ROYAL CANADIAN AIR CADETS

PROFICIENCY LEVEL TWO

INSTRUCTIONAL GUIDE

SECTION 6

EO C232.02 – IDENTIFY THE CHARACTERISTICS OF ROCKET ENGINES

Total Time: 90 min

PREPARATION

PRE-LESSON INSTRUCTIONS

Resources needed for the delivery of this lesson are listed in the lesson specification located in A-CR-CCP-802/PG-001, Chapter 4. Specific uses for said resources are identified throughout the Instructional Guide within the TP for which they are required.

Review the lesson content and become familiar with the material prior to delivering the lesson.

Create slides or photocopy the handouts located at Annexes A, B, C, D and Annex A to EO C232.03.

PRE-LESSON ASSIGNMENT

N/A.

APPROACH

An interactive lecture was chosen for TP1, TP3, TP4 and TP5 to introduce rocket engines and give an overview of them.

An in-class activity was chosen for TP2 as it is an interactive way to provoke thought and stimulate an interest among cadets.

INTRODUCTION

REVIEW

N/A.

OBJECTIVES

By the end of this lesson the cadet shall be expected to identify the characteristics of rocket engines.

IMPORTANCE

It is important for cadets to know about the characteristics of rockets so that they can understand the Canadian Space Agency's mission to promote the peaceful use and development of space, to advance the knowledge of space through science and to ensure that space science and technology provide social and economic benefits for Canadians.

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Teaching point 1 **Explain Aspects of Reactive Thrust Used in Propulsion**

Time: 5 min Method: Interactive Lecture

Every method of propulsion relies on Newton's third law, which states that for every action there is an equal and opposite reaction. This is most obvious when the original action affects an object that is close in size to the object that the reaction affects, such as when a swimmer pushes a floating object. In that case, the swimmer is pushed backward when the object is pushed forward.

However, when the object to be pushed is as large as the Earth, as in the case of a person taking a step forward, it is not so obvious that the Earth moves in the opposite direction when the step is taken. Yet the tiny motion of the Earth is in the opposite direction. The difference in the amount moved is proportional to the difference in weight between the Earth and the walker, so that the reaction is equal, as well as opposite.

In that same way, a wheeled vehicle such as an automobile pushes on the Earth when it begins its journey. Since the automobile is much smaller than the Earth, the smaller mass of the automobile moves much more than the great mass of the Earth. The swimmer, the person walking and the wheeled automobile are all relying on traction to propel them forward.

Newton's third law of motion also dictates the movement of propeller-driven aircraft and jet aircraft. The forward motion of aircraft depends on pushing gases backward instead of pushing the Earth backward. A propeller pushes air backwards and this is called prop wash. A jet engine ejects hot exhaust gases backwards. To move in any direction, all objects and all creatures, whether living or artificial, must push matter of some sort in the opposite direction.



Newton's third law of motion states that for every action there is an equal and opposite reaction. The third law can be correctly interpreted to mean that for every desired reaction there must be an equal and opposite action.

CONFIRMATION OF TEACHING POINT 1

QUESTIONS

Q1. What does Newton's third law of motion state?

Q2. Why does the Earth not seem to move backwards when a person steps forward?

Q3. What does a propeller-driven aircraft create to move forward?

ANTICIPATED ANSWERS

A1. Newton's third law of motion states that for every action there is an equal and opposite reaction.

A2. The Earth does move when a person steps forward, but the ratio of the weight of the Earth versus the weight of the person is so great that the movement of the Earth is too small to be seen.

A3. A propeller-driven aircraft creates prop wash to move forward.

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Teaching point 2 **Explore Newton's Third Law of Motion by Operating Balloon Rockets**

Time: 20 min Method: In-Class Activity

ACTIVITY

OBJECTIVE

The objective of this activity is to have the cadets explore Newton's third law of motion by staging and operating balloon rockets.

RESOURCES

- Instructions for staging balloon rockets located at Annex A,
- Balloons,
- String,
- Straw,
- Tape, and
- Paper or Styrofoam cup.

ACTIVITY LAYOUT

This activity requires a large area to suspend a string guidance system. Place the string through two drinking straws and suspend the string horizontally about 1-1/2 metres above the floor with the ends as far apart as possible. Tighten the string.

ACTIVITY INSTRUCTIONS

1. Tape two inflated but untied balloons to the two drinking straws as shown in Figures A-1 and A-2.

2. Cut off the bottom of the paper or Styrofoam cup and place it over the junction between the two balloons so that air cannot escape from the second stage until the first stage is spent and jettisoned.

3. Release the first stage balloon and allow the two-stage rocket to travel as far as possible down the guidance string.



Point out to the cadets that the air ejected from the balloon causes the balloon to accelerate forward according to Newton's third law of motion. Point out that the energy involved came from cadets when they puffed hard to inflate the balloons.

SAFETY

N/A.

CONFIRMATION OF TEACHING POINT 2

The cadets' participation in the activity will serve as the confirmation of this TP.

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Teaching point 3 **Explain How Rocket Systems Operate in Space**

Time: 5 min Method: Interactive Lecture

A balloon rocket would work in outer space. The air that is ejected from the balloon would produce the same opposite and equal reaction in space that it does in the Earth's atmosphere, except that form drag from the atmosphere would not slow the balloon's travel. The balloon rocket's performance would be improved in space, without the form drag of air.

A reactive propulsion system can operate by ejecting any material. However, the higher the speed of the ejected material, the greater the resulting propulsive force will be. To raise the velocity of ejection, material is most often heated to create pressure. This has been the preferred solution since Hero used steam to operate his toy Aeolipile (pronounced A – O – lipile).



Show the cadets a slide or distribute handouts of Aeolipile in Figure B-1.

Hero of Alexandria invented a rocket-like sphere called an Aeolipile, in about 150 BC, which used steam as a propulsive gas. Hero mounted it on top of a water kettle. A fire below the kettle turned the water into steam, which travelled through pipes to the Aeolipile. Two L-shaped tubes on opposite sides of the sphere allowed the steam to escape and so gave thrust to the sphere that caused it to rotate.

Heating of the material to be ejected most often involves combustion in contemporary rockets although other methods could be used. Rocket combustion systems operate in space because they are self-contained and require no atmospheric oxygen.



Show the cadets a slide or distribute handouts of Combustion in Figure B-2.

Combustion in a rocket engine or a jet engine requires the rapid oxidization of fuel. A jet engine gets access to oxygen by drawing it from the surrounding air, so that a jet's range is limited to the atmosphere. A rocket develops thrust in much the same way as a jet, but a rocket carries its own oxygen supply. Rocket engines and jet engines both have nozzles to generate thrust.



Show the cadets a slide or distribute handouts of a rocket nozzle in Figure B-3.

A rocket engine uses a nozzle to accelerate hot exhaust to produce thrust as described by Newton's third law of motion. The amount of thrust produced by the engine at any given moment depends on both the amount of gas ejected each second and its velocity. These are determined by the rocket nozzle design.



A rocket works in outer space because it brings everything it needs with it.

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The Earth's atmosphere is mostly nitrogen. Oxygen is only a fifth of the atmosphere's composition. Therefore, simply storing air for combustion would waste most of the storage space on unreactive nitrogen. To make good use of storage space, oxygen is stored in more pure forms, including liquid oxygen, or LOX. This gives the rocket engine the ability to operate for a longer period in outer space.

CONFIRMATION OF TEACHING POINT 3

QUESTIONS

Q1. What must a reactive propulsion system eject to move forward?

Q2. Why is oxygen stored for a rocket's combustion instead of just air?

Q3. Why does a contemporary rocket engine heat the material to be ejected?

ANTICIPATED ANSWERS

A1. A reactive propulsion system can eject any material to move forward.

A2. Oxygen is stored for combustion instead of air because air is mostly nitrogen.

A3. A rocket engine heats the material to be ejected to create pressure to raise the velocity of the ejected material.

Teaching point 4 — **Explain the Differences Between Solid-fuel and Liquid-fuel Rocket Engine Systems**

Time: 10 min — Method: Interactive Lecture

CONSTRUCTION

There are three main categories of rocket engines; liquid rockets and solid rockets.

Liquid rocket propellants, the fuel and the oxidizer, are stored separately as liquids and are pumped into the combustion chamber of the nozzle where burning occurs.

Solid rocket propellants, both fuel and oxidizer, are mixed together to form a composite fuel and then packed into a solid cylinder. Under normal temperature conditions the solid rocket propellants do not burn until exposed to a source of heat provided by an igniter. Once the burning in a solid rocket starts, it proceeds until all the propellant is exhausted.



With a liquid rocket the pilot can stop or modify the thrust by turning off the flow of propellants; but with a solid rocket, the casing must be destroyed to stop the engine.

Liquid rockets tend to be heavier and more complex because of the pumps and storage tanks. The propellants are loaded onto the rocket just before launch. A solid rocket is much easier to handle and can sit for years before firing.



Show the cadets a slide or distribute handouts of Figure C-1 (Solid Rocket) and Figure C-2 (Liquid Rocket).

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VEHICLE APPLICATIONS

Solid rocket engines are used on air-to-air and air-to-ground missiles, on model rockets and as boosters for satellite launchers, including the space shuttle's two solid rocket boosters (SRBs).

Liquid rocket engines are used in the Space Shuttle's main engines to place humans in orbit, on many robot missiles to place satellites in orbit and on several high-speed research aircraft.

FUELS AND OXIDIZATION

In a solid rocket, the fuel and oxidizer are mixed together into a solid propellant, which is packed into a solid cylinder. A hole through the cylinder serves as a combustion chamber. When the mixture is ignited, combustion takes place on the surface of the propellant. A flame front is generated which burns into the mixture. The combustion produces great amounts of exhaust gas at a high temperature and pressure. The amount of exhaust gas that is produced depends on the area of the flame front and engine designers use a variety of hole shapes to control the change in thrust for a particular engine. The hot exhaust gas is passed through a nozzle, which accelerates the flow. Thrust is then produced according to Newton's third law of motion.

In a liquid rocket, stored fuel and stored oxidizer are pumped into a combustion chamber where they are mixed and burned. The combustion produces great amounts of exhaust gas at high temperature and pressure. The hot exhaust is passed through a nozzle, which accelerates the flow. Thrust is produced according to Newton's third law of motion.



Show the cadets a slide or distribute handouts of Figure C-3 (Liquid System Rocket).

There are many parts that make up a liquid-fuelled rocket. For design and analysis, engineers group parts which have the same function into systems. There are four major systems in a full scale rocket: the structural system, the payload system, the guidance system and the propulsion system.

CONFIRMATION OF TEACHING POINT 4

QUESTIONS

Q1. What does the term "composite" solid rocket fuel mean?

Q2. What operational advantages does a solid rocket have over a liquid rocket?

Q3. What great operational advantage does a liquid rocket have over a solid rocket?

ANTICIPATED ANSWERS

A1. A composite rocket fuel has both fuel and oxidizer mixed together.

A2. A solid rocket weighs less and is less complex.

A3. A liquid rocket can be controlled and shut off after ignition.

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Teaching point 5 **Discuss American, Russian, European and Chinese Launch Vehicles**

Time: 15 min Method: Interactive Lecture

Although space-age rocketry is often considered to be in its early stages, there are many launch vehicles to explore. One example each of American, Russian, European and Chinese launchers follow:

American Launch Vehicle – Ares

NASA currently has many launchers that they can match to particular missions. For manned space flight after the space shuttle program, the Ares series of rockets has been developed.



Show the cadets a slide or distribute handouts of Figure D-1 (Ares I Launch Vehicle).

Ares I is an in-line, two-stage rocket configuration topped by the Orion crew vehicle and its launch abort system. In addition to the vehicle's primary mission – carrying crews of four to six astronauts to Low Earth Orbit (LEO) – Ares I may also use its 22.5-tonne payload capacity to deliver resources and supplies to the International Space Station, or to "park" payloads in orbit for retrieval by other spacecraft bound for the Moon or other destinations.

The Ares I first stage is a single, five-segment Reusable Solid Rocket Booster (RSRB) derived from the Space Shuttle Program's reusable solid rocket motor, which burns a specially formulated and shaped solid propellant.

The Ares I second, or upper, stage is propelled by a J-2X main engine fuelled with liquid oxygen and liquid hydrogen.



Show the cadets a slide or distribute handouts of Figure D-2 (Ares V Launch Vehicle).

The first stage of the Ares V vehicle relies on two, five-segment reusable solid rocket boosters for lift-off. The twin solid rocket boosters of the first stage flank a single, liquid-fuelled central booster element.

The central booster tank delivers liquid oxygen and liquid hydrogen fuel to five RS-68 rocket engines. The RS-68 engines serve as the core stage propulsion for Ares.

Atop the central booster element is an interstage cylinder, which includes booster separation motors and a newly designed forward adapter that mates the first stage with the Earth Departure Stage. A J-2X main engine fuelled with liquid oxygen and liquid hydrogen propels the Earth Departure Stage, the same J-2X engine as is used in the Ares I upper stage.

Russian Launch Vehicle – Proton



Show the cadets a slide or distribute handouts of Figure D-3 (Proton Launch Vehicle).

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The Proton engines burn a liquid fuel called hydrazine (UDMH) with an oxidizer called Nitrogen Tetroxide. Nitrogen Tetroxide and UDMH burn when they come in contact, without any ignition, so they are said to be hypergolic.

The Proton launch vehicle is currently used for national programs and commercial launches of foreign satellites. Proton is designed as a tandem launch vehicle available in three-stage and four-stage options.

European Launch Vehicle – Ariane 5



Show the cadets a slide or distribute handouts of Figure D-4 (Ariane Launch Vehicle).

Ariane 5's cryogenic main stage is referred to as the EPC from its title in French, *Etage Principal Cryotechnique.* The EPC is essentially composed of an aluminum tank with two compartments: one for liquid oxygen and one for liquid hydrogen. Both propellants are produced at plants located inside Europe's Spaceport in French Guiana.

Weighing 37 tonnes each when empty, the SRBs (Solid-Rocket Boosters) provide 1100 tonnes of thrust, roughly 92% of the total thrust at liftoff.

Chinese Launch Vehicles – Changzheng (Long March) Rockets



Show the cadets a slide or distribute handouts of Figure D-5 (Changzheng [Long March] Launch Vehicles).

The main stages and the booster rockets of Long March rockets use liquid storable propellants with hydrazine (UDMH) as fuel and nitrogen tetroxide as the oxidizing agent—the same hypergolic system used by the Proton rocket discussed above. The upper stages of Long March CZ-3A and CZ-3B use liquid hydrogen (LH2) as fuel and liquid oxygen (LOX) as oxidizer.

CONFIRMATION OF TEACHING POINT 5

QUESTIONS

Q1. What family of spacecraft does the Ares family replace?

Q2. Where are the Ariane 5's LOX and liquid hydrogen produced?

Q3. What fuel oxidization system does the Proton rocket share with the Long March rockets?

ANTICIPATED ANSWERS

A1. The Ares rockets replace the Space Shuttle.

A2. Both propellants are produced at plants located inside Europe's Spaceport in French Guiana.

A3. Both the Proton and the Long March rockets use hydrazine fuel with nitrogen tetroxide oxidizer.

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END OF LESSON CONFIRMATION

QUESTIONS

Q1. What does Newton's third law of motion state?

Q2. Why is oxygen stored for a rocket's combustion instead of just air?

Q3. What great operational advantage does a liquid rocket have over a solid rocket?

ANTICIPATED ANSWERS

A1. Newton's third law of motion states that for every action there is an equal and opposite reaction.

A2. Oxygen is stored for combustion instead of air because air is mostly unreactive nitrogen.

A3. A liquid rocket can be controlled and shut off after ignition.

CONCLUSION

HOMEWORK/READING/PRACTICE

N/A.

METHOD OF EVALUATION

N/A.

CLOSING STATEMENT

Of all the methods of propulsion, rockets have the longest history. They also have the most exciting future in helping fulfill the Canadian Space Agency's mission.

INSTRUCTOR NOTES/REMARKS

Website references should be made available for cadets to explore on their own time.

REFERENCES

C3-016 EG-2003-01-108-HQ NASA. (2003). *Rockets: A Teacher's Guide With Activities in Science, Mathematics, and Technology.* Washington, DC: NASA.

C3-037 *Space Exploration.* (2006). Retrieved 25 May 2006, from http://www.space.gc.ca/asc/eng/exploration/exploration.asp.

C3-057 (ISBN 10-1-59647-055-0) Sobey, E. (2006). *Rocket-powered Science.* Tucson, AZ. Good Year Books.

C3-087 NASA Glenn Research Center. *Propulsion Index.* Retrieved 21 February 2007, from http://www.grc.nasa.gov/WWW/K-12/airplane/shortp.html.

C3-088 NASA Glenn Research Center. *Beginner's Guide to Rockets.* Retrieved 21 February 2007, from http://exploration.grc.nasa.gov/education/rocket/bgmr.html.

C3-100 China In Space. *The Long March Space Rockets.* Retrieved 26 February 2007, from http://www.spacetoday.org/China/ChinaRockets.html.

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C3-112 Federal Space Agency. *Roket1Show.* Retrieved 26 February 2007, from http://www.roscosmos.ru/RoketsMain.asp.

C3-113 European Space Agency. *ESA Launch Vehicles.* Retrieved 26 February 2007, from http://www.esa.int/esaCP/index.html .

C3-114 NASA. *Countdown! NASA Launch Vehicles and Facilities.* Retrieved 27 February 2007, from http://www-pao.ksc.nasa.gov/kscpao/nasafact/count1.htm#nasa.

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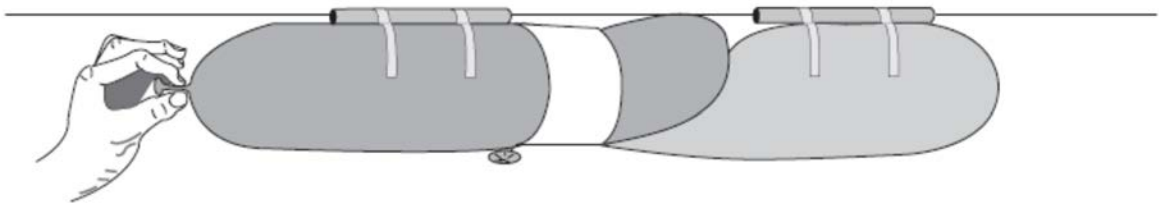
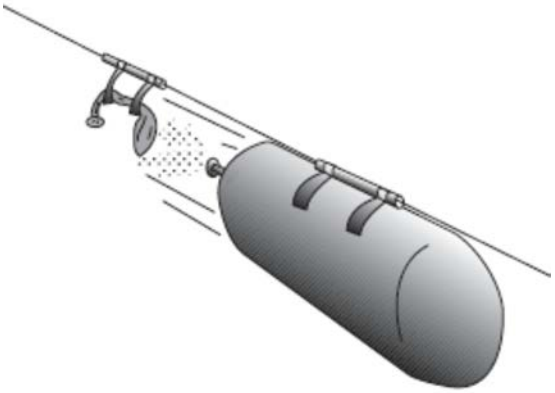
STAGING BALLOON ROCKETS INSTRUCTIONS



NASA, Rockets: A Teacher's Guide with Activities in Science, Mathematics and Technology, NASA (p. 64)

Figure A-1 Staging Balloon Rockets



NASA, Rockets: A Teacher's Guide with Activities in Science, Mathematics and Technology, NASA (p. 63)

Figure A-2 Jettisoning the First Stage

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ROCKET SYSTEM OPERATION IN SPACE



HERO ENGINE

"Rockets" A Brief History of Rockets. Retrieved 24 March 2007, from http:// www.grc.nasa.gov/WWW/K-12/TRC/Rockets/history_of_rockets.html

Figure B-1 The First Reactive Engine

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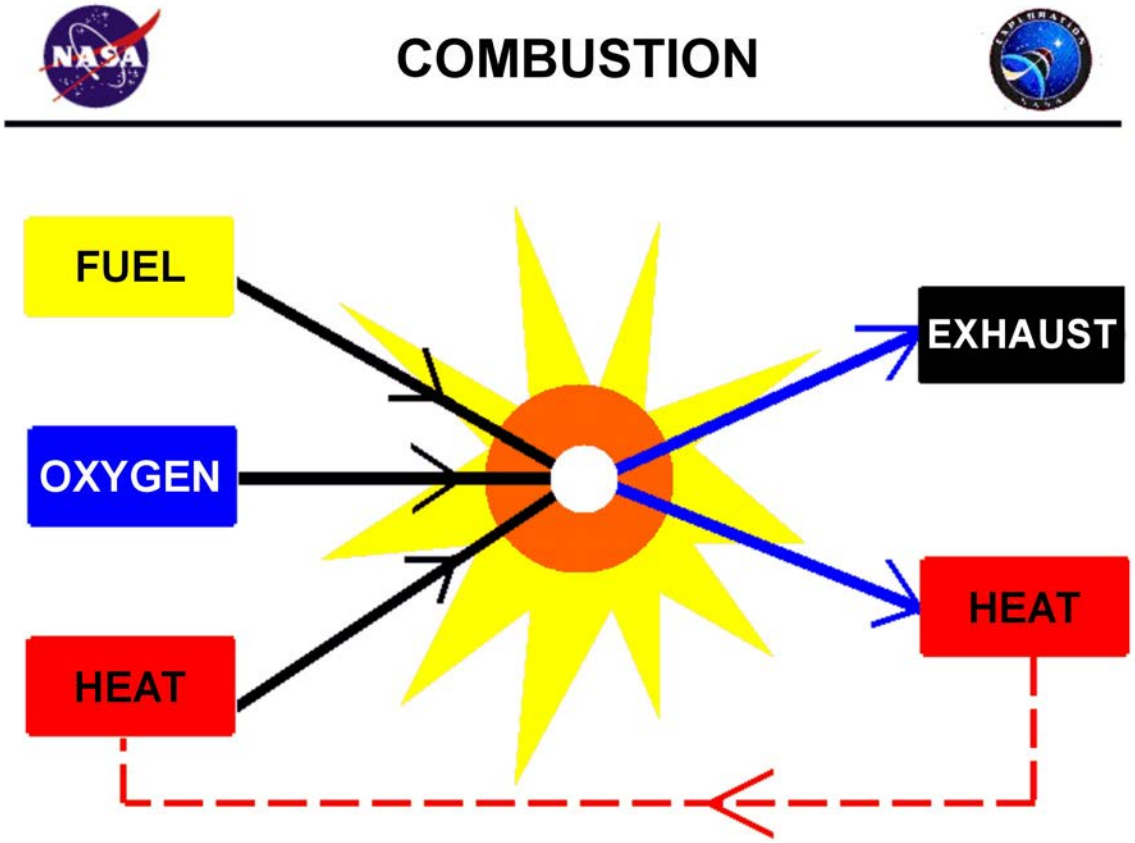

"Beginner's Guide to Rockets" Combustion. Retrieved 25 March 2007, from http://exploration.grc.nasa.gov/education/rocket/combst1.html

Figure B-2 Combustion

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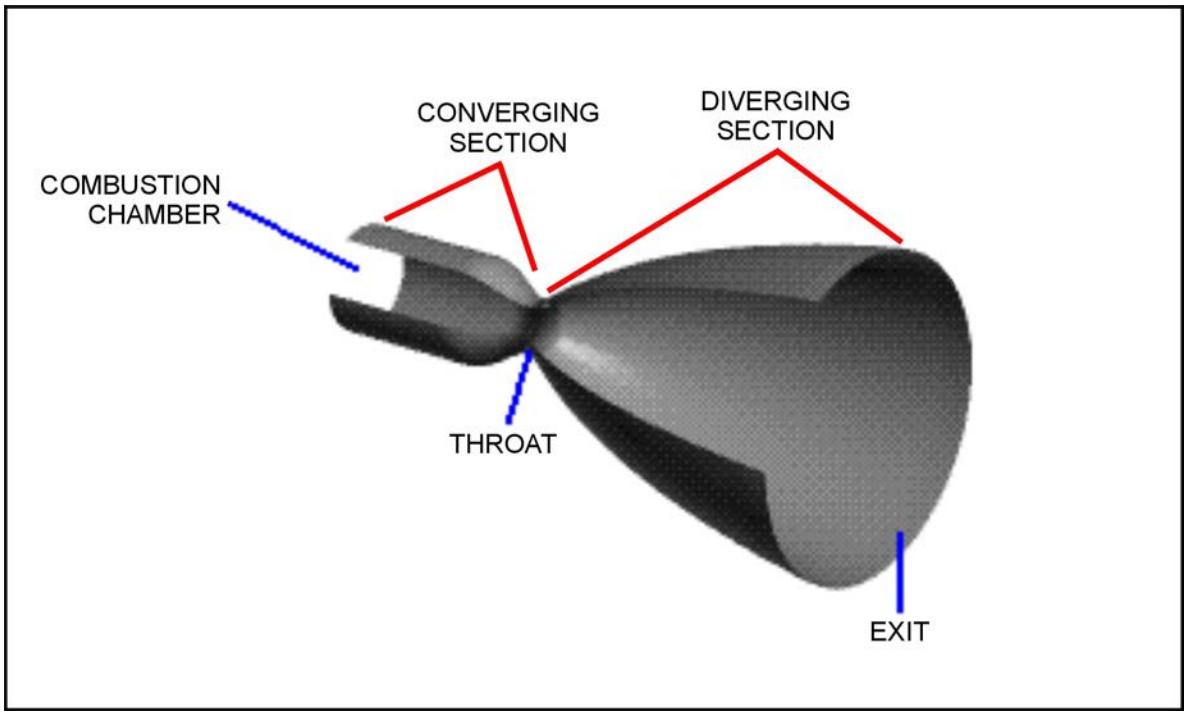

"Beginner's Guide to Rockets" Combustion. Retrieved 25 March 2007, from http://exploration.grc.nasa.gov/education/rocket/nozzle.html

Figure B-3 A Rocket Nozzle

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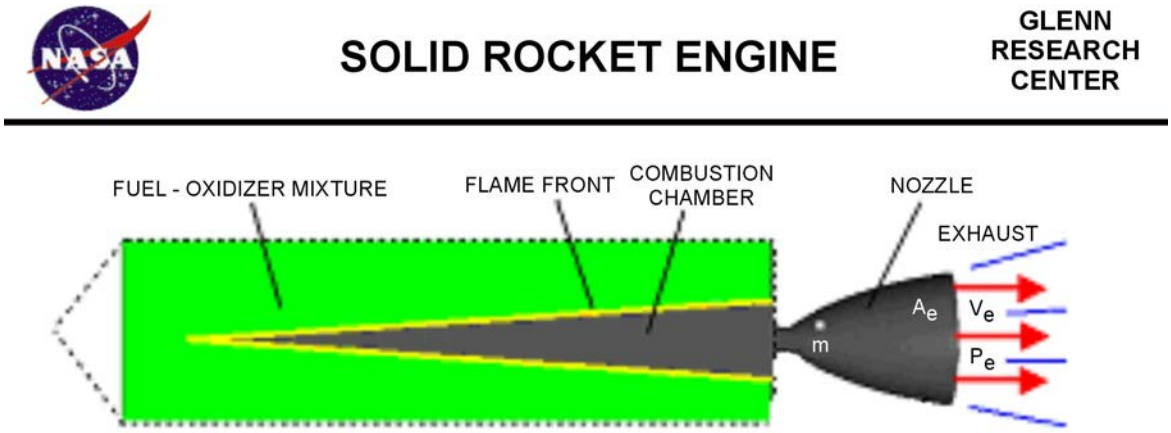
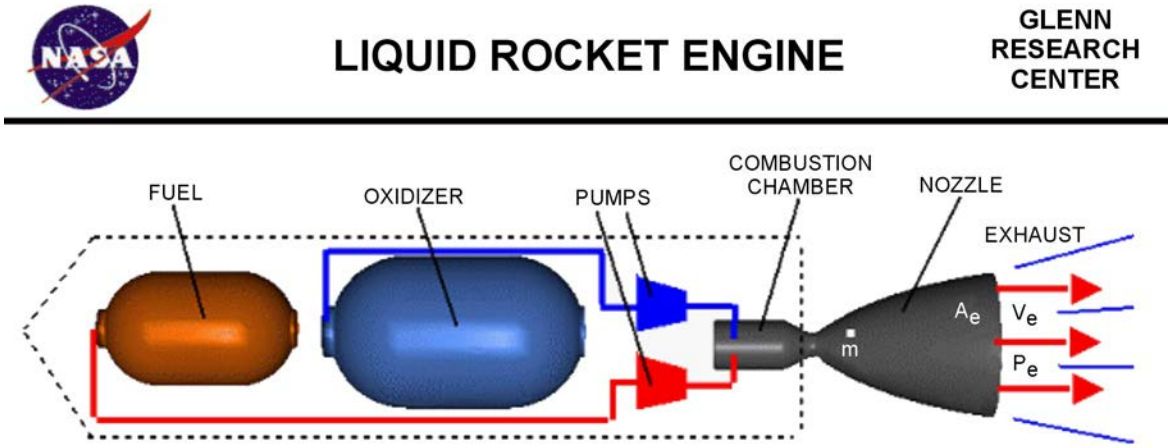
SOLID AND LIQUID ROCKET ENGINES



"Beginner's Guide to Rockets" Solid Rockets. Retrieved 25 March 2007, from http://exploration.grc.nasa.gov/education/rocket/lrockth.html

Figure C-1 Solid Rocket Design



"Beginner's Guide to Rockets" Liquid Rockets. Retrieved 25 March 2007, from http://exploration.grc.nasa.gov/education/rocket/lrockth.html

Figure C-2 Liquid Rocket Design

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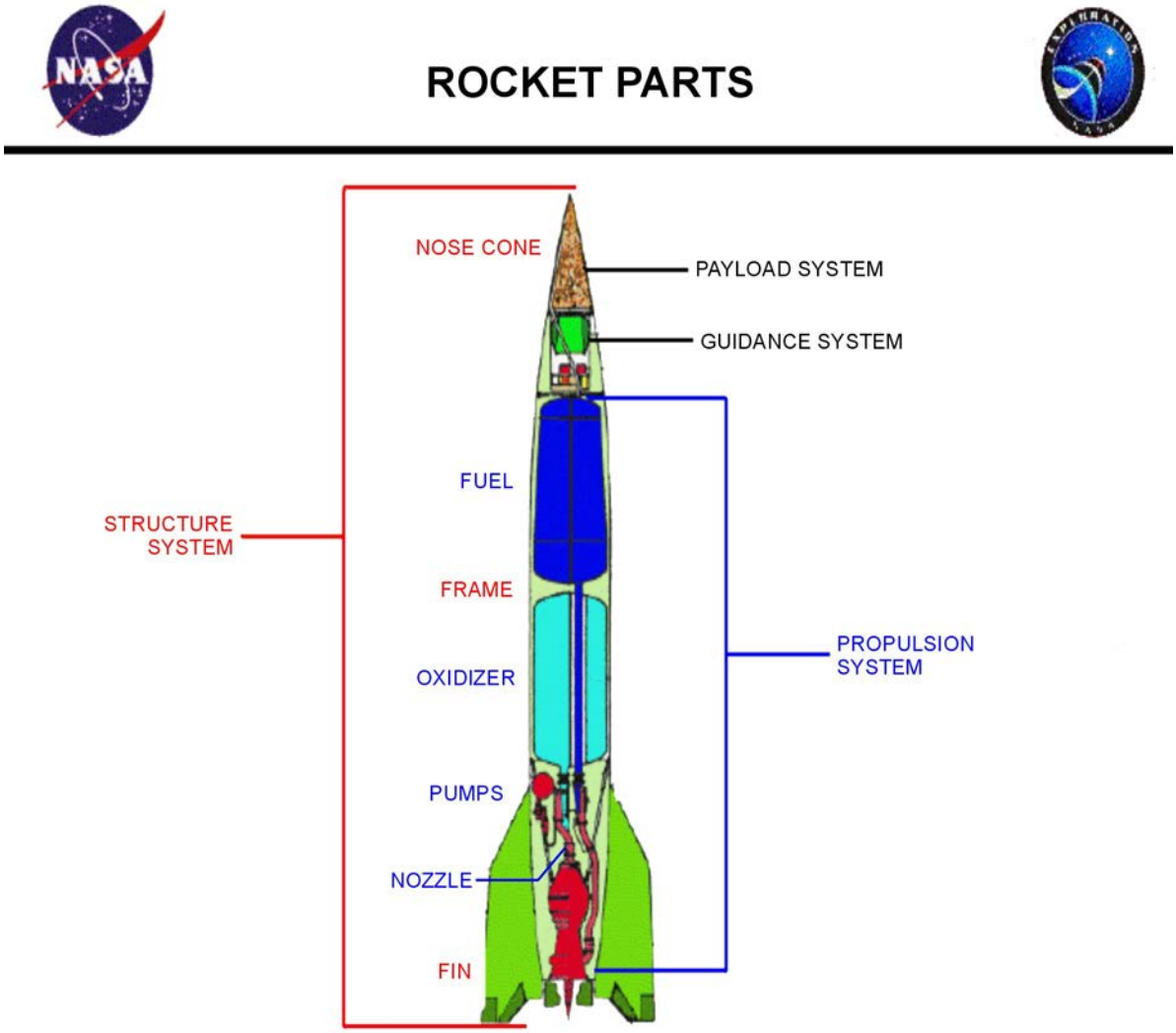

"Beginner's Guide to Rockets" Rocket Parts. Retrieved 25 March 2007, from http://exploration.grc.nasa.gov/education/rocket/rockpart.html

Figure C-3 Liquid System Rocket

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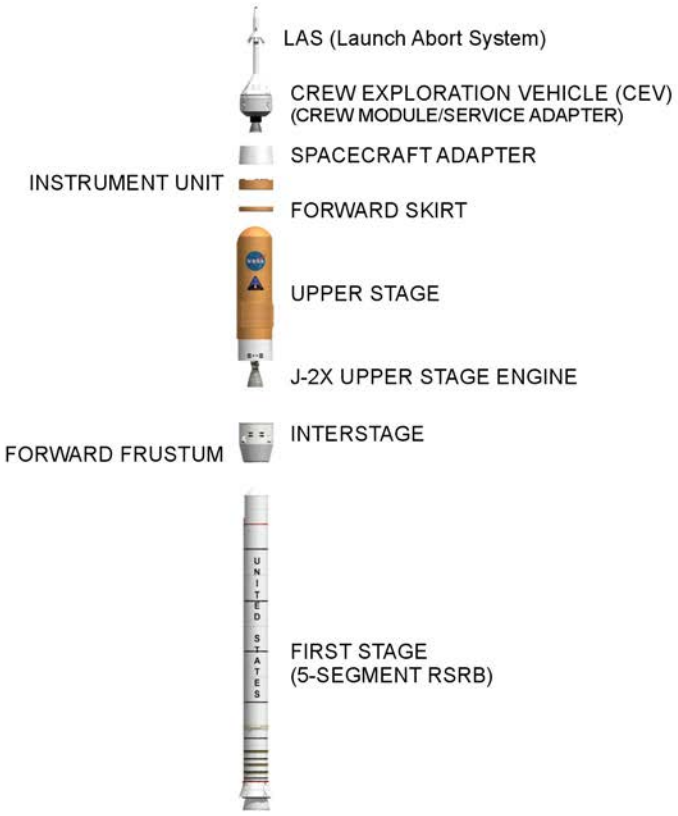
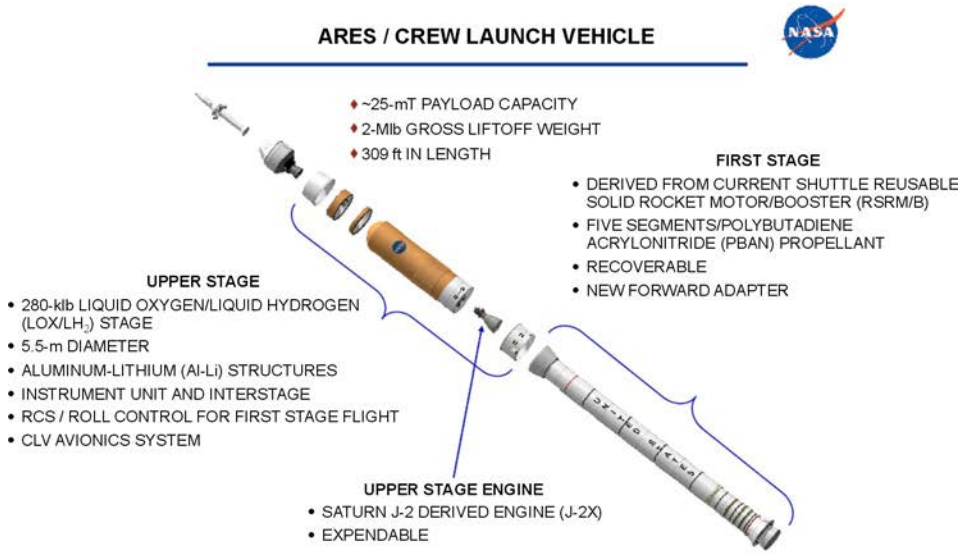
LAUNCH VEHICLES





NASA "Constellation Program" Ares Launch Vehicles. Retrieved 24 March 2007, from http://www.nasa.gov/mission_pages/constellation/ares/aresI.html

Figure D-1 Ares 1 Launch Vehicle

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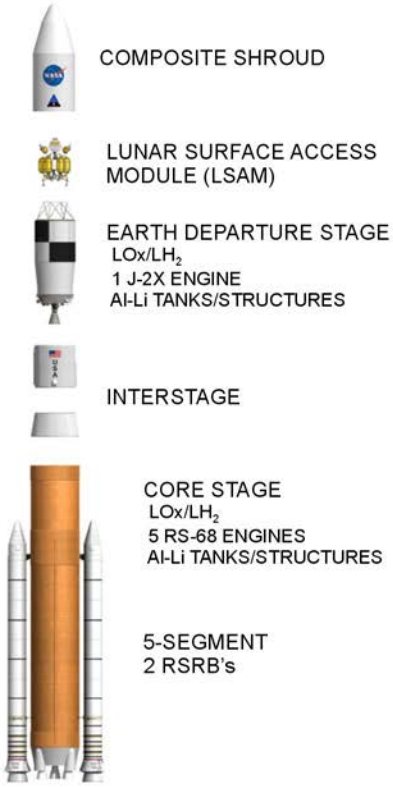

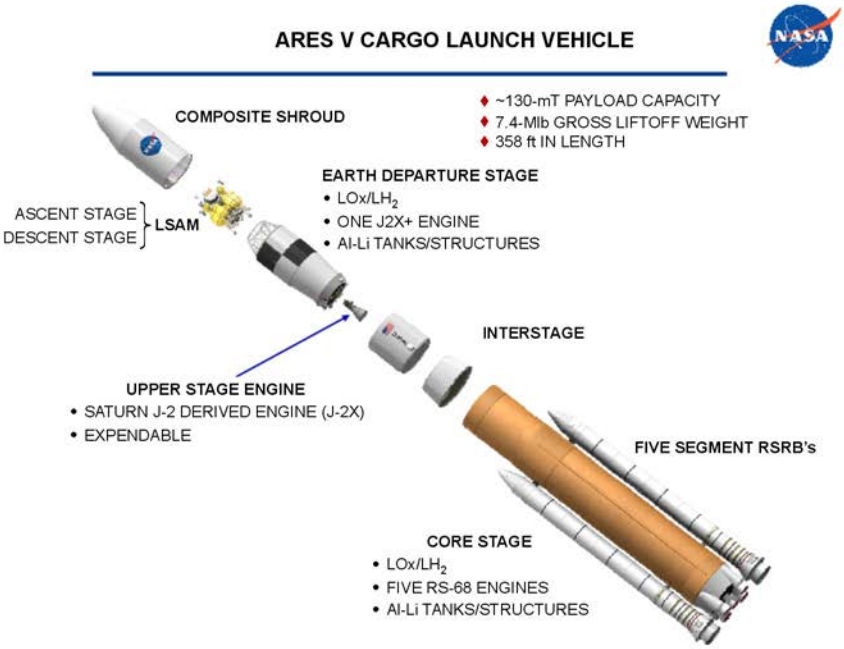

NASA "Constellation Program" Ares Launch Vehicles. Retrieved 24 March 2007, from http://www.nasa.gov/mission_pages/constellation/ares/aresV.html

Figure D-2 Ares V Launch Vehicle

Unofficial convenience copy of A-CR-CCP-802/PF-001, cached 2026-11-08 from https://app.cadets.gc.ca/cadet-publications/A-CR-CCP-802-PF-001/A-CR-CCP-802-PF-001.pdf.
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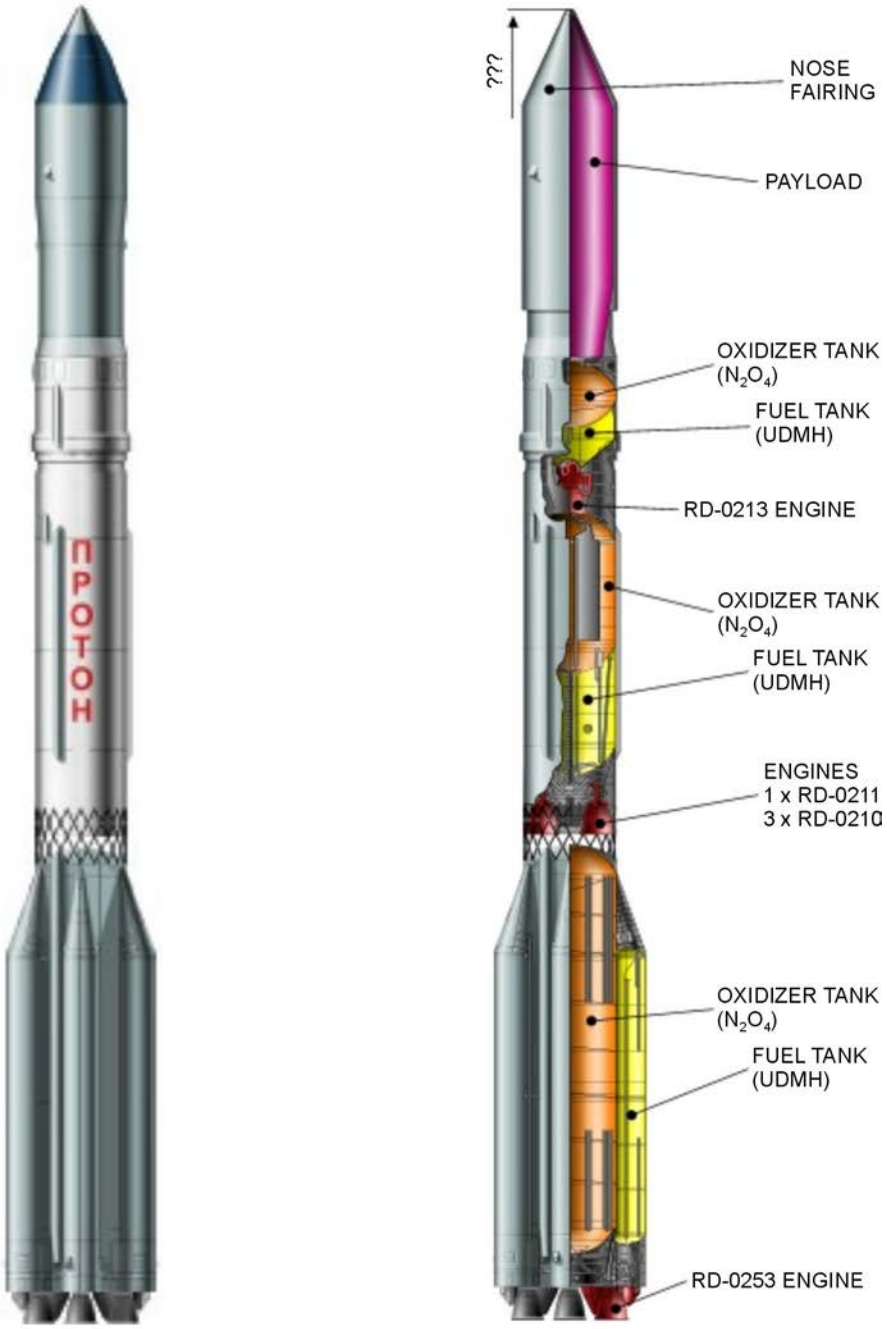


From "Roscosmos Rocket Families" Proton. Retrieved 27 March 2007, from http://www.roscosmos.ru/RoketsMain.a

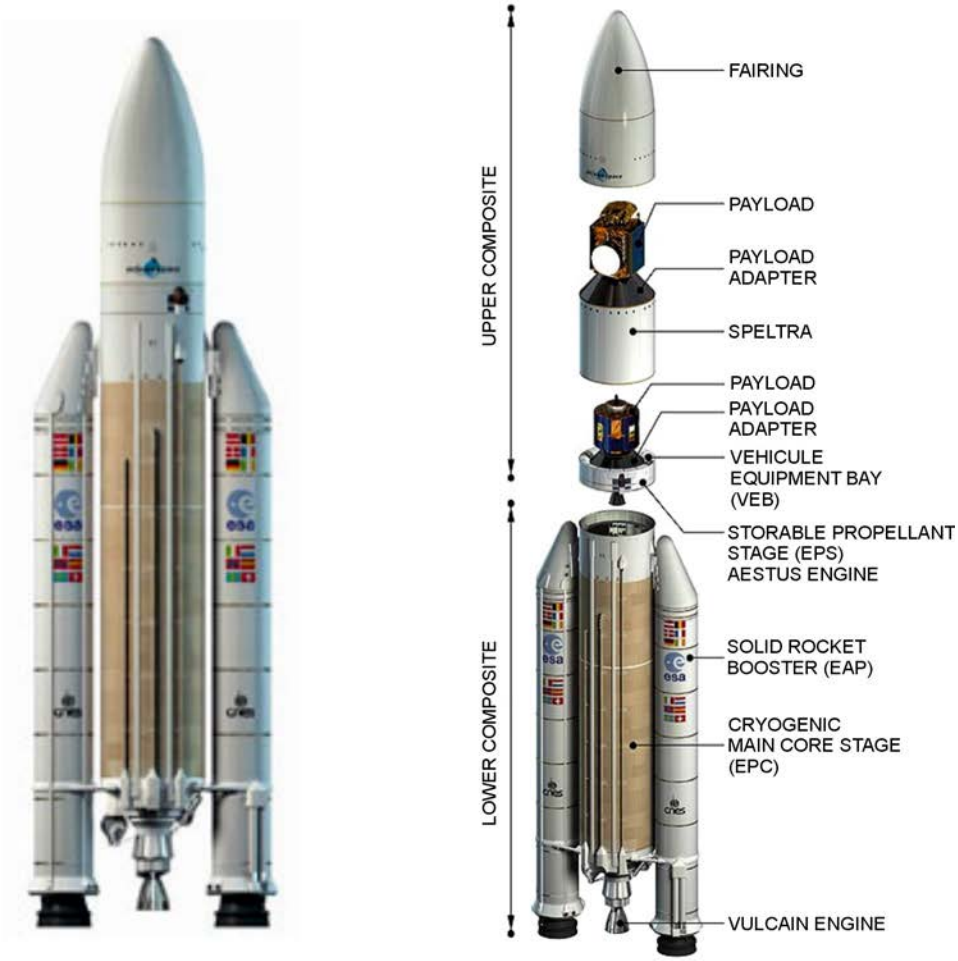
Figure D-3 Proton – Federal Space Agency Launch Vehicle

Unofficial convenience copy of A-CR-CCP-802/PF-001, cached 2026-11-08 from https://app.cadets.gc.ca/cadet-publications/A-CR-CCP-802-PF-001/A-CR-CCP-802-PF-001.pdf.
Verify against the official publication.

THE ARIANE 5 BOOSTER (SRB) PROPELLANT FUEL IS SOLID.

MAIN ENGINES BURN LIQUID OXYGEN AND LIQUID HYDROGEN.

MAIN DATA:	ARIANE 5G
HEIGHT:	46 TO 52 m
DIAMETER:	UP TO 5.4 m
LIFTOFF MASS:	746 TONNES



From "European Space Agency" Launch Vehicles. Retrieved 24 March 2007, from http://www.esa.int/SPECIALS/Launchers_Access_to_Space/SEMH3E67ESD_0.html

Figure D-4 Ariane 5 – European Space Agency

Unofficial convenience copy of A-CR-CCP-802/PF-001, cached 2026-11-08 from https://app.cadets.gc.ca/cadet-publications/A-CR-CCP-802-PF-001/A-CR-CCP-802-PF-001.pdf.
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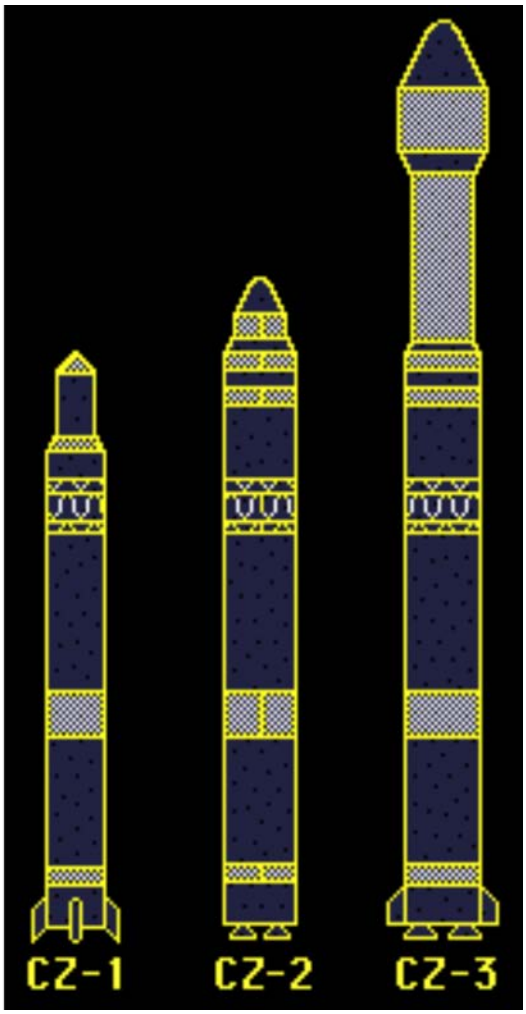

"China in Space" China's Space Rockets. Retrieved 24 March 2007, from http://www.spacetoday.org/China/ChinaRockets.html#LongMarchRockets

Figure D-5 Long March (Changzheng) Rockets

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