SLS Block II with Pyrios Boosters, 2xJ–2X optimised upper stage and heavy core. Payload to 200 km LEO = 133.2 t. 23 Aug. 2014. Author: Steven S. Pietrobon, PhD.

The dimensions of the Pyrios LOX/RP–1 booster and F–1B nozzle diameter were estimated from Figure 6 of [1]. The Isp of the F–1B is not given, so this was estimated from the available values. The F–1A [2] nozzle efficiency of $\eta = 0.973$ allowed an estimation of the chamber pressure of P_c = 7456.5 kPa and the sea level thrust coefficient of C_f = 1.667 using the formula $F_{sl} = P_c A_t C_f \eta$ and an Isp calculation program [3], where F_{sl} is the sea level thrust and A_t is the throat area. The estimated F–1B chamber pressure is 5% less than the F–1A at 7846 kPa. The F–1A Isp efficiency of 90.25% was then used to estimate the F–1B Isp of 2,932.7 m/s. This is 2% less than the F–1A Isp due to the lower chamber pressure and reduced area ratio (12 instead of 16).

Figure 3 of [1] allowed an estimation of the Pyrios useful propellant mass of 800.1 t and total mass of 924.09 t. To understand what these values mean, we used the Saturn 1C–1 graph point to give a 2103.1 t propellant mass and 2273.6 t total mass for the Saturn V S–1C stage. Using the Apollo 14 launch vehicle report [4], the closest values were the 2113.8 t propellant mass and 2283.3 t total mass at lift–off. Both these values are 0.5% less than the values obtained from the graph, which is within the range of measurement error. Therefore, we interpreted the useful propellant mass and total mass to be the values at liftoff. The startup and reserve propellant masses were estimated using the same proportions as for the S–1C.

Boosters	2C4J2.1	2C4J2.2
Booster Name	Pyrios	Pyrios
Engine Name	F–1B	F–1B
Number of Engines per Booster	2	2
Nacelle Diameter (m)	3.854	3.854
Booster Diameter (m)	5.486	5.486
Additional Area (m^2)	14.100	14.100
Nozzle Diameter (m)	3.185	3.185
Sea Level Thrust at 0.2 s (N)	8,029,040	8,029,040
Maximum Vacuum Thrust (N)	8,836,221	8,836,221
Vacuum Isp (m/s)	2,932.7	2,932.7
Total Mass (kg)	942,030	942,030
Startup Propellant (kg)	17,940	17,940
Usable Propellant (kg)	787,311	787,311
Residual/Reserve Propellant (kg)	12,789	12,789
Burnout/Dry Mass (kg)	123,990	123,990
Action Time (s)	131.8	131.8

The core values have been updated according to [5] and other sources with RS–25E engines. The dry mass of the heavy core in [6] is used.

Core Stage:	2C4J2.1	2C4J2.2
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:	2C4J2.1	2C4J2.2
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)	166,975	172,560
Usable Propellant (kg)	142,706	147,743
Reserve/Residual Propellant (kg)	2,406	2,491
Startup Propellant (kg)	771	771
RCS Propellant (kg)	125	124
Dry Mass (kg)	20,636	21,102
Ullage Motors Propellant (kg)	169	168
Ullage Motors Dry Mass (kg)	162	161
Ullage Motors Action Time (s)	3.87	3.87
Ullage Motors Thrust (N)	95,235	94,722
Ullage Motors Offset Angle (°)	30	30
Interstage Mass (kg)	9,593	9,472

The LAS/SAJ jettison time was obtained from [7]. Simulation results for 2C4J2.2 are shown in Figures 1–4. The increase in core mass results in a decrease of 6,464 kg or 4.6% of the payload from 139.7 t to 133.2 t.

	2C4J2.1	2C4J2.2
Orbit (km)	200 ± 0.2	200 ± 0.1
Liftoff Thrust at 0.2 s (N)	39,709,245	39,709,245
Liftoff Mass (kg)	3,247,624	3,261,517
Liftoff Acceleration (m/s^2)	12.23	12.18
MaxQ (Pa)	28,377	28,126
Maximum Acceleration (m/s^2)	31.78	31.47
LAS/SAJ Jettison Time (s)	330	330
Launch Abort System (kg)	7,394	7,394
Orion Jettisoned Adaptors (kg)	920	920
Total Payload (kg)	139,654	133,190
Total Delta–V (m/s)	9,668	9,714

[1] S. Cook, K. Doering, A. Crocker and R. Bachtel, "Enabling an affordable advanced liquid booster for NASA's Space Launch System," *63rd Int. Astronautical Congress*, Naples, Italy, IAC–12–D2.8.10, Oct. 2012.

[2] NASA, "Liquid engine comparison," Slide PD24, 12 Jan. 1992.

[3] C. Selph, "United States Air Force chemical equilibrium specific impulse (Isp) code," Mar. 1992. http://www.dunnspace.com/isp.htm

[4] Saturn Flight Evaluation Working Group, "Saturn V launch vehicle flight evaluation report AS–509 Apollo 14 mission," *George C. Marshall Space Flight Center*, MPR–SAT–FE–71–1, Apr. 1971.

[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] 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.

[7] 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 II

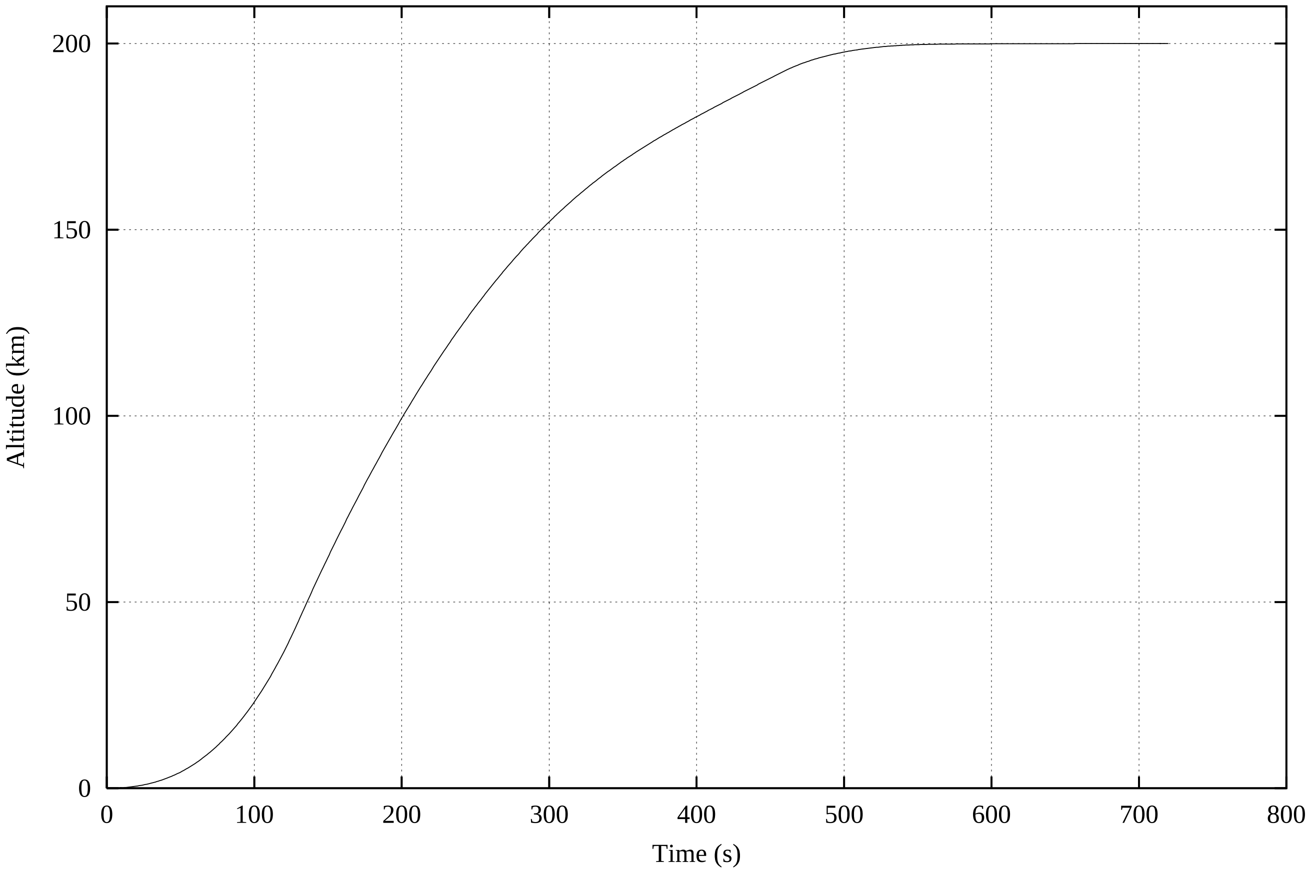

Figure 2: Speed versus time for SLS Block II

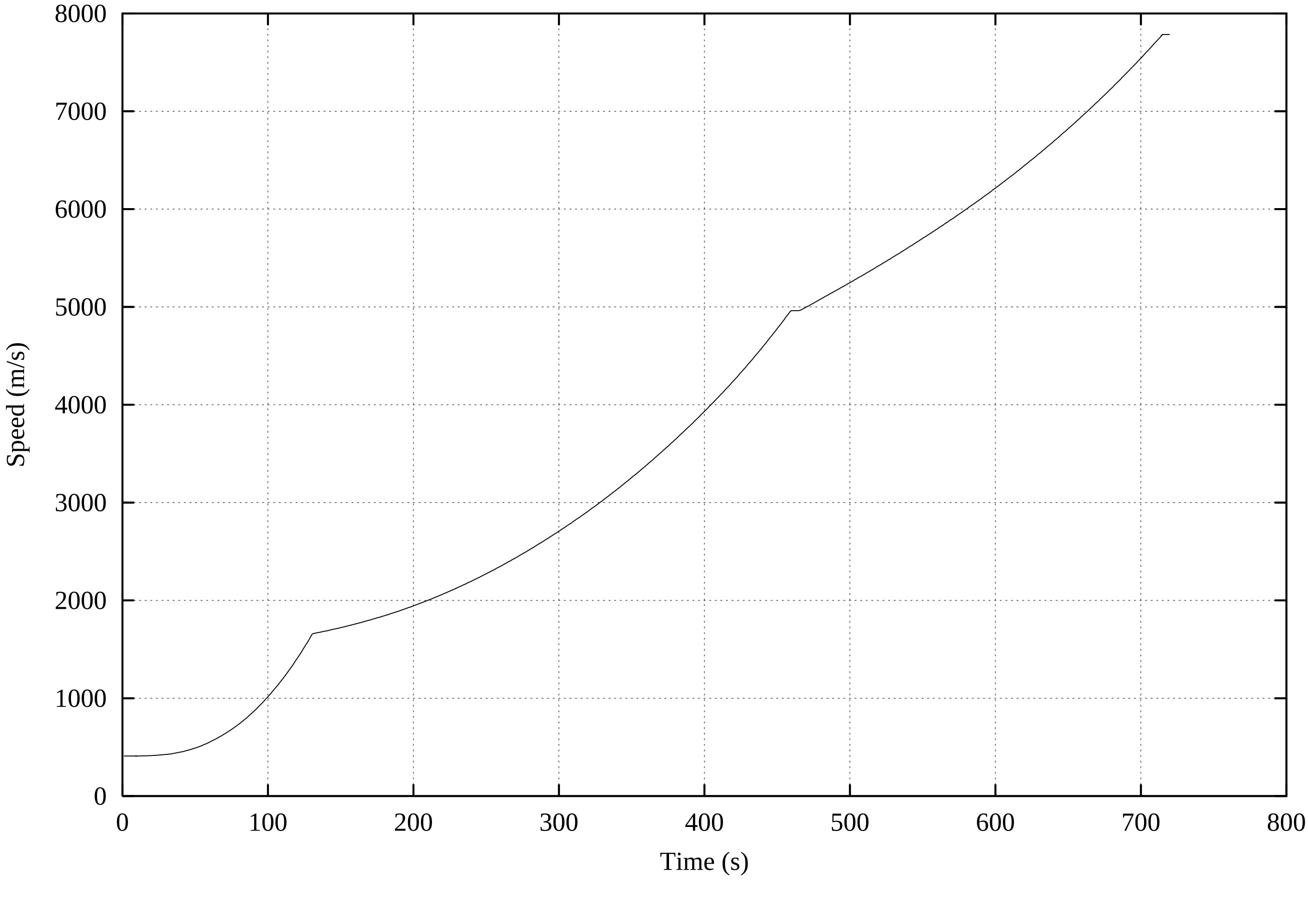

Figure 3: Acceleration versus time for SLS Block II

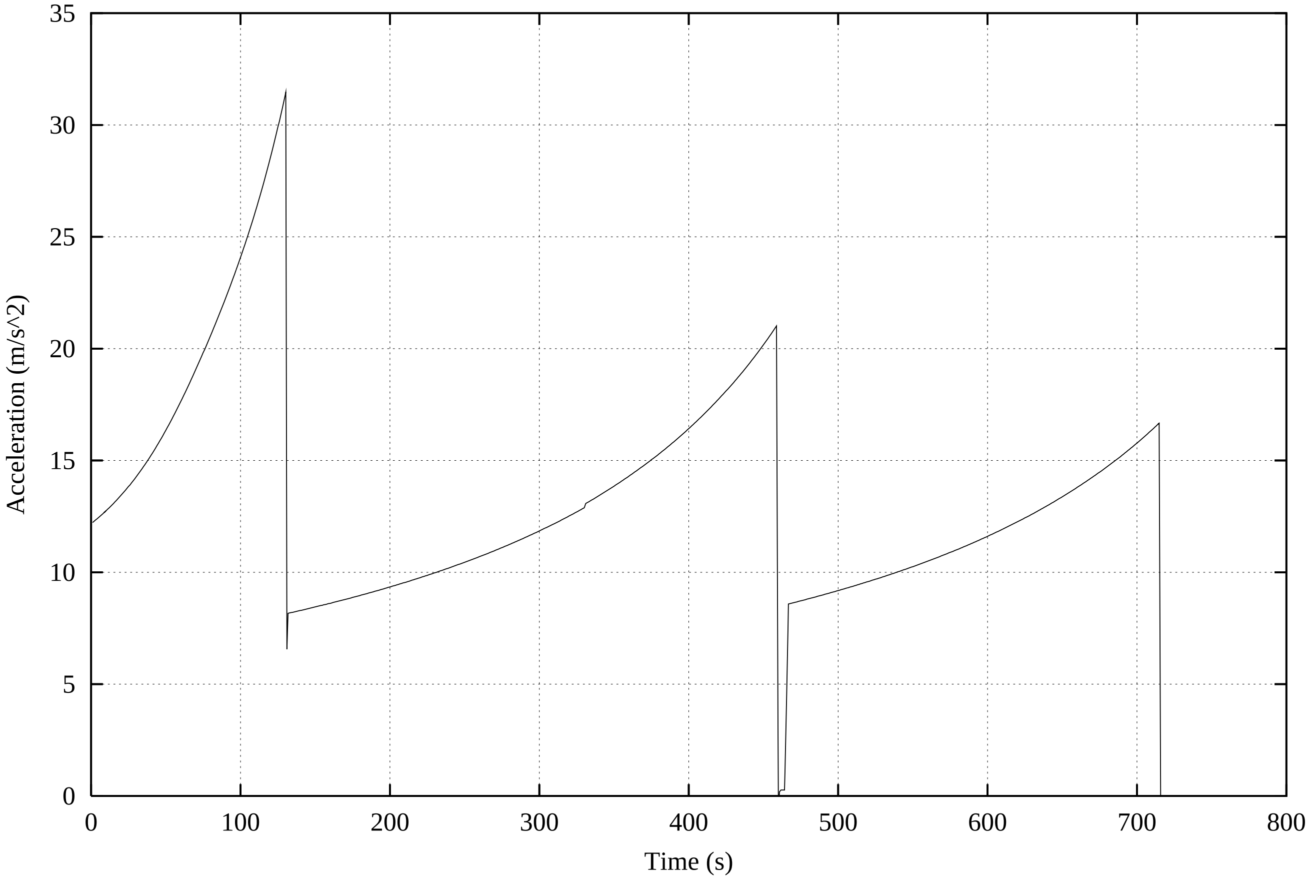

Figure 4: Dynamic pressure versus time for SLS Block II