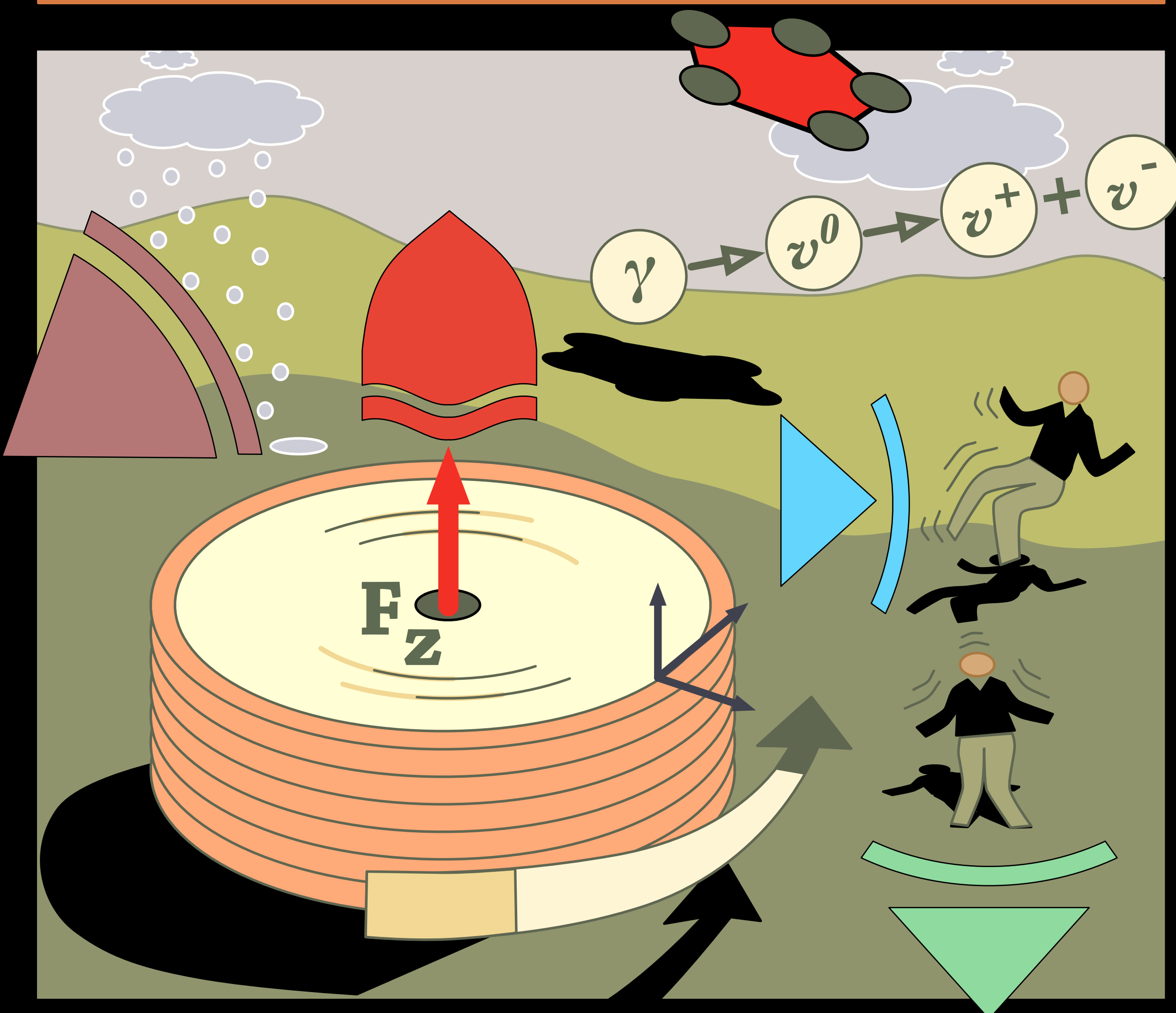
GRAVITY 2.0

Design Strategies for a Gravity Modified World



by GREGORY DAIGLE

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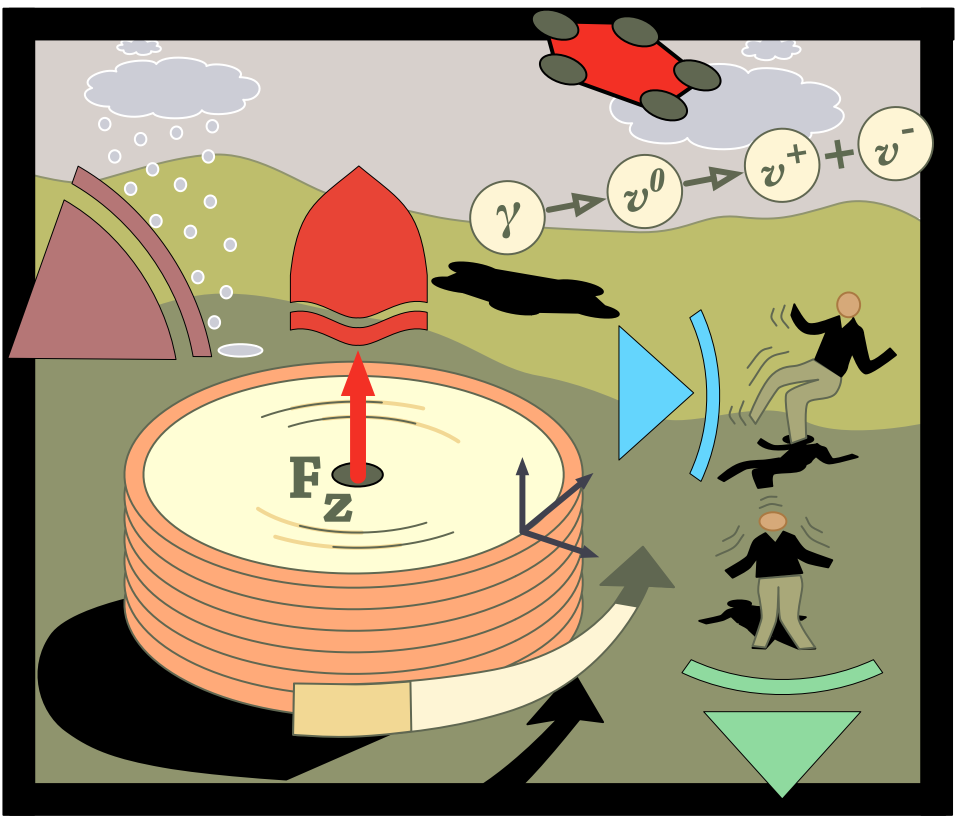
1st Edition



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Dedication

This work is dedicated to Gary and Leslie who encouraged me, and Roberta who is my rock.

I would like to thank Dr. rer. nat. Jochem Hauser, Professor HPC, Ostfalia, Scientific Director HPCC-Space, and Faculty H on the Campus Suderburg of Ostfalia University of Applied Sciences, and also Dr. Martin Tajmar, Professor at the Korea Advanced Institute of Science and Technology's Advanced Space Propulsion Systems Lab, Division of Aerospace Engineering for their generous efforts in reviewing this book and suggesting improvements.

Introduction

The approach of this book

This book explores the design opportunities found in a unique and evolving theory of quantum gravity. If confirmed, it will dramatically change – and possibly save – our world.

It is about the impacts of a technology to modify gravity and how a new discipline of "gravity design" will guide new designs in transportation, architecture, medicine, sports, and possibly make our world a greener place to live.

This is neither science fiction nor junk science. The peer reviewed scientific studies cited here are part of a growing body of work to understand the nature of gravity and to provide answers as to why general relativity is incomplete in describing our universe. We are on the brink of another incredible expansion of science – and gravity is at its center.

The writings that inspired this book were a series of several articles written on the modification of gravity for Korean online journal OhmyNews from December 2005 through March 2006. Though the articles were speculative and not based upon peer reviewed science, within months they were overtaken by very real published studies from respected researchers in Europe. These researchers generated a gravitational anomaly in a lab that, under the rules of general relativity, could only have been produced by the mass of a white dwarf star.

Generating a substantial "gravity-like" (i.e. not dependent upon mass alone) field would be the equivalent of demonstrating an electric generator to Sir Isaac Newton in an era when electricity (even static electricity) was not well understood. Such a breakthrough would take the "known" rules of science and stand them on their heads.

What are the possible outcomes? Can a vehicle be propelled with gravity-like fields? Can a zero-g field be built on the ground? Can such a field push as well as pull? What about shielding your home from hurricanes? From brush fires? Could it be used to condition an athlete? Could it detonate a land mine from a distance? What are the potential social impacts of employing gravity-like fields, both beneficial and harmful?

Although much of the interest around this physics centers upon a propellant-less means to explore the planets, this book attempts to look beyond its promise for space travel. The focus of this text is primarily upon employing this technology on our home planet and addressing the many economic, social and technological needs of our times.

In the early decades of space exploration, pulp science fiction novels and even some of the glossier magazines adorned their covers with brilliant illustrations of visualizations of the future. From 1952-54 Collins magazine famously published a series of articles entitled, "Man Will Conquer Space Soon!" featuring articles by Wernher von Braun, Fred Whipple and other notable rocket scientists and astronomers to engage the imagination of their readers – and to sell some magazines. By that time most of the physics of rocket propulsion was well understood. What advocates lacked was a vision that would fascinate the general public and create a demand for government-backed funding.

The reader will not find highly rendered illustrations of future gravity designs in this book. We are in early days for this technology and it would be a mistake to jump immediately to glossy renderings of spaceships and flying cars when the basis of the physics is not more widely understood and accepted.

There will be plenty of time later for glossy cover art. For now, think of this book as what a designer would call a "scoping document" – a road map that defines the boundaries and addresses the strategies to be undertaken. It is a tool of discovery for assessing potential applications and for delineating strategies that will lead to economic growth right here on earth.

Designers, for whom this book is written, should not be taken aback by the modicum of physics they'll encounter in the next few chapters. It is necessary to touch lightly on the physics to aid in understanding this phenomenon. Fortunately, talented mathematicians and physicists have done the heavy lifting for us so we need not venture into the maths proofs of eigenvalue equations, Ricci tensors and Reimannian geometry. But it will require light exercise of the left-hemisphere for you right-hemispheric designers.

As a former professor of industrial design, I know how the intersection between science, engineering and art is very tightly woven in our discipline. It requires practitioners to constantly refresh their knowledge of developments in several technical fields. Willingness to wade through the physics – even if not completely comprehended – is part of that complex mix of background information that designers are confronted with daily. But for those who wish to skip the history and physics feel free to go right to Part II of this book.

This book is also not a treatise on validating the science, but rather about designed futures. Validation of the science is appropriately left to others. The book is written from a designer's perspective and borrowing from the great design visionaries of the past, the chapters are written as prognostications of future states as if all of the difficult work of the scientists has already been achieved.

To that end, readers will encounter the occasional "Design Vision", a future-based scenario that describes new applications of gravity modification as if they were already a commonly experienced technology. These scenarios are denoted with a blue colored background to differentiate them from the rest of the text.

The book's chapters are organized into three main parts: I. A New Technological Domain, II. Gravity Design Applications, and III. Cleaning our Gravity Well. Part I is an introduction to the theory and experiments behind gravity modification. Part II begins design methods and then gets right into the potential applications. Part III reviews the "green" impacts on earth and in space and concludes with a new linguistic use of the word "gravity" that may arise.

The first chapter, "Gravity is Still a Puzzle", reviews the historical attempts to escape our gravity well, how to separate bogus science from real science that can be tested and found false, and reviews the preferred terminology for this new technological domain.

"Breakthrough Programs" reviews the research and experiments conducted that led to gravity modification. Several studies were facilitated by the American and European space agencies and new efforts to discover "game-changing" physics are underway.

"Heim Theory" addresses the historical and current developments of a leading theory explaining how "gravity-like" fields can be generated in the laboratory. It had its beginnings during the cold war but is currently experiencing a revival of interest as other physicists extend it into a nascent theory of everything.

"Making a Gravity Engine" addresses some of the known experiments to turn theory into practice by generating gravity-like fields. Although laboratory experimenters have been the driving force in building devices, a few past and present day inventors may have come very close in generating gravity-like fields.

In Part II, its initial chapter "Designing a World without Gravity" discusses design approaches and philosophies for designers and architects when approaching a world-changing technology. What are the domains for consideration when practicing gravity design? How do we wield a tool with such potential for creative destruction? What philosophies and ethics should guide us?

"Where's My Flying Car?" highlights the transportation applications of gravity modification. Discussions range from making existing vehicles more energy efficient to establishing the rules and regulations when your daily commute is a thousand feet above the ground. Will transit resemble the idyllic futuristic vision of the animated cartoon series "The Jetsons" or a typical Los Angeles traffic jam? And will our air corridors be dominated by commuter gravityships or by packages shipped autonomously via FedEx?

"Gravitecture+" looks at mythical, historical and fictional antecedents of cityscapes that dot the sky rather than the land. It discusses incremental uses of gravity modification to structurally augment architecture or to make possible fantastic architectural edifices that float in the air. What happens when residency is not related to geography? Who gets the best view? What are the issues of rights to light, to rainfall and how might we establish systems to allocate those rights?

The final chapter of the section explores the other potential applications of gravity design. "Gravity Design for Products" is a grab bag of potential product applications from sports to medicine to mining. Will entertainment be one of the first beneficiaries? Will it be the sex industry? Or will it be something unimagined? It explores a future zeitgeist of how movement in three-dimensional space will impact our social interactions, demography, democracy, class warfare and uses that may be illegal – or merely unsavory.

Part III, looks at cleaning up our planet-wide messes and gravity as a new cultural mindset. "Is Gravity Green?" details forecasting the use of gravity-like fields to produce clean energy, reduce consumption of fossil fuels, sequester greenhouse gases, slow the rate of sea level change and deliver potable water to drought stricken regions impacted by climate change. The first planet we modify with gravity-tech will be our own.

It is not until "Industrial Spaceports" that the discussion addresses the promise of gravity modification for space flight. With gravity modification we can clear near-earth orbit of dangerous debris, establish communications satellites practically anywhere in orbit and develop full industrial spaceports transferring millions of tons of cargo annually. Want that Martian "blueberry" hematite for your kitchen counter top? Put your orders in now!

Finally, "The New Gravity Meme" addresses how advances in the arts and sciences can change how we think, how we speak, how we see ourselves and relate to others. Like the discoveries of "perspective" and "relativity" before, new ways of thinking about gravity will change how we perceive the world around us.

The content of this book concludes with appendices A-D on potential stakeholders for the advancement of gravity science in academia, government and business, the disciplines that have the most obvious intersections with gravity design, key article references to peer published research and gravity-related articles by this author.

BEYOND THIS BOOK

Our future is not only uncertain, but often unimaginable. Who would have dreamed ten years ago that the top 10 jobs in demand in 2010 would not exist in 2004, or that today the number of text messages sent and received daily exceeds the total population of the planet [1]? In that spirit this book will be developing digital companions to expand its reach into the future.

The information and designs speculated upon in this book are not an end but rather a beginning point for an online exploration and experience about gravity design. There are two companion blogs for this book. They are the UThink blog at the University of Minnesota entitled "gMod: gravity modification"[2] and its expanded companion site Gravity Modification[3] which also includes a discussion section containing dozens of subchapter discussion points relating to the content of this book. Readers and non-readers of this book are welcomed to engage in discussions and fanciful speculations on the design future for this new technology domain.

Along with this book and Web site, two interactive online experiences are being planned to encompass ideas generated by readers and the general public. The first will be examples of potential impacts upon existing cities and their transportation systems. It will be designed to employ layers in Google Earth allowing designers to share in architectural and urban planning. The first such interactive file can be accessed at the bottom of Figure 6.1 of Chapter 6. As the capabilities of Google Earth evolve so too will the presentation and design capabilities of an imaginary city where gravity is optional.

Readers should also watch for the establishment of a "sandbox" devoted to gravity design in the virtual world Second Life. Second Life is a virtual 3D world where avatars can already fly (no gravity pack required!) and visit or create simulations of gravity design applications. There will be testable models of gravity vehicle traffic flow, labs for gauging the "right to a view" impact of floating architecture and the shadows they cast, and examples of gravity design in medicine, manufacturing, sports and more. If you are not yet a member of Second Life you can join for free or find out more at http://www.secondlife.com[4]. Watch for announcement on the Gravity Modification Web site about the planned virtual playground.

Part I: A New Technological Domain

Discussions on methods of escaping our gravity well, breakthrough studies by space agencies, extended theories on gravitation, and new experiments to generate gravity-like fields.

1. *Gravity is Still a Puzzle*

The nature of gravity is one of the great remaining mysteries in physics. Since the time of Sir Isaac Newton our understanding of the nature of gravity has advanced far but is still incomplete.

When the 20th century found Newton's descriptions of the force of gravity lacking, Einstein brought us a more complete understanding. Yet by the end of that century it was clear that Einstein's theory of general relativity was also incomplete. It lacked the ability to explain the action of "dark" energy and matter that apparently make up 93% of the universe and are responsible both for its increasing expansion and the cohesion of galaxies.

Today teams of astrophysicists propose competing theories on gravity that push the boundaries of "new physics" because standard models, including Einstein's general relativity, are lacking in some respects. These are not unskilled laypersons advocating theories composed of unsubstantiated claims or agenda-driven "junk science", but rather mainstream academicians. These scientists are willing to push convention and consider experiments and/or theories that might reveal new discoveries and new understanding about the nature of our universe.

Most of us simply enjoy gravity's small pleasures. The joy of walking, coasting down a bike path, watching colorful balloons ascend skyward, or the anticipated thrill of a roller coaster ride. Gravity makes the sun, our planet and the delicate balance of life possible. Its force can be awesome, capable of collapsing stars – yet it is the weakest force in the universe.

If we were ever able to modify gravity or gravity-like forces what would we do with such control over nature? Would we emulate its most terrifying capabilities or employ it to create wondrous new possibilities in our world? Would it benefit only the most technically advanced cultures or would it be put to work to solve some of the more vexing global issues of the day? Would it create new social and economic prosperity in these financially difficult times or would it merely accentuate and widen existing economic gaps?

It was in February of 2003 that I was first introduced to a community of academicians, experimenters and enthusiasts who maintained a strong belief in the possibility of gravity modification. That belief was based upon ad hoc reports from engineers and inventors, but also academic studies funded by the American and European space agencies, NASA and ESA. Though many of the most adamant speculators were simply hobbyists and dreamers, there were those with highly technical backgrounds in engineering and physics who advocated for a rigorous investigational route to demonstrate the manipulation of gravity.

As I was to find out years later, such communities of researchers interested in real-world applications of gravity control reached their peak in the 1950s and counted among their number millionaire industrialists, some of the largest aeronautics firms in the world, and top academic institutions including MIT. Their common bond was the interest in discovering ways to harness gravity through better understanding its nature

LIFE IN A GRAVITY WELL

Gravity, along with electromagnetism, is one of only two fundamental forces in nature that we can directly sense with our bodies. Fewer than 1 in 10 million people in the world have ever been without gravity for more than a minute, yet is there anyone who has not dreamed of flying free of its grasp over rooftop and hillside? Its downward pull on us is incessant and relentless. Freedom from gravity is tantamount to cheating death. The words *grave* and *gravity* even possess the same Latin root.

Over time gravity can bring down mountains, but it is so weak that compared to electromagnetism – the force that mediates light and magnetism – it is a billion, billion, billion, billion times weaker. That is a one, followed by 36 zeros. Comparing the magnitude of the force of gravity to the force of electromagnetism is like comparing the minuscule force needed to lift the weight of a single cell in the human body to the titanic force needed to lift the weight of the entire earth – if that were even possible!

The theory of general relativity holds that gravity shapes the planets and holds us to earth's surface by the curvature of space itself. The very tired but useful analogy of a heavy object lying upon a flexible sheet comes in handy for visualizing an indentation representing curved space. Imagine a bowling ball on a thin sheet of rubber with the bowling ball representing a moon or planet. It is an instructive, yet somewhat inaccurate, representation of the mathematical relationship between gravity and space.

In an unperturbed space without objects (a very "special" case as Einstein put forward in his theory of special relativity) the sheet would be taut and flat. A massive object such as a planet occupying the space results in a deep indentation in the sheet – a "gravity well" exhibiting gravitational potential. The greater the mass, the greater the gravitational potential and the deeper the gravity well.

From the perspective of an outside observer unaffected by gravity the relationship between mass and the gravity well is logically objective and mathematically predictable. But is it much more than that to any beings that inhabit the surface of that massive moon or planet within the gravity well. To them gravity is not just objective – it is experientially subjective. Living life sandwiched between that great massive object and the rubber sheet defines and limits our lives.

As inhabitants pinned to the surface of our planet we may not be consciously aware of our plight until we slip on ice or fall from a ladder. When that occurs we are immediately reminded that we live our lives pressed to the surface of our terrestrial home. Like a moth pinned against the radiator of a moving vehicle we can either lament our trapped existence or enjoy the ride.

For millennia humans have only been able to look up and wonder what life would be like beyond our gravity well. Our minds possess the ability to imagine what escape from our lowly sump might offer both as benefits and dangers. Desire to know "life beyond the well" grew around that ability since ancient times.

From the Greek myth of Icarus to da Vinci's models of man-powered flight, dreams of extricating ourselves from this two-dimensional existence have been with us. Yet only in the past few centuries have we been able to engineer the tools to match our imaginations. Slowly, we have been able to match our dreams with our accomplishments and raise ourselves from the very bottom of our gravity well. We have done so with three cleverly devised solutions:

Climb. Jump. Float.

Consider the following scenario. You find yourself stranded at the bottom of a deep debris-filled well. Question: How do you get out?

The first method for our escape is perhaps the most obvious – climb out. Find a rope, vine or root growing out of the side of the well and scale them. Or use branches, planks and other debris to bring the walls down and climb the embankment. Climbing requires the lowest application of technology and power yet the longest sustained effort. For some a prolonged struggle upward and toward the heavens has more purpose than just overcoming gravity.

Whether scaling a well or the face of a mountain the devout have for millennia climbed upward seeking a means to reach the heavens and thereby attain a more spiritual and elevated existence. Children's tales are filled with quests involving the scaling of castle towers or magical beanstalks in search of what we desire most for ourselves. What we need as we imagine our future beyond our gravity well is not a beanstalk to climb but a dangling rope suspended from above. It will not be made of a princess's hair, but rather, it will be thin, flat and made of carbon nanotubes.

Clever engineers are devising plans for us to climb up to the lip of our gravity well on the thin carbon ribbon of a "space elevator"[5]. Such an elevator will take us into earth orbit using less energy, less cost and lower levels of pollutants than chemical rockets. Though anchored to the ground, the ribbon's other end is suspended far out in space by the same force we experience when swinging a weighted rope above our heads. New methods for manufacturing ultra strong carbon nanotubes into long flat cable structures are proceeding quickly. Before the midpoint of this century we may be able to use a steady application of power to slowly climb that nanotube ribbon like a spider climbing a silky thread to a point affixed in space. All this requires is remarkable materials and sufficient power to take us up and out to just beyond the lip of our gravity well.

But what if we wish to go beyond the lip of the well? Answer: It's time to try jumping.

If you were quick enough and strong enough you could throw yourself clear of the well. Jumping conquers (at least temporarily) gravity by generating an opposite force. Newton's Third Law of Motion can be described as, "to every action there is an equal and opposite reaction." You need an action to propel yourself against the pull of gravity. Legs not up to the task? How about a rocket?

A rocket rises by throwing propellant (usually expanding gas) downward. If there is sufficient force (mass times acceleration) then the rocket will rise upward. A well-engineered rocket will get into *near-space* (the lip of the gravitational well). It wasn't until the advent of modern rocketry, advanced by scientists including Robert Goddard and Wernher von Braun, that humans achieved a beyond-the-well experience through rockets.

One problem with throwing rocket propellant is that unless you throw hard enough and long enough, the rocket will eventually return to earth. If a rocket is not beyond the influence of the gravity well by the time the propellant is exhausted then the rocket will eventually fall back – usually catastrophically. If the throw is high enough the fall will continue nearly endlessly and orbit has been achieved. Rise fast enough, long enough, and orbit is broken and finally we are free of our gravity well.

Congratulations... almost.

Floating with the Montgolfiers & Wrights

Out of the gravity well and now without propellant, there is no longer any ability to navigate. Once again the rocket is at the mercy of gravity – not only of the earth but the gravity of any nearby bodies in the solar system. Yet in this situation gravity can also work to an advantage. By understanding gravity's ability to warp space it can be used to slingshot the rocket around planets and navigate around the solar system.

Except for a few early deployments of ion engines and solar sails as a means for propulsion in space, this is our current state of the exploration of space at the end of the first half-century of exploration. This is how NASA and the European Space Agency (ESA), the two leading governmental space agencies, currently see our future "beyond the well." Despite science fiction's offering of warp drives and wormhole travel this is currently the best there is to offer.

There is a third method of getting clear of the bottom of the well, though it can't provide a means for complete escape. It takes one to the lip of the well but does not go beyond. It is to float.

Returning to the debris-filled well, you notice that water is slowly trickling in through a crack in the wall. It's just enough to get your feet wet so you're in no danger of drowning. Then you get an idea. You grab a thick plank of wood from the debris pile and use it to dig at the crack until it becomes an inrushing torrent. You grab the plank and any other objects that will float. The wood plank and flotsam will float you close enough to the top of the well where you can call for help.

When a plank *floats* what is meant is that the wood is less dense (has a lower specific gravity) than the surrounding medium – water. The plank is pushed to the water's surface by the force of gravity pulling down on the more dense medium (water). Floating is our final method of escaping the bottom of the well. It is also how humans first devised flight.

The history of manned flight began with floating. Experiments with hot-air balloons by the Montgolfier brothers in the 1780s soon led to balloons filled with lighter-than-air gas (often hydrogen) allowing even greater heights to be reached. Hot-air and gas-filled balloons rose upward because the average density of the volume they occupied was less dense than the surrounding atmosphere. Gravity pulls down on the more dense surrounding medium and displaces the less dense gas in the balloon thus forcing it upward. Up, up and away.

Hydrogen-filled balloons have great lifting potential but are also dangerous. Zeppelins were lighter-than-air rigid airships that flourished in the 1920s and provided luxurious passenger travel across the Atlantic. That era came to a close soon after the burning of the Hindenburg in 1937. The closest present-day relatives of the zeppelin with which readers may be familiar are the non-rigid *blimps* that act as floating billboards and camera platforms far above outdoor football stadiums. More recently, new designs of zeppelins proposed for forestry and freight hauling have been designed to achieve a highly fuel efficient lifting of tonnage. On a more personal scale, interest in armchair ”cluster ballooning”[6] inspired the animated film “Up” and gives evidence that our fascination with things that float, beginning with the Montgolfier brothers, is far from over.

Controlled heavier-than-air flight was first demonstrated with gliders more than a century after flight by balloon began. At the dawn of the 20th century, powered heavier-than-air flight was achieved by the Wright brothers. Apparently, like the Montgolfier brothers, flight and fraternity go hand-in-hand.

Airships and heavier-than-air flight both are made possible by employing gravity rather than by overcoming it. Heavier-than-air flight (powered and unpowered) employs airfoil-shaped wings. When in forward motion a volume of air above an airfoil travels a greater distance than that below the airfoil. This faster moving air “stretches” above the wing and possesses a lesser density than the air below the wing. Much like the blimp or the floating plank within our well, gravity pulls down on the more dense surrounding atmosphere which then applies a force upward on the wing displacing the less dense medium above. In the parlance of flight this force is known as “lift.”

Most of us have experienced flight-by-airfoil. We fly commercial airlines to business meetings and to take vacations. Passengers who have ridden in hydrofoil boats have experienced how the shape of a submersed hydrofoil works just as well to provide lift up to the surface of the water while moving forward. Some of us may have flown in helicopters, their airfoil-shaped rotors allowing a more maneuverable and balloon-like ability to hover without forward motion.

When employing a foil for lift one cannot rise above the surface of the water or above the atmosphere into space because there is no ambient medium left to displace. Even the lightest balloons used to haul scientific instruments to the edge of space have a maximum achievable altitude. They cannot rise any further. The floating of balloons and airplanes is good only for flight inside-the-well.

Climb, jump, or float. Those are the current options as best we know them. Each has a specific range where it is most effective and each has limitations and drawbacks. Climbing gets us to the lip of our gravity well, but a deployable technology for doing so is still decades away. Jumping can get us into and beyond orbit but only by polluting our atmosphere with noxious fumes. Floating is useful for transportation within our well but is unable to raise us to orbit, plus its carbon footprint is too high to maintain indefinitely.

Gravity that Repels

Gravity only attracts, but imagine that there was a form of gravity that could be either attractive or repulsive. It would be analogous to the dipolar ends of a magnet. If the earth were a magnetic sphere with one pole facing outward and the other facing inward, the opposite poles of all nearby smaller magnets would be drawn to its surface. However, make those other magnets spheres with like polarity on their outward surfaces and they would all be strongly repelled from the earth and flung into space.

Of course, gravity doesn’t work like that. Gravity is always attractive and objects with mass attract other objects with mass because they all similarly warp space. But if there were an opposite polarity for gravity, then it might repel rather than attract. Or better yet, a dipolar body exhibiting both attractive and repulsive gravitational "poles" similar to a magnet might be either attracted to or repulsed from other bodies depending upon its orientation.

A device capable of generating a dipolar form of gravity and oriented in repulsion would oppose earth's gravitational pull (also known as "little g" or just "g"). If of sufficient repulsive strength (and ideally much, much smaller than the earth itself) the generating device would float. Increase that repulsive force sufficiently and it would be forcefully repelled from the surface of the earth.

Recall that normal floating occurs when objects with a lower specific gravity are displaced away from gravitational attraction when immersed in a more dense medium. Think of a repulsive gravitational potential as a less dense medium immersed in earth's more dense gravitational medium. A slightly repulsive field for the object may lessen its weight, while a repulsive field equal to earth's results in floating. That is, no gravity at all – zero-g.

The fourth solution to escaping our gravity well is "repulsion." And though it has been imagined for centuries and is part of our literature in fiction, there has been no evidence that a repulsive gravitational force exists – until recently. A small handful of researchers backed by space agency funding and awarded by professional organizations of propulsion engineers and physicists have published results in scientific journals indicating that it has been found. What is at stake is a new era of propellant-less propulsion.

NASA searched for such repulsive gravity for over a decade and generated over a dozen peer-reviewed papers on topics related to "breakthrough propulsion", but found no clear evidence of its existence. Other researchers under funding from a large Austrian research institution did find evidence and have suggested that this generation of local gravity fields may represent a "new technological domain." It is a nascent and not well understood technology but has the potential to be a game-changer. But if you were to ask any school-aged child what it is, they would simply call it "antigravity."

This book is about the design applications of research funded by NASA, ESA and other scientific organizations for the purpose of identifying and generating propulsion through gravity modification. Unlike flight (floating) it would be a means of travel both within and outside of our gravity well. Unlike rocketry (jumping) it produces few if any pollutants. Unlike climbing (space elevators) it can take us far beyond our gravity well – perhaps even to other stars.

Gravity modification isn't only about propulsion. Exploring the planets and solar system is just the most obvious of applications. It also has the potential to reshape our cities, our modes of transportation, manufacturing, health sciences, and leisure pursuits. Like airships or powered flight, this new technological domain represents an ability that does not depend upon overcoming gravity but instead arises from an improved understanding of the nature of gravity.

Gravity modification could lead to "zero gravity" manufacturing of defect-free silicon wafers, "hypergravity" training regimens for athletes and "microgravity" intensive care units for burn victims. But before these applications can be realized the experimentation behind gravity modification must be refined and retested until no doubt remains that it is both achievable and economically practical. At the same time, distancing this new technology from "fringe science" is important to establishing its credibility.

This book will delve into some of the background of one particular theory of gravity modification that is an offshoot of Einstein's theory of general relativity and which has recently gained advocates in the physics community even though its theoretical roots were first proffered several decades ago. And while the main focus of this book is design and is written by a practicing designer, it will be necessary to understand a little about physics and why this model is at odds with the prevailing theories of gravitation as well as the standard model of particle physics.

The discoverers have challenged conventional theory and in doing so they have risked careers and grant opportunities to "push the envelope" in exploring this frontier. Designers should first understand this technology's history, its capabilities, its risks and its potential benefits to our designed world. If peer reviewed research in this nascent field should continue to confirmed through experimentation, then designers, architects, city planners, and sociologists should be encouraged to embrace its study as part of their disciplinary practices and begin viewing gravity modification as another tool for designers.

Striking out in new directions requires some risk, but the benefits outweigh the professional hazards. Keeping abreast of new theories and findings in this technological domain is the only way to anticipate and understand the extraordinary opportunities that will be available to designers to change our world.

In the end, gravity modification is simply a tool like a ladder or an airfoil or a rocket. But tools change us. How ladders, escalators and elevators have become commonplace as gravity-defying tools, how airfoils have changed our concept of distances across the globe, and how rockets have seized our collective imaginations about the discovery of space, have all changed us. They have changed our perceptions of space, distance and time, but also connectedness, collaboration and familial ties.

AVOIDING THE COLD FUSION DEBACLE

Using terminology employed by physicist Lee Smolin of Canada's Perimeter Institute, we designers must align ourselves with the "valley crossers" of science. Smolin views valley crossers as scientists who have broader technical skills and tend to have strong scientific intuition driving them to strike out in new directions. These individuals are contrasted with "hill climbers" who are technicians with deeper skills who incrementally build their deep expertise into silos of knowledge, establish bailiwicks and defend their intellectual territories.

When valley crossers strike out in new directions possessing exciting potential they risk losing the support of their institutions. They are occasionally subject to unscientific criticism by their own scientific colleagues. Challenging the standard models of science can be deleterious to careers. Designers who follow their lead are also subject to criticism. To stem this lack of support and unwarranted criticism we must ask and answer two important questions early in the process of proposing radical new design visions of the future:

1. *"How do we identify the point when promising new research that eschews established scientific doctrine becomes institutionally acceptable"?*

2. *"How do we restrain criticism of formative ideas before they can reach maturity"?*

Science proceeds at its own pace. That pace may be perceived as slow when compared to all the global humanitarian challenges demanding more immediate solutions. Some challenges require radical thinking to make radical advances. The danger is that stepping up the pace may inadvertently give rise to slipshod or poorly conducted science.

Slipshod science may take root under several conditions. Experimental setups may be poorly designed. Methodologies employed may lack rigor or be poorly selected. The experimenters may lack proficient understanding of the science. Or it may arise from scientific results published with good intent, but done so prematurely and without the benefit of peer review.

Peer review is the process by which scientific papers presented at conferences or published in journals bear the scrutiny of others in the same fields of research before finally being released. The process can reveal faulty assumptions or methods that inadvertently bias or invalidate results. Without it announcements of remarkable new discoveries may be met (and validly so) with skepticism. Are there any reasons not to undergo a lengthy full process of peer review? Yes. Simply stated, it is competition.

Sometimes results seem so ground-breaking that rather than risk premature leaks of information or being "scooped" by other researchers in the same field, researchers rush them quickly into the public domain. This may arise from pressure to provide a new drug or therapy to those in need. Or it may arise from fears that other researchers are about to stake claims on a similar "breakthrough" (and the Nobel committee may be watching!) Premature public announcements can damage even well-established professional reputations and turn the scientific establishment against potential new discoveries. No one wants a "cold fusion" debacle.

The announcement in 1989 of what was then termed "table top fusion" by Drs. Stanley Pons and Martin Fleischmann was guaranteed to create controversy in physics circles and it has not disappointed. Their challenge to the orthodoxy of nuclear fusion and the inability for other labs to replicate their results fueled a backlash from other physicists that tarnished their sterling careers and depleted funding for research in this arena for many years. Only in 2009 at the annual meeting of the American Chemical Society[7] (also the twentieth anniversary of Pons and Fleischman's original press conference) did recent research on the topic receive an official nod from that professional organization for chemists – but notedly not from its professional counterparts in the field of physics.

In that meeting the ACS reported that the Navy's Space and Naval Warfare Systems Center had established that energetic neutrons (a product of nuclear mechanisms including fusion) had been detected and tracked in experiments related to Pons and Fleischmann's discovery. Rather than the term "cold fusion" the preferred term is "low energy nuclear reactions", or LENR.

The reason for the name change is that the heat released may not be due to nuclear reactions other than fusion[8] but just as energetic. Other researchers also presented their findings on the generation of heat in excess of what can be understood by standard models of chemistry. This was followed within weeks by a feature story in the television news program "Sixty Minutes" describing those advances in LENR and reporting on interviews with respected research managers who confirmed the tenability of the recent findings.

Addressing the first question, *"How do we identify the point when promising new research that eschews established scientific doctrine becomes institutionally acceptable?"*, the lesson of the cold fusion story is clear. A science "debacle" that has been quiescent for decades can be resurrected to the status of "promising" by qualified and persistent researchers. In this case the ACS wanted to make a statement that encouraged scientific inquiry over the defense of doctrine. At some point those in the upper ranks of the ACS determined that there was sufficient evidence from a range of credible research laboratories to warrant such an unusual press statement to the media.

What are the lessons learned that pertain to gravity modification? For any researchers it should be clear that challenging established belief systems publicly and somewhat prematurely may be institutionally unacceptable and potentially "toxic" to careers. However, if claims are validated through replication by reputable colleagues then even the most unassailable of existing scientific doctrines may be successfully challenged given enough time and evidence. Gravity modification is quickly becoming one such challenger in the field of gravity study.

The second question, "*How do we restrain criticism of formative ideas before they can reach maturity?*" usually concerns researchers with less seniority trying to navigate their *valley crossing* ideas through to funding without endangering professional status or tenure. They often do not have the professional track record nor gravitas of a tenured professor to carry them past the doubts of faculty research review committees. It is not every researcher who is allowed to conduct experiments for years and run hundreds of tests in secrecy before publishing their results. Even when such autonomy was given to Fleischmann, who was a world renounced electrochemist and a member of the Fellowship of the Royal Society, this did not inoculate him from being ridiculed by other academic disciplines and force his departure from his university.

Research projects that challenge traditional findings and are of long duration do occur. They are most often found in research university settings where lead investigators have tenure or in private institutions such as the Perimeter Institute where the mission of the organization is to inspire and support "*approaches to fundamental questions, both orthodox and unorthodox.*" Perimeter Institute, where Dr. Smolin is posted, was founded by the Co-CEO of Research In Motion (RIM) — maker of the successful BlackBerry mobile device.

Tight budgets and the quest for quarterly profits in the corporate laboratories make pursuit of high-risk science a question of risk assessment. Managers often find it difficult to justify risky research investigations despite the potential of higher returns. Yet ground-breaking research does happen in corporate settings and the primary reason is their corporate culture. For decades scientists at 3M have been expected to devote 15% of their time to projects of their own choosing. At Google employees are allowed to devote 20% of their work week to innovative ideas. Those corporate cultures place a high value on self-directed discovery by their research staff.

Studies of unorthodox questions in science are occasionally found in corporate "skunkworks" projects or departments established in secret (or at least not widely known). In these settings sufficient autonomy is established to ensure freedom from interference until the innovation (often purely technological) is ready for development. Unorthodox "breakthrough" innovations may be in the works but they remain unknown to the public as they are behind corporate firewalls. The Internet itself was once a skunkworks project hidden from public view by the U.S. government defense agency DARPA.

The general public is fascinated by stories of "black ops" and "secret hangars" and "underground laboratories" that feed the imagination. Unfortunately, what the public gravitates to are the hundreds and thousands of Web sites that report on not just poorly conducted research but advocacy-driven junk science on UFO propulsion, "overunity" free-energy generators, and gas mileage "breakthroughs" and all available (ironically) through DARPA's Internet.

The Web is rife with sites and forums touting theories describing antigravity. One can even send away for "kits" and DVDs on how to build your own antigravity device. Such public sites almost always lack the even-handed, critical commentary of established scientific discourse. Visitors not steeped in a rigorous science education are often swayed by unsubstantiated claims professing scientific legitimacy. How is an educated non-scientist to tell the difference between cutting-edge research, speculation and pure hoax?

BOGUS SCIENCE AND TESTABILITY

Identifying claims that are either arrived at unscientifically or that offer scant/flawed evidence has been a topic addressed by professor Robert L. Park in his essay *The Seven Warning Signs of Bogus Science*[9]. In it the author identifies seven indicators that a scientific claim lies outside the bounds of rational scientific discourse.

Those warning signs are:

1. The discoverer pitches the claim directly to the media.
2. The discoverer says that a powerful establishment is trying to suppress his or her work.
3. The scientific effect involved is always at the very limit of detection.
4. Evidence for a discovery is anecdotal.
5. The discoverer says a belief is credible because it has endured for centuries.
6. The discoverer has worked in isolation.
7. The discoverer must propose new laws of nature to explain an observation.

Park tempers his heuristic list with a caveat that even legitimate claims may possess several of these indicators and some, though sounding extraordinary, may be quite true. A quick historical review finds some excellent examples of extraordinary-yet-true claims.

For example, claims of powered flight were famously discounted in 1907 by Britain's Minister of War Lord Haldane who declared, "The aeroplane will never fly." Of course what he didn't know was that Orville and Wilbur Wright had already proven him wrong on Dec. 17, 1903. He was unaware because the Wright brothers worked in isolation (#6 on the list) and had to invent the wind tunnel to test and explain their new laws of nature (#7 on the list).

We hold Lord Haldane's statement up to ridicule now because we know how wrong he was. But even after the Wrights' demonstrations in 1908 for the purpose of winning military contracts, the scientific community was skeptical until the brothers staged a media event (#1 on the list). The commonly accepted orthodoxy that powered flight was impossible proved difficult even for Wilbur Wright who famously said, "I confess that in

1901, I said to my brother Orville that man would not fly for fifty years... Ever since, I have distrusted myself and avoided all predictions."

The powered flight claims of the Wright Brothers, the source of meteorites, the theory of continental drift (i.e. plate tectonics) are all examples of scientific work painted too quickly and with too broad a brush as either "pseudoscience", "junk science" or outright fraud. Sometimes these claims of fraud are even made in the face of strong evidence to the contrary.

Nobel Laureate Brian Josephson terms such vehement denial of phenomena for which there is strong evidence "pathological disbelief." Josephson cites several historical instances when scientists who are critical of new findings have been offered access to original test data disproving scientific orthodoxy, yet have rejected the offers. Were they afraid of being lulled into acknowledging their own biases? Skepticism is normally a valuable mindset for the scientist, but at some point a significant accrual of evidence in support of new claims must be acknowledged and accepted by letting go of theories shown to be wrong.

Yet solid proof is sometimes difficult to find even for mainstream theory. Some very legitimate areas of scientific inquiry exist without the means for rigorously testing their claims. One such area in physics is "string theory." Some hypotheses that would shed light on aspects of string theory are so difficult to test that perhaps we need to change the definition of science itself.

An article in the publication New Scientist, *Do We Need to Change the Definition of Science* [10], explores this very position of redefining science in light of the difficulty of testing some theories through a concept known as "falsifiability."

Falsifiability is the cornerstone of modern science. Beginning in the 1930s philosopher Karl Popper employed the metaphor of the "black swan" to emphasize the importance of falsifiability. In his example, Europeans knew only of the existence of white swans. A black swan had never been seen. *Inductive reasoning* would assume that all swans are white. However, when early explorers of Australia returned to Europe with black swans it became clear that inductive reasoning can be faulty. As Popper pointed out, there is always the possibility of an exception or counter-example (i.e. the black swan). One can never prove that a proposition is always true. One can only prove through *deductive reasoning* that a proposition is *not* true.

As Popper states in *Science as Falsification* [11], "*It is easy to obtain confirmations, or verifications, for nearly every theory - if we look for confirmations.*" Yet dominant theories in physics can be notoriously difficult to confirm. As mentioned previously, string theory and its variants within theoretical physics have been found to be very difficult to test because they have made few quantitative experimental predictions. That is not completely surprising because some theories are more testable than others.

Popper states that testability *is* falsifiability. Therefore the lack of testability keeps the progression of scientific knowledge at bay. Where testability exists there should be no need to describe findings as unassailable or irrefutable. Popper finds no use for irrefutable findings. "*A theory which is not refutable by any conceivable event is non-scientific. Irrefutability is not a virtue of a theory (as people often think) but a vice.*"

Black swans do more than just prove the exception, they have the power to change the mindset. In his book, *The Black Swan*, Nassim Nicholas Taleb suggests that it is the extraordinary exceptions – the *black swans* of discovery – that matter most to the advancements of science as they are the ones most likely to cause profound shifts in our ordered world. Discoveries such as germ theory, penicillin, general relativity, plate tectonics, the transistor, all have led to profound paradigm-shifting reconsiderations of our understanding of nature. What Taleb calls "normal science" (the process of incremental discovery) is more common but less likely to lead to game-changing and paradigm-shifting advances.

When paradigms shift, science and society benefit. Less beneficial (at least in the short term) are the inevitable economic impacts upon established markets, industries and careers as their core technologies become outmoded and obsolete. Old assumptions and rules are displaced and give way to new economic realities. Joseph Schumpeter's theory of "creative destruction"[12] asserts that an essential part of capitalism is to have radical innovations supplant old paradigms and break the back of virtual monopolies. Any radically new technology that changes the economics for transportation, manufacturing, health care or other sectors of the economy would have to be considered a threat by stakeholders tied to business models formulated under older assumptions. These stakeholders include the decision makers such as CEOs, corporate share holders and shapers of government policy.

The exception would be those who have anticipated the new changes, or whose business models are facile enough to take advantage of the technology shifts. It also would include those who own any new intellectual property (IP) favored by the new paradigm. They will become the new early adopters and will benefit from their lead until a new set of rules has been established and equilibrium is again attained under these once-radical ideas. Innovative change plateaus and "normal science" again becomes the rule.

Such economic volatility fomented by game-changing science or engineering-driven innovations can supplant long-established organizations holding to old paradigms (e.g. IBM) with those who generate the new paradigms (e.g. Microsoft). And without much warning that new paradigm holder can be superseded by an even newer paradigm holder (e.g. Google). A game-changing *black swan* discovery can pose a threat to profitability for those holding on to the older ways. The potential threat entices those of the status quo to react with a range of tools to slow the rate of change and its adoption by the marketplace. Change can be painful, but *lack of change* is the greater long term threat to economic security, productivity and – on a global scale – human fulfillment.

Change also implies the adoption of new terminology to describe a new state into which we are transitioning. Established terminology may be co-opted from old uses and applied in new ways to the changing paradigm. The problem with employing established terminology is that it can carry with it baggage in the form of inaccurate preconceptions and old usages that retard rather than advance the new paradigm. And there is probably no better example of deleterious baggage affixed to a term than "antigravity."

DID YOU SAY ANTIGRAVITY?

Antigravity. The word elicits both eye-rolling skepticism and disbelief from many in the scientific community. The use of the term *antigravity* has been a hinderance to serious investigators and researchers alike. It brings to mind what designers have come to call "blue-sky thinking"[13] which is defined as "thinking that is not grounded or in touch in the realities of the present." Blue-sky thinking has included futuristic visions of flying cars, cloud cities and gravity drives for space travel. But until now it has been a vision without a basis in science, a vision that has only benefited science fiction authors, screen writers and futurists.

At the end of the 19th century H.G. Wells imagined a type of antigravity in his novel "*First Men in the Moon*." In that story a scientist discovers "cavorite", a mineral impervious to gravity that can also shield other materials from its effects. Though cavorite is pure fiction it spurred the imaginations of many a science-fiction writer and generated many popular notions of antigravity materials or devices. A mythology around antigravity has arisen that proposes it was either discovered then lost by ancient civilizations or has already been discovered by some gifted inventor but is suppressed by governmental powers.

In online forums and popular novels the mythology of antigravity has been associated with UFO investigators, secret Nazi projects from the last World War and claims that it was employed to build the Egyptian pyramids. Just a five minute search on the Internet will bring up hundreds of Web sites with untested ideas of how to violate the laws of physics to produce antigravity. With such a diverse range of advocates and groups using the same term how can we even be sure that they are all talking about the same thing?

The first problem with the term *antigravity* is its sloppy, uneven usage in science fiction stories, movies, television fiction and Saturday morning cartoon shows. Its usage has become stereotyped and lowered to the level of unsophisticated imagery instead of lending itself to further serious examination as a tool for design and engineering.

Are those who employ the term referring to a field that shields gravity? One that repels gravity? A negative gravitational field? This lack of clarity and inconsistency of usage provides no basis for understanding and grounds for much confusion.

Employing the proper definitions and parsing their distinctions is important to this discussion. Below are some commonly accepted definitions employed in discussions of gravity that may be confused with claims of antigravity:

- Artificial gravity – Gravity-like effect produced by centrifugal forces during rotation.
- Gravity shield – A material that blocks the propagation of gravity (like the fictional cavorite).
- Gravity lensing – Used by astronomers to describe gravity's bending of light near astronomical bodies.
- Negative mass – Hypothetical exotic matter possessing a repulsive gravitational field.
- Graviton – The particle carrying the gravitational force.
- Gravitophotons (also graviphoton) – Hypothetical graviton-like particles with neutral, repulsive or attractive fields.
- Quintessence – Weakly repulsive gravitational field (associated with *dark energy*)

Though employing the term *antigravity* can be a powerful tool for marketing films, comic books, museum exhibits and other venues, it doesn't promote real understanding. Unfortunately it is very difficult to dissuade the public from using a term with which they have grown comfortable and is part of the cultural vernacular, even if it has no consistent usage. The word has so permeated the popular culture that trying to end its use would have little effect. It would be better to just avoid its usage altogether and employ a term derived from the scientific study of gravity.

To the non-scientist the mix of methods and theories related to gravity modification and its effects ranges widely. There are peer-reviewed papers suggesting the possibility of supernova-generated "gravity waves"[14] and "gravity mirrors"[15] that can reflect and manipulate gravity fields. There are papers suggesting the generation of "gravity-like fields"[16] by rotating "low temperature" superconductors (LTSC) and somewhat analogous "gravity beams"[17] by rotating "high temperature" superconductors (HTSC). Some of these outcomes have also been described as generating "artificial gravity", but since they arise from natural forces the use of the modifier *artificial* also seem inappropriate.

Another problem with the term *antigravity* is that it has different meanings depending upon whom you are addressing. Dr. Ron Koczor of the Science Directorate, NASA/ Marshall Space Flight Center knows about choosing the terminology to match your audience. Speaking for himself in a 2005 interview he reflected, "When you talk to the general public or the kids whose eyes are half-glazed with anticipation, call it 'antigravity.' But when you talk to people who control the course of research and who themselves have the credibility of their decisions questioned by higher-ups, I think you need to rethink your use of that term."[18] It's probably best to leave the term antigravity as a pedestrian descriptor of an overall effect but don't employ it in serious works. In lieu of the term "antigravity", Dr. Koczor prefers terms such as "gravity modification" or "microgravity generation."

A similar term "modified gravity" has been employed by researchers to describe the gravitational theory of Modified Newtonian Dynamics, or MOND. MOND was first theorized to explain the existence of dark energy by suggesting that gravity's strength on a galactic scale is dependent upon each galaxy's matter distribution. MOND itself has generated several variants with different names, but more on the competing theories in a later chapter.

Several research programs initiated over the past decade forecast an ability to produce "microgravity" effects (that is, reduce an object's weight to a fraction of earth's 1g gravitational field) as well as the ability to produce "hypergravity" effects (greater than earth's gravitational field) that could make objects heavier. Pilots who "pull g's" in their aircraft are experiencing an acceleration as a temporary hypergravity. These terms are also potential contenders to describe variations in gravity.

Some gravitational effects reported sporadically in the literature are suggested to be produced through the generation of either a "repulsive" gravity-like field or an "attractive" gravity-like field. The term "gravity-like" suggests fields (and associated particles) generated through a mechanism related to but differentiated from gravity we normally associate with the planets and moons. A field which is attractive would act similarly to standard gravity. A repulsive field would be closer to "dark energy", that mysterious force that makes up 74% of the mass/energy in the universe and keeps it expanding at an ever increasing rate.

The term preferred in this book is *gravity modification.* It falls closest to Dr. Koczor's preferences and has been used by NASA to describe gravity studies by the European Space Agency. However, NASA and ESA are not the only groups to use this term. In his book "Introduction to Gravity Modification", Dr. Benjamin Solomon[19] uses the term to describe his mass-independent theory of modifying the effects of gravity. And Dr. John Moffat employs the term modified gravity, or MOG, to distinguish his theory of modifying the strength of gravity at large distances. Several different theoretical mechanisms under study may accurately be described as gravity modification or modified gravity.

To distinguish this book's use of gravity modification from others it seems appropriate to employ a shorthand that could be used to distinguish the application of gravity-like fields for architects and designers from those terms for describing different theories of gravitation. Therefore "gMod" (shorthand for *gravity modification*) was selected as a term for the purposeful application of gravity-like effects described here.

The use of a lower case "g" as a prefix follows a recent trend of indicating a new and distinctive technology approach in design, such as Apple's usage of the lower case "i" preceding its line of mobile products iPad, iPhone, iPod, iMac, and iSight. Apple's defense of the use of "i" [20] against other associated product trademarks shows how important they see the use of their prefix of choice, but they are not unique. Like the first generation of "e" functions including e-mail, e-learning, e-commerce, or e-waste to indicate something electronic, the newer usage of such prefixes is considered useful although a minor crime against grammar[21]. So consider gMod as the root for a new category of "g-devices" employing the effects of "gravity modification." Hopefully Google, owner of "gmail", won't mind!

Despite competing theories and terminology there is one commonality that is central to this book and its exploration – that there exists evidence that gravity-like fields can be generated, manipulated and eventually employed to alter our world through purposeful design and engineering. It is doubtless that the theories touched upon here will continue to evolve and mature over the next decade and longer, but a practical demonstration may not be far away. Breakthroughs in theory and experiment in this field have already been reported in the peer reviewed scientific literature from several sources.

It's time to think differently about gravity. To borrow a phrase, "It's not your father's gravity" – it's Gravity 2.0.

LIKE PREDICTING THE TRAFFIC JAM

What will be the everyday applications of this technology? How will such a technology change social institutions, daily commuting, privacy or land ownership rights? How does a potentially disruptive and destabilizing technology establish itself without the widespread creative destruction of existing industries? And how long before such a breakthrough technology becomes unremarkable and fades into the banal background of everyday living?

The application of controlled gravity technology would be a sea change in everyday life. There isn't a part of our society that would not be affected. As a cover story in New Scientist magazine [22] forecast, "Levitating cars, zero-g playgrounds, tractor beams to pull objects towards you, glass-less windows that use repulsive fields to prevent things passing through. Let your imagination run riot: a gravitomagnetic device ... would be the basis for a general-purpose force field."

Zero-g industrial fabrication facilities initially planned for the International Space Station could be achieved at a fraction of the cost here on earth. Microgravity industrial applications for growing perfect silicon semiconductors, zero-defect drug manufacture, and metals and glass with perfect molecular structures would be possible. And yes, even levitating cars.

gMod has the potential to change nearly every aspect of how we live, how we play, how we work, even how we think about the world. Its theoretical underpinnings unite the wide expanse of the universe with the smallest events and particles in nature. It is a bridge from our dreams to a hopeful future that embraces green technology and eschews fossil fuels. And like any new technology it has the potential to do harm as well as good.

Science fiction writer-critic Ed Bryant wrote, "If this were 1890, it would take an inventor to predict the automobile, and it would take a real visionary to predict highways and gas stations. But it would take a science fiction writer to predict the traffic jam." We are currently at the moment of the inventor and possibly that of the visionary, yet there is much to be left for both the science fiction writer and writer of science fact.

How do we educate our first generation of gMod engineers and designers? How do we implement a process for assessing future impacts upon cities, public policy, transportation, medicine, industry and social structures? Preparing the next generation of industrial designers, architects, city planners, and policy makers to develop and employ new products, vehicles, buildings, cities and infrastructures that employ these new gMod technologies is a task well suited for higher education in technological fields. But that is only the beginning

The potential impacts that we can already imagine for gMod suggests that it will require its own set of qualifications for professional practice. Just as industrial designers, graphic designers and architects were instructed through a common curriculum in the Bauhaus in the late 1930s, there will be elements common to the design applications of gMod that underlie other disciplines as well. Those practices eventually grew into their own disciplines and professional areas of development. Similarly, gravity modification and its application through gMod will eventually mature into its own specialty of "gravity design."

When Tim Berners-Lee invented the World Wide Web it took researchers at universities little time to create Web browsers, the first being "Gopher." Soon entrepreneurs were imagining the social impact of graphical browsers and Web sites. After Gopher came Netscape and the first generation of Web applications which led to new areas of expertise in digital media, interface design, interaction design, e-learning, social networking and more. A new technology may first be introduced for highly technical applications, but it can soon find its way to less technical areas of society.

If gravity modification is successfully demonstrated as a reliable and robust technology, then it might be adopted even more quickly than was the Web. Institutions of higher learning could graduate the gravity design equivalents of Mark Andressen and Shaun Fanning.

The time to begin assessment of this potent new technology is now, followed closely by the first phase of public policy planning. The next generation of entrepreneurs will quickly expand this nascent science into the next big technology capable of leapfrogging existing industries, infrastructures and social structures. Get ready for a remarkable future.

2. Breakthrough Programs

It has only been since the 90s that NASA and ESA began a new generation of interest in gravity modification for propulsion. But why were NASA and ESA interested in funding such a radical and "blue sky" departure from their very successful programs in rocket propulsion? The "breakthrough" programs represented a turn from traditional physics and toward exotic or unconventional physics with the hope of achieving radical new means for space propulsion. As mentioned in the last chapter, once fuel for rockets is expended the craft is at the mercy of gravitational fields. The breakthrough programs were developed to find alternative means through new physics and extend humankind's ability to explore space.

From 1996 through 2002, NASA actively funded research for the Breakthrough Propulsion Physics (BPP) Project to assess emerging fields of physics to replace traditional rocketry. A wide selection of propulsion candidates were reviewed ranging from the warping of space, to the study of gravity as a means for propelling spaceships, to distant planets – even other solar systems – without the need for chemical propulsion or nuclear rockets. The main Web site for the project can be found at NASA's Breakthrough Propulsion Web site [23].

The BPP Project's mission was to formulate a comprehensive strategy for advancing propulsion over the next 25 years. Their strategy, called the "Advanced Space Transportation Program" (ASTP) sought technology improvements all the way through to the breakthroughs that could revolutionize interstellar travel. The project made for an interesting public relations balance. While on one hand the research strove to study credible application it also pursued a mission more visionary than typical projects funded by NASA. To be truly successful the project had to make advances that leapfrogged conventional physics, yet it also had to make regular progress on short-term goals to ensure its continued funding.

The project was operated through NASA's Marshall Space Flight Center and was headed by Dr. Marc G. Millis of NASA's Lewis Research Center. As the title of the project implied, the project specifically was investigating breakthroughs in physics rather than refinements of existing propulsion technologies. Research was focused upon three specific project goals representing breakthroughs known as the "Grand Challenges." As stated in the project's final report they were:

Grand Challenge 1: Mass – Discover new propulsion methods that eliminate or dramatically reduce the need for propellant mass. This implies discovering fundamentally new ways to create motion, presumably by interaction with the properties of space, or by the interaction of matter, energy, and spacetime, including the possibility of manipulating gravity or inertia.

Grand Challenge 2: Speed – Discover how to circumvent existing limits to dramatically reduce transit times. This implies discovering a means to move a vehicle at or near the actual maximum speed limit for motion through space, or by some other means, such as by interaction with spacetime itself to circumvent normal limits.

Grand Challenge 3: Energy – Discover fundamentally new modes of onboard energy generation to power these propulsion devices. This third goal is included since the first two breakthroughs could require breakthroughs in energy generation, and since the physics underlying the propulsion goals is closely linked to energy physics.

The BPP Project established for itself particularly challenging goals. The final project management report states, "... genuinely new ideas often extend beyond the established knowledge base, or worse, can appear to contradict this base. In other words, a genuinely new, credible idea is very likely to appear non-credible." Candidate research approaches for the project included:

- Coupling of gravity, electromagnetism and spacetime
- Properties of the space vacuum and inertial frames
- Quantum level effects
- Warp drives
- Wormholes
- Anomalous effects of force-production or energy-exchange.

The methods report from this project is available online at the Technical Report Server of the NASA Glenn Research Center[24]. There were sixteen peer-reviewed articles[25] that resulted from BPP Project sponsorship. An outcomes technical memorandum, "Prospects for Breakthrough Propulsion From Physics"[26] was published in 2004 and is available on the NASA site.

Were any of these research directions fruitful? Of sixteen incremental research tasks completed by the project and from other sponsors, about a third were found not to be viable, a quarter were reported to have clear opportunities for subsequent study and the rest remained unresolved. Although the research component of the study had ended years earlier the publications support continued into early 2008. Funding for the project was withdrawn on October 1, 2008. The final NASA contribution was to assist in the compilation of a graduate-level technical book, "Frontiers of Propulsion Science"[27], which was made available as a book in early 2009. A more recent effort[28] by the book's author presents a condensed summary of the approaches from that book and identifies next-step questions toward determining if, and how, such breakthroughs might eventually be achieved.

One of the closing statements in the BPP's final report addressed the lack of predictability of this field of research. It states, "At this stage it is still too early to predict which, if any, of the approaches might lead to a successful breakthrough. Objectively, the desired breakthroughs might be impossible to achieve. Reciprocally, history has shown that breakthroughs tend to take the pessimists by surprise." As we have already noted, breakthroughs that catch the world by surprise are called "black swans" and as we will see later they prove the rule rather than the exception in making the most important discoveries in science.[29]

THE NASA PROGRAMS

The Breakthrough Propulsion Physics program wasn't NASA's only effort in innovative approaches to space science, and such advanced concepts thinking didn't end with the program's conclusion of active research in 2002. In early 1998 the Universities Space Research Associate (USRA) established the NASA Institute for Advanced Concepts (NIAC) in cooperation with NASA but administered it as an external organization.

On its summary page the independent institute states that, "NIAC has inspired an atmosphere for innovation that stretched the imagination of the technical community and encouraged revolutionary creativity." In a 2006 message from its director, Robert A. Cassanova, he remarked that, "Visionary thinking is an essential ingredient for maintaining global leadership in the sciences, technology innovation and expansion of knowledge. NIAC has sought creative researchers who have the ability to transcend current perceptions of scientific knowledge and, with imagination and vision, to leap beyond incremental development towards the possibilities of dramatic breakthroughs in performance of aerospace systems."

Fully funded by NASA, the institute pursued several breakthrough concepts that are still under development by other government agencies or private industry including the space elevator, space tethers, and electrodynamic (propellant-less) propulsion. Despite these and other successes NASA, faced with the competing fiscal constraints of achieving the Vision for Space Exploration, ceased operation of NIAC in August 2007. But NIAC was to rise again.

In July 2010 it was announced by the NASA/Goddard Space Flight Center that NIAC would begin again in fiscal year 2011 as an internal NASA program under the Office of the Chief Technologist. The new NIAC is seeking concepts on several levels for innovative advanced concepts, space systems and space technology. Their efforts will focus upon technology activities at a very low Technology Readiness Levels (TRL) [30] rated at 1-3, that is,

- basic principles observed and reported,
- technology concept and/or application formulated, or
- analytical and experimental critical function and/or characteristic proof of concept

In the fall of 2010 the final request for information (RFI) went out for the Game Changing Development Program (GCDP) [31]. This new program will develop novel aerospace capabilities that have more technical risk yet higher potential payoff than the technologies being developed in support of NASA's mission directorates. The GCDP focuses on developing radically new approaches to NASA's future space missions and is designed to mature such technologies starting from a TRL of 2/3 to a TRL of 4. TRL-4 indicates validation in laboratory environment as a standalone prototype fully implemented and tested.

According to their requests for information the new NIAC is seeking:

1. Revolutionary concepts and technologies that will greatly advance NASA's missions
2. Ideas that may result in beneficial changes to NASA's long-range plans

3. Cross-cutting technologies that contribute new technological approaches for aerospace applications and, ideally, also fulfill national needs in areas such as communications, power, energy storage, propulsion, safety, and security.

So we may yet see validation of breakthrough physics under the hand of NASA.

A DWARF STAR IN THE LABORATORY

In the final technical memorandum released by NASA's Breakthrough Propulsion Physics program there was reference to a parallel study by the European Space Agency (ESA), and their "gravity modification study." The memorandum said that ESA sponsored a study on the prospects of gravity control for propulsion including the following research avenues:

1. Search for violations of the Equivalence Principle with ongoing in-space experiments.

2. Resolve the anomalous trajectories of Pioneer 10/11 spacecraft and others.

3. Experimentally explore gravitomagnetic fields in quantum materials.

Where the BPP Project found no revolutionary breakthroughs in physics, that would not be the case with the ESA group. They not only had the benefit of NASA's experience but also held a different set of expertise within its research team.

In 2001 ESA funded studies to evaluate the concept of gravity control. This was undertaken in light of current theories of gravity and field theory, as well as to assess the scientific credibility of claims of anomalous gravitational experiments and phenomena in the literature. However, the 2002 summary publication found no basis for a breakthrough in propulsion devices, concluding that "... control of gravity, even if achievable, would not imply a breakthrough for propulsion...", but it went on to say, "even though it could be of major importance for e.g. possible microgravity applications on Earth."

The authors of the study were Drs. Martin Tajmar, AIT/ARC (Austrian Institute of Technology/Austrian Research Center) Seibersdorf Research GmbH and Orfeu Bertolami, Instituto Superior T´ecnico, Departamento de F´ısica, Lisbon, Portugal. The publication, Hypothetical Gravity Control and Implications for Spacecraft Propulsion [32] was funded by ESA's General Studies Programme. Dr. Tajmar's Ph.D. is in Numerical Plasmaphysics from the Vienna Institute of Technology. His work at ARC, Austria's largest research institution, has encompassed work on satellite microthruster propulsion and simulations for electric propulsion thrusters, so he was well versed in propulsion physics. The underlying fundamental physical principles of known theories of gravity were analyzed and it was shown that even if gravity could be modified it would bring only somewhat modest gains in terms of launching of spacecraft but no breakthrough for space propulsion. At least that was their conclusion at the time.

Despite lack of a true breakthrough Dr. Tajmar and other collaborators, notably Dr. Clovis de Matos, continued their investigations. Clovis de Matos of ESA-ESTEC, Directorate of Scientific Programmes, The Netherlands (and later ESA-HQ, Paris) had been ESA's technical officer for the Tajmar/Bertolami study and ESA's General Studies Officer. This new team continued to perform their research under funding by AIT/ARC, the U.S. Air Force Office of Scientific Research and with support by ESA. They made measurements of what they termed the gravitomagnetic equivalent of the London moment, that is, gravitational effects generated by the spinning of "superconducting" materials. This avenue of inquiry was inspired by Dr. Janet Tate's studies of the mass of Cooper pairs in niobium, which did not match with theoretical predictions.

Superconducting temperatures produce quantum effects that, if we saw them occur at room temperature, would appear quite strange. The study of unique properties at such lower temperatures is referred to as "condensed matter physics." Condensed matter may exhibit the property of superconductivity where electrical resistance goes to zero, or "superfluidity" where a liquid's viscosity goes to zero and quantum states becomes shared.

In essence, a pooled group of thousands or millions of atoms act in unison as if they were a single atom. This is referred to as a Bose-Einstein condensate, after the pioneering work done by Satyendra Nath Bose and Albert Einstein from 1924 to 1925. Tajmar and de Matos had hoped to establish how superconducting materials could slightly alter gravitational predictions. By early 2006 Tajmar and de Matos had co-published a dozen investigative peer-reviewed articles, and the best was yet to come.

In March of 2006 ESA made a remarkably bold announcement on their Web site [33]. Tajmar along with F. Plesescu, K. Marhold and de Matos had succeeded in measuring "frame dragging-like signals" in the AIT/ARC laboratory indicating the generation of "artificial gravity". In essence they had created a gravity-like field in their laboratory. The field was small – on the order of a tiny fraction of a single percentage of "g" the constant representing the local gravitational field on the surface of the earth. The authors predicted in their paper "Experimental Detection of the Gravitomagnetic London Moment" [34] that this new chapter on gravity could "form the basis for a new technological domain, which would have numerous applications in space and other high-tech sectors." The basis for gMod had been demonstrated.

The 1916 theory of general relativity predicts that a rotating mass will generate a gravitomagnetic field, just as a moving electrical charge creates a magnetic field. Gravitomagnetism was first extracted from Maxwell's field equations in 1893, more than 20 years before Einstein's publication of general relativity. That a rotating body drags a small amount of spacetime with it is known as "frame-dragging", or the "Lense-Thirring effect" (named for Joseph Lense and Hans Thirring after their prediction of the effect in 1918). Apparently, Tajmar's team had produced in the laboratory an effect previously only predicted to occur around large planetary objects.

Gravity-like fields are analogous to electromagnetic fields and the forces they produce. A field produced by a stationary mass would exert a gravitoelectric force, while the field generated by a moving mass would exert a gravitomagnetic force. Similar to how the strength of an electromagnetic field is related to the movement of an electrical charge and its current density, a mass moving together with a "mass density current" determines the strength of a gravitomagetic field. Both forces are said to be "gravity-like" in that they are smaller than, but generated by, the primary effect of gravity.

In Tajmar's study a gyroscopic ring of superconducting material was spun at 6,500 RPM (about 13 times faster than the rotation of an audio CD) to study discrepancies between actual measures of mass in superconductors and predictions by quantum theory. They measured an unpredictably strong anomaly that could be explained by the appearance above the spinning superconductor of a gravitomagnetic-like field. The existence of gravitomagnetic fields had been predicted by Einstein, yet these were incredibly stronger than general relativity theory had predicted.

The field measured by Tajmar's team was a surprising billion billion (18 orders of magnitude, or a 1 with 18 zeros after it) times larger than those predicted by general relativity. It was measured at nearly a thousandth of 1% of the force of gravity, something that might seem weak to the non-physicist but is actually completely unworldly. For example, the strength of the gravitational frame dragging effect produced by 400 grams of material in their setup is what would have been expected in the vicinity of a white dwarf – a star the size of the earth but with the mass of the sun. This cannot be explained by the classical frame dragging effect of general relativity and represents a new kind of physical phenomenon without any explanation under standard physics.

Tajmar and de Matos view this effect as the gravitational analogue of Faraday's electromagnetic induction experiment performed in 1831. A relationship between gravitational force and a "co-gravitational" force was also predicted in the late 1800s by Oliver Heaviside. This relationship between electromagnetism and gravity implies that gravitational forces depend not only on mass and the distance between interacting bodies, but also on their velocities and accelerations.

Initially, the researchers were reluctant to believe their own results. "We ran more than 250 experiments, improved the facility over 3 years and discussed the validity of the results for 8 months before making this announcement. Now we are confident about the measurement," said Tajmar, adding that they do believe that further experimentation could "produce even larger gravitational fields in laboratories."

In 2007 Tajmar et al. [35]published a further analysis of a more comprehensive set of experiments. This very detailed view of his findings did suggest other possible causes of the effects. However the conclusion of the analysis again stated that the most likely cause was the existence of a gravitomagnetic-like effect ("gravitomagnetic-like" because the effect does not scale with the mass of the rotating rings employed). In a publication by Dr. Tajmar (with Plesescu and Seifert) titled, "Anomalous Fiber Optic Gyroscope Signals Observed above Spinning Rings at Low Temperature" [36] Tajmar refined his methodology with additional setups and measurement techniques employing accelerometers confirming his earlier findings.

In July 2007 Graham et al. [37] at the Canterbury Ring Laser Group in New Zealand published a paper where his team attempted the generation of a gravitomagnetic field by rotating a disk of cryogenic lead (one of the superconducting materials originally tested by Tajmar and de Matos). The ring laser gyro is one of the largest facilities in the world. It should have been able to detect the effect measured by Tajmar and de Matos when rotating a sample of lead under supercooled conditions.

However, the New Zealand authors did not verify the Tajmar/de Matos theoretical prediction with their measurements, saying, "Within the uncertainty of the experiment there is no indication of any inertial frame dragging due to the rotation of the nearby lead superconductor." That level of uncertainty has become a critical issue. They write in their conclusion: "There have been recent claims of measured effects similar to frame dragging, of strength about two orders of magnitude lower than predicted..." and continue, "Our experimental results do not have the sensitivity to either confirm or refute these recent claims."

In a reply to Graham's study, Tajmar, Plesescu, Seifert, Schnitzer, and Vasiljevichet in their 2007 paper "Search for Frame-Dragging in the Vicinity of Spinning Superconductors"[38] reviewed Graham's study and found several discrepancies to account for the difference in results. Among other factors Canterbury's setup employed a rotating disk rather than a rotating ring, the distribution of the experimental data was analyzed differently and, as acknowledged by Graham, the accuracy of the laser gyroscope employed was about two orders of magnitude lower than for the gyroscope measuring rotation employed at AIT/ARC.

Initially, the data from Canterbury was very noisy and seemed to not support Tajmar's findings, but closer analysis showed that the effect – though weaker – was present. Tajmar concluded (referring to the Canterbury facility) with the statement that "Our results also compare well to recent measurements of the world's largest gyro response to a spinning lead superconductor."

Though the results from Canterbury were mixed, there was another experiment that had recently been concluded – also with mixed results – that could be explained if the AIT/ARC findings were taken into account. That experiment was Gravity Probe-B.

Gravity Probe-B

A century ago the minuscule warping of time due to frame-dragging would have had no impact on the day-to-day lives of people on the surface of the earth. Today it is a big concern to industry and the military. The Global Positioning System (GPS) works on the basis of accurate clocks housed within satellites in geosynchronous orbits. GPS would not work properly if corrective algorithms were not used to adjust for the effect of gravity and orbital speed on the passage of time. Even Hollywood knows about the reliance upon the accuracy of GPS clock algorithms as it was a major plot line in the James Bond movie *Tomorrow Never Dies*.

Developing those corrective equations requires understanding of what happens to satellites undergoing the angular momentum of a rotating body dragging spacetime (that is, frame-dragging) into tornado-like whirls around it. In 1976 Gravity Probe-A (GP-A) was sent into orbit by the Smithsonian Astrophysical Observatory to test general relativity and its effect on time. It was the first direct test of Einstein's equivalence principle and showed that time slows near the earth by 4 parts in 10 billion. Its results were later confirmed to an accuracy of 0.01 per cent. But this was only the first space-based test of general relativity.

A different mission was planned for its successor, Gravity Probe-B (GP-B). It was funded more than a decade before the launch of GP-A. Its mission was to gathered data to measure Einstein's geodetic effect (another prediction of general relativity) and how spinning objects in gravitational fields drag spacetime with them. Such curvature of spacetime and frame-dragging is so small that it only accounts for one part in a few trillion. GP-B and was one of the most precisely designed space-based research projects in NASA's history. Central to its design were two pairs of counter-rotating superconducting niobium spheres ten thousand times smoother than a billiard ball in a near-perfect vacuum. In April 2004, about 40 years after its first funding from NASA, GP-B was launched.

According to the theoretical concepts, a frame-dragging-like field should be produced directly proportional to the spinning object's angular velocity. Another aspect of Einstein's theory is that a time-varying frame-dragging field should give rise to non-Newtonian gravitational fields (also called accelerational frame-dragging). Therefore, any angular acceleration (change in speed of rotation) of the spinning superconductor should produce a gravitational field along the superconductor's surface in a direction opposite to the angular acceleration.

Though the GP-B experiment concluded data collection and final calibrations in late 2005 its analysis was expected to continue through 2010. The first part of the experiment achieved early success with a confirmation of the geodetic effect to a total uncertainty of just 1%. That is good, but not as good as the projected accuracy of 0.01%. The effect being measured is very small. The wobbling, or precession of the gyro-spin axis being measured is only 0.0018 degrees in the orbital plane of the spacecraft.

A similar precession for frame-dragging would be only 0.000011 degrees. However the data for GP-B's gravitomagnetic frame-dragging experiment did not match theoretical predictions and had an uncertainty of 15% rather than the hoped for 1%. As reported in New Scientist [39], the probe's data was unexpectedly noisy. Even though the probe measured with unprecedented accuracy the precession of superconducting gyros in a polar orbit around earth, one would have expected to see the clear effect of an enhanced frame-dragging field in their setup. Instead, the officially listed causes of error including electrostatic "patch effect" anomalies along the gyros' niobium surface.

For electrostatic impurities to have caused this effect of exactly the same size on each sphere is regarded by some outside the project team as unlikely. In May 2008 the Senior Review Committee at NASA Headquarters did not grant the Gravity Probe B team its final funding extension, though funding was found elsewhere. The team hoped that the additional time for analysis would result in a more clear and complete understanding of the unexpected and anomalous data.

Tajmar's previously mentioned paper on frame-dragging [40] reviewed NASA's official results. Recall that the AIT/ARC studies had employed measurements of a spinning ring of niobium, the same superconducting material composing the gyroscopic spheres in GP-B. Tajmar's team found in their analysis that the signal cannot be explained by mechanical influence or by carefully monitored magnetic fields surrounding the sensors, especially for an experiment that NASA boasted was one of the most accurate ever undertaken in the history of that agency.

The results of the AIT/ARC studies were compared to the data from GP-B. Tajmar's conclusion is that the GP-B data does not rule out their gravitomagnetic-like effect. The AIT/ARC findings could provide an alternative explanation without resorting to NASA's use of a correction term to account for the additional measured torques. At the least it could provide a new error factor to the anomalous results.

FINDING THE SOURCE

More recent papers by Tajmar have investigated questions about the source of the effect. Was it due to the acceleration of the supercooled niobium ring? Or was it due to the swirling helium vapor (also a superconductor) used to cool the apparatus. More about this will be discussed in Chapter 4.

Some questions still remain unanswered about the results of the ARC studies. These will likely be answered in coming years but remain issues for understanding the nature of the anomaly. Before these questions could be definitively answered at ARC other opportunities presented themselves and Dr. Tajmar now continues his research at the Korea Advanced Institute of Science and Technology (KAIST) located in Daedeok

Science Town which is the home to more than 60 government-supported and private research institutes, four universities, and numerous venture businesses.

Tajmar's 2006 AIT/ARC study reporting the generation of "artificial gravity" was the culmination of over a dozen published investigations and three years of constant experimentation. As of the end of 2010 with eight years of experiments conducted it can be said that Dr. Tajmar did observe an anomaly that could be measured, most notably with fiber-optic-gyroscopes and to a lesser extent with accelerometers. However, with improvements to shield the apparatus from other noise sources (acoustic, etc.) the effect has became smaller. Although still observable, it has become so small that it may well be within the noise level of Dr. Tajmar's experimental setup.

Though remarkable, the AIT/ARC studies were not the first to suggest using gravitational fields to enable space travel without chemical propellants. Neither were the NASA studies of Breakthrough Propulsion Physics established in the 1990s. Decades prior to these studies there was a tremendous worldwide interest in any new physics – discoveries that might even eclipse the power of the atom. This was a time in the 1950s when physicists, suddenly finding themselves in the public spotlight at the end of World War II, had the admiration of a grateful world. The discovery of "atomic energy" offered the hope of power "too cheap to meter" and seemed to open the door on a completely new vision of the future.

Soon Wernher von Braun, the German rocket scientist, would capture the imagination of the public zeitgeist about space travel, possibly even space travel with nuclear engines. But it was a contemporary of von Braun's who was to take a different direction. A physicist who similarly had an interest in space flight yet thought that a better way to propel humanity to the stars was to modify gravity itself.

About the Author

Gregory Daigle is an educator, project manager and technology writer. Mr. Daigle is a former Associate Professor of Industrial Design at the Minneapolis College of Art and Design and currently teaches interface and Web design at the University of Minnesota. He has collaborated on designs produced by Herman Miller Inc., and has been a design consultant for manufacturers such as 3M, Cray Research and Stratasys. For years he worked for Bill Stumpf, an iconic industrial designer, and served as the firm's Research Manager and as a Senior Designer.

He is also a project manager and instructional designer for the e-learning industry with clients in the medical, financial and airlines industries. He co-founded ICONOS inc., a pioneering firm producing STEM learning software for children. His software productions have garnered several dozen national and international awards and distinctions from the software, film and video industries. He also managed creative and production staffs for the interactive division of Bozell Kamstra, an Ad Age and Adweek Top-100 interactive advertising agency.

Greg has written about science and technology innovations including such diverse topics as gravity modification, metamaterials, printable robots and digital tattoos for one of the first online news journals in Korea, OhmyNews. He also acts as Executive Director of Digital Watershed, a non-profit engaged in developing wireless tools, place-based learning and global education for young adults on the topic of climate change. His Web site on advances in gravity research and development, "Gravity Modification", was established in 2007.

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