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# 2. Identification and Significance of the Innovation

## 2.1 Introduction

NASA, U.S. Navy and U.S. Air Force have commissioned a number of interesting yet disjointed studies on asymmetric capacitors with the goal of evaluating their usefulness to propulsion applications. The nature of propulsive forces arising in asymmetric capacitors under high voltage was attributed to mysterious Biefeld–Brown effect, which hinted at new physics. Thorough examination by the aforementioned government agencies have conclusively proved that thrust in atmosphere is definitely due to ionic wind as the magnitude of the observed force closely matches ion transport calculations. Consequently, no thrust was observed in high vacuum. However, propulsive forces were noted when an electric arc jumped between the capacitor electrodes. Because ablation was the only logical conventional explanation, none of the studies pursued the subject further. The 2004 NASA study commissioned by NASA Breakthrough Propulsion Project was the only one to cast a shadow of doubt on the ablation hypothesis: *the calculated mass loss was not supported by observations*. Clearly, some other hitherto unknown mechanism must be at play. If this mechanism is genuine, it may be a manifestation of “new physics” with far reaching consequences and immediate applications in space propulsion (e.g., purely electromagnetic momentum-exchange propellantless propulsion).

Because of the potential importance of an unambiguous identification of the nature of the propulsive force arising from an asymmetric capacitor arcing in vacuum, we propose an experiment that will a) accurately measure thrust resulting from the arc (better than $10^{-4}$ N); b) accurately measure material loss due to ablation (better than $10^{-4}$ g); c) account for parasitic effects due to electrostatic/electromagnetic interaction with vacuum chamber walls. To our knowledge no such experiment has been performed. The experiment will be performed in a bell-jar vacuum chamber (<$10^{-5}$ Torr) using torsion balance similar to the one employed in the 2004 NASA study.

**Confirmation of thrust without ablation will be a truly significant accomplishment of American science (with significant public benefit) indicating that new and hitherto unrecognized phenomena may be at play. This discovery will have far reaching consequences for science and technology and thus corresponds for high-payoff research. We may be only $116,000 dollars away from the next major technological breakthrough. At a very minimum successful confirmation of ablation-less propulsive force will lead to development of new generation of propellantless thrusters for near-Earth maneuvering and deep space travel that will markedly reduce the cost of space missions and may even solve the space-junk problem (see Section 10). Numerous other applications will follow.**

## 2.2 Asymmetric Capacitor Thruster (ACT)

Asymmetric capacitor thruster (ACT) is an extremely simple and lightweight device with no moving parts comprising two dissimilar electrodes charged to a high DC voltage (typically 15–60 kV). ACTs come in all shapes and sizes and a common configuration is shown on Fig. 1.

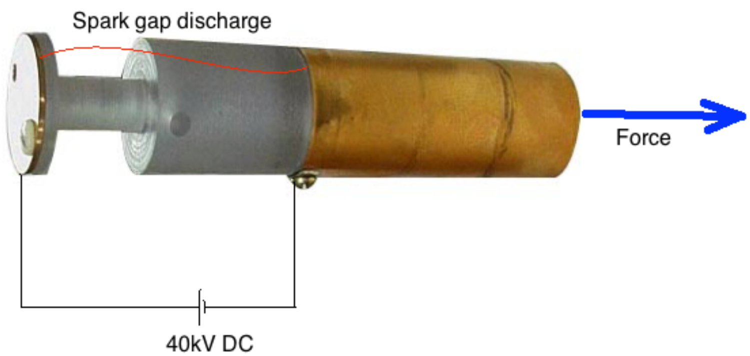


Fig. 1. Cylindrical ACT configuration: in the presence of DC voltage between the electrodes net propulsive force is generated in the direction shown.

For decades, the operating principles of ACTs have remained a mystery. The mystery was precipitated by the controversial claims of the ACT inventor, Thomas Townsend Brown, who claimed an electrogravitics connection [1]. The ambiguity was sustained by the apparent lack of interest in ACTs by the mainstream physics community, which did not conclusively settle the matter of the physics behind the operation of the ACT. As a result, confusion spread as more and more enthusiasts began building various kinds of ionocrafts (Fig. 2), ascribing various “magical” properties to them.

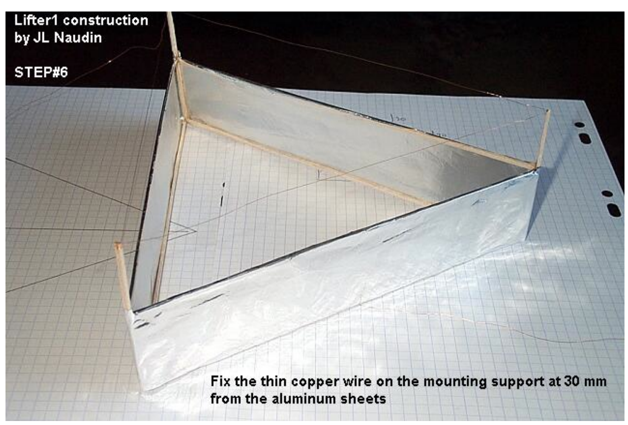


Fig. 2. Typical ionocraft (aka lifter) configuration: thin copper wire is stretched above the aluminum foil wrapped around balsa wood frame. Such lifter takes off easily when 40-kV DC voltage is applied between the wire and the foil.

Eventually, government entities (i.e., NASA, ESA, U.S. Air Force, and U.S. Navy) followed suit with their own ionocraft and asymmetric capacitor experiments [2–6]. The objective in these experiments was to determine if lifter technology could be developed for practical atmospheric and space-based applications. Careful measurements performed at government laboratories quickly poured cold water on the electrogravitics claims ascribed to the Biefeld–Brown effect: in the atmosphere, lifter operation can be completely and accurately accounted for with conventional ionic wind model [2, 8, 9]. Consequently, lifter tests under high vacuum conditions revealed no thrust [2–5, 7]. Somewhat paradoxically, NASA received a patent on ACT thrusters based on Biefeld–Brown effect [10], which is now known to be unworkable.

Despite notable effort, the book was not completely closed on ACTs: a weak propulsive force *was observed* in vacuum when an electric arc jumped between the capacitor electrodes [2, 3]. Because ablation was the only logical conventional explanation, none of the studies pursued the subject further. The 2004 NASA study [2] commissioned by NASA Breakthrough Propulsion Project (BPP) was the only one to cast a shadow of doubt on the ablation hypothesis. The following discussion is adopted from [2]. Ablation is expected to produce charged particles with thermal velocity $v$ given by:

$$v = (8kT/\pi m)^{0.5}, \qquad (1)$$

where $k$ is Boltzmann's constant, $T$ is temperature in Kelvin, and $m$ is particle mass. For a copper electrode, the temperature is likely to be around 2600 K [2], hence Equation (1) yields particle velocity $v$ = 930 m/s. If we substitute this velocity in the mass flow rate equation

$$dm/dt = F/v, \qquad (2)$$

where $F$ is the observed propulsive force, we get the mass loss rate of $1.5 \times 10^{-5}$ kg/s (the magnitude of the propulsive force attributed to the arc was $F$ = 0.014 N according to the 2004 NASA study). **This mass loss rate is simply too large to support the ablation hypothesis. Therefore, the authors of the 2004 NASA study conclude the "0.005 kg electrode would be completely ablated 10 times over in one hour of testing."** Moreover, repeated testing did not result in *any* visible electrode erosion [2]. Clearly, some other hitherto unknown mechanism must be at play.

At this point, we do not wish to speculate about the possible nature of the propulsive force; however, the following are possible explanations:

1) The force is due to ablation. **The 2004 NASA study (or any known study for that matter) did not directly measure mass loss** and instead relied on theoretical calculations. Mass loss in electrodes must be measured to conclusively rule out the ablation hypothesis.
2) The force is due to parasitic interaction with vacuum chamber walls. All studies note static charges [2–4] that are easily felt by hand yet none attempted to eliminate them or subject the parasitic electrostatic/magnetic interaction to any formal analysis.
3) The force is due to "new physics" or unexpected outcome of conventional physics. This is the most exciting possibility with far-ranging consequences, which among other things will lead to simple and lightweight propellantless

thruster designs for near-Earth maneuvering and deep space acceleration.

Because of the potential importance of unambiguous identification of the nature of the propulsive force arising from asymmetric capacitor arcing in vacuum, we propose an experiment that will a) accurately measure thrust resulting from the arc; b) accurately measure material loss due to ablation; c) account for parasitic effects due to electrostatic/electromagnetic interaction with vacuum chamber walls. To our knowledge no such experiment has been performed.

# 3. Technical Objectives

## 3.1 Objective #1: Rule Out Ablation

The experiment must be performed in a vacuum chamber under high-vacuum conditions. An ideal chamber for such experiment is a turbo-evacuated (vacuum better than $10^{-5}$ Torr) large-volume glass bell jar. Using a glass jar is essential for visual observations and reduction of parasitic magnetic interactions with chamber walls: nonconductive glass cannot carry induction currents that otherwise will arise due to the transient nature of the arc discharge. The downside of using a glass chamber is the ability of glass to accumulate static charges. This is where large chamber size will play a significant role: the larger the chamber, the weaker the electrostatic interaction due to dielectric polarization. Our company has a vacuum system in our possession that fits the above requirements.

The proposed experimental setup hosted inside the vacuum chamber is depicted in Fig. 3, which is similar to the setup used in the 2004 NASA study [2]. We propose to build a very low friction torsion balance: the central rod (which also hosts twisted high-voltage power wires) supports a horizontal arm with the ACT on one end counterbalanced by a dummy weight on the other end. When a spark jumps across the ACT electrodes, the balance will rotate and we will measure the displacement (the torsion balance will be calibrated using etalon forces prior to ACT experimentation). For maximum accuracy we will employ thin copper power wires with enough length to allow for at least one full revolution of the balance. The entire balance will rest on very low-friction bearing such that we could measure forces with sensitivity of at least $10^{-4}$ N (the 2004 NASA study observed thrust on the order of $10^{-2}$ N).

To gauge possible parasitic electrostatic interaction we will experiment with different horizontal arm lengths: shorter length will put the ACT farther away from chamber walls, hence reducing electrostatic interaction that falls of as $r^{-2}$. No change in measured torque (adjusted for the variable arm length) will rule out electrostatic interaction as a possible source of error.

To rule out electrostatic/magnetic interactions, we will build two torsion balance systems: one from Plexiglas (dielectric) and another from aluminum. Consistent torque readings for systems built from dielectric and conductive materials will rule-out any parasitic electrostatic/magnetic interaction due to the torsion balance hardware.

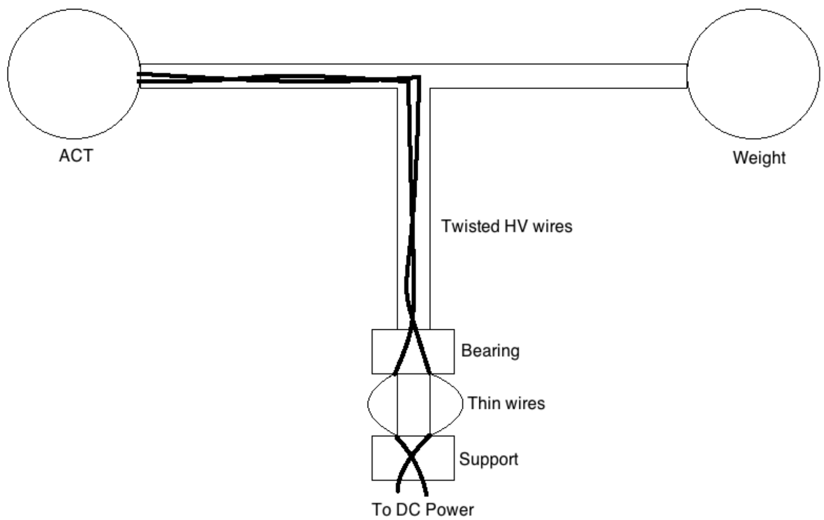


Fig. 3. The experimental setup for the proposed Experiment #1. This is a torsion balance analogous to the one used in the 2004 NASA study [2].

To estimate the force due to power wires and other current-related parasitic effects, we will rotate the ACT cylinder 90 degrees such that the spark is directed upwards and a force due to arc will be acting vertically and thus results in no torque. If we observe rotation in this configuration, we will rearrange the wiring and/or tweak the design until the rotation disappears. Once the movement is eliminated we will rotate the ACT back into the horizontal position and measure the rotational torques again.

Variations of the experiment include measuring torque as a function of voltage/current, and discharge duration. To measure the ablation, we will weigh the electrodes before and after the experiments with high-precision lab scales to precisely gauge the material loss and compare it against the observed torque measurements.

One unexpected outcome of conventional physics is potentially much hotter electrode temperature due to arc (e.g., in excess of the 2600 K reported in [2]). To exclude this possibility, we will experiment with different electrode materials ranging from aluminum to tungsten in order to account for higher-than-expected electrode temperature hypothesis: if the higher temperature is the culprit we will see larger torques when lower-melt-temperature electrode materials are used.

## 3.2 Objective #2: Identify the Force

Assuming that the proposed Experiment #1 rules out the ablation hypothesis, we will conduct a different experiment intended to discriminate against the point of application of the propulsive force. Because the arc jumping between the electrodes causes rotation, a larger force has to be acting on one of the electrodes in apparent violation of the Newton's Third Law (the Third Law is violated only for a subsystem that includes ACT electrodes; the momentum must be preserved for a larger system that includes the entire experimental apparatus, electromagnetic fields, which also harbor momentum, and the emitted radiation). The proposed experimental setup is shown in Fig. 4.

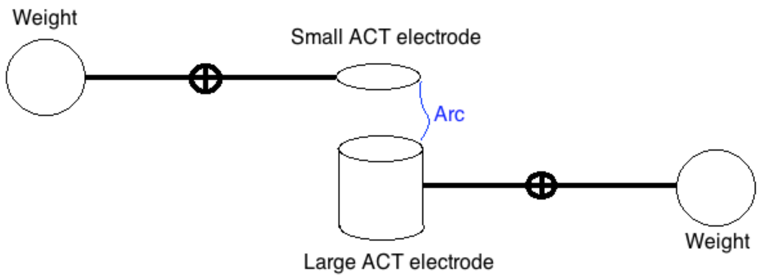


Fig. 4. The experimental setup for the proposed Experiment #2 (top view). The ACT electrodes are split between two torsion balances that are free to rotate under the influence of an arc jumping between the small and the large ACT electrodes

In this experiment, the ACT electrodes are not joined together by means of a dielectric and instead are mounted on two separate torsion balances that are free to rotate with minimal friction. As in Experiment #1, the balances will be calibrated for torque. A net-force generating arc will result in different torques measured by the two balances. We will further experiment with different voltages/currents, different distances between the electrodes, and various electrode compositions to study the propulsive force.

## 3.3 Objective #3: Determine the Role of Dielectric

An earlier SBIR study commissioned by the Air Force reported a *propulsive force caused by a spark* between ACT electrodes [3]. The study [3] also focused on ACT thrust in high vacuum ($10^{-5}$ to $10^{-7}$ Torr) and reports small (on the order of 10 nN) thrust in vacuum under pulsed DC voltage conditions. Furthermore, the study [3] reports observation of thrust when a piezoelectric dielectric material such as lead titanate or lead zirconate (high relative dielectric constants of $k$ = 1750) was used between the ACT electrodes. The thrust was apparently produced by slow pulsing spark-initiated breakdown of the dielectric. The magnitude of the propulsive force increases with the intensity of sparking across the dielectric. The study [3] recommended further exploration of sparking across dielectrics as a source of propulsive forces in ACTs. Unfortunately, no such follow-up study was conducted.

Encouraged by NASA and Air Force results, we have decided to conduct our own investigation, which commenced in summer of 2008 in collaboration with Superconductive Microelectronics Lab (SCME) at the Moscow Institute of Electronic Engineering (MIEE), Russia. We have studied cylindrical ACTs behavior under pulsed DC voltage in the range of 20–40 kV in a vacuum chamber evacuated to $10^{-5}$ Torr. We were able to confirm the existence of significant propulsive forces in ACTs that arise during a spark-gap discharge. The resulting force was strong enough to visibly displace thread-suspended ACT from equilibrium. Maximum spark current was on the order of 1 mA. We have also observed an unusual and previously unreported effect of the current loop levitation in ACT’s electrostatic field, Fig. 5. Contrary to our expectation the positively charged loop-shaped ACT electrode was not attracted to the negatively charged cylindrical electrode as one would expect from electrostatic considerations. Instead the ring levitated above the cylinder both in high vacuum and air experiments. In later experiments, the loop was cut to prevent circular currents (and associated magnetic fields); however, the levitation effect persisted.

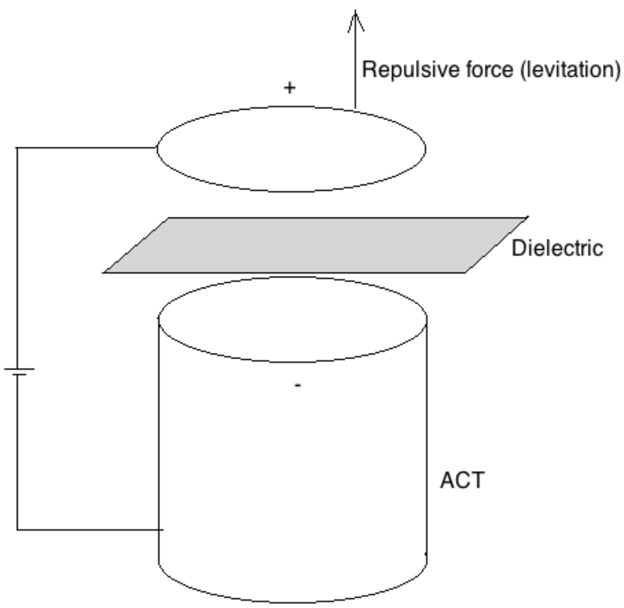


Fig. 5. Unexpected circular ACT electrode levitation in electric field. Later, the electrode was cut to prevent circular currents, yet the effect persisted.

Thus, to evaluate the role of dielectric we will repeat Experiments #1 and #2 with different high-*k* dielectrics inserted between the ACT electrodes. The objective is to measure the torque dependency on thickness and *k*-value of the dielectric layer. Because the dielectric can also be a source of charged particles, we will weigh the dielectric separately from the electrodes to maintain a cap on the ablation theory.

# 4. Work Plan

We propose a 6 months project. Once the funding is received the project will proceed as follows:

1) First, project technologist will rebuild our vacuum system since it has been sitting dormant for sometime.
2) In the same time project engineer in consultation with the project PI and co-PI will begin working on experimental setup design. Once the mechanical design is complete the part drawings will be made and their manufacturing will be subcontracted to a third party machine shop (see Section 9). The project engineer will work on high-voltage power supply (to be purchased) and build necessary electric circuits to power the experimental apparatus in a safe and satisfactory manner.
3) Once the experimental hardware is built, the project engineer and the project technologist will test the hardware on air using the electric circuits built by the project engineer.
4) By the end of the **2nd month** we plan to achieve the **first milestone** where the vacuum system is online and the experimental hardware is built and tested on air.
5) Then the project technologist in consultations with the project engineer, the project PI and co-PI will begin the Experiment #1 outlined in Section 3.1 of this document. Completion of data acquisition for the Experiment #1 will be concluded by the **3rd month** and correspond to the **second milestone**.
6) The project PI and co-PI will analyze the data and suggest changes (if any) to the Experiment #2 outlined in Section 3.2.
7) Then the project technologist in consultations with the project engineer, project PI and co-PI will begin the Experiment #2. Completion of data acquisition for the Experiment #2 will be concluded by **4th month** and correspond to the **third milestone**.
8) The project PI and co-PI will analyze the data and suggest changes (if any) to the Experiment #3 outlined in Section 3.3.
9) Then the project technologist in consultations with the project engineer, project PI and co-PI will begin the Experiment #3. Completion of data acquisition for the Experiment #3 will be concluded by **5th month** and correspond to the **fourth milestone**.
10) During the 6th month of the project PI and co-PI will analyze the data for all three experiments and draw conclusions with respect to the role of ablation and nature of the propulsive force, write a report and a paper to be published in a peer-reviewed journal as well as make recommendations regarding the feasibility of commercial development of ACT propulsion technology and Phase II of the project.

# 5. Related R&D

Related R&D by NASA, U.S. Navy and U.S. Air Force has been summarized in Section 1 of this document. Additionally, the proposed project PI has performed extensive ACT testing in vacuum while visiting Moscow Institute of Electronic Engineering. Significant thrust associated with sparks between ACT electrodes was observed and no damage to electrodes (within 0.01 g measurement accuracy) was detected. However, experimental setup limitations did not allow eliminating electrostatic interactions or permitted accurate thrust measurements.

Other technologies that are similar to ACT in the sense that they do not require propellants are solar sails and electrodynamic tethers. The downside of an electrodynamic tether is that it requires a planet with a magnetic field plasma sphere and thus is not suitable for interplanetary travel. The disadvantages of solar sails are bulky design, lack of control and the reduction of propulsive force as a square of distance to the sun. Thus, at least in principle, ACT offers clear advantages over all known propellantless thruster technologies. ACT potential post-applications are summarized in Section 10.

# 6. Key Personnel and Bibliography

## 6.1 Max Fomitchev-Zamilov, Ph.D. – PI

Dr. Fomitchev-Zamilov is the leading force behind Quantum Potential Corporation. The mission of the company is high-risk/high-payoff projects in science and technology. Physicist and computer engineer by training, Dr. Fomitchev-Zamilov's designs the equipment produced by Quantum Potential Corporation. Dr. Fomitchev-Zamilov's relevant experience includes extensive lifter in vacuum and spark discharge in vacuum studies that he conducted at Moscow Institute of Electronic Engineering.

### Education

Ph.D. in Computer Engineering, 2001, Moscow Institute of Electronic Engineering

Ph.D. Candidate in Computer Science, 1998, University of Tulsa, Tulsa, OK

M.S. in Computer Engineering, 1997, Moscow Institute of Electronic Engineering

### Employment

2006-present, Pennsylvania State University, Assistant Professor of Computer Science

2002-present, Quantum Potential Corporation, President

1997-2001, Software Development Consultant, LeapNet, Inc.

### Selected Patents and Publications

1. Fomitchev, M.I., US6167758, Ultrasound Imaging Device that Uses Optimal Lag Pulse Shaping Filters, issued 01/02/2001.
2. Fomitchev et al., Ultrasonic Pulse Shaping with Optimal Lag Filters, International Journal of Imaging Systems and Technology, 10, 5, pp. 397-403, 1999
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5. Fomitchev et al., Cost-Effective Ultrasound Imaging Apparatus that Uses Optimal-Lag Pulse Shaping Filters, 1999 IEEE International Ultrasonics Symposium Proceedings, 1, pp. 691-694, 1999
6. Grigorashvily, Y.E., Fomitchev, M.I., Ultrasound System with Pulse-Shape Control, In Proceedings of International Conference "Sensor-2000", Sudak, pp. 112, 2000
7. Fomitchev, M.I., Dark Matter and Dark Energy as Effects of Quantum Gravity, http://arxiv.org/abs/1009.1369, 2010

## 6.2 Sven Bilén, Ph.D., P.E. – Co-PI

Sven Bilén is a plasma/electromagnetics expert and careful experimentalist with a solid track record of successful NASA-related contracts and grants. Sven G is Associate Professor of Engineering Design, Electrical Engineering, and Aerospace Engineering at Penn State. In EE he is a member of the Communications and Space Sciences Laboratory and the Propulsion Engineering Research Center. He serves as the Chief Technologist for the Center for Space Research Programs at Penn State. Dr. Bilén's research interests are in the areas of electrodynamic-tether science, technology, and applications; in situ measurements of space plasmas and environments; circuit modeling of plasmas and spacecraft–plasma interactions; high-voltage applications and issues; space systems design; and plasma diagnostics for space plasmas, plasma electric thrusters, and semiconductor plasma processing. He is member of IEEE, AIAA, AGU, ASEE, and Sigma Xi.

### Education

Ph.D. in Electrical Engineering, 1998, University of Michigan, Ann Arbor, MI

M.S.E. in Electrical Engineering, 1993, University of Michigan, Ann Arbor, MI

B.S. in Electrical Engineering, 1991, Pennsylvania State University, University Park, PA

### Employment

2005–present, Assoc. Prof., Electrical Engineering and Engineering Design, Penn State

2000–2005, Asst. Prof., Electrical Engineering and Engineering Design, Penn State

1998–1999, Research Fellow, Radiation Laboratory, EECS Dept., University of Michigan

1998–1999, Research Fellow, Electronics Manufacturing Laboratory, Univ. of Michigan

1997-1998, Graduate Student Research Assistant, Radiation Laboratory, EECS Dept., Univ. of Michigan

1993-1996, NASA GSRP Fellow, Radiation Lab., EECS Dept., Univ. of Michigan

### Selected Publications

1. Bilén, S.G., J.K. McTernan, I.C. Bell, B.E. Gilchrist, N.R. Voronka, R.P. Hoyt, "Electrodynamic Tethers for Energy Harvesting and Propulsion on Space Platforms" AIAA Space 2010, 30 Aug–2 Sep, 2010.
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3. Kummer, Allen T., Sven G. Bilén, Richard T. Fissinger, and Brian A. Herrold, "The Hybird Plasma Probe: A unique combination for plasma probes for in situ space environment characterization," 19th ESA Symposium on Rocket and Balloon Programmes, Bad Reichenhall, Germany, 7–11 June 2009.

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## 6.3 Sergei Godin – Engineer

Mr. Godin is an experienced practitioner and an exceptional experimentalist. He will be responsible for high-voltage experiment design (power supplies, wiring, etc.) and high-voltage safety. Mr. Gofin is an expert in electrical engineering, digital / analog electronics, measurement devices and experimental setup design. Prior to joining Quantum Potential Mr. Godin has worked as an engineer at the Central Research Institute for Communications (Moscow), then as a research associate at IMASH (Moscow) and for the following 12 years as a research associate at the Institute for High Temperatures (IHT) of the Russian Academy of Sciences. During his tenure at IHT Mr. Godin was a key investigator in a number of research projects focused on sonoluminescence, cavitation, plasma discharges, and nuclear fusion.

Mr. Godin has a valuable experience of research commercialization and has a knack for discovering multiple practical applications of scientific ideas. He leads a diverse group of cross-disciplinary researchers. Besides his duties at Quantum Potential Mr. Godin servers as a consultant on a oil cracking research project for a large Russian oil and gas company.

Mr. Godin has co-authored a book on fundamental physics, numerous research papers and holds several patents.

### Education

1988-1989, Moscow State University, MechMat, Ph.D. Candidate

1982-1983, Moscow Institute of Radio-engineering and Automation, Certificate of Accomplishment in Signal Processing

1976-1981, Moscow Institute of Communications and Informatics, M.S., Electrical Engineering

### Positions

1996-2008, Institute for High Temperatures of Russian Acad. of Sci., Research Associate

2010-present, Quantum Potential Corporation, Research Associate

### Selected Publications

1. Karimov, A.R., Godin, S.M., Coupled radial–azimuthal oscillations in twirling cylindrical plasmas, Physica Scripta, 80, 3, 2009
2. Godin, S.M., Botvinsly, V. V., Measurements of displacement current with fammeter, Radiotechnology & Electronics, 54, 9, 2009, 1049-1152
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## 6.4 Vladimir Getman, Ph.D. – Technologist

Vladimir Getman is a vacuum system expert and experimentalist with a solid track record of successful NASA-related contracts and grants; he will be responsible for vacuum system and experimental hardware preparation, measurements, and experimentation in general.

Dr. Getman has designed unique astronomical instruments and was invited to the International AIDA campaign by the Cornell and Penn State Universities (Puerto-Rico, 1989). At Penn State University Dr. Getman has designed the Multipurpose Oil-Free High Vacuum Facility on the basis of one of the biggest vacuum tanks in the USA (17,700 liters volume) for the laboratory simulation of space environment, calibration of radiation detectors, physical and chemical experiments and the 1,000 liter volume Thermal High Vacuum Chamber, equipped with the Residual Gas Analyzer (RGA 200) and the Cryogenic Quartz Microbalances (CQCM), which was used for the NASA SWIFT Midsize Explorer (MIDEX) mission and for the CREAM (Cosmic-Ray Energetics and Mass) Balloon Experiment. Also designed the Plasma Diagnostic Experimental System and served as the main operator of the AMS-100 "I-Speeder" Advanced Deep Plasma Etching Tools (Adixen/Alcatel) with High Density Decoupled ICP DRIE (Deep Reaction Ion Etching) source for high aspect ratio; high etch rate etching of Silicone.

Dr. Getman is a consultant of International Astronomical Union (IAU), Member of International Meteor Organization (IMO), Treasurer of American Meteor Society.

### Education

Ph.D. in Astrophysics, 1976, Tajik State University, Dushanbe, Tajikistan

M.S. in Physics, 1962, Tajik State University, Dushanbe, Tajikistan

### Positions

1998-2011, Research Associate of Penn State University

1998-2011, Research Consultant for Septor, Inc.

## 6.6 References

[1] T. T. Brown, "Electrokinetic Apparatus," U.S. Patent 2,949,550, 1957.

[2] Francis X. Canning, Cory Melcher, and Edwin Winet, "Asymmetrical Capacitors for Propulsion," NASA/CR—2004-213312, 2004.

[3] R. L. Talley, "Twenty First Century Propulsion Concept," Phillips Laboratory Report PL-TR-91-3009, Edwards AFB, 1991.

[4] Thomas B. Bahder and Chris Fazi, "Force on an Asymmetric Capacitor," Army Research Laboratory Report, 2003.

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# 7. Relationship with Phase II

Successful completion of Phase I of the project will prove beyond any doubt that ACT can function in vacuum without requiring any propellant (e.g. without being consumed by ablation). If that is the case the following activities must commence in the second phase of the project:

1) An in-depth inquiry must be lunched into the underlying physical nature of the propulsive force (perhaps as a collaborative project involving other academic institutions such as Penn State);
2) An ACT space-worthy prototype must be designed and tested in a large NASA vacuum chamber.
3) Engineering effort must be undertaken to maximize thrust with respect to power usage.

Thus, the outcome of Phase II will be a space-worthy thruster that can be tested during a space mission as well as our understanding of how to design and optimize thrusters for specific space applications.

# 8. Facilities and Equipment

Quantum Potential Corporation (www.quantum-potential.com), maintains a fully equipped laboratory at Penn Eagle Industrial Park. We possess a full range of analytical equipment, including a high-vacuum (better than $10^{-6}$ Torr) turbomolecular bell jar vacuum system that meets the requirements set forth in the experimental section of this proposal. We also have a range of high-voltage power supplies (20–40 kV) necessary for the project.

# 9. Subcontracts and Consultants

Machining work will be subcontracted to Butler Machine Shop, Bellefonte, PA. We frequently use this company for machining services as they provide competitive rates and high quality of work.

# 10. Potential Post Applications

Upon completion of the Phase I of the project two outcomes are possible:

1) Contrary to NASA's and Air Force's prior work, we may prove the ablation hypothesis and thus close the book on Biefeld–Brown effect.

**2)** Alternatively, we may prove that the force is *not due to ablation*. **In this event and regardless of the nature of the propulsive force, an engineering effort (Phase II) towards the development of lightweight compact thrusters based on ACT-design will be feasible.**

We must emphasize that ruling out of the ablation theory will necessitate an in-depth inquiry into the nature of the propulsive force that may lead to the discovery of new physics with far-reaching consequences. Potential candidates for "new physics" include non-locality, a new type of radiation, vacuum interaction, or zero-point energy. In other words, **confirmation of the effect will open vast engineering and scientific possibilities with far reaching consequences that are impossible to quantify at the moment of writing due to breakthrough nature of the results.** This is a very exciting feature of this project that characterizes it as **high-payoff research**.

At the very minimum confirmation of ablation-less propulsion action of ACTs will provide NASA with a new generation of inexpensive propellantless propulsion devices that will significantly aid NASA in achieving its long-term goals for deep space and near-earth exploration. The direct benefits are as follows:

1. **No Propellant Needed = Enhanced Mission Longevity.** Currently, space travel almost exclusively relies on chemical propellants for propulsion. Besides added mass (up to 99% of launch mass), the propellant inevitably runs out, thus limiting maneuverability and mission longevity. For that matter, any form of propellantless propulsion offers significant advantages (such as increasing mission longevity and reduced payload mass), and ACT falls into this category.
2. **Simple + Lightweight Design = Low Cost.** Unlike conventional thruster technologies, the ACT has an advantage of being extremely lightweight and of simple design. The ACT requires only conventional electric hardware such as voltage multipliers, etc. and can use ordinary solar photovoltaic cells, chemical batteries, or conventional nuclear reactors for power.
3. **Faster, Cheaper Interplanetary Travel.** While the ACT cannot compete with chemical propellants for low Earth orbit boosting due to much lower thrust when compared to conventional rocket engines, the ACT may become an attractive alternative for spacecraft orbital maneuvering, attitude control, and interplanetary travel. While the ACT produces only a small thrust, the thruster can operate for a long time and thus allow achieving substantial acceleration (greater than that of chemical boosters) in a short period of time (e.g., weeks). Thus, for planetary exploration, it may be feasible to use chemical thrusters to boost a spacecraft into low earth orbit and then let ACTs accelerate the spacecraft into an interplanetary trajectory in a matter of days. Substantial

orbital correction for interplanetary travel is also possible with the help of ACTs as well as approach braking (given that enough time is allowed for the spacecraft to decelerate).

4. **Cheaper Near-Earth Maneuvering.** Commercial satellites (even ISS) often suffer from orbit decay and eventually fall to Earth and burn up in the Earth's atmosphere. Installation of solar panel powered ACTs on such satellites will provide a low cost solution for attitude control with an added benefit of orbital maneuvering. Rotating ACTs can be used to boost or decrease the satellite orbit as well as influence other orbital parameters without requiring shuttle mission to perform such maintenance.
5. **Clearing Near-Earth Space Junk.** Space junk represents a significant problem for new lunches. Extreme low cost of ACTs make it feasible to develop and autonomous space station outfitted with compact (~1 $ft^3$) solar-powered ACT-fitted space-bots that will navigate earth orbit, attach to space junk and gradually reduce its orbit until atmospheric burnout.