Human Missions to Mars

Enabling Technologies for Exploring the Red Planet

Donald Rapp

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Contents

Preface xv

List of figures xvii

List of tables xxiii

List of abbreviations and acronyms xxvii

1 Why explore Mars? 1
  1.1 Robotic exploration—the Establishment's view 1
  1.2 The curmudgeon's view on the search for life on Mars 5
  1.3 Why send humans to Mars?—the enthusiast's view 7
  1.4 Sending humans to Mars—the skeptic's view 10

2 Planning space campaigns and missions 13
  2.1 Campaigns 13
  2.2 Planning space missions 14
  2.3 Architectures 15
  2.4 A mission as a sequence of steps 19
  2.5 What's at the destination? 22
  2.6 What's in low Earth orbit 24
  2.7 What's on the launch pad? 25
  2.8 IMLEO requirements for space missions 25

3 Getting there and back 27
  3.1 Propulsion systems 27
    3.1.1 Propellant requirements for space transits 28
    3.1.2 The rocket equation 30
    3.1.3 Dry mass of rockets 33

3.2 Trajectory analysis . . . 35
  3.2.1 Rocket science 101 . . . 35
    3.2.1.1 Constants of motion . . . 35
    3.2.1.2 Energy of an orbit . . . 36
    3.2.1.3 Measured values for the Sun, Earth, and Mars. 38
    3.2.1.4 Escaping the influence of a planet . . . 39
    3.2.1.5 Earth and Mars solar orbit velocities . . . 40
    3.2.1.6 Hohmann transfer to Mars . . . 40
    3.2.1.7 Earth and Mars low-orbit velocities . . . 42
    3.2.1.8 Earth escape . . . 42
    3.2.1.9 Mars orbit insertion—part 1 . . . 43
    3.2.1.10 Summary of transfers to and from Hohmann orbit . . . 44
    3.2.1.11 Orbital period . . . 45
    3.2.1.12 Mars orbit insertion—part 2 . . . 47
    3.2.1.13 Summary. . . . 49
  3.2.2 Mars mission duration and propulsion requirements . . . 50
  3.2.3 More realistic models . . . 53
3.3 Earth to low Earth orbit . . . 54
3.4 Departing from LEO . . . 58
  3.4.1 The Δv requirement . . . 58
  3.4.2 Mass sent toward Mars . . . 59
  3.4.3 Nuclear thermal rocket for TMI . . . 61
  3.4.4 Solar electric propulsion for orbit raising . . . 63
3.5 Mars orbit insertion . . . 65
3.6 Ascent from the Mars surface . . . 68
3.7 Trans-Earth injection from Mars orbit . . . 69
3.8 Earth orbit insertion . . . 69
3.9 Gear ratios . . . 71
  3.9.1 Introduction . . . 71
  3.9.2 Gear ratio calculations . . . 71
  3.9.3 Gear ratio for Earth departure . . . 73
3.10 LEO to Mars orbit . . . 73
3.11 LEO to the Mars surface . . . 76
3.12 IMLEO for Mars missions . . . 76
  3.12.1 Chemical propulsion and aero-assist . . . 76
  3.12.2 Use of Nuclear Thermal Propulsion . . . 79
  3.12.3 Use of ISRU . . . 82

4 Critical Mars mission elements . . . 85
4.1 Life support consumables . . . 85
  4.1.1 Consumable requirements (without recyling) . . . 85
  4.1.2 Use of recycling systems . . . 87
  4.1.3 Life support summary . . . 90

4.2 Radiation effects and shielding requirements 91
  4.2.1 Radiation sources 91
  4.2.2 Definitions and units 92
  4.2.3 Radiation effects on humans and allowable dose 93
    4.2.3.1 Allowable exposure 93
    4.2.3.2 Radiation effects on humans 94
  4.2.4 Confidence intervals and point estimates 95
  4.2.5 Radiation in space 96
  4.2.6 Radiation levels in Mars missions 97
  4.2.7 Radiation summary 99
4.3 Effects of microgravity 99
  4.3.1 The Whedon–Rambaut review of low-*g* effects 99
  4.3.2 Artificial gravity 101
  4.3.3 NASA plans for low-*g* effects 105
4.4 Abort options and mission safety 106
  4.4.1 Abort options and mission safety in ESAS lunar missions 106
  4.4.2 The Mars Society Mission 108
  4.4.3 Abort options conclusions 109
4.5 Habitats 111
  4.5.1 DRM-1 Habitats 111
  4.5.2 DRM-3 Habitats 112
  4.5.3 Dual Landers Habitat 113
  4.5.4 The “MOB” design 113
    4.5.4.1 Basic design 113
    4.5.4.2 ISRU 117
    4.5.4.3 Habitat mass 118
    4.5.4.4 Habitat structure 119
    4.5.4.5 ECLSS 120
  4.5.5 Sasakawa International Center for Space Architecture . . 121
    4.5.5.1 Habitat configurations 121
    4.5.5.2 Logistic and crew support 125
  4.5.6 Inflatable Habitats 125
4.6 Aero-assisted orbit insertion and entry, descent, and landing . . . 127
  4.6.1 Introduction 127
  4.6.2 Challenges for aero-assist technology 131
    4.6.2.1 Atmospheric variations 132
    4.6.2.2 Aeroshell shape and size 132
    4.6.2.3 Supersonic parachute 134
    4.6.2.4 Landing accuracy 135
  4.6.3 Entry, descent, and landing requirements for human missions to Mars 135
    4.6.3.1 Initial results 135
    4.6.3.2 Updated results: 2006 140
  4.6.4 Precision landing 143
  4.6.5 Development, test, and validation program 145

5 *In situ* utilization of indigenous resources 149
5.1 Value of ISRU 149
5.2 Lunar ISRU 150
5.2.1 Introduction 150
5.2.2 Potential products of ISRU 151
5.2.2.1 Ascent propellants 151
5.2.2.2 Life support consumables 152
5.2.2.3 Propellants delivered to LEO from the Moon . 153
5.2.2.4 Propellants delivered to lunar orbit for descent (and ascent) 154
5.2.2.5 Regolith for radiation shielding 155
5.2.2.6 Visionary concepts 155
5.2.3 Lunar resources 158
5.2.4 Lunar ISRU processing 159
5.2.4.1 Oxygen from FeO in regolith 159
5.2.4.2 Oxygen from regolith silicates 160
5.2.4.3 Extracting putative volatiles 161
5.2.4.4 Utilizing polar ice deposits 162
5.2.5 Cost analysis for ESAS lunar ISRU 168
5.2.6 A new paradigm for lunar ISRU 170
5.3 Mars ISRU 172
5.3.1 Introduction 172
5.3.2 Timeline for ISRU on Mars 173
5.3.3 Mars ISRU products. 175
5.3.4 Mars ISRU processes 180
5.3.4.1 Oxygen-only processes 180
5.3.4.2 The Sabatier/Electrolysis process 185
5.3.4.3 Timeline for ISRU 187
5.3.4.4 CO_2 acquisition from the Mars atmosphere . . 187
5.3.5 Mass and power requirements of a Mars ISRU system . 188
5.4 Fueling Mars-bound vehicles from lunar resources 190
5.4.1 Introduction 190
5.4.2 Value of lunar water in LEO 190
5.4.3 Percentage of water mined on the Moon transferred to LEO 192
5.4.3.1 Transfer via LL1 192
5.4.3.2 Dependence on junction site 196
5.5 Lunar ferry for descent propellants 200
5.6 Staging, assembly, and refueling in near-Earth space 202
5.6.1 Introduction 202
5.6.2 Michael Griffin and orbiting fuel depots 203
5.6.3 Propellants for Earth departure 204
5.6.4 On-orbit staging 206
5.7 Transporting hydrogen to Mars 209
5.7.1 Terrestrial vs. space applications 209

5.7.2 Storage of hydrogen in various physical and chemical states . . . 211
  5.7.2.1 Storage as high-pressure gas at about room temperature . . . 211
  5.7.2.2 Storage as a cryogenic liquid . . . 213
  5.7.2.3 Storage as a dense gas at reduced temperature 215
  5.7.2.4 Storage as solid hydrogen . . . 216
  5.7.2.5 Storage as solid–liquid slush . . . 217
  5.7.2.6 Storage as hydrogen at its triple point . . . 218
  5.7.2.7 Storage as adsorbed hydrogen on a sorbent . . 218
  5.7.2.8 Storage in metal hydrides . . . 220
  5.7.2.9 Storage in glass microspheres . . . 221
5.7.3 Boil-off in space . . . 222
  5.7.3.1 Rate of boil-off from MLI tanks . . . 222
  5.7.3.2 Mass effect of boil-off in space . . . 225
  5.7.3.3 Boil-off rate on Mars . . . 227
5.7.4 Zero boil-off systems . . . 228
5.7.5 Potential space applications for hydrogen . . . 231
  5.7.5.1 Shuttle H_2 tanks . . . 231
  5.7.5.2 Hydrogen storage trade study for a solar electric orbital transfer vehicle . . . 233
  5.7.5.3 Estimates of boil-off by a lunar mission focused study . . . 233
  5.7.5.4 Transporting hydrogen to the lunar surface . . . 234
  5.7.5.5 Transporting hydrogen to Mars for ISRU . . . 234
5.7.6 Summary and conclusions . . . 235

6 Mars mission analysis . . . 237
6.1 Previous Mars mission studies . . . 237
  6.1.1 Office of Exploration case studies (1988) . . . 237
  6.1.2 Office of Exploration case studies (1989) . . . 238
  6.1.3 NASA 90-Day Study (1989) . . . 239
  6.1.4 America at the threshold—"The Synthesis Group" (1991) 239
  6.1.5 First lunar outpost (1993) . . . 240
  6.1.6 Human lunar return (1996) . . . 241
  6.1.7 Mars Exploration Design Reference Missions (1994–1999) 241
  6.1.8 Decadal Planning Team/NASA Exploration Team (2000–2002) . . . 242
  6.1.9 Integrated Space Plan (2002–2003) . . . 242
  6.1.10 Exploration Systems Mission Directorate (2004–2005) . . 242
  6.1.11 Constellation (2006–?) . . . 246
6.2 Mars Design Reference Missions (DRMs) . . . 248
  6.2.1 DRM-1 . . . 248
    6.2.1.1 Introduction . . . 248
    6.2.1.2 DRM-1 vehicles . . . 249

6.2.1.3 Mission sequence 250
6.2.1.4 Mars Ascent Vehicle (MAV) 252
6.2.1.5 Surface power 253
6.2.1.6 Interplanetary transportation system 253
6.2.1.7 Launch vehicles 255
6.2.1.8 *In situ* resource utilization 256
6.2.1.9 Life support consumables 258
6.2.2 DRM-3 258
6.2.3 Mass comparisons: DRM-3 and DRM-1 261
6.2.4 The Dual Landers Reference Mission 262
6.2.5 Common characteristics of 1990s' JSC Mars DRMs . . . 266
6.3 Mars DRMs in the 2005–2006 era 268
6.3.1 The ESAS Report Mars plans 268
6.3.2 2006 Mars DRM 272
6.4 Non-NASA Design Reference Missions 274
6.4.1 Mars Direct 274
6.4.2 The Mars Society Mission 278
6.4.3 TeamVision approach to space exploration 281
6.4.4 The MIT Study 282
6.4.5 ESA Concurrent Design Facility Study (2003) 284
6.5 IMLEO for human missions to Mars 286

7 How NASA is dealing with return to the Moon 291
7.1 Introduction 291
7.1.1 Need for a Heavy Lift Launch Vehicle 291
7.1.2 Urgency in returning to the Moon at the earliest possible opportunity 293
7.2 Moon–Mars connection 293
7.2.1 The Moon as a means of risk reduction for Mars 293
7.2.2 ISRU as a stepping-stone from the Moon to Mars . . . 295
7.2.3 The ESAS viewpoint on the Moon–Mars connection . . 298
7.2.4 A European viewpoint 299
7.3 Lunar architecture options 300
7.3.1 Zubrin's analysis. 300
7.3.2 MIT analysis 303
7.3.3 The Broad Study 308
7.3.4 The Focused Study 311
7.3.5 Comparison of Broad and Focused Study estimates of Δv 314
7.3.6 ESAS Report Δv estimates 314
7.3.7 Lunar orbit rendezvous vs. L1 rendezvous or direct return 319
7.3.7.1 Broad Study 319
7.3.7.2 Focused Study 319
7.3.8 ESAS report architecture comparison 320
7.4 The ESAS lunar architecture 324
7.4.1 Description 324

7.4.2 Independent mass estimates 324
7.5 Do we need a CEV? 326
7.6 The NASA lunar architecture process 329

8 Why the NASA approach will likely fail to send humans to Mars prior to c. 2080 331
8.1 Major differences between Mars and Lunar missions 331
8.2 Is NASA too busy for Mars missions? 332
8.3 Mars architecture planning 334
8.4 Need for new technology 340
8.4.1 Space Science Enterprise (SSE) 340
8.4.1.1 SSE scope of technology 340
8.4.1.2 Lead Centers 344
8.4.1.3 On again/off again 346
8.4.1.4 SSE technology summary 347
8.4.2 Human exploration technology 348
8.4.3 Exploration Systems Research and Technology (ESRT) . 349
8.5 2020 vision 351
8.6 Human exploration strategy. 354
8.6.1 Background 354
8.6.1.1 Destination-driven vs. constituency-driven programs 354
8.6.1.2 The 2004–2005 Human Exploration Initiative . 355
8.6.2 Current NASA plans (2006–2007) 357
8.6.3 Recommended strategy 358
8.6.3.1 Propulsion systems 359
8.6.3.2 Aero-assisted entry, descent, and landing 360
8.6.3.3 Habitats and capsules 361
8.6.3.4 Life support consumables 361
8.6.3.5 *In situ* resource utilization 362
8.6.3.6 Power systems 363
8.6.3.7 Site selection 363
8.6.3.8 Precursor missions at Mars 364
8.6.3.9 Mitigation of dust effects 366
8.6.3.10 Use of Moon for testing and demonstrations . 366
8.6.3.11 Testing in Earth orbit 367
8.7 Conclusions 368

APPENDICES

A Solar energy on the Moon 369
A.1 First approximation to lunar orientation 369
A.2 Solar insolation on a horizontal surface 371
A.3 Solar insolation on a vertical surface 373
A.4 Insolation on a surface tilted at latitude angle toward the equator 373

A.5 A surface that is always perpendicular to the solar rays 374
A.6 Effect of non-ideal lunar orbit 377
A.7 Operating temperature of solar arrays on the Moon 378
A.8 Solar energy systems at the equator 378
A.8.1 Short-term systems (<354 hours) 378
A.8.2 Long-term systems (>354 hours) 380
A.9 Effects of dust 382
A.10 Solar energy systems in polar areas 383
A.10.1 Polar sites 383
A.10.2 GRC solar polar study 386

B Solar energy on Mars 389
B.1 Solar intensities in current Mars orbit 389
B.1.1 Introduction 389
B.1.2 Irradiance in a clear atmosphere 391
B.1.3 Effect of atmosphere 391
B.1.3.1 The direct beam 393
B.1.3.2 Simple "two-flux" model of scattering and absorption of sunlight in the Mars atmosphere . . 395
B.1.3.3 Sophisticated model of scattering and absorption of sunlight in the Mars atmosphere 398
B.2 Solar intensities on a horizontal and tilted surfaces. 400
B.2.1 Nomenclature 402
B.2.2 Solar intensity on a horizontal surface 403
B.3 Solar intensities on a fixed tilted surface 404
B.3.1 The diffuse component on a tilted surface 405
B.3.2 Reflection from ground in front of tilted collector 407
B.3.3 Total intensity on a tilted surface 407
B.3.4 Rotating tilted surfaces 407
B.4 Numerical estimates of solar intensities on Mars 408
B.4.1 Solar energy on horizontal surfaces 408
B.4.1.1 Daily total insolation 408
B.4.1.2 Hourly insolation patterns on a horizontal surface 411
B.4.1.3 Total insolation on a horizontal surface over a Martian year 411
B.4.2 Solar intensities on sloped surfaces 411
B.4.2.1 Fixed slope surfaces 411
B.4.2.2 Rotating Sun-facing tilted planes 415
B.4.3 Solar energy on Mars over the last million years 418
B.4.3.1 Variations in the Mars orbit 418
B.4.3.2 Insolation on horizontal surfaces over a million years 419
B.4.3.3 Insolation on tilted surfaces over a million years 421

B.5 Effect of dust on array surfaces—simple models 425
  B.5.1 Introduction 425
  B.5.2 Optical depth 426
  B.5.3 Particle size distribution 426
  B.5.4 Number of dust particles in vertical column 428
  B.5.5 Rate of settling of dust particles 428
  B.5.6 Initial rate of obscuration 429
  B.5.7 Longer term buildup of dust 429
B.6 Pathfinder and MER data on dust obscuration 432
B.7 Aeolian removal of dust from surfaces 438
B.8 Obscuration produced by dust on solar arrays 440
  B.8.1 JPL experiments—2001 440
  B.8.2 Summary and conclusions on dust obscuration 441

C Water on Mars 445
C.1 Introduction 445
C.2 Background information 448
  C.2.1 Temperatures on Mars 448
  C.2.2 Pressures on Mars 451
  C.2.3 Water vapor concentrations on Mars 453
C.3 Equilibrium models for subsurface ice 455
  C.3.1 Introduction 455
  C.3.2 Models for stability of subsurface ground ice on Mars—current conditions 457
  C.3.3 Long-term evolution of water on Mars 464
  C.3.4 Effect of Mars orbit variations during the past ~1 million years 465
  C.3.5 Evolution of south polar cap 471
C.4 Experimental detection of water in Mars' subsurface by neutron spectroscopy from orbit 472
  C.4.1 Introduction 472
  C.4.2 Original data reduction 474
  C.4.3 Modified data reduction 474
  C.4.4 Water content based on uniform regolith model 475
  C.4.5 Water content based on a two-layer regolith model at equatorial and mid-latitudes 475
  C.4.6 Interpretation of depth from neutron measurements . . . 476
C.5 Comparison of neutron data with physical properties of Mars . . 478
  C.5.1 Surface and atmospheric properties 478
  C.5.2 Water deposits vs. topography at low and mid-latitudes . 481
  C.5.3 Seasonal distribution of equatorial near-surface water . . 484
C.6 The polar caps 484
C.7 Liquid water on Mars 486
  C.7.1 Regions where surface temperature excursions exceed 273.2 K 486

C.7.2 Liquid water below the surface 491
C.7.3 Imaging indications of recent surface water flows 493
C.7.3.1 Gullies 493
C.7.3.2 Surface streaks 496
C.8 Evidence from craters 498
C.8.1 Introduction 498
C.8.2 The work of Nadine Barlow (and friends) 500
C.8.3 Other crater studies 505
C.8.4 Commentary 506
C.9 Summary 510

Index 513

Preface

The basis of science is observation. By making repeated observations of relevant phenomena, we discover patterns in the behavior of natural systems, and from this we formulate theories that allow us to predict the outcome of future observations.

While this description of science works well for topics that have been heavily explored and are fairly well understood, there are many occasions in the real world at the cutting edge of knowledge where we have not yet made enough observations to draw conclusions, or where the phenomena of interest occurred so long ago that it is extremely difficult to fathom what might have actually taken place in ancient epochs.

One important case in point is the question of how, where, and when life originated from inanimate matter. The one basic piece of data that we have is that we know that life existed in a primitive form on Earth over 3 billion years ago (BYA). This was determined from fossil remains of early forms of life in dated deposits. Some of the questions that arise include:

- Where and when did life on Earth begin (on Earth, or somewhere else)?
- What was the process by which inanimate matter formed life in its primitive form?
- Is there life elsewhere in the solar system or external to the solar system?

All of these questions are in some sense subservient to the big question:

- Is the formation of life from inanimate matter a likely (or even a deterministic) process, given a reasonable length of time and a warm climate, liquid water, and a smattering of chemical elements in the lower periodic table?

In addressing these questions, some scientists have applied analysis and imagination to conceive of a wide variety of hypothetical scenarios for the formation of life, none of which is supported by evidence, and all of which seem highly dubious in retrospect. The world of science does not seem to be able to flatly say: “We simply do not understand much about the formation of life,'' and leave it at that. Just as nature abhors a vacuum, so does science abhor the absence of answers to vital questions. As a result, the science community has jumped on a series of bandwagons over the past several decades purporting to ''explain'' how life began, although many of these have now fallen by the wayside. Nevertheless, it is widely believed that formation of life from inanimate matter is a likely (or even a deterministic) process, and, given that belief, the most natural place to seek extraterrestrial life is Mars. Thus, the NASA exploration programs are heavily centered on a search for life on Mars.

Human missions to Mars represent the pinnacle of solar system exploration for the next half-century. In addition to providing a means of searching for life on Mars, such missions would represent an inspiring engineering achievement, and create a new era of expansion of humanity into space. Because such missions would require a major technological effort as well as very large expenditures, they remain for the moment as futuristic concepts embodied in paper studies by advocates and enthusiasts.

In the world of science and engineering, there is room for advocates and skeptics. Advocates play an important role in imagining what might be, and stubbornly pursue a dream that may be difficult to realize, but which in the end may be achievable. Skeptics identify the barriers, difficulties, pitfalls, and unknowns that impede the path, and point out the technical developments needed to enable fulfillment of the dream.

In the realm of human missions to Mars, we have a number of studies by advocates and enthusiasts, but there seems to be a total absence of skepticism in this arena. This book represents the first skeptical analysis of human missions to Mars, and it is offered as a counter-balance to the optimism so widely promulgated by the NASA Johnson Space Center, the Mars Society, and others.

Donald Rapp
April 2007

Figures

2.1 NASA ESAS architecture for lunar sortie missions 16
2.2 ESAS lunar sortie architecture 17
2.3 MIT lunar architectures 18
2.4 States and steps for Mars mission 21
2.5 Typical Δv for lunar sortie missions 22
2.6 Typical Δv (km/s) for Mars missions 23
2.7 Vehicles in JSC's Mars DRM-3 23
3.1 Model of a rocket burn 28
3.2 Specific impulse of methane/oxygen rocket . . . . color
3.3 Flight path at periapsis showing flight path is perpendicular to radius 36
3.4 Spacecraft in orbit about a planet 36
3.5 Force balance for a circular orbit 37
3.6 Typical hyperbolic trajectory 38
3.7 Escape from Earth 39
3.8 Transfer from moving with the Earth to Hohmann orbit 41
3.9 Transfer from Earth orbit to Hohmann orbit 45
3.10 Kepler's second law 46
3.11 Properties of the ellipse 47
3.12 Mars orbit insertion 49
3.13 Hyperbolic and elliptical trajectories at Mars 50
3.14 Typical "pork-chop" plot for 2022 . . . . color
4.1 Probability of radiation exposure induced death 96
4.2 Dose for GCR at Solar Minimum 96
4.3 BFO dose equivalent vs. lunar regolith thickness 97
4.4 Parameters for artificial gravity 102
4.5 Concept for artificial gravity 103
4.6 Dual connected Habitats in DRM-1 113
4.7 DRM-3 Habitat 114
4.8 Dual Landers vehicle 116
4.9 MOB concept for Habitat 117

4.10 MOB plan for upper floor 118
4.11 MOB plan for lower floor 118
4.12 SICSA layout/configuration options 123
4.13 SICSA logistic module concept. 123
4.14 Habitat module geometry. 124
4.15 Inflatable Habitat concept 126
4.16 MGS aerobraking process 129
4.17 Sequence of events in aerocapture. 130
4.18 Typical aeroshell 133
4.19 Mass of entry system for Mars 139
4.20 Elements of Mars entry system. 139
4.21 Payload mass fraction to the Martian surface 142
5.1 Time-line for a Mars mission 174
5.2 Zirconia cell 181
5.3 Ion current from zirconia cell. 182
5.4 Composition vs. temperature in RWGS process. 184
5.5 Composition vs. temperature in Sabatier process 185
5.6 Earth–Moon Lagrange Points 191
5.7 Transporting water from the Moon to LEO 191
5.8 Potential saving in IMLEO 202
5.9 Density of gaseous hydrogen 215
5.10 Isotherms for hydrogen adsorption 219
5.11 Boil-off rate for hydrogen 224
5.12 Performance of insulation vs. pressure. 227
5.13 Tank insulation. 230
6.1 Mission sequence for Mars DRM-1 252
6.2 Solar electric propulsion orbit-raising with a solar electric propulsion tug. . . 265
6.3 Dual Landers mission 267
6.4 ESAS Version of Mars DRM. 269
6.5 MIT architectures for Mars missions. 284
7.1 Lunar sortie missions. 302
7.2 Lunar architectures in the MIT Study 304
7.3 Lunar orbit insertion 309
7.4 Δv for lunar orbit insertion—no loitering 316
7.5 Δv for lunar orbit insertion—loitering 317
7.6 Plane change for worst-case rendezvous 318
7.7 ESAS Report estimates of probability of loss of crew. . . . . color
7.8 ESAS Report estimates of probability of loss of mission. . . . . color
7.9 1.5-launch EOR–LOR architecture 325
8.1 Campaign for human exploration of Mars. 335
8.2 NASA Mars DRM (c. 2006) . . . . color
8.3 2006 NASA Mars DRM . . . . color
A.1 The Moon in the ecliptic plane. 370
A.2 Motion of Earth and Moon 370
A.3 Lunar orbit in ecliptic plane. 371
A.4 Horizontal surface on the Moon. 372
A.5 Solar intensity on a horizontal surface 372
A.6 Solar intensity on a horizontal surface—contour plot 373
A.7 Total energy per 14.77-day cycle. 374

A.8 Vertical surface on the Moon 374
A.9 Tilted surface on the Moon 375
A.10 Tilted plane on the Moon 375
A.11 Surface perpendicular to solar rays 376
A.12 Rotating plane that always faces the Sun. 376
A.13 Solar intensity for rotating planes 377
A.14 Tent array structure. 379
A.15 Solar power generated by tent array 379
A.16 Effect of high nighttime power fraction 381
A.17 Effect of low nighttime power fraction 381
A.18 Solar intensity through a dust layer 383
A.19 Deposition of dust near Apollo 383
A.20 Elevation of the Sun at the lunar pole. 384
A.21 The height needed to see over the pole in winter 384
A.22 Illumination map of the lunar south pole . . . . . color
A.23 Craters that contain permanent shadow . . . . . color
A.24 Illumination map of the Moon's north pole. . . . . color
B.1 Mars axis of rotation. 390
B.2 An element of path length 393
B.3 Optical depth 394
B.4 Simple model of the Mars atmosphere 396
B.5 Transmission coefficients of the two-flux model 399
B.6 Mars atmospheric transmission. 401
B.7 Comparison of atmosphere transmission models 401
B.8 Tilted array surface on Mars 404
B.9 Photograph of Sun near sunset by Mars Pathfinder . . . . . color
B.10 Photograph of Sun near sunset by Mars Pathfinder . . . . . color
B.11 Parameters for tilted solar array 406
B.12 Fraction of sky "seen" by tilted array. 406
B.13 Reflected solar rays on tilted array 407
B.14A Insolation for optical depth = 0.3 408
B.14B Insolation for optical depth = 0.5 409
B.14C Insolation for optical depth = 1.0 409
B.14D Insolation for optical depth = 2.0 410
B.14E Insolation for optical depth = 4.0 410
B.15A Hourly solar intensities at 70°N 412
B.15B Hourly solar intensities at 70°S. 412
B.15C Hourly solar intensities at 15°N 413
B.15D Hourly solar intensities at 15°S. 413
B.15E Hourly solar intensities at 45°N 414
B.15F Hourly solar intensities at 45°S. 414
B.16 Yearly insolation for various optical depths. 415
B.17 Solar intensity on an equator-facing slope 416
B.18 Solar intensity on a pole-facing slope 416
B.19 Pole-facing and equator-facing slopes 417
B.20 Solar intensity on tilted surface at 80°S. 417
B.21 Solar intensity on tilted surface at 65°N 418
B.22 Historical variation of Mars orbit 419
B.23 Historical insolation in the northern hemisphere 420

B.24 Historical insolation in the southern hemisphere 420
B.25 Comparison of southern and northern hemispheres 421
B.26 Historical insolation tilt toward equator—south. 422
B.27 Historical insolation tilt toward equator—north. 423
B.28 Historical insolation tilt toward pole—north 423
B.29 Historical insolation tilt toward pole—south 424
B.30 Optical depths on Pathfinder mission 426
B.31 Optical depths on MER mission. 427
B.32 Optical depth on Viking Landers 427
B.33 Distribution of dust particles by layers 430
B.34 Obscuration vs. sol for multiple layers. 431
B.35 Dependence of obscuration on dust loading. 431
B.36 Obscuration on Pathfinder array. 433
B.37 Modeled daily irradiance at MER. 434
B.38 Modeled noon irradiance at MER 435
B.39 Daily total solar energy—Spirit 435
B.40 Noon total solar energy—Spirit 436
B.41 Noon total solar energy—Opportunity 436
B.42 Daily total solar energy—Opportunity 437
B.43 Long-term power output of Opportunity. 438
B.44 Self-cleaning of Opportunity solar array . . . . color
B.45 Effect of dust on Spirit solar arrays 438
B.46A Solar cells coated with simulated Mars dust ("JSC 1") . . . . color
B.46B Solar cells coated with simulated Mars dust ("Carbondale Clay") . . . . color
B.47 Obscuration of solar cells vs. dust loading. 441
C.1 High-resolution thermal inertia map of Mars. . . . . color
C.2 Subsurface temperatures for a homogeneous subsurface 450
C.3 Subsurface temperatures for a two-layer subsurface 451
C.4 Geothermal gradient 452
C.5 Viking measurements of pressure on Mars. 453
C.5A Global water vapor. 454
C.5B Column abundance of water vapor on Mars . . . . color
C.5C Seasonally averaged water vapor column abundance on Mars. . . . . color
C.5D Water vapor abundance. 455
C.6 Subsurface ice—Leighton and Murray 458
C.7 Subsurface ice—Farmer and Doms. 459
C.8 Subsurface ice—Paige 460
C.9 Annual mean surface temperature. 461
C.10 Subsurface ice—Mellon and Jakosky. 462
C.11 Ice table depth . . . . color
C.12 Subsurface ice—Schorghofer and Aharonson. 463
C.13 Atmospheric water vapor vs. obliquity 466
C.14 Stability of ground ice vs. Mars obliquity 470
C.15 Global variation of water content in upper ~1 m of Mars. . . . . color
C.16 Depth and content of water layer—north 477
C.17 Depth and content of water layer—south 478
C.18 Maps showing distribution of eight properties on Mars . . . . color
C.19 Albedo and thermal inertia on Mars. 481
C.20 Distribution of water-equivalent hydrogen. . . . . color

C.21 Water-equivalent hydrogen vs. elevation 482
C.22 Dependence of neutron flux on season . . . . color
C.23 Phase diagram for water 487
C.24 Regions of Mars where $T > 273\,\mathrm{K}$ 488
C.25 Illustration of polar sun angles 491
C.26 Gully profile 494
C.27 Model for underground aquifer 496
C.28 Dark streaks inside crater 497
C.29 Two images of the same area, with new streaks present in the later photo . . 497
C.30 Cryolithosphere. 499
C.31 Examples of the SLE and MLE ejecta morphologies 501
C.32 Ejecta morphology 503
C.33 Percentage of craters with ejecta due to volatiles . . . . color
C.34 Percentage of craters that have DLE morphology . . . . color
C.35 Distribution of onset diameters for rampart formation . . . . color
C.36 Locations of DLE craters. 506
C.37 A possible distribution of H_2O in the Mars subsurface . . . . color

Tables

2.1 State–Step table for mission to Mars orbit . . . 20
3.1 LSAM masses for ascent and descent systems . . . 34
3.2 Effect of Δv on trip time . . . 52
3.3 Mars "short-stay" missions . . . 53
3.4 Cost per kg delivered to LEO . . . 55
3.5 JSC DRM-1 Launch Vehicle concepts . . . 56
3.6 Earth departure—fast and slow trips . . . 60
3.7 Mass sent toward Mars as % of mass in LEO . . . 61
3.8 Payload reduction to orbit vs. altitude . . . 62
3.9 Fraction of mass in LEO sent toward Mars . . . 63
3.10 Mass of SEP orbit-raising system . . . 64
3.11 Ascent systems from JSC DRMs . . . 69
3.12 Fast and slow trips to Earth from Mars orbit . . . 70
3.13 Gear ratios from LEO to Mars orbit—propulsion . . . 77
3.14 Gear ratios from LEO to Mars orbit—aerocapture . . . 78
3.15 Gear ratios from LEO to Mars surface—propulsion . . . 78
3.16 Gear ratios from LEO to Mars surface—aero-assist . . . 78
3.17 IMLEO to Mars—propulsion . . . 79
3.18 IMLEO to Mars—aero-assist . . . 79
3.19 Effect of NTP on Earth departure . . . 80
3.20 Benefit factor from NTP . . . 80
3.21 Mars orbit insertion using NTP . . . 81
4.1 Consumable requirements . . . 86
4.2 Consumable requirements for a Mars mission . . . 89
4.3 Required IMLEO for consumables . . . 90
4.4 Recommended organ dose limits . . . 93
4.5 LEO career dose limits . . . 94
4.6 Risk in round-trip missions to Mars . . . 99
4.7 DRM-1 Mars Transit/Surface Habitat . . . 112
4.8 Comparison of Crew Lander masses DRM-1 vs. DRM-3 . . . 114

4.9 Comparison of ERV masses DRM-1 vs. DRM-3 115
4.10 Masses of Dual Lander Vehicles 117
4.11 Mass, power, and volume of MOB Habitat 119
4.12 MOB Habitat structural mass 120
4.13 MOB estimates for ECLSS 121
4.14 Sequence for direct entry 128
4.15 MSP 2001 Orbiter aerocapture system 131
4.16 Comparison of aerocapture and aerobraking 131
4.17 Mass breakdown for large entry vehicle 142
4.18 Brief summary of EDL roadmap—I 146
4.19 Brief summary of EDL roadmap—I 146
5.1 Key ISRU capabilities 157
5.2 FeO content of regolith 159
5.3 Power to extract oxygen from Mare regolith 159
5.4 Power to extract oxygen from highlands regolith 160
5.5 Power to drive off volatiles from regolith 162
5.6 Power to heat regolith to drive off water 164
5.7 Propellant mass/payload mass 178
5.8 IMLEO for orbit insertion, ascent, and departure—no ISRU 179
5.9 IMLEO for orbit insertion, ascent, and departure with ISRU 180
5.10 Unit mass and power requirements for Mars ISRU 189
5.11 Gross mass and power requirements for Mars ISRU 189
5.12 Δv for various lunar transfers 192
5.13 Sample spreadsheet for lunar water transfer 193
5.14 Sample spreadsheet for return from LL1 to Moon 195
5.15 Sample spreadsheet for transfer from LL1 to LEO 197
5.16 Sample spreadsheet for return from LEO to LL1 198
5.17 Mass of water transferred from lunar surface to LEO 199
5.18 Fraction of water transferred from lunar surface to LEO 199
5.19 Values of Δv for lunar transfers 199
5.20 Fraction of water transferred from Moon to LEO 200
5.21 Percentage of water transferred from Moon to lunar orbit 202
5.22 Payload sent toward Mars vs. level of staging 207
5.23 Δv for Mars long-stay round trip 207
5.24 Payload mass to Mars vs. level of staging—long stay 207
5.25 Δv for Mars short-stay round trip 208
5.26 Payload mass to Mars vs. level of staging—short stay 208
5.27 High-pressure hydrogen tanks 212
5.28 APL high-pressure hydrogen tank 213
5.29 Pressure–temperature–density data for hydrogen 213
5.30 Properties of liquid hydrogen 217
5.31 Hydrogen densities on metallic sorbents 221
5.32 % hydrogen by weight on metallic sorbents 221
6.1 Mass estimates for Earth Return Vehicle 262
6.2 Mass estimates for MAV/Cargo Lander 263
6.3 Mass estimates for Crew Lander 263
6.4 NASA estimates of masses for Mars vehicles 273
6.5 Reverse-engineered mass estimates for DAV and SH 273
6.6 Reverse-engineered mass estimates for CTV 274

6.7 Mass allocations for Mars Direct 275
6.8 Reverse engineering for Mars Direct ERV. 276
6.9 Vehicles involved in the MSM 278
6.10 MSM vehicle mass budget 279
6.11 Mass budget for Habitats. 280
6.12 ISRU products in DRM-3 compared with MSM 280
6.13 ESA estimates for 2033 missions. 285
6.14 IMLEO for human mission to Mars 288
7.1 MIT-estimated values of IMLEO for three architectures and variable parameters. 306
7.2 MIT-estimated values of payload delivered to the surface for three architectures and variable parameters. 307
7.3 Lunar mission segment Δv and time of flight. 312
7.4 Focused Study estimates of Δv requirements for lunar missions 313
7.5 Comparison of Focused Study and Broad Study estimates of Δv 315
7.6 Vehicle mass estimates. 325
7.7 Steps in human lunar mission. 326
7.8 Example spreadsheet for Case 4 327
7.9 Summary of mass estimates for seven cases from Tables 7.8 and 7.9 328
8.1 JPL reverse-engineering of CTV 337
8.2 JPL reverse-engineering of Surface Habitat 337
8.3 JPL reverse-engineering of Descent/Ascent Vehicle. 338
8.4 Comparison of NTR systems for TMI for three vehicles. 338
8.5 2006 Exploration Systems Research and Technology (ESRT) Program. 352
B.1 Peak irradiance on a horizontal surface on Mars—no atmosphere. 392
B.2 Daily total solar irradiance on Mars—no atmosphere. 392
B.3 Transmission coefficient vs. zenith angle and optical depth 400
B.4 Historical variation of Mars orbit. 422
B.5 Solar energy on tilted surfaces (northern hemisphere). 424
B.6 Solar energy on tilted surfaces (southern hemisphere). 425
C.1 Regions of ground ice stability within latitude range −60° to +60° 468
C.2 Peak water content vs. elevation along six traverses 483
C.3 Excavated depths of craters 502

Abbreviations and acronyms

ALS	Advanced Life Support
AEDL	Aero Entry, Descent, and Landing (the process of using a aerodynamic forces to decelerate spacecraft at Mars or Earth for orbit insertion or descent)
AIAA	American Institute of Aeronautics and Astronautics
ALARA	As Low As Reasonably Achievable (refers to a philosophy for controlling radiation to astronauts)
ALS	Advanced Life Support (NASA program to develop advanced systems for life support)
Am	Amorphous
AM0	Area Mass
APL	Applied Physics Laboratory
ARC	NASA-Ames Research Center
AS	Ascent Stage (propulsion stage to ascend from Moon or Mars)
ASEE	American Society of Electrical Engineers
ASME	American Society of Mechanical Engineers
AU	Astronomical Unit
BAA	Broad Agency Announcement
BFO	Blood-Forming Organ (critical human element subjected to radiation).
BYA	Billion Years Ago
CaLV	Cargo Launch Vehicle (used to deliver $\sim$125 mT of cargo to LEO)
CEV	Crew Exploration Vehicle (holds crew for transfer to lunar orbit—includes both CM and SM)
CI	Confidence Interval
CL	Cargo Lander

CLV	Crew Launch Vehicle (used to deliver crew in CEV to LEO)
CM	Crew Module (part of CEV that holds crew); Crew-Member
CRV	Crew Return Vehicle (a small crew capsule that tags along with the Habitat on the outbound trip to Mars to provide the crew with a back-up spacecraft)
CSI	Control–Structure Interaction (technical field dealing with control systems and structures)
CTV	Crew Transfer Vehicle (used to transfer crew from LEO to Mars and back)
DAV	Descent/Ascent Vehicle (combination of DS and AS)
DDT&E	Design, Development, Test, & Evaluation
DGB	Disk Gap Band
Di	Diverse
DIPS	Dynamic Isotope Power System
DLE	Double-Layer Ejecta
DOD	Department Of Defense
DOE	Department Of Energy
DPT	Decadal Planning Team (NASA committee)
DRM	Design Reference Mission (a paper analysis of requirements and potential systems for carrying out an end-to-end human mission to the Moon or Mars)
DS	Descent Stage (the propulsion stage used to descend from orbit to the surface)
ECLSS	Environmental Control & Life Support System (the system that controls the human environment in a Habitat and recycles resources)
EDL	Entry, Descent, and Landing (the process for orbit insertion and descent and landing at the Moon or Mars)
EDS	Earth Departure System (propulsion system for departure from LEO to go toward the Moon or Mars)
EHDP	bisphosphonate etidronate
EIRA	ESAS Initial Reference Architecture
ELV	Expendable Launch Vehicle
EOR	Earth Orbit Rendezvous (assembly point prior to departure for the Moon or Mars)
ERV	Earth Return Vehicle
ES	Exploration Systems (branch of NASA for human exploration)
ESA	European Space Agency
ESAS	Exploration Systems Architecture Study (2005 study of architecture for human return to Moon)
ESM	Equivalent System Mass
ESMD	Exploration Systems Mission Directorate (same as ES)
ESRT	Exploration Systems Research and Technology
ET	External Tank

ETSI	ExtraTerrestrial Solar Intensity
EVA	Extra-Vehicular Activity (operations by astronauts in suits outside of Habitats)
FOM	Figure Of Merit
GCR	Galactic Cosmic Ray (source of high-energy, low-level radiation in space)
GEO	Geostationary Earth Orbit
GRC	Glenn Research Center (NASA)
GSFC	Goddard Space Flight Center (NASA)
H	Habitat
HEO	High Earth Orbit (typically $>$10,000 km altitude)
HIMS	High Resolution Image Management System
HLLV	Heavy Lift Launch Vehicle
HLR	Human Lunar Return (a paper study by JSC in the mid-1990s)
HLV	Heavy Lift Vehicle
HQ	HeadQuarters
HZE	High charge and Energy for $Z > 3$
ICP	Intramural Call for Proposals
IMLEO	Initial Mass in Low Earth Orbit (total mass that must be transported to LEO from Earth to implement a space mission)
ISPP	*In Situ* Propellant Production (production of ascent propellants on the Moon or Mars from indigenous resources)
ISRU	*In Situ* Resource Utilization (production of useful products—e.g., ascent propellants—on the Moon or Mars from indigenous resources)
ISS	International Space Station
ITV	Interplanetary Transfer Vehicle (used to transfer crew from LEO to Mars and back)
JANNAF	Joint Army, Navy, NASA, Air Force Interagency Propulsion Committee
JIMO	Jupiter Icy Moon Orbiter (space mission to explore the icy moons of Jupiter using NEP; mission has not been funded)
JLMS	JPL/Lockheed-Martin Study in 2004–2005 (estimated masses and power needs of ISRU systems for Mars).
JPL	Jet Propulsion Laboratory (NASA)
JSC	Johnson Space Center (NASA)
L/D	Length/Diameter
L2	Libration Point
LaRC	Langley Research Center (NASA)
LCC	Life Cycle Cost (cost of a system over its life).
LCH_4	Liquid methane

LEO	Low Earth Orbit (typically, a circular orbit with altitude in the range 200 to 400 km)
LET	Linear Energy Transfer (process to extrapolate radiation impact data from one energy regime to another)
LH_2	Liquid hydrogen
LANL	Los Alamos National Laboratory
LLO	Low Lunar Orbit (typically, a circular orbit of altitude 100 km)
LLT	LL1-to-LEO Tanker
LMO	Low Mars Orbit
LOC	Loss Of Crew (mission failure where crew dies)
LOI	Lunar Orbit Insertion (process to decelerate a spacecraft so as to inject it into lunar orbit)
LOM	Loss Of Mission (mission failure where crew is saved)
LOR	Lunar Orbit Rendezvous (process of transfer of crew from Ascent Vehicle to Earth Return Vehicle in lunar orbit)
LOX	Liquid OXygen
LPS	Lunar Power System
LRO	Lunar Reconnaissance Orbiter (space mission to observe the Moon from orbit)
LS	Lunar Surface
LSAM	Lunar Surface Access Module (transports crew from lunar orbit to lunar surface and return)
LSH	Landing and Surface Habitat
LSR	Lunar Surface Rendezvous
LSS	Life Support System (provides food, water, air, and waste disposal to Habitats)
LST	Local Solar Time
LV	Launch Vehicle
LWT	Lunar Water Tanker
MAE	Materials Adherence Experiment
MARIE	Mars Radiation Environment Experiment
MARSIS	Mars Advanced Radar for Subsurface and Ionosphere Sounding
MAV	Mars Ascent Vehicle (vehicle used to transport crew from the surface to Mars orbit)
MEP	Mars Exploration Program
MEPAG	Mars Exploration Program Advisory Group
MER	Mars Exploration Rovers (robotic mission to Mars in 2004–2006)
MEx	Mars Express
MGS	Mars Global Surveyor (Mars orbiter)
MIT	Massachusetts Institute of Technology
MLE	Multiple-Layer Ejecta
MLI	Multi-Layer Insulation

MMH	Mono-Methyl Hydrazine (space-storable propellant)
MMOD	MicroMeteoroid/Orbital Debris
MMSSG	Moon–Mars Science Linkage Science Steering Group
MOB	Mars Or Bust (student project)
MOC	Mars Orbiter Camera
MOI	Mars Orbit Insertion (process to decelerate a spacecraft so as to inject it into Mars orbit)
MOLA	Mars Orbiter Laser Altimeter (measures altitude of surface on Mars)
MOR	Mars Orbit Rendezvous (process of transfer of crew from Ascent Vehicle to Earth Return Vehicle in Mars orbit)
MPLO	Mars PayLoad Orbit
MSFC	NASA-Marshall Space Flight Center
MSM	Mars Society Mission (DRM)
mT	metric Tons
MTV	Mars Transit Vehicle (serves as the interplanetary support vehicle for the crew for a round-trip mission to Mars orbit and back to Earth)
NASA	National Aeronautics and Space Administration
NASP	National AeroSpace Place
NCRP	National Council on Radiation Protection and Measurement
NEP	Nuclear Electric Propulsion (propulsion system using a nuclear reactor to generate electric power for electric propulsion).
NERVA	Nuclear Engine for Rocket Vehicle Application
NExT	NASA Exploration Team (NASA analysis team c. 2001)
NRC	National Research Council
NRPS	Nuclear Reactor Power System (used to supply power to outposts)
NS	Neutron Spectrometer (used to detect hydrogen in planetary surfaces)
NTO	Nitrogen TetrOxide (space-storable oxidant for rockets)
NTP	Nuclear Thermal Propulsion (same as NTR)
NTR	Nuclear Thermal Rocket (rocket that employs a nuclear reactor to heat hydrogen to a high temperature prior to efflux from a rocket nozzle)
OD	Optical Depth
OExP	Office of ExPloration
OOS	On-Orbit Staging
ORU	Orbital Replacement Unit
OSHA	Occupational Safety and Health Administration
P(LOC)	Probability of Loss Of Crew
P(LOM)	Probability of Loss Of Mission
P/C	PhysicoChemical

PEM	Proton Exchange Membrane
PF	Mars PathFinder Mission
PMAD	Power Management And Distribution
Pn	Pancake
POD	Point Of Departure
pp	partial pressure
pr μm	precipitable microns
PSR	Precision Segmented Reflector (a now-defunct NASA program to develop a sub-millimeter telescope)
PVA	PhotoVoltaic Array
R&T	Research & Technology
RCS	Reaction Control System (propulsion system used for minor orbit corrections)
Rd	Radial delineated
REID	Risk of Exposure-Induced Death (effect of exposure of humans to radiation)
RFC	Regenerative proton exchange membrane Fuel Cell
RLEP	Robotic Lunar Exploration Program (NASA program to utilize robotic precursors to gain information prior to human landings on the Moon)
RQ	ReQuirements Division
RTG	Radioisotope Thermal Generator (device to convert heat from radioisotopes into electric power on spacecraft)
RTOP	Research/Technology Operation Plan
RWGS	Reverse Water–Gas Shift (chemical process to convert CO_2 to O_2)
S/E	Sabatier/Electrolysis
SAE	Society of Automotive Engineers
sccm	standard cubic centimeters per minute
SDHLV	Shuttle-Derived Heavy Lift Vehicle
SEI	Space Exploration Initiative (an abortive attempt by NASA to establish a human exploration initiative in the early 1990s)
SEOTV	Solar Electric Orbital Transfer Vehicle
SEP	Solar Electric Propulsion (propulsion system using solar arrays to generate electric power for electric propulsion)
SH	Surface Habitat
SHAB	Surface HABitat
SHARAD	SHAllow RADar on 2005 Mars Reconnaissance Orbiter
SI	*Système International* (international system of units of measurement)
SICSA	Sasakawa International Center for Space Architecture
SLE	Single-Layer Ejecta
SLH	SLush Hydrogen

SM	Service Module (part of CEV that supplies resources to CM and propels CM back to Earth)
SOE	Solid-Oxide Electrolysis
SPE	Solar Particle Event (sudden process in which large flux of protons is emitted by the Sun that travel through the solar system)
SPS	Solar Power Satellite
SRM	Solid Rocket Motor (used to boost capability of Launch Vehicles)
SS	Space Shuttle
SSE	Space Science Enterprise
SSME	Space Shuttle Main Engine
STS	Space Transportation System
TAO	Take-off and Ascent to Orbit (TAO)
TEI	Trans-Earth Injection (the process of using propulsion to depart from Mars orbit or lunar orbit and head toward Earth)
TES	Thermal Emission Spectrometer
THEMIS	Thermal Emission Imaging System
TLI	Trans-Lunar Injection (the process of using propulsion to depart from LEO and head toward the Moon)
TMI	Trans-Mars Injection (the process of using propulsion to depart from LEO and head toward Mars)
TPH	Triple-Point hydrogen
TPS	Thermal Protection System (protects spacecraft from extreme heat generated in aero-entry)
TRL	Technology Readiness Level
TSH	Transfer and Surface Habitat
UVVIS	UltraViolet and VISible
W&R	Whedon & Rambaut (authors of paper on effects of exposure to zero-*g*)
WEH	Water-Equivalent Hydrogen
WEU	Water Extraction Unit (conceptual system to remove water from putative ice-containing regolith on Moon)
YBP	Years Before Present
YSZ	Yttria-Stabilized Zirconia (used for solid-state electrolysis of CO_2)
ZBO	Zero Boil-Off