

SLS Block IIB with Advanced ATK Orbital Boosters, five RS–25E core and four MB–60 upper stage. Payload to 200 km LEO = 136.1 t. 20 May 2016. Author: Steven S. Pietrobon, PhD.

RSRMV thrust curve obtained from page 56 of [1]. A number of corrections have been made so as to match the parameters in [2] and other sources. The propellant mass and dry mass of ATK's Advanced Boosters (AB) were obtained from [3]. 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 [3] and has the same impulse given by the Isp multiplied by the propellant mass. This resulted in a burn time of 130.2 s, compared to the 110 s reported in [3]. The same skirt and nozzle diameters as the RSRMV was assumed. The thrust curve is shown in Figure 1.

Boosters	IB	IIB	IIB5C4	IIB5B4
Name	RSRMV	Dark Knight	Dark Knight	Dark Knight
Segments	2x5	2x4	2x4	2x4
Aft Skirt Diameter (m)	5.288	5.288	5.288	5.288
Additional Area (m ²)	−0.038	−0.038	−0.038	−0.038
Nozzle Diameter (m)	3.875	3.875	3.875	3.875
Sea Level Thrust at 0.2 s (N)	15,471,544	18,027,271	18,027,271	18,027,271
Maximum Vacuum Thrust (N)	17,355,582	20,016,997	20,016,997	20,016,997
Vacuum Isp (m/s)	2,605.4	2,756.6	2,756.6	2,756.6
Total Mass (kg)	729,240	777,004	777,004	777,004
Usable Propellant (kg)	631,185	679,920	679,920	679,920
Residual Propellant (kg)	1,304	469	469	469
Burnout Mass (kg)	96,751	96,615	96,615	96,615
Action Time (s)	128.4	130.2	130.2	130.2

The core values have been updated according to [2] and other sources with RS–25E engines.

Core Stage	IB	IIB	IIB5C4	IIB5B4
Stage Diameter (m)	8.407	8.407	8.407	8.407
Additional Area (m ²)	2.073	2.073	2.073	2.073
Engines	RS–25E	RS–25E	RS–25E	RS–25E
Number of Engines	4	4	5	5
Nozzle Diameter (m)	2.304	2.304	2.304	2.304
Vacuum Isp (m/s)	4,420.8	4,420.8	4,420.8	4,420.8
Engine Thrust (N)	2,320,637	2,320,637	2,320,637	2,320,637
Engine Thrust Rating (%)	111	111	111	111
Total Mass at Liftoff (kg)	1,074,908	1,074,908	1,084,256	1,084,256
Dry Mass (kg)	100,682	100,682	112,139	112,139
Total Propellant (kg)	982,663	982,663	982,663	982,663
Usable Propellant (kg)	964,564	964,564	962,035	962,035
Reserve Propellant (kg)	7,984	7,984	7,984	7,984
Fuel Bias Propellant (kg)	1,678	1,678	2,098	2,098
Startup Propellant (kg)	8,437	8,437	10,546	10,546

The size of the upper stage mass parameters were obtained from [4]. The interstage mass was adjusted according to total maximum weight carried by the core. Ullage engine data is from [5]. Choice and number of ullage engines is from [6].

Upper Stage:	IB	IIB	IIB5C4	IIB5B4
Stage Diameter (m)	8.407	8.407	8.407	8.407
Engines	RL-10C-2	RL-10C-2	RL-10C-2	MB-60
Number of Engines	4	4	4	4
Nozzle Diameter (m)	2.146	2.146	2.146	2.286
Vacuum Isp (m/s)	4,530.7	4,530.7	4,530.7	4,530.7
Single Engine Thrust (N)	110,093	110,093	110,093	266,893
Ullage Engines	R-40B	R-40B	R-40B	R-40B
Number of Ullage Engines	4	4	4	4
Ullage Nozzle Diameter (m)	0.040	0.040	0.040	0.040
Ullage Vacuum Isp (m/s)	2,873.3	2,873.3	2,873.3	2,873.3
Ullage Single Engine Thrust (N)	4,003	4,003	4,003	4,003
Total Mass (kg)	63,450	63,958	69,554	123,622
Total Propellant (kg)	48,864	49,372	54,968	107,880
Usable Propellant (kg)	45,764	46,260	51,814	104,086
Deorbit Propellant (kg)	189	190	190	209
Reserve Propellant (kg)	387	398	440	797
Unusable Propellant (kg)	2,524	2,524	2,524	2,788
RCS Propellant (kg)	71	71	71	71
Dry Mass (kg)	14,515	14,515	14,515	15,671
Interstage Mass (kg)	3,752	3,900	4,791	5,368

The PLF jettison time was obtained from [6]. Simulation results are shown in Figures 2–5.

	IB	IIB	IIB5C4	IIB5B4
Orbit (km)	200 ± 0.0	200 ± 0.0	200 ± 0.0	200 ± 0.0
Liftoff Thrust at 0.2 s (N)	38,536,173	43,647,627	45,545,898	45,545,898
Liftoff Mass (kg)	2,707,388	2,819,916	2,840,264	2,913,064
Liftoff Acceleration (m/s ²)	14.24	15.49	16.05	15.65
MaxQ (Pa)	25,445	30,486	35,331	32,286
Maximum Acceleration (m/s ²)	33.65	31.69	36.71	29.84
PLF Jettison Time (s)	330	330	330	330
Payload Fairing (kg)	9,707	9,707	9,707	9,707
Total Payload (kg)	97,091	113,435	117,948	136,103
Total Delta-V (m/s)	9,516	9,349	9,067	9,230

- [1] Alliant Techsystems Inc., “ATK space propulsion products catalog,” Aug. 2012.
- [2] 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.
- [3] 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.
- [4] B. Donahue and D. Sauvageau, “The Space Launch System capabilities for beyond Earth missions,” *Space Access Int. Conf.*, Paris, France, Apr. 2014.
- [5] Aerojet, “R-40B 4,000 N (900-lbf) bipropellant rocket engine,” IAF-1987-0283, June 2006.
- [6] S. Creech, J. Holladay and D. Jones, “SLS dual use upper stage (DUUS) opportunities,” NASA, Apr. 2013.

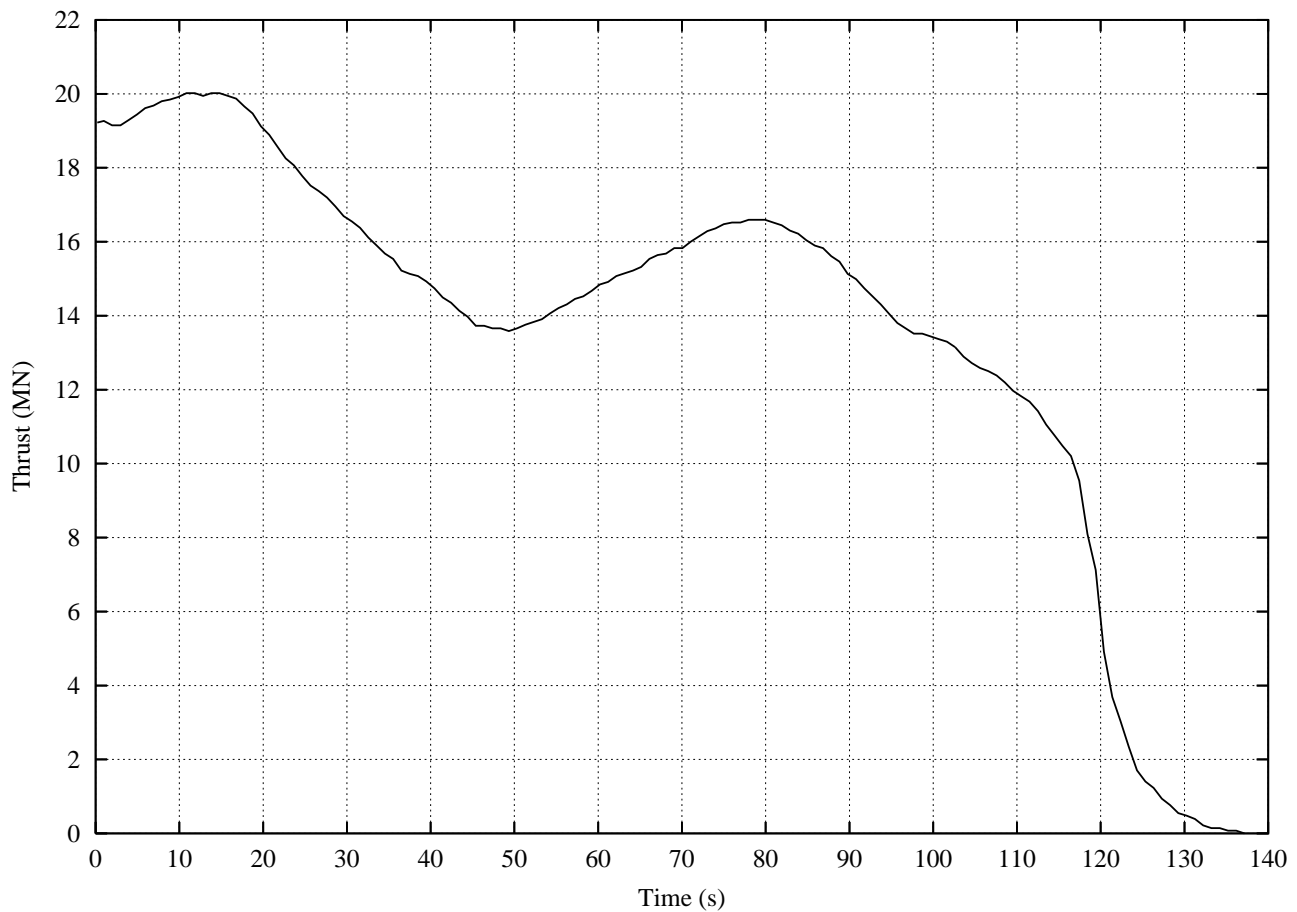


Figure 1: SRB Thrust versus time.

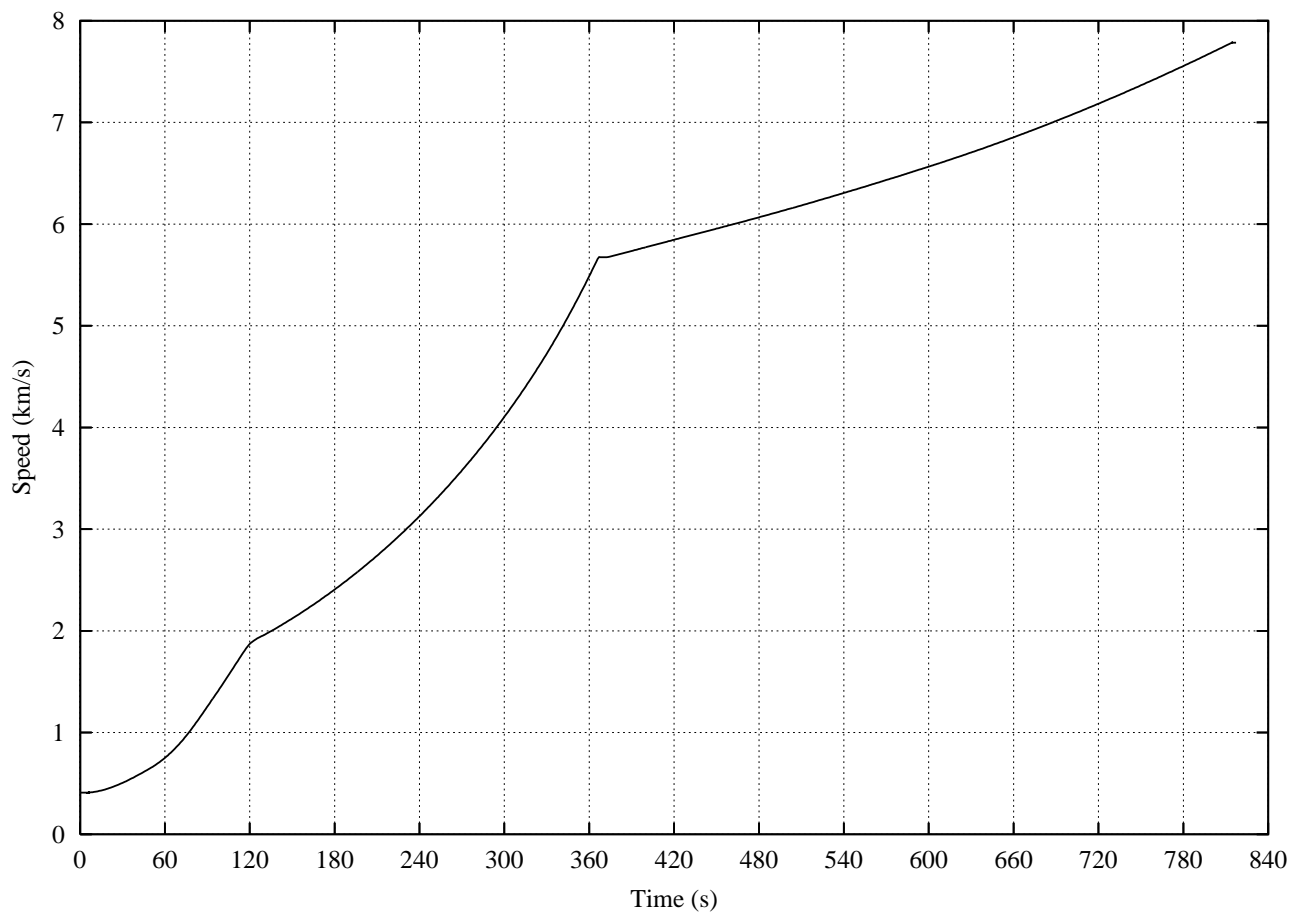


Figure 2: Speed versus time.

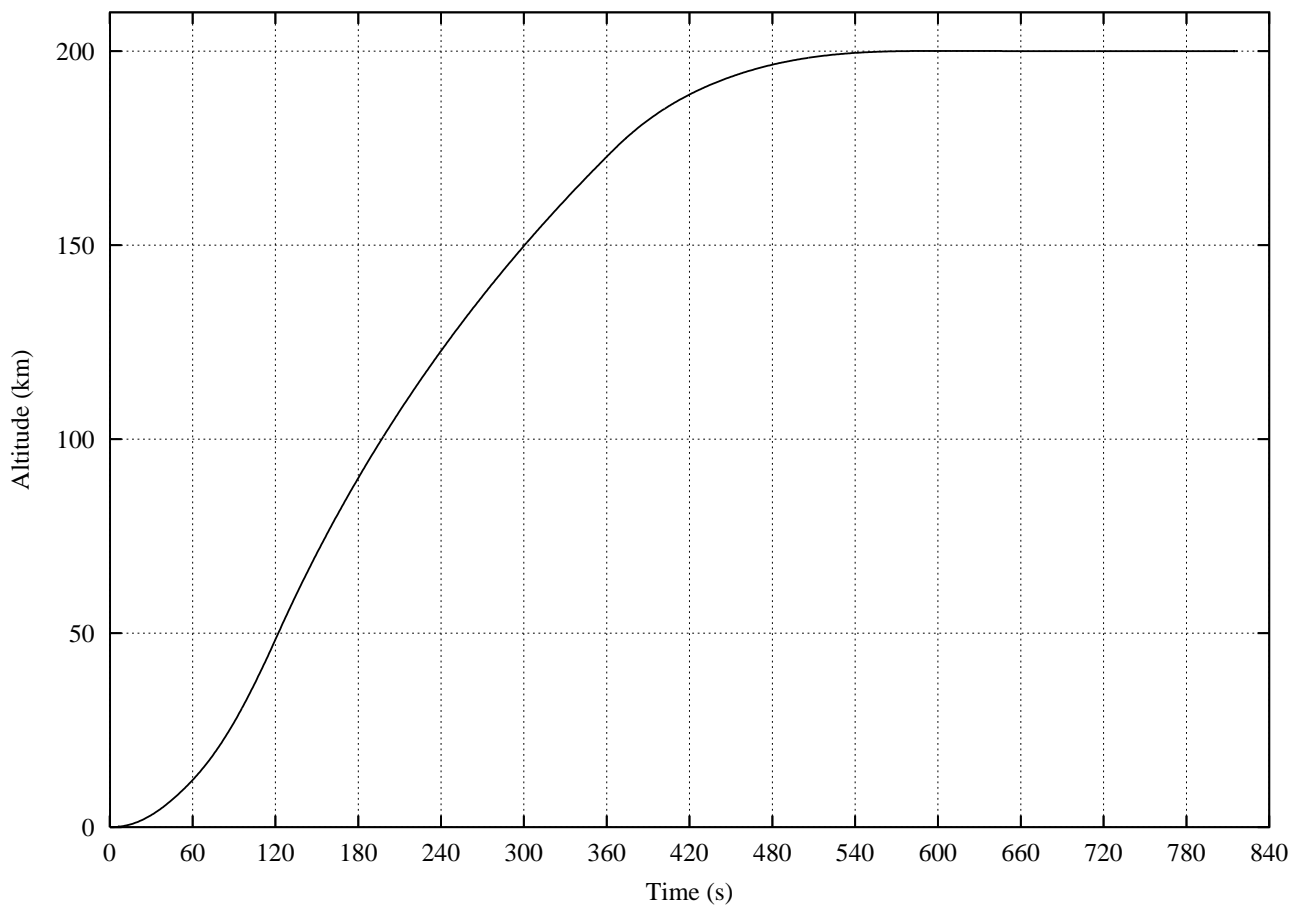


Figure 3: Altitude versus time.

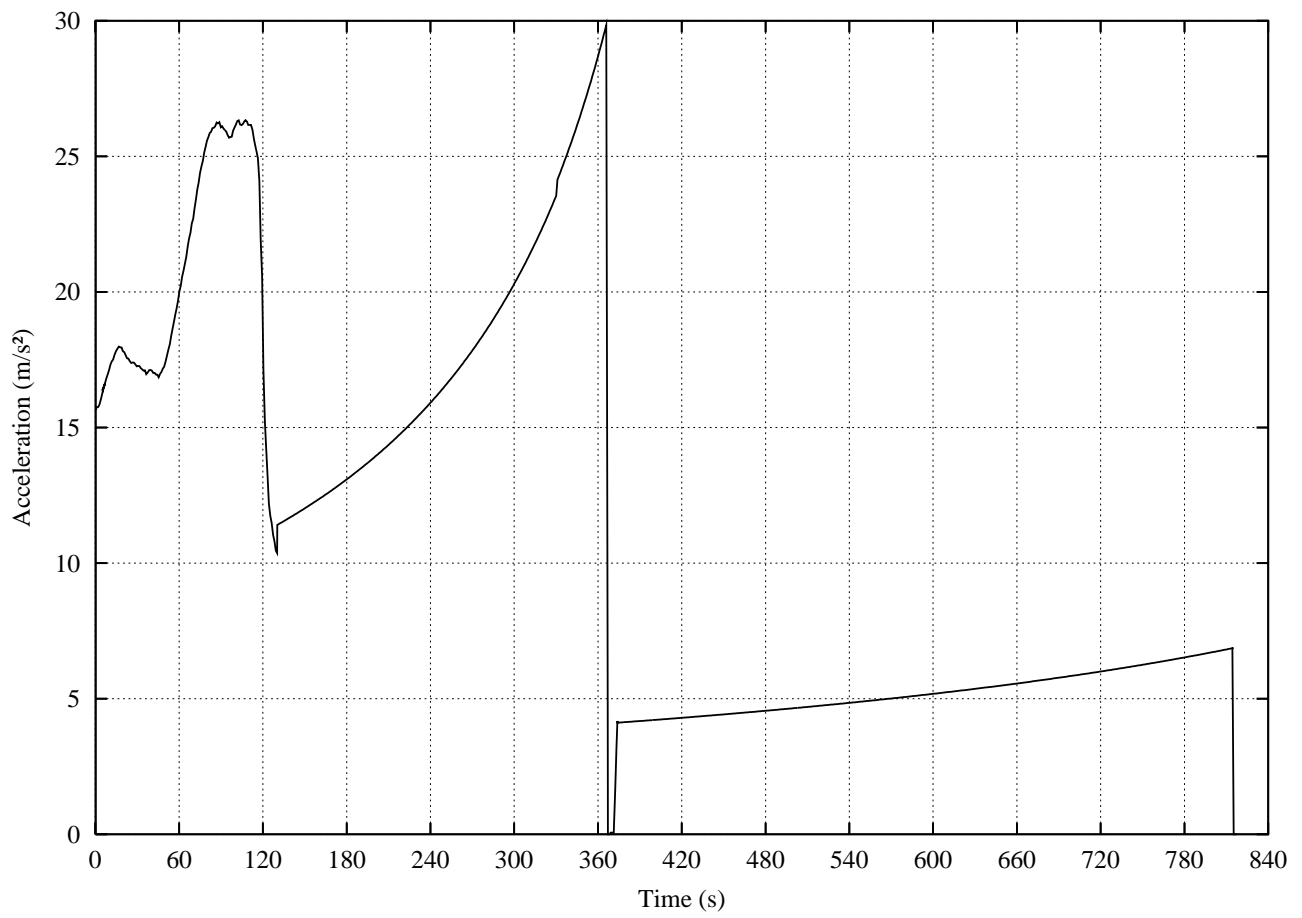


Figure 4: Acceleration versus time.

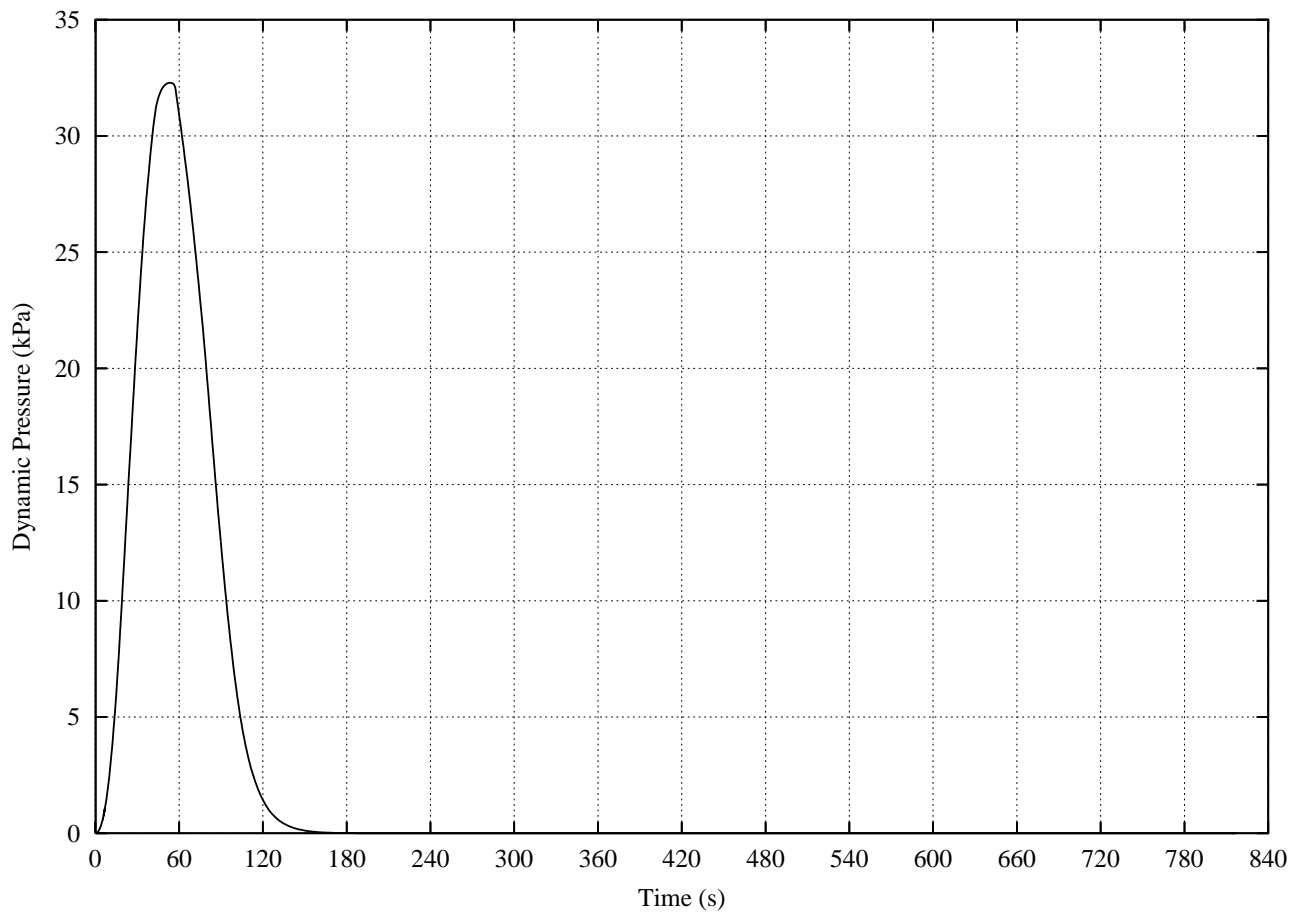


Figure 5: Dynamic pressure versus time.