Colonizing the Red Planet*

Prof. Dr. V. David Sánchez A., Ph.D.
Brilliant Brains, Palo Alto, California

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Abstract

Next to establishing a permanent basis on the Moon, our natural satellite, and populating it, the next celestial body to expand our presence in space is Mars, the Red Planet, due to being a neighbor planet that can be made habitable to humans. Through these developments, life on Earth itself will be heavily and positively impacted. The NASA's Mars Exploration Program (MEP) [1], currently on-going, which includes the future exploration of Mars by humans is only a first step in the right direction. The author has been intensively working in key preparatory and/or precursor space programs to colonize the Red Planet including being active participant in the ESA-ESTEC's Mars Express mission [2, 3], NASA-JPL-CNES' Mars Micromissions [4, 5], NASA-MSFC's SLS-based Human Space Exploration of the Moon, Mars, and beyond [6, 7], and currently NASA-ESA's Mars Sample Return (MSR) [8, 9], cf. Figure 1, developing NASA's next generation of fully autonomous space robotic systems and missions to deep space and for operational Mars autonomous aerial vehicles beyond NASA's Perseverance [10] and Ingenuity [11].

Figure 2 shows the Red Planet's size in comparison with the size of the Earth and of the Moon [12]. The Mars' volume is about 15% of Earth's volume. It also shows the Mars' atmosphere composition: 96% carbon dioxide, less than 2% argon, less than 2% nitrogen, and less than 1% other. The Earth's atmosphere is over

*This abstract has been granted permission for public release. The author is currently developing next-generation space aerial robotic technology and systems to fly in the mission campaign to Mars under the NASA JPL MSR Program Management, cf. Figure 1.

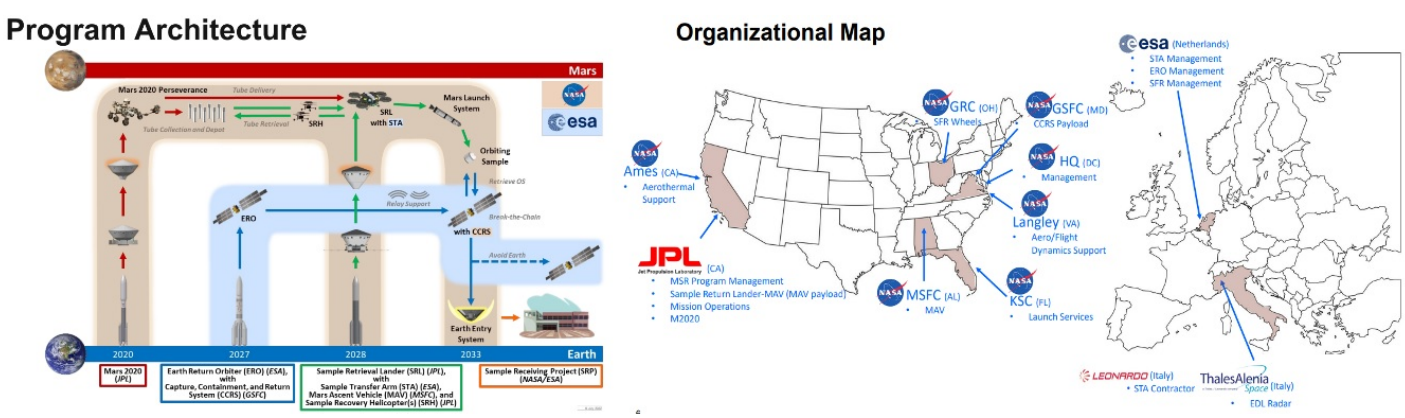

Figure 1: NASA-ESA's Mars Sample Return (MSR) Mission Campaign [8]

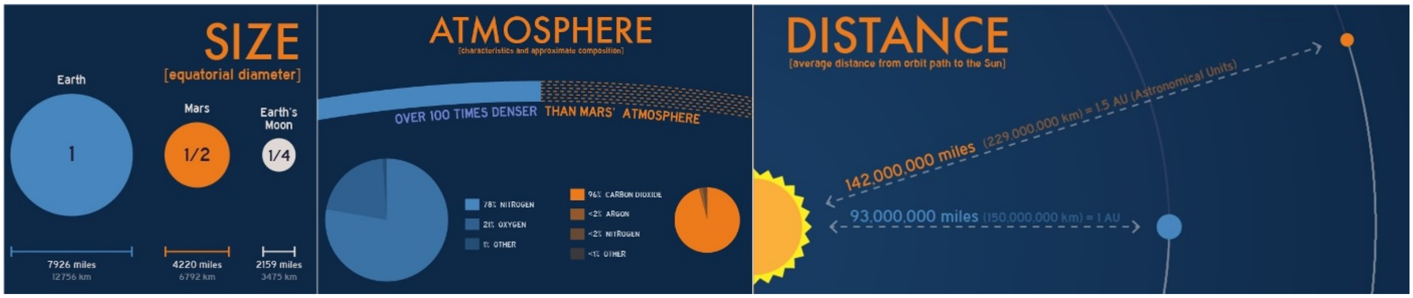

Figure 2: Mars – Size, Atmosphere, and Distance to the Sun [12]

Figure 3: Mars – Gravity, Day, Tilt, and Temperature [12]

100 times denser than Mars' atmosphere. Finally, the distance to the sun is shown: the Earth is 93,000 miles away whereas Mars is 142,000 miles away from the sun. Figure 3 shows Mars' gravity, which is about 37.5% of the Earth's gravity. It also shows that the tilts of both planets, Earth and Mars, are similar: 23.5° and 25° respectively, Mars has also four seasons, longer than the Earth's seasons, due to a Martian year being almost twice as long. Finally, the temperature range on Mars is shown: from -284°F to +86°F in comparison to the Earth's temperature range from -126°F to +136°F.

Previous Mars missions have shown – in practice, repeatedly – some of the currently, most challenging mission and spacecraft requirements, in particular to land payloads on the surface of the Red Planet. Figure 4 shows the Soyuz launch vehicle and ESA's Mars Express spacecraft configuration. That mission was launched on June 2, 2003 with a Soyuz-FG/Fregat of the Russian Federal Space Agency. The operations were carried out from ESA's Operation Centre (ESOC) in Darmstadt, Germany. The orbital insertion of the Mars Express orbiter was performed on December 25, 2003. That same day, the Mars Express lander, Beagle 2, entered the Mars atmosphere and was expected to land after having been released from the orbiter 6 days before on a ballistic cruise towards the surface, but no communication could be established with the lander which was declared lost on February 6, 2004.

The lander remains were spotted by the High Resolution Imaging Science Experiment (HiRISE) camera of NASA's Mars Reconnaissance Orbiter (MRO) in 2013 and 2014, that discovery was confirmed in January of 2015. The full deployment of all solar panels of Beagle 2 was required to expose the radio antenna to transmit data and receive commands from Earth. The MRO images showed only a partial deployment explaining why no communication with that lander could be established. Figure 5 shows the Entry, Descent, and Landing (EDL) sequence of Beagle 2, the lander on Earth, and its remains on Mars within the plain called Isidis Planitia. It also shows one of the scienific instruments of the payload of the Mars Express orbiter, the 20.4 kg High Resolution Stereo Camera (HRSC) which produces color images with up to 2 m resolution improving the cartographic base down to scales of 1:50,000. Also shown is one example of the topographic mapping on the entire planet which HRSC provided.

The experience with the Beagle 2 lander was just one of a series that historically has proven that the nearly 7 minute long Mars Entry, Descent and Landing (EDL) is the most challenging phase of a Mars mission. More recent missions have utilized further developed landing techniques, so for example during the Mars 2020/Perseverance mission, see Figure 6. Since it takes about 11 minutes for radio signals to arrive on Earth

Figure 4: ESA Mars Express – Launch Vehicle, Spacecraft Configuration [2, 3]

Figure 5: ESA Mars Express – Beagle 2 Lander, Mapping of the Planet [13]

from Mars, the entire EDL sequence needs to be executed 100% autonomously. At the top of the Martian atmosphere the spacecraft's speed was 12,500 mph. It then descelerated thank the drag produced by the Martian atmosphere under the protection of the heat shield to under 1,000 mph when it was safe to deploy about 240 seconds after entry at an altitude of about 7 miles and a speed of 940 mph the 70.5 ft diameter large supersonic parachute using the Range Trigger technique to determine the distance to the landing target and significantly shrinking the rover's landing ellipse.

The heat shield was dropped away 20 seconds after parachute deployment. Among others, the rover's landing radar provided signals to determine its altitude above the Martian surface, this time another EDL techique was used: Terrain-Relative Navigation (TRN), which avoids hazards and sends the lander to safer terrain after divert maneuvers based on descent photos it takes and the comparison to orbital maps, allowing for more science interesting terrain to land on at far less risk. The parachute was able in the thin Martian atmosphere to slow the lander down to about 200 mph. At about 6,900 ft above the surface, the rover separated itsef from the backshell and the 8-engine rocket-powered descent stage was fired up and its direction was diverted to avoid being hit by the parachute or backshell coming down and based on the safe target selected by TRN. As the final descent speed of 17 mph was reached, the skycrane maneuver was initiated. At about 66 ft above the surface and 12 seconds before touchdown, using a 21ft long set of cables the descent stage lowered the rover, which meanwhile had unstowed its legs and wheels into landing position. The cables were cut from the descent stage as soon as the rover wheels sensed they had touchdown. The descent stage flied away from, and safely for the rover to its own landing site. This successful EDL happened on February 21, 2021.

According to the on-going NASA-ESA Mars Sample Return (MSR) [8, 9] mission campaign, see Figure 7, sample Martian rocks and soil will be transported back to Earth from the Red Planet, where they are being collected and stored in sealed tubes by the Perseverance rover. The Sample Retrieval Lander (SRL) [15] will carry a Mars Ascent Vehicle (MAV) [16] with which a sample container will be launched into Martian orbit

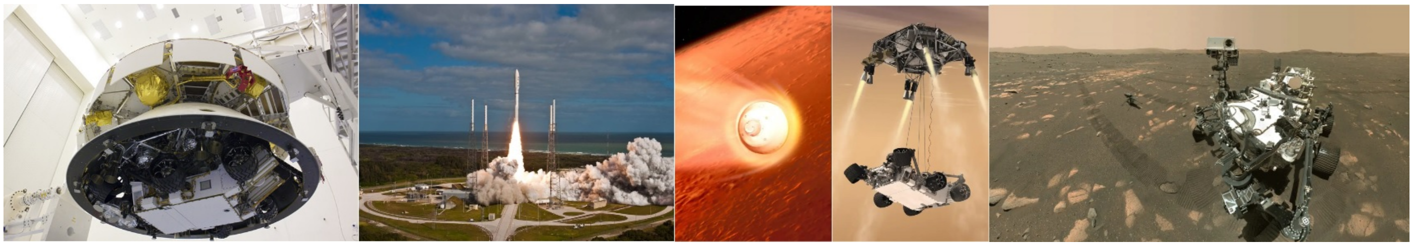

Figure 6: NASA Mars 2020 Perseverance Mission, MSR Mission Campaign [14]

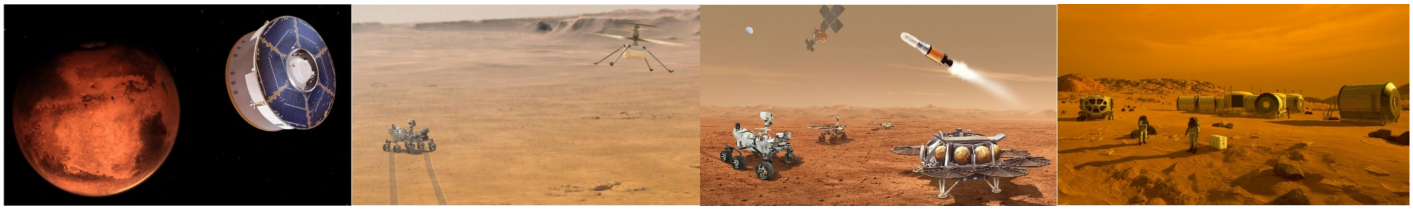

Figure 7: NASA-ESA Mars Sample Return (MSR) and Beyond [8, 9]

towards the Earth Return Orbiter (ERO) [17] after being brought to the SRL by Sample Recovery Helicopters (SRH). In orbit, the ERO's Capture/Containment, and Return System (CCRS) [15] will capture the orbiting sample container and return it to our planet inside the Earth Entry System (EES) [15].

Once landing on the Red Planet with our human-rated spacecraft, it is needless to state that we need to be able to return not only samples, but also humans, back to Earth. Despite the current planet's hostility, i.e., extremely low atmospheric pressure, unbreathable air, extremely cold temperature, ionizing radiation, the own scarce human life supporting planet's resources can still help the initial survival environment development via Synergetic Material Utilization (SMU) [18] and In-Situ Resource Utilization (ISRU) [19, 20] and special-purpose sustainable habitats [21, 22, 23] transported from Earth, necessary for human settlement based on a self-sustaining infrastructure while we continue exploring the existence of ancient life and start colonizing the planet utilizing without a doubt in-situ symbiotic human-robotic activities and more explicitly biological and artificial intelligence cooperative systems. Technology systems still to be developed to completion will provide the protection and adaptation of the human body during the interplanetary cruise and on the target planet per se. An in-depth taxonomic analysis of past and current efforts to colonize the Red Planet, flown and not yet defined to completion, i.e., overall strategies, specific technologies, missions, campaigns, and programs, is reported providing rationales for optimal selection. The committed establishment of the right succession of missions will guarantee endeavor success beyond the factual deployment of initial settling colonies to further sustain human life and nature as well as the reflourishing of human civilization beyond planet Earth throught the universe with the Moon and Mars being only the first milestones towards that goal.

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