NASA/TM–20210023715

Futures of Civil Air Transportation Including Personal Air Vehicles

Dennis M. Bushnell
Langley Research Center, Hampton, Virginia

January 2022

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NTRS Registered and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counter-part of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include organizing and publishing research results, distributing specialized research announcements and feeds, providing information desk and personal search support, and enabling data exchange services.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at http://www.sti.nasa.gov

- E-mail your question to help@sti.nasa.gov

- Phone the NASA STI Information Desk at 757-864-9658

- Write to:
  NASA STI Information Desk
  Mail Stop 148
  NASA Langley Research Center
  Hampton, VA 23681-2199

NASA/TM–20210023715

Futures of Civil Air Transportation Including Personal Air Vehicles

Dennis Bushnell
Langley Research Center, Hampton, Virginia

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

January 2022

Available from:

NASA STI Program / Mail Stop 148
NASA Langley Research Center
Hampton, VA 23681-2199
Fax: 757-864-6500

Introduction

The prospective futures of civilian air transportation are changing rapidly, responding to serious issues and opportunities with solution spaces having truly major societal and wide-ranging commercial and industrial level implications. The overarching issues being addressed going forward include emissions/climate/energy, road congestion/infrastructure costs, the shift to tele-everything including tele-travel, on site printing vice air cargo for some commodities, the rapidly developing shift to automation on the way to autonomy, electron ubiquity and vulnerabilities, the limited capacity of existing airports, acoustic strictures, safety, affordability, and increasing delays (air traffic control (ATC), security, hub/spoke, ground traffic). A projected civilian air transportation renaissance is enabled by a plethora of advanced to revolutionary technologies including renewable/“green”/increasingly inexpensive energy, electric propulsion, nano materials and materials processing, printing manufacture, artificial intelligence (AI)/autonomy, an emerging global sensor grid, safety/reliability attainment, and resilient navigation and communications.

The projected nature of the civilian aero renaissance includes a 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, autonomous vehicle operation and air traffic control, large air transport cost reductions, and improved metrics for all speed ranges from personal air vehicles to supersonic transports. The buildout of the personal aircraft markets is projected at over $1T/year, with many millions of flying things in controlled airspace vs. the current thousands. The benefits of such personal air transportation are legion, including much reduced costs for roads and bridges/current auto infrastructures, shortened travel time, electrics recharged by renewables resulting in major favorable climate, ecosystem, and pollution impacts, and with autonomous operations hopefully saving lives currently being lost in ground traffic accidents. A major emerging competition for air travel is tele-travel, virtual/digital reality, immersive presence, as made apparent in the historic COVID-19 impacts upon air travel.

The tele-travel, immersive, virtual presence alternative to air travel has long been forecast and in development. The technology, especially regarding requisite bandwidth and five senses virtual reality, is at the point where this alternative to physical travel is now serious competition for physical travel of all varieties as proven in the COVID 19 changes. Tele-travel is one aspect of the rapidly developing tele-everything virtual age 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 immersive/tele-travel benefits are many and include far less cost, major reductions in climate impacts, far less time and “hassle”, minimal time away from family, more engagement opportunities, and can be anywhere, virtually, at any time.

The emerging functionalities for small/personal class aircraft include an extensive number of service, business, and governmental applications and far longer, easier, faster commute possibilities. Given vehicle improvements and a viable ATC system, personal air vehicles could supplant much of the domestic airline service. Initially, it would be competitive with the some half of civil air travel that is shorter range. PAVs replacing autos would also reduce the auto/ground infrastructure costs for creation and maintenance of roads and bridges.

For long haul air transport (especially intercontinental) at transonic and supersonic speeds, the outlook includes emissionless electrics with increasing ranges recharged by the rapidly developing, cost reducing renewable energy approaches slated to provide 80% of electricity in two decades or less. The same energy source is increasingly producing “green” hydrogen and hydrocarbons from CO_2 captured from the atmosphere. Then there are biofuels, with a potential huge capacity enabled by halophytes, which are salt plants grown on wastelands using saline or seawater. Also enabling would be doubled aero performance via drag reduction, which could increase the achievable range for a given battery energy density,which is on a rapid performance improvement and cost reduction trend. Then there are advanced nano composites and nano scale metal printing with superb microstructures, positing major dry weight reductions and consequent further range increases.

The Personal Air Vehicle (PAV)

Soon after the development of the automobile and the airplane in the early 1900s, many started envisioning flying automobiles, including Henry Ford. Technical work on personal air vehicles (PAV) dates from a 1903 patent. In 1940, Henry Ford famously predicted “Mark my word: a combination airplane and motorcar is coming. You may smile, but it will come.” Henry Ford was proved correct when “The Aerocar, designed and built by Molt Taylor, made a successful flight in December 1949, and in following years versions underwent a series of road and flying tests” [ref. 1, which also has several photographs of early roadable aircraft]. Reference 2 also has flying car photographs, including recent versions. Reference 3 considers the long history of flying car attempts and discusses the current, altered state that is more amenable to their success.

What has changed and is changing in regard to PAVs is primarily a result of the IT and other ongoing technology revolutions [ref. 4]. First, there was an absolute requirement for a human pilot, and there are few with the time and treasure to be pilots, ensuring limited production runs and therefore expensive vehicles. What is rapidly evolving now is autonomous flight where humans are passengers, making PAVS usable by non-pilots, the infirm, and the young. The IT revolution has also vastly reduced the size and costs and increased the capability of avionics as a whole. There have been many decades of military and civilian developments of unmanned air systems and vehicles (unmanned air systems (UAS), unmanned aerial vehicles (UAV)) that have been created for a wide variety of missions. PAVs are UAS carrying human passengers. There are also lighter weight materials and computational methods for aerodynamic and systems design optimization. The major impetus for the current increased interest and progress in application of UAVs carrying passengers is urban region transportation or urban air mobility (UAM). This under consideration as a solution to the huge traffic problems in most urban areas, especially with the development of more efficient batteries and consequent recognition of their enablement for distributed electric propulsion and vertical and short takeoff and landing (EVSTOL) capabilities. The current efforts for EVSTOL for UAM involves five hundred vehicle designs worldwide. Some of those designs are PAVs. These PAVs would operate out of driveways or local streets, enabling personal vehicle flying from anywhere to anywhere or “door to door.”

The potential PAV markets are the automobile markets; PAVs are auto replacements with far greater range and utility. These markets are in the trillions per year. At this juncture, updated PAV vehicles are under development. As their markets mature, the economies of scale will greatly reduce their cost, as will printing manufacturing. The current major impediments to developing these markets involve infrastructures, the foremost such is the need for an autonomous air traffic management (ATM) system capable of handling tens of millions of air vehicles. There are also safety and other issues as discussed herein. The putative impacts of this shift to personal air transportation from ground vehicles and their huge costs for roads, bridges, and major ecosystems include other potential impacts including replacing much of domestic scheduled air transportation and enabling folks to live anywhere, wholly off roads, along with providing capability for very long commutes. Overall, much would change regarding human society. We change our technology and in turn are changed by our technology. Ref. 5

provides a superb summary of flying cars and roadable aircraft over the years, including over 100 designs. Ref.6 provides an assessment of their status and the issues regarding AAM going forward.

Automation [refs. 7 and 8]

To enable utilization by "anyone" and for effective ATM of tens of millions of flying things operating out of driveways and streets, PAV vehicle operation must be autonomous, and for safety and other reasons, it has to be trusted autonomy. The fundamental aspects and precepts of trusted autonomy are safety, security, reliability, and resilience for both "on design" and "off design," where on design refers to the functionalities and states required to execute the design mission, and off design refers to conditions and operations at other than those included in the parameters and conditions for design operability. For design missions involving the usual architectures and technologies and having a considerable historical experience base, most of the issues required to be satisfied are "knowns." However, as new/unique/experimental technologies are employed and/or for new and untoward mission conditions and functionalities there arises—especially for off design—the specter of both "known unknowns" and "unknown unknowns."

As autonomy is increasingly applied to an ever-broader spectrum of conditions and functionalities, including both new technologies and new operability conditions, what is required is trusted autonomy in the potential presence of known unknowns and unknown unknowns. An obvious overarching example of a known unknown requirement to be considered for all autonomous systems going forward is the preservation of electron or electronic operability—the bedrock requirement for autonomy.

Thus, trusted full autonomy (systems fully operated by machines) requires the identification of and solutions spaces for "untoward events" (also referred to as "edge cases"), conditions/occurrences beyond the operational automation functionalities and design, along with associated system functionalities capable of accommodating such in a safe manner. Untoward events can be defined as operational and system inputs, changes and/or occurrences beyond the functional/operational "on design" events/capabilities. An obvious way forward is to minimize the number of unknown unknowns and maximize the number of knowns so that most "off design" conditions can be dealt with via the ab initio design—if that is determined to be efficacious—and the rest can be dealt with by an on-board resilience system. The obvious key to doing such is data, information, knowledge of everything connected with the system and its surroundings, including potential and actual variations thereof. Also included in this is the knowledgeability and projection of combinational interactions up to the systems of systems level.

For autonomous aviation, potential sources of untoward events include combinations of weather issues, traffic, the health of the vehicle's systems along with its degradation and limits, and the many safety issues associated with human factors—if such vehicle is not fully autonomous. In aviation, some 80% of the safety issues have been traceable to human factors. Presumably an autonomous system should—and could—be safer via obviation of human factors, errors, latency, etc. However, autonomous operations are typically held to much stricter standards than manned operations. Tens of thousands are killed by human operated motor vehicles each year but society has not allowed such safety performance in an autonomous system. We have long had the capability to do wheels up to down autonomous flight, but such a system has not yet been fully implemented on aircraft transporting human passengers due to the lack of trusted autonomy, and the resultant apparent need to have humans to handle "untoward events."

The current overall essential capability to design and operate trusted autonomy aviation systems is the recently developed and still undergoing maturation combination of big data, deep learning, neural nets, and sizable/capable computing machines, now in many applications providing AI niches with, at, or beyond human capabilities. Such a capability knows far more than individual humans, obviates the many sources of human error, has much reduced latency compared to humans, and other favorable attributes. Given sufficient information, this big data/deep learning approach could determine to the extent possible the known unknowns and the unknown unknowns via the now several related approaches to machine ideation, including Generative Adversarial Networks (GANs). Then the system could conduct risk assessments and determine which of these issues are worrisome enough to be included in the ab in-itio system design as additional to the usual "on design" functionalization. This includes self-repair. Other issues identified, but not directly included in the vehicle design, are carried over to be dealt with by an on-board resilience system. This on-board resilience system consists of an on-board big data/deep learning system which continually updates the "data" across the board and determines extant and emerging potential threats/problems, determines solution/coping spaces via GANS or other approaches for machine ideation, decides which is most efficacious, and executes the solution spaces to preserve lives and property. An important aspect of this approach is that an overall aviation corporate memory is built up via such interactive communications and learning. Thus, the envisaged resilience system is broadly capable and knowledgeable, and not limited to a particular aircraft or type of aircraft. Such an on-board resilience system would be given authority to utilize the entire vehicle system capabilities to develop and execute solution spaces for untoward problems—those not included in the ab initio system design. The intent is that the resilience system enables the aircraft to "fly while hurt." This capability is related to current NASA research efforts termed "Learn to Fly."

This overall approach uses big data/deep learning to both improve the initial design and improve reliability/resilience (over and above the automation of the "on design" vehicle functionalities) via a continually updated on board "lifeboat" resilience system. It should provide trusted autonomy to a level such that humans would no longer be required for operation, which, as already stated, would obviate the large panoply of human factors errors, thereby further ensuring and improving safety. The major key to such an approach to trusted autonomy, which will only improve as AI further develops, is defining which/what is subsumed in the initial design and continually updated both off-board and on-board "big data" sets.

Some obvious cogent databases include:

- Weather: Predictions and combinational historical extremes associated therewith
- Integrated vehicle health management, including on-board sensors for vehicle health assessment/management of all systems, including structural
- Aircraft traffic/ATM data. This includes projections to inform potential collision possibilities and wake vortex hazard issues, which enables constant planning of avoidance maneuvers
- Documentation of aviation accidents and near misses of any kind, both civilian and military, worldwide, along with appropriate or actualized solution/obviation approaches [Those who do not study history are consigned to repeat it]
- Reliability data analyses for all vehicle components and systems
- Complete performance specifications of system design parameters, individual components, and as systems of systems
- Details concerning potential terrorist attacks of any type
- Potential cyber and EMP issues, threats, and potential impacts, and known workarounds
- Redundant navigation approaches and positioning
- Complete digital twin databases as available
- Communications functionality
- Bird prevalence and sizes
- Aircraft security sitrep

These databases consider, address, and subsume the usual sources of aircraft accidents including pilot error (responsible for some 50% of all aircraft crashes), mechanical error (23%, includes some components of human error), weather (10%), sabotage/terrorism (9%), and other human errors including ATC and human-caused fuel starvation (7%) [ref. 9].

The above is only one suggested approach to trusted autonomy for PAV vehicles. The anticipated buildout of the PAV market is dependent upon the successful development and operationalization of trusted autonomy for both the vehicle and ATM systems.

PAV ATM [ref. 10]

The requirements that dictate the need for and capabilities of the requisite new PAV-class ATM system include the following:

- Ongoing development of capable and affordable UAS designs for a multiplicity of government, commercial, service tasks, and eventually a PAV replacement for the automobile with prospective markets in the tens of millions of flying things. The current air fleet is in the thousands. The current UAM research planning is for just tens of thousands. The putative markets for UAS including PAV are estimated in the trillion dollar level, doubling the commercial/civilian aero market value.
- These UAS will operate across the altitude range and largely over developed areas with diverse vehicle types and capabilities across the speed range.
- Control of such huge numbers of air vehicles, in what will become very congested and dynamic air space over large, developed areas, is beyond the capability of human air controllers. What is required is latency and safety only available from autonomous robotic systems, for both ATM and the vehicles.
- Typically, these UAS will operate largely quasi-randomly from/to multitudinous locations in the countryside, including individual holdings, instead of from “airports.”
- Superb communications are required between the ATM system and the flight vehicles to exchange sensor data, intentions/directions, and for control.
- To the extent possible, systems should be “fail-safe,” including the piece parts, with robust, scalable capabilities.
- Crucial technologies and integrated piece parts include trusted autonomy, navigation, sensors, flow control for all weather, safety, electron security, and the requisite architectural approach.

From a market development standpoint, such an ATM system is required on the order of 5 to 10 years (versus decades), without its development interfering with the operation of the current ATM system. The technologies to enable and execute such a requisite ATM system are either available or rapidly developing. What is needed is the foresight with regards to what the rapidly developing UAS markets will require of an enabling ATM system. Also useful would be the courage to work the much less expensive, far shorter, and much safer approach of a wholly new system instead of attempting to morph the existing, wholly inadequate for the projected markets, system. Going forward, because ATM will be co-operative with regard to both a central system/distributed systems and flying vehicles, capabilities and equipage are needed that is ATM related on both vehicles and central/distributed ATM systems. The foremost requisite for PAV is autonomy, both for the ATM system and the air vehicles. This is the only approach that can scale to tens of millions of flying things in controlled air space. Such a single system should obviously be scalable to the tens of millions level and be inexpensive to develop, install, and operate. It must be operational in the time frame of the market’s needs for a single system operable at the tens of millions level of use. The requisite components, on board and on the ground/in space, of such a single ATM system for tens of millions include: navigation that is fail safe to GPS jamming, sensors writ large, collision avoidance, trusted autonomy, detection, and control of noncooperating air vehicles, resilient communications, an architecture that involves cooperative information sharing across all components, and the requisite Artificial Intelligence (AI) and computational equipage. For the longer term with tens of millions of flying things, a wholly new single autonomous ATM system is required. Evolution of the current ATM would take far longer and cost far more than the approach described herein because of the human operated systems that, even if morphed into autonomous operation, must continuously function in the process. This is evidenced by the many years and much treasure required to modify it for "Next Gen" capabilities, a pale shadow of what will be required for the PAV buildout. The nominal time frame for such a new system to go live should be on the order of 5 to 10 years or so. The development time frame will be dictated by the rapidly evolving UAS markets which will require air space access in the buildout for on the order of a trillion-dollar new aero market, including replacing automobiles.

The overall suggestion discussed herein is to build a giant simulation around the current ATM system(s), extracting data from them for development, but not changing them in any way, at least initially [ref. 11]. The initial development of such a simulation began in the NASA "Smart NAS (National Air System)" effort [ref. 12]. Step two is development of each of the related requisite functionalities noted above in the simulation, followed by further development at the system of systems level, always keeping fail-safe design in mind. Then, virtually stress testing the operation of the new ATM system developed in the sim, followed by physical testing in the desert would need to be completed. Once the new system is physically certified, the existing system is then turned off and the sim becomes the wholly new ATM system.

The overall ATM architecture for tens of millions suggested herein has at its core a trusted autonomous anti-collision system. This system includes the many piece parts necessary for successful actualization such as communications, navigation, sensors, data/knowledge access including vehicle characteristics, weather, etc., and electron security. Needed is a distributed ground and space-based system incorporating the "controlled" vehicles and continuous system/vehicles communications/updates. Prime vehicle control function is owned by the system, which can take control of/flying both compliant and non-compliant vehicles. Vehicles have a secondary control function to cooperatively avoid collisions with adjacent vehicles as a fail-safe anti-collision backup. The computing power and the technologies and AI to develop such a wholly new autonomous ATM system appear to exist or be developable soon enough to enable a timely PAV market.

The primary purpose of an ATM system is to avoid collisions. The PAV buildout will have vehicles popping up all over the place from driver's driveways, going to nearly random destinations, a very dynamic N body problem. What would help is traffic lanes in the sky but without stoplights (obviously), although with Vertical Take-Off and Landing (VTOL) that is possible. Otherwise, the situation would degenerate to Brownian Motion as traffic increases. Airspeed and direction would have to be controlled for each vehicle, based upon a constantly changing optimization problem. Only machines can do this system of systems control problem and the system must have control of the vehicles. The worrisome latency is that of the control effectors and speed brakes on the vehicles. Thrust vectoring and reverse thrusters, especially via utilization of the components of electric distributed propulsion systems, would provide additional vehicle controllability. Flow control can be used to help ensure they can keep flying, as well as aid the VTOL capability. The vehicles will have heterogenous capabilities, but that is just more details to load into the system, part of the requisite problem and solution spaces.

PAV Acoustics

Acoustics, being neighborly, able to operate from the driveway or local street, is a serious-to-existential enabling metric for PAV market development [ref. 13]. For VTOL operation, the prime noise sources are engine, transmission, airframe, lift, controls, and propulsion. Going electric largely obviates engine and transmission noise, leaving lift, propulsion, airframe, and controls noise, of which lift is the dominant source. The major historical approaches and technologies for VTOL operation, rotary wing and powered lift are noisy, major acoustic quieting R&D has been and is required to ensure PAV societal acceptance and marketability.

Fortunately, there are a sizable number of technical and system level approaches to reduce the acoustic levels of PAV vehicles (e.g., ref. 14). These include:

- Electric motors, vice combustion devices, obviating exhaust, engine, transmission noise, a significant overall reduction
- Slow turning rotors, tip speed reduction
- Shifting radiated frequencies to above or below human hearing, perception
- "Cleaner" fluid flows, less and weaker vortex production, no flow separation, innately unsteady flows
- Utilization of aircraft portions and ground infrastructure as acoustic shields
- Identification and reduction of the strength of acoustic sources
- "Noise Perfume," generation of acceptable to desirable covering noise
- Active noise cancellation
- Landing gear and flap flow cleanup
- Distributed propulsion, larger number of noise sources at different frequencies
- Injection of water droplets to reduce turbulence and associated noise source strength
- Flow turned 'Grim Wheels" to make inlet and exhaust flows more uniform
- Drag and weight reductions to reduce requisite power, lift requirement
- Wall acoustic absorbers
- Altered duct acoustic modes
- Broad band, distributed vice sharp, narrow band noise generation
- Obviate as possible vortex breakdown
- Modulate blade rotation to mitigate blade/vortex interaction
- Vary blade spacing
- Active flaps and twist
- Tip treatments to reduce strength of tip vortex
- Tip electric turbines to turn rotor, obviate tail rotor, and reduce strength of tip vortex
- Serrated blade trailing edges

Overall, at the system of systems and configuration and operational design levels, acoustic performance is of such importance that it should be included as a prime critical design metric vice a fix-it-later consideration. The nominal approach to VTOL/PAV acoustic level reduction includes slow turning large high lift blades with weakened tip vortices on a minimum weight, high L/D (during VTOL flight especially) configuration. Electrics, distributed propulsion, active flow control, CFD, morphing smart active materials, and miniaturized sensors have created major opportunity spaces for PAV acoustic level reduction(s).

PAV Aerodynamics, Configuration [refs. 11 and 15]

The current ODM/UAM and PAV efforts are investigating, building, and flying over 500 prototypes of alternative VTOL approaches. The literature is rife with large numbers of non-helo electric propulsion VTOL devices and approaches, some with several to many lift fans. The many issues and drawbacks of helo approaches are well known and documented. These newer, evolving VTOL approaches are an advance over helos, with some utilizing tilting components and some of the fans for cruise propulsion. Typical benefits include lower noise, drag, vibration, cost, maintenance, and greater safety. As the costs of renewables for electrical generation continue to drop and the batteries continue to improve, it is increasingly feasible to afford the decreased efficiency and unload the lift fans for improved acoustics. The usual approaches to VTOL lift production include powered lift, such as tilting nacelles, wings, rotors, fan-in-wing, and aero lift such as rotary wing including tail sitters. One possibility for ODM/UAM or PAV for VTOL operation is a stacked, stopped rotor for efficient cruise. This could possibly reduce drag due to lift via a biplane effect, with the stacked, stopped rotors distributing the lift in the vertical direction. For super STOL operation there is the channel wing with circulation control, and for lower cruise speed STOL various flavors of auto gyro.

The major design metrics for UAS/ODM/PAV vehicles include acoustics, emissions, reliability/safety, range, efficiency, and cost. Batteries and the renewable energy to charge them are evolving to where electric propulsion is feasible for increasing ranges, thereby seriously addressing emissions. Electric propulsion proffers scalable distributed VTOL propulsion with numerous rotors/lift fans that address noise. In terms of design, concomitant with reliability/safety is range and efficiency. A lower weight/lower drag/efficient airframe reduces the requisite battery capability and increases range for a given battery SOA. There is a plethora of approaches to reduce weight and drag on airframes, both individual technologies and synergistically. Among these approaches is one that is particularly interesting: the stopped rotor.

The stopped rotor approach utilizes a low noise, lightly loaded tip driven rotor (no tail rotor needed) to provide VTOL which, once in the air, is stopped and the rotor becomes the wing for cruising. The improved performance of this approach was recognized early on and has been worked since the 1950's with two sizable efforts. The first was the X-wing in the 80's, which used circulation control and never flew. The second was the Canard Rotor Wing program in the early 2000's, which after two crashes, was stopped. More recently the Navy and the Australians have been pursuing versions of the CRW approach. The major issue with the stopped rotor approach occurs when the rotor is stopped, which is the transition period. At that point one of the blades are facing the wrong way. Various solution spaces to address this issue have been tried. Two such approaches that appear to work are rapidly rotating the errant blade 180 degrees and circulation control. As the blade stops, lift forces dynamically shift and the cruise propulsion system kicks in, creating worrisome aircraft stability and control issues.

Some suggested ways forward that may be of interest to actualize the stopped rotor VTOL PAV approach include the following:

- Utilize electric tip drives on the blade which obviates the need for tail rotors and reduces the blade drag due to lift. These can contribute to propulsion during cruise.
- Thrust vectoring, AI, morphing surfaces, etc. for stability and control.
- 180-degree rotation of the errant blade or morphing leading/trailing edge regions to alter the blade contour during rotor stoppage. One approach for morphing surfaces is using thin blades that project backward at the desired trailing edge to stretch a tailored elastic airfoil covering. This forms a suitable trailing edge region contour that retracts into the airfoil in the desired leading-edge region. Inflation and contour tailoring of these elastic coverings might be efficacious.
- Strut-braced blades for greater span, lower drag due to lift, and to support the tip drives.

UAS/PAV approaches to reduce weight and drag, reducing the requisite battery energy density, and increasing range include:

- Flow control or designer fluid mechanics - Designer fluid mechanics subsumes a large number of flow control approaches and applications. These include laminar flow control

(LFC), mixing enhancement, and separated flow control for high lift, vortex control, turbulence control, and favorable wave interference for drag reduction. With the advent of the issue of battery weight for electric vehicles, LFC is especially under active consideration to reduce the requisite battery capacity. For turbulent drag reduction, the options include relaminarization and riblets. Electric propulsion proffers the possibility of straightforward distributed energy for flow separation control.

- Aero/propulsion synergies – Conventional design practice in civilian aeronautics is to essentially separate the aerodynamics and the propulsion systems.
- Circulation control wings up to a factor of four increase in Cl (Lift Coefficient)
- Boundary layer inlet: Ingesting lower momentum air for up to 10% to 15% propulsion efficiency increase.
- Wing tip engines: To reduce drag due to lift. Wing strut and truss bracing are conducive to wing tip engine placement.
- Thrust vectoring: Placing the engines at the rear of the fuselage and utilizing them for aero controls in lieu of the weight and drag of the empennage.
- Hybrid laminar flow with leading edge suction utilized for high lift separation control.

PAV Flight in Weather [ref. 16]

Weather issues caused or contributed to approximately 35% of fatal general aviation accidents in the United States from 1982 to 2013, according to researchers from Northern Illinois University, which, in 2016 reviewed decades of accident data. Winds, especially updrafts and downdrafts, are the most prevalent cause. The delivery drones, commercial unmanned aircraft systems, and PAVs under development today could be more prone to weather-related accidents or upsets because many are smaller in size and weight than GA aircraft and therefore have lower inertia. Some of the coming advanced air mobility aircraft, which will include on-demand passenger aircraft, will be about the same size and weight as some GA aircraft and will be equally vulnerable. All of them will fly at low altitudes, home to the worst of the weather, including snow, rain, fog, tornadoes, lightning, icing, excessive heat, hail, sleet, microbursts, and wind shifts near thunderstorms. In fact, a study by the U.S. Army Research Laboratory concerning weather impacts on its Aerostar tactical unmanned aerial system notes that the manufacturer recommends against flying the aircraft in severe turbulence. Those conditions can amount to 5% to 70% of the time, depending on the time of day, region, and season. Delivery drones and small on-demand passenger aircraft will be similarly vulnerable, and they will fly mostly over built-up areas in increasingly large numbers, constituting an increasingly worrisome safety hazard. They could be blown off course, possibly into buildings or other aircraft. All told, weather conditions can affect aircraft visibility, navigation, performance, and controllability and reduce flight duration. Therefore, for reasons of safety, operability, reliability, utilization and econometrics, designers should improve the next AAM and UAS vehicles so that they can fly in challenging weather.

Given that cost is a major metric for producing these vehicles, prospective solution spaces must be both effective and affordable. Also, the eventual replacement of automobiles with on-demand-mobility passenger aircraft will require operability in weather conditions at least to the extent that automobiles have. The usual conventional aeronautics approaches for weather issues include designing for service in all but extreme conditions and detecting and avoiding or flying around the extreme cases. Many of the initial UAS designs are essentially "fair-weather" machines, not waterproofed for rain and moisture. Many are electric, operating off batteries sensitive to cold and heat, and can fly in winds on the order of up to two thirds of the maximum flight speed. Wind gusts can be up to the order of twice the average wind speed while AAM and UAS flights near buildings and trees or in urban canyons can encounter largescale organized dynamic vorticity. Waterproofing and de-icing are probably essential for practical, safe operability in many areas and seasons. The issue of battery sensivity to heat and cold could be addressed by a combination of insulation and regeneration of battery heat losses and added energy from external photovoltaic films or other energy sources operating a battery pack climate control system. For vehicles carrying passengers, the cabin environmental control system could be designed to include the battery enclosure. Flight in poor weather will, in general, require IFR equipage for visibility and air traffic control. The major remaining weather issues are wind and rain. Therefore, affordable solution spaces for these that are effective for relatively low speeds and inertia are of interest. Rain can affect flight by direct momentum exchange, by decambering wing surfaces and thereby inducing loss of lift and control authority, by increasing the vehicle mass, changing the center of pressure, by creating roughness and drag, and possibly by flow separation. Weather can affect controllability, speed, angle of attack and sideslip, and reduce range by requiring increased energy expenditure.

The current major weather-related efforts regarding AAM, including UAS and PAV, involve improvements in detailed local flight weather forecasting and maneuvering. Options for enhancing AAM/UAS/PAV for safe maneuvering in wind and rain include: increased onboard energy for thrust vectoring for controllability beyond what is available from the usual controls and to maintain speed/range. These increased energy and thrust vectoring capabilities could, in fair weather in the absence of significant weather effects, be utilized to extend the range and increase controllability for vertical takeoff and landing, VTOL and operations, aero controls with morphing surfaces, and flow control. Of the preceding, thrust vectoring is probably the more effective overall approach. Thrust vectoring for lift can be achieved by tilting wings or just the nacelles, or by vectoring jet engine nozzles. These designs have been flown over the years on military aircraft and missiles, as well as on some lighter-than air applications.

Options to enable thrust vectoring for enhanced AAM/UAS weather operability include:

- Gimbaled engines, nozzles, and propulsors
- Fluid injection into the exhaust stream to redirect momentum
- Auxiliary thrusters
- Exhaust/jet vanes for directing exhaust

PAV Energetics, Propulsion [refs. 11, 16]

There are many rationales responsible for PAV development being electrics. The most fundamental one is climate change, reducing CO2 emissions, along with the resultant huge cost crash and consequent massive growth of renewable electrical generation, enabling the projected tens of millions of PAVs to be essentially emissionless.

The drivers for electric PAV vehicles include:

- No motor gear boxes
- Regenerative energy recovery during descent and landing
- Battery heat production could be utilized for cabin heating, deicing, or regeneration via thermoelectric generators
- Higher altitude operation feasible
- Reduced cooling drag
- Quieter
- Reduced vibration
- Fewer inspections
- No engine flameouts or restarts
- No fuel explosions during crashes
- Power train efficiency greater than 90%, nominally twice or greater than IC and GTE chemically fueled propulsion

- Much lower energy costs
- No power lapse with altitude at high temperatures
- Continuously variable transmission
- High reliability
- High efficiency over most of the power envelope
- Up to six times motor power to weight compared to combustion engines
- Reduced maintenance
- Far fewer parts
- Less expensive
- Higher torque
- No vehicle emissions
- Distributed, scalable propulsion

Renewable energy sources include hydro, solar PV, solar thermal, terrestrial wind, offshore wind, geothermal, ocean tides/waves/currents, osmatic power, biofuels, solar hydrogen, hydrocarbons (from sequestered CO_2), and high-altitude wind. Their capacity is truly massive compared to the usage requirements. The major sources (hydro, solar PV, and wind) require storage. Hydro utilizes pumped storage. For the others, many storage options are under development and their utilization is rapidly increasing. Storage costs have dropped 70% in the last three years; solar PV costs have dropped over 80% in the last eight years and all are still dropping. The cost of PV plus storage is now half the cost of a gas peaker plant. The costs of many renewables are below parity with fossil fuels and in some cases far below. Consequently, nuclear and coal plants are closing, renewables are 90% of new generation and currently generate 28% of electricity, with that percentage growing rapidly. There are transparent PV films in development which can be put on the exterior of PAV vehicles to enable recharging during flight and while on the ground outside. Overall, renewable electricity to power and enable emissionless PAVs is developing rapidly now.

Starting with renewable electricity, there are several approaches to propel PAV vehicles. Batteries is one such approach that has the greatest overall efficiency. The current lithium-ion batteries are being replaced by lithium metal at twice the energy density. Metal air batteries are being worked with 5X or perhaps greater energy density. Other approaches to propel PAVS with renewable electricity include using green electricity to produce green hydrogen and hydrocarbons, and either combusting these to turn on board generators or using fuel cells to produce onboard electricity. The electricity-to-electricity efficiency of batteries and hybrids using hydrogen are 80% and 40% respectively. Systems wise the weight/costs of batteries compared to that of fuels including storage and thermodynamic or fuel cell conversion devices is another consideration. As has been noted, electrics enable distributed propulsion for flow control, vehicle control including in weather, propulsion out issues, safety, acoustics, powered and more efficient lift, DDL reduction, and aeroelasticity.

PAV Financials

To achieve the potential PAV market buildout, a significant portion of the automobile market requires cost competitiveness with vehicle costs on the order of SUV ground vehicles. This cost level for a fly or fly/drive machine that is autonomous will ultimately require the economies of scale associated with build out numbers in the tens of millions. The current aero fleets for passenger carrying air vehicles number in the hundreds to the low thousands, so significant economies of scale cost reductions can be realistically anticipated. Beyond that, there are two fundamental approaches to cost reduction: conventional and unconventional. The conventional approach is often incremental, evolutionary, and involves examining all aspects of supply, production, and operation in a process usually termed "continuous improvement." The unconventional approach involves ideating and innovating solution spaces with often greater to far greater performance and functionality at the same or lower cost. Typically, the unconventional approach, which requires risk embracing and courage, yields far greater effective cost reduction and often creation of whole new markets. Analyses of major determiners of costs, both in regards to production and product, indicate that 80% to 90% of the cost is "designed in" at the initial 10% conceptual and design stage [refs. 17, 18]. This necessitates serious early efforts involving a multiplicity of concepts and ideas that are triaged for the major, real-world metrics, one of the most important of which is cost. That requires superb knowledgeability regarding worldwide technology, marketability, real world metrics, societal requirements-to-desirements, and competitiveness, along with raw ideation and inventiveness.

Examples in society of unconventional cost reduction approaches include the phenomenal reductions occurring across the spectrum of renewable electrical generation approaches and their consequent impacts upon society and markets [ref. 19]. The reasons for the cost reductions include usual approaches such as economies of scale. The unconventional aspects and impacts include the ideation, invention, development of advanced technologies for both approach, efficiency, and cost reduction, and stimulation of equally major cost reductions in energy storage and creation of new markets. These include green hydrogen and hydrocarbons and electric transportation, with major favorable impacts upon societal and planet altering climate change. The unconventional shift to prevention and tele-med is slated to reduce medical costs. Tele-ed is the only affordable approach to very widespread STEM Ed; in the process, we'll see a reduction in taxes spent on physical education including infrastructures. Digital reality, tele-commuting, tele-travel, and tele-work are reducing the cost of personal transportation and enabling folks to live in areas with lower housing costs. AI/robotics and machines are increasingly replacing humans for employment, production, etc. This is lowering the costs of a wide variety of products and services. Printing manufacture is projected, via printing homes, buildings, and nearly everything contained therein, to reduce housing costs, The increasing capability of machines to ideate and invent will improve functionalities, efficiencies, and reduce costs. There is a rich literature on conventional cost reducing approaches [ref. 20].

Cost reducing/market increasing approaches applicable to PAV development include:

- Increasing utilization of Mod-Sim, computation in lieu of usually more expensive experiments, especially at the initial development stages where many options need to be evaluated for optimization
- Detailed studies at the initial systems of systems level using the real-world metrics and boundary conditions to optimize costs across research and development (R&D), applications, certification, and customer costs; it is at this initial stage where most of the costs are "designed in"
- Printing, robotic manufacturing to the extent that these are cost-reducing
- Planning for a major key to cost reduction, large quantity increasingly inexpensive production and maintenance
- Utilization of light weight external PV films to supplement and enable smaller batteries
- Thrust vectoring for flying in weather
- Optimized materials, reduced dry weight, and advanced VTOL and cruise aerodynamics to enable less expensive battery costs and weight
- As in automobiles, a range of models/applications from the "people's PAV" to luxury, longer haul PAVs to optimize markets

PAV Safety

The major aerospace metrics are cost, safety/reliability, and performance. Reliability analysis can be defined as the study of why, how, and when things fail. Safety is what happens when they do fail. Conventionally, reliability involves serious testing and operational experiences and statistics derived therefrom. This approach, as applied to civilian airliners, resulted in a magnificent reliability and safety record. UAS/ODM/PAV involve small, mainly vertical take-off and landing (VTOL), increasingly autonomous electric aircraft for a plethora of national security, service, commercial, and personal applications [ref. 11]. A major requirement for PAV safety and reliability includes greatly decreased crash/hull loss rates as compared to/to account for the far smaller numbers of extant commercial aircraft, which are already inordinately safe. There are some 39,000 aircraft now and estimates for future UAS/ODM/PAV numbers are in the tens of millions. The projected requisite improvements in safety and reliability for UAS/ODM/PAV could be up to a factor of 1,000 to account for 1,000 times more of them in the nation's airspace projected going forward (millions versus thousands). The ultimate market is a fly/drive replacement for the automobile.

Additional requirements for UAS/ODM/PAV safety include: an air traffic control (ATC) system capable of handling millions versus thousands of aircraft, and operational/safety certification. All aspects of this emerging market are being invented and developed in real time. There are over two hundred plus vehicle designs being researched by tens of companies. This ongoing UAS R&D is rapid, very competitive, explores technologies with new capabilities, and has application trade spaces with cost as a major metric. As such, it is termed by some as the "wild west" of aeronautics. Thus far, the enabling safety requirements mentioned above are not as well developed as is necessary. The overall much lower crash rate requirement is made more worrisome by the fact that these air vehicles will spend much of their time over populated areas, versus commercial aircraft that fly over sparsely populated and water covered regions much of the time. For a given crash, there is therefore a greater chance of property and personal damage. However, there is usually less total overall impact per incident due to the smaller size of these vehicles, depending on what they impact.

Causes of aircraft accidents/crashes: [ref. 9]

- 50% Pilot (human) error
- 23% Equipment failure
- 10% Environment/weather
- 7 to10% Sabotage, terrorism, etc.
- 7% Other human error

Causes of UAS and drone crashes: [refs. 21-23]

- 64% Equipment failure (e.g., controls, power/propulsion, communications)
- 32% Human factors

Sampling of safety and reliability related issues in aerospace: [refs. 24-28]

- Human error, major source of safety problems, crashes, even after many decades of R&D and technologies to reduce such (including controlled flight into terrain (CFIT))
- Equipment failures, due to design, installation, operational employment, maintenance, aging, environmental effects, and tipping points for cascading system failures
- Electron/photon related failures including cyber/software issues, EMP/space weather/radiation, jamming, failure of equipment essential for navigation, controls, sensing, propulsion, and communications, etc.
- Inadequate margins, especially regarding a cascading system of systems failures where reduced capability does not fail the parent part but adversely impacts in serious ways the functionalities/piece parts that the overall system depends on for robust performance.

- Operation in extreme environments/in the presence of discrete extreme environmental/operational conditions (e.g., hurricanes/typhoons, bird strikes, extreme icing/rain/ dust)
- Air Traffic Control (ATC) functionality, possibilities of collisions, reduced system capacity, as the current ATC system is largely human operated – human factors.
- Collisions/impacts with debris, birds, other vehicles, and the ground
- Wake vortex hazard, causing forces which cannot be controlled
- Fuel starvation (due to human factors), lack of sufficient fuel
- Costs/profits/schedule exigencies, "corner cutting"
- Lightning and electrostatics, causing electronic failures, fires, and explosions
- Fatigue and fracture, a prime design metric for much of aerospace equipage
- Weather, storms, wind, space weather
- Unknown unknowns, it is usually not possible to anticipate all combinational situations, conditions which will result in a reliability issue, we can become surprised reliability-wise
- Inadequate analysis and testing, due usually to either cost or inadequate knowledge or study reliability writ large
- "Hazards", hazards are major drivers for reliability design and engineering. As complete a set of especially combinational hazards is required.

Reliability and Safety Precepts/Hazards Approaches

Considering UAS/ODM systems and vehicles, thus far 64% of the increasing number of crashes are due to equipment failures such as propulsion/power, flight control, and communications. The rest are cited as human error and miscellaneous. This is quite different from extant commercial aviation, which has a sterling safety record and where only 23% of crashes are due to equipment failures versus equipment failure as the dominant cause for UAS/ODM. This difference strongly and obviously indicates the need for much better design and certification for UAS/ODM, which is thus far a class of vehicles and an overall business based upon inexpensive equipment. Market viability will likely dictate serious reductions in crash rates to account for the increase in the number of flying vehicles.

A sampling of the components, arenas, and approaches for reliability/safety in aerospace that have been found or suggested to be useful include: (e.g., refs. 7,8 29-36)

- Redundancy, backup systems, utilized on human rated systems especially
- Certification, regulatory (IAF, American Society for Testing and Materials (ASTM) standards)
- Inspection, including NDE, to identify emerging problems early for remediation
- Integrated vehicle health management (IVHM), utilization of the increasing capability of sensors, actuators, computers, and AI to identify safety issues early and enable corrections
- Positive margins-to-fail-safe in the limit design approach, to build in "margins" for inaccuracies in specification of design parameters and design details
- Digital twin, where the in-service impacts on equipment are computed and compared with onboard sensors in real time for identification of emerging issues
- Manufacturing/installation care (level of workmanship including requisite training)
- Repairability-to-self repair, related to larger margins
- Recovery approaches (e.g., Safe to ditch, chutes, and morphing)
- Emergency systems, including those that ensure human survivability
- Electric propulsion to obviate fuel fires
- Reliability analysis including probabilistic methodologies informed by applicable big data/sensorization, uncertainty quantification
- Preventive maintenance, a first order approach, guided by inspections, digital twin

- Obviate single points of failure, as a design approach
- Detailed operational mod sim, systems level, all disciplines, as an evolving alternative to physical testing
- Resiliency/graceful degradation, fault tolerant systems
- Commonality, for parts exchange, may enable reduced testing requirements
- Reliability and safety a major design metric, along with the usual weight, cost, functionality major design issues
- Collision avoidance, the ever-increasing sensor and computing capabilities is enabling major improvements in this
- Preflight checks, increasingly such checks will be accomplished by sensors/robotics and AI
- Configuration management, as a major aid to ensure overall design and operational integrity
- Sources, nature of, checks for, and minimization of human error, since human error is a major source of safety/issues/accidents this is critical, and has proven to be very difficult
- Ability to override autonomous robotics systems; we are not yet at the technical state termed “trusted autonomy,” robotics and AI are designed largely by humans, and therefore, human error possibilities exist
- Simplicity, lower part count (including via printing manufacturing) has proven to be an effective safety approach, less parts, functions to fail
- Testing at all complexity levels from piece parts to system of systems, given the developing status of computation and knowledge of initial conditions in detail it is still important to conduct physical testing including at the operational, systems level
- Requirement’s specification and their validation, involves checking design assumptions and adequacy and predictions of operability, service life
- Materials and morphing materials/structure, ensuring that the materials utilized are the ones specified. Morphing materials and some multifunctional materials are at an early stage of development, require detailed scrutiny
- Zero defects manufacturing, a goal which is useful to increase overall safety awareness and care
- Condition documentation, materials processing, construction, and in-service activities alter the condition of everything from materials to systems of systems, inspection, computation and associated documentation are a requirement for decisions regarding potential safety issues, reliability, and remaining service life/requisite repairs
- Operational impacts forecasting, projecting the various loads and conditions, including combinationally a device will be subjected to operationally
- Crash proofing, flying while hurt, identify safe local landing areas and using backup flight controls and lift land versus crash
- Continual study of previous reliability, safety experiences, issues, instantiations, crashes, knowledgeability, National Transportation Safety Board (NTSB) data bases, NASA lessons learned, and the nuclear weapons stockpile stewardship efforts
- Cost reductions to afford greater safety/reliability, the usual major metrics are cost and functionality, it is often possible, if cost is reduced, to employ the savings, or a portion thereof, to improve safety

PAV Electron Protection

PAVS, as is the case now for human civilization on the planet, are wholly dependent on electrons or electronics. These can be attrited in many ways including cyber/software, jamming and EMP (electromagnetic pulse). Cyber is a major problem; nearly everything at this point has been “hacked” at all levels, with massive implications including the loss of personal, industrial, and national security information and operability (including via ransomware). As a result, encryption is increasingly used with the ongoing development of quantum technologies proffering both decryption of current encryption approaches and a much more robust quantum-based encryption technology. Much of the software, hardware, and firmware is built elsewhere and there are many errors therein, some that are difficult to determine and that can proffer access. There are huge efforts, both private and governmental, to try to ensure the security of software. Vulnerabilities can be reduced, cyber-attacks can be made more difficult, but at this point there are no panaceas. Therefore, backups are needed. Jamming is straightforward. An effective jammer for GPS, due to its ultra-low signal strength, is the size of a pen top. GPS is the go-to navigation approach for PAVS and very much else. Therefore, alternative navigation approaches are of interest. The most straight forward of such is utilizing fixed, known E-M emitters such as TV towers. There are other options, but this one is the most economical and is accurate. EMP is interesting; at one time there was concern and research regarding flight over high voltage power lines and electronic equipment. As the electronic feature size has reduced over the years, it is becoming possible to disable circuitry with less energy than before. A worrisome source of EMP is solar storms such as the Carrington event. This event, according to the congressional EMP commission, could affect the large transformers and much else, couple into the long lines and result over just a year in huge loss of life. We are that dependent now on electrons.

So, what can be done to protect electrons for operability and provide communication? For EMP, the solution is faraday cages and decouplers. These are not inexpensive, but effective. For jamming, alternative frequency operation or optical and photons vice electrons, make it harder to jam optical communications. For cyber, there is an extensive suite of approaches, with the most effective based on quantum mechanics. One such approach is quantum crypto, which has far more secure encryption. The other is nascent but a breakthrough in cyber security, based upon utilization of vector, scaler potential quantum signals [ref. 37]. This is not E-M, cannot be detected, jammed, or co-opted, has high band width, and even works through water.

PAV Technologies

It is the enabling technologies and their ever-decreasing costs which are responsible for the current major progress, even after a century since the concept of a flying car was put forth. Chief among these technologies is the IT revolution, ongoing since the 60s, which has miniaturized and reduced the costs of avionics and communications by orders of magnitude, produced computers, and with developments in AI, is well on the way to trusted autonomy. Other major enabling PAV technologies include lightweight composite materials, computation for design optimization, printing manufacture for cost and weight reduction, low-cost green renewable energy, electrical propulsion, advanced batteries, and miniaturized sensors. These technologies, not heretofore available together can and are providing the infrastructures and affordable vehicles required for a viable, safe, and affordable revolution in personal transportation. The major market drivers are safety, cost, and operability. For safety/ATM and utilization, trusted autonomy is essential throughout for serious market buildout. The development of GANS and other approaches to machine ideation, enabling successful operation in the presence of unknown unknowns and obviation of human operation, is the key technology to open the PAV market to everyone, not just those with the time, health, and treasure to become pilots. The battery technologies are moving beyond lithium ion to factors greater energy density, enabling lower weight/cost and greater range. Overall, the nearly perfect nexus of the maturation of multiple frontier technologies, a burgeoning market driven to escape from current ground transportation near gridlock, loss of time in traffic, miniaturization, and manufacturing cost reduction technologies.

Concluding Remarks - PAV Societal Impacts

There are major obvious societal impacts of a PAV buildout with vehicles operable, safely, affordably, and quietly, from a local holding or street. These impacts include much faster and longer commutes, as on-board energy density/vehicle range improves, ever greater encroachment upon scheduled domestic air travel, with trusted autonomy operation, reduced carnage on the roads, major cost reductions for ground transportation infrastructures, including roads and bridges, reduced flooding desiccation, and heat islands. Then there is the shift to living off roads.

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 their 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 effective do-it-yourself independent living. With tele-everything, folks can, and many now do, live wherever they want, such as on mountaintop acreage. 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 (PAV) enable physical transportation without requiring road access to the homesite or fuels. With the bio revolution, it is possible to grow significant amounts of food on a small holding, where water can be drilled for, captured from rain, recycled, etc., potentially freeing homeowners from all the physical, electricity, road, and water grids. The development of massive numbers of low-Earth-orbiting satellites provides worldwide highspeed internet, with an emerging competition situation that should keep prices low. This provides superb communications for tele-everything without wires. The development of the already large gig economy, where employment is via the web, would add to the telework options in the rest of the economy. With tele-everything, we can do tele-education and telemedicine, as discussed. Then there is tele manufacturing or on-site printing. With carbon, hydrogen, and oxygen available on site, 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, and education. With a shift to prevention, medicine is affected as well. Such a shift back to the future to independent DIY living would have massive favorable impacts upon climate, the ecosystem, and the economic 1% and 99% inequity problem. The current econometrics associated with manufacturing, finance, fossil fuels, service industries, employment, etc., would be massively changed, with an option for nearly jobless independent living, and would 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 from agriculture to industrial. This high-tech-enabled back-to-the-land rebirth, with the technologies once envisioned for the greening of society now emerging, should be successful this time due to tech developments—if that is the way humans decide to live. The alternatives are “interesting” as we increasingly, in the present econometrics milieu, try to compete with the ever more intelligent machines—machines that can now ideate and create the heretofore touted last bastions of human exclusivity.

References

1. Rare Historical Photos, "The Weird History of Flying Cars", 1920 – 1970, https://rarehistoricalphotos.com/flying-cars-history/
2. Patches, Matt, "The Long, Weird History Of The Flying Car", Popular Mechanics, May 18, 2015, https://www.popularmechanics.com/technology/infrastructure/g2021/history-of-flying-car/
3. Hall, David, "Flying Cars: Why Haven't They Taken Off Yet?", The Guardian, 19 June, 2018, https://www.theguardian.com/technology/2018/jun/19/flying-cars-why-havent-they-taken-off-yet
4. Liu, Yaolong et al, "Overview of Recent Endeavors on Personal Air Vehicles: A Focus on The U.S. And Europe Led Research Activities", Progress In Aerospace Sciences, V. 91, May 2017, pp. 53 – 66
5. Roadable Times, "Flying Cars and Roadable Aircraft", http://ww.roadabletimes.com/index.html
6. Lineberger, Robin, et al, "Advanced Air Mobility, Can the United States Afford to Lose the Race", Deloitte Insights, 26 January 1021, https://www2.deloitte.com/us/en/insights/industry/aerospace-defense/advanced-air-mobility.html
7. Bushnell, Dennis M., "A Systems Approach to Enable True Trusted Autonomy", Professional Pilot, Nov. 2016
8. Bushnell, Dennis M., "Autonomous Systems", Professional Pilot, December 2015
9. Oster, Clinton V. & Strong, John S. & Zorn, Kurt, 2010. Why Airplanes Crash: Causes of Accidents Worldwide, https://ideas.repec.org/p/ags/ndtr10/207282.html, 51st Annual Transportation Research Forum, Arlington, Virginia, March 11-13, 2010, Transportation Forum.
10. Bushnell, Dennis M., "ATM For Many Millions of Flying Things: An Alternative Approach", NASA /TM-20205010812
11. Bushnell, Dennis M., "Enabling Electric Aircraft Applications and Approaches", NASA / TM-2018-220088, 2018.
12. Palopo, Kee, et al., "Shadow Mode Assessment Using Realistic Technologies for the National Airspace System [Smart NAS] Test Bed Development", AIAA 2015 – 2794, June 2015.
13. Rizzi, Stephen A. et al, "Urban Air Mobility Noise: Current Practice, Gaps and Recommendations", NASA / TP – 2020-5007433, 2020
14. Sadeghian, Mojtaba and Bandpy, Mofid Gorji, "Technologies for Aircraft Noise Reduction: A Review", Journal of Aeronautics and Aerospace Engineering, 2020, V. 9. Issue 1, https://www.longdom.org/open-access/technologies-for-aircraft-noise-reduction-a-review-47567.html
15. Bushnell, Dennis M. and Moses, Robert W., "Reliability, Safety, and Performance for Two Aerospace Revolutions – UAS/ODM And Commercial Deep Space", NASA/TM-2019-220274, 2019
16. Bushnell, Dennis M., "Weather Alert", Aerospace America, November 2020, pp. 38-40
17. Leithem, Scott and Soden, Richard, '" Reducing Cost in Satellite Development Through a Holistic Approach to Device Test". Design World, Dec. 7, 2017, https://www.designworldonline.com/reducing-cost-in-satellite-development-through-a-holistic-approach-to-device-test/
18. Wertz, James, "Commentary/Reinventing Space: Dramatically Reducing Space Mission Cost", Space News, Feb. 4, 2013, https://spacenews.com/reinventing-space-dramatically-reducing-space-mission-cost/
19. Marcacci. Silvio, "Plunging Renewable Energy Prices Mean U.S. Can Hit 90% Clean Energy By 2035 – AT NO EXTRA COST", Forbes, June 9, 2020,

https://www.forbes.com/sites/energyinnovation/2020/06/09/plunging-renewable-energy-prices-mean-us-can-hit-90-clean-electricity-by-2035at-no-extra-cost/?sh=34a97e372f9b
20. Hammelburger, Michael, "15 Cost Reduction Strategies for Your Business", The Bottom Line Group, 2021, https://thebottomlinegroup.com/15-cost-reduction-strategies-for-your-business/
21. Wild, Graham, Murray, John, Baxter, Glenn "Exploring Civil Drone Accidents and Incidents to Help Prevent Potential Air Disasters", Aerospace, 2016, 3,22, https://www.mdpi.com/2226-4310/3/3/22
22. Williams, Kevin W., A Summary of Unmanned Aircraft Accident/Incident Data: Human Factors Implications, DOT/FAA/AM-04/24, Dec. 04, https://apps.dtic.mil/dtic/tr/fulltext/u2/a460102.pdf
23. Asim, Mohammad, Ehsan, Nadeem, Rafique, Khalid, "Probable Cause Factors in UAV Accidents Based on Human Factor Analysis and Classification System", 27th International Congress of The Aeronautical Sciences, https://pdfs.semanticscholar.org/9963/90462b3baa7a7fa50584ef021a66035dd98a.pdf
24. Huber, Mark "Sikorsky Exec Stresses Urban Air Safety", 2018, https://www.ainonline.com/aviation-news/general-aviation/2018-05-01/sikorsky-execstresses-urban-air-safety
25. Battcher, Duane "9 Essential Facts About Drones", Property casualty.com, Dec. 5, 2017, https://www.ainonline.com/aviation-news/general-aviation/2018-05-01/sikorsky-execstresses-urban-air-safety
26. Hansen, George, et al., "Reliability of UAVs and DRONES", DSIAC, Spring 2017, Vol 4, no 2, https://www.dsiac.org/resources/journals/dsiac/spring-2017-volume-4-number-2/reliabilityuavs-and-drones
27. Susini, Alberto, "A Technocritical Review of Drones Crash Risk Probabilistic Consequences and Its Social Acceptance", Nov. 2015, RIMMA Conference, Berlin. https://www.researchgate.net/publication/291697791_A_Technocritical_Review_of_Drones_Crash_Risk_Probabilistic_Consequences_and_its_Societal_Acceptance
28. Embry-Riddle, "Drones Pose Increasing Risks to Aircraft", Oct. 2018, UAS vision.com, https://www.uasvision.com/2018/10/29/drones-pose-increasing-risks-to-aircraftembryriddle-study-confirms/
29. Lum, Christopher W. et al "Assessing and Estimating Risk of Operating Unmanned Serial Systems in Populated Areas", AIAA Paper 2011-6918, Sept. 2011.
30. Lum, Christopher W. and Waggoner, Blake "A Risk Based Paradigm and Model For Unmanned Aerial Systems in The National Airspace", AIAA paper 2011-1424, 2011
31. Paulitsch, Michael, et al, "Evidence-Based Security in Aerospace", 2012 IEEE 23rd International Symposium on Software Reliability Engineering Workshops, https://ieeexplore.ieee.org/document/6405409
32. Stamatelatos, Michael et al "Probabilistic Risk Assessment Procedures Guide for NASA Managers and Practitioners", NASA /SP-2011-3421, Dec 2011
33. Button, Keith, "Wringing Out the Risks", Aerospace America, March 2018, ppgs 17-21
34. FAA, "Guide to Probability of Failure Analysis for New Expendable Launch Vehicles", Version 1, Nov. 2005 https://www.faa.gov/about/office_org/headquarters_offices/ast/licenses_permits/media/Guide_Probability_Failure_110205.pdf
35. Podofillini, et al Editors "Safety and Reliability of Complex Engineered Systems", Sept. 2015, Proceedings of the 25th European Safety and Reliability Conference,
36. Kreinovich, Vladik, "Reliability Analysis for Aerospace Applications: Reducing Over-Conservative Expert Estimates in the Presence of Limited Data", http://www.cs.utep.edu/vladik/slides/moscow11industry.pdf

37. Puthoff, Harold E., “Communications Method and Apparatus Comprising Scalar and Vector Potentials Without Electromagnetic Fields”, U.S. Patent 5845220A, 1998