



## **Building Habitats on the Moon**

Engineering Approaches to Lunar Settlement

Haym Benaroya, Professor of Mechanical & Aerospace Engineering, Rutgers University, New Brunswick, New Jersey, USA

Springer Praxis Publishing Chichester,  
UK ISBN 978-3-319-68242-6  
2018

This is a very needed book: After a long time of abstinence of making plans to settle the Moon permanently a new initiative seems to arise, triggered also by the bold announcement of ESA's Director-General Johann-Dietrich Woerner who discussed his concept of an international "Moon Village" cooperation at the International Astronautical Congress (IAF) in Jerusalem in October 2016 and which is gradually making progress. [1]

The book "Building Habitats on the Moon" is a snapshot and a profound summary of the current ideas, concepts, technologies and plans to take the next step with respect to settling the Moon permanently.

The book's purpose is, to provide an overview enhanced with details about all the engineering, scientific, medical, psychological, political, and economic aspects that have a role in the creation of a significant and permanent human presence on the Moon. The author first discusses the lunar environment (Gravitation, Radiation, Regolith) and how it affects humans in so many ways, because the structures designed to house them must also safeguard them against that environment. Additionally giving the indoor life awaiting the inhabitants of the moon, the provision of a psychological pleasing and nurturing haven within which to thrive is needed.

The main body of the book covers concepts and designs of structures and habitats on the Moon in detail, supported by results of earlier studies and by detailed interviews with experts, concluding with in-depths discussions on safety and redundancy aspects as well as regulation and certification aspects.

With the author's own words: "The book is about the structural engineering of settlements on the lunar surface, and a bit on sub-lunar sites. It is about the Moon, rather than Mars, for two reasons. The first is that we know the most about the Moon. Humans have been there six times.

Getting people safely to the moon for a very long stay is fairly within the abilities of our highly technological society. Some aspects are a bit beyond our abilities, but much is within that horizon of our talents. Mars however, is another story. Much of what we need to be able to do to get people to Mars is beyond that horizon. It is not a matter of money, but rather a matter of experience in space, of surviving in space, more specifically, experience and survival on the Moon. If someone gave me as much money as I wanted to make humanity a space-faring civilization, I would still choose the Moon as our first goal from. This book will provide some insight into that choice."

Haym Benaroya asks and delivers answers to the following questions:

**Why Moon and not Mars?**

The moon is our closest planetary body, roughly three days flying time away, with almost instantaneous communications with Earth. The rival Mars is essentially as hostile to human life as the Moon, but also requires about a year of travel time from Earth, with a significant communications delay. A strategic view of space exploration and settlement places the Moon and Mars in the proper order, based on their proximity to Earth.

Why going to the Moon again right now?

We periodically return to the onset of humanity's return to the Moon. United States administrations change every 4 to 8 years, and with new administrations, space policy and goals go through discontinuities that have been generally painful and costly. Looking back at 1989, 1993, 2001, 2009, and now 2017/18 we are in the middle of choices to be made about space generally and the Moon particularly.

How?

In order to advance the mission to the Moon outlined above, we will need the following: access to orbit, low earth orbital operations, human rated transportation to the Moon along with all the technologies for descent and landing, Lunar habitats, solar battery and nuclear power systems.

Challenges?

Development of life support and shielding systems to safeguard against radiation and micrometeorites, and cope with zero and 1/6 gravity, the ability to perform surface missions, in-situ resource utilization in conjunction with necessary logistics and technologies, and fuel to ascend into lunar orbit for a return to Earth are the most important challenges. We will need to be able to ameliorate the adverse psychological effects of close-quarters cohabitation and isolation from Earth and family. Supporting human life requires a number of additional basic capabilities in particular, plant growth in a closed and reduced gravity environment, waste processing and nutrient recovery, atmosphere revitalisation and water management.

Engineering challenges include propulsion, power, structures, optics, instrumentation, environmental controls, guidance and control, data management and storage and communications and much more.

Benefits?

The money spent on space exploration is spent on Earth and in the most productive sectors of the economy. The money that is spent goes to manufacturing, research and development, salaries, benefits, insurance companies, doctors, teachers, scientist, students, blue- and white-collar workers, and corporations and businesses both large and small. The money disperses throughout the economy in the same way as money spent on medical research, building houses or any other activities to engage in with government or even private spending.

“Specifically, in 1987, the NASA procurement budget generated \$7.8 billion in total industry sales, and a multiplier effect of 2.1 on the economy, created 209,000 private sector jobs and \$2.9 billion in business profit and generated \$5.6 billion in federal, state and local tax revenues. These benefits cascaded throughout the United States even though the initial Nasa expenditures were in only a few States.” [2]

Ethics?

Once activity begins on the Moon, Mars, asteroids and beyond, we also expect development of the rules that govern such activities. Laws and ethics need to be written that will be viewed as legitimate by the participants, as well as the observers on the sidelines. Livingston [3] proposed a code of ethics with the aim of facilitating an increase in commercial activity in space. The code of ethics covers areas such as environmental stewardship of space, the promotion of honest dealings, making safety an important concern insuring a free market economy, and disclosure of conflicts of interest or political contributions. In addition, the unique nature of outer space requires its development be done with care, with thoughtful long-term planning, and with consideration of future generations.

The rules by which we will operate in space are not yet set, but there have been efforts to begin to outline them. There is a United Nations report that provides the text of treaties and principles that govern the activities of countries in the exploration and use of outer space. While the UN General Assembly has ratified these treaties, there is little legal weight to them without further ratification by all the individual members of the UN. The existing five space treaties are listed and referenced in the book.

Whether the Moon will become a “better world” is questionable – as T.C. Boyle (Terranauts) and Andy Weir (Artemis) discuss in their recent bestsellers. As a Moon-settlement, or any outer space settlement is basically driven by industrial and/or political interests, and taking underlying human

shortcomings into account, a lot of attention has to be given to psychological and human behavioral studies and insights besides solving the “looming”, much easier technical problems.

HOW could it be done?

As mentioned above, the main body of the book covers how a human settlement on the Moon can be accomplished. Exhaustive historical and present arguments from all the prominent sources ranging from Sci-Fi authors to O’ Neill, Carl Sagan, JFK at Rice University, Edward Teller, David Livingston, James Logan, Marc Cohen, Donald Rapp, and the author Benaroya [2] himself, are collected and put in perspective with the current state of affairs.

One can use the book twofold: (1) Reading through all the arguments and interviews addressing the educated pros and cons to the above questions, you will be able to form your own opinion according to your own background. Although the author provides an enthusiastic plea for going to the Moon he does not provide an all-inclusive single answer; (2) Or you can study the main chapters of the book as guidance to implement the “going to the Moon and stay” either as an involved engineer or as decision maker or manager to make sure all aspects are addressed and nothing is forgotten.

Globally a growing interest can be observed in going the Moon again after 50 years and we might be able to see the fulfillment of Benaroya’s prediction that humans will set foot on the Moon again by 2024. The mature plans, concepts and technologies are there - all that's left is a global political will and combined global funding by governments and industry.

Studying the book will give the reader a deep insight into all the technical, physiological and psychological problems and lets him establish the odds for the realization of a successful global “Moon Village” vision.

“It’s hot, toxic and rains bullets  
...but fun, it’s a great place to live.” [2]

The detailed references and registers, including all relevant interviews and quotations at the end of each chapter provide pointers to a whole universe of additional information.



ESA Image “Moon Village” Vision[1]

## References:

[1] Space 4.0 definition [http://www.esa.int/About\\_Us/Ministerial\\_Council\\_2016/What\\_is\\_space\\_4.0](http://www.esa.int/About_Us/Ministerial_Council_2016/What_is_space_4.0)

[2] Dr. Haym Benaroya is a Professor of Mechanical and Aerospace Engineering at Rutgers University. He is working since 1981 in space exploration and research, his research interests are focused on the conceptualization and analysis of structures placed in challenging environments. Primary examples include offshore drilling structures, structures subjected to explosions, and lunar surface structures for manned habitation.

[3] Dr. Livingston's profound interviews for the book are included in the relevant chapters. Dr. David Livingston is the founder and host of the Space Show with the website [www.thespaceshow.com](http://www.thespaceshow.com). For nearly 17 years and close to 3000 interviews, it has been the nations only talk radio program exclusively focusing on space commerce, space tourism, and facilitating our becoming a space-faring economy and society. Dr. Livingston is also the executive director of the One Giant Leap Foundation, Inc. (OGLF), the 501(C)3 that controls the Space Show, OGLF strives to promote space education. David is also an Adjunct Professor of space in the Odegard School of Aerospace Sciences at the University of North Dakota. He teaches credit classes and commercial space. Livingston has a BA in political science, and MBA specialising in international business management, and a doctorate in business administration (DBA). His dissertation was titled: "*Outer Space Commerce: Its history and prospects*".

April 2018, Joachim J. Kehr, Editor SpaceOps News for the "Journal of SpaceOperations & Communicator"  
<http://opsjournal.org>  
joachimkehr@aol.com