# Preface to Third Edition

The third edition of this book was born not only to update the state of the art of propulsion technology, but, more significantly, also to honor the memory of Paul A. Czysz, who was instrumental in proposing and leading the previous two editions. Paul Anthony Czysz died on August 16, 2013. He is credited with the development of a pragmatic system-level propulsion and aerospace design methodology. This was born from his design and testing experience in the USAF and at McDonnell Douglas, with the purpose of supporting the decision-maker by mathematically and visually identifying the available hardware solution space as a function of the mission. In addition to this book, Paul's work has been published in four books and in numerous technical articles. His original style in guiding and quantifying "design to mission" will remain a model for generations of engineers to come. A second difference with the two previous editions is the much greater emphasis placed on the integration of propulsion systems for hypersonic cruise aircraft and hypersonic accelerators facilitating space launch. This is the work of Professor Bernd Chudoba, the new co-author and specialist in this field.

The prime motivation for this book is the fact that humankind has been dreaming of traveling to space for a long time. In the early 1960s, there was a dedicated push to develop vehicle configurations that would permit us to travel to space and back through the atmosphere as readily and conveniently as flying on an airliner. That idea was unavoidably coupled with propulsion concepts that relied on capturing the oxygen within our atmosphere, instead of carrying it onboard from the ground up as expendable satellite launchers still do now. Given the slow technology progress since 1957, space access and space flight still suffer from limited performance due to high cost, mass consumption, and energy requirements, with consequent limited acceleration and relatively slow speed. During the 1960s, the concept of space travel extended beyond our planet, to our Solar System and the galaxy beyond (see Chap. 1), using power sources other than chemical, such as fission and fusion. It was then and still is recognized that any operational space flight transportation system is defined and limited by three key elements: (a) propulsion, (b) gravity, and (c) inertia. Future space flight requires advancing the understanding of all three areas. The first area (a) is primarily an engineering domain and is hardware driven, while the remaining two (b and c) are the domain of physics.

Accordingly, any significant advance in operational space capability will be a direct effect of revolutionary breakthroughs in high-thrust/high-efficiency propulsion and of gravity and inertia modulation. As the present outlook for breakthroughs in gravity and/or inertia is very uncertain, this book does focus on propulsion and the effect of its integration on the mission, the hardware and key technologies. The development of new manned space vehicles and launchers involves thousands of man-years. From the initial concept and through its gestation phase to the final product, how can the design team develop confidence in its performance and understanding of risks while committing very costly resources (see Chap. 2)? In this context, the trend toward space commercialization suggests the same approach seen with more conventional markets, where the mission objective is guided by continuous and sound evaluation of the product design and of its engineering or economics margins. This is in fact the integrated approach developed in Chap. 3.

Traveling to space in the near future is a multi-step process. The *first* is to realize a two-way transport to and from low Earth orbit (LEO); see Chaps. 4 and 5. This is a critical first step as it is the key to moving away from our Earth environment while being very expensive. In any future space scenario or market, economics dictates that travel to and from LEO must be frequent and affordable. From a vision of spacecraft parked in LEO, there are then several options. The geosynchronous orbit or geostationary orbit (GSO) is at an altitude of 35,853 km (22,278 statute miles) and has an equatorial orbital period of 24 hours, so it is stationary over any fixed point on Earth. These orbits are home to commercial telecommunication satellites.

The *second* critical step is an elliptical transfer orbit to the Moon. The orbital speed to reach the Moon is less than the speed to escape Earth's gravity, so the transfer orbit is elliptical (a closed curve) which does require less energy (but more logistics) than reaching GSO. Depending on the specific speed/orbit selected, the time to reach the Moon ranges from 56 to 100 hours. The Apollo program selected a 72-hour travel orbit from LEO (see Chap. 6). In terms of time, the Moon is truly close to us.

A *third* and far more eventful critical step is to achieve escape speed. This is a factor square root of two (about 1.41) faster than orbital speed. At escape speed and faster, the spacecraft trajectory is an open parabola or hyperbola. There is no longer a closed path for returning the spacecraft to Earth. So now we can move away from the gravitational control of Earth (not from gravity!) to explore our Solar System (see Chap. 7) and beyond.

There is a challenge of time, distance, and propulsion as we proceed farther and farther to explore our Solar System, then nearby Galactic space, and finally our galaxy. Exploring beyond our galaxy is technically far beyond our current or projected capabilities. Our understanding of propulsion, mass, inertia, and time will have to be different (see Chaps. 8 and 9). Understanding mass and inertia may be the most challenging. Inertia is a resistance to change of speed or direction. As we approach light speed, inertia/mass approaches infinity. As the mass approaches infinity, the thrust required to maintain constant acceleration approaches also infinity. Thus, at present, we do not know how to exceed the speed of light. If that remains the case, we are trapped within the environs of our Solar System.

An inertia-linked issue is human tolerance of continuous acceleration for long periods. Nominally that is assumed about three times the Earth's gravitational acceleration at sea level. At that acceleration, the time to reach a distant destination is numerically on the same order as the distance in light years. So, if a crewed spacecraft is to return to Earth within the lifetime of its occupants, we are again limited to about 20 light-years. That is within the distances to the seven or eight closest stars to our Sun.

As much as the authors would like to show how to travel in Galactic space, that will require breakthroughs in physics, not just propulsion. Until that time, we have much to explore and discover within the environs of our Solar System.

Coming down from Galactic space to life on Earth, these authors would like to acknowledge our spouses, Elena Prestini and Andrea Chudoba for their patience and support, and Christian Dujarric (formerly at ESA), Georg Poschmann (formerly at Airbus Industrie), Paul March at NASA, and Friedwardt Winterberg at The University of Nevada, for providing figures, articles, and comments. Special thanks go to our Editor at Springer, Ms. Janet Starrett-Brunner for her constant attention to our requests; without her, writing this book would have taken much longer.

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# Preface to First and Second Edition

Humankind has been dreaming of traveling to space for a long time. Jules Verne thought we could reach the moon with a giant cannon in the 1800s. In the early 1960s, there was a dedicated push to develop the vehicle configurations that would permit us to travel to space, and back through the atmosphere, as readily and conveniently as flying on an airliner to another continent and back. That idea, or intuition, was necessarily coupled with advanced propulsion system concepts, that relied on capturing the oxygen within our atmosphere instead of carrying it onboard from the ground up, as rockets developed in Germany in the 1940s did, and as satellite launchers still do. During the 1960s, the concept of space travel extended beyond our planet, to our Solar System and the galaxy beyond (see Chap. 1), using power sources other than chemical, such as fission and fusion. Not much is left nowadays of those dreams, except our present capability to build those advanced propulsion systems.

Traveling to space in the foreseeable future is a multi-step process. The first step is to achieve a two-way transport to and from orbit around our Earth, that is, a low Earth orbit (LEO); see Chaps. 2, 4, and 5. This is a critical first step as it is the key to moving away from our Earth environment. For any future development in space, travel that transits to and from LEO must be frequent and affordable. From a vision of spacecraft parked in LEOs, there are then several options. One is a geosynchronous orbit or geostationary orbit (GSO) that is at an altitude of 35,853 km (22,278 statute miles) and has an equatorial orbital period of 24 hours, so it is stationary over any fixed point on Earth. Another option for the next step is an elliptical transfer orbit to the Moon. The orbital speed to reach the Moon is less than the speed to escape Earth's orbit, so the transfer orbit is elliptical, and requires less energy to accomplish (but more logistics) than reaching GSO. Depending on the specific speed selected, the time to reach the Moon is between 100 and 56 hours. In fact, the Apollo program selected a speed corresponding to a 72-hour travel time from LEO to the vicinity of the Moon (see Chap. 6): in terms of the time needed to reach it, the Moon is truly close to us. All circular and elliptical orbits are, mathematically speaking, closed conics.

Another and far more eventful option is to achieve escape speed, that is a factor square root of two faster than orbital speed. At escape speed and faster the spacecraft trajectory is an open conic (i.e., a parabola or hyperbola), and there is no longer a closed path returning the spacecraft to Earth. So now we can move away from the gravitational control of Earth (not from gravity!) and proceed to explore our Solar System and beyond. However, after taking such a step, there is a challenge of time, distance, and propulsion as we proceed farther and farther to explore our Solar System, then nearby Galactic space, and finally our galaxy. Exploring beyond our galaxy is technically beyond our current or projected capabilities. In order to achieve travel beyond our galaxy, our current understanding of thrust, mass, inertia, and time will have to be different (see Chaps. 8 and 9). Mass/inertia may be the most challenging. An article by Gordon Kane in the July 2005 Scientific American entitled "The Mysteries of Mass" explains our current understanding of what we call mass. From another paper presented by Theodore Davis at the 40th Joint Propulsion Conference [Davis, 2004], we have the following statement:

> E = mc2 is the expression of mass-energy equivalence and applies to all forms of energy. That includes the energy of motion or kinetic energy. The faster an object is going relative to another object, the greater the kinetic energy. According to Einstein mass and energy are equivalent, therefore the extra energy associated with the object's inertia manifests itself in the same way mass manifests itself ... As a result, the kinetic energy adds to the object's inertial component and adds resistance to any change in the objects motion. In other words, both energy and mass have inertia.

Inertia is a resistance to change in speed or direction. As we approach light speed, the inertia/mass approaches infinity. As the mass approaches infinity the thrust required to maintain constant acceleration also approaches infinity. Thus, at this point we do not know how to exceed the speed of light. If that remains the case, we are trapped within the environs of our Solar System.

There is a second major issue. Human tolerance to a continuous acceleration for long periods has yet to be quantified. Nominally that is considered about three times the surface acceleration of gravity. At that rate of acceleration the time to reach a distant destination is numerically on the same order as the distance in light years. So if a crewed spacecraft is to return to Earth within the lifetime of its occupants, we are again limited to 20 light years of so. That is within the distance to the seven or eight closest stars to our star, the Sun.

As much as the authors would hope to travel in Galactic space, it will require a breakthrough in our understanding of mass, acceleration and propulsion. Until that time we have much to explore and discover within the environs of our Solar System.

Coming down from Galactic space to intelligent life on Earth, the authors would like to acknowledge the contributions of Elena and David Bruno, Catherine Czysz, Dr Babusci at the INFN (Italian Nuclear Physics Institute), Dr Romanelli at the ENEA Fusion Laboratories, Mr Simone, GS, H. David Froning, Gordon Hamilton, Dr Christopher P. Rahaim and Dr John Mason, Praxis Subject Advisory Editor. Special thanks go to Clive Horwood of Praxis, for his patience, constant encouragement, and prodding, without which writing this book would have taken much longer.

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