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Prospective Futures of Civilian Air Transportation

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Civilian air transportation is changing rapidly, is undergoing a renaissance with truly major societal and wide-ranging commercial and industrial level implications. This renaissance is enabled by a plethora of advanced to revolutionary technologies including renewable / "green"/ increasingly inexpensive energy, electric propulsion, nanomaterials and materials processing, printing manufacture, artificial intelligence (AI)/autonomy, an emerging global sensor grid, safety/reliability attainment, miniaturization and resilient navigation and communications. The major component of this renaissance is an ongoing shift to essentially emissionless fly/drive aircraft including personal aircraft, the latter flown from the local street, eventually replacing much of ground transportation and scheduled commercial air traffic. Due to the projected tremendous increase in the number of flying vehicles, autonomous vehicle operation and air traffic control will be essential. The buildout of the personal aircraft markets is projected to be the order of $1T/ year. The benefits of such personal air transportation include major reduced costs for roads and bridges and current auto infrastructures, much shortened travel time, the electric propulsion recharged by renewables resulting in major favorable climate, ecosystem and pollution impacts, and autonomous operation proffers the possibility of saving lives. The applications for small/personal class aircraft include an extensive number of service, business, and governmental uses and far longer, easier, faster commute possibilities. Given projected vehicle improvements and a suitable air traffic control (ATC) system, personal air vehicles could replace much of domestic airline service. They can be used for sport, and should be suitable, being autonomous, for use by the aged and the infirm.

The emerging competition for this aero renaissance was apparent in the major-to-historic COVID-19 impacts upon air travel. Tele-travel, immersive, virtual presence as an alternative to air travel has long been under development. The technology, especially bandwidth and virtual reality, has been developed to where this alternative to physical travel is now a serious competition for physical travel of all varieties as proven in the COVID 19 impacts. Tele-travel is one aspect of the rapidly developing tele-everything virtual age that we are entering, including tele-work, tele-commuting, tele-education, tele-medicine, tele-shopping, tele-commerce writ large, tele-politics/entertainment/socialization and with onsite printers, tele-manufacturing. The tele-travel benefits include far less cost, major reductions in climate impacts, far less time, minimal time away from family *etc*., and far more engagement opportunities, efficiency.

For long haul air transport at transonic and supersonic speeds, projections include emissionless electrics with increasing ranges recharged or via green fuels produced by the cost reductions of renewable energy. Then there are biofuels, with a potential huge capacity enabled by halophytes, salt plants grown on wastelands using saline, seawater. Also enabling would be doubled aero performance via drag reduction, which could increase achievable range for given battery energy density. In addition, there are advanced nanocomposites and nanoscale metal printing with superb microstructures, which could provide dry weight reductions and additional range increases.

Renewable energy is now at or below cost parity with fossil carbon generation with their costs still continuing to fall. Currently renewables are some 95% of new generation capacity and generate now some 28% of electricity worldwide, with projections for 80% generation in two to three decades. The still ongoing cost reductions for both the renewables and energy storage, which dropped some 70% over the last three years, appear to proffer minimal emissions for electric or green fueled aircraft going forward.

There are two disparate approaches being pursued for improved materials, stronger, lighter weight, more durable, *etc*. The first of these is nanotube composites. The second is motivated by observations over the years that the performance of metals is, by factors up to the order of 20, degraded by the dislocations and grain boundary issues produced by various materials processing approaches. The improvement approach for this is printing at the nanoscale, producing much improved microstructure and properties by a factor of 5 with projections

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up to a factor of 10. These improved metals would then, at less cost but equal or better properties and improved repairability, constitute competition for composite materials. The major trends in manufacturing are printing and robotic AI to enable autonomous production. These are more adaptable, lower cost, and can produce unique, complex designs.

Conventional, current commercial aviation has established an excellent safety record with some 80% or so of the remaining concerns due to "human factors". The expected growth in numbers of aircraft from thousands to many millions will require much improved safety. Most of the millions of small aircraft operations will be over populated, developed areas.

The first order approach to greatly improved aero safety is autonomy. Additional safety improvement arenas include inspections/vehicle health management, fly while hurt, crashproof, obviation of single points of failure/redundancy, resiliency, zero defect manufacturing and flow control. All of these are best addressed during design. Safety, even in designs where cost is a prime issue, needs to be an independent variable. Nearly everything in the entire aviation system, ground, flight and ATC etc. is now executed by electrons. These are unfortunately extremely vulnerable to electromagnetic pulse (EMP), jamming, co-opting and cyber-attacks. Autonomy and the shift to all electric aircraft vice mechanical/hydraulic systems compounds the vulnerabilities. The low amplitude of the GPS signals makes it very easy to jam and will require at least backup Navigation systems if not replacements. Several navigation alternatives are under development, including "cold atoms" or atom optics, a Bose-Einstein condensate controlled by lasers providing some 3 orders of magnitude inertial navigation improvement. Then there is the use of stationary/ambient sources of RF such as television towers and, in analogy to the earlier terrain contour matching (tercom) systems, using highly sensitive quantum graviometers or magnetometers.

1. Emerging Civilian Aeronautics Possibilities

PAVs - Personal, affordable, quiet, safe, autonomous, fly/drive from personal driveway/ holding, nearby street, electric vertical take-off and landing (EVTOL) vehicles with increasing range are developing, powered by green renewable energy, enabling the ability to live nearly anywhere, including off roads. The technologies to produce and operate these are essentially here, such capabilities have been desired by society since the 1920's.

Truss braced wing designs for long haul - Use of an external wing truss provides major structural benefits,and allows reduced wing weight, thickness and sweep, resulting in a tremendously enhanced, easily maintained, with reduced sensitivity to roughness, insect remains, ice clouds, and reduced cross flow, extent of natural-to-easily forced low drag laminar flow. The truss also enables the doubling of the span. This allows a reduction in wing chord, further enhancing the extent of laminar flow, as well as a reduced vortex hazard and a major reduction in drag due to lift. Plenninger's and VPI designs for such aircraft yielded lift to drag ratio (L/D) values in the 40's, over twice current levels. Such aerodynamic performance would increase the range of electric transports. Pfenninger also designed a supersonic transport (SST) that was strut braced with an L/D in the 16 range (Fig. 1).

Fig. 1 Pfenninger SST concept with strut-braced wings.

An enabling, Less Expensive Autonomous ATC System for Millions of Aircraft. The current, thousands of aircraft, ATC system has to always function, and is operated by humans with their associated latency and errors. Morphing the existing system to what will be required for many millions of aircraft is essentially a bridge too far, decades probably, compared to the rapidly developing market needs. The enabling ATC system for unmanned aircraft system (UAS)/personal air vehicle (PAV) will be a major issue regarding the development of these new markets. A suggested approach that is better, faster, cheaper, and is an alternative to evolving the existing ATC system is to develop a giant simulation around the current system, taking data from, but not inputting into or interacting with, the existing system. This simulation is then used to develop requisite software and associated hardware including the communications, navigation, sensors, collision avoidance, architectures, and AI. The piece parts and their system of systems, which interact to create a new, wholly autonomous, minimal latency, and fail safe ATC system capable of handling millions of air vehicles, could be rapidly developed in the simulation, This simulation could then be physically demonstrated in the desert and once proven, becomes the next ATC system. Oftentimes the best approach is to start over, especially when as in this case, there is a plethora of new enabling technologies and vastly altered performance requirements and time frames. The altered, new requirements include many orders of magnitude greater numbers of air vehicles and substantial reductions in latency and improvements in safety.

2. PAV a Major Enabler for AN Off-Road Do-It-Yourself Mode of Living

Before the Industrial Age, few had "jobs," folks were farmers who lived almost wholly in a do-it-yourself mode. The Industrial Age required factory workers, which necessitated proximity to factories. The resulting requisite population density led to the expansion of cities and urban areas and later the automobile enabled suburbs. In that process, many lost the time and the land area for serious do-it-yourself living and associated independence. As we move out of the Industrial Age into the Virtual Age, the technologies enable a return to seriously effective do-it-yourself independent living. With tele-everything including telework, folks can, and many now do, live wherever they want. The massive and decreasingly expensive renewable energy developments are enabling distributed electricity generation and storage, obviating the need for wires to deliver electricity. The burgeoning electric personal air vehicle developments enable physical transportation without requiring road access to the homesite or fuels. With the bio revolution, it is possible to grow serious amounts of food on a small holding, where water can be drilled for, captured from rain, recycled, etc., so folks could be freed from all the physical, electricity, road, and water grids. The development of massive numbers of Low Earth Orbiting (LEO) satellites provides worldwide high-speed internet. This provides superb communications for tele-everything without wires. The development of the already large GIG economy, where employment is via the web, adds to the tele-work options in the rest of the economy. With tele-everything, we can do tele-ed and tele-med, as discussed. Then there is tele-manufacture or on site printing. With carbon, hydrogen, and oxygen from onsite, we can make and print plastics. In fact, 3D printing is now being used to manufacture homes. Overall, we are now seeing develop the option to shift to independent, tele-everything, off all the physical grids, back to independent living enabled by tech developments. This shift, if sizable, would have truly massive econometric impacts on industrial agriculture, power and water companies, cell towers, ground transportation infrastructures as a whole, manufacturing, education and with a shift to prevention, medicine is affected. Such a shift to back to the future independent DIY living would have massive favorable impacts upon climate and the ecosystem and the economic 1% and 99% problem as the current econometrics associated with manufacture, finance, fossil fuels, service industries, employment, etc. would be massively changed, with an option for nearly jobless independent living and mitigate greatly the impacts of the ongoing replacement of human labor by machines. Humans have twice before wholly changed their living and "working" arrangements, from hunter/gatherer to agriculture and agriculture to industrial.

3. Concluding Remarks

Technology, after nearly a century of attempts, is now capable of shifting personal transportation from the ground to the air, with the many associated benefits. The current Urban Air Mobility efforts with over five hundred vehicles in design and many in flight test are the stalking horse for the developing futures, of what will be a greatly expanded capability for civilian aeronautics. UAM initially will be fee for hire vice personal, private transportation, Concurrently, now, there are very sizable markets developing for unmanned aerial system (UAS) applied to societal, service, governmental and commercial needs. Both the UAM and UAS developments feed directly into the small EVTOL capabilities required for the ultimate PAV future with its massive markets/scale and personal and societal impacts.

At higher speeds, transonic and supersonic long haul, the combination of frontier aerodynamics, materials and advanced batteries and fuel cells, inexpensive renewable energy and green hydrogen and hydrocarbons (HCs) should enable electrics, with less expensive propulsive energy costs. Overall, a quieter, cleaner, less expensive and ubiquitous, down to the personal level, air transportation system writ large is developing rapidly now, driven by markets and climate and the enabling technologies with along the way in the PAV buildout a doubling of the civilian air transportation markets value into the multiple trillions.

A major issue going forward wrt civilian air futures is the concomitant societal shift to tele-everything including tele-travel. We are already seeing decreasing physical travel because of this virtual presence alternative with its many and major benefits. 5 senses virtual/digital reality should greatly accelerate its already rapid adoption as an alternative to physical travel, whether by air or otherwise. The Covid -19 impacts on air travel, and the substantial shift of such to tele-travel etc. is indicative of the increasing competition from virtual presence. Major forward work to enable the futures discussed herein include batteries and fuel cells, certification of in many cases very different from traditional air vehicles, weather issues, safety, vehicle cost/ affordability, noise, ground interface infrastructures, and autonomy, electric propulsion, an ATM for many tens of millions of flying things and printing manufacture. To this author's knowledge, these are all workable.

Conflict of Interest

There is no conflict of interest

Supporting Information

Not applicable.

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