SAMPLE

# FULTON RESEARCH INITIATIVE (FURI)

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FURI Project for Spring 2012

# Control-Relevant Design of Scramjet-Powered Hypersonic Vehicles

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## PROPOSAL

*GOAL.* The goal of the proposed research is to gain insight into the design of sramjet-powered air-breathing hypersonic vehicles (ABHVs) using control-relevant models. Here, "hypersonic" refers to flight speeds in the range Mach 5-15; i.e. 5-15 times the speed-of-sound.

*MOTIVATION.* Such ABHVs are expected to play a key role in achieving NASA's airplane-based two-stage-to-orbit (TSTO) vision. As such, they represent the next critical stage toward attaining rapid, affordable, reliable space access and global reach capabilities.

The ABHVs under consideration are characterized by an aerodynamic-wedge-shape (side view), low aspect ratio geometry (top view), lower-forebody compression-ramps, a rearward-shifted scramjet engine, and a large external nozzle.

The scramjet (supersonic combustion) engine is the centerpiece of the ABHV. In contrast to conventional jet engines, the scramjet has no moving parts. High compression ratios are achieved by virtue of the significant pressure rise across the oblique bow shock wave – a consequence of supersonic operation.

In contrast to rocket-based vehicles which must carry their own oxygen supply (e.g. space shuttle external tank provided liquid oxygen), ABHVs exploit atmospheric oxygen thus opening the possibility for a larger payload.

The airplane-like operation of the targeted ABHVs also offer a significantly enlarged landing footprint as well as increased reliability over rocket-based alternatives.

*HISTORIC FLIGHTS.* The historic 2004 Mach 7, 10 flights of the NASA X-43A demonstrated scramjet propulsion – monumental milestones only 100+ years after the Wright brothers' 1903 flight. In 2010, Boeing demonstrated its scramjet-powered-hydrocarbon-fueled X-51 waverider at Mach 6. Two recent DARPA FALCON flights examined Mach 20+ glider operation during re-entry.

*CONTROL-RELAVANT ISSUES.* The ABHVs under consideration are characterized by (1) unstable nonlinear dynamics associated with a forward center-of-pressure and rearward center-of-gravity, (2) undesirable inverse-altitude-response attributed to a transient loss-of-altitude for an upward elevator deflection, (3) limited elevator control authority, (4) low thrust/acceleration margins, (5) a hostile thermal environment - requiring a carefully designed thermal protection system (TPS) and that fundamentally governs the vehicle design, and (6) significant aero-thermo-elastic-propulsive dynamic coupling and uncertainty. These characteristics present a great challenge to control engineers – engineers charged with designing a flight control system to maximally exploit sensor readings (e.g. gyroscopes, GPS, FADS, etc.), control-relevant models, and control algorithms in order to coordinate (in real-time) vehicle controls (elevators, ailerons, rudders, fuel flow) to ensure acceptable and predictable performance without the assistance of a pilot.

*A DANGEROUS DESIGN PHILOSOPHY.* Traditionally, aerospace vehicles have been designed with little/no consultation of control engineers. This philosophy has resulted in fundamental problems for high performance aircraft (e.g. X-29). This lack of consulting control engineers has also been seen in other arenas – the most flagrant example being the 1986 Chernobyl disaster – a disaster that could've been avoided had proper attention had been paid to control system fundamentals (Stein, Respect the Unstable, 1989); i.e. operating an unstable system in the presence of limited control authority (like the ABHVs under consideration) can be disastrous. This provides substantive and overwhelming motivation for the **control-relevant vehicle design approach** to be taken for the proposed project.

*CRITICAL TRADEOFFS AND LIMITATIONS.* The proposed work will specifically seek to reveal critical tradeoffs and fundamental performance limitations associated with vehicle geometry as well as propulsion system characteristics as they relate to critical metrics; i.e. instability, lift-to-drag-ratio/range, fuel use, structural flexibility, elevator/wing placement/sizing.

*ADVISOR BACKGROUND.* Dr. Rodriguez has been sponsored by NASA Ames to work on the above topic during the past 6 years. This work has resulted in 3 MS students and 2 PhD students. A former MS student is currently working at NASA Ames. I hope that the proposed project will put me in a good position to apply for a NASA graduate fellowship. One of Dr. Rodriguez' PhD students was supported by a NASA PhD fellowship.

**TIMELINE FOR PROPOSED HYPERSONIC VEHCILE PROJECT**

The following timeline will be followed to guide the proposed Spring 2012 FURI project on control-relevant hypersonic vehicle design:

Week 1 – 3 Comprehensive literature survey; i.e. journal and conference papers, books, theses, etc.

Week 2 – 10 Examination of nonlinear model – to be provided by my faculty advisor: Dr. Armando A. Rodriguez (Professor of Electrical Engineering)

Week 8 – 15 Generate relevant vehicle geometry and propulsion flow path trade studies to understand the impact on the vehicle's static and dynamic characteristics

Week 12 – 13 Prepare poster for presentation at FURI symposium (April 20, 2012)

Week 11 – 15 Document all results in a final comprehensive report

**PERSONAL STATEMENT**

*MOTIVATION.* My main motivation for pursuing the proposed hypersonic vehicle design project is to establish a foundation for a senior design project, an MS thesis, and a PhD thesis in the area of hypersonic vehicle design. My ultimate goal is to become a professor of Aerospace engineering at a Research I university. This would allow me to teach, conduct world-class research, mentor students, supervise their work, and contribute significantly to the technological development of the nation. These goals have been fueled by my collective experiences.

*CAREER PLANNING ANS SEMINARS.* I've had many career planning discussions with my advisor/mentor: Dr. Armando A. Rodriguez (Professor, Electrical Engineering). He has been supported by NASA to work in my area of interest during the past 6 years (see Proposal). These discussions and specific seminars have deeply influenced my career choice.

COURSEWORK. My math, physics, and engineering courses have steadily steered/guided my career path. More specifically, my courses in thermodynamics, heat and mass transfer, structural mechanics, aerodynamics, and sensors and controls have provided a very good foundation for my proposed work and career objectives. Through innovation, engineers continue to revolutionize the way we live. My coursework has given me a foundation to participate in this ongoing technological revolution; one day as a professor.

*TUTORING AND GRADING.* I've tutored mathematics since 2010. This has given me a wonderful glimpse into the world of teaching. It has (1) taught me the value of explaining technical material to others, (2) forced me to deeply think about what I have learned and how to best communicate it, and it has also (3) taught me the value of exploring and comparing alternative problem approaches. I've also served as a grader in Calculus I-II. This has further sharpened my problem solving skills as well as given me greater insight into student thinking. The latter should help me become a better tutor/teacher. I can see how fun it would be to introduce cutting-edge research ideas into the classroom – something I'd be able to do as a professor.

*RESEARCH EXPERIENCE.* Since the Summer of 2011, I've had the opportunity to work with Dr. Patrick Phelan (Professor, Mechanical Engineering) and his solar-nanofluids group on the development of a thermodynamic model that captures the use of solar cells to achieve supercritical conditions in order to efficiently convert methanol to a biofuel. This has given me a great foundation to understand/address many of the critical thermodynamic problems that govern the design of hypersonic vehicles (Anderson, Hypersonic and High-Temperature Gas Dynamics, 2006); see Proposal.

*WORK EXPERIENCE.* An internship at General Dynamics (February-August 2010) exposed me to issues associated with military satellite communications. Seeing PhDs working on the most cutting-edge issues/problems clearly reinforced the value of a engineering doctorate.

*SUMMARY.* In summary, I'm very eager to pursue the proposed project. It will (1) strengthen my analytical capabilities, (2) prepare me for advanced graduate work and my chosen career path, (3) give me the opportunity to publish and present my research, and (4) assist me financially.