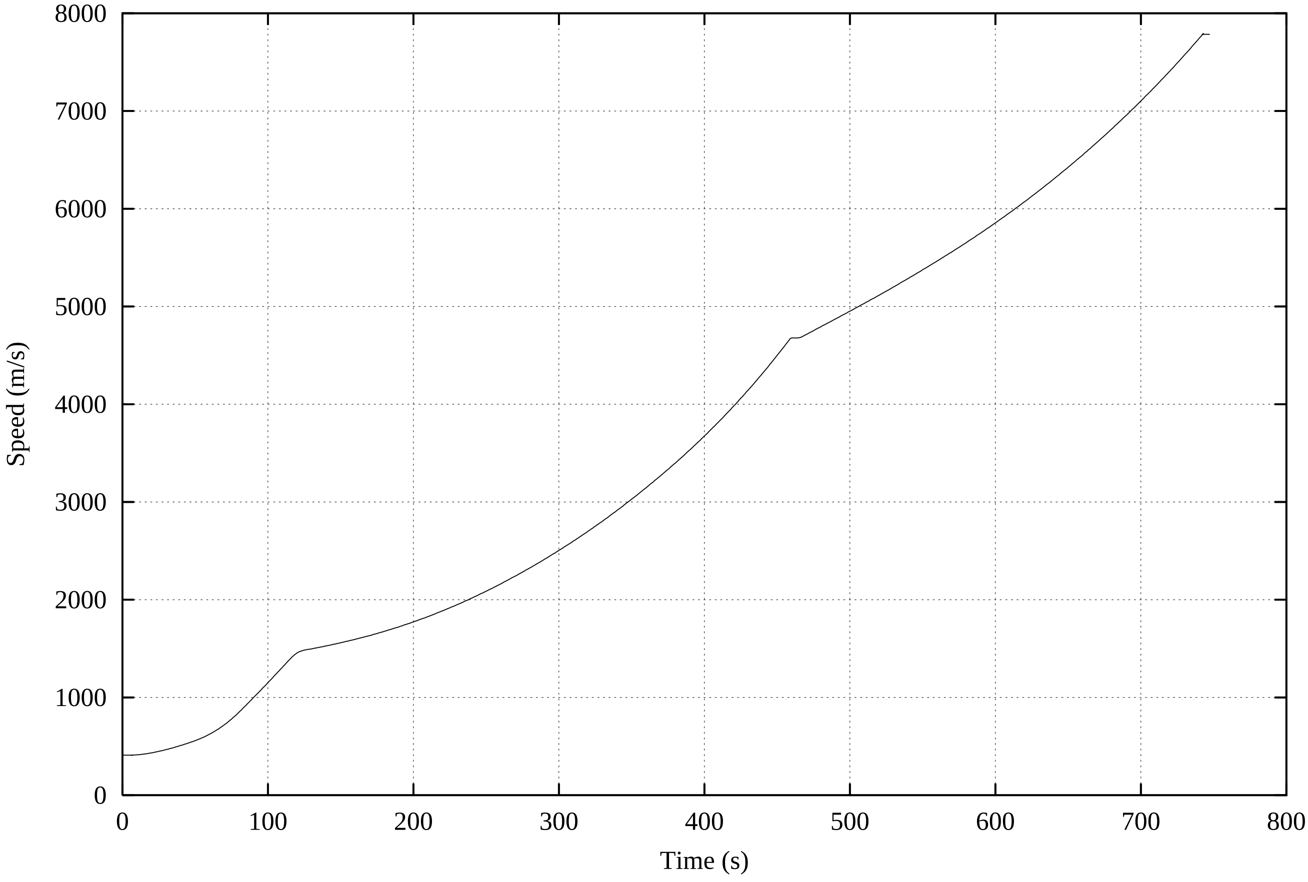

Figure 4: Acceleration versus time for SLS Block II

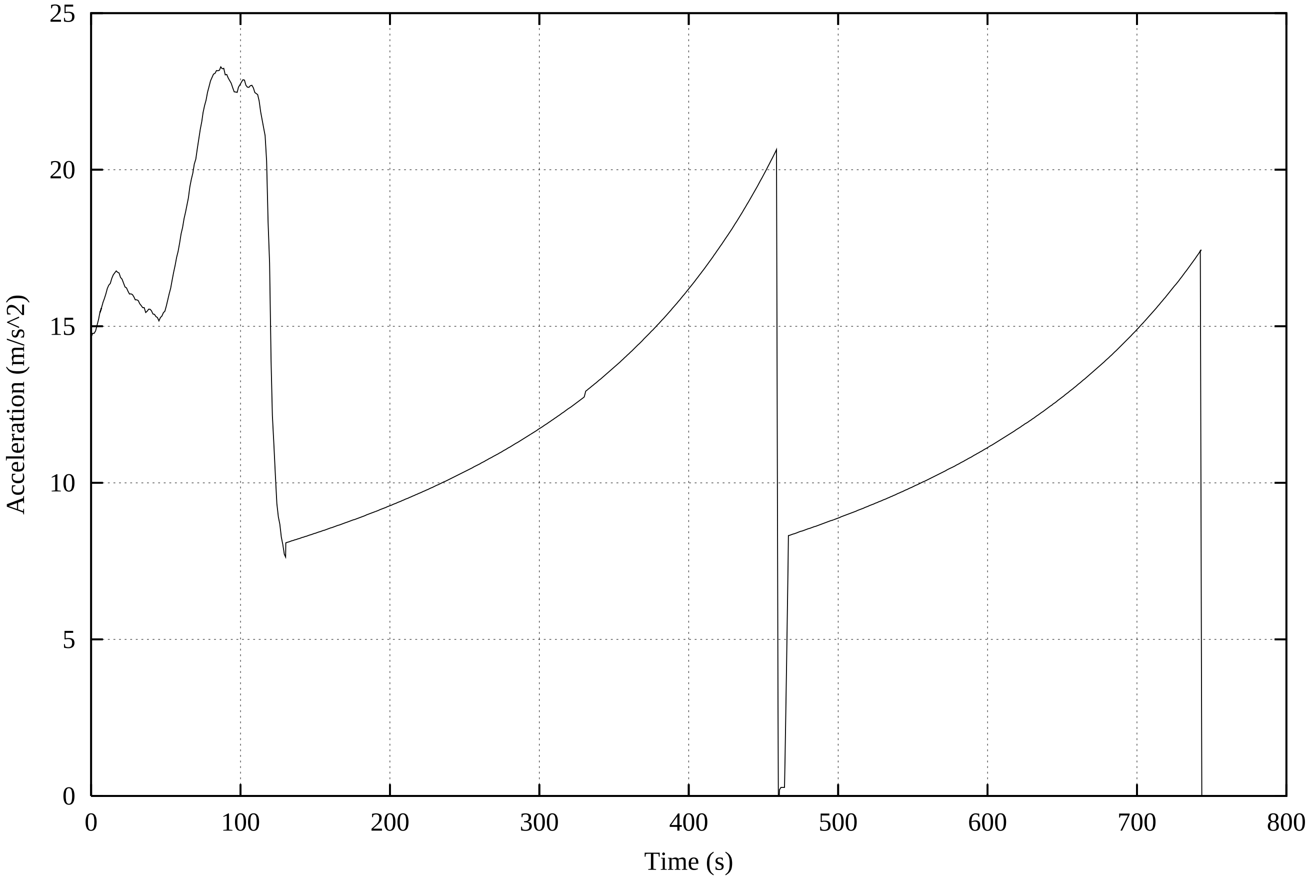

Figure 5: Dynamic pressure versus time for SLS Block II