SLS Block 1C with ATK Advanced Boosters, Core with 5xRS–25D engines and 2xJ–2X optimised upper stage. Payload to 96x241 km LEO = 146.2 t. 1 Dec. 2013. 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	1C4J2.2	4C4J2	4C5J2	4C5J2.1
Booster Name	RSRMV	ATK AB	ATK AB	ATK AB
Number of Boosters	2	2	2	2
Engine Name	–	–	–	–
Number of Engines per Booster	1	1	1	1
Aft Skirt Diameter (m)	5.156	5.156	5.156	5.156
Booster Diameter (m)	3.711	3.708	3.708	3.708
Nozzle Diameter (m)	3.875	3.875	3.875	3.875
Sea Level Thrust at 0.2 s (N)	15,599,386	18,027,271	18,027,271	18,027,271
Maximum Vacuum Thrust (N)	17,866,606	20,016,997	20,016,997	20,016,997
Vacuum Isp (m/s)	2,622.3	2,756.6	2,756.6	2,756.6
Total Mass (kg)	733,776	777,004	777,004	777,004
Startup Propellant (kg)	0	0	0	0
Usable Propellant (kg)	632,791	679,920	679,920	679,920
Residual/Reserve Propellant (kg)	442	469	469	469
Burnout/Dry Mass (kg)	100,543	96,615	96,615	96,615
Action Time (s)	131.9	130.2	130.2	130.2

The simulations have no thrust bucket and reduced the thrust rating to 109%, as reported in [5].

Core Stage: 4xRS–25 Engines	1C4J2.2	4C4J2	4C5J2	4C5J2.1
Stage Diameter (m)	8.407	8.407	8.407	8.407
Nozzle Diameter (m)	2.304	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)	2,278,824	2,278,824	2,278,824	2,278,824
Engine Thrust Rating (%)	109	109	109	109
Thrust Bucket (%)	109	109	109	109
Total Mass (kg)	1,091,525	1,091,525	1,102,512	1,102,512
Usable Propellant (kg)	966,061	966,061	963,800	963,800
Reserve Propellant (kg)	8,210	8,210	8,191	8,191
Fuel Bias Propellant (kg)	1,678	1,678	2,098	2,098
Startup Propellant (kg)	7,439	7,439	9,299	9,299
Dry Mass (kg)	115,575	115,575	119,124	119,124

The size of the upper stage was optimised to maximise payload delivered into a 96x241 km orbit for 4C5J2.1. 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:	1C4J2.2	4C4J2	4C5J2	4C5J2.1
Engines	J–2X	J–2X	J–2X	J–2X
Number of Engines	2	2	2	2
Stage Diameter (m)	8.407	8.407	8.407	8.407
Nozzle Diameter (m)	3.048	3.048	3.048	3.048
Vacuum Isp (m/s)	4,275.7	4,275.7	4,275.7	4,275.7
Single Engine Thrust (N)	1,281,088	1,281,088	1,281,088	1,281,088
Single Engine Mass (kg)	2,472	2,472	2,472	2,472
Total Mass (kg)	147,516	172,544	202,336	181,455
Usable Propellant (kg)	125,292	147,751	174,542	155,720
Reserve Propellant (kg)	2,114	2,491	2,940	2,625
Startup Propellant (kg)	771	771	771	771
Residual Propellant (kg)	0	0	0	0
RCS Propellant (kg)	102	120	139	133
Dry Mass (kg)	19,005	21,103	23,542	21,835
Ullage Motors Propellant (kg)	115	156	208	191
Ullage Motors Dry Mass (kg)	117	152	194	180
Ullage Motors Action Time (s)	3.87	3.87	3.87	3.87
Ullage Motors Thrust (N)	65,032	87,998	117,254	117,254
Ullage Motors Offset Angle (°)	30	30	30	30
Interstage Mass (kg)	5,944	7,226	8,691	8,691

The LAS/SAJ jettison time was obtained from [6]. Simulation results for 4C5J2.1 are shown in Figures 2–6. The elliptical 96x241 km orbit compared to 200 km circular allows an increase in payload of 6.0 t or 4.3% from 140.2 t to 146.2 t.

	1C4J2.2	4C4J2	4C5J2	4C5J2.1
Orbit (km)	200 ± 0.4	200 ± 0.4	200 ± 0.4	96.3×240.9
Liftoff Thrust at 0.2 s (N)	38,623,742	43,479,514	45,335,756	45,335,756
Liftoff Mass (kg)	2,823,613	2,955,068	3,006,757	2,991,757
Liftoff Acceleration (m/s^2)	13.69	14.72	15.09	15.16
MaxQ (Pa)	21,877	25,492	28,636	31,864
Maximum Acceleration (m/s^2)	23.80	23.41	24.63	24.82
LAS/SAJ Jettison Time (s)	330	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)	102,762	121,452	140,195	146,157
Remaining Propellant (kg)	0	0	0	0
Total Payload (kg)	102,762	121,452	140,195	146,157
Total Delta–V (m/s)	9,905	9,735	9,332	9,141

[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] 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

[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

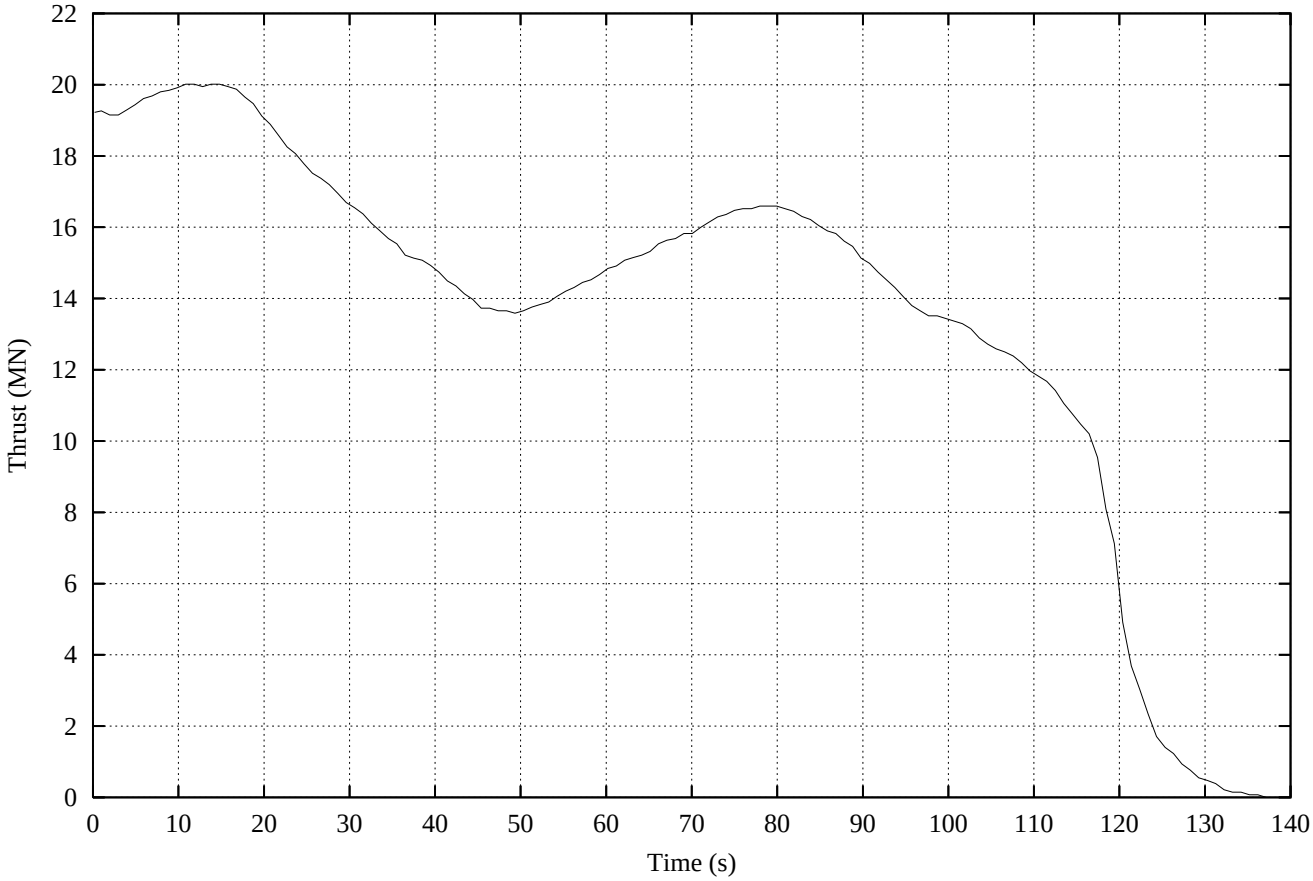

Figure 2: Altitude versus time for SLS Block 1C

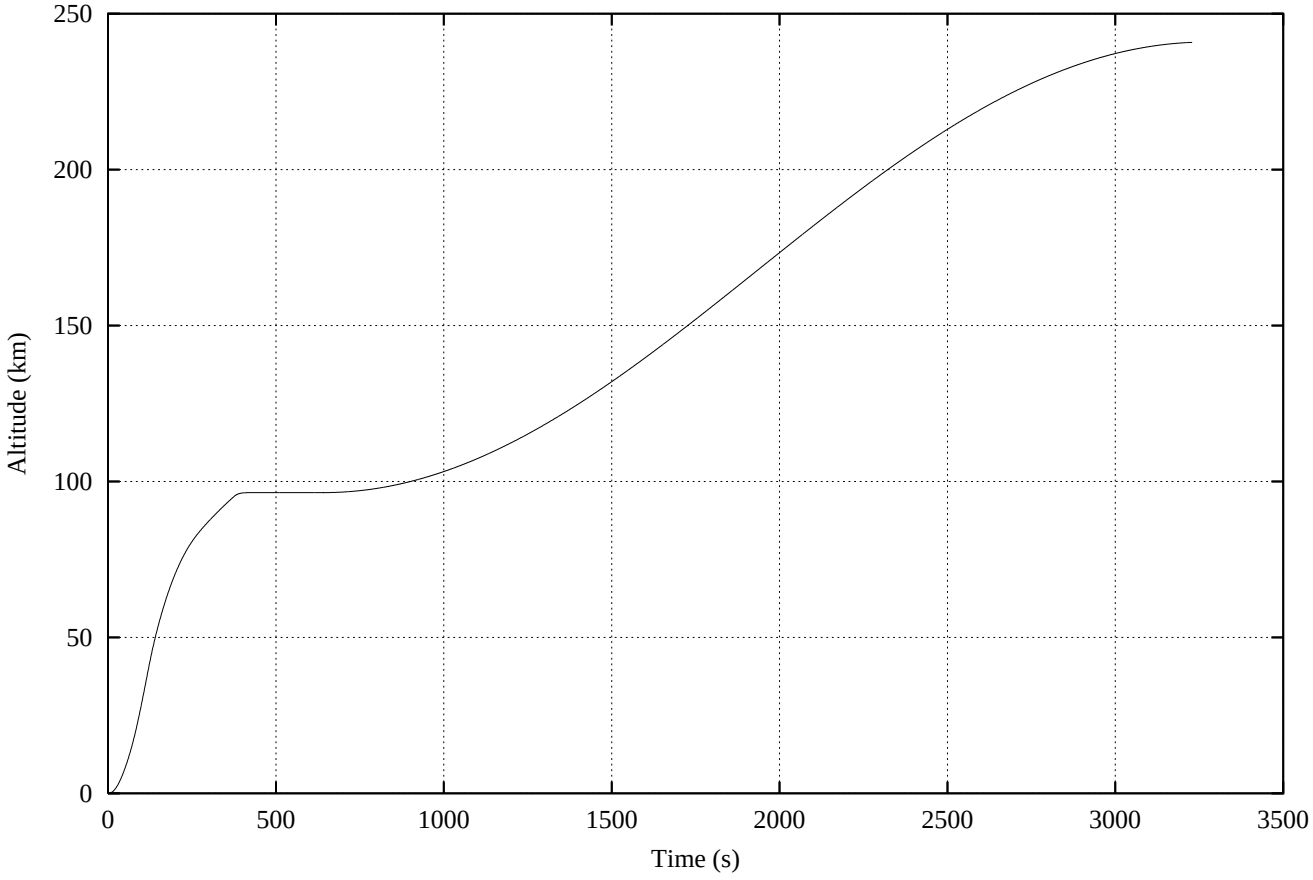

Figure 3: Altitude versus time for SLS Block 1C

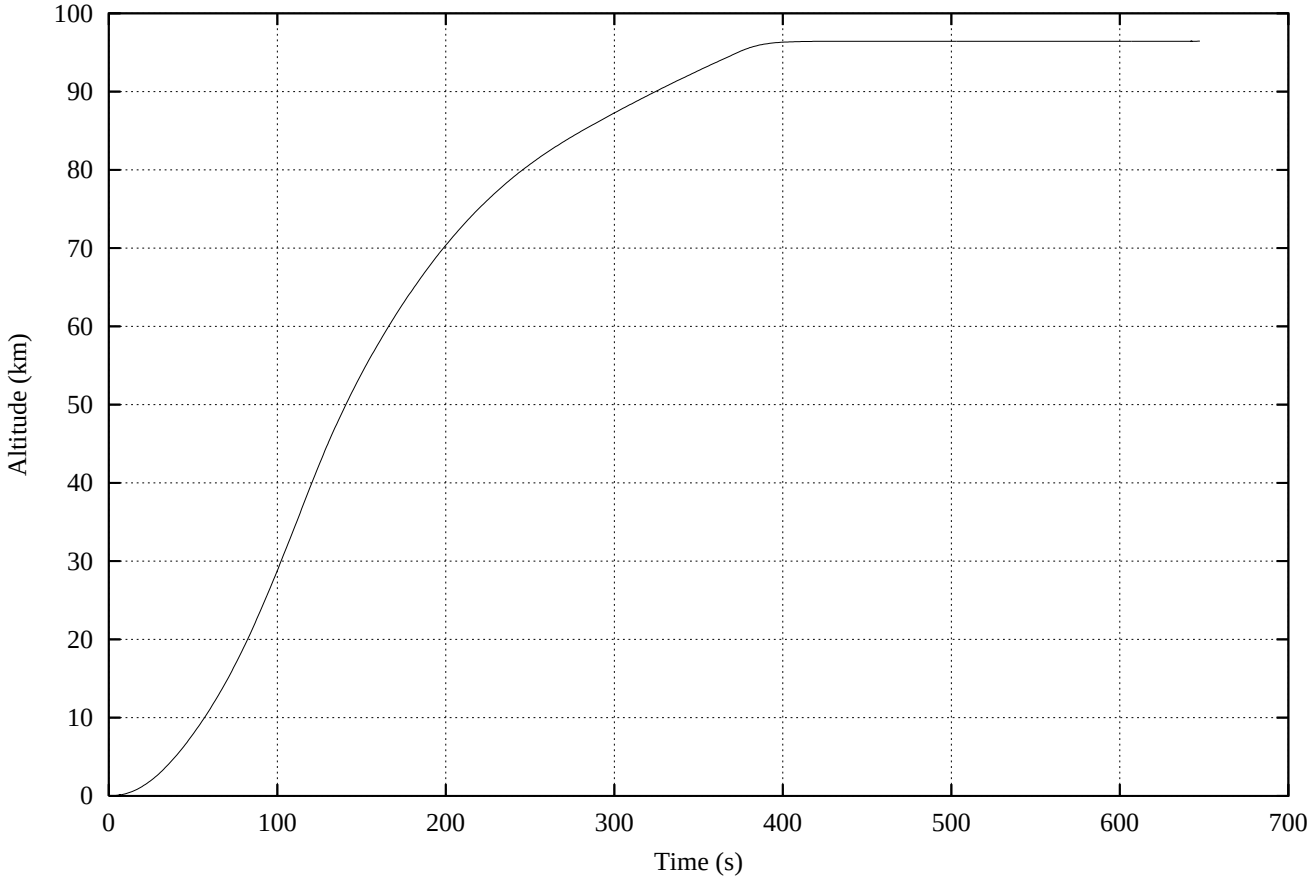

Figure 4: Speed versus time for SLS Block 1C

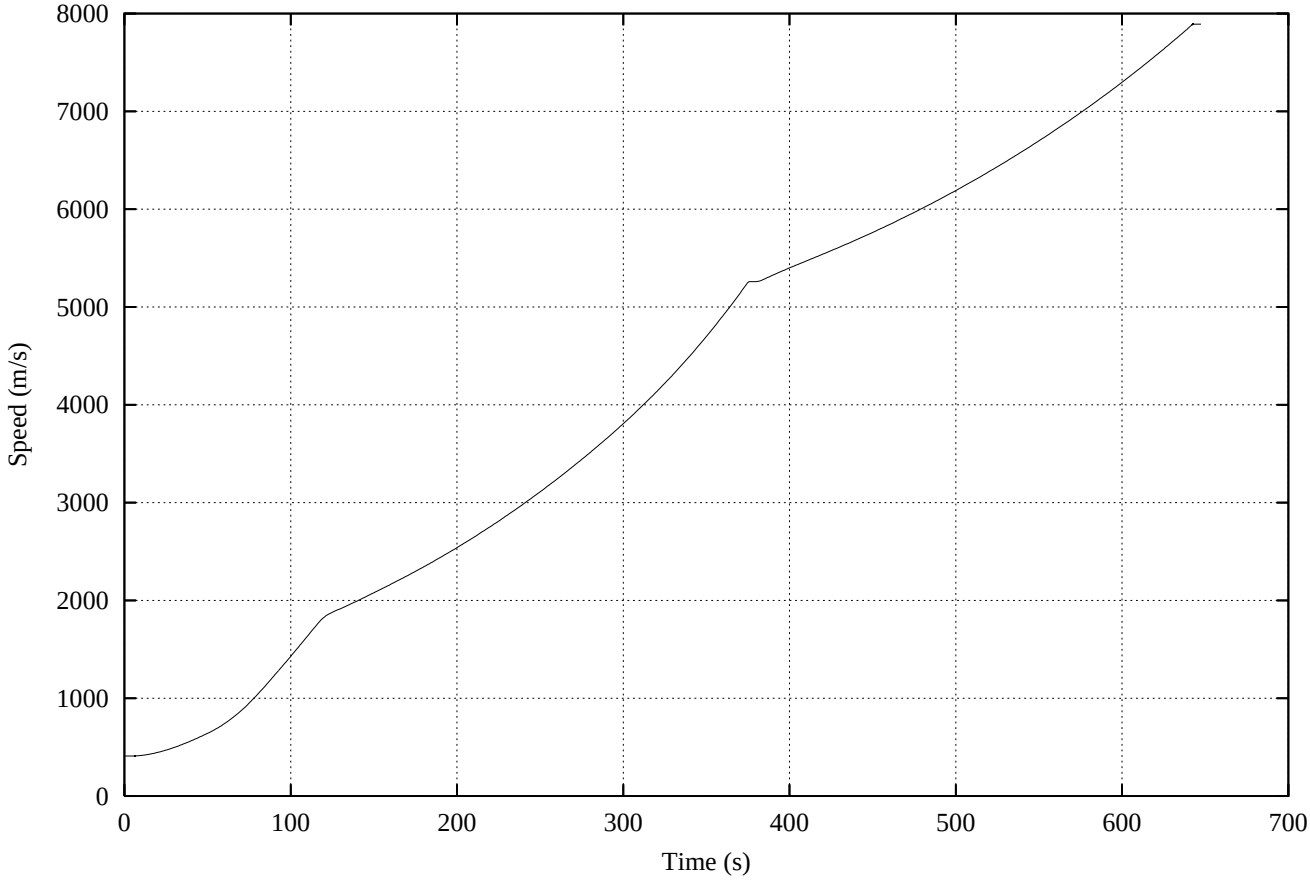

Figure 5: Acceleration versus time for SLS Block 1C

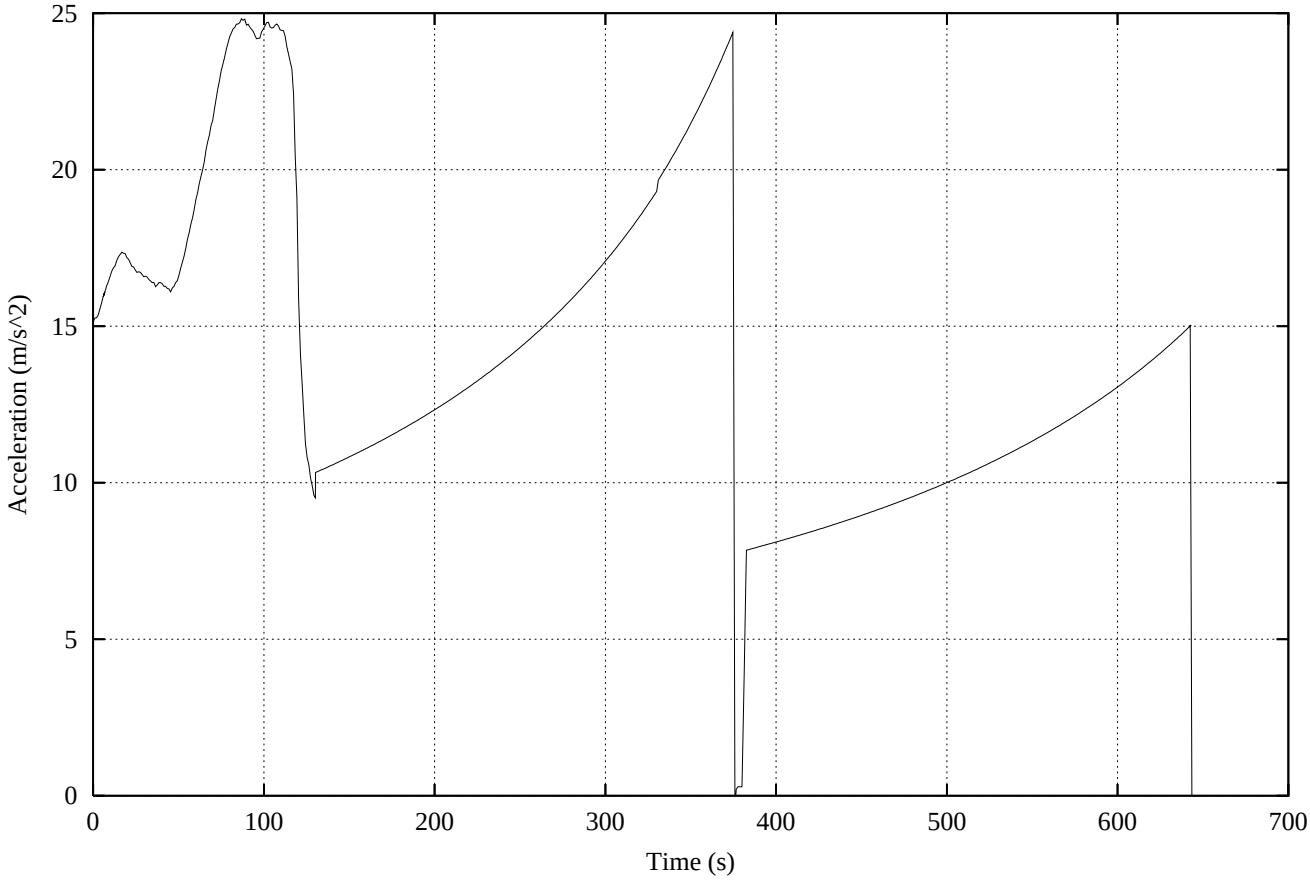

Figure 6: Dynamic pressure versus time for SLS Block 1C