A Comparative Analysis and Study on Martian Satellites

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Abstract— **The use of satellites in communication systems is very much a fact of everyday life, as is evidenced by the many homes equipped with antennas or dishes used for the reception of satellite television. Satellites offer a number of features not readily available with other means of communication. Satellite signals ignore political boundaries as well as geographic ones, which may or may not be a desirable factor. Satellites are also used for remote sensing which helps in the detection of water pollution and the monitoring and reporting of weather conditions. In this paper, we discuss about three satellites – Curiosity Rover, Mangalyaan and Maven, which were launched to explore the Martian atmosphere.**

Keywords – Launching Vehicles, Mangalyaan, Mars, Maven, Rover, Satellite

I. INTRODUCTION

The idea of a satellite communication network is no longer a science fiction [1]. Satellite is an artificial object which is placed in an orbit so that they could find and analyze the unknown secrets present in the universe. World's first satellite, SPUTNIK 1 was launched by Soviet Union in 1957 [2]. Following this all countries started research to explore the space. Satellites to Moon, Jupiter, Pluto, Mars etc. are launched till now. Satellites are used for various purposes like military, civilian, Earth observation, communication, navigation, weather study etc. The spatial separation of satellites help to achieve wider aperture for radar and interferometric applications, coverage in communication applications, and additional reference point in navigation applications [3]. They are commonly semi-independent computer controlled system.

Each satellites are sent to different orbits. Well known classes of orbits include low earth orbit (LEO), geostationary orbit and polar orbit. Leo orbit is an orbit with altitude of 160 km and with a period of 127 minutes. To maintain a stable Leo orbit, it requires an orbital velocity of 7.8km/s. Spy satellites and earth observing satellites uses Leo orbits. Geo stationary orbit is an orbit located 35,900 km above the earth's surface [4]. This orbit is widely used for communication purpose. Polar orbit is an orbit in which all the satellites passes nearly above the poles of the orbited body. No one particular spot can be continuously traced using this orbit which is a disadvantage.

Satellites have a number of equipment packed inside it. Normally a satellite contains seven sub systems and each one is assigned different works. The propulsion subsystem contains a rocket motor that helps to keep the space craft in its position. The power sub system present helps in generating electricity using solar panels and they store the energy in batteries. The communication sub system handles all the transmission and reception of signal from the base station and the satellite. A stable framework is provided by the structure sub system which helps in keeping satellite in the right position. A large amount of heat is evolved from the satellite. In order to keep the active parts of satellite cool, a thermal sub system is present. The attitude control subsystem helps the space craft to maintain its communication footprints in the correct position. Telemetry and command system helps the ground station to communicate with the satellites.

Recent research are mainly focused on the planet Mars. Since the presence of water is detected in Mars, furthermore research on the atmospheric characters, pressure are going on in all countries. In this paper, we are comparing the three satellites which have already reached Mars. The three satellites took for the comparison are Curiosity Rover, Mangalyaan and Maven.

A. Curiosity Rover

Curiosity is a car shaped robotic rover exploring Gale Crater on Mars launched by NASA. Gale Crater is a crater on Mars near the North western part of Aeolis quadrangle at 5.4 °S 137.8 ° E [5]. It is 154 km in diameter [6] and is about 3.5 to 3.8 billion years old approximately [7]. The rover was launched in November 26, 2011. It landed on Aeolis Palus in Gale Crater after a long journey on August 6, 2012. The goals of the rover include: investigation of Martian climate and geology, assessment of weather the field sites inside the Gale crater is suitable for microbial life, investigation of water and planetary habitability studies in preparation for future human exploration [8]. Curiosity is comprised of 23 percent of mass of 3,893 kg Mars Science Laboratory (MSL) space craft which helps in the smooth landing of rover on the surface of Mars. Curiosity has a mass of approximately 900 kg including 80 kg of scientific equipments. Radioisotope thermoelectric generator is the power source of Curiosity. It is more flexible and is designed to produce 125 watts of electricity from 2000 watts of thermal power.

B. Mangalyaan

Mangalyaan, formally called Mars Orbiter Mission (MOM) is launched by ISRO on 5 December, 2013. The primary objective of MOM is to design and realization of Mars orbiter with a capability to perform on – orbit phase around Mars. It is also launched to study about the Mars' surface features, morphology, mineralogy and Martian atmosphere [9]. Space craft is of 1340 -3/+0 kg by mass. Space craft bus is a modified 1-1 K structure. The satellite structure is of Aluminum and composite fiber reinforced plastic (CFRP) sandwich construction. Electric power is generated by three solar array panels. This power is stored in batteries. A telemetry and command network present perform the navigation and tracking operations for the launch with the ground stations.

C. Maven

NASA launched Mars Atmosphere and Evolution (MAVEN) probe, its newest Mars probe towards the red planet on a mission to determine the Martian atmosphere [10]. The Maven space craft has the capability of acting as a relay point between the rovers' already present .The mission of Maven to determine the Martian atmosphere and about the water present in Mars. It was launched on November 18, 2013.

II. LAUNCHING VEHICLES

A launch vehicle provides the velocity needed by the space craft to escape from the Earth's gravity and to set it on the orbit. The launching vehicles used for launching Curiosity Rover, Mangalyaan and Maven are discussed in this section.

A. Curiosity Rover

Atlas V 541 is the launching vehicle used to launch Curiosity Rover on to Mars. Atlas V is an expandable launching system in the Atlas family. Curiosity Rover was launched on a two stage Atlas V 541, provided by United Launch Alliance, a joint venture of Boeing Co. and Lockheed Martin Corp. The height with payload of Atlas V 541 is 191 feet [11]. The two stages of Atlas are Atlas Common core stage and Centaur. It has a four solid rocket boosters in its first stage.

The Atlas V 541 uses a single engine common core booster along with a RD – 180 dual chamber engine. The Centaur acts as the second stage. The Centaur can be powered by using a single engine or a dual engine system. Recently they are using single engine Centaurs. The Centaurs engine can handle multiple start – ups in space which helps in inserting the payload on orbit. It includes three main components – Interstage Adapter, Aft sub Adapter and Boattail [12]. Atlas V was selected for the Mars mission because it has the right lift off capability for heavy weight requirements.

Stage 1 Atlas V Rocket: Fuel and oxygen tanks that feed an engine for the ascent and also it powers space craft to the earth.

Solid Rocket Motors: It increases the engine thrust.

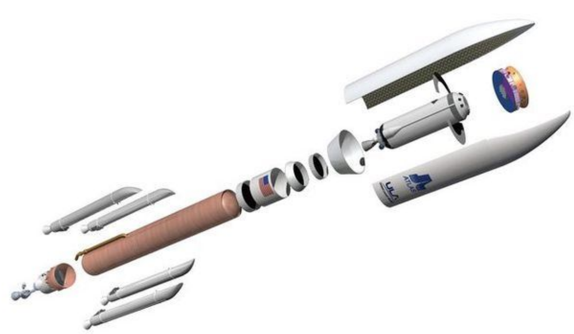

Fig 2. Atlas V 541 configuration (Source: NASA)

Stage 2 Centaur: It is the brain of vehicle and is fired twice. Once to insert the vehicle – space craft stack in to the low earth orbit and then to accelerate the space craft out of the earth orbit and makes a path to Mars.

Payload Fairing: Thin composite or nose cone to protect the space craft.

B. Mangalyaan

India used its PSLV C25 launching vehicle for launching Mangalyaan in Mars. PSLV C25 was the 25th mission of PSLV and the 5th mission in XL configuration.

PSLV is mainly meant for launching satellites in Sun synchronous and low earth orbits. It is a four stage vehicle with alternate solid and liquid propulsion stages. First and third stages uses solid propulsion where in second and fourth stages it uses liquid propulsion method. PSLV C25 uses XL configuration which consists of six extended strap – on motors attached to its first stage [13]. PSLV is a multi – payload, multi – mission capability in a single launch and has its geosynchronous launch capability. It is having a launch azimuth of 104 degree. The other specifications are listed in the table below [14]:

TABLE 1
PSLV SPECIFICATIONS

EPO PARAMETER	SPECIFICATIONS
Perigee Height (Km)	250 (+/- 5km)
Apogee Height (Km)	23,500 (+/- 675km)
Inclination (deg)	19.2 (+/- 0.2 deg)
Argument of Perigee (deg)	282.55 (+/- 0.2 deg)
Right Ascension of ascending node (deg)	Function of launch time

The PSLV in its XL version stands 44.5 meters tall, and has a core diameter of 2.8 meters. The launcher can deliver payload up to 1,410 kg of Geosynchronous Transfer Orbit. The PSLV launcher consists of a large core stage which holds 138,000 kg of solid propellant. The second stage of the launch vehicle uses storable propellants like unsymmetrical Dimethyl hydrazine fuel and Nitrogen Tetroxide oxidizer that provides 81,500kg of vacuum thrust. This stage is 12.8 long and has a capacity of 40,700kg of propellant load. The third stage of the launch is solid-fueled. This stage is of 2.02 meter diameter, 3.54 m long and it can hold up to 6,700 kilogram of HTPB (Hydroxyl – terminated Polybutadiene) based propellants. The thrust provided is of 24,900kg. The stack top of this stage includes another stage which is known as PS4 upper stage. This stage is having a diameter of 2.02 meters and 2.6 meter long. It features a fuel load of 2,920 kilogram and the upper stage thrust is 1,500kg. The fourth stage is powered by two L-2-5 engines each producing a thrust of 7.4 kN. These engines are gimbaled by up to 3 degrees for pitch and yaw control while the roll control is provided by the reaction systems [15].

C. Maven

Atlas V 401 is the launching vehicle used to launch Maven on to the Mars surface. Atlas V 401 is the smallest rocket in the Atlas family featuring no solid boosters and a 4.2 meter payload fairing. This launching vehicle has two stages of operation. Similar to Atlas V 541, the first stage is the Atlas Common Core Booster and the second stage is the Centaur Upper stage. It has a height of 58.3 meter and a diameter of 3.81 meter. Also it has a launch mass of 338.045 kg [16].

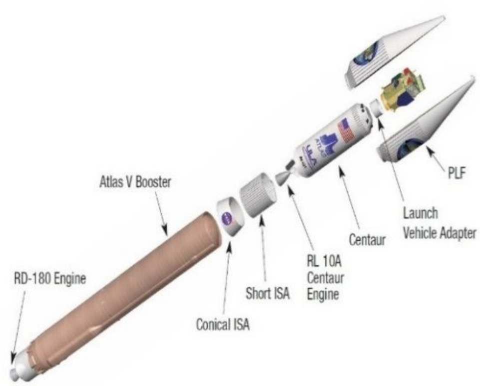

Fig 4. Atlas V 401 Components (Source: NASA)

The first stage Common core booster works on an oxidizer to fuel ratio of 2.72. The drawback of an oxygen rich combustion is that high pressure, high temperature gaseous oxygen must be transported throughout the engine. The engine is based on the RD-170 engine that features four combustion chambers. First stage separation is initiated by pyrotechnics and the core stage ignites eight retro rockets to drop away from the launcher.

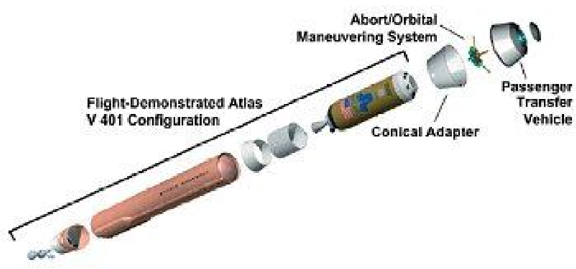

Fig 5. Atlas V 401 Configuration (Source: NASA)

The first and second stages are connected by interstage adapters. The upper stage of Atlas is a single engine Centaur stage. It is a cryogenic rocket stage that uses Liquid Hydrogen and Liquid Oxygen as propellants. Payload adapters present helps in connecting payload with the vehicle. The payload fairing is present in the top most of the vehicle and the integrated payload. It protects the space craft from various environmental problems [17].

III. METHODOLOGY

In this section, we discuss about the hardware and software used in designing and implementing the considered satellites.

A. Curiosity Rover

Rover consists of a transmitter, receiver, power supply, Mast Camera, Navigation Cameras, Environmental monitoring systems, Alpha particle X-Ray spectrometer etc.

The Mast Camera systems provides a multiple spectra and true color imaging with two cameras [18]. One camera is having a focal length of 34mm and the other with a focal length of 100mm. Each camera has an eight gigabytes of flash memory. These cameras have auto focusing capability so that they could take the clear images. The navigation cameras mounted on the Mast helps in supporting the ground navigation [19]. The REMS comprises instruments to measure the mars environment like moisture, humidity, pressure, temperature etc. It helps in analyzing the daily variation in all the atmospheric parameters [20]. The Alpha particle X-ray spectrometer is used to determine the elemental samples present in the Mars [21].

The Rover communicates with the orbits and Deep Space Network (DSN) through the radio waves. They communicate with each other through X-band. The DSN antennas are very large with a size of 34 meters and 70 meters. These antennas enables humans to reach out to spacecraft millions of miles away. The larger the antenna, the stronger will be the signal and hence the information. Rover uses both Low gain and high gain antennas to communicate with the earth station. Low gain antenna is an omni directional antenna that sends and receives data in every direction. High gain antenna can send only a beam of information to a particular direction only.

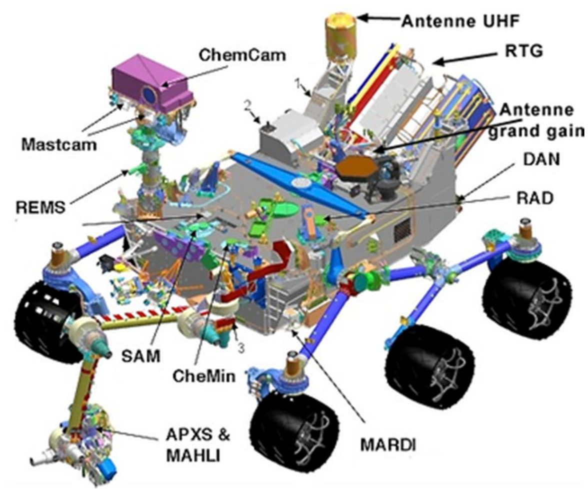

Fig 5. Curiosity Rover – Hardware (Source: NASA)

DSN communicates with all spacecraft flying throughout the solar system. The DSN antennas are extremely busy in tracking all of these space crafts. So a particular time schedule is allotted to the Mars Curiosity Rover. During the landing, multiple antennas on Earth and Mars Global Surveyor (MGS) orbiter will track the signals to reduce the risk of communication loss. At the same time Rover utilizes the multiple space craft per aperture capability of DSN which allows a single DSN antenna to receive downlink from up to two spacecraft simultaneously. The Rover downlink is limited to a couple of hours [22].

The DSN antennas picks the signals and helps the navigators to locate the space craft. The navigation system is called tracking coverage and it includes Doppler, ranging and Delta differential one way ranging. Doppler data is used to plot the velocity along the line of sight between Earth and space craft. The Doppler shift depends on the speed of light moving relative to the observer. Ranging is sending a code to the space craft. Space craft receives code and send it back to the space craft's antenna and finally receives the code back on earth. The time between sending and receiving code, minus the delay in turning the signal around the space craft is, twice the light time of space craft. DeltaDor is similar to ranging. It helps to give a more accurate location of the space craft. During Entry, Descent and Landing (EDL), the space craft encounters turbulent conditions. It experiences an intense heating from friction caused by speeding in to the atmosphere. The quick and intense movements make it difficult to track the space craft [23].

The data rate direct to earth varies from about 500 bits to 32,000 bits per second. The data rate to the orbiters is a constant about 128,000 bits per second. An orbiter passes over the rover with a vicinity of sky to communicate with the rover for about eight minutes at a time. In that time, 60 MB of data can be transmitted to the orbiter [24].

B. Mangalyaan

Mangalyaan, the first Mars mission of India is largely based on Chandrayaan – 1 which is launched for exploring Moon. The hardware used in Mangalyaan are – Antennas, propellant tank, solar panel, Mars color camera, Lyman Alpha photometer (LAP), Thermal Infrared Imaging System (TFI), Methane Sensor for Mars (MSM), Martian Exospheric Neutral Composition Analyzer (MENCA). The propellant tank has a capacity of 390 liters and can accommodate a maximum of 852kg propellants.

A liquid engine of 440N thrust is used to raise and insert the spacecraft in the orbit. The solar panel of dimension 1800 x 1400 mm is used for compensating the lower solar irradiance. It is also equipped with a 36 AH Lithium – ion battery for power storage [25].

Mangalyaan used a low gain, medium gain and a high gain antenna for the transmission and reception of informations. The high gain antenna is based on a single 2.2 meter reflector illuminated by a feed at S band. It is used to transmit the Telemetry, Tracking and Command (TTC) and data to and from the Deep Space Network (DSN).

The LAP consist of an ultra violet detector which is equipped in a gas filled pure molecular hydrogen and deuterium cells. It weighs about 1.5kgs. Its objective is to measure the deuterium – hydrogen ratio which is an indicator for atmospheric loss process and the role of water in the process.

The MENCA instrument operates at a range of 1 to 300u with a mass resolution of 1.5u which allows a detailed examination of the species present there. The core objective of MENCA is to study the exospheric neutral density and composition at altitudes lower than 372km above the Martian surface. It is capable of examining the radial, diurnal, and seasonal variations in the Martian surface.

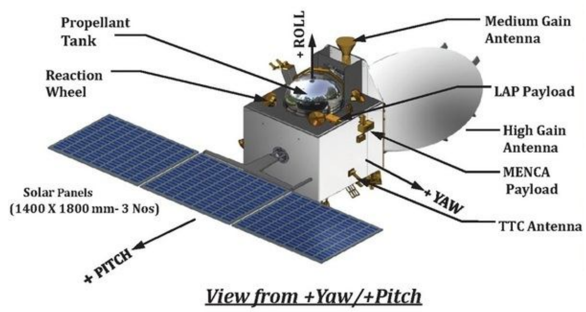

Fig. 6 Mangalyaan – Hardware (Source: ISRO)

Mangalyaan carries a color camera which is capable of taking color images of the planet. The spectral range varies from 400nm – 700nm. The camera includes a multi – element lens assembly and a 2000 x 2000 pixel array detector with RGB Bayer Filter. The MSM payload weighs about 3.6kg and is designed to measure the methane concentration in Martian atmosphere. It uses a Fabry-Perot-Etalon (FPE) sensor that uses multi beam interferometry at wavelengths of 1,642 to 1,658 nm to detect the presence of methane. The FPE sensor is comprised of an optical resonator consisting of a single plate with two parallel reflecting surface.

Light can pass only through the system when the wavelength corresponding to the resonance of the etalon creates a narrow band spectrum on the focal length. TIS comprise of a spectrometer that features a typical infrared grating spectrometer design. It uses 120 by 160 element bolometer array detector. Bolometer receivers measure the energy of incoming photons. TIS is used to measure the thermal emissions from the Martian surface to deduce surface composition and mineralogy [26].

Mangalyaan communicates to the earth station by the antennas present in it. The range of communication distance varies from 214 million to 375 million kilometers. It uses S frequency band for both TTC and data transfer. It consist of two Travelling Wave Tube Amplifiers (TWTA) of 230W and two coherent transponders [27]. The sensitive receiver is having a bandwidth of -135dBm carrier acquisition threshold.

It provides a selectable data rates of 5kbps, 10kbps, 20kbps and 40kbps without Turbo coding. The S band Delta DOR are used for improving the orbit determination accuracy.

C. Maven

Maven is mainly used to study about the upper atmosphere its interaction with the solar wind. Three main scientific instruments used in Maven are Particle and Fields Package (PFP), Remote Sensing Package (RSP) and Neutral Gas and Ion Mass Spectrometer (NGIMS). PFP is used to characterize the solar wind and ionosphere of the planet. PFP includes Solar Energetic Particle (SEP), Solar Wind Ion Analyzer (SWIA), Solar Wind Electron Analyzer (SWEI), Supra Thermal and Thermal Ion Composition (STATIC), Langmuir Probe and Waves (LPW) and Magnetometer.

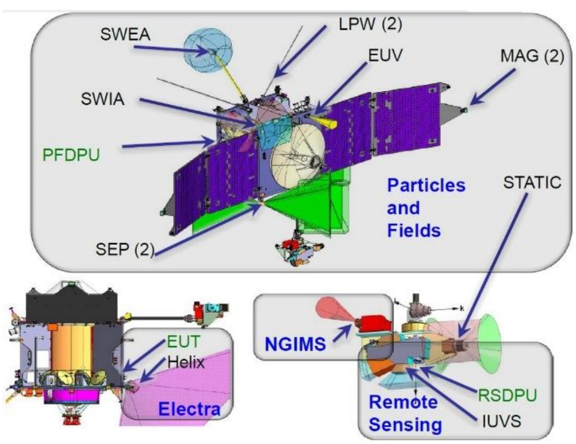

Fig 7 Maven Hardware configuration (Source: NASA)

SEP is used to determine SEP input in to the atmosphere as a function of altitude. It consist of a two dual double – ended telescope. SWIA is used to measure the solar wind and the magneto sheath proton flow around the Mars surface and the nature of interaction of solar wind with the upper atmosphere. SWEA measures the solar wind and the ionospheric electrons. It also evaluates the plasma environment, electron impact ionization rates etc. The azimuth and elevation angle are 360 and 120 degrees respectively. STATIC measures the thermal ions to moderate energy escaping ions. It also allows direct measurement of Martian sheath plasma, separating solar wind and the planetary ions that populate the sheath and the planetary ions. LPW determines ionospheric properties and it also measures wave heating of upper atmosphere and solar extreme ultra violet input to the atmosphere.

The global characteristics of the upper atmosphere and ionosphere is determined by RSP. The Neutral Gas and Ion Mass spectrometer is used to measure the composition and isotopes of thermal neutral ions.

MAVEN is equipped by a RAD-750 central processing board that is a single card computer. It operates at a temperature of -55 to 125 degree Celsius with a power consumption of 10W. The Data Handling System receives the data from payload and sends command to the payload as a part of stored operational sequences. It is having both high gain and low gain communication systems. The high gain antenna of MAVEN is of 2.1 m diameter dish with a dual reflector X band system to achieve a downlink of 550kbps. This antenna features a travelling wave tube amplifier to generate a strong signal that can be picked up by the DSN stations on earth. The low gain system is used to command uplink and downlink of low rate telemetry such as tones that are used during Mars orbit insertion.

In addition to the X band communication system, MAVEN is equipped by an Electra UHF terminal. This terminal consists of a dual string UHF Transceiver, dual string ultra-stable oscillators for precision navigation and positioning. The oscillator provides a stable frequency as well as one way Doppler ranging capability. The Electra terminal monitors the signal strength of the ground based station so that it could request for different data rates. The data rate can be as low as 1kbps and as high as 2,048kbps at favorable conditions [20].

IV. COMPARISON

In this section, the comparison of the three Martian Satellites - Curiosity Rover, Mangalyaan and Maven are discussed. The parameters considered for the comparison of these space crafts are: Angle of inclination, payload mass, frequency, data rate, accuracy, efficiency, cost, speed, time, distance, velocity, heat map, orbital path, apogee, perigee etc.

TABLE 2
Comparison of Satellites

PARAMETER	ROVER	MOM	MAVEN
Launching date	Nov 26, 2011	Nov 5, 2013	Nov 18, 2013
Landing date	Aug 6, 2012	Sep 24, 2014 (exp)	Sep 2014 (exp)
Angle of inclination	65-75 deg	150 deg	75 deg
Azimuth angle	30 deg	44 deg	94 deg

Elevation angle	11.04 deg	25 deg	20 deg
Payload mass	899 kg	15 kg	65 kg
Frequency	437 MHz	15-25 MHz	2.1-7.1 GHz
Accuracy	1.5 miles error	40.5 sec timing error	20 sec timing error
Speed	70,000 mph	3.2 km/s	2.5 km/s
Current distance	161 feet	5,36,000km	780 million km
Velocity	21,000 km/h	29 km/sec	111,820 km/h
Data rate	12,000 – 3,500 bps	5/10/20/40 kbps	Up to 10 Mbps
Apogee	10,000 km	80,000 km	6,200 km
Perigee	180 km	365.3 km	150 km
Power	100 W	840 W	1135 W
Orbital path	Elliptical polar orbit	elliptical	Elliptical

V. CONCLUSION

The research and development in the field of satellite technology is having an incredible growth now a days. Recent research in satellite are mainly focused on exploring the atmosphere of Mars. Present day satellites have four stages – gas, liquid, solid and cryogenic, in which the fuels are stored and used. This will increase the weight of space craft. As a result, the cost will also be high. Now the cryogenic stage is used in the fourth stage. If the cryogenic stage is implemented in the first stage, the weight of the craft can be reduced to some extent. The fuel tank size can be minimized. The cost can also be reduced if the cryogenic stage is implemented in the first stage. We can hope for the same in near future.

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