Expendable Launch Systems

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Ariane

The first ever Ariane 4 launch from Kourou on June 14, 1988

Ariane is a series of a European civilian expendable launch vehicles for space launch use. The name comes from the French spelling of the mythological character Ariadne; the word is also used in French to describe some types of hummingbird.

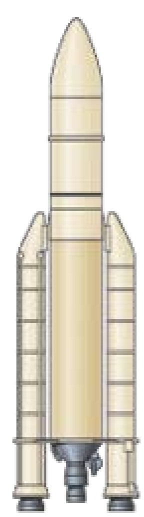
France first proposed the Ariane project and it was officially agreed upon at the end of 1973 after delicate discussions between France, Germany and the UK. The project was Western Europe's second attempt to develop its own launcher following the unsuccessful Europa project. The Ariane project was code-named L3S (the French abbreviation for third-generation substitution launcher). The European Space Agency (ESA) changed the EADS subsidiary EADS Astrium to the development of all Ariane launchers and of the testing facilities, while Arianespace, a 32.5% CNES commercial subsidiary created in 1980, handles production, operations and marketing.

Arianespace launches Ariane rockets from the Centre Spatial Guyanais at Kourou in French Guiana, where the proximity to the equator gives a significant advantage for the launch.

Ariane versions

The several versions of the launcher include:

- Ariane 1, first successful launch on December 24, 1979
- Ariane 2, first successful launch on November 20, 1987 *(the first launch on May 30, 1986 failed)*
- Ariane 3, first successful launch on August 4, 1984
- Ariane 4, first successful launch on June 15, 1988
- Ariane 5, first successful launch on October 30, 1997 *(the first launch on June 4, 1996 failed)*.



The Ariane 5

Ariane 1 was a three-stage launcher, derived from missile technology. Arianes 2 through 4 are enhancements of the basic vehicle. The major differences are improved versions of the engines, allowing stretched first- and third-stage tanks and greater payloads. The largest versions can launch two satellites, mounted in the SPELDA (Structure Porteuse Externe pour Lancements Doubles Ariane) adapter.

Such later versions are often seen with strap-on boosters. These layouts are designated by suffixes after the generation number. First is the total number of boosters, then letters designating liquid- or solid-fueled stages. For example, an Ariane 42P is an Ariane 4 with two solid-fuel boosters. An Ariane 44LP has two solid, two liquid boosters, and a 44L has four liquid-fuel boosters.

Ariane 5 is a nearly-complete redesign. The two storable lower stages are replaced with a single, cryogenic core stage. This simplifies the stack, along with the use of a single core engine (Vulcain). Because the core cannot lift its own weight, two solid-fuel boosters are strapped to the sides. The boosters can be recovered for examination but are not reused. The upper stage is storable and restartable, powered by a single Aestus engine.

On 4 May 2007, an Ariane 5-ECA rocket set a new commercial payload record, lifting two satellites with a combined mass of 9.4 tonnes.

As of January 2006, 169 Ariane flights have boosted 290 satellites, successfully placing 271 of them on orbit (223 main passengers and 48 auxiliary passengers) for a total mass of 575,000 kg successfully delivered on orbit. Attesting to the ubiquity of Ariane launch vehicles, France's Cerise satellite, which was orbited by an Ariane in 1995, struck a discarded Ariane rocket stage in 1996. The incident marked the first verified case of a collision with a piece of catalogued space debris.

On February 16 2011, the 200th Ariane rocket was launched, successfully carrying the Johannes Kepler ATV into low Earth orbit.

Industrials

Arianespace has 24 shareholders from 10 European countries, including:

- CNES (34%)
- EADS (30%)

Country	Shareholders	Capital
Belgium	3	3.15%
Denmark	1	0.01%
France	7	60.12%
Germany	2	18.62%

Italy	2	9.36%
Netherlands	1	1.82%
Norway	1	0.10%
Spain	3	2.01%
Sweden	2	2.30%
Switzerland	2	2.51%

Total of 99.99% due to round-off

Corporate management is structured as follows:

Position	Name
CEO & Chairman	Jean-Yves Le Gall
Quality Vice-President	Gérard Gradel
Senior Vice-President of Programs	Patrick Bonguet
Senior Vice-President of Marketing	Philippe Berterottière
General Secretary, Senior Vice-President of Finances	Françoise Bouzitat
Senior Vice-President of Engineering	Édouard Perez

Offices

Location of Office	Head of Branch
Évry, France	Jean-Yves Le Gall
USA	Clayton Mowry
Tokyo, Japan	Jean-Louis Claudon
Singapore	Richard Bowles

As of 1 July 2006, Arianespace employed 271 personnel at its French HQ, at its launch complex at the Guiana Space Centre in French Guiana and at offices in Washington DC, Singapore and Tokyo.

To be upgraded

- CNES is Prime, on behalf of European Space Agency
- The main industrial Prime is Aerospatiale, which will become EADS.
- The rockets are made by Société Européenne de Propulsion, now Snecma.

Ariane's Cup

Ariane's Cup is a sailing competition organized on behalf of the Industrials participating to the Ariane programme.

Models

Flyable models of the Ariane 4 and 5 are available as kits from Noris Raketen in Germany. In 1987 Lambert Shelter built a 5.40 metre long flyable model of the Ariane, now displayed at the Hermann Oberth Space Travel Museum in Feucht. A 4.5 m, 85 kg flyable model of the Ariane 4, built by the Advanced Rocketry Group Of Switzerland (ARGOS), was launched in 2002 in Amarillo, Texas and successfully again on 19 September 2004 at 12:15 local time in the Val de Ruz in the Canton of Neuchâtel, Switzerland.

Chapter- 2

Ariane (1-4)

Ariane 1

Ariane 1

Ariane 1 mock-up (Photo taken at Musée de l'Air et de l'Espace, Le Bourget, France)

Function	Medium Lift Launch System
Manufacturer	Les Mureaux for ESA
Country of origin	Europe
Size	
Height	50 m (164 ft)

Diameter	3.8 m (12.4 ft)
Mass	207,200 kg (456,700 lb)
Stages	4
	Capacity
Payload to LEO	1,400 kg
Payload to GTO	1,850 kg
	Launch history
Status	Retired
Launch sites	ELA-1, Guiana Space Centre
Total launches	11
Successes	9
Failures	2
Maiden flight	24 December 1979
Last flight	22 February 1986
Notable payloads	Giotto
	First stage
Engines	4 Viking-2
Thrust	2,771.940 kN (623,157 lbf)
Specific impulse	281 s
Burn time	145 seconds
Fuel	UDMH/N2O4
	Second stage
Engines	1 Viking-4
Thrust	720.965 kN (162,079 lbf)
Specific impulse	296 s
Burn time	132 seconds
Fuel	UDMH/N2O4
	Third stage
Engines	1 HM7-A
Thrust	61.674 kN (13,865 lbf)
Specific impulse	443 sec
Burn time	563 seconds
Fuel	LH2/LOX
	Fourth stage
Engines	1 Mage 1
Thrust	19.397 kN (4,361 lbf)
Specific impulse	295 sec
Burn time	50 seconds
Fuel	HTPB (solid)

Ariane 1 is the first version of the Ariane launcher family. Ariane 1 was designed primarily to put two telecommunications satellites at a time into orbit, thus reducing

costs. As the size of the satellites grew Ariane 1 gave way to the more powerful Ariane 2 and Ariane 3 launchers.

Vehicle description

Ariane 1 was the first launch vehicle to be developed by the European Space Agency. It was developed from the L3S Europa launch vehicle replacement design. The development of the vehicle was authorized in July 1973. The cost of program is estimated at 2 billion euros. With lift-off mass of 210,000 kg (460,000 lb), Ariane I was able to put in geostationary orbit one satellite or two smaller of a maximal weight of 1,850 kg (4,100 lb).

The Ariane 1 was a four stage vehicle. The first stage was equipped with 4 Viking engines developed by the Société Européenne de Propulsion. The second stage had a single Viking engine. The third stage had one LOX/LH2 bipropellant engine capable of a thrust of 7,000 kgf (69 kN). The fourth stage was powered by a single Mage-1 solid rocket booster producing a thrust of 20 kN.

This design was kept in the Ariane series until Ariane 4.

Launches

The first launch was on 24 December 1979, and was successful. The second launch, in 1980, failed shortly after launch due to a combustion instability in one of the Viking first stage engines. The third launch succeeded in orbiting three satellites, and the fourth and last qualification launch was also a success.

During the next launch, the first commercial one, the rocket ceased functioning after 7 minutes of flight due to a turbopump failure in the third stage. After a complete review of the launcher, the next 6 flights were all successful. The Giotto mission's spaceprobe was successfully launched on the tenth Ariane 1 (flight V14) on 2 July 1985.

The first SPOT satellite was put into orbit by the eleventh and last launch of Ariane 1 on 22 February 1986.

Launch history

Flight	Date	Launch Pad	Payload	Outcome	Remarks
L-01	24 December 1979	ELA-1	CAT-1	Success	First Flight
L-02	23 May 1980	ELA-1	Firewheel Subsat-1,2,3,4	Failure	Combustion instability in one of the Viking first stage engines

			Amsat P3A CAT 2		
L-03	19 June 1981	ELA-1	Meteosat 2 Apple CAT 3	Success	
L-04	20 December 1981	ELA-1	MARECS 1 CAT 4	Success	
L-5	10 September 1982	ELA-1	MARECS B Sirio 2	Failure	First commercial launch The rocket ceased functioning after 7 minutes of flight due to a turbopump failure in the third stage
L-6	16 June 1983	ELA-1	ECS 1 Amsat P3B (Oscar 10)	Success	
L-7	19 October 1983	ELA-1	Intelsat 507	Success	
L-8	5 February 1984	ELA-1	Intelsat 508	Success	
V-9	23 May 1984	ELA-1	Spacenet 1	Success	
V-14	2 July 1985	ELA-1	Giotto	Success	
V-16	22 February 1986	ELA-1	SPOT 1 Viking	Success	Last Flight

Ariane 2

	Ariane 2
Function	Carrier rocket
Manufacturer	Aérospatiale Arianespace
Country of origin	Europe
	Size
Height	49 metres (161 ft)
Diameter	3.8 metres (12 ft)
Mass	217,000 kilograms (480,000 lb)
Stages	Three

Capacity	
Payload to GTO	2,175 kilograms (4,800 lb)
Associated rockets	
Family	Ariane
Derivatives	Ariane 3
Launch history	
Status	Retired
Total launches	6
Successes	5
Failures	1
Maiden flight	31 May 1986
Last flight	2 April 1989

Ariane 2 was a European expendable carrier rocket, which was used for six launches between 1986 and 1989. It was a member of the Ariane family of rockets, and was produced by Aérospatiale in France.

The Ariane 2 was derived from the earlier Ariane 1, with stretched first and third stages. Its payload capacity was increased to 2,175 kilograms (4,800 lb) to a geosynchronous transfer orbit. It first flew on 31 May 1986 carrying the Intelsat-5A F-14 satellite. The third stage failed to ignite, and the rocket was destroyed by range safety. Following this, five more launches were conducted, all of which were successful. The last Ariane 2 launch occurred on 2 April 1989, successfully placing Tele-X into orbit.

Ariane 3

Ariane 3	
Function	Carrier rocket
Manufacturer	Aérospatiale Arianespace
Country of origin	Europe
Size	
Height	49 metres (161 ft)
Diameter	3.8 metres (12 ft)
Mass	237,000 kilograms (520,000 lb)
Stages	Three or four
Capacity	
Payload to GTO	2,700 kilograms (6,000 lb)
Associated rockets	
Family	Ariane
Launch history	
Status	Retired
Total launches	11
Successes	10
Failures	1
Maiden flight	4 August 1984
Last flight	12 July 1989

Ariane 3 was a European expendable carrier rocket, which was used for six launches between 1986 and 1989. It was a member of the Ariane family of rockets, derived from the Ariane 2, although it flew before this. It was designed by the Centre National d'Etudes Spatiales, and produced by Aérospatiale in France.

The Ariane 3 followed the same basic design as the earlier Ariane 1, but incorporated modifications made for the Ariane 2, including stretched first and third stages, and uprated first and second stage engines. It also featured the larger payload fairing flown on the Ariane 2. Unlike the Ariane 2, two solid-fuelled PAP strap-on booster rockets were used to augment the first stage at liftoff.

The core of the Ariane 3 was essentially an Ariane 2. The first stage was powered by four Viking 2B bipropellant engines, burning Nitrogen tetroxide in an UH 25 oxidiser, which was a mixture of three parts UDMH and one part Hydrazine. The second stage was powered by a Viking 4B, which used the same fuel-oxidiser combination. The third stage used a cryogenically-fuelled HR7-B engine, burning liquid hydrogen in liquid oxygen. On some flights, a Mage 2 kick motor was flown as a fourth stage.

Launch history

The Ariane 3 made its maiden flight on 4 August 1984, almost two years before Ariane 2 from which it had been derived, placing the ECS-2 and Télécom 1A satellites into geosynchronous transfer orbit. Eleven were launched with ten successes and one failure. The failure occurred on the fifth flight, launched on 12 September 1985, when the third stage failed to ignite resulting in the rocket failing to achieve orbit. The ECS-3 and Spacenet-3 satellites were lost in the failure.

The Ariane 3 was quickly replaced by the more capable Ariane 4, resulting in a comparatively small number of launches. It made its final flight on 12 July 1989, carrying the Olympus F1 satellite.

Ariane 4

Ariane 4

The 52nd Ariane 4 carrying TOPEX/Poseidon

Function	Expendable launch vehicle
Manufacturer	Arianespace
Country of origin	Europe
Size	
Height	58.72 m (192.7 ft)
Diameter	3.8 m (12.5 ft)
Mass	240,000 - 470,000 kg (529,110 - 1,036,175 lb)
Stages	2
Capacity	
Payload to LEO	5,000 - 7,600 kg (11,024 - 16,756 lb)
Payload to GTO	2,000 - 4,300 kg (4,410 - 9480 lb)
Launch history	
Status	Retired
Launch sites	Kourou ELA-2
Total launches	116 (**40:** 7, **42P:** 15, **42L:** 13) (**44P:** 15, **44LP:** 26, **44L:** 40)
Successes	113 (**40:** 7, **42P:** 14, **42L:** 13)

	(**44P:** 15, **44LP:** 25, **44L:** 39)
Failures	3 (**42P:** 1, **44L:** 1, **44LP:** 1)
Maiden flight	**40:** 22 January 1990 **42P:** 20 November 1990 **42L:** 12 May 1993 **44P:** 4 April 1991 **44LP:** 15 June 1988 **44L:** 5 June 1989
Last flight	**40:** 3 December 1999 **42P:** 4 May 2002 **42L:** 23 January 2002 **44P:** 25 September 2001 **44LP:** 27 November 2001 **44L:** 15 February 2003
Boosters (Ariane 42L, 44LP or 44L) - PAL	
N^o boosters	0, 2 or 4
Engines	Viking 6
Thrust	752.003 kN (169,057 lb_f)
Specific impulse	278 sec
Burn time	142 seconds
Fuel	N_2O_4/UDMH
Boosters (Ariane 42P, 44LP or 44P) - PAP	
N^o boosters	0, 2 or 4
Engines	
Thrust	650 kN
Burn time	33 sec
Fuel	CTPB 1613
First Stage - L220	
Engines	4 Viking 5C
Thrust	3,034.1 kN
Specific impulse	278 sec
Burn time	205 sec
Fuel	N_2O_4/UDMH
Second Stage - L33	
Engines	1 Viking 4B
Thrust	720.965 kN
Specific impulse	296 sec
Burn time	132 seconds
Fuel	N_2O_4/UDMH
Third Stage - H10	
Engines	1 HM7-B
Thrust	62.703 kN
Specific impulse	446 sec
Burn time	759 seconds

Fuel	Lox/LH2

Ariane 4 was an expendable launch system, designed by the Centre National d'Etudes Spatiales and manufactured and marketed by its subsidiary Arianespace. Ariane 4 was justly known as the 'workhorse' of the Ariane family. Since its first flight on 15 June 1988 until the last, on 15 February 2003, it made 113 successful launches. It was known to be an extremely versatile launcher.

The Ariane 4 proved ideal for launching communications and Earth observation satellites as well as those for scientific research. During its working life, Ariane 4 captured 50% of the market in launching commercial satellites, demonstrating Europe's ability to compete in the commercial launch sector.

History

In 1973 eleven countries, called together by the European Space Agency (ESA), decided to take Europe down its own path in the space field: and so the Ariane programme was born. Six years later in 1979, Ariane 1 was launched from Kourou. Following development work on variants 1, 2 and 3, Ariane 4 was able to draw on the experience gained from these earlier variants.

The development program began in 1983 and the first successful launch was on 15 June 1988. The system became the basis for a European satellite launching program with a stellar record of 113 successful missions and only three launch failures. Ariane 4 provided a payload increase from 1700 kg for Ariane 3 to a maximum of 4800 kg to geostationary transfer orbit (GTO). The record for Ariane 4 to GTO was 4946 kg.

The Ariane 4 Launch Team was awarded the Space Achievement Award by the Space Foundation in 2004.

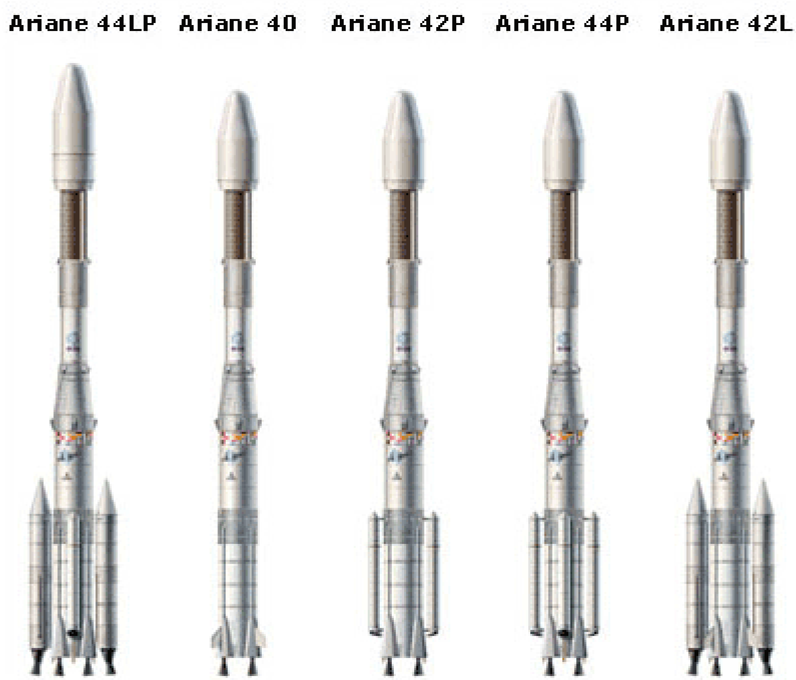
Vehicle Description

The Ariane 4 was the ultimate development from the Ariane 1,2,3. Compared with the Ariane 2/3, the Ariane 4 featured stretched first (61%) and third stages, a strengthened structure, new propulsion bay layouts, new avionics, and the SPELDA (*Structure Porteuse Externe de Lancement Double Ariane*) dual-payload carrier. The basic 40 version used no strap-on motors, while the Ariane 42L, 44L, 42P, 44P, and 44LP versions used various combinations of solid and liquid propellant strap-on motors. Development was authorised in January 1982, with the objective of increasing payload by 90%. Total development cost 476 million 1986 ECU's.

Originally designed to place 2-4.2 tonne payloads in geostationary orbit, the six Ariane 4 variants, aided by strap-on boosters, enabled the launch of payloads in excess of 4.9 tonnes on several occasions.

Variants

The rocket was used in a number of variants - it could be fitted with two or four additional solid (PAP - *Propulseurs d'Appoint à Poudre*) or liquid fueled booster rockets (PAL - *Propulseurs d'Appoint à Liquide*). The launcher included a satellite payload carrier system called *Spelda* (*Structure Porteuse Externe de Lancement Double Ariane*, French for 'External carrying structure for Ariane double launches') for launching more than one satellite at a time. The rocket captured nearly 60% of the world's commercial launch services market, serving both European and international clients.



5 of the 6 versions of Ariane 4

Ariane 4 AR 40 was the basic version, with three stages: 58.4 m high, a diameter of 3.8 m, a liftoff mass of 245 t and a maximum payload of 2100 kg to GTO or 5000 kg to Low Earth orbit (LEO). Main power was from four Viking 2B motors each producing 667 kN of thrust. The second stage had a single Viking 4B motor, and the third stage had an HM7-B liquid oxygen/liquid hydrogen motor. AR 44L, with the maximum additional boost of four liquid fuel rocket strap-ons, was four-stage, weighed 470 t and could transfer a payload of 4730 kg to GTO or 7600 kg to LEO.

Model	PAL	PAP	Payload to GTO, kg	Launches	Successes	Failure date
AR 40	-	-	2100	7	7	-
AR 42P	-	2	2930	15	14	1 December 1994
AR 42L	2	-	3480	13	13	-
AR 44L	4	-	4720	40	39	22 February 1990

AR 44LP	2	2	4220	26	25	24 January 1994
AR 44P	-	4	3460	15	15	-

Launches

The inaugural flight of Ariane 4 took place in 1988. Since then has accomplished 116 flights with a success rate of more than 97%. The final launch of Ariane 4 rocket occurred on 15 February 2003, placing Intelsat 907 into geosynchronous orbit.

Retirement

Ariane 4 was phased out in favour of Ariane 5 and Soyuz ST (a Russian rocket originally designed in the 1950's). The former can carry heavier payloads than Ariane 4. The latter, which is completely produced in Russia and then shipped to the Guiana Space Centre will be used for launching smaller payloads depending on the availability of these Russian-produced rockets. Spacecraft launched by the Soyuz will reuse the payload platform and the large carbon fiber fairing from the Ariane 4.

Comparable Rockets

- Delta II
- GSLV
- Long March 2
- Soyuz-U

Chapter- 3

Athena

Athena

Athena II with Lunar Prospector

Function	Small, modular component launch vehicle
Manufacturer	Lockheed Martin Alliant Techsystems
Country of origin	United States
Size	
Height	19.8 - 30.48 m (65 - 100 ft)

Diameter	2.36 m (92 in)
Mass	66,344 - 120,202 kg (146,264 - 265,000 lb)
Stages	2 or 3
Capacity	
Payload to LEO	794 - 1,896 kg (1,750 - 4,350 lb)
Launch history	
Status	Retired, To be reactivated
Launch sites	Cape Canaveral Air Force Station Launch Complex 46, Vandenberg AFB Space Launch Complex 6, Kodiak Launch Complex 1
Successes	5
Failures	2
Maiden flight	August 1995
Notable payloads	Lunar Prospector
First stage - Castor-120	
Engines	1
Thrust	1,900 kN (435,000 lb_f)
Specific impulse	280 seconds
Burn time	83.4 seconds
Fuel	Class 1.3 Hydroxyl-terminated polybutadiene (HTPB-a polymer) propellant
Second stage - ORBUS 21D	
Engines	1
Thrust	194 kN (43,723 lb_f)
Specific impulse	293 seconds
Burn time	150 seconds
Fuel	Class 1.3 Hydroxyl-terminated polybutadiene (HTPB-a polymer) propellant

Athena is a Lockheed Martin expendable launch system which has undergone several name changes in its lifetime. Development began at the Lockheed Corporation in 1993, where the design was known as the Lockheed Launch Vehicle. The name was changed to the Lockheed Martin Launch Vehicle when Lockheed merged with Martin Marietta. Late in the program's life the name was finally changed to Athena, and all of the launches after the demonstration flight in August 1995 were conducted using that name. Athena was retired from service in 2001, however in 2010 it was announced that it would be put back into production, with launches set to resume in 2012. In September 2010 Athena was added to NASA's Launch Services II contract.

Variants

The Athena comes in two versions, Athena I and Athena II. The Athena I has two stages, the Thiokol Castor-120 first stage and a Pratt & Whitney ORBUS 21D upper stage. The Athena II has three stages, the Castor-120 first and second stages, and an ORBUS 21D upper stage. When flights resume in 2012, the Athena Ic and Athena IIc configurations will use Castor 30 stages instead of the Orbus 21D stages on the original versions.

The Athena rocket uses an Orbit Adjust Module (OAM) developed by Primex Technologies. Primex was acquired by General Dynamics in 2001. For the September 28th, 2001 Athena launch, the OAM was built by General Dynamics Space Propulsion Systems of Redmond, WA. The OAM houses the attitude control system and avionics subsystem (guidance and navigation, batteries, telemetry transmitters, command and destruct receivers and antennas). This 1 meter (3.3 ft) long module is fueled with monopropellant hydrazine. After payload separation, the OAM performs a contamination and collision avoidance maneuver, distancing itself from the payload and burning any remaining fuel to depletion. Athena solid rocket motor provider ATK produces integrated upper stages using spin-stabilized or 3-axis stabilized *Star* solid motors that can provide higher velocities for GEO and escape (e.g. lunar and planetary) missions. Such an integrated upper stage based on a 2531 lb *Star 37FM* was employed for the launch of *Lunar Prospector*, the first lunar probe launched by a commercially developed launch vehicle.

Athena III

An Athena III rocket was planned, but never developed. It was to add two, four or six Castor-4A strap-on boosters to the stack.

The designation was later reused for a proposed rocket for the Commercial Orbital Transportation Services project. Sometime after 2005, PlanetSpace reused the **Athena III** designation for a 2.8-million-pound-thrust shuttle-derived space station resupply booster rocket, in a joint venture with Lockheed Martin and Alliant Techsystems (ATK). As of 2008, the three companies had teamed up with Boeing and the State of Florida to obtain financing for project.

Launches

Athena 1 rocket launching from Kodiak Island in Alaska (Sept. 30, 2001)

- The Demonstration Launch Vehicle, an Athena-I, failed to launch the GEMstar 1 communications satellite on Aug. 15, 1995. (Destroyed by range safety after control malfunction.)
- An Athena I launched the NASA Lewis satellite on Aug. 22, 1997.
- An Athena II launched NASA's Lunar Prospector on Jan. 6, 1998.
- An Athena I launched ROCSAT-1 for the Republic of China (Taiwan) on Jan. 26, 1999.

- An Athena II failed to launch IKONOS-1, a commercial earth observation satellite, on April 27, 1999. (Failed to orbit because the payload fairing did not separate properly.)
- An Athena II launched IKONOS-2, a commercial earth observation satellite, on Sept. 24, 1999.
- An Athena I carried out the Kodiak Star mission for NASA and the Space Test Program, launching Starshine 3, Sapphire, PCSat, and PICOSat on Sept. 30, 2001. The mission was the Kodiak Launch Complex's first orbital launch.

Chapter- 4

Athena I & Athena II

Athena I

Athena I

Launch of an Athena I on the Kodiak Star mission.

Function	Small expendable launch system
Manufacturer	Lockheed Martin Alliant Techsystems
Country of origin	United States

Size

Height	18.9 metres (62 ft)
Diameter	2.36 metres (7 ft 9 in)
Mass	66,300 kilograms (146,000 lb)
Stages	Three
Capacity	
Payload to LEO	820 kilograms (1,800 lb)
Payload to SSO	360 kilograms (790 lb)
Associated rockets	
Family	Athena
Derivatives	Athena II
Comparable	Falcon 1 Minotaur IV Taurus
Launch history	
Status	Temporarily inactive
Launch sites	Kodiak LP-1 MARS LP-0B Spaceport Florida LC-46 Vandenberg SLC-6 & SLC-8
Total launches	4
Successes	3
Failures	1
Maiden flight	**Athena I:** 15 August 1995 **Athena Ic:** 2012
Last flight	**Athena I:** 30 September 2001
First Stage - Castor 120	
Engines	1 solid
Thrust	1,900 kilonewtons (430,000 lb_f)
Specific impulse	280 sec
Burn time	83 seconds
Fuel	HTPB
Second Stage (Athena I) - Orbus 21D	
Engines	1 solid
Thrust	189.2 kilonewtons (42,500 lb_f)
Specific impulse	293 sec
Burn time	150 seconds
Fuel	HTPB
Second Stage (Athena Ic) - Castor 30	
Engines	1 solid
Thrust	258.9 kilonewtons (58,200 lb_f)
Specific impulse	294 sec
Burn time	143 seconds

Fuel	HTPB
	Third Stage - OAM
Engines	4 MR-107
Thrust	882 newtons (198 lb_f)
Specific impulse	222 sec
Burn time	1,500 seconds
Fuel	Hydrazine

The **Athena I**, known as the **Lockheed Launch Vehicle** (**LLV**) at the time of its first flight and **Lockheed Martin Launch Vehicle** (**LMLV**) at the time of its second flight, is an American small expendable launch system which was used for four launches between 1995 and 2001, and which is scheduled to return to service in 2012. It is a member of the Athena family of rockets, along with the larger Athena II. Launches from 2012 will use the Athena Ic configuration, which features a different second stage.

The Athena I is a three stage rocket, consisting of solid first and second stages, and a monopropellant liquid-fuelled third stage. The first stage is a Castor 120, which is also used on some versions of the Taurus rocket. An Orbus 21D motor was used as the second stage on launches up to 2001, however when it returns to service in 2012, the Castor 30, which is under development for the Taurus II, will be used instead. The third stage is an Orbital Adjustment Module, fuelled by hydrazine and propelled by four MR-107 engines, which is used for final insertion.

Prior to its retirement in 2001, Athena I launches were made from Space Launch Complex 6 at Vandenberg Air Force Base, Launch Complex 46 at Spaceport Florida, and Pad 1 of the Kodiak Launch Complex. The pads at Kodiak and Canaveral will be used for Athena Ic launches, with Launch Pad 0B of the Mid-Atlantic Regional Spaceport also offered. If a launch from Vandenberg is ordered, Space Launch Complex 8 will be used instead of SLC-6, which was rebuilt as a Delta IV launch complex following the Athena's initial retirement.

Four Athena I launches have been conducted, with one failure. Its maiden flight was conducted from SLC-6 at Vandenberg, and lifted off at 22:30 GMT on 15 August 1995. It was intended to place GemStar-1 into orbit, however the rocket was destroyed by the range safety officer after the failure of its thrust vectoring system resulted in a loss of control. The launch was the first from SLC-6, which had originally been built for the Titan III rocket for launches of the Manned Orbital Laboratory, and was later rebuilt for polar orbit Space Shuttle launches. Both MOL and polar Shuttle flights were cancelled before any launches were made from SLC-6. The next Athena I launch was on 23 August 1997, and successfully placed the Lewis satellite into orbit for NASA. This launch also took place from SLC-6 at Vandenberg. The third Athena I launch was from LC-46 at Spaceport Florida, and took place on 27 January 1999. The payload, ROCSAT-1, was the first satellite to be operated by the Republic of China. The fourth launch, which was conducted on 30 September 2001, was the first orbital launch to be made from Kodiak Island. Known as the *Kodiak Star* mission, it successfully placed the Starshine 3, Picosat 9, PCSat and Sapphire satellites into orbit.

Athena II

Athena II

Athena II at LC-46 with Lunar Prospector

Function	Small expendable launch system
Manufacturer	Lockheed Martin Alliant Techsystems
Country of origin	United States
Size	
Height	28.2 metres (93 ft)
Diameter	2.36 metres (7 ft 9 in)
Mass	120,700 kilograms (266,000 lb)
Stages	Four
Capacity	
Payload to LEO	2,065 kilograms (4,550 lb)
Payload to SSO	1,165 kilograms (2,570 lb)
Payload to GTO	593 kilograms (1,310 lb)
Associated rockets	
Family	Athena
Comparable	Falcon 1

	Minotaur IV Taurus
	Launch history
Status	Temporarily inactive
Launch sites	Kodiak LP-1 MARS LP-0B Spaceport Florida LC-46 Vandenberg SLC-6 & SLC-8
Total launches	3
Successes	2
Failures	1
Maiden flight	**Athena II:** 7 January 1998 **Athena IIc:** NET 2012
Last flight	**Athena II:** 24 September 1999
	First Stage - Castor 120
Engines	1 solid
Thrust	1,900 kilonewtons (430,000 lb_f)
Specific impulse	280 sec
Burn time	83 seconds
Fuel	HTPB
	Second Stage - Castor 120
Engines	1 solid
Thrust	1,900 kilonewtons (430,000 lb_f)
Specific impulse	280 sec
Burn time	83 seconds
Fuel	HTPB
	Third Stage (Athena II) - Orbus 21D
Engines	1 solid
Thrust	189.2 kilonewtons (42,500 lb_f)
Specific impulse	293 sec
Burn time	150 seconds
Fuel	HTPB
	Third Stage (Athena IIc) - Castor 30
Engines	1 solid
Thrust	258.9 kilonewtons (58,200 lb_f)
Specific impulse	294 sec
Burn time	143 seconds
Fuel	HTPB
	Fourth Stage - OAM
Engines	4 MR-107
Thrust	882 newtons (198 lb_f)
Specific impulse	222 sec
Burn time	1,500 seconds

Fuel	Hydrazine

The **Athena II** is an American small expendable launch system which was used for three launches between 1998 and 1999, and which is scheduled to return to service in 2012. It is a member of the Athena family of rockets, along with the smaller Athena I. Launches from 2012 will use the Athena IIc configuration, which features a different third stage.

The Athena II is a four stage rocket, consisting of solid first, second and third stages, and a monopropellant liquid-fuelled fourth stage. The first and second stages are Castor 120s, which are also used on some versions of the Taurus rocket. An Orbus 21D motor was used as the third stage on launches during the 1990s, however when it returns to service in 2012 the Castor 30, which is under development for the Taurus II, will be used instead. The fourth stage is an Orbital Adjustment Module, fuelled by hydrazine and propelled by four MR-107 engines, which is used for final insertion.

Prior to its retirement in 1999, Athena II launches were made from Launch Complex 46 at Spaceport Florida and Space Launch Complex 6 at Vandenberg Air Force Base. LC-46 will also be used for Athena IIc launches, with Launch Pad 0B of the Mid-Atlantic Regional Spaceport and Pad 1 of the Kodiak Launch Complex also offered. If a launch from Vandenberg is ordered, Space Launch Complex 8 will be used instead of SLC-6, which was rebuilt as a Delta IV launch complex following the Athena's initial retirement.

During the 1990s, three Athena II launches were conducted, with one failure. Its maiden flight was conducted from LC-46 at Spaceport Florida, and lifted off at 02:28 GMT on 7 January 1997. The launch, which was the first to take place from Spaceport Florida, successfully placed the Lunar Prospector spacecraft into orbit for NASA. The next Athena II launch took place from SLC-6 at Vandenberg on 27 April 1999, with the Ikonos satellite for Space Imaging. The launch ended in failure after the payload fairing failed to separate, and as a result the rocket had too much mass to achieve orbital velocity. The third launch also took place from SLC-6 at Vandenberg, on 24 September 1999. The payload, Ikonos 1, was also for Space Imaging, and successfully reached orbit.

Chapter- 5

Atlas-Able, Atlas-Agena & Atlas-Centaur

Atlas-Able

Atlas-Able

An Atlas-Able launching Pioneer P-30

Function	Expendable launch system
Manufacturer	Convair General Dynamics
Country of origin	United States
	Launch history
Status	Retired
Launch sites	LC-12, *13* & 14, Cape Canaveral
Total launches	3
Failures	3
Maiden flight	26 November 1959

Last flight	15 December 1960

The **Atlas-Able** was an American expendable launch system derived from the SM-65 Atlas missile. It was a member of the Atlas family of rockets, and was used to launch several Pioneer spacecraft towards the Moon. Of the five Atlas-Able rockets built, two failed during static firings, and the other three failed to reach orbit.

The Atlas-Able was a three and a half stage rocket, with a stage and a half Atlas missile as the first stage, an Able second stage, and an Altair third stage. The first Atlas-Able used an Atlas C as the first stage, but this exploded during a static fire test. The remaining launches used Atlas D missiles. Launches were conducted from Launch Complexes 12 and 14 at the Cape Canaveral Air Force Station. On launch was planned from Launch Complex 13, however this became the second Atlas-Able to be destroyed during a static firing, and hence never launched.

Atlas-Agena

Atlas-Agena

An Atlas-Agena launching Lunar Orbiter 4

Function	Expendable launch system
Manufacturer	Convair General Dynamics
Country of origin	United States

Launch history

Status	Retired
Launch sites	LC-12, 13 & 14, CCAFS SLC-3 & 4, Vandenberg
Total launches	119
Successes	103
Failures	13
Partial failures	3
Maiden flight	26 February 1960
Last flight	27 June 1978

The **Atlas-Agena** was an American expendable launch system derived from the SM-65 Atlas missile. It was a member of the Atlas family of rockets, and was used for 119 orbital launches between 1960 and 1978.

The Atlas-Agena was a two and a half stage rocket, with a stage and a half Atlas missile as the first stage, and an RM-81 Agena second stage. Initially, Atlas D missiles, redesignated as the LV-3, were used as the first stage These were later replaced by the standardised Atlas SLV-3, and its derivatives, the SLV-3A and B. The final Atlas-Agena launch used an Atlas E/F.

Launches were conducted from Launch Complexes 12, 13 and 14 at the Cape Canaveral Air Force Station, and Launch Complexes 1 and 2 at Point Arguello (now SLC-3 and 4 at Vandenberg Air Force Base).

Variants

Name	First launch	Last launch	Launches	Successes	Failures	Partial failures	Remarks
Atlas LV-3 Agena-A	1960-02-26	1961-01-31	4	2	2	0	
Atlas LV-3 Agena-B	1961-07-12	1965-03-21	28	21	5	2	
Atlas LV-3 Agena-D	1963-07-12	1965-07-20	15	15	0	0	
Atlas SLV-3 Agena-D	1964-08-14	1967-11-05	47	41	5	1	
Atlas SLV-3B Agena-D	1966-04-08		1	0	0	0	
Atlas SLV-3 Agena-B	1966-06-07		1	1	0	0	
Atlas SLV-3A Agena-D	1968-03-04	1978-04-08	12	11	1	0	
Atlas E/F	1978-06-27		1	1	0	0	

Agena D

Notable launches

On 1965-10-25 the Agena stage of an Atlas-Agena D failed to orbit the first Gemini Agena Target Vehicle (GATV), which was planned for use as the rendezvous target for the Gemini 6 mission. The failure of the GATV launch led NASA to instead have Gemini 6 rendezvous with another piloted spacecraft, Gemini 7.

Atlas-Centaur

Atlas-Centaur

An Atlas-Centaur launching Surveyor 1

Function	Expendable launch system
Manufacturer	Convair General Dynamics
Country of origin	United States
Launch history	
Status	Retired
Launch sites	LC-36, Cape Canaveral
Total launches	61
Successes	51
Failures	8

Partial failures	2
Maiden flight	9 May 1962
Last flight	19 May 1983

The **Atlas-Centaur** was an American expendable launch system designed and built by General Dynamics Convair Division in San Diego, CA. It was derived from the SM-65 Atlas missile. It was a member of the Atlas family of rockets, and was used for 61 orbital launches between 1962 and 1983. It was replaced by the Atlas G, which still contains a Centaur upper stage on top of an Atlas rocket. It was the first rocket to use cryogenic fuel; the Centaur stage featured two Pratt and Whitney RL-10 engines that used cryogenic propellant: liquid hydrogen(LH2)-473 deg. F and liquid oxygen(LO2) -320 deg. F.

The Atlas-Centaur was a three stage launch vehicle system. Atlas providing the first two stages, and the Centaur providing the upper stage. The Atlas first stage burned kerosene and LO2 due to its higher specific energy. Once depleted the first stage (two parallel booster engines on either side of the central sustainer engine) separated and fell to earth. The Atlas second (center JPL-5 engine) continued to propel the Atlas and Centaur upper stage to low earth orbit (LEO). On LEO, a pyrotechnic super-zip system would fire and the Centaur would float away from the second stage. Once away, the Centaur could perform multiple burns as required for the specific satellite mission (e.g., slingshot around the sun, achieve geostationary earth orbit, etc.).

Initially, a modified Atlas D, designated LV-3C, was used as the first stage This was quickly replaced by SLV-3C, and later the SLV-3D, both derived from the standard Atlas SLV-3 rocket. Two spaceflights, with the Pioneer 10 and Pioneer 11 space probes to Jupiter, Saturn, exiting the Solar System, used a three- and-one-half stage configuration, with a "Star-37E" solid-fueled final stage.

Launches were conducted from Launch Complex 36 at the Cape Canaveral Air Force Station. The fifth launch of an Atlas-Centaur exploded on the launch pad, causing significant damage, and persuading NASA and the Air Force to proceed with the completion of a previously abandoned back-up launch pad at Launch Complex-36B.Such launch failures turned out to be very rare during the use of the Atlas-Centaur rocket, and its successors.

A number of later rockets were derived from the Atlas-Centaur; the Atlas G, Atlas I, Atlas II, Atlas III, and the Atlas V, the latter of which is still in service.

Variants

Name	First launch	Last launch	Launches	Successes	Failures	Partial failures	Remarks
Atlas LV-3C Centaur-A	1962-05-09		1	0	1	0	

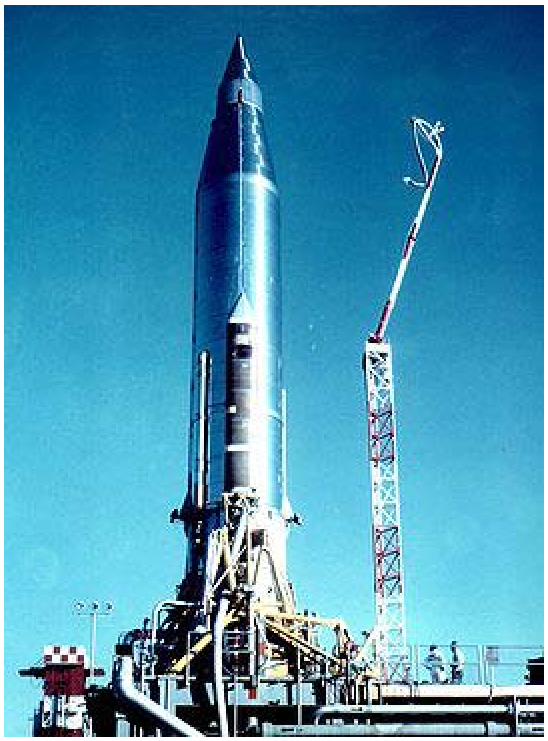
Atlas LV-3C Centaur-B	1963-11-27		1	1	0	0	
Atlas LV-3C Centaur-C	1964-06-30	1965-03-03	3	0	2	1	
Atlas LV-3C Centaur-D	1965-08-11	1967-07-14	7	7	0	0	
Atlas SLV-3C Centaur-D	1967-09-08	1972-08-21	17	14	3	0	One flight with Star-37E upper stage
Atlas SLV-3D Centaur-D1A	1974-03-05	1975-05-22	6	5	1	0	One flight with Star-37E upper stage
Atlas SLV-3D Centaur-D1AR	1975-09-26	1983-05-19	26	24	1	1	
Later rockets derived from the Atlas-Centaur							
Atlas G	1984-06-09	1989-09-25	7	5	2	0	(Atlas G Centaur-D1AR)
Atlas I	1990-07-25	1997-04-25	11	8	3	0	
Atlas II	1991-12-07	2004-08-31	63	63	0	0	
Atlas III	2000-05-24	2005-02-03	6	6	0	0	
Atlas V	2002-08-21	Active	14	13	0	1	

Chapter- 6

Atlas (B-H)

SM-65B Atlas

Atlas B (SM-65B)



Atlas B before the launch of SCORE (USAF)

Function	Prototype ICBM Expendable launch system
Manufacturer	Convair
Country of origin	United States
	Launch history
Status	Retired
Launch sites	LC-11, LC-13 & LC-14, CCAFS

Total launches	10
Successes	6
Failures	4
Maiden flight	19 July 1958
Last flight	4 February 1959

The **SM-65B Atlas**, or **Atlas B**, also designated **X-12** was a prototype of the Atlas missile. First flown on 19 July 1958, the Atlas B was the first version of the Atlas rocket to use the stage and a half design.

Ten flights were made. Nine of these were sub-orbital test flights of the Atlas as an Intercontinental Ballistic Missile, with five successful missions and four failures. The seventh flight, launched on 18 December 1958, was used to place the SCORE satellite into low Earth orbit, the first orbital launch conducted by an Atlas rocket.

All Atlas-B launches were conducted from Cape Canaveral Air Force Station, at Launch Complexes 11, 13 and 14.

Launch history

Date	Time (GMT)	Pad	Serial	Apogee	Outcome	Remarks
1958-07-19	17:36	LC-11	3B	10 kilometres (6.2 mi)	Failure	
1958-08-02	22:16	LC-13	4B	900 kilometres (560 mi)	Success	
1958-08-29	04:30	LC-11	5B	900 kilometres (560 mi)	Success	
1958-09-14	05:24	LC-14	8B	900 kilometres (560 mi)	Success	
1958-09-18	21:27	LC-13	6B	100 kilometres (62 mi)	Failure	
1958-11-18	04:00	LC-11	9B	800 kilometres (500 mi)	Failure	
1958-11-29	02:27	LC-14	12B	900 kilometres (560 mi)	Success	First full-range test flight
1958-12-18	22:02	LC-11	10B	N/A	Success	Placed SCORE satellite into 185km x 1,484km x 32.3° orbit
1959-01-16	04:00	LC-14	13B	100 kilometres (62 mi)	Failure	
1959-02-04	08:01	LC-11	11B	900 kilometres (560 mi)	Success	

SM-65D Atlas

Atlas D (SM-65D)

An Atlas D LV-3B launching Mercury-Atlas 6

Function	ICBM Expendable launch system
Manufacturer	Convair
Country of origin	United States
Launch history	
Status	Retired
Launch sites	LC-11, 12, 13 & 14, CCAFS LC-576, VAFB
Total launches	135
Successes	103
Failures	32
Maiden flight	14 April 1959
Last flight	7 November 1967

The **SM-65D Atlas**, or **Atlas D**, was the first operational version of the U.S. Atlas missile. It first flew on April 14, 1959. Atlas D missiles were also used for orbital launches, both with upper stages and on their own as a stage-and-a-half vehicle.

Atlas D launches were conducted from Cape Canaveral Air Force Station, at Launch Complexes 11, 12, 13 and 14, and Vandenberg Air Force Base at Launch Complex 576.

Most Atlas D launches were sub-orbital missile tests; however several were used for other missions, including orbital launches of manned Mercury, and unmanned OV1 spacecraft. Two were also used as sounding rockets as part of Project FIRE. A number were also used with upper stages, such as the RM-81 Agena, to launch satellites.

For Mercury, the Atlas D was used to launch four manned Mercury spacecraft into low Earth orbit. The modified version of the Atlas D used for Project Mercury was designated **Atlas LV-3B**.

Atlas E/F

Atlas E/F

Launch of an Atlas E/F with a US Navy payload

Function	Expendable launch system Sounding rocket
Manufacturer	Convair General Dynamics Lockheed
Country of origin	United States
Launch history	
Status	Retired
Launch sites	LC-576 & SLC-3, VAFB
Total launches	65
Successes	56
Failures	9
Maiden flight	5 August 1965

Last flight	24 March 1995

The **Atlas E/F**, also designated **SB-1A** was an American expendable launch system and sounding rocket built using parts of decommissioned SM-65 Atlas missiles. It was a member of the Atlas family of rockets.

The first stage was built using parts taken from decommissioned Atlas-E and Atlas-F missiles, with various solid propellant upper stages used, depending on the requirements of the payload. The Atlas E/F was also used without an upper stage for a series of re-entry vehicle tests. On a single launch, an RM-81 Agena liquid-propellent upper stage was used.

Variants

Atlas E/F

Thirty Atlas E/F rockets were launched without upper stages for ABRES and BMRS re-entry vehicle tests between 1965 and 1974. Three of these launches failed. Five ABRES launches were also conducted whilst the missiles were still operational, however these did not use the Atlas E/F configuration.

Atlas E/F-Agena

An RM-81 Agena upper stage was used on a former Atlas-F, to launch the Seasat-1 satellite on 27 June 1978. This was the final flight of the Atlas-Agena. Previous Atlas-Agena launches had used Atlas D or Atlas SLV-3 rockets as first stages.

Atlas E/F-Altair

An Atlas E/F with an Altair-3A upper stage was used to launch three Stacksat spacecraft on 11 April 1990. The rocket was capable of placing 210 kilograms (460 lb) of payload into low Earth orbit.

Atlas E/F-Burner

A Burner-2 upper stage was used on an Atlas E/F to launch the Radsat and Radcat satellites on 2 October 1972. The rocket had a payload capacity of 950 kilograms (2,100 lb) to low Earth orbit.

Atlas E/F-MSD

Atlas E/F rockets with MSD upper stages were used for four launches, with NOSS naval reconnaissance satellites between 1976 and 1980. The fourth of these launches failed when one of the booster unit engines shut down early. This configuration had a maximum payload capacity of 800 kilograms (1,800 lb) to LEO.

Atlas E/F-OIS

The OIS upper stage was used for two Atlas E/F launches in 1979 and 1985, with the Solwind and Geosat spacecraft respectively. The rocket could place 870 kilograms (1,900 lb) into low Earth orbit.

Atlas E/F-OV1

The Atlas E/F was used between 1968 and 1971 to launch four groups of OV1 satellites, using OV1 upper stages. Each payload had its own upper stage. Three of the launches carried two OV1 satellites, and one carried three. Two of the launches also carried secondary payloads. In this configuration, the rocket could place 363 kilograms (800 lb) into LEO.

Atlas E/F-PTS

The PTS was used to launch the NTS-1 satellite on 14 July 1974. The upper stage gave the vehicle a payload capacity of 295 kilograms (650 lb) to a medium Earth transfer orbit.

Atlas E/F-SGS

The SGS upper stage, which consisted of two series-burning solid rocket motors, was used on twelve Atlas E/F launches, with early GPS satellites. The first eight used the SGS-1, which could place 455 kilograms (1,000 lb) of payload into a medium Earth transfer orbit, whereas the last four used the more powerful SGS-2. The eighth launch failed.

Atlas E/F-Star

The Star was used to propel most of the other upper stages used on the Atlas E/F, however it was also used in its own right on several launches. A Star-17A was used in the launch of the RM-20 spacecraft on 12 April 1975, giving the rocket a LEO payload of 725 kilograms (1,600 lb), while the Star-37S-ISS was used to launch nineteen DMSP, NOAA and Tiros weather satellites between 1978 and 1995. With the Star-37 upper stage, the rocket could place 1,100 kilograms (2,400 lb) into a Sun-synchronous orbit. The RM-20 launch failed due to damage to the first stage, caused by the explosion of residual fuel in the flame trench during launch. Another launch failed due to stage separation occurring at the correct time despite the first stage burn being extended by fifty seconds to resolve an underperformance issue, the end result of which was the upper stage separating and igniting whilst the first stage was still firing.

Atlas E/F-Trident

The Atlas E/F was used with a Trident upper stage, between 1967 and 1971, for suborbital tests of re-entry vehicles. Nineteen were launched, of which two failed.

Atlas G

Atlas G

Launch of FLTSATCOM-7 on an Atlas G.

Function	Expendable launch system
Manufacturer	Convair General Dynamics
Country of origin	United States
Launch history	
Status	Retired
Launch sites	LC-36B, Cape Canaveral
Total launches	7
Successes	5
Failures	2
Maiden flight	9 June 1984
Last flight	25 September 1989

The **Atlas G**, also known as **Atlas G Centaur-D1AR** was an American expendable launch system derived from the Atlas-Centaur. It was a member of the Atlas family of rockets, and was used to launch seven communication satellites during the mid to late 1980s. It was replaced by the Atlas I, which had an improved guidance system.

The first stage was derived from the SM-65 Atlas missile, and a Centaur was used as the second stage. The first stage was also flown without the Centaur, as the Atlas H.

Atlas H

Atlas H	
	
Launch of the last Atlas H with NOSS-9.	
Function	Expendable launch system
Manufacturer	Convair General Dynamics
Country of origin	United States
Launch history	
Status	Retired
Launch sites	SLC-3E, Vandenberg
Total launches	5
Successes	5
Maiden flight	9 February 1983
Last flight	15 May 1987

The **Atlas H** was an American expendable launch system derived from the SM-65 Atlas missile. It was a member of the Atlas family of rockets, and was used to launch five clusters of NOSS satellites for the US National Reconnaissance Office. Two flights also carried LIPS satellites, as secondary payloads for the United States Naval Research Laboratory.

The Atlas H was a stage and a half rocket, using the enhanced Atlas rocket designed for use as the first stage of the Atlas G rocket, which differed from the Atlas H in having a Centaur upper stage. This stage was later reused as the first stage of the Atlas I. In practice, an MSD upper stage was flown on all five launches.

Chapter- 7

Black Arrow

Black Arrow

A mockup of the Black Arrow in the rocket park at Woomera.

Function	Carrier rocket
Manufacturer	Royal Aircraft Establishment Westland Aircraft
Country of origin	United Kingdom
	Size
Height	13 metres (43 ft)
Diameter	2 metres (6 ft 7 in)
Mass	18,130 kilograms (40,000 lb)

Stages	Three
Capacity	
Payload to 220 km LEO	135 kilograms (300 lb)
Payload to 500 km LEO	102 kilograms (220 lb)
Launch history	
Status	Retired
Launch sites	Woomera LA-5B
Total launches	4
Successes	2
Failures	2
Maiden flight	27 June 1969
Last flight	28 October 1971
First Stage	
Engines	Gamma 8
Thrust	256.4 kilonewtons (57,600 lb_f)
Specific impulse	265 sec
Burn time	131 seconds
Fuel	RP-1/HTP
Second Stage	
Engines	Gamma 2
Thrust	68.2 kilonewtons (15,300 lb_f)
Specific impulse	265 sec
Burn time	116 seconds
Fuel	RP-1/HTP
Third Stage - Waxwing	
Engines	1 Solid
Thrust	27.3 kilonewtons (6,100 lb_f)
Specific impulse	278 sec
Burn time	55 seconds
Fuel	Solid

Black Arrow, officially capitalised **BLACK ARROW**, was a British satellite carrier rocket. Developed during the 1960s, it was used for four launches between 1969 and 1971. Its final flight was the first successful orbital launch to be conducted by the United Kingdom, and placed the Prospero satellite into low Earth orbit.

Black Arrow originated from studies by the Royal Aircraft Establishment for carrier rockets based on the Black Knight rocket, with the project being authorised in 1964. It was initially developed by Saunders-Roe, and later Westland Aircraft as the result of a merger.

Black Arrow was a three-stage rocket, fuelled by RP-1 paraffin and high test peroxide, a concentrated form of hydrogen peroxide. It was retired after only four launches in favour of using American Scout rockets, which the Ministry of Defence calculated to be cheaper than maintaining the Black Arrow programme.

Development

Black Arrow originated from a Royal Aircraft Establishment proposal for a rocket capable of placing a 144-kilogram (320 lb) payload into low Earth orbit, in order to test systems designed for larger spacecraft. In the autumn of 1964, the programme was authorised by Conservative Aviation Minister Julian Amery, however following a general election in October, the incoming Labour government put the project on hold to reduce expenditure.

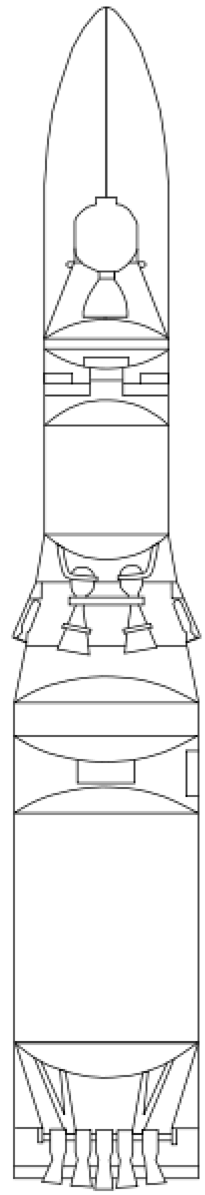
Following another election, the government approved the continuation of the programme with several modifications, including the reduction of the test programme from five to three launches. The first launch was set for 1968.

Most of the technology and systems used on Black Arrow had already been developed or flight-proven on the Black Knight rocket, or the Blue Steel missile. Black Arrow was designed to reuse as much technology from the earlier programmes as possible in order to reduce costs, and simplify the development process. Many senior staff of the Black Knight programme transferred directly to Black Arrow, including the Chief Missile Scientist, Roy Dommett, the Chief Design Engineer, Ray Wheeler and the Deputy Chief Engineer, John Underwood.

Initial development was conducted by Saunders-Roe, which merged into Westland Aircraft in 1964. Westland was subsequently the prime contractor for the Black Arrow, and assembled the first and second stages at East Cowes on the Isle of Wight. Bristol Siddeley produced the first and second stage engines at a factory in Ansty, Warwickshire. The engines were test fired at the factory before being shipped to the Isle of Wight, where they were integrated into the rocket and the first stage engines were fired again at High Down. Bristol Aerojet produced the third stage in Somerset, while the Explosives Research and Development Establishment produced its solid propellent in Waltham Abbey, Essex. The Rocket Propulsion Establishment, based in Westcott, Buckinghamshire, was responsible for the design and integration of the stage.

The name *Black Arrow* came from the Ministry of Supply policy of assigning designations consisting of a colour and a noun, unofficially known as Rainbow Codes, to research programmes conducted by the Armed Forces.

Vehicle



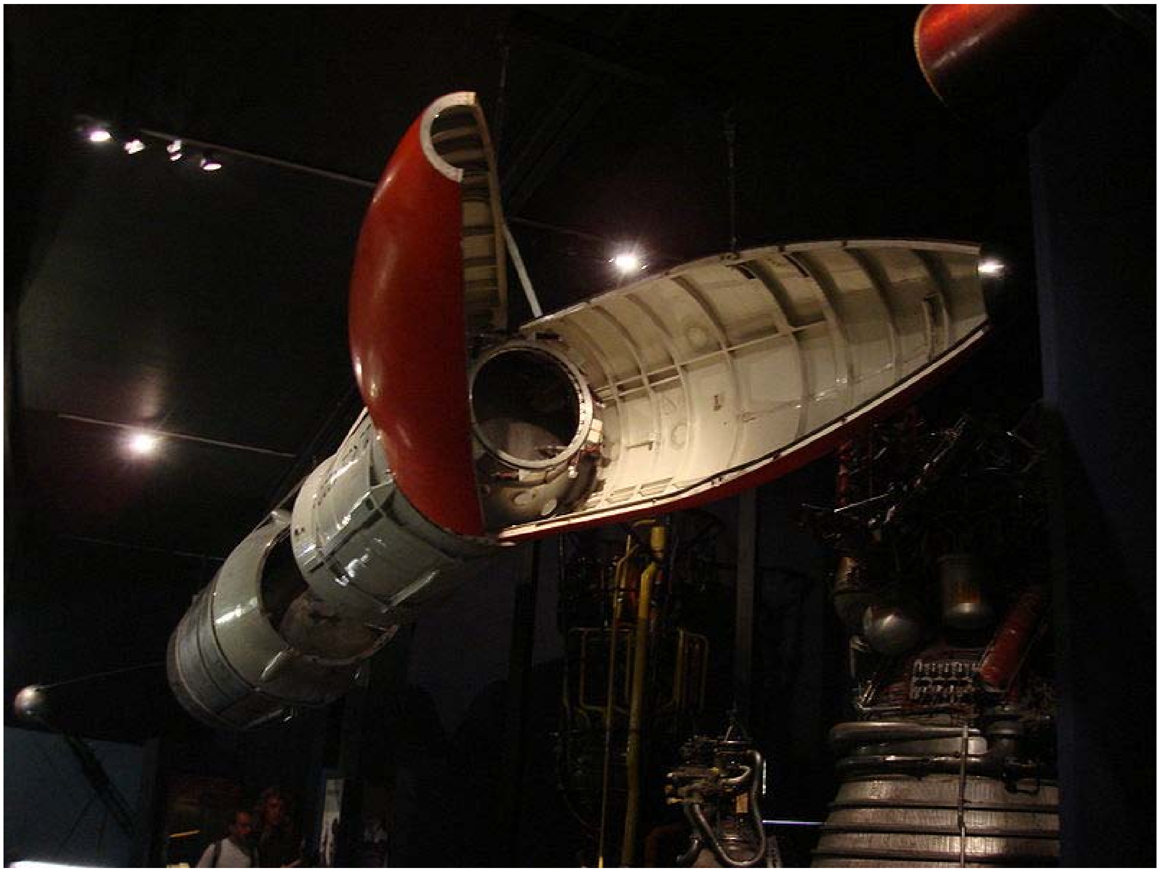
Cutaway diagram, showing the positions of fuel and oxidiser tanks, engines, and the third stage inside the fairing.

The first and second stages of the Black Arrow were fuelled by RP-1 paraffin, burnt using high test peroxide as an oxidiser. Due to the optimum mixture ratio being about 7 a larger oxidiser tank was required compared to many contemporary launch systems. The oxidiser tanks were located below the fuel tanks, following the practice of putting the more dense propellent at bottom in order to lower the centre of gravity and make the rocket easier to control. This arrangement had been pioneered by Germany and the United States, whereas the Soviet Union had placed oxidiser tanks above fuel tanks, making it easier for the lower tank to be filled first.

Thrust vectoring was used to provide attitude control on the first two stages. The eight first stage combustion chambers were arranged in pairs which could gimbal either way along one axis. Two of the pairs were arranged perpendicular to the other two, and when all four pairs were used together, they provided roll, pitch and yaw control. The second stage had two combustion chambers, which could gimbal along two axes, providing the same level of control. During a coast phase after second stage cut-off, the rocket was controlled by a reaction control system. The third stage did not have an attitude control system, and was instead spin-stabilised.

The first stage was powered by a single Gamma 8 engine, which burned for 127 seconds. The Gamma 8 was an eight-chamber engine, derived from the Gamma 301 engine used on the Black Knight. It was 6.9 metres (23 ft) long, and had a diameter of 2 metres (6 ft 7 in), the same diameter as the French Coralie. Coralie was used as the second stage of the Europa rocket, and the decision to give Black Arrow the same diameter as Coralie was taken in order to make it compatible with Blue Streak, which was used as the first stage of Europa. This would have allowed Black Arrow's payload capacity to have been increased, and would also have allowed Britain to use the first stage of Black Arrow as a backup to the Coralie. For this reason, all dimensions in the original specification were given in imperial units except the first stage diameter, which was given in metres.

The first and second stages were connected by an interstage structure containing four Siskin IB separation and ullage motors, which separated and ignited seven seconds after the first stage had cut off. The interstage separated from the second stage six seconds later. The second stage, which was 2.9 metres (9 ft 6 in) long and measured 1.37 metres (4 ft 6 in) in diameter, was powered by a two-chamber Gamma 2 engine which ignited shortly after the separation motors, and continued to burn for 123 seconds. Three minutes after launch, during the second stage burn, the payload fairing separated.


The first two stages and open payload fairing of R4 on display at the Science Museum in London

About 257 seconds into the flight, the second stage cut off, and the rocket entered a coast phase to apogee. Immediately after cut-off, the second stage attitude control system was pressurised. During the coast the correct orientation for third stage separation was maintained by means of the attitude control system. Towards the end of the coast period, the third stage was be spun up to a rate of 3 hertz (180 rpm) by means of six Imp rockets. Five seconds later, the third stage separated, and following ten more seconds of coasting, it ignited. The third stage was a Waxwing solid rocket motor, which burned for 55 seconds.

Just over a minute after the third stage had burned out, the payload was released, and gas generators were used to push the spacecraft and spent upper stage apart. The delay between burnout and separation was intended to reduce the risk of recontact between the upper stage and payload due to residual thrust. Despite this, following spacecraft separation on the R3 launch, the upper stage collided with the Prospero satellite, damaging one of the spacecraft's communications antennae; however the spacecraft was still able to successfully complete its mission. On the R3 launch, the ascent took 710 seconds (11.8 min) from liftoff to spacecraft separation.

Although none was ever built, several derivatives of Black Arrow were also proposed, as ways of increasing its payload capacity. One proposal added eight Raven solid rocket motors from the Skylark programme to the first stage as booster rockets. Another suggestion was to mount the entire rocket atop a Blue Streak missile, while a third proposal involved replacing the Gamma engines with the more powerful Larch.

Launches

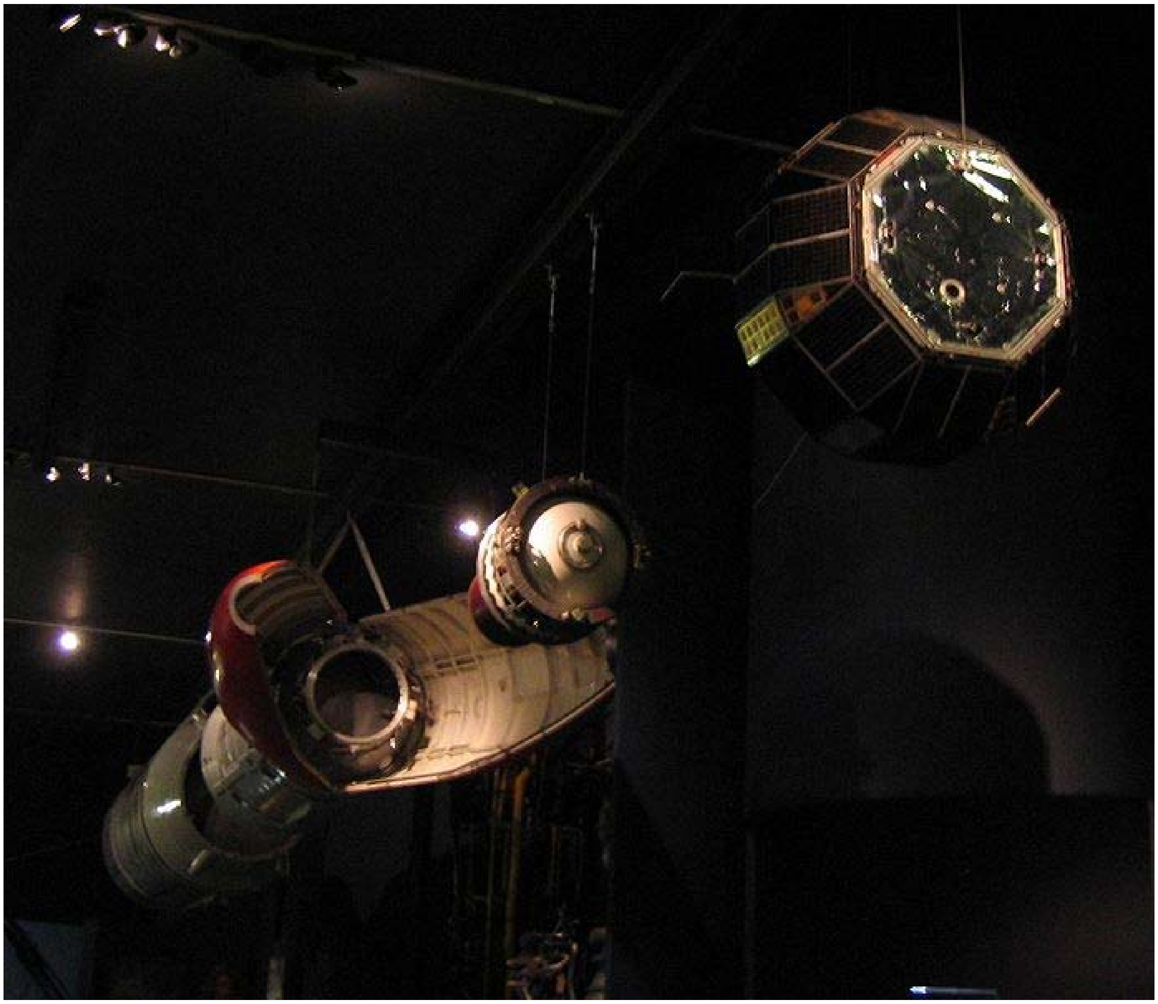
The colour scheme used on all flights except R0, with stripes on the first stage for identification, and a coloured fairing to increase visibility.

Four Black Arrows were launched between 1969 and 1971. The first two launches were demonstration flights, with battleship third stages and a boilerplate payload. On the first flight an electrical fault caused a pair of first stage combustion chambers to pivot back and forth. Before it cleared the launch pad, the rocket was rolling erratically, and about a minute later it began to disintegrate. After the first stage engine failed, and the rocket began to fall back to earth, it was destroyed by range safety. The second launch was successful. The first all-up launch on 2 September 1970 was the third launch of the Black Arrow, and Britain's first attempt to launch a satellite. The launch failed due to a leak in the second stage oxidiser pressurisation system, which caused it to cut out early. The third stage fired, but the rocket did not reach orbit, and re-entered over the Gulf of Carpentaria. The fourth launch successfully orbited the Prospero satellite, making the United Kingdom the sixth nation to place a satellite into orbit by means of an indigenously developed carrier rocket. The satellite, also known as X-3, was named Prospero after the character Prospero in Shakespeare's *The Tempest*. The name was chosen as a reference to events in the play, in which Prospero, a sorcerer, gives up his powers. Prior to the cancellation of the Black Arrow programme, the satellite was to be named after Puck from *A Midsummer Night's Dream*.

All four launches were conducted from Launch Area 5B at the Woomera Prohibited Area in Australia, which had previously been used as a test site for the Black Knight rocket. During the development programme, launch sites in Barbados, Uist and Norfolk were also considered. The launch sites at Uist and Norfolk were rejected because the former was too remote, while there was a risk that a rocket launched from the latter might drop spent stages on an oil rig in the North Sea.

Serial number	Launch date/time (GMT)	Payload	Outcome	Remarks
R0	28 June 1969, 22:58	None	Failure	Suborbital test of first and second stages, thrust vectoring failed
R1	4 March 1970, 21:15	None	Successful	Suborbital test of first and second stages
R2	2 September 1970, 00:34	Orba	Failure	Second stage failed to pressurise
R3	28 October 1971, 04:09	Prospero	Successful	Successfully reached Earth orbit
R4	Not launched			Preserved at the Science Museum in London

Cancellation



Black Arrow R4 on display in the Science Museum, with the stages and fairing separated, and a mockup of the Prospero satellite

The Minister of State for Trade and Industry, Frederick Corfield, announced the cancellation of the Black Arrow project in the House of Commons on 29 July 1971. As the R3 rocket had already been shipped to the launch site, the second stage having arrived three days earlier, permission was given for it to be launched.

The programme was cancelled on economic grounds, as the Ministry of Defence decided that it would be cheaper to use the American Scout rocket, which had a similar payload capacity, for future launches. Prior to the cancellation of Black Arrow, NASA had offered to launch British payloads for free; however this offer was withdrawn following the decision to cancel Black Arrow.

The final Black Arrow to be completed was R4, which did not fly, and is preserved in the Science Museum, London, along with the flight spare for the *Prospero* satellite. A replica of the Black Arrow rocket stands in the Rocket Park at Woomera. In addition, the remains of the first stage of Black Arrow R3 were recovered from the Anna Creek cattle station and are displayed in the William Creek Memorial Park.

The first stage of Black Arrow R3, on display at William Creek following its return to Earth

The launch facilities at Woomera were demolished within a year of the final flight, and half of the engineers who had worked on the programme were laid off. The X-4 satellite, which had been manifested for launch by Black Arrow R4, was eventually launched on 9 March 1974, by an American Scout D-1 rocket flying from Space Launch Complex 5 at the Vandenberg Air Force Base in California.

As of 2010, the United Kingdom is the only country to have successfully developed and then abandoned a satellite launch capability. All other countries to have developed such capability have retained it either through their own space programme, or in the case of France through its involvement in the Ariane programme.

Chapter- 8

NOTS-EV-2 Caleb

NOTS-EV-2 Caleb

Caleb launch vehicle on loading trolley

Function	Expendable launch system Sounding rocket Anti-satellite weapon
Manufacturer	US Navy
Country of origin	United States
Size	
Height	4.9 metres (16 ft)
Diameter	0.6 metres (2 ft 0 in)
Mass	1,350 kilograms (3,000 lb)
Stages	One (test) Two (test) Four (unflown)
Capacity	
Payload to LEO	7 kilograms (15 lb)
Launch history	
Status	Retired
Launch sites	Point Arguello San Nicolas
Total launches	2 Caleb

	2 SIP 3 Hi-Hoe
Successes	1 Caleb (1 stage) 2 SIP 1 Hi-Hoe
Failures	1 Caleb 2 Hi-Hoe
Maiden flight	Caleb: 1960-07-28 SIP: 1961-10-01 Hi-Hoe: 1961-10-05
Last flight	Caleb: 1960-10-24 SIP: 1962-05-05 Hi-Hoe: 1962-07-25

The **NOTS-EV-2 Caleb**, also known as **NOTS-500**, **Hi-Hoe** and **SIP** was an expendable launch system, which was later used as a sounding rocket and prototype anti-satellite weapon. It was developed by the United States Navy Naval Ordinance Test Station (NOTS) as a follow-up to the NOTS-EV-1 Pilot, which had been abandoned following ten consecutive launch failures. Two were launched in July and October 1960, before the cancellation of the project. Following cancellation, two leftover Calebs were used in the Satellite Interceptor Program, or SIP, whilst three more were used as sounding rocktets, under the designation Hi-Hoe. These derivatives flew until July 1962, when the Hi-Hoe made its final flight.

Development

The Caleb was originally designed as a fast-response orbital launch system, to place small reconnaissance satellites, and other military payloads, into orbit at short notice. The orbital configurations were four-stage vehicles, whilst test launches used one and two stage configurations. The project was cancelled due to pressure from the United States Air Force, who were responsible for all other orbital launches conducted by the US military, and no attempts to launch the vehicle into orbit were made.

Caleb was an air-launched rocket, with its two launches being conducted from F4D Skyray #747, the same aircraft used in the Pilot trials. Hi-Hoe was also air-launched, however it was released from an F4H Phantom II, which provided greater performance. SIP launches were conducted from a ground launch pad on San Nicolas Island. The aircraft used for the airborne launches took off from Point Arguello, which later became part of Vandenberg Air Force Base.

Operational history

Hi-Hoe rocket mounted on F4H Phantom II

The Caleb made its maiden flight, in a single-stage test configuration, on 28 July 1960. Its second flight was made on 24 October of the same year, and used a two-stage configuration. It was unsuccessful, due to the second stage's failure to ignite. Both test launches were suborbital.

Both SIP launches used the two stage configuration. The first was conducted on 1 October 1961. It was successful and reached an apogee of 20 kilometres (12 mi). The second test, launched on 5 May 1962 was also successful, and reached the same apogee. The three Hi-Hoe launches were conducted on 5 October 1961, and 26 March and 25 July 1962. On the first two launches the second stage failed to ignite, however the third was successful, and reached an apogee of 1,166 kilometres (725 mi).

Despite the program's turn torwards success, the project was cancelled soon after the final Hi-Hoe test, the Department of Defense choosing to concentrate on the U.S. Air Force's Blue Scout sounding rocket program.

Launch history

Caleb rocket mounted on F4D Skyray

Date/Time (GMT)	Rocket	S/N	Outcome	Remarks
1960-07-28	Caleb	TV-1	Success	Single stage
1960-10-24	Caleb	TV-2	Failure	Second stage failed to ignite
1961-10-01	SIP	SIP-1	Success	Ground launch
1961-10-05, 19:10	Hi-Hoe	NC17.116	Failure	Second stage failed to ignite
1962-03-26, 19:03	Hi-Hoe	NC17.121	Failure	Second stage failed to ignite
1962-05-05	SIP	SIP-2	Success	Ground launch
1962-07-25, 15:41	Hi-Hoe	NC17.117	Success	

Chapter- 9

Diamant

Diamant

Function	Small launch vehicle
Manufacturer	SEREB
Country of origin	France
Size	
Height	A: 18.95 m B: 23.5 m BP4: 21.6 m (A: 62.17 ft B: 77 ft BP4: 70.7 ft)
Diameter	1.34 m (4.39 ft)
Mass	18,400 kg (40,500 lb)
Stages	3
Capacity	
Payload to LEO	160 kg (350 lb)
Launch history	
Status	Retired
Launch sites	A: Hammaguir B/BP4: Kourou
Total launches	12 (A :4, B: 5, BP4: 3)
Successes	9 (A: 3, B: 3, BP4: 3)
Failures	3 (A: 1, B: 2)
Maiden flight	A: 26 November 1965

	B:10 March 1970 BP4:6 February 1975
Last flight	A: 15 February 1967 B:21 May 1973 BP4: 27 September 1975
First stage (Diamant A) - Emeraude	
Engines	4 Vexin B
Thrust	301.55 kN (67,791 lb_f)
Specific impulse	221 sec
Burn time	93 seconds
Fuel	N2O4/UDMH
First stage (Diamant B/BP4) - L-17	
Engines	4 Vexin C
Thrust	396.52 kN (89,142 lb_f)
Specific impulse	221 sec
Burn time	110 seconds
Fuel	N2O4/UDMH
Second stage (Diamant A/B) - Topaze	
Engines	1 Solid
Thrust	120.082 kN (26,996 lb_f)
Specific impulse	255 sec
Burn time	39 seconds
Fuel	Solid
Second stage (Diamant BP4) - P-4	
Engines	1 Solid
Thrust	176 kN (39,566 lb_f)
Specific impulse	273 sec
Burn time	55 seconds
Fuel	Solid
Third stage (Diamant A) - P-6	
Engines	1 Solid
Thrust	29.4 kN (6,609 lb_f)
Specific impulse	211 sec
Burn time	39 seconds
Fuel	Solid
Third stage (Diamant B/BP4) - P-6	
Engines	1 Solid
Thrust	50 kN (11,240 lb_f)
Specific impulse	211 sec
Burn time	46 seconds
Fuel	Solid

The **Diamant** rocket (*diamant* is French for "diamond") was the first exclusively French expendable launch system and at the same time the first satellite launcher not built by either the USA or USSR. As such it is the main predecessor of all subsequent European launcher projects. It was derived from the military program *Pierres précieuses* (fr.: gemstones) that included the five prototypes Agathe, Topaze, Emeraude, Rubis and Saphir (Agate, Topaz, Emerald, Ruby and Sapphire). Design of the Diamant began in 1962, as the inaugural spacecraft project of France's space agency, the CNES. Out of 12 launch attempts between 1965 and 1975, 9 were successful. Most notably, the Diamant was used to put the first French satellite, Astérix, into orbit on November 26, 1965. Despite the success, France abandoned its national launcher program in favor of the European Ariane launcher in 1975.
Three successive versions of the Diamant rocket were developed, designated A, B and BP4. All versions had three stages and a payload of approximately 150 kg for a 200 km orbit.

Diamant A

This was the first version of the Diamant rocket. It was used to launch the Astérix and subsequently three other small satellites during 1965-67 from the base at Hammaguir in Algeria. Remarkably for a newly developed system, all four attempted launched were partly successful, the only failure occurring on the second launch when the payload was inserted into a lower orbit than planned. It possessed a first stage of 10 m, 1.4 meters in diameter, and a weight of 14.7 metric tons. Their engines of the type LRBA Vexin supplied a thrust of 269 kN for 93 seconds. The second stage was 4.7 meters long and had a diameter of 80 centimeters. It weighed 2.9 metric tons and developed a thrust of 165 kN for a duration of 44 seconds. The third stage of 2.65 m in diameter. Its weight amounted to 709 kilograms. It burned for 45 seconds and developed a thrust of 27 kN to 53 kN. Completely installed, a Diamond A was 18.95 meters high and weighed 18.4 metric tons.

Diamant B

An improved version of the Diamant A with a more powerful first stage. Five satellite launches were attempted between 1970 and 1973, of which the last two failed. All launches took place from Kourou in French Guyana, which thus became established as the sole French and European spaceport, a status that it still holds today (2008).

Its first stage was 14.2 meters long, had a diameter of 1.4 meters and weighed 20.1 metric tons. Its engine developed a thrust of 316 kN to 400 kN (as a function of the flight altitude) for 116 seconds. The second stage the Diamond B corresponded to that the Diamond A. The third stage was 1.67 meters long and had a diameter of 80 centimeters. It developed a thrust of 24 kN for 46 seconds. Completely assembled a Diamond B was 23.5 meters high and weighed 24.6 metric tons.

Diamant BP4

This version incorporated a new second stage, while carrying the first and third stages over from its predecessor. It performed three successful launches in 1975, putting a total of four satellites into orbit. Its second stage, which was derived from the MSBS rocket, was 2.28 meters long and 1.5 meters in diameter and developed a thrust of 180 kN for 55 seconds.

Launch list

Date	Type	Launch Site	Payload	Remarks
November 26, 1965	Diamant A	Hammaguir	Asterix	
February 17, 1966	Diamant A	Hammaguir	Diapason	
February 8, 1967	Diamant A	Hammaguir	Diadème 1	partial failure, orbit too low
February 15, 1967	Diamant A	Hammaguir	Diadème 2	
March 10, 1970	Diamant B	Kourou	Mika/Wika	
December 12, 1970	Diamant B	Kourou	Péole	
April 15, 1971	Diamant B	Kourou	Tournesol	
December 6, 1971	Diamant B	Kourou	Polaire	second stage failed
May 21, 1972	Diamant B	Kourou	Castor/Pollux	fairing not separated
February 6, 1975	Diamant BP4	Kourou	Starlette	

May 17, 1975	Diamant BP4	Kourou	Castor/Pollux	
September 27, 1975	Diamant BP4	Kourou	Aura	

Chapter- 10

Energia

Energia (Энергия)

Energia mated with Buran shuttle (model).

Function	Manned heavy-lift multi-purpose carrier rocket

Manufacturer	NPO "Energia"
Country of origin	Soviet Union
Size	
Mass	2,400,000 kg (5,291,408 lb)
Stages	1
Capacity	
Payload to LEO	100,000 kg (220,462 lb) (200,000 kg (Vulkan))
Payload to GSO	20,000 kg (44,093 lb)
Launch history	
Status	Retired
Launch sites	Baikonur
Total launches	2
Successes	1
Partial failures	1
Maiden flight	15 May 1987
Last flight	15 November 1988
Boosters (Stage 0) - Zenit	
N^{o} boosters	4
Engines	1 RD-171
Thrust	29,000-32,000 kN
Specific impulse	309-338 sec
Fuel	RP-1/LOX
Core Stage	
Engines	4 RD-0120
Thrust	5,800-7,500 kN
Specific impulse	359-454 sec
Burn time	480-500 sec
Fuel	LH2/LOX

Energia (Russian: **Энергия**, *Energiya*, "Energy") was a Soviet rocket that was designed by NPO Energia to serve as a heavy-lift expendable launch system as well as a booster for the Buran spacecraft. Control system main developer enterprise was the NPO "Electropribor". The Energia used four strap-on boosters powered by a four-chamber RD-170 engine burning with kerosene/LOX, and a central core stage with 4 one-chamber RD-0120 (11D122) engines fueled with liquid hydrogen/LOX.

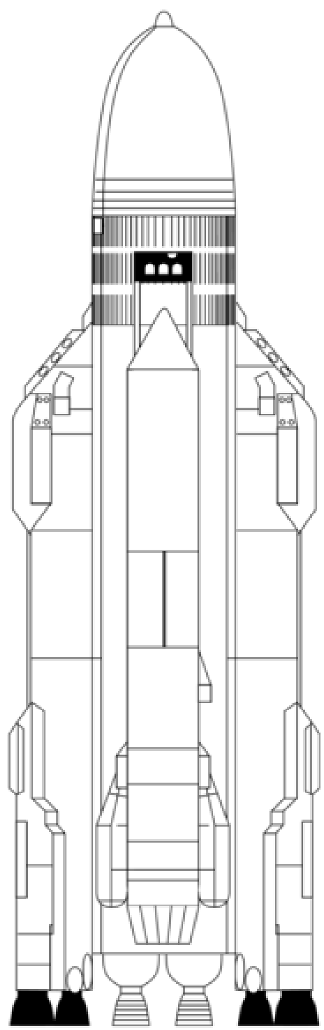
The launch system had two functionally different operational variants: *Energia-Polyus*, the initial test configuration, in which the Polyus system was used as a final stage to put the payload into orbit, and *Energia-Buran*, in which the Buran spacecraft was the payload.

The rocket had the capacity to place about 100 metric tons in Low Earth orbit, up to 20 t to the geostationary orbit and up to 32 t to the lunar mission trajectory.

History

Development

Work on the Energia/Buran system began in 1976 after the decision was made to cancel the unsuccessful N1 rocket. The cancelled N1 rocket-based Manned Lunar Launch Facilities and Infrastructure were used for Energia (notably the huge horizontal assembly building), just as NASA reused infrastructure designed for the Saturn V in the Space Shuttle program. Energia also replaced the "Vulkan" concept, which was a design based on the Proton rocket and using the same hypergolic fuels, but much larger and more powerful. The "Vulkan" designation was later given to a variation of the Energia which has eight boosters and multiple stages.



Polyus satellite on Energia launch vehicle

The Energia was designed to launch the Russian "Buran" reusable shuttle, and for that reason was designed to carry its payload mounted on the side of the stack, rather than on the top, as is done with other launch vehicles. After design of the Energia-Buran system, it was also proposed that the booster could be used without the Buran as a heavy-lift cargo launch vehicle; this configuration was originally given the name "Buran-T". This configuration required the addition of an upper stage to reach orbit. In fact, the first launch of the Energia was in the configuration of a heavy launch vehicles, with a large military satellite as a payload.

Due to the termination of the Buran program the Energia program was concluded after only two launches, and further the payload on the first launch didn't perform the final boost properly. The legacy of Energia/Buran project manifests itself most visibly in form of the RD-170 family of rocket engines, and the Zenit launcher, with the first stage roughly the same as one of the Energia first stage boosters.

First launch (Energia-Polyus)

The Energia was first test-launched on 15 May 1987, with the Polyus spacecraft serving both as the payload. A FGB ("Functional Cargo Block") engine section originally built as a cancelled Mir module was incorporated into the upper stage used to inject the payload into orbit, since the planned "Buran-T" upper stage had not yet progressed beyond the planning stage. The intended orbit was altitude 280 km (170 mi), inclination 64.6º.

The Russians had originally announced that the launch as a successful sub-orbital test of the new Energia booster with a dummy payload, but some time later it was revealed that the flight had, in fact, been intended to orbit the Polyus, a UKSS military payload. The two stages of the Energia functioned as designed, but the third stage, the Polyus payload, failed to make the orbital insertion to reach orbit. Due to a software error in its attitude control system, the burn of the orbital insertion motor failed to insert the payload into orbit. Instead, the payload reentered the atmosphere over the Pacific ocean.

Second launch (Energia-Buran)

The second flight, and the first one to successfully reach orbit, was launched on 15 November 1988. This mission launched the unmanned Soviet Shuttle vehicle, Buran. At apogee, the Buran spacecraft made a 66.7 m/s burn to reach a final orbit of 251 km x 263 km. Both the Energia and Buran programs were designed to maintain strategic parity with the United States.

Discontinuation

Production of Energia rockets ended with the fall of the Soviet Union and the end of the Buran shuttle project. Ever since, there have been persistent rumors of the renewal of production, but given the current political realities, that is highly unlikely. While the Energia is no longer in production, the Zenit boosters are still in production and in use. The four strap-on liquid-fuel boosters, which burned kerosene and liquid oxygen, were the basis of the Zenit rocket which used the same engines. The engine is the RD-170, a powerful, modern, and efficient design. Its derivative, the RD-171, is still used on the Zenit rocket. A half-sized derivative of the engine, the RD-180, powers Lockheed Martin's Atlas V rocket. The quarter size derivative of the engine, the RD-191, has been used to launch Korean Naro-1 rocket and is to be used in the Russian Angara rocket.

Variants

Energia II ("Uragan") rocket was planned to be completely reusable and would be able to land on a conventional airfield.

Three major variants were planned after the original configuration, each with vastly different payloads.

Energia M

The Energia M was the smallest design configuration. The number of Zenit boosters was reduced from four to two, and instead of four RD-0120 engines in the core, it had only one. It was designed to replace the Proton rocket, but lost the 1993 competition to the Angara rocket.

Energia II (*Uragan*)

Energia II, named **Uragan** (Russian: **Ураган**, *Hurricane*), was a rocket planned to be fully reusable and would have been be able to land on a conventional airfield. Unlike the Energia, which was planned to be semi-reusable (like that of the U.S. Space Shuttle), the Uragan design would have allowed the complete recovery of all Buran/Energia elements, like that of the original totally reusable Orbiter/Booster concept of the U.S. Shuttle. The Energia II core as proposed would be capable of re-entering and gliding to a landing, presumably using technology developed for the Buran.

Vulkan-Hercules

The final unflown configuration was also the largest. With eight Zenit booster rockets and an Energia-M core as the upper stage, the "Vulkan" (which was interestingly the same name of another Soviet heavy lift rocket that was cancelled years earlier) or "Hercules" (which is the same name designated to the N-1 rockets) configuration could have launched up to 175 tonnes into orbit.

Chapter- 11

Falcon 1

Falcon 1	
	
Falcon 1 rocket.	
Function	Orbital launch vehicle
Manufacturer	SpaceX
Country of origin	United States
Size	
Height	21.3 m (70 ft)
Diameter	1.7 m (5.5 ft)
Mass	38,555 kg (85,000 lb)
Stages	2
Capacity	
Payload to LEO	670 kg (1480 lb)
Payload to SSO	430 kg (990 lb)
Launch history	
Status	Retired
Launch sites	Omelek Island Vandenberg AFB
Total launches	5

Successes	2
Failures	3
Partial failures	0
Maiden flight	March 24, 2006 22:30 GMT
First stage	
Engines	1 Merlin 1C
Thrust	454 kN (102,000 lb_f)
Specific impulse	255 s (sea level) (2.6 kN·s/kg)
Burn time	169 seconds
Fuel	RP-1/LOX
Second stage	
Engines	1 Kestrel
Thrust	31 kN (7,000 lb_f)
Specific impulse	327 s (vacuum) (3.2 kN·s/kg))
Burn time	378 seconds
Fuel	RP-1/LOX

The **Falcon 1** is a partially reusable launch system designed and manufactured by SpaceX, a space transportation company in Hawthorne, California. The two-stage-to-orbit rocket uses LOX/RP-1 for both stages, the first powered by a single Merlin engine and the second powered by a single Kestrel engine. It was designed by SpaceX from the ground up and is the first successful fully liquid-propelled orbital launch vehicle developed with private funding.

The Falcon 1 achieved orbit on its fourth attempt, on 28 September 2008, with a mass simulator as a payload. On 14 July 2009, Falcon 1 successfully delivered the Malaysian RazakSAT satellite to orbit on SpaceX's first commercial launch (fifth launch overall). Following its fifth launch, the Falcon 1 was retired in favour of an enhanced variant, the Falcon 1e.

Design

According to SpaceX, the Falcon 1 is designed to minimize price per launch for low-Earth-orbit satellites, increase reliability, and optimize flight environment and time to launch. It is also intended to verify components and structural design concepts that will be reused in the Falcon 9.

First stage

First-stage view of the Merlin engine.

The first stage is made from friction-stir-welded aluminum alloy. It employs a common bulkhead between the LOX and RP-1 tanks, as well as flight pressure stabilization. It can be transported safely without pressurization (like the heavier Delta II isogrid design) but gains additional strength when pressurized for flight (like the Atlas II, which could not be transported unpressurized). The resulting design has the highest propellant mass fraction of any current first stage. The parachute system, built by Irvin Parachute Corporation, uses a high-speed drogue chute and a main chute.

Second stage

The second stage tanks are built with a cryogenic-compatible aluminum–lithium alloy. The helium pressurization system pumps propellant to the engine, supplies pressurized gas for the attitude control thrusters, and is used for zero-*g* propellant accumulation prior to engine restart. The Kestrel engine includes a titanium heat exchanger to pass waste heat to the helium, thereby greatly extending its work capacity. The pressure tanks are made by Arde corporation and are the same as those used in the Delta IV. They consist of an inconel shell wrapped by a composite.

Reusability

It is planned that the first stage will return by parachute to a water landing and be recovered for reuse but this has not yet been demonstrated. The second stage is not designed to be reusable.

Operation

At launch, the first stage engine (Merlin) is ignited and throttled to full power while the launcher is restrained and all systems are verified by the flight computer. If the systems are operating correctly, the rocket is released and clears the tower in about seven seconds. The first-stage burn lasts about 2:49 minutes. Stage separation is accomplished with explosive bolts and a pneumatically actuated pusher system.

The second stage Kestrel engine burns for about six minutes, inserting the payload into a low Earth orbit. It is capable of multiple restarts.

Private funding

The Falcon 1 rocket was developed with private funding. The only other orbital launch vehicle to be privately funded and developed is the Pegasus, first launched in 1990; however, it requires a large aircraft as its first stage. If recovery and reuse of the first stage is accomplished, Falcon 1 will become the second partially-reusable orbital rocket, and the first such to be developed without public funding.

While the development of Falcon 1 was privately funded, the first two Falcon 1 launches were purchased by the United States Department of Defense under a program that evaluates new US launch vehicles suitable for use by DARPA.

Pricing

SpaceX is one of the few launch system operators that publishes its launch prices, which are quoted as being same for all customers. In 2005 Falcon 1 was advertised as costing $5.9 million ($6.4 million when adjusted for inflation in 2009). In 2006 until 2007 the quoted price of the rocket when operational was $6.7 million. In late 2009 SpaceX announced new prices for the Falcon 1 and 1e at $7 million and $8.5 million respectively, with small discounts available for multi-launch contracts.

As of the summer of 2010, the SpaceX website states that the Falcon 1 has been replaced by the Falcon 1e, with an "open and fixed" price of $10.9 million.

Launch sites

All flights have been launched from Kwajalein Atoll using the SpaceX launch facility on Omelek Island and range facilities of the Reagan Test Site. All upcoming Falcon 1 flights shown on the SpaceX manifest are also planned for Kwajalein. Other launch sites which have been discussed for Falcon 1 flights include:

- Vandenberg Air Force Base Space Launch Complex 3W. According to Elon Musk, SpaceX may be evicted from Vandenberg because of safety concerns expressed by United Launch Alliance, which launches the Atlas V rocket from neighboring site SLC-3E.

- Cape Canaveral Air Force Station Space Launch Complex 40.

Variants

Falcon 1 Versions	Merlin A; 2006–2007	Merlin C; 2007–2009	Falcon 1e; 2010
Stage 1	1 × Merlin 1A	1 × Merlin 1C	1 × Merlin 1C
Stage 2	1 × Kestrel	1 × Kestrel	1 × Kestrel
Height (max; m)	21.3	22.25	26.83
Diameter (m)	1.7	1.7	1.7
Initial thrust (kN)	318	343	454
Takeoff weight (tonnes)	27.2	33.23	38.56
Fairing diameter (Inner; m)	1.5	1.5	1.71
Payload (LEO 185 KM; kg)	570 (less to SSO)	450 (less to SSO)	1,010 (430 to SSO)
Payload (GTO; kg)	—	—	—
Price (Mil. USD)	6.7	7	10.9
minimal **Price/kg** (LEO 185 KM; USD)	11,754	15,556	10,800 (25,348 to SSO)
minimal **Price/kg** (GTO; USD)	—	—	—
Success ratio (successful/total)	0/2	2/3	—

Launch history

As of 2009, the Falcon 1 has made five launches. The first three failed, however the subsequent two flights were successful, the first successful launch making it the first privately funded and developed liquid-propellent rocket to reach orbit. The fifth launch was its first commercial flight, and placed RazakSAT into low Earth orbit.

As part of the $15 million contract, Falcon 1 was to carry the TacSat-1 in 2005. By late May 2005, SpaceX was ready to launch TacSat-1 from Vandenberg, but the Air Force did not want the launch to occur until the final Titan 4 flew from nearby SLC 4E. Subsequent and repeated delays due to Falcon 1 launch failures delayed TacSat-1's launch. After TacSat-2 was launched on an Orbital Sciences Minotaur I on December 16, 2006, the Department of Defense re-evaluated the need for launching TacSat-1. In August 2007, the Department of Defense canceled the planned launch of TacSat-1 because all of the TacSat objectives had been met.

Flight Nº	Date & Time (GMT)	Payload	Customer	Outcome	Remarks
1	24 March 2006, 22:30 (25 March, 09:30 local)	FalconSAT-2	DARPA	Failure	Engine failure at T+25 seconds Loss of vehicle
2	21 March 2007, 01:10 (13:10 local)	DemoSat	DARPA	Failure	Successful first stage burn and transition to second stage, maximum altitude 289 km Harmonic oscillation at T+5 minutes Premature engine shutdown at T+7 min 30 s Failed to reach orbit Failed to recover first stage Claimed to be a "Partial success" as it gathered enough data for operational flights
3	3 August 2008, 03:34 (15:34 local)	Trailblazer PRESat NanoSail-D Explorers	ORS NASA NASA Celestis	Failure	Residual stage 1 thrust led to collision between stage 1 and stage 2
4	28 September 2008, 23:15 (11:15 local/16:15	RatSat	SpaceX	Successful	Initially scheduled for 23–25 Sept, carried dummy payload – mass simulator, 165 kg (originally intended to be RazakSAT)

	PDT)				
5	14 July 2009 03:35	RazakSAT	ATSB	Successful	
			Scheduled Launches		
	2011	TBD	SpaceDev	Scheduled	maiden flight of 1e configuration
	2010–2014	O2G	Orbcomm	Scheduled	18 satellites, number of launches to be confirmed
	2013	Formosat-5	NSPO	Scheduled	Launch vehicle is Falcon 1e
	2014 through 2015	Small satellites	Astrium	Scheduled	Launch vehicles are Falcon 1e

Chapter- 12

Saturn I

Saturn I

The first Saturn I was launched October 27, 1961

Function	Manned LEO launch vehicle

Manufacturer	Chrysler (S-I) Douglas (S-IV) Convair (S-V) - Unflown
Country of origin	United States
	Size
Height	55 m (180 ft)
Diameter	6.52 m (21.39 ft)
Mass	509,660 kg (1,123,600 lb)
Stages	2 or 3 (3rd stage never flown)
	Capacity
Payload to LEO	9,000 kg (2 stage)
Payload to TLI	2,200 kg (2 stage)
	Launch history
Status	Retired
Launch sites	LC-37 & LC-34, Cape Canaveral
Total launches	10
Successes	10
Failures	0
Maiden flight	October 27, 1961
Last flight	July 30, 1965
Notable payloads	Apollo CSM (boilerplate) Pegasus
	First stage - S-I
Engines	8 H-1
Thrust	6.7 MN (1,500,000 lb_f)
Burn time	~150 seconds
Fuel	RP-1/LOX
	Second stage - S-IV
Engines	6 RL10
Thrust	400 kN (90,000 lb_f)
Burn time	~482 seconds
Fuel	LH2/LOX
	Third stage - S-V (Centaur-C) - unflown
Engines	2 RL10
Thrust	133 kN (30,000 lb_f)
Burn time	~430 seconds
Fuel	LH2/LOX

The **Saturn I** was the United States' first heavy-lift dedicated space launcher, a rocket designed specifically to launch large payloads into low Earth orbit. Most of the rocket's power came from a clustered lower stage consisting of tanks taken from older rocket designs and strapped together to make a single large booster, leading critics to jokingly refer to it as "Cluster's Last Stand". However, its design proved sound and very flexible. Its major successes were launching the Pegasus satellites and flight verification of the Apollo Command and Service Module aerodynamics in the launch phase. Originally intended as a near-universal military booster during the 1960s, it served only for a brief period and only with NASA; ten Saturn Is were flown before it was replaced by the derivative Saturn IB, which featured a more powerful upper stage and improved instrumentation.

History

Origins

The Saturn project was started as one of a number of proposals to meet a new Department of Defense (DoD) requirement for a heavy-lift vehicle to orbit a new class of communications and "other" satellites. The requirements called for a vehicle capable of putting 9,000 to 18,000 kilograms into orbit, or accelerating 2,700 to 5,400 kg to escape velocity. Existing launchers could place a maximum of about 1,400 kg in orbit, but might be expanded to as much as 4,500 kg with new high-energy upper stages. In any event, these upper stages would not be available until 1961 or 62 at the earliest, and would still not meet the DoD requirements for heavy loads.

Wernher von Braun's team at the U.S. Army Ballistic Missile Agency (ABMA) started studying the problem in April 1957. They calculated that a rocket with the required performance would require a lower stage booster with a thrust of about 1.5 million pound-force (6.7 MN) thrust at takeoff. As it happened, the Air Force had recently started work on just such an engine, eventually emerging as the F-1, but this would not be available in the time frame that the DoD was demanding and would be limited to about 1 million lbf in the short term anyway. Another possibility was a Rocketdyne engine, then known as the E-1, which provided about 360,000 to 380,000 lbf (1,700 kN), four of which would reach the required thrust levels. This approach became the favorite, and in order to quickly provide fuel tankage to supply the engines, a new stage consisting of the tank from a Jupiter wrapped with eight taken from the Redstone would be used along with a thrust plate on the bottom where the engines would be attached.

Von Braun returned the design to DoD in December, 1957 as *A National Integrated Missile and Space Vehicle Development Program*, outlining the new design, then known simply as "Super-Jupiter". Several variations were proposed, using a common clustered first stage, and upper stages based on either the Atlas or Titan I. ABMA favored the Titan as the Atlas production was extremely high-priority and there was little or no excess capacity to spare. They proposed using the existing Titan tooling at 120" diameter, but lengthening it to produce a new 200-foot (61 m)-long stage. A Centaur would be used as a third stage, which was expected to be ready for operational use in 1963, right when the lower two stages would have completed their testing. The resulting three-stage design was much taller and skinnier than the Saturn design that was eventually built.

Advanced Research Projects Agency (ARPA) was formed in February 1958 as part of DoD and was in charge of the requirements. ARPA asked for only one change to the design; concerned that the E-1 was still in early development, they suggested looking at alternatives in order to ensure the rocket would enter production as soon as possible. ABMA quickly responded with a slightly modified design replacing the four E-1's with eight H-1 engines, a minor upgrade to the S-3D engine used on Thor and Jupiter missiles. They estimated that changing the engines would save about $60 million and as much as two years research and development time. Von Braun had earlier referred to Redstone and Jupiter rockets being used as space launchers as the Juno I and Juno II, respectively, and made proposals for multi-stage versions as the Juno III and IV, and so he changed the name of the new design to **Juno V**. The total development cost of $850 million ($5.6 billion in year-2007 dollars) between 1958-1963 also covered 30 research and development flights, some carrying manned and unmanned space payloads.

Work begins

Satisfied with the outcome, ARPA Order Number 14-59, dated 15 August 1958, ordered the program into existence:

> Initiate a development program to provide a large space vehicle booster of approximately 1,500,000-lb. thrust based on a cluster of available rocket engines. The immediate goal of this program is to demonstrate a full-scale captive dynamic firing by the end of CY 1959.

This was followed on 11 September 1958 with another contract with Rocketdyne to start work on the H-1. On 23 September 1958, ARPA and the Army Ordnance Missile Command (AOMC) drew up an additional agreement enlarging the scope of the program, stating "In addition to the captive dynamic firing..., it is hereby agreed that this program should now be extended to provide for a propulsion flight test of this booster by approximately September 1960." Further, they wanted ABMA to produce three additional boosters, the last two of which would be "capable of placing limited payloads in orbit."

Von Braun had high hopes for the design, feeling it would make an excellent test-bed for other propulsion systems, notably the F-1 if it matured. He outlined uses for the Juno V as a general carrier vehicle for research and development of "offensive and defensive space weapons." Specific uses were forecast for each of the military services, including navigation satellites for the Navy; reconnaissance, communications, and meteorological satellites for the Army and Air Force; support for Air Force manned missions; and surface-to-surface logistics supply for the Army at distances up to 6400 kilometers. Von Braun also proposed using the Juno V as the basis of a manned lunar mission as part of Project Horizon. Juno could lift up to 20,000 pounds (9,000 kg) into low earth orbit, and he proposed launching 15 of them to build a 200,000 lb (91,000 kg) lunar spacecraft in Earth orbit.

Even by this point the name "Saturn", as "the one after Jupiter" was being used. One early ARPA report noted "The SATURN is considered to be the first real space vehicle as the Douglas DC-3 was the first real airliner and durable work-horse in aeronautics." The name change became official in February 1959.

Enter NASA

The formation of NASA on July 29, 1958 led to an effort to collect the existing heavy-launch rocket programs and select a single set of designs for future work. At the time, both the Air Force and US Army had teams developing such vehicles, the Army's Saturn and the Air Force's **Space Launching System** (SLS). The SLS used a set of common modular components with solid fuel boosters and hydrogen/oxygen upper stages to allow a wide variety of launch configurations and payload weights. Both groups had also developed plans for manned lunar bases, ABMA's Horizon with its Earth Orbit Rendezvous method of building a large lunar rocket in Earth orbit, and the Air Force's Lunex Project which planned on launching a single huge lander using the largest of the SLS configurations. As if this were not enough, NASA's own engineers had started the design of their own Nova design series, planning to use it in the direct ascent profile similar to the Air Force's approach.

Von Braun was asked to chair a committee to study the existing efforts and write up recommendations. They presented their report on 18 July, starting with a criticism of how the US program had been mishandled to date and pointing out that the Soviet program was definitely ahead. It went on to describe five "generations" of rockets, starting with the early Vanguard, through the Junos, ICBMs like Atlas and Titan, clustered designs like the Saturn, and finally the ultimate development, a cluster using the F-1 with 6 million pounds of thrust. The report went on to outline a manned exploration program using these rockets as they became available; using existing ICBMs a small four-man space station could be operational 1961, the clusters would support a manned lunar landing in 1965-1966 and a larger 50-man space station by 1967, while the largest of the rockets would support large moon expeditions in 1972, set up a permanent moon base in 1973-1974, and launch manned interplanetary trips in 1977.

In December all of the teams gathered to present their designs. NASA selected von Braun's proposal on January 6, giving it a vital boost. At the end of January NASA outlined their complete development program. This included the Vega and Centaur upper stages, as well as the Juno V and their own Nova boosters. Vega was later cancelled when information on the formerly secret Agena upper stage was released (then known as "Hustler"), and it had performance roughly comparable to NASA's design.

Near-cancellation

Progress on the Saturn design seemed to go smoothly. In April the first H-1 engines started arriving at ABMA, and test firings started in May. Construction of the Complex 34 launch sites started at Cape Canaveral in June.

Then, quite unexpectedly, on 9 June 1959, Herbert York, Director of Department of Defense Research and Engineering, announced that he had decided to terminate the Saturn program. He later stated that he was concerned that the project was taking ARPA money from more pressing projects, and that as it seemed upgrades to existing ICBMs would provide the needed heavy-lift capability in the short term. As ABMA commander John B. Medaris put it:

> By this time, my nose was beginning to sniff a strange odor of "fish." I put my bird dogs to work to try to find out what was going on and with whom we had to compete. We discovered that the Air Force had proposed a wholly different and entirely new vehicle as the booster for Dynasoar, using a cluster of Titan engines and upgrading their performance to get the necessary first-stage thrust for take-off. This creature was variously christened the Super Titan, or the Titan C. No work had been done on this vehicle other than a hasty engineering outline. Yet the claim was made that the vehicle in a two-stage or three-stage configuration could be flown more quickly than the Saturn, on which we had already been working hard for many months. Dates and estimates were attached to that proposal which at best ignored many factors of costs, and at worst were strictly propaganda.

Looking to head off the cancellation, Saturn supporters from the DoD and ARPA drafted their own memo arguing against the cancellation. Working against them was the fact that neither the Army nor NASA had any in-writing requirement for the booster at that time. A three-day meeting between 16 and 18 September 1959 followed, where York and Dryden reviewed Saturn's future and discussed the roles of the Titan C and Nova. The outcome was equally unexpected; York agreed to defer the cancellation and continue short-term funding, but only if NASA agreed to take over the ABMA team and continue development without the help of the DoD. NASA was equally concerned that by relying on 3rd parties for their boosters they were putting their entire program in jeopardy.

As the parties continued discussions over the next week and agreement was hammered out; von Braun's team at ABMA would be kept together and continue working as the lead developers of Saturn, but the entire organization would be transferred to NASA's management. By a presidential executive order on 15 March 1960, ABMA became NASA's George C. Marshall Space Flight Center (MSFC).

Selecting the upper stages

In July 1959 a change request was received from ARPA to upgrade the upper stage to a much more powerful design using four new 20,000 lbf (89 kN) liquid hydrogen/liquid oxygen powered engines in a larger-diameter 160" second stage, with an upgraded Centaur using two engines of the same design for the third stage. On this change Medaris noted:

> For reasons of economy we had recommended, and it had been approved, that in building the second stage, we would use the same diameter as the Titan first stage – 120 inches. The major costs of tooling for the fabrication of missile tanks

and main structure is related to the diameter. Changes in length cost little or nothing in tooling. How the tanks are divided internally, or the structure reinforced inside, or the kind of structural detail that is used at the end in order to attach the structure to a big booster below, or to a different size stage above, have very little effect on tooling problems. However, a change in diameter sets up a major question of tools, costs, and time.

Suddenly, out of the blue came a directive to suspend work on the second stage, and a request for a whole new series of cost and time estimates, including consideration of increasing the second stage diameter to 160 inches. It appeared that Dr. York had entered the scene, and had pointed up the future requirements of Dynasoar as being incompatible with the 120-inch diameter. He had posed the question of whether it was possible for the Saturn to be so designed as to permit it to be the booster for that Air Force project.

We were shocked and stunned. This was no new problem, and we could find no reason why it should not have been considered, if necessary, during the time that the Department of Defense and NASA were debating the whole question of what kind of upper stages we should use. Nevertheless, we very speedily went about the job of estimating the project on the basis of accepting the 160-inch diameter. At the same time it was requested that we submit quotations for a complete operational program to boost the Dynasoar for a given number of flights. As usual, we were given two or three numbers, rather than one fixed quantity, and asked to estimate on each of them.

In order to reach some sort of accommodation, a group pulled from NASA, Air Force, ARPA, ABMA, and the Office of the Department of Defense Research and Engineering formed under the Silverstein Committee in December. Originally skeptical, the Committee convinced von Braun that liquid hydrogen was the way to go on upper stage development. Once these changes had been made, NASA's booster project was now entirely free of any dependence on military developments. At that point any sort of upper stage was fair game, and "If these propellants are to be accepted for the difficult top-stage applications," the committee concluded, "there seem to be no valid engineering reasons for not accepting the use of high-energy propellants for the less difficult application to intermediate stages."

The Committee outlined a number of different potential launch configurations, grouped into three broad categories. The "A" group were low-risk versions similar to the Saturn designs proposed prior to the meeting; the original design using Titan and Centaur upper stages became the A-1, while another model replacing the Titan with cluster of IRBMs became A-2. The B-1 design proposed a new second stage replacing the A-2s cluster with a new four-engine design using the H-1 like the lower stage. Finally there were three C-series models that replaced all of the upper stages with liquid hydrogen ones. The C-1 used the existing S-I clustered lower, adding the new S-IV stage with four new 15,000 to 20,000 lbf (89 kN) engines, and keeping the two-engine Centaur on top, now to be known as the S-V stage. The C-II model added a new S-III stage with two new 150,000 to 200,000 lbf (890 kN) engines, keeping the S-IV and S-V on top. Finally, the C-3 configuration added the S-II stage with four of these same engines, keeping only the S-III and S-IV on top. The C models easily outperformed the A's and B's, with the added advantage that they were interchangeable and could be built up in order to fit any needed payload requirement.

Saturn emerges

Ironically, of these new stage designs only the S-IV would ever be delivered, and not in the form that was drawn up in the Committee report. In order to meet development schedules a cluster of six Centaur engines were placed in the new 220" stage to produce the "new" S-IV of roughly the same performance as the original four upgraded engines. A large number of small engines is less efficient and more problematic than a smaller number of large engines, and this made it a target for an early upgrade to a single J-2. The resulting stage, the S-IVB, improved performance so much that the Saturn was able to launch the Apollo CSM, proving invaluable during the Apollo Project.

In the end the Titan C was never delivered, and the Air Force instead turned to "thrust augmented" Titan II's using clustered solid fuel rockets. These new designs, the Titan III's, became the workhorse of the Department of Defense's launch needs. A Titan III has about the same lift capability as a Saturn IB but costs less to manufacture and launch. Likewise, the development of the Titan III eliminated the need for the "flexible" staging concepts of the Saturn, which was now only intended to be used for manned launches in the Apollo program. With the need for flexibility in launch configuration removed, most of these designs were subsequently dropped. Only the S-V survived in its original form, while the S-IV would appear in modified form and the Saturn V would feature an entirely different S-II stage.

The main payload of the Saturn I was the boilerplate version of the Apollo Command and Service Modules and Launch Escape System. It was also considered at one time for launch of the X-20 Dyna-Soar spaceplane and later, for launching a Gemini capsule on a proposed lunar mission. The final three were used to launch the three Pegasus micrometeoroid satellites.

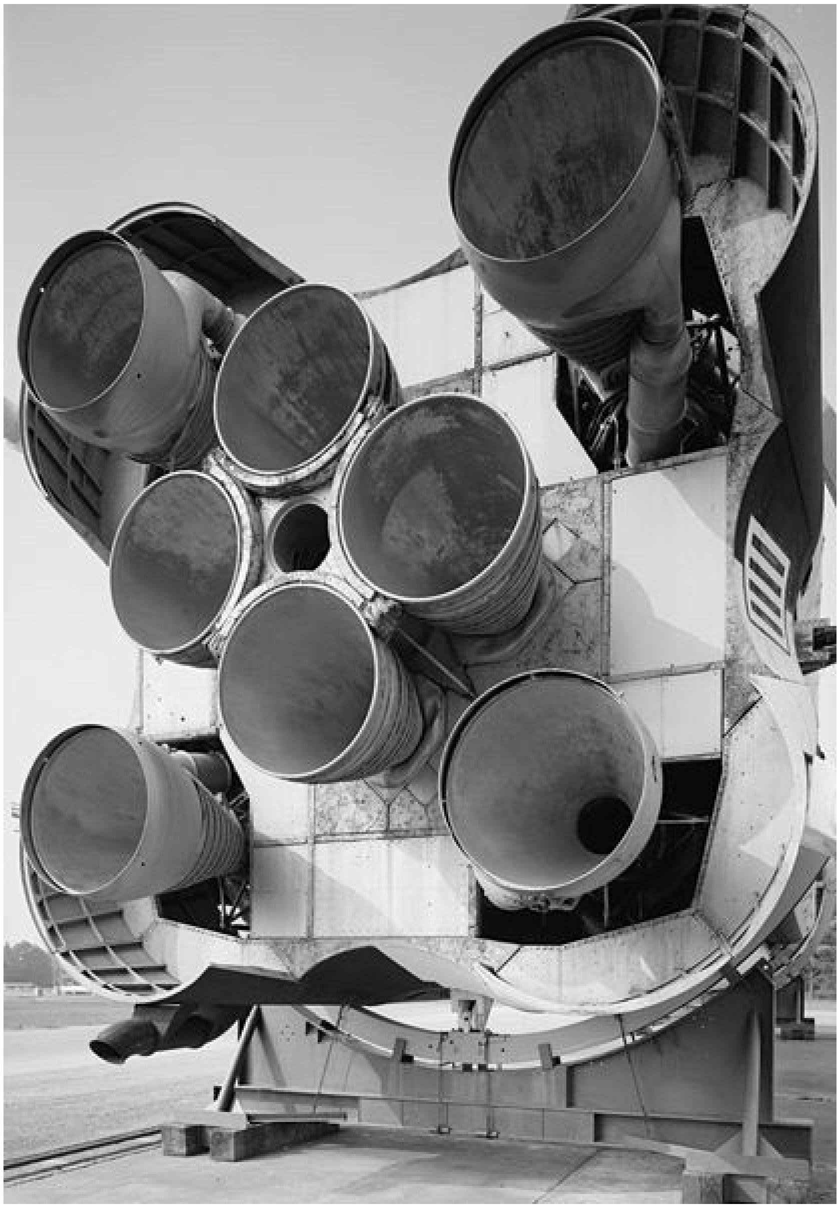
Description

Data for the original Saturn I

Parameter	S-I - 1st Stage	S-IV - 2nd Stage	S-V - 3rd Stage
Height (m)	24.48	12.19	9.14
Diameter (m)	6.52	5.49	3.05
Gross mass (kg)	432,681	50,576	15,600
Empty mass (kg)	45,267	5,217	1,996
Engines	Eight - H-1	Six - RL10	Two - RL10
Thrust (kN)	7,582	400	133
ISP (seconds)	288	410	425

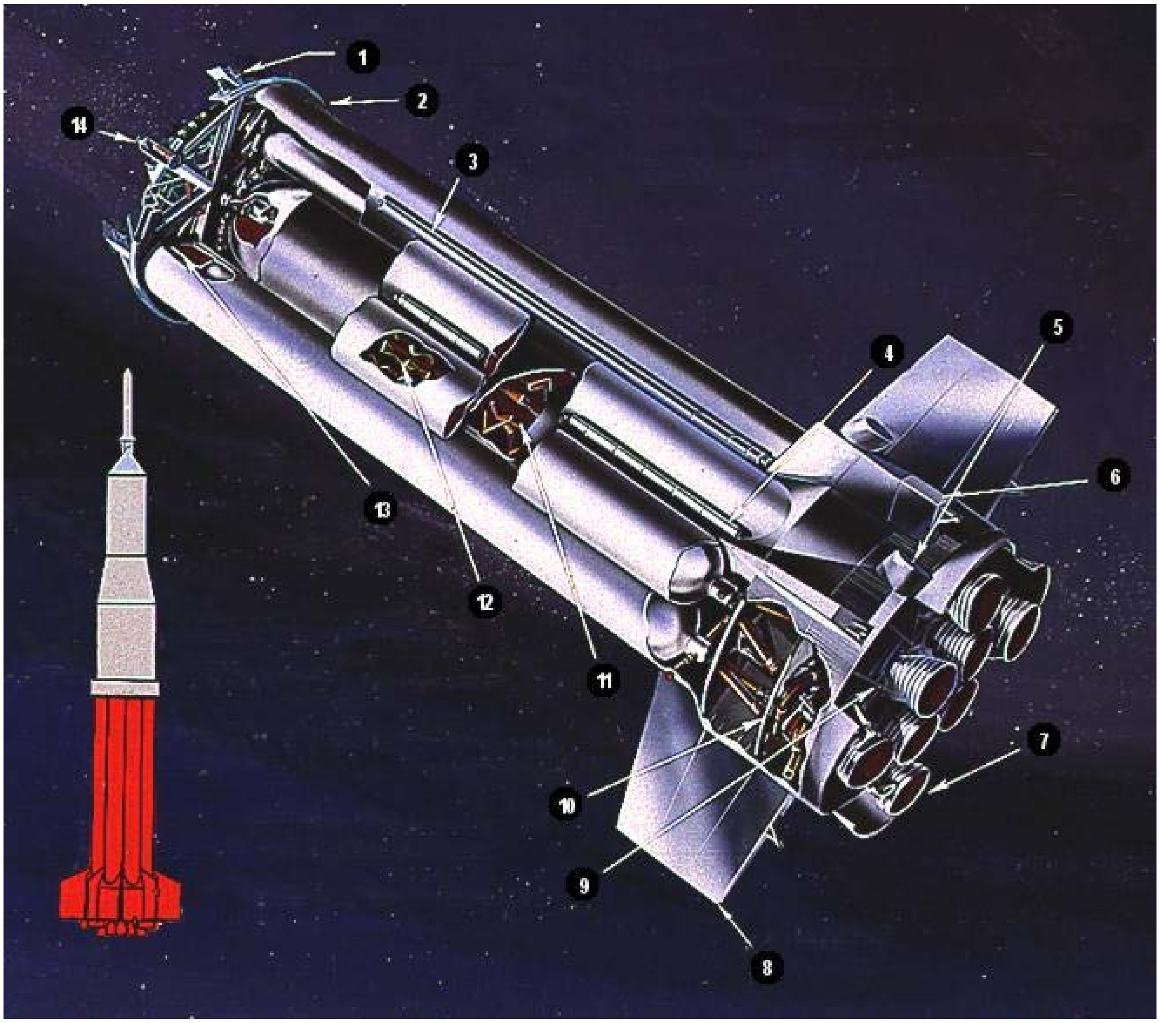
ISP (kN·s/kg)	2.82	4.02	4.17
Burn duration (s)	150	482	430
Propellant	LOX/RP-1	LOX/LH2	LOX/LH2

S-I stage



A Saturn I first stage lies on its side between tests at MSFC.

The S-I first stage was powered by eight H-1 rocket engines burning RP-1 fuel with liquid oxygen (LOX as oxidizer. The propellant tanks consisted of a central Jupiter rocket tank containing LOX, surrounded by a cluster of eight Redstone rocket tanks: four painted white, containing LOX; and four painted black, containing the RP-1 fuel. The four outboard engines were mounted on gimbals, allowing them to be steered to guide the rocket. On the Block II vehicles (SA-5 through SA-10), eight fins provided aerodynamic stability in the flight through the atmosphere.



First stage diagram

Specifications:

Height: 80.3 feet (24.5 m)
Diameter: 21.4 feet (6.5 m)
Engines: 8 H-1
Thrust: 1,500,000 pounds-force (6,700 kN)
Fuel: RP-1 (Refined kerosene), 41,000 US gal (155 m^3)
Oxidizer: liquid oxygen (LOX), 66,000 US gal (250 m^3)
Burn time: 150 sec
Burnout altitude: 37 nautical miles (69 km)

S-IV stage

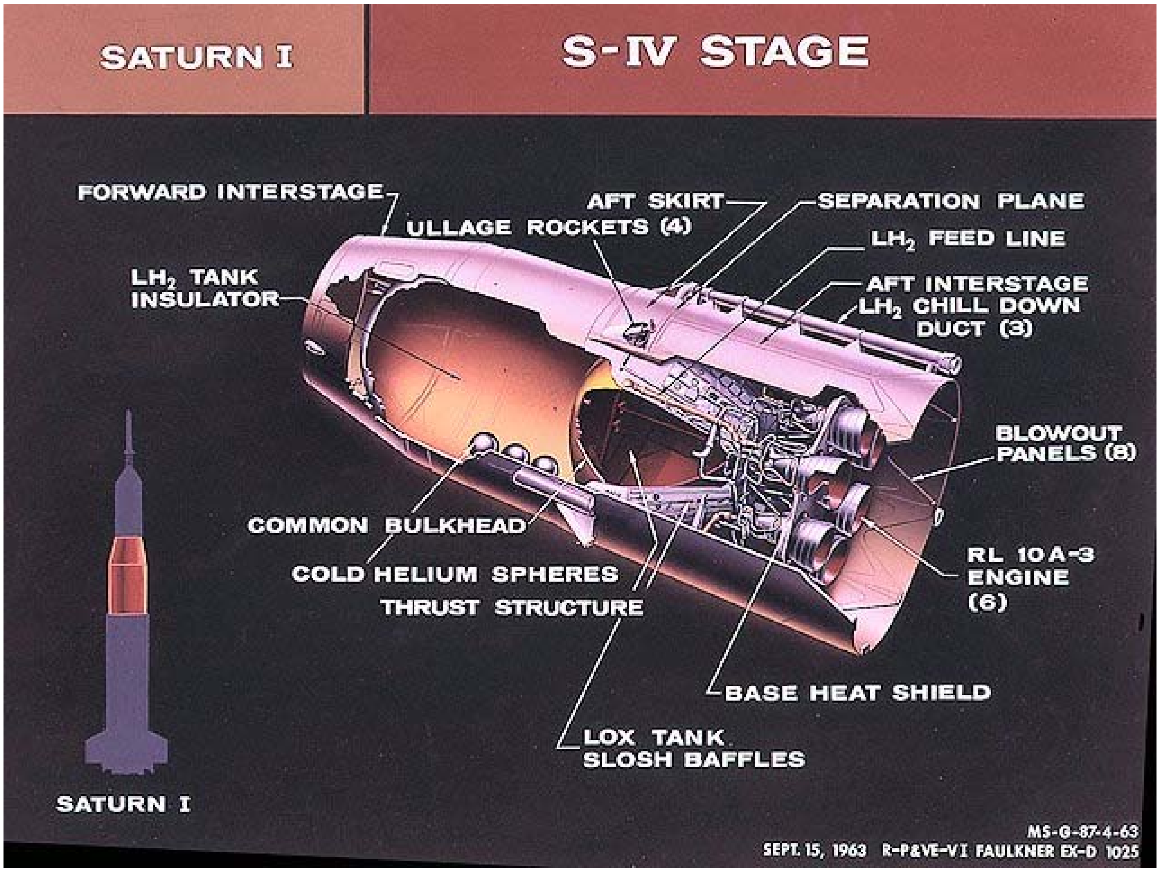


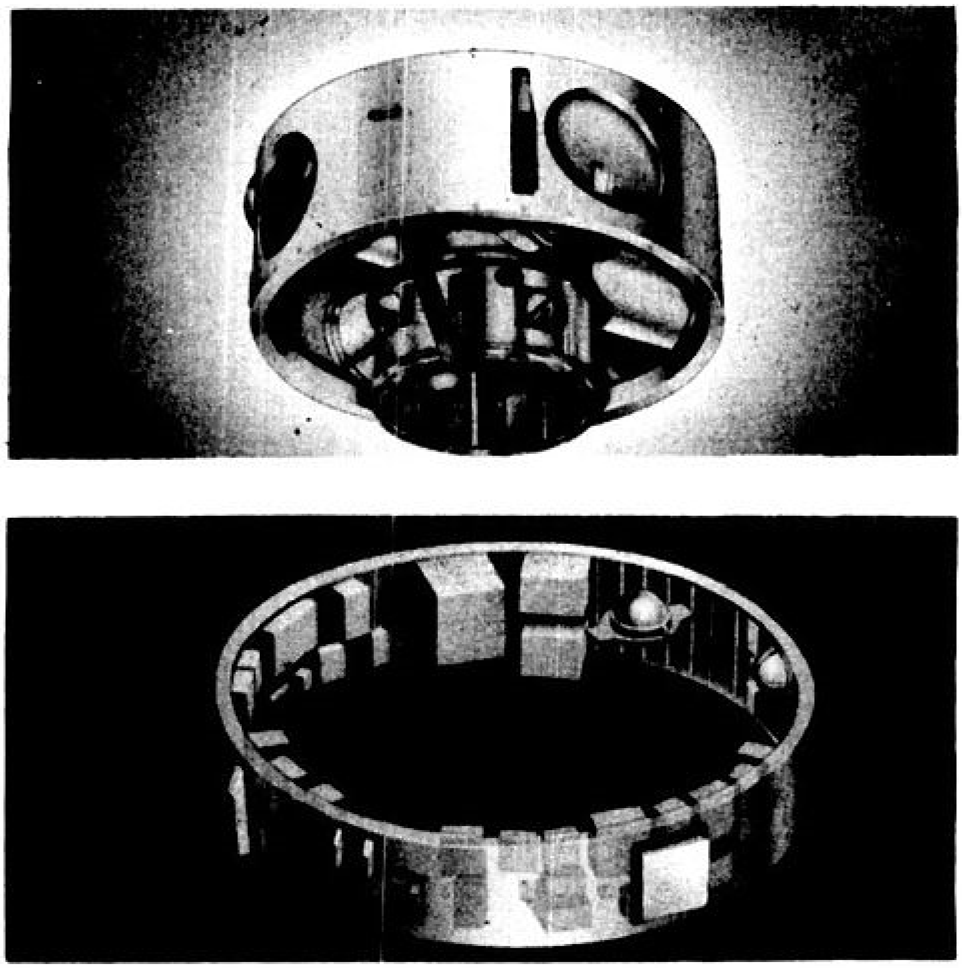
Diagram of the S-IV second stage of the Saturn I.

The S-IV stage was powered by six LOX/LH2-fueled RL10 engines, mounted on gimbals. The propellant tanks used a single, common bulkhead to separate the LOX and LH2 propellant tanks, saving about ten tons of weight.

Specifications:

Height: 40 feet (12 m)
Diameter: 18 feet (5.5 m)
Engines: 6 RL10
Thrust: 90,000 pounds-force (400 kN)
Fuel: liquid hydrogen (LH2)
Oxidizer: liquid oxygen (LOX)
Burn time: approx. 410 sec
Burnout altitude: up to 240 nautical miles (440 km)

Saturn I Instrument Unit



Block II Instrument Units. The simplification of systems reduced weight markedly in the later version.

Version 1 (top) and version 2 (bottom) of the Instrument Unit.

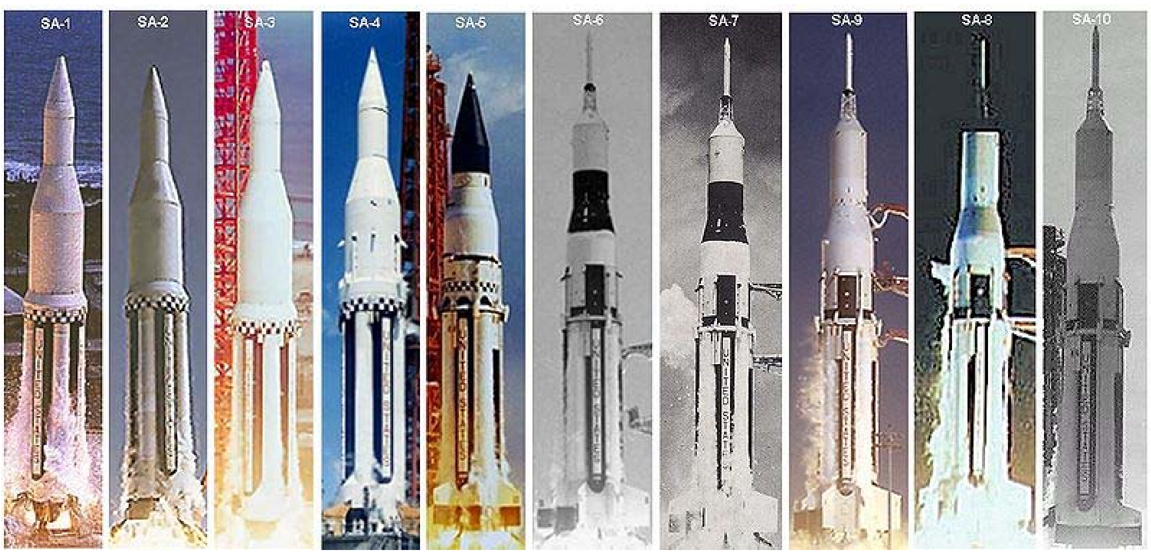
Saturn I Block I vehicles (SA-1 to SA-4) were guided by instruments carried in canisters on top of the S-I first stage, and included the ST-90 stabilized platform, made by Ford Instrument Company and used in the Redstone missile. These first four vehicles followed ballistic, non-orbital trajectories, and the dummy upper stages did not separate from the single powered stage.

The Block II vehicles (SA-5 to -10) included two powered stages, and went into orbits. Beginning with SA-5, the guidance instruments were carried on a separate stage, the instrument unit (IU), just ahead of the S-IV stage. The first version of the IU was 154 inches (3,900 mm) in diameter and 58 inches (1,500 mm) high, and was both designed and built by Marshall Space Flight Center. Guidance, telemetry, tracking and power components were contained in four pressurized, cylindrical containers attached like spokes to a central hub. This version flew on SA-5, 6, and 7.

MSFC flew version 2 of the IU on SA-8, 9 and 10. Version 2 was the same diameter as version 1, but only 34 inches (860 mm) high. Instead of pressurized containers, the components were hung on the inside of the cylindrical wall, achieving a reduction in weight.

The guidance computer for Block II was the IBM ASC-15. Other instruments carried by the IU included active components, that guided the vehicle; and passenger components, that telemetered data to the ground for test and evaluation for use in later flights. The ST-90 stabilized platform was the active IMU for SA-5 and the first stage of SA-6. The ST-124 was the passenger on SA-5 and active for the second stage of SA-6 and subsequent missions. The IU had an optical window to allow alignment of the inertial platform before launch.

Saturn I launches



Saturn I rocket profiles SA-1 through SA-10

Serial number	Mission	Launch date	Notes
SA-1	SA-1	October 27, 1961	First test flight. Block I. Suborbital. Range 398 km, Apogee 136.5 km. Apogee Mass 115,700 lb (52,500 kg).
SA-2	SA-2	April 25, 1962	Second test flight. Block I. Suborbital. 86,000 kg water released at apogee of 145 km.
SA-3	SA-3	November 16, 1962	Third test flight. Block I. Suborbital. 86,000 kg water released at apogee of 167 km.
SA-4	SA-4	March 28, 1963	Fourth test flight. Block I. Suborbital. Dummy SIV second stage. Apogee 129 km, range 400 km.

SA-5	SA-5	January 29, 1964	First live S-IV second stage. First Block II. Orbit 760 by 264 km. Mass 38,700 lb (17,550 kg). Decayed 30 April 1966.
SA-6	A-101	May 28, 1964	First Apollo boilerplate CSM launch. Block II. Orbit 204 by 179 km. Mass 38,900 lb (17,650 kg). Apollo BP-13 Decayed 1 June 1964.
SA-7	A-102	September 18, 1964	Second Apollo boilerplate CSM launch. Block II. Orbit 203 by 178 km. Mass 36,800 lb (16,700 kg). Apollo BP-15 Decayed 22 September 1964.
SA-9	A-103	February 16, 1965	Third Apollo boilerplate CSM; first Pegasus micrometeoroid satellite. Orbit 523 by 430 km. Mass 3,200 lb (1,450 kg). Pegasus 1 Decayed 17 September 1978. Apollo BP-26 Decayed 10 July 1985.
SA-8	A-104	May 25, 1965	Fourth Apollo boilerplate CSM; second Pegasus micrometeoroid satellite. Orbit 594 by 467 km. Mass 3,200 lb (1,450 kg). Pegasus 2 Decayed 3 November 1979. Apollo BP-16 Decayed 8 July 1989.
SA-10	A-105	July 30, 1965	Third Pegasus micrometeoroid satellite. Orbit 567 by 535 km. Mass 3,200 lb (1,450 kg). Pegasus 3 Decayed 4 August 1969. Apollo BP-9A Decayed 22 November 1975.

Chapter- 13

Saturn V

Saturn V	
	
The first Saturn V, AS-501, before the launch of Apollo 4	
Function	Manned LEO and Lunar launch vehicle
Manufacturer	Boeing (S-IC) North American (S-II) Douglas (S-IVB)
Country of origin	United States
Size	
Height	363.0 feet (110.6 m)
Diameter	33.0 feet (10.1 m)
Mass	6,699,000 pounds (3,039,000 kg)
Stages	3
Capacity	

Payload to LEO	262,000 pounds (119,000 kg)
Payload to TLI	(100,000 pounds (45,000 kg))
	Associated rockets
Family	Saturn
Derivatives	Saturn INT-21
Comparable	N1 rocket
	Launch history
Status	Decommissioned
Launch sites	LC-39, Kennedy Space Center
Total launches	13 (including INT-21)
Successes	12
Failures	0
Partial failures	1 (Apollo 6)
Maiden flight	November 9, 1967 (SA-501)
Last flight	December 6, 1972 (May 14, 1973 - INT-21)
	First Stage - S-IC
Engines	5 Rocketdyne F-1
Thrust	7,648,000 pounds-force (34,020,000 N)
Specific impulse	263 sec (2580 N-s/kg)
Burn time	150 seconds
Fuel	RP-1/LOX
	Second Stage - S-II
Engines	5 Rocketdyne J-2
Thrust	1,000,000 pounds-force (4,400,000 N)
Specific impulse	421 sec (4130 N-s/kg)
Burn time	360 seconds
Fuel	LH2/LOX
	Third Stage - S-IVB
Engines	1 Rocketdyne J-2
Thrust	225,000 pounds-force (1,000,000 N)
Specific impulse	421 sec (4130 N-s/kg)
Burn time	165 + 335 seconds (2 burns)
Fuel	LH2/LOX

The **Saturn V** (pronounced "Saturn Five") was an American expendable man-rated rocket used by NASA's Apollo and Skylab programs from 1967 until 1973. A multistage liquid-fueled booster, NASA launched 13 Saturn Vs from the Kennedy Space Center, Florida with no loss of crew or payload. It remains the largest and most powerful launch vehicle ever brought to operational status from a height, weight and payload standpoint.

The largest production model of the Saturn family of rockets, the Saturn V was designed under the direction of Wernher von Braun and Arthur Rudolph at the Marshall Space Flight Center in Huntsville, Alabama, with Boeing, North American Aviation, Douglas Aircraft Company, and IBM as the lead contractors. Von Braun's design was based in part on his work on the Aggregate series of rockets, especially the A-10, A-11, and A-12, in Germany during World War II.

History

The origins of the Saturn V rocket begin with the US government choosing Wernher von Braun to be one of about seven hundred German scientists in Operation Paperclip, a program created by President Truman in September 1946. It was intended to bring these scientists and their expertise to the United States, thereby giving America an edge in the Cold War. To legally bring over scientists who had been active in the Nazi Party, members of the War Department's Joint Intelligence Objectives Agency doctored dossiers, including von Braun's, to downplay their Nazi sympathies.

Von Braun was put into the rocket design division of the Army due to his direct involvement in the creation of the V-2 rocket. Between 1945 and 1958, his work was restricted to conveying the ideas and methods behind the V-2 to the American engineers. Despite Von Braun's many articles on the future of space rocketry, NASA continued funding Air Force and Naval rocket programs to test their Vanguard missiles despite numerous costly failures. It was not until the 1957 Soviet launch of Sputnik that the Army and the government started taking serious steps towards putting Americans in space. Finally, they turned to von Braun and his team, who during these years created and experimented with the Jupiter series of rockets. The Jupiter C was the rocket that launched the first American satellite in January 1958, and part of the last ditch plan for NASA to get its foot in the Space Race. The Jupiter series was one more step in von Braun's journey to the Saturn V, later calling that first series "an infant Saturn".

With the success of the Jupiter-series rockets and the new sense of urgency to beat the Russians in the Race to the moon caused by then-brand-new President John F. Kennedy, von Braun and his team made an immediate and easy transfer from their work for the Army to their work for NASA. Shortly after Kennedy's speech, von Braun was asked to head the main effort behind the design and construction of a rocket to get man into space.

The Saturn V's design stemmed from the designs of the V-2 and Jupiter series rockets. As the success of the Jupiter series became evident, the Saturn series emerged—first with the Saturn I and IB, and finally with the Saturn V. Von Braun headed a team at the Marshall Space Flight Center in building a vehicle capable of launching a crewed spacecraft on a trajectory to the moon. Before they moved under NASA's jurisdiction, von Braun's team had already begun work on improving the thrust, creating a less complex operating system, and designing better mechanical systems. It was during these revisions that the decision to reject the single engine of the V-2's design came about, and the team moved to a multiple-engine design. The Saturn I and IB reflected these changes, but still did not have the potential to send a crewed spacecraft to the moon. These designs, however, provided a basis for which NASA could determine its best method towards landing a man on the moon.

The Saturn V's final design had several key design features. Engineers determined that the best engines were the F-1s coupled with the new liquid hydrogen propulsion system called J-2, which made the Saturn C-5 configuration optimal. By 1962, NASA had finalized its plans to proceed with von Braun's Saturn designs, and the Apollo space program gained speed.

With the configuration finalized, NASA turned its attention to mission profiles. Despite some controversy, a lunar orbit rendezvous for the lunar module was chosen over an Earth orbital rendezvous. Issues such as type of fuel injections, the needed amount of fuel for such a trip, and rocket manufacturing processes were ironed out, and the designs for the Saturn V were selected. The rocket was to be built in three sections from the bottom up: SI-C, S-II, and S-IVB. Each section was designed by von Braun in Huntsville and built by outside contractors such as Boeing, North American Aviation, Douglas Aircraft, and IBM.

Mission configuration

Early in the planning process, NASA considered three leading ideas for the moon mission: Earth Orbit Rendezvous, Direct Ascent, and Lunar Orbit Rendezvous (LOR). A direct ascent configuration would launch a larger rocket which would land directly on the lunar surface, while an Earth orbit rendezvous would launch two smaller spacecraft which would combine in Earth orbit. A LOR mission would involve a single rocket launching a single spacecraft, but only a small part of that spacecraft would land on the moon. That smaller landing module would then rendezvous with the main spacecraft, and the crew would return home.

NASA at first dismissed LOR as a riskier option, given that an orbital rendezvous had yet to be performed in Earth orbit, much less in lunar orbit. Several NASA officials, including Langley Research Center engineer John Houbolt and NASA Administrator George Low, argued that a Lunar Orbit Rendezvous provided the simplest landing on the moon, the most cost–efficient launch vehicle and, perhaps most importantly, the best chance to accomplish a lunar landing within the decade. Other NASA officials were convinced, and LOR was officially selected as the mission configuration for the Apollo program on 7 November 1962.

Development

C-1 to C-4

Between 1960 and 1962, the Marshall Space Flight Center (MSFC) designed rockets that could be used for various missions.

The C-1 was developed into the Saturn I, and the C-2 rocket was dropped early in the design process in favor of the C-3, which was intended to use two F-1 engines on its first stage, four J-2 engines for its second stage, and an S-IV stage, using six RL-10 engines.

NASA planned to use the C-3 as part of the Earth Orbit Rendezvous concept, with at least four or five launches needed for a single mission, but MSFC was already planning an even bigger rocket, the C-4, which would use four F-1 engines on its first stage, an enlarged C-3 second stage, and the S-IVB, a stage with a single J-2 engine, as its third stage. The C-4 would need only two launches to carry out an Earth Orbit Rendezvous mission.

C-5

On January 10, 1962, NASA announced plans to build the C-5. The three-stage rocket would consist of five F-1 engines for the first stage, five J-2 engines for the second stage, and a single, additional J-2 engine for the third stage. The C-5 was designed for the higher payload capacity necessary for a lunar mission, and could carry up to 90,000 pounds (41,000 kg) to the Moon.

The C-5 would undergo component testing even before the first model was constructed. The rocket's third stage would be utilized as the second stage for the C-IB, which would serve both to demonstrate proof of concept and feasibility for the C-5, but would also provide flight data critical to the continued development of the C-5. Rather than undergoing testing for each major component, the C-5 would be tested in an "all-up" fashion, meaning that the first test flight of the rocket would include complete versions of all three stages. By testing all components at once, far fewer test flights would be required before a manned launch.

The C-5 was confirmed as NASA's choice for the Apollo Program in early 1963, and was given a new name—the Saturn V.

Technology

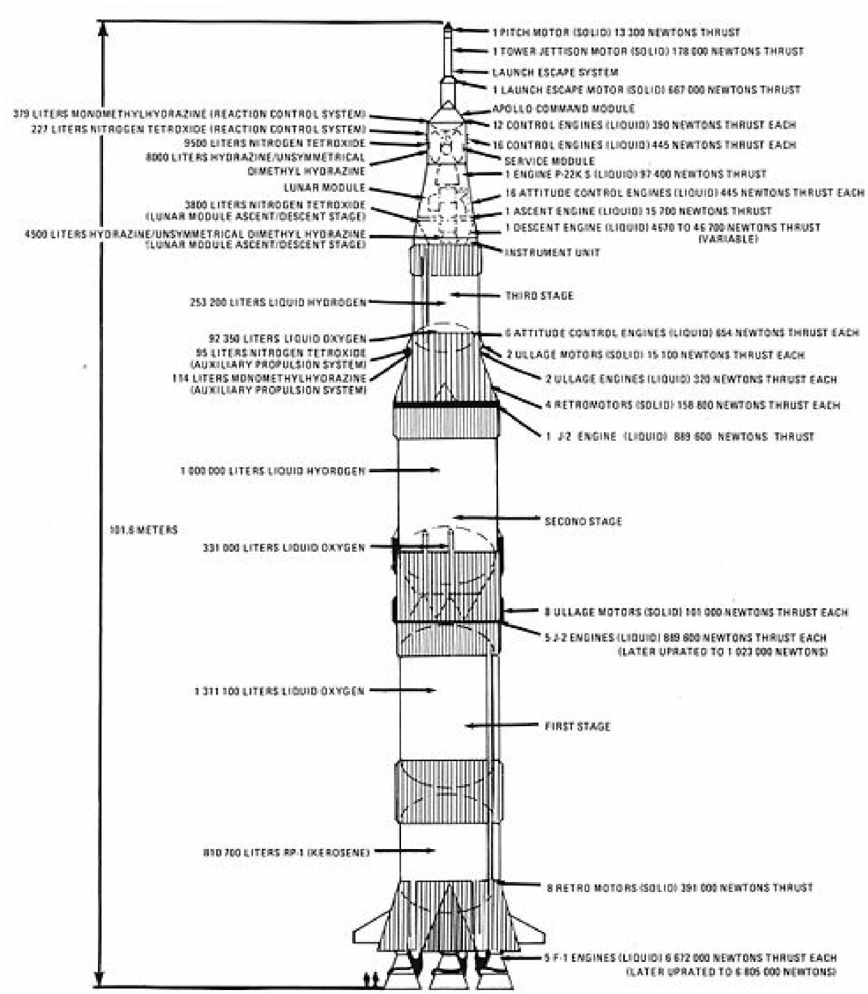
An S-II stage hoisted onto the A-2 test stand at the Mississippi Test Facility

The Saturn V's huge size and payload capacity dwarfed all other previous rockets which had successfully flown at that time. With the Apollo spacecraft on top it stood 363 feet (111 m) tall and without fins it was 33 feet (10 m) in diameter. Fully fueled it had a total mass of 6.5 million pounds (3,000 metric tons) and a payload capacity of 260,000 pounds (120,000 kg) to LEO. Comparatively, at 363 feet (111 m), the Saturn V is just one foot shorter than St Paul's Cathedral in London, and only cleared the doors of the Vehicle Assembly Building (VAB) by 6 feet (1.8 m) when rolled out. In contrast, the Mercury-Redstone Launch Vehicle used on Freedom 7, the first manned American spaceflight, was just under 11 feet (3.4 m) longer than the S-IVB stage, and less powerful than the Launch Escape System rockets mounted on the Apollo command module.

Saturn V was principally designed by the Marshall Space Flight Center in Huntsville, Alabama, although numerous major systems, including propulsion, were designed by subcontractors. It used the powerful new F-1 and J-2 rocket engines for propulsion. When tested, these engines shattered the windows of nearby houses. Designers decided early on to attempt to use as much technology from the Saturn I program as possible. Consequently, the S-IVB-500 third stage of the Saturn V was based on the S-IVB-200 second stage of the Saturn IB. The Instrument Unit that controlled the Saturn V shared characteristics with that carried by the Saturn I-B.

A popular urban myth has the blueprints for the Saturn V either lost or purposely destroyed. The blueprints and other plans still exist on microfilm at the Marshall Space Flight Center.

Stages



Saturn V diagram

The Saturn V consisted of three stages—the S-IC first stage, S-II second stage and the S-IVB third stage—and the instrument unit. All three stages used liquid oxygen (LOX) as an oxidizer. The first stage used RP-1 for fuel, while the second and third stages used liquid hydrogen (LH2). The upper stages also used small solid-fueled ullage motors that helped to separate the stages during the launch, and to ensure that the liquid propellants were in a proper position to be drawn into the pumps.

S-IC first stage

The first stage of Apollo 8 Saturn V being erected in the VAB on February 1, 1968

The five F-1 engines on the rear of a Saturn V on display at the Kennedy Space Center

The S-IC was built by The Boeing Company at the Michoud Assembly Facility, New Orleans, where Space Shuttle External Tanks would later be built. Most of its mass of over two thousand metric tonnes at launch was propellant, in this case RP-1 rocket fuel and liquid oxygen oxidizer. It was 138 feet (42 m) tall and 33 feet (10 m) in diameter, and provided over 34 meganewtons (7,600,000 lb_f) of thrust to get the rocket through the first 200,000 feet (61 km) of ascent. The S-IC stage had a dry weight of about 288,000 pounds (131,000 kg) and fully fueled at launch had a total weight of 5,000,000 pounds (2,300,000 kg). The five F-1 engines were arranged in a cross pattern. The center engine was fixed, while the four outer engines could be hydraulically turned ("gimballed") to control the rocket. In flight, the center engine was turned off about 26 seconds earlier than the outboard engines to limit acceleration. During launch, the S-IC fired its engines for 168 seconds (ignition occurred about 7 seconds before liftoff) and at engine cutoff, the vehicle was at an altitude of about 200,000 feet (61 km), was downrange about 58 miles (93 km), and was moving about 7,700 feet per second (2,300 m/s).

S-II second stage

The S-II was built by North American Aviation at Seal Beach, California. Using liquid hydrogen and liquid oxygen, it had five J-2 engines in a similar arrangement to the S-IC, also using the outer engines for control. The S-II was 81 feet 7 inches (24.87 m) tall with a diameter of 33 feet (10 m), identical to the S-IC, and thus was the largest cryogenic stage until the launch of the STS. The S-II had a dry weight of about 80,000 pounds (36,000 kg) and fully fueled, weighed 1,060,000 pounds (480,000 kg). The second stage accelerated the Saturn V through the upper atmosphere with 5.1 meganewtons (1,100,000 lbf) of thrust (in vacuum). When loaded, significantly more than 90 percent of the mass of the stage was propellant; however, the ultra-lightweight design had led to two failures in structural testing. Instead of having an intertank structure to separate the two fuel tanks as was done in the S-IC, the S-II used a common bulkhead that was constructed from both the top of the LOX tank and bottom of the LH2 tank. It consisted of two aluminum sheets separated by a honeycomb structure made of phenolic resin. This bulkhead had to insulate against the 70 °C (158 °F) temperature difference between the two tanks. The use of a common bulkhead saved 3.6 tonnes (7,900 lb). Like the S-IC, the S-II was transported by sea.

S-IVB third stage

The S-IVB was built by the Douglas Aircraft Company at Huntington Beach, California. It had one J-2 engine and used the same fuel as the S-II. The S-IVB used a common bulkhead to insulate the two tanks. It was 58 feet 7 inches (17.86 m) tall with a diameter of 21 feet 8 inches (6.604 m) and was also designed with high mass efficiency, though not quite as aggressively as the S-II. The S-IVB had a dry weight of about 25,000 pounds (11,000 kg) and, fully fueled, weighed about 262,000 pounds (119,000 kg).

The S-IVB-500 model used on the Saturn V differed from the S-IVB-200 used as the second stage of the Saturn IB, in that the engine was restartable once per mission. This was necessary as the stage would be used twice during a lunar mission: first in a 2.5 min burn for the orbit insertion after second stage cutoff, and later for the trans-lunar injection (TLI) burn, lasting about 6 min. Two liquid-fueled Auxiliary Propulsion System (APS) units mounted at the aft end of the stage were used for attitude control during the parking orbit and the trans-lunar phases of the mission. The two APSs were also used as ullage engines to settle the propellants in the aft tank engine feed lines prior to the trans-lunar injection burn.

The S-IVB was the only rocket stage of the Saturn V small enough to be transported by plane, in this case the Guppy.

Instrument Unit

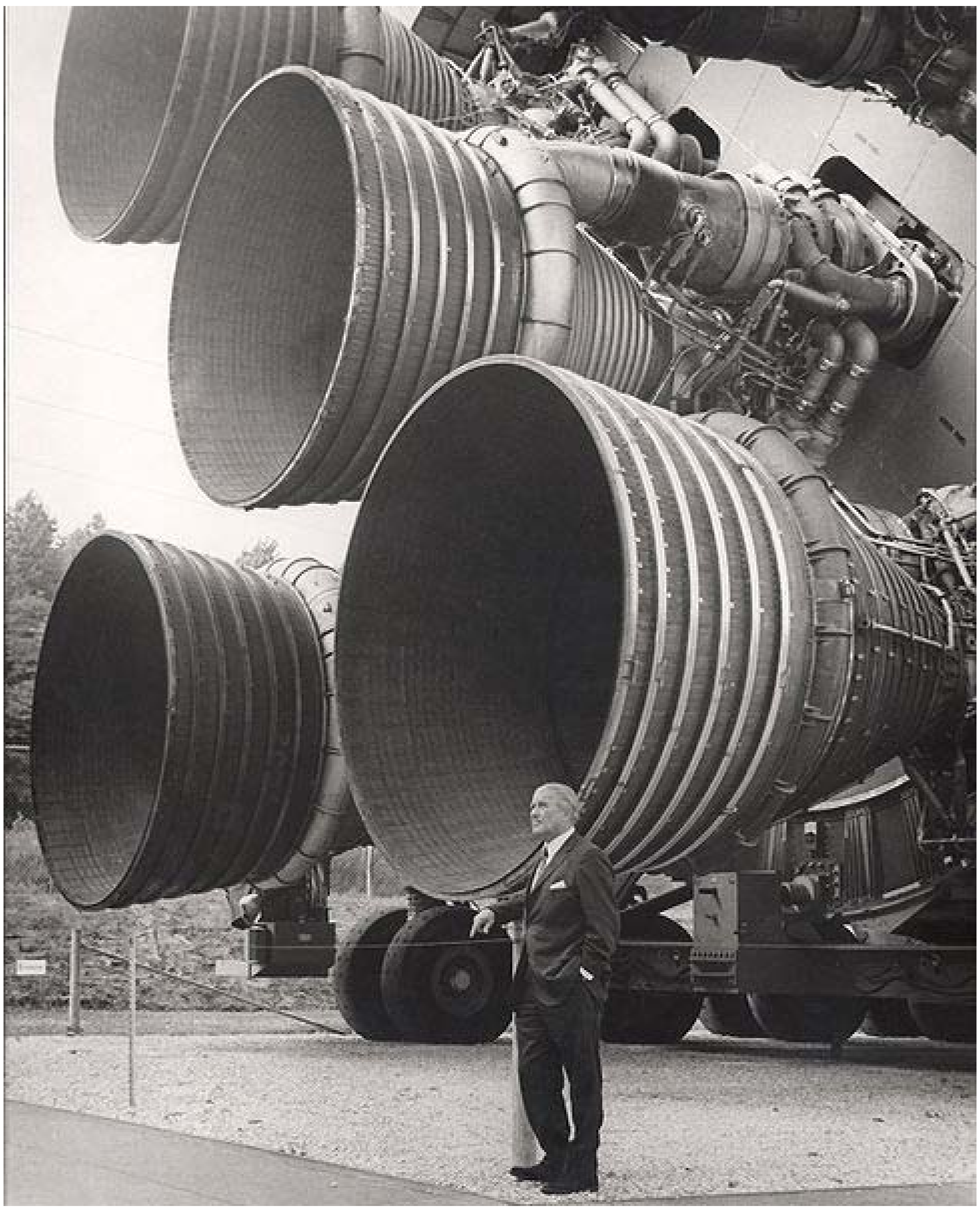
The Instrument Unit for the Apollo 4 Saturn V

The Instrument Unit was built by IBM and rode atop the third stage. It was constructed at the Space Systems Center in Huntsville. This computer controlled the operations of the rocket from just before liftoff until the S-IVB was discarded. It included guidance and telemetry systems for the rocket. By measuring the acceleration and vehicle attitude, it could calculate the position and velocity of the rocket and correct for any deviations.

Range safety

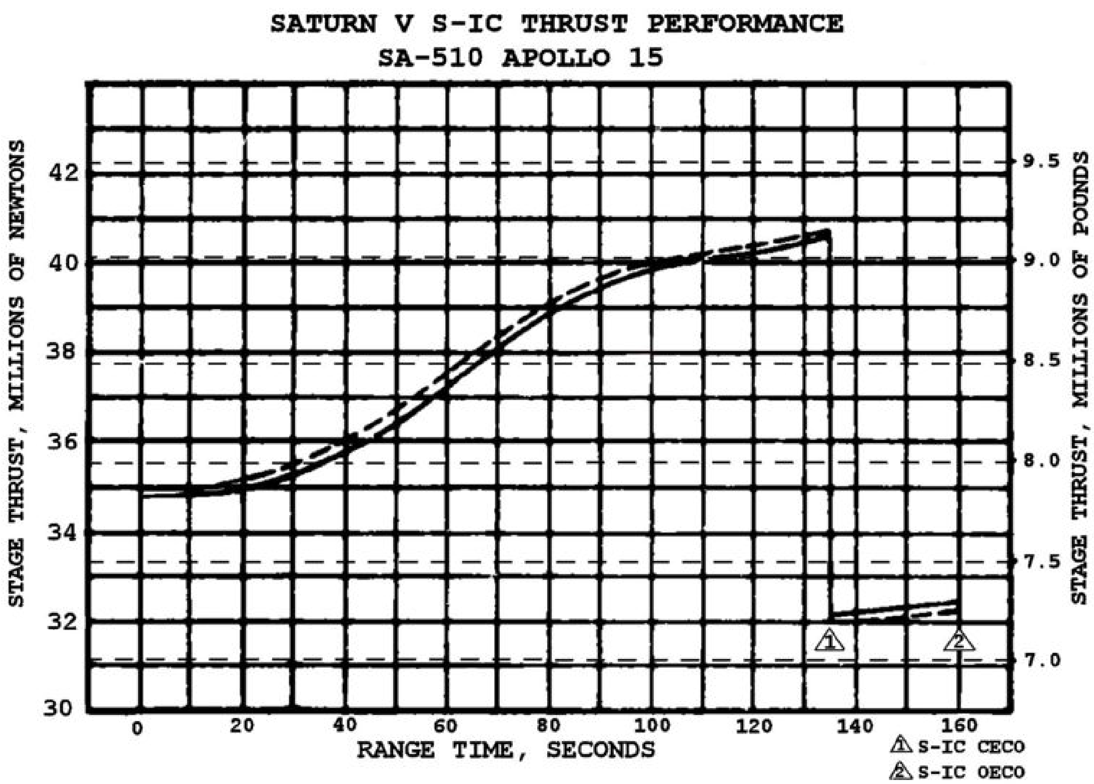
In the event of an abort requiring the destruction of the rocket, the range safety officer would remotely shut down the engines and after several seconds send another command for the shaped explosive charges attached to the outer surfaces of the rocket to detonate. These would make cuts in fuel and oxidizer tanks to disperse the fuel quickly and to minimize mixing. The pause between these actions would give time for the crew to escape using the Launch Escape Tower or (in the later stages of the flight) the propulsion system of the Service module. A third command, "safe", was used after the S-IVB stage reached orbit to irreversibly deactivate the self-destruct system. The system was also inactive as long as the rocket was still on the launch pad.

Comparisons



The F-1 engines of the S-IC first stage dwarf their creator, Wernher von Braun.

The Soviet counterpart of the Saturn V was the N-1 rocket. The Saturn V was taller, heavier and had greater payload capacity, but the N-1 had more liftoff thrust and a larger first stage diameter. The N1 had four test launches, each resulting in the vehicle catastrophically failing early in the flight, before the program was canceled. The first stage of Saturn V used five powerful engines rather than the 30 smaller engines of the N-1. During two launches, Apollo 6 and Apollo 13, the Saturn V was able to recover from engine loss incidents. The N-1 likewise was designed to compensate for engine failures, but the system never successfully saved a launch from failure.



Saturn V first stage thrust performance during Apollo 15 launch. 7,823,000 pounds-force (34.80 MN) liftoff thrust. CECO stands for Center Engine Cut-off and OECO is for Outer Engine(s) Cut-off

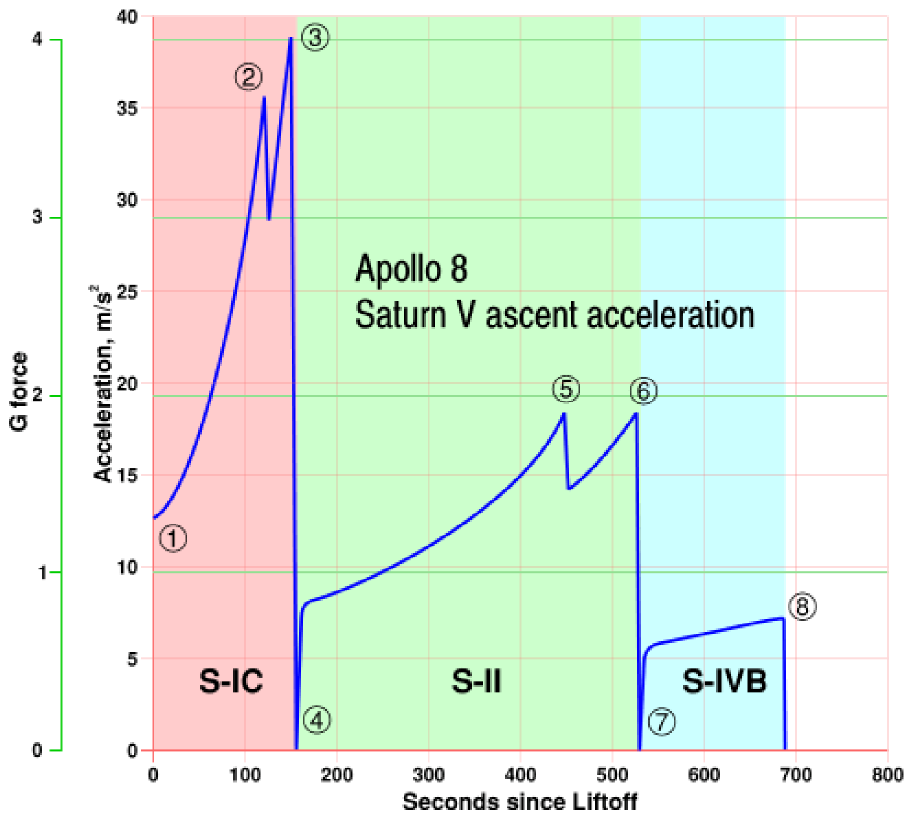
The three-stage Saturn V had a peak thrust of at least 7,650,000 pounds-force (34.02 MN) (SA-510 and subsequent) and a lift capacity of 118,000 kg to LEO. The SA-510 mission (Apollo 15) had a liftoff thrust of 7,823,000 pounds-force (34.80 MN). The SA-513 mission (Skylab) had slightly greater liftoff thrust of 7,891,000 pounds-force (35.10 MN). No other operational launch vehicle has ever surpassed the Saturn V in height, weight, or payload. If the two Soviet Energia test launches are counted as operational, it had the same liftoff thrust as SA-513, 7,900,000 pounds-force (35.1 MN). The N-1 had a sea-level liftoff thrust of about 9,900,000 pounds-force (44.0 MN), but it never achieved orbit.

Hypothetical future versions of the Soviet Energia might have been significantly more powerful than the Saturn V, delivering 46 MN of thrust and able to deliver up to 175 metric tonnes to LEO in the "Vulkan" configuration. Planned uprated versions of the Saturn V using F-1A engines would have had about 18 percent more thrust and 137,250 kilograms (302,600 lb) payload. NASA contemplated building larger members of the Saturn family, such as the Saturn C-8, and also unrelated rockets, such as Nova, but these were never produced.

The Space Shuttle generates a peak thrust of 30.1 MN, and payload capacity to LEO (excl. Shuttle Orbiter itself) is 28,800 kg, which is about 25 percent of the Saturn V's payload. If the Shuttle Orbiter itself is counted as payload, this would be about 112,000 kilograms (250,000 lb). An equivalent comparison would be the Saturn V S-IVB third stage total orbital mass on Apollo 15, which was 140,976 kilograms (310,800 lb).

Some other recent launch vehicles have a small fraction of the Saturn V's payload capacity: the European Ariane 5 with the newest versions Ariane 5 ECA delivers up to 10,000 kg to geostationary transfer orbit (GTO). The US Delta 4 Heavy, which launched a dummy satellite on December 21, 2004, has a capacity of 13,100 kg to geosynchronous transfer orbit. The as yet unflown Atlas V Heavy (using engines based on a Russian design) may deliver up to 25,000 kg to LEO and 13,605 kg to GTO.

S-IC thrust comparisons



Typical acceleration curve

Because of its large size, attention is often focused on the S-IC thrust and how this compares to other large rockets. However, several factors make such comparisons more complex than first appears:

- Commonly-referenced thrust numbers are a *specification*, not an actual measurement. Individual stages and engines may fall short or exceed the specification, sometimes significantly.
- The F-1 thrust *specification* was uprated beginning with Apollo 15 (SA-510) from 1.5 million lbf (6.67 MN) to 1.522 million lbf (6.77 MN), or 7.61 million lbf (33.85 MN) for the S-IC stage. The higher thrust was achieved via a redesign of the injector orifices and a slightly higher propellant mass flow rate. However, comparing the specified number to the actual measured thrust of 7.823 million lbf (34.8 MN) on Apollo 15 shows a significant difference.
- There is no "bathroom scale" way to directly measure thrust of a rocket in flight. Rather a mathematical calculation is made from combustion chamber pressure, turbopump speed, calculated propellant density and flow rate, nozzle design, and atmospheric conditions, in particular, external pressure.
- Thrust varies greatly with external pressure and thus, with altitude, even for a non-throttled engine. For example on Apollo 15, the calculated total liftoff thrust (based on actual measurements) was about 7.823 million lbf (34.8 MN), which increased to 9.18 million lbf (40.8 MN) at T+135 seconds, just before center engine cutoff (CECO), at which time the jet was heavily underexpanded.
- Thrust specifications are often given as vacuum thrust (for upper stages) or sea level thrust (for lower stages or boosters), sometimes without qualifying which one. This can lead to incorrect comparisons.
- Thrust specifications are often given as average thrust or peak thrust, sometimes without qualifying which one. Even for a non-throttled engine at a fixed altitude, thrust can often vary somewhat over the firing period due to several factors. These include intentional or unintentional mixture ratio changes, slight propellant density changes over the firing period, and variations in turbopump, nozzle and injector performance over the firing period.

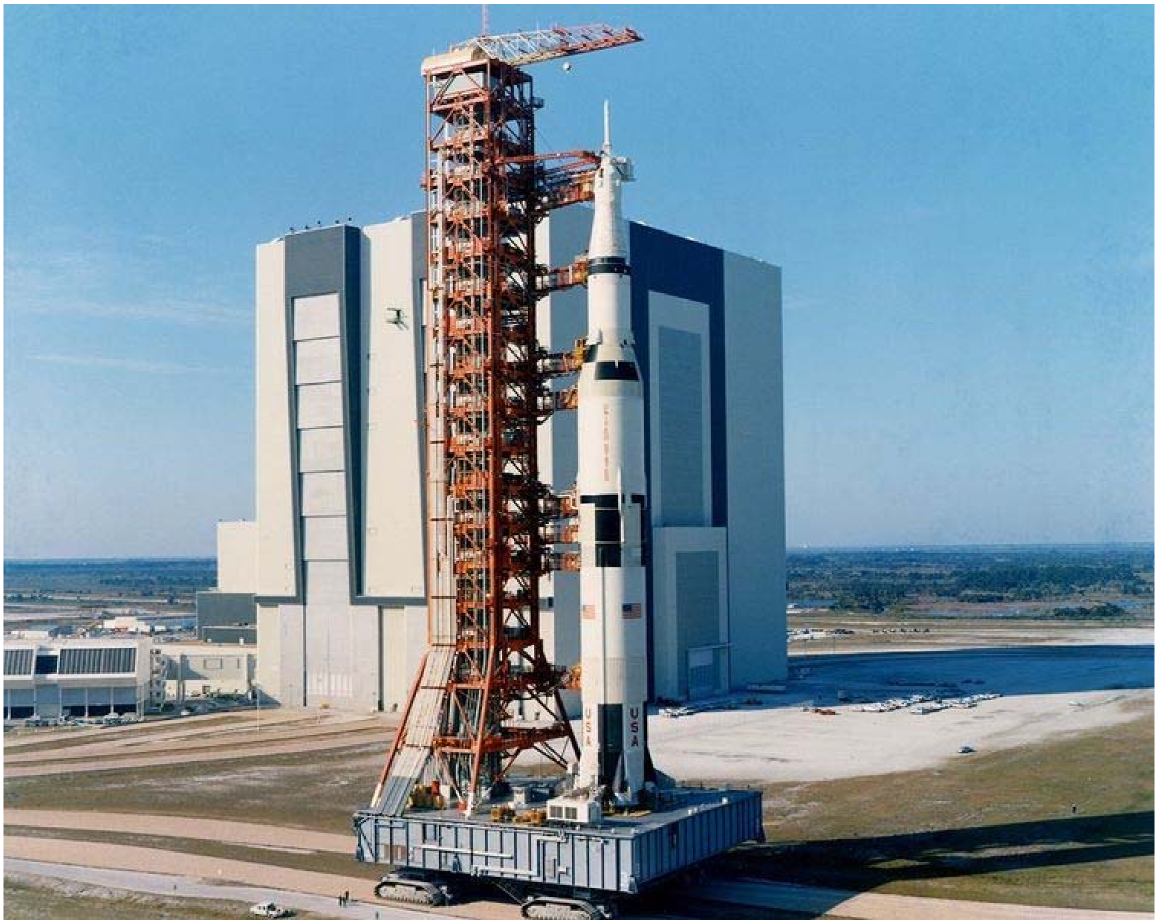
Without knowing the exact measurement technique and mathematical method used to determine thrust for each different rocket, comparisons are often inexact. As the above shows, the specified thrust often differs significantly from actual flight thrust calculated from direct measurements. The thrust stated in various references is often not adequately qualified as to vacuum vs sea level, or peak vs average thrust.

Similarly, payload increases are often achieved in later missions independent of engine thrust. This is by weight reduction or trajectory reshaping.

The result is there is no single absolute figure for engine thrust, stage thrust or vehicle payload. There are specified values and actual flight values, and various ways of measuring and deriving those actual flight values.

The performance of each Saturn V launch was extensively analyzed and a Launch Evaluation Report produced for each mission, including a thrust/time graph for each vehicle stage on each mission.

Assembly



The Apollo 10 Saturn V during rollout

After the construction and ground testing of a stage was completed, it was then shipped to the Kennedy Space Center. The first two stages were so large that the only way to transport them was by barge. The S-IC, constructed in New Orleans, was transported down the Mississippi River to the Gulf of Mexico. After rounding Florida, it was then transported up the Intra-Coastal Waterway to the Vertical Assembly Building (now called the Vehicle Assembly Building). This is in essence the same route used by NASA today to ship Space Shuttle External Tanks. The S-II was constructed in California and so traveled via the Panama Canal. The third stage and Instrument Unit could be carried by the Aero Spacelines Pregnant Guppy and Super Guppy, but could also have been carried by barge if warranted.

On arrival at the Vertical Assembly Building, each stage was checked out in a horizontal position before being moved to a vertical position. NASA also constructed large spoolshaped structures that could be used in place of stages if a particular stage was late. These spools had the same height and mass and contained the same electrical connections as the actual stages.

NASA *stacked* or assembled the Saturn V on a Mobile Launcher Platform (MLP), which consisted of a Launch Umbilical Tower (LUT) with nine swing arms (including the crew access arm), a "hammerhead" crane, and a water suppression system which was activated prior to launch. After assembly was completed, the entire stack was moved from the VAB to the launch pad using the Crawler Transporter (CT). Built by the Marion Power Shovel company, and still in use today for transporting the smaller and lighter Space Shuttle, the CT runs on four double-tracked treads, each with 57 'shoes'. Each shoe weighs 900 kg (2,000 lb). This transporter was also required to keep the rocket level as it traveled the 3 miles (5 km) to the launch site, especially at the 3 percent grade encountered at the launch pad. The CT also carried the Mobile Service Structure (MSS), which allowed technicians access to the rocket until eight hours before launch, when it was moved to the "halfway" point on the Crawlerway (the junction between the VAB and the two launch pads).

Lunar mission launch sequence

Liftoff of Apollo 11, the first mission to land humans on the Moon, July 16, 1969

The Saturn V carried all Apollo lunar missions. All Saturn V missions launched from Launch Complex 39 at the John F. Kennedy Space Center. After the rocket cleared the launch tower, flight control transferred to Johnson Space Center's Mission Control in Houston, Texas.

An average mission used the rocket for a total of just 20 minutes. Although Apollo 6 and Apollo 13 experienced engine failures, the onboard computers were able to compensate by burning the remaining engines longer, and none of the Apollo launches resulted in a payload loss.

S-IC sequence

A condensation cloud surrounds the Apollo 11 Saturn V as it works its way through the dense lower atmosphere.

The first stage burned for 2.5 minutes, lifting the rocket to an altitude of 42 miles (68 km) and a speed of 6,164 miles per hour (9,920 km/h) and burning 2,000,000 kilograms (4,400,000 lb) of propellant.

At 8.9 seconds before launch, the first stage ignition sequence started. The center engine ignited first, followed by opposing outboard pairs at 300-millisecond intervals to reduce the structural loads on the rocket. When thrust had been confirmed by the onboard computers, the rocket was "soft-released" in two stages: first, the hold-down arms released the rocket, and second, as the rocket began to accelerate upwards, it was slowed by tapered metal pins pulled through dies for half a second. Once the rocket had lifted off, it could not safely settle back down onto the pad if the engines failed.

It took about 12 seconds for the rocket to clear the tower. During this time, it yawed 1.25 degrees away from the tower to ensure adequate clearance despite adverse winds. (This yaw, although small, can be seen in launch photos taken from the east or west.) At an altitude of 430 feet (130 m) the rocket rolled to the correct flight azimuth and then gradually pitched down until 38 seconds after second stage ignition. This pitch program was set according to the prevailing winds during the launch month. The four outboard engines also tilted toward the outside so that in the event of a premature outboard engine shutdown the remaining engines would thrust through the rocket's center of gravity. The Saturn V quickly accelerated, reaching 400 feet per second (120 m/s) at over 1 mile (1,600 m) in altitude. Much of the early portion of the flight was spent gaining altitude, with the required velocity coming later.

Apollo 11 S-IC separation

At about 80 seconds, the rocket experienced maximum dynamic pressure (max *Q*). The dynamic pressure on a rocket varies with air density and the square of relative velocity. Although velocity continues to increase, air density decreases so quickly with altitude that dynamic pressure falls below max *Q*.

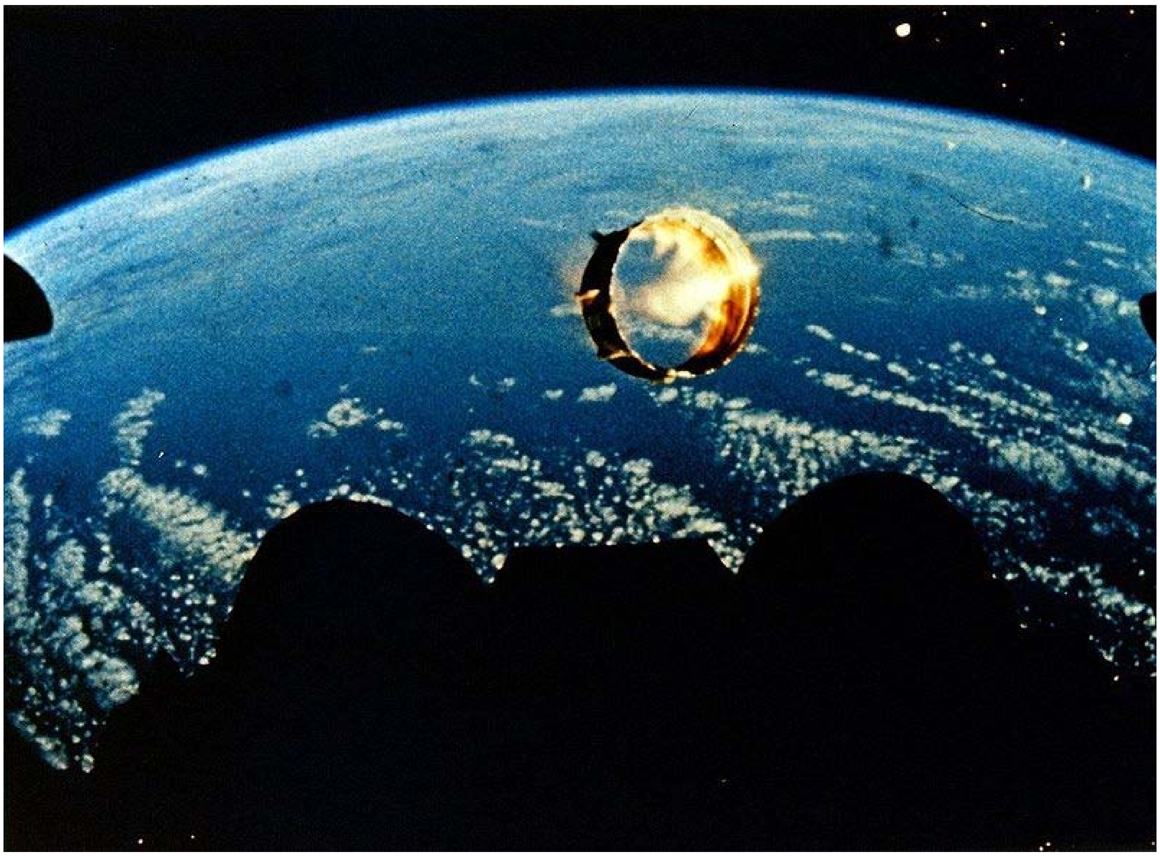
Acceleration increased during S-IC flight for two reasons: decreasing propellant mass, and increasing thrust as F-1 engine efficiency improved in the thinner air at altitude. At 135 seconds, the inboard (center) engine shut down to limit acceleration to 4 *g* (39.2 m/s^2). The other engines continued to burn until either oxidizer or fuel depletion is detected by sensors in the suction assemblies. First stage separation was a little less than one second after cutoff to allow for F-1 thrust tail-off. Eight small solid fuel separation motors backed the S-IC from the interstage at an altitude of about 67 kilometers (42 mi). The first stage continued ballistically to an altitude of about 109 kilometers (68 mi) and then fell in the Atlantic Ocean about 560 kilometers (350 mi) downrange.

S-II sequence

Still from film footage of Apollo 6's interstage falling away (NASA)

After S-IC separation, the S-II second stage burned for 6 minutes and propelled the craft to 109 miles (176 km) and 15,647 mph (25,182 km/h– 7.00 km/s), close to orbital velocity.

For the first two unmanned launches, eight solid-fuel ullage motors ignited for four seconds to give positive acceleration to the S-II stage, followed by start of the five J-2 engines. For the first seven manned Apollo missions only four ullage motors were used on the S-II, and they were eliminated completely for the final four launches. About 30 seconds after first stage separation, the interstage ring dropped from the second stage. This was done with an inertially fixed attitude so that the interstage, only 1 meter from the outboard J-2 engines, would fall cleanly without contacting them. Shortly after interstage separation the Launch Escape System was also jettisoned.



Apollo 6 interstage falling away. The engine exhaust from the SII-C stage is clearly shown impacting the falling stage.

About 38 seconds after the second stage ignition the Saturn V switched from a preprogrammed trajectory to a "closed loop" or Iterative Guidance Mode. The Instrument Unit now computed in real time the most fuel-efficient trajectory toward its target orbit. If the Instrument Unit failed, the crew could switch control of the Saturn to the Command Module's computer, take manual control, or abort the flight.

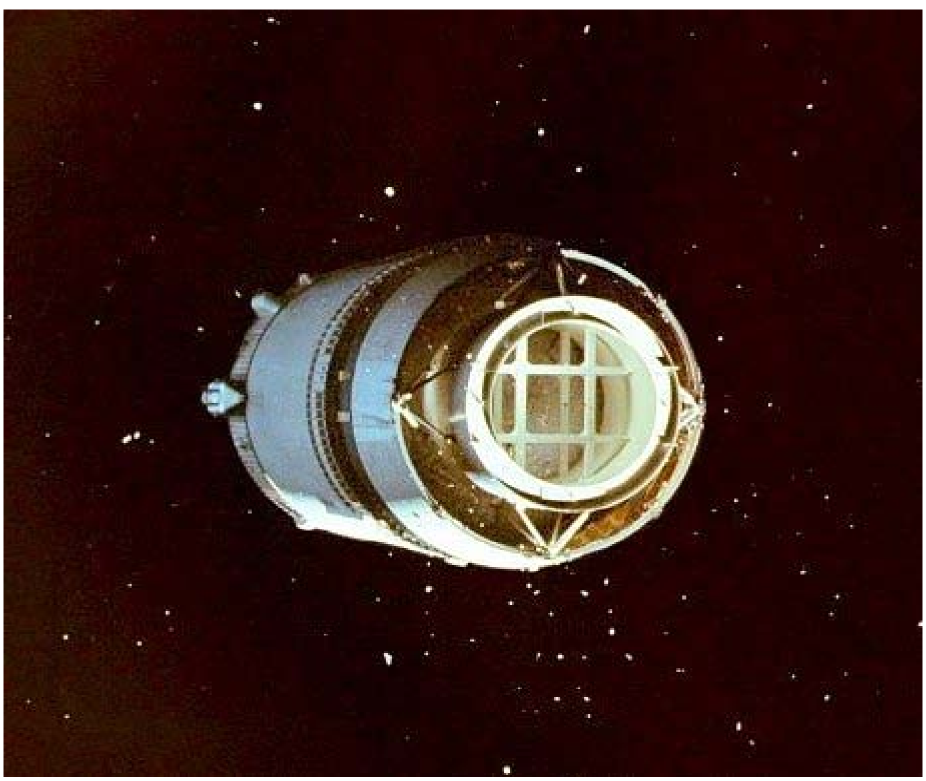
About 90 seconds before the second stage cutoff, the center engine shut down to reduce longitudinal pogo oscillations. A pogo suppressor, first flown on Apollo 14, stopped this motion but the center engine was still shut down early to limit acceleration G forces. At around this time, the LOX flow rate decreased, changing the mix ratio of the two propellants, ensuring that there would be as little propellant as possible left in the tanks at the end of second stage flight. This was done at a predetermined delta-v.

Five level sensors in the bottom of each S-II propellant tank were armed during S-II flight, allowing any two to trigger S-II cutoff and staging when they were uncovered. One second after the second stage cut off it separated and several seconds later the third stage ignited. Solid fuel retro-rockets mounted on the interstage at the top of the S-II fired to back it away from the S-IVB. The S-II impacted about 4200 km (2,300 miles) from the launch site.

S-IVB sequence

Unlike the two-plane separation of the S-IC and S-II, the S-II and S-IVB stages separated with a single step. Although it was constructed as part of the third stage, the interstage remained attached to the second stage.

During Apollo 11, a typical lunar mission, the third stage burned for about 2.5 minutes until first cutoff at 11 minutes 40 seconds. At this point it was 1,640 miles (2,640 km) downrange and in a parking orbit at an altitude of 118.8 miles (191.2 km) and velocity of 17,432 mph. The third stage remained attached to the spacecraft while it orbited the Earth two and a half times while astronauts and mission controllers prepared for translunar injection (TLI).



Apollo 8 S-IVB rocket stage, shortly after separation

This parking orbit was quite low by Earth orbit standards, and it would have been short-lived due to aerodynamic drag. This was not a problem on a lunar mission because of the short stay in the parking orbit. The S-IVB also continued to thrust at a low level by venting gaseous hydrogen, to keep propellants settled in their tanks and prevent gaseous cavities from forming in propellant feed lines. This venting also maintained safe pressures as liquid hydrogen boiled off in the fuel tank. This venting thrust easily exceeded aerodynamic drag.

For the final three Apollo flights, the temporary parking orbit was even lower (approximately 150 kilometers (93 mi)), to increase payload for these missions. The Apollo 9 Earth orbit mission was launched into the nominal orbit consistent with Apollo 11, but the spacecraft were able to use their own engines to raise the perigee high enough to sustain the 10-day mission. The Skylab was launched into a quite different orbit, with a 434-kilometer (270 mi) perigee which sustained it for six years, and also a higher inclination to the equator (50 degrees versus 32.5 degrees for Apollo).

On Apollo 11, TLI came at 2 hours and 44 minutes after launch. The S-IVB burned for almost six minutes giving the spacecraft a velocity close to the Earth's escape velocity of 11.2 km/s (40,320 km/h; 25,053 mph). This gave an energy-efficient transfer to lunar orbit with the moon helping to capture the spacecraft with a minimum of CSM fuel consumption.

About 40 minutes after TLI the Apollo Command Service Module (CSM) separated from the third stage, turned 180 degrees and docked with the Lunar Module (LM) that rode below the CSM during launch. The CSM and LM separated from the spent third stage 50 minutes later.

If it were to remain on the same trajectory as the spacecraft, the S-IVB could have presented a collision hazard so its remaining propellants were vented and the auxiliary propulsion system fired to move it away. For lunar missions before Apollo 13, the S-IVB was directed toward the moon's trailing edge in its orbit so that the moon would slingshot it beyond earth escape velocity and into solar orbit. From Apollo 13 onwards, controllers directed the S-IVB to hit the Moon. Seismometers left behind by previous missions detected the impacts, and the information helped map the inside of the Moon.

Apollo 9 was a special case; although it was an earth orbital mission, after spacecraft separation its S-IVB was fired out of earth orbit into a solar orbit.

On September 3, 2002, astronomer Bill Yeung discovered a suspected asteroid, which was given the discovery designation J002E3. It appeared to be in orbit around the Earth, and was soon discovered from spectral analysis to be covered in white titanium dioxide paint, the same paint used for the Saturn V. Calculation of orbital parameters identified the apparent asteroid as being the Apollo 12 S-IVB stage. Mission controllers had planned to send Apollo 12's S-IVB into solar orbit, but the burn after separating from the Apollo spacecraft lasted too long, and hence it did not pass close enough to the Moon, remaining in a barely-stable orbit around the Earth and Moon. In 1971, through a series of gravitational perturbations, it is believed to have entered in a solar orbit and then returned into weakly-captured Earth orbit 31 years later. It left Earth orbit again in June 2003. Another near-earth object, discovered in 2006 and designated 6Q0B44E, may also be part of an Apollo spacecraft.

Skylab

The last Saturn V launch carried the Skylab space station to low Earth orbit in place of the third stage.

In 1968, the Apollo Applications Program was created to look into science missions that could be performed with the surplus Apollo hardware. Much of the planning centered on the idea of a space station, which eventually spawned the Skylab program. Skylab was launched using a two-stage Saturn V, sometimes called a Saturn INT-21. It was the only launch not directly related to the Apollo lunar landing program.

Originally it was planned to use a 'wet workshop' concept, with a rocket stage being launched into orbit by a Saturn 1B and its spent S-IVB outfitted in space, but this was abandoned for the 'dry workshop' concept: An S-IVB stage from a Saturn IB was converted into a space station on the ground and launched on a Saturn V. A backup, constructed from a Saturn V third stage, is now on display at the National Air and Space Museum.

Three crews lived aboard Skylab from May 25, 1973 to February 8, 1974, with Skylab remaining in orbit until July 11, 1979.

Proposed post-Apollo developments

The (canceled) second production run of Saturn Vs would very likely have used the F-1A engine in its first stage, providing a substantial performance boost. Other likely changes would have been the removal of the fins (which turned out to provide little benefit when compared to their weight); a stretched S-IC first stage to support the more powerful F-1As; and uprated J-2s for the upper stages.

A number of alternate Saturn vehicles were proposed based on the Saturn V, ranging from the Saturn INT-20 with an S-IVB stage and interstage mounted directly onto an S-IC stage, through to the Saturn V-23(L) which would not only have five F-1 engines in the first stage, but also four strap-on boosters with two F-1 engines each: giving a total of thirteen F-1 engines firing at launch.

The Space Shuttle was initially conceived of as a cargo transport to be used in concert with the Saturn V, even to the point that a "Saturn-Shuttle," using the current orbiter and external tank, but with the tank mounted on a modified, fly-back version of the S-IC, would be used to power the Shuttle during the first two minutes of flight, after which the S-IC would be jettisoned (which would then fly back to KSC for refurbishment) and the Space Shuttle Main Engines would then fire and place the orbiter into orbit. The Shuttle would handle space station logistics, while Saturn V would launch components. Lack of a second Saturn V production run killed this plan and has left the United States without a heavy-lift booster. Some in the U.S. space community have come to lament this situation, as continued production would have allowed the International Space Station, using a Skylab or Mir configuration with both U.S. and Russian docking ports, to have been lifted with just a handful of launches, with the "Saturn Shuttle" concept possibly eliminating the conditions that caused the *Challenger* Disaster in 1986.

The Saturn V would have been the prime launch vehicle for the canceled *Voyager* Mars probes, and was to have been the launch vehicle for the nuclear rocket stage RIFT test program and the later NERVA.

Proposed successors

U.S. proposals for a rocket larger than the Saturn V from the late 1950s through the early 1980s were generally called Nova. Over thirty different large rocket proposals carried the Nova name, but none were developed.

Wernher von Braun and others also had plans for a rocket that would have featured eight F-1 engines in its first stage allowing it to launch a manned spacecraft on a direct ascent flight to the Moon. Other plans for the Saturn V called for using a Centaur as an upper stage or adding strap-on boosters. These enhancements would have increased its ability to send large unmanned spacecraft to the outer planets or manned spacecraft to Mars.

In 2006, as part of the cancelled Constellation Program that would have replaced the Space Shuttle, NASA unveiled plans to construct the heavy-lift Ares V rocket, a Shuttle Derived Launch Vehicle using some existing Space Shuttle and Saturn V infrastructure. Named in homage of the Saturn V, the original design, based on the Space Shuttle External Tank, was 360 ft (110 m) tall, and powered by five Space Shuttle Main Engines (SSMEs) and two uprated five-segment Space Shuttle Solid Rocket Boosters, which a modified variation would be used for the crew-launched Ares I rocket. As the design evolved, the Ares V was slightly modified, with the same 33 ft (10 m) diameter as that of the Saturn V's S-IC and S-II stages, and in place of the five SSMEs, five RS-68 rocket engines, the same engines used on the Delta IV EELV, would be used. The switch from the SSME to the RS-68 was due to the steep price of the cost of the SSME, as that it would be thrown away along with the Ares V core stage after each use, while the RS-68 engine, which is expendable, is cheaper, simpler to manufacture, and more powerful than the SSME.

In 2008, NASA again redesigned the Ares V, lengthening and widening the core stage and added an extra RS-68 engine, giving the launch vehicle a total of *six* engines. The six RS-68B engines, during launch, would have been augmented by two "5.5-segment" SRBs instead of the original five-segment designs, although no decision was made on the number of segments NASA would have used on the final design. If the six RS-68B/5.5-segment SRB variant had been used, the vehicle would have had a total of approximately 8,900,000 lbf (39.6 MN) of thrust at liftoff, making it more powerful than the Saturn V or the Soviet/Russian Energia boosters, but less than 50–43 MN for the Soviet N-1. An upper stage, known as the Earth Departure Stage and based on the S-IVB, would have utilized a more advanced version of the J-2 engine known as the "J-2X," and would have placed the Altair lunar landing vehicle into a low earth orbit. At 381 ft (116 m) tall and with the capability of placing 180 tons into low Earth orbit, the Ares V would have surpassed the Saturn V and the two Soviet/Russian superboosters in both height, lift, and launch capability.

The RS-68B engines, based on the current RS-68 and RS-68A engines built by the Rocketdyne Division of Pratt and Whitney (formerly under the ownerships of Boeing and Rockwell International), produce less than half the thrust per engine as the Saturn V's F-1 engines, but are more efficient and can be throttled up or down, much like the SSMEs on the Shuttle. The J-2 engine used on the S-II and S-IVB would have been modified into the improved J-2X engine for use both on the Earth Departure Stage (EDS) as well as on the second stage of the proposed Ares I. Both the EDS and the Ares I second stage would have used a single J-2X motor, although the EDS was originally designed to use two motors until the redesign employing the five (later six) RS-68Bs in place of the five SSMEs.

Cost

From 1964 until 1973, a total of $6.5 billion ($43.99 billion present day) was appropriated for the Saturn V, with the maximum being in 1966 with $1.2 billion ($8.12 billion present day).

One of the main reasons for the cancellation of the Apollo program was the cost. In 1966, NASA received its biggest budget of US$4.5 billion, about 0.5 percent of the GDP of the United States at that time. In 1969, the cost of a Saturn V including launch was US $ 185 million (inflation adjusted US$ 1.11 billion in 2011).

Saturn V vehicles and launches

A montage of all Saturn V launches, 1967–1973.

Serial Number	Mission	Launch Date	Notes
SA-500F	Facilities integration		Used to check precise fits and operations of facilities before a flight model was ready. First stage scrapped, second stage converted to S-II-F/D, third stage whereabouts unknown.

SA-500D	Dynamic testing		Used to evaluate the systems' response to vibrations. On display at the U.S. Space & Rocket Center, Huntsville, Alabama
SA-501	Apollo 4	November 9, 1967	First test flight, complete success
SA-502	Apollo 6	April 4, 1968	Second test flight, with some serious second and third stage problems occurring
SA-503	Apollo 8	December 21, 1968	First manned flight of Saturn V and lunar orbit
SA-504	Apollo 9	March 3, 1969	Earth orbit LM test
SA-505	Apollo 10	May 18, 1969	Lunar orbit LM test
SA-506	Apollo 11	July 16, 1969	First manned lunar landing
SA-507	Apollo 12	November 14, 1969	Landed near Surveyor 3. Vehicle was struck twice by lightning after liftoff with no serious damage.
SA-508	Apollo 13'	April 11, 1970	Severe, near catastrophic pogo oscillations in second stage caused early center engine shutdown. Service Module O_2 tank rupture caused mission abort en route to moon, crew saved.
SA-509	Apollo 14'	January 31, 1971	Landed near Fra Mauro
SA-510	Apollo 15	July 26, 1971	First Lunar Rover
SA-511	Apollo 16'	April 16, 1972	Landed at Descartes
SA-512	Apollo 17	December 6, 1972	First and only night launch; final Apollo lunar mission
SA-513	Skylab 1	May 14, 1973	Two-stage Skylab version (Saturn INT-21). The third stage (S IV-513) was replaced for flight by the Skylab module and is on display at Johnson Space Center.
SA-514	Unused		Designated but never used for Apollo 18 or 19. First stage (S-IC-14) on display at Johnson Space Center, second stage (S-IC-T) on display at Kennedy Space Center.
SA-515	Unused		Designated but never used as a backup Skylab launch vehicle. The first stage is on display at Michoud Assembly Facility. The second stage (S-II-15) is on display at Johnson Space Center. The third stage was converted to a backup Skylab orbital workshop and is on display at the National Air and Space Museum.

Saturn V displays

- Two at the U.S. Space & Rocket Center in Huntsville:

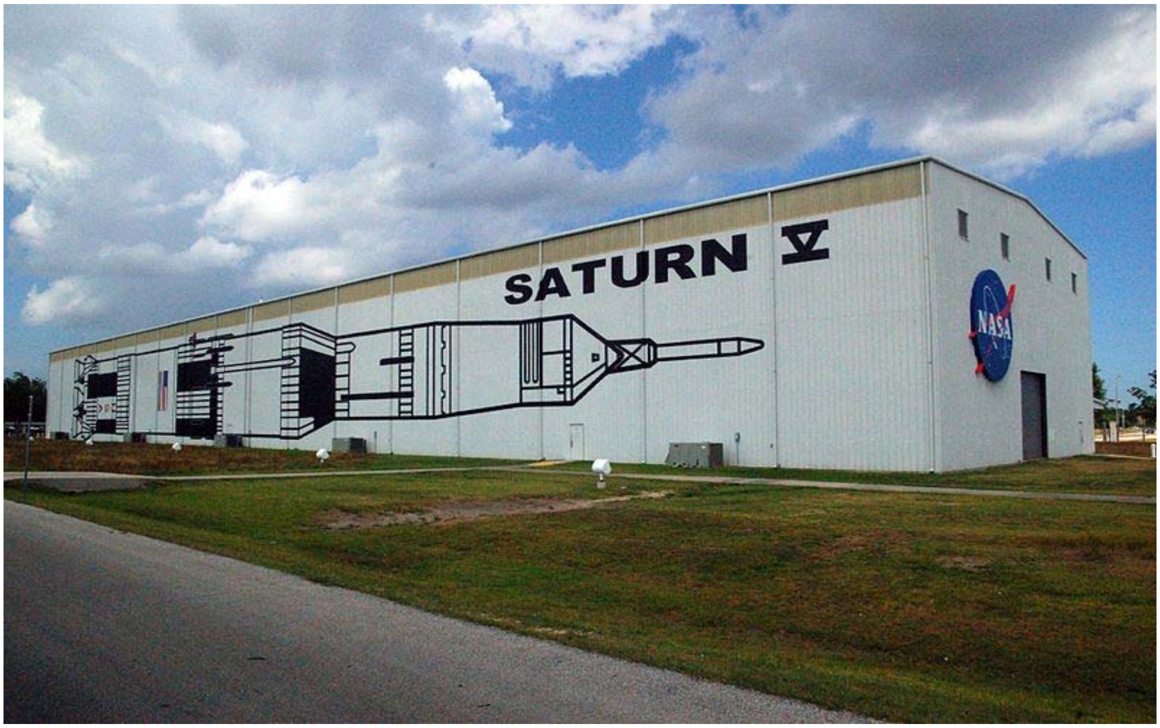
    - SA-500D is on horizontal display made up of S-IC-D, S-II-F/D and S-IVB-D. These were all test stages not meant for flight. This vehicle was displayed outdoors from 1969 to 2007 (there is a poignant photo above of Wernher von Braun next to it), was restored, and is now displayed in the Davidson Center for Space Exploration.
    - Vertical display (replica) built in 1999 located in an adjacent area.

- One at the Johnson Space Center made up of first stage from SA-514, the second stage from SA-515 and the third stage from SA-513 (replaced for flight by the Skylab workshop). With stages arriving between 1977 and 1979, this was displayed in the open until its 2005 restoration when a structure was built around it for protection. This is the only display Saturn consisting entirely of stages intended to be launched.

- One at the Kennedy Space Center Visitor Complex made up of S-IC-T (test stage) and the second and third stages from SA-514. It was displayed outdoors for decades, then in 1996 was enclosed for protection from the elements in the Apollo/Saturn V Center.

- The S-IC stage from SA-515 is on display at the Michoud Assembly Facility in New Orleans, Louisiana.
- The S-IVB stage from SA-515 was converted for use as a backup for Skylab, and is on display at the National Air and Space Museum in Washington, D.C..

U.S. Space & Rocket Center



Johnson Space Center

Kennedy Space Center