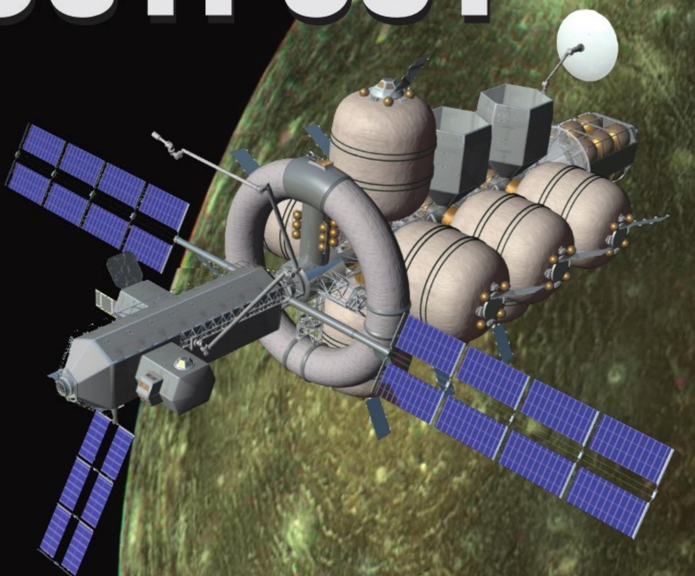
Erik Seedhouse

Interplanetary Outpost

The Human and Technological Challenges of Exploring the Outer Planets



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Contents

Preface

On August 22nd, 2001, when NASA's adventurous Galileo spacecraft skimmed just 138 km above the surface of Jupiter's moon Callisto, on-board cameras captured the sharpest pictures ever of that moon's mysterious landscape: an icy surface that happens to be the most heavily cratered place in the Solar System. For billions of years, little has changed on Callisto other than the relentless accumulation of craters, but magnetic readings picked up by Galileo suggest the pock-marked satellite harbors one of the Solar System's biggest salty oceans. But the water, if it's really there, doesn't lie atop the frigid surface, but may instead be hidden deep below the moon's crust – a tantalizing puzzle for future spacecraft and explorers.

Human interplanetary missions are widely considered the next logical step in space exploration. Scientific motivations include the search for extraterrestrial life, while inspirational, cultural, and economic considerations are also key factors. The prospect of these and future new discoveries will eventually fuel the impetus to embark upon a manned mission to far-flung destinations such as Callisto. After decades of speculation, such a mission may go far towards answering the question of whether extraterrestrial life exists in our Solar System. But how will such a mission be designed, what propulsion system will be used, and what are the hazards to humans embarking upon such a mission?

Interplanetary Outpost answers these questions by following the mission architecture template of NASA's plan for Human Outer Planet Exploration (HOPE), which envisages sending a crew to Callisto to conduct exploration and sample return activities. To realize such a mission, the spacecraft will be the most complex interplanetary vehicle ever built, representing the best technical efforts of several nations. A wealth of new technologies will need to be developed and qualified, including new propulsion systems, hibernation strategies, and revolutionary radiation shielding materials. Some of the technology development will require quantum leaps in innovation, while others may appear to be more science fiction than science. Step by step, this book describes how the mission architecture will evolve, how crews will be selected and trained, and what the mission will entail from launch to landing.

The focus of *Interplanetary Outpost* is on the human element. Just as a six-month tour of duty on board the International Space Station is fundamentally different from a two-week trip to the Moon, the challenges of a five-year mission to Jupiter will be unique. Although the three types of missions share superficial similarities, the extended duration, logistical challenges, radiation concerns, communication lag times, isolation, and deleterious effects upon the human body will conspire to not only significantly impair human performance, but also affect the behavior of crewmembers. *Interplanetary Outpost* addresses each of these issues in detail while still providing the reader with a background to the necessary elements comprising such a mission.

Throughout human history, explorers have ventured into the unknown and challenged harsh environments. Nansen, Amundsen, and Shackleton are but a few of the more prominent members of this intrepid class of individuals, many of whom spent months, if not years, actively and successfully investigating remote regions without any contact with their home base. Humans are long overdue for an era of exploration that rivals these earlier journeys in terms of scope, duration, isolation from sources of supply and assistance, and potential for exciting new discoveries. Spaceflight opened a new realm of exploration for human crews with its first tentative steps in the early sixties. In the intervening years, capabilities have been gradually developed for a long-term, sustained presence in this realm. These capabilities will shortly reach the level of sophistication and durability necessary for human crews to explore the surfaces of the outer planets.

Acknowledgments

In writing this book, the author has been fortunate to have had five reviewers who made such positive comments concerning the content of this publication. He is also grateful to Maury Solomon at Springer and to Clive Horwood and his team at Praxis for guiding this book through the publication process. The author also gratefully acknowledges all those who gave permission to use many of the images in this book, especially Mark Holderman and scientists Dr Robert Freitas and Philippe van Nedervelde.

The author also expresses his deep appreciation to Christine Cressy, whose attention to detail and patience greatly facilitated the publication of this book, to Jim Wilkie for creating the cover of this book, and to Stewart Harrison who sourced several of the references that appear in this book.

Once again, no acknowledgment would be complete without special mention of our cats, Jasper, MiniMach, and Lava, who provided endless welcome (and occasionally unwelcome!) distraction and entertainment.

This book is dedicated to the future space pioneers who will venture outward to expand our presence to the outer planets and beyond

About the author

Erik Seedhouse is a Norwegian aerospace scientist whose ambition has always been to work as an astronaut. After completing his first degree in Sports Science at Northumbria University, the author joined the legendary 2nd Battalion the Parachute Regiment, the world's most elite airborne regiment. During his time in the "Para's", Erik spent six months in Belize, where he was trained in the art of jungle warfare and conducted several border patrols along the Belize–Guatemala border. Later, he spent several months learning the intricacies of desert warfare on the Akamas Range in Cyprus. He made more than 30 jumps from a Hercules C130 aircraft, performed more than 200 abseils from a helicopter, and fired more light anti-tank weapons than he cares to remember!

Upon returning to the comparatively mundane world of academia, the author embarked upon a master's degree in Medical Science at Sheffield University. He supported his master's degree studies by winning prize money in 100 km ultradistance running races. Shortly after placing third in the World 100 km Championships in 1992 and setting the North American 100 km record, the author turned to ultradistance triathlon, winning the World Endurance Triathlon Championships in 1995 and 1996. For good measure, he also won the inaugural World Double Ironman Championships in 1995 and the infamous Decatriathlon, the world's longest triathlon – an event requiring competitors to swim 38 km, cycle 1,800 km, and run 422 km. Non-stop!

Returning to academia once again in 1996, Erik pursued his Ph.D. at the German Space Agency's Institute for Space Medicine. While conducting his Ph.D. studies, he still found time to win Ultraman Hawaii and the European Ultraman Championships as well as completing the Race Across America bike race. Due to his success as the world's leading ultradistance triathlete, Erik was featured in dozens of magazines and television interviews. In 1997, *GQ* magazine nominated him as the "Fittest Man in the World".

In 1999, Erik decided it was time to get a real job. He retired from being a professional triathlete and started his post-doctoral studies at Vancouver's Simon Fraser University's School of Kinesiology. In 2005, the author worked as an astronaut training consultant for Bigelow Aerospace in Las Vegas and wrote

Tourists in Space, a training manual for spaceflight participants. He is a Fellow of the British Interplanetary Society and a member of the Aerospace Medical Association. Recently, he was one of the final 30 candidates of the Canadian Space Agency's Astronaut Recruitment Campaign. Erik currently works as a manned spaceflight consultant, triathlon coach, and author. He is the Training Director for Astronauts for Hire (*www.astronautsforhire.org*) and plans to travel into space as a paid astronaut on board one of the new commercial spacecraft.

In addition to being a triathlete, sky-diver, pilot, and author, Erik is an avid scuba-diver and mountaineer and is currently pursuing his goal of climbing the Seven Summits. *Interplanetary Outpost* is his eighth book. When not writing, he spends as much time as possible in Kona on the Big Island of Hawaii and at his real home in Sandefjord, Norway. Erik is owned by three rambunctious cats – Jasper, Mini-Mach, and Lava – who each provided invaluable assistance in writing this book (!).

Figures

Tables

Panels

Abbreviations

ADC	Attitude Determination and Control
AG	Artificial Gravity
AI	Artificial Intelligence
ALARA	As Low As Reasonably Achievable
AMPDXA	Advanced Multiple-Projection Dual-energy X-ray Absorptiometry
AOCS	Attitude and Orbit Control System
APS	Active Pixel Sensor
ARS	Air Revitalization System
ATCV	Active Thermal Control System
ATP	Adenosine Triphosphate
BIT	Built-In Test
BLSS	Bioregenerative Life-Support System
BMD	Bone Mineral Density
BMDO	Ballistic Missile Defense Organization
BNL	Brookhaven National Laboratory
BNTR	Bi-modal Nuclear Thermal Rocket
CAD	Coronary Artery Disease
CCAFS	Cape Canaveral Air Force Station
CCD	Charged-Coupled Device
CCI	Callisto-Centered Inertial
CELSS	Closed Ecological Life-Support System
CG	Center of Gravity
CMC	Central Monitoring Computer
CMO	Crew Medical Officer
COSPAR	Committee on Space Research
CRM	Crew Resource Management
CSA	Canadian Space Agency
CSF	Callisto Surface Fixed
CT	Computed Tomography
CTV	Crew Transfer Vehicle
DARPA	Defense Advanced Research Projects Agency

DDOR	Delta Differential One-way Ranging
DEM	Digital Elevation Map
DIMES	Descent Image Motion Estimation Subsystem
DNA	Deoxyribonucleic Acid
DSN	Deep Space Network
DTE	Direct to Earth
ECLSS	Environmental Closed Life-Support System
EPA	Eicosapentaenoic Acid
ESA	European Space Agency
EVA	Extravehicular Activity
FDIR	Failure Detection Isolation and Ranging
FOV	Field of View
FRU	Field Replaceable Unit
FSP	Fission Surface Power
GCR	Galactic Cosmic Ray
GHz	Gigahertz
GN&C	Guidance, Navigation and Control
HDA	Hazard Detection and Avoidance
HGA	High Gain Antenna
HIT	Hibernation Induction Trigger
HOPE	Human Outer Planets Exploration
ICRH	Ion Cyclotron Resonance Heating
ICRP	International Commission on Radiological Protection
IGF	Insulin-Growth Factor
IHASM	Intelligent Health and Safety Monitoring
IHSI	Integrated Health Status Information
IMU	Inertial Measurement Unit
IQC	Interplanetary Qualification Course
ISRU	In-Situ Resource Utilization
ISS	International Space Station
JSC	Johnson Space Center
LBM	Low Bone Mass
LEO	Low-Earth Orbit
LET	Linear Energy Transfer
LG	Low Gate
LIDAR	Light Detection and Ranging
LOC	Loss of Crew
LOM	Loss of Mission
LOS	Line-of-Sight
LOX	Liquid Oxygen
LSS	Life-Support System
LVLH	Local-Vertical, Local-Horizon
MCMI	Million Clinical Multiphasic Inventory
MCP	Mechanical Counter Pressure
MDA	Missile Defense Agency

MECO	Main Engine Cut-Off
MFS	Magnetic Field Strategy
MHz	Megahertz
MIT	Massachusetts Institute of Technology
MMPI	Minnesota Multiphasic Personality Inventory
MPD	Magnetoplasma-dynamic
MRI	Magnetic Resonance Imaging
MSBL	Microwave Scan Beam Landing
MTF	Magnetized Targeted Fusion
NAUTILUS-X	Non-Atmospheric Universal Transport Intended for Lengthy
MMSEV	United States X-ploration, Multi-Mission Space Exploration Vehicle
NCRP	National Council on Radiation Protection
NCS	National Contamination Standard
NFKB	Nuclear Factor Kappa B
NIAC	NASA Institute for Advanced Concepts
NIMS	Near Infrared Mapping Spectrometer
NRC	National Research Council
NSBRI	National Space Biomedical Research Institute
OBIRON	On-Board Image Reconstruction for Optical Navigation
ORU	Orbital Replacement Unit
PCAD	Power Conditioning and Distribution
PCHM	Propulsion Control and Health Monitoring
PDI	Power Descent Initiation
PDP	Propulsive Descent Phase
PDR	Preliminary Design Review
PV	Photovoltaic
RASC	Revolutionary Aerospace Systems Concepts
RBC	Red Blood Cell
RBE	Relative Biological Effectiveness
RCS	Reaction Control System
ROV	Remotely Operated Vehicle
SAR	Synthetic Aperture Radar
SCNT	Somatic Cell Nuclear Transfer
SEP	Solar Electric Propulsion
SFRM	Space Flight Resource Management
SIFT	Scale Invariant Feature Transform
SOI	Sphere of Influence
SPE	Solar Particle Event
SRC	Short-Radius Centrifuge
SRL	Space Radiation Laboratory
SRU	Shop Replaceable Unit
SSME	Space Shuttle Main Engine
SST	Single System Trainer
SVD	Synthetic Vision Display