Application of Cryogenic H2 storage for:

low-altitude electric powered VTOL-PAV

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ABSTRACT:

Fundamental properties of cryogenic materials and system's performance developed for unique deep space exploration have direct application to 21st century electric powered aircraft. Key to both are: reliability, ultra-light-weight, low power consumption, and solar energy input. For "inner-space" we can add the generation, storage and use of refrigerated H2 as an essential energy carrier. H2's low gravimetric density makes it a perfect energy source for potentially massive numbers of ultra-light electric powered personal vehicles (PAVs). As has been the case for all H2 applications, gas storage has been the central challenge. Given a new mission, a new/radical aircraft architecture, potential high production volumes and recent breakthroughs in material science, hydrogen and cryogenics will be found in wide spread consumer use this century. We here define the broad and unique architecture of a total aircraft system likely to evolve due to a world-wide energy and transportation crisis forecast for this century. Initial experimental focus by aviation pioneers has been on solar photo-voltaic energy conversion mounted on the wings of ultra-light experimental craft and high temperature super-conducting materials for possible commercial "jet" aircraft electric motor/generators. Rather, we here define the system parameters of a VTOL flight regime that can be practical and popular within 20 years. Major research needs are defined in terms of materials, construction methods, and the unprecedented level of system integration that will be needed. Specific attention is given to the Cryo technique for a closed nitrogen refrigeration circuit that safely stores 2 to 10 gigajoules of H2.

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KEYWORDS:
hydrogen, VTOL, fuel-cell, Cryo-refrigeration, electric-powered-flight.

(this reprint is of a paper submitted at the NASA Space Cryogenic Engineering workshop, Coeur d'Alene Idaho, June 2011,) Also available is: "hydrogen fuel storage on electric powered VTOL Personal Aircraft Vehicle (PAV)" presented as a poster talk at the Cryogenic Engineering Conference (CEC), June 13-17 2011, in Spokane Washington.) budskriba@hydrogen-vtol.com)

1.1 INTRODUCTION

1.1.1 Under ideal conditions, major scientific breakthroughs lead to publications that permit engineers to identify practical applications with identifiable markets. We are no longer living under ideal conditions for major innovations for space cryogenics. Public/political priorities, that certainly should be supportive, are now obviously internationalized and widely diverse, if not out-rightly antagonistic. R&D objectives, beyond our long standing: (man-in-space) space station, and (deep-space science) planetary exploration, are not yet well established or securely funded. It is time for a new approach, perhaps to bring advanced "space" Cryo engineering technologies back down closer to earth.

1.2 RESEARCH OBJECTIVES

1.2.1 We here define an entirely new research objective for "inner space" (within the atmosphere and below commercial air traffic) so demanding that only the most advanced Space-Cryogenic refrigeration and gas storage technologies are candidates for a potential successful outcome. With the help of NASA researchers, DOE scientists, major corporate engineers, and university educators, we have been able to define a new aircraft paradigm that is based on hydrogen as the essential energy carrier. Politically, our craft is to do what the DOE's "freedom car" has failed to do: To liberate the world's needs for "transportation" from its history of near absolute dependence on the productivity, and total system efficiencies, of petroleum based fuels. Scientifically, we have identified a new field of application oriented research, namely: "ULTRA-LIGHT CRYOGENICS"

1.2.2 It is practical to assume that for the intermediate future of inter-city and inter-continental passenger travel, as well as FedEx type air-freight traffic, the best approach will continue to be: large, high-speed, petroleum-fueled, jet-powered commercial aircraft built using well established "wing-tube" Airbus and Boeing type designs. However, given the increasing scarcity of reliable petroleum at cheap prices, the world's relentless population growth in previously non-technical nations, and the economic/financial uncertainties of the international credit markets, the long range future of this approach to "flight" is no longer attractive.

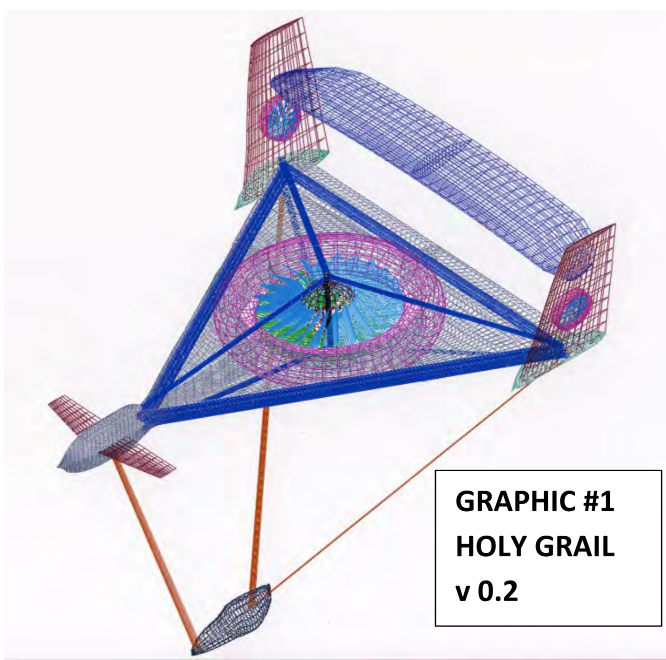
1.2.3 Certainly, out of the history of Cryo-engineered superconductivity, radically light designs of electric generators and motors might permit the development of electric powered jet engines powerful enough for these heavy commercial craft, sometime this century. However, if hydrogen were to be the fuel in such aircraft, the problem of its unbelievable low density creates insurmountable problems for storage of great, transcontinental, volumetric amounts of fuel. Hence, Gigmedia Consulting postulates that, if hydrogen is to fly in anything other than uniquely massive deep-space launch vehicles, the craft has to be pre-emptively designed using unique structures centered first on viable hydrogen storage over any other criteria. It is this hydrogen fuel storage centricity that has led us to propose the following new craft and its even newer mission.

2.1 VEHICLE MISSION STATEMENT:
TO LIFT OFF VERTICALLY ON ELECTRICITY GENERATED FROM HYDROGEN

2.1.1 "Flight" may finally have an opportunity to be redefined as a serious option for small, slow, low-altitude craft powered by electric motors. In that window of growing opportunity, the most exciting option would be a craft that is simultaneously: ultra-light, super quiet, and capable of vertical take-off. The best example of that has been the recent work of Dr. Mark D. Moore (2), NASA (Langley) and his approach to Personal Aircraft Vehicles (PAVs) powered by ultra-light electric motors for single passenger flight. His approach's success, however, depends on powerful, small, light, and inexpensive batteries. There is hope for his success, since such batteries are needed if we are to have electric powered automobiles.

2.1.2 However, the major result of DOE's massive research, on the storage subsystems for fuel-cells running on hydrogen, is their documentation that the core problem is the combination of size, weight, cost, reliability and safety of the storage tank options thus far proposed. Worse was their identifying the massive costs needed to make and distribute industrially supplied hydrogen safely to "GAS-stations." The same would also apply to conventionally designed wing and tube aircraft fueled by hydrogen, (this was also concluded by Lockheed Martin's brilliant designer Kelly Johnson; aka "skunk works," trying to build CIA's cold war supersonic spy planes).

2.1.3 A graphical and conceptual representation of Gigmedia Consulting's proposed VTOL craft is presented here to help as a visual reference for the remaining discussions. Comprehensive description of the vehicle's features and technical performance is beyond the scope of this article. Currently, this work-in-progress draft image is identified as "Holy Grail v0.2".



GRAPHIC #1
HOLY GRAIL
v 0.2

3.1 HYDROGEN STORAGE METHODS

3.1.1 Our preliminary feasibility study (limitedly available upon request) has determined that hydrogen-fueled, electric-powered VTOLs do NOT have to be small, but ALL components must be ultra-light including Cryo-refrigerators, heat-exchangers, insulation materials, etc. Unobvious is the idea that the hydrogen does NOT have to be supplied and stored as a 20K liquid, and that the gas can rather be stored at liquid nitrogen temperatures, under modest pressures, by using absorber materials similar to activated carbon. This work was proposed and patented by Dr. J. A. Schwartz (3) at Syracuse University in 1988 during our first "petroleum" energy crisis due to international politics rather than climate changes.

3.1.2 However, it is further unobvious to those skilled in the Cryo-arts, even using Dr. Schwartz's "metal assisted" principles, that, for our unique VTOL craft, the costs of supplying hydrogen have to ALSO be integrally solved. The most efficient and economical approach is to use the very specialized aerodynamic structures that are used to provide highly efficient VTOL lift to ALSO be the very means to intercept "free" (wind) energy to power hydrogen generating electrolyzers, compressors and Cryo-coolers.

3.1.3 This innovative approach in turn demands a studious effort at integrating various functions into single devices and various separate devices into a single ultra-light structure. This "outside the box" approach requires a "start from scratch" blank-page for the design of the aircraft's mechanical structures (and common materials) which can be both: generators and motors; electrolyzers and fuel cells; airframe structures and storage tanks; chemical process controls and aerodynamic flight controls. It is only by this absolutely essential effort at extremely integrated design that this craft can be built as a VTOL vehicle light enough to be powered electrically. The overall challenge of this earth bound craft is certainly equal to the design of a lunar habitat for astronauts. Indeed, NASA's previous Cryo fuel research for THAT mission can contribute handsomely to that which is necessary for an ultra-light (400 kilogram) aircraft to fly at 1,000 meter altitudes and 100 Kmph speeds, piloted by brilliant autonomous computer control.

3.2 UNCONVENTIONAL ENERGY STORAGE THEORY AND DESIGN PHILOSOPHY

3.2.1 Specifically, previously proposed moon based energy systems, using fuel cells for heat and electricity, created the demand for reversible catalytic chemical pathways that permit solar energy input to electrolyze locally discovered water, and subsequently permit consumption of generated/stored hydrogen and oxygen to again provide on-demand electrical power (in the absence of strong sunlight) and conserve the resulting water and oxygen for human biological needs. Properly selected catalysts (apparently originally proposed as variations of noble metal amalgams) were researched by NASA for an electrolyzer/fuel-cell unit that could be compatible with the ultra-low weight structural requirements needed to be supplied from the earth by rocket. Given the logic that not many moon based units would be required, that the highest "efficiencies" of every electro-chemical step is an absolute necessity, and that the costs of development could be expensed without limitations, such previous work might need to be re-evaluated. Our proposed craft, on the other hand, someday will be made in the millions of units/year, necessarily at materials and labor costs competitive to automobile manufacture, and used by untalented owners who would be expected to supply regular maintenance as we now do with tires, oil filters, and windshield wipers.

4.1 APPROACH TO SYSTEM RELIABILITY: CHEAP TO REPLACE FREQUENTLY

4.1.1 Specifically, the needed electro-chemical catalysts (and their supporting PEMs/conductors) cannot be based exclusively on precious metals for reasons of their safety and long range higher efficiencies. In our case, efficiency (in most system performances) is not the overwhelming important driving criteria. The key feature must be, in ALL cases, the lowest conceivable cost. As an example, we are considering variations of catalysts that could be made via electroplated/chemical-vapor-depositions of nickel/chrome type amalgams. Even more cost effective could be the fabrication of the PEM electrolyte membranes in situ rather than as a Nafion membrane separately purchased from conventional suppliers. All this should be attractive from the point of view of manufacturing costs, even if obviously, or slightly, less efficient electrochemically.

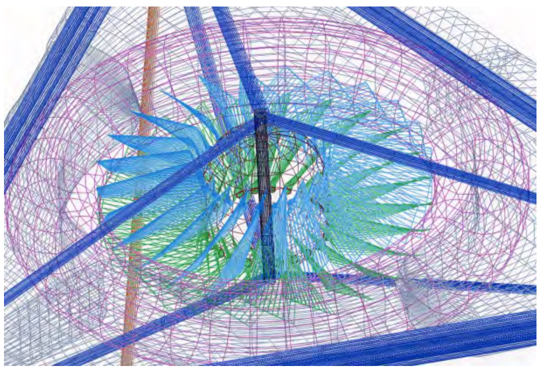
4.1.2 Totally unacceptable for a moon base, but essential to our design of an "inner"-spacecraft is our approach that makes the fuel-cell structure an easily removable/serviceable component. Those skilled in the electrochemical arts, working on fuel cells for vehicles, understand fully the difficult MTBF limitations due to catalyst migrations, poisonings, membrane short circuits, etc. 10,000-hr MTBF may have been the Holy Grail for the "Freedom Car". In our case, given the proper design of this essential sub-system as an inexpensive replaceable element, we have the freedom to use materials and techniques previously researched and rejected from deep space travel consideration. It is time to do some NASA and DOE/NREL data-mining.

4.1.3 The same approach to "integration" must be directed at the needed electric motors/generators. Electric powered human flight has very recently become a reality as an outgrowth of brushless DC electric motors designed to be light enough for model aircraft hobbies. With Lithium battery designs resulting from the growth of consumer markets for cell phones and laptop computers, a few minutes of General Aviation flight time are now possible by intermittently powering an aircraft designed much like a sailplane. Our feasibility study suggests that batteries will NEVER be the final and exclusive solution for electric flight.

4.1.4 The reliability of existing brushless DC motors capable of continuous 1 to 5 horsepower per pound, is certainly not up to NASA deep space performance criteria, but their failure modes are most likely related to thermal management design issues. Hence, a motor-generator that is appropriate for manned VTOL power levels cannot be a separate, point-load device, remotely manufactured by a supplier and installed. Rather, for what are essentially thermal management reasons, the magnets, wires, and their locations, must be designed by appropriate aerospace engineers who are more concerned about maximizing total trust and minimizing aerodynamic drag, at almost zero weight. As Burt Rutan was once heard to say, regarding the design of winning ultra-light craft, "if you throw it (construction material candidate) up into the air, and it comes back down, it's too heavy!"

5.1 DISCUSSION OF THE DESIGN APPROACH AND DISCOVERIES

5.1.1 To move energy to/from the fuel-cells/electrolyzers (multiple, for reasons of failure avoidance) and motors/generators, long lengths of large diameter copper cables are not an option. Nor are multiple AC/DC to DC/AC power conditioning devices to deal with variable device load demands and efficient distribution. New structural materials for such components, chosen for their ultra-light-weight per gigajoule must be an integral part of a unique airframe design. An aircraft is a wind machine, and hence all "process" cooling issues must be made in the context of where the air is and how fast it is passing a hot component. For our design, we believe that the only possible solution has been to propose a ducted fan turbine that has an integrated generator/electrolyzer-AKA-fuel-cell/motor built into the fan's aerodynamic blade structures. Such a device has never before been needed. It is essential for successful hydrogen fueled VTOLs.



GRAPHIC # 2
INTEGRATED
DUCTED LIFT FAN

5.1.2 An ultra-light electrochemical process to do what fuel cells did for space-applications and potential terrestrial transportation would be impossible for VTOL flight if all the classical support plumbing and gas/water flow controls of existing technology are employed for reasons of their added weight. Rather, a totally integrated design must avoid the building of high pressure, multi-layered fuel cell stacks that generate high voltages. Worse would be to again recondition high voltages in yet other motor speed control supporting devices. In our case, control of motor speed must be done via digital electronic control of gas flows (ultimately from storage), using miniature computer sub-processors communicating to a network of similar processors. All this must be done to replace pounds of weight with "bits" of RF signals. That is, this craft must exploit the massive processing power per nanogram of devices the size of cellphones to automatically/programmatically deal with hydrogen and its generation, storage and use.

5.1.3 As for our novel approach to hydrogen storage, past DOE research has focused on the "weight percent" performance criteria of storage tanks. This originally flowed from the use of metal hydrides that simply weighted too much to store a few kilos/gigajoules of hydrogen for a passenger car. Most DOE solutions tried to develop ultra-light "nanocarbon" materials that could temporarily absorb hydrogen. But their total volumes were considered too big to be the petroleum gas-tank replacement. Other research focused on using graphite fiber composite pressure tanks, with metal (aluminum) liners, to hold the gas at 10,000 PSI. Even though the volumes of such tanks were almost acceptable, the weight, cost and shape of such tanking were not attractive to automobile designers. Hence the "weight-percent" issue asked: "what percent of the 'tank's' total weight is to be that of usable hydrogen?" The typical answer from this DOE history of excellent research has always been: "not enough." The right answer will cost more in future R&D.

5.2 MULTIFUNCTIONAL TANKING, THE SOLUTION TO "HYDROGEN WEIGHT PERCENT"

5.2.1 We have solved that "weight percent" problem simply by a design approach that could never be used in terrestrial vehicles but is common in aircraft design. The wing of a 747 is NOT just a lifting-force appendage, but it is also the housing for weighty fuel that is close to the consuming jet engines as well as close to critical aerodynamic lifting structures (flaps) for fully loaded take-off conditions. "Wings" must also be strong enough to carry and survive landing gear operation. Such total system design integration issues, controlled by the aerodynamicists, have long been part of NASA spacecraft development history.

5.2.2 Our approach to a VTOL craft's design assumes that the major structural components needed to withstand air pressures created by 100 Kmph flight must also be designed to contain from 1 to 10 gigajoules of hydrogen on a very large surface area of a cooled-absorber material. Even more demanding, the flow control of hydrogen to/from storage, in our unique case, is asymmetric… The hydrogen is slowly generated and cooled to liquid nitrogen temperatures, but, upon use, to power a VTOL launch, flow rates to the fuel cells have to be rather high for short periods of time. The "Freedom Car" had the opposite problem. Their tanks had to be filled in minutes at a "gas-filling-station" and the gas had to be stored and/or used for MANY days between refills. This is the challenge we believe can be easily resolved. How the hydrogen is to be cooled to practical physi-sorption temperatures, is dramatically different than the methods used to feed the gas into fuel-cell driven electric motors. Little of this seems to be obvious.

6.1 CONCLUSIONS FOR CRYO-HYDROGEN ENGINEERING DESIGN OBJECTIVES

6.1.1 For those skilled in the art of Cryo refrigeration at liquid nitrogen temperatures, the challenges to cool up to 10 gigajoules of H2 are serious if total system weight must be near zero. We address this aspect as an issue for the aircraft's structural and total system design rather than as sub-component electrical efficiency optimization. Since we generate hydrogen via the collection of "FREE ENERGY", environmental energy (wind/solar), store it ONLY on this very same craft, and use it primarily for occasional, and brief vertical flight, we therefore potentially have an excess of hydrogen at our disposal.

6.1.2 First, we use hydrogen also to fill lifting bladders to reduce the craft's weight that a lift-fan thruster must deal with. The upper airfoil of this two-body craft has ever-so-slight positive buoyancy due to available and inevitable H2 boil-off from its cold storage condition. Also, it can be assumed that hydrogen can be used as an in-craft, super-light-weight energy "carrier" (vs. heavy copper conductive wires) to supply the energy for the pumping forces that could drive pulse tube refrigeration techniques. We have to deal only with a closed system to re-liquefy nitrogen at a rather slow cool down rate once the entire system is brought up to pressure and down to operating temperatures before launch. Exactly how this is best done is certainly an opportunity for future research. Today, we believe we already have viable approaches.

6.1.3 With all of the above as background, we have identified many opportunities for research, innovation and invention. The required application background (re this VTOL craft's needs for H2 storage) is:

1) Upper body delta-shaped airfoil Blended-Wing-Body span ranges: from 10 to 20 meters.
2) Upper body airfoil total dry weight: maximum 200 kilos (which includes storage tank structures)
3) Upper body located ducted turbine-generator power range: from 50 to 100 kilowatts
(weight of the integrated motor/generator unit: 20 kilos…included in total upper body weight)
4) Turbine fan blades (with integrated PEM membranes) weight: 30 kilos (included in upper total)
5) Long term hydrogen storage capacity: 5 to 10 gigajoules. (Initially 1-3 gigajoules acceptable)
6) Cost: initial demo= $10-50 million, First production unit= $1 million, future= under $100K.

6.1.4 Other specifications regarding the craft's design are to be published by Gigmedia Consulting in the 2011 Spokane conference proceedings of the CEC.

6.1.5 Examples of needed research opportunities are:
1) composite aircraft structural methods/materials for Cryo-cooled pressure tanks used for H2 storage
2) ultra-light weight methods to power an electric VTOL aircraft
3) methods to generate hydrogen using inexpensive catalysts
4) micro-miniature computerized methods to wirelessly control all aircraft electrochemical subsystems
5) methods to rapidly extract hydrogen from cold storage (in the liquid nitrogen range…70K-100K)
6) extremely-light PEM electrolyzer/fuel-cell structures
7) techniques to control and eliminate hydrogen gas leakage
8) ultra-light "motors" for pulse-tube Cryo-re-refrigeration of nitrogen
(more opportunities available upon request)

REFERENCES

(1) www.Gigmedia.com

(2) Mark Moore PAV http://www.nasa.gov/topics/technology/features/puffin.html

(3) J.A. Schwartz US Patent # 4716736, 1988

VITAE

Lou Skriba is an entrepreneur with major career contributions to the Optical Recording Media Industry. He holds: a BA in Engineering Science, BS degree in Mechanical/Industrial Engineering, and an MBA in Marketing. Starting in Central Research Labs of 3M, he provided product development, acquisitions and joint ventures which eventually led to BD-RE HD media. Research into the generation, storage and use of hydrogen has been a 40+ year effort as a privately funded "citizen scientist." His current interest is to build a model of the Hydrogen-VTOL aircraft using the construction philosophy of EAA "experimental" aircraft.