Civilian Aeronautical Futures – The Responsibly Imaginable

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Introduction

Since 1940 Aeronautics has had an immense impact upon Global Human lifestyles and affairs – in both the Civilian and Military arenas. During this period Long distance Train and Ship passenger transport were largely supplanted by Air Travel and Aviation assumed a dominant role in warfare. The early 1940's to the mid 1970's was a particularly productive period in terms of Aeronautical Technology. What is interesting is that, since the mid 1970's, the rate of Aeronautical Technological Progress has been far slower, the basic technology in nearly all of our current Aero Systems dates from the mid 70's or earlier. This is especially true in terms of Configuration Aerodynamics, Aeronautics appears to have "settled" on the 707, double delta and rotary wing as the approach of choice for Subsonic long haul, supersonic cruise and VTOL respectively. Obviously there have been variants and some niche digression from this/these but in the main Aeronautics, particularly civilian Aeronautics, has become a self-professed "mature", Increasingly "Commodity", Industry. The Industry is far along an existing/deployed technology curve and focused, now for decades, on incremental/evolutionary change – largely Appliers vs. developers of technology. This is, of course, in sharp contrast to the situation in the early-to-later 20th century where Aeronautics was viewed as A Major Technological Engine, much the way IT/Bio/Nano/Energetics/Quantum Technologies are viewed today. A search for Visionary Aeronautical "Futures" papers/projections indicates a decided dearth thereof over the last 20 plus years compared to the previous quarter Century.

Aeronautics is part of Aerospace and Aerospace [including Aeronautics] has seen major cutbacks over the last decades. Some numbers for the U.S. Aerospace Industry serve as examples. Order of 600,000 jobs lost, with some 180,000 more on the block over the next 10 years. Approximately 25% of the Aerospace workforce is eligible to retire and the average Engineer age is in the mid-50's. Firms such as Microsoft, Intel and Walmart are individually capitalized at a factor of 4 or more than the Aerospace industry as a whole. Aerospace Research levels are in the less than 5% range in terms of overall U.S. Research Investments. Industry editorial comments/observations include Poor Morale, "Mindless Cost Cutting," "Lack of Vision at the Top," and Technology Stagnation. A large percentage of U.S. Airlines are entering, in, or emerging from receivership, and

then there are the greatly increased costs of fuel with projections for even higher prices in the future. Overall, The Aeronautical Industry appears to be following in the steps of the earlier development Process and twilight exhibited by Ship and Train Technology.

This Aeronautical Industry assessment/situation is also in contrast to the IT industry, which has long been enjoying “Moores’ Law” and driving much of Human Technological Progress over recent decades. Computing has improved some factor of ten-to-the-ninth since ’59 on Silicon and as we leave Silicon and go to Bio, optical, Quantum, Nano and Molecular Computing there are projections of some 10-to-the-eighth to 10-to-the-12th to go. Optical Comms, both free-space and fiber, are making bandwidth nearly “free”. In addition there is the nascent development of effective and inexpensive Immersive Presence, Virtual Reality or Holographic projection with 5 senses capability, the haptic taste, touch and smell are patented. Tele-Travel, even before Virtual Reality/Immersive Presence and on the current flat screens, is providing a faster [at electronic speeds] and far more inexpensive in terms of both time and treasure alternative to “physical” travel/interactions. The major impacts of Tele-travel upon Aeronautics in the shorter term concern major projected reductions in Business Air Travel, responsible for much of whatever profits the Airlines are able to garner. Tele-travel provides a relatively recent and increasingly serious Civilian Air Travel “competition”. Also, IT, along with Bio and MEMS/Nano are enabling on-site manufacture of increasing intricate products via free form fabrication/ various forms of “printing” .This rapidly developing technology could in time erode the Air Freight side of Civilian Aeronautics.

Other Current Aeronautical “Problems” include Safety and, especially since “9/11”, Security Concerns, Noise strictures, Flight Delays, A U.S. DOD and DHS National Security Requirement to operate UAV’s etc. in controlled Air Space, exceedingly long TRANSPAC travel times [this going into the “Pacific Century] , and Warming/Emissions. The Emissions issues now include the “usual Suspects” [CO2,NOx] and Water Vapor/droplets/cirrus clouds. The deposition of water vapor above some 27K ft causes long residence cirrus clouds which alter the Earths’ Albedo. Burning [otherwise “clean”] Hydrogen Fuel would only exacerbate this water problem.

Overall, Civilian Aeronautics is, using a Nautical sailing Analogy, nearly stuck in “Irons”. A self-professed/self fulfilling prophecy Matur[ing] Industry beset with Multiple and increasing serious-to-potentially terminal problems. The present work attempts to suggest “ways forward” to essentially “Re-invent” Civilian Aeronautics and in the process greatly increase its’ Economic viability as an Industry whilst addressing the myriad problem areas.

Integrated Autonomous Airspace

"The Fundamental Key" to "Reinvention" of Civilian Aeronautics is an integrated Digital Airspace system enabling Autonomous Flight. Up until relatively recently the FAA in the U.S. was purportedly one of the few remaining major users of vacuum tubes. Current Air Traffic Control Systems are typified by "Marching Armies" of Human Controllers and various generations of Expensive-to-operate and Maintain Equipment .The existing systems are minimally-to-unable to cope even with existing Air Traffic, ATC delays are becoming common. The existing systems do not appear to scale well and in many cases have grown in a heterogeneous fashion with largely unknown non-linear behavioral characteristics. What is needed is a modern "Digital" Airspace which is triply redundant for "failsafe". The IT revolution[s], coupled with the Sensor and Comms advancements could enable such a system. The ever-reducing costs and ever-increasing capabilities for/of IT services and devices suggests that such a system is not a question of if but when and would probably be considerably less expensive, in terms of life-cycle costs, than the current paradigm.

Components of an "Automatic"/Robotic Digital Air Space System might include Fail-Safe Triply Redundant Nav – via GPS, INS, and utilization of Television Tower Signals. The requisite Communication infrastructure could include multiple SATCOM and, increasingly, free space optical comms. The Military Research and application experience in the areas of "Swarm" Technology and UAV/UCAV operations might also play a role. The system could be a combination of Autonomous free flight and centrally monitored with overall scheduling and deconfliction.

Such an advanced/automatic ATC/Nav/Operation system would allow utilization of UAV's etc. in "controlled" Air Space , prevent utilization of Aircraft as cruise missiles ala 9/11 and even obviate" CFIT" [Controlled Flight into Terrain"]. An examination of the causes of Aircraft Safety issues indicate most are due to "Human Error". Automatic Operation using the system capabilities emerging and in the pipeline might increase Air Transport Safety overall. The system would also "fix" the ATC delay problems and allow both energy saving and noise minimization flight operations. A future enabler for the latter, as well as greatly improving overall system flexibility and "weather" ops would be utilization of flow control and "morphing" to greatly increase the platform/aircraft operating "envelope" – approaching eventually "bird-like" Flight.

This "Integrated Autonomous Digital Airspace" would also enable civilian utilization of UAV's for robotic package delivery and Robotic/Autonomous Personal Air Vehicles [PAVE]. One of the major reasons why PAVE's were never

successful was a requirement that there be a ‘pilot”. The portion of the population with the time, health and treasure to be a pilot was/is not large. Automatic/robotic flight, i.e. UAV’s with passengers, removes that impediment to the next major increase in human mobility.

Personal Air Vehicles/Personal Air Transportation

Emerging Technologies along with the Integrated Autonomous digital Automatic flight-capable Airspace just briefly described enables serious [re]consideration of Personal Air vehicles. Such vehicles have been considered periodically at least since the 1920’s but were never deemed feasible – due to a combination of piloting requirement[s] and technology shortfalls. The current PAVE requirement set includes a Combination of fly/drive to avoid the necessity of airport utilization / major capitol investments and to avoid having to buy two [disparate] vehicles. Other requirements-to-nice to have[s] include < $50K, Super STOL [< 30M takeoff length], and of course Automatic operation.

Three generations/classes of such vehicles are probable. The/an initial version could be Robotic Package delivery using UAV’s, largely via civilian application of Military UAV investments. Once this is proven safe the UAV’s could become passenger-carrying , evolving into PAVE vehicles. An initial PAVE/Passenger-carrying UAV could be relatively modest in terms of air-side capability but tremendously useful/popular – a 2 carriage 100 Kn device to address the “Commuter” mission. The intent is to not let them fly “downtown” [the vision of many thousands converging on a sporting event is simply “not on” for awhile – quite a while], but there are now Myriads of “Satellite” semi-urban areas [e.g. Tysons Corner near Washington D.C.] where their Air Operation should be feasible, including bypass of the nearby infamous Interstate Intersection termed the “mixing bowl”. The third class of PAVE would have greater speed, range and carriage, including, with a few “pit stops”, Intercontinental Operations. There simply is FAR more [3-D] Airspace available than hyper-expensive and often highly congested [1-D] ribbons of concrete.

The implications of such vehicles are tremendous, including cost avoidance for new roads and bridges at some $40M/mile or so, Major land use changes/population decentralization, Accident Avoidance/ reduction of the “road Carnage” [some 45,000 lives lost on U.S. roads/year], and probable replacement of scheduled Air Service by go anytime/anywhere PAVE vehicles – much faster than the latency-plagued hub/spoke commercial system. In general, a true revolution in personal transportation not seen since the horse-to-auto change in the early 1900’s. Such vehicles would provide a, largely missing, convenient and rapid transportation system for Island Nations and portions of the Planets’ landmass

without intercity roads [many such]. Overall, the PC version/vision of Civilian Aviation as opposed to the current scheduled Airline “main Frame” version with an estimated yearly worldwide market in the Trillion Dollar Range. This overall projected market is composed of robotic Delivery vehicles, a military market for “Flying Humvees’, a Personal use market for both local and long[er] haul and a “Developing world” market where an inexpensive “electronic Infrastructure” could substitute and provide major cost avoidance for the otherwise requisite immense investments in roads and bridges. NASA studies of potential rotary wing PAVE vehicles indicated that Rotary wing approaches appeared to be too heavy, too expensive, too slow and, in general, not “stylish”. Subsequent NASA PAVE efforts indicated several alternative Aerodynamic configuration approaches perhaps the most interesting of which is the combination of Circulation Control and Ring Wing – not VTOL but certainly Super STOL [all that is required for Airport Independence, a 33 meter or so stretch of local roadway].

CTOL/”Subsonic” Long Haul

The stupendous success of long haul Civilian Aviation was largely due to the Military-inspired marriage of swept wings and gas turbine engines. This is commonly referred to as the 707 Paradigm and has constituted the basis and conventional wisdom of Long Haul Aircraft for some 5 Decades. This configuration is now quite far out on the maturation Plateau. Lift-to-Drag Ratio has been nearly flat for much of that time. The only major Range improvements accrued from increasing use, for both efficiency and acoustic s, of ever higher bypass Turbofans, not from Aerodynamics. Civilian Aviation is now beset with a myriad of problems including Emissions, Fuel Economy, Safety, Security, Noise, and “Airspace Productivity”. There is simply insufficient margin and flexibility in the “707” paradigm to enable viable and simultaneous solutions of the extant problem set. The current solution approach to these problems is a set of Individual Problem approaches/campaigns with little consideration for synergistic/overall solution possibilities. There are two “killer Ap” approaches to these problems, one is an Advanced Aerodynamic Configuration and the other is a high lift approach.

The advanced configuration is an externally Truss braced wing. CFD has now become sufficiently accurate to enable design of such a configuration without the adverse Interference drag expected from ad hoc designs. The external truss allows increases in wing span, major wing weight reductions and wing thickness reductions. The latter in turn allow major reductions in wing sweep which enables major realization of “Natural” Laminar Flow Viscous Drag Reduction. In addition, the truss enables wingtip placement of engines which, from Whitcombs data, considerably reduces Induced drag. The APU can provide circulation on the

vertical tail to increase vertical tail “lift” coefficient to handle tip “engine out”, to avoid “pin-wheeling”. Overall, such a strut-braced configuration should be capable of lift-to-drag improvements in the range of 50% plus, with attendant weight reductions.

The high lift approach is circulation control, wherein bleed air is injected downstream from just above the wing trailing edge to greatly increase Lift Co-efficient. This high lift approach synergistically combines the Aerodynamic and propulsion systems, an approach which the Military has long employed but which Civilian Aeronautics has thus far eschewed. Such a high lift approach has sufficient capability to enable, given wake vortex/flow control of various persuasions to mitigate the wake vortex hazard, simultaneous multiple landings and takeoffs on the same runway [or much shorter runway requirement[s]], thereby increasing airport/airspace productivity. In addition, the high lift approach should enable a configuration redesign for efficient cruise below 27kft, thereby obviating the cirrus cloud/water addition/warming problem./ Obviously flow control would be needed at cruise to provide reasonable ride quality “down there”, in the “weather”.

These configuration and high lift approaches synergistically mitigate Fuel Burn and increase Efficiency/economics, and Productivity while “solving” the [water] Emissions issue . The automatic/autonomous Airspace also addresses productivity as well as other Civilian transport problems such as security [“takeover”], safety and, with flow control, Acoustics. Farther term there are the potential revolutionary potential benefits of Structural Carbon Nano Tubes [some factor of 5+ dry weight reduction?] and fuel cell propulsion to obviate the remaining emissions issues [CO2,NOx]. Currently fuel cells are an order of magnitude too heavy for Civilian Transport propulsion utilization, but their performance is rapidly improving – making them a possible propulsion “player” in the out years.

TransPac Supersonics

Transpacific travel times are currently barely tolerable – in the 12 to 18 hour range depending upon city pair. Given the increasing economic and ppolitical importance of the Pacific Rim this/the current Air Travel paradigm is not satisfactory. There are two obvious “fixes” for this situation, aside from “Virtual Reality/Immerse Presence [which may well largely “win” in the end/as IT continues to improve]. The first of these is to make the passenger more comfortable during a 12 to 18 hours flight via providing more personal room and amenities – executable through use of the Blended Wing Body configuration currently under serious study in several countries. This configuration is quite efficient, due primarily to a reduction in [fuselage per se] wetted area and has

major volume increases compared to the 707 mantra. This is probably the most inexpensive Aeronautical approach.

The other approach is a viable supersonic Transport, viable in terms of economics as well as the various environmental issues – radiation, emissions, Ozone, and Acoustics. Supersonic Air Travel, due to the occurrence of additional shock wave drag, will always be less fuel efficient/more expensive than the subsonic option but there is a sizable market willing to pay a fare premium to accrue the "time savings". Whether this market is sufficient to launch a new aircraft is to be determined.

A major key to such a viable supersonic machine is Aerodynamic efficiency. Conventional Transport L/D is the order of 20, whereas the Concord value was ~ 7.3. The U.S. HSR effort resulted in a value of ~ 9.6, still far from sufficient. There are two Configuration approaches capable of providing sufficient L/D for efficient supersonic cruise – the R.T.Jones Yawed Wing for low supersonics and the Pfenninger strut-braced extreme arrow configuration for higher supersonic Mach Numbers. The Pfenninger machine provides minimization of wave drag due to lift, increased aspect ratio, mid-wing fuel canisters for favorable wave interference and load alleviation, low wing Reynolds Numbers for suction Laminar Flow Control and some "natural" laminar flow control on the fuselage and mid-wing canisters. Additional enabling technologies include automatic landings and 'chutes for refused takeoff in liu of heavy brakes to reduce the weight of the landing gear, the weight of which can be up to half of the fuselage weight for this class of aircraft. Another enabling technology could be the replacement of the usual "mixer-ejector" for takeoff noise reduction by the injection of liquid water/creation of water droplets within the noise-generating shear layers to disable the noise sources.For the HSR effort the noise-reducing mixer ejector was large and heavy with a large multiplicative effect upon overall vehicle weight. Additionally, flow control at cruise could be especially important for supersonics, enabling favorable wave interference, increased fuselage and upper surface lift and enhanced leading edge thrust. Overall, there is a more advanced technology suite, not explored in the HSR project, which should enable realization of a viable Transpac Supersonic Machine.

Summary

A non-evolutionary, non-near term view of the Futures of Civilian Aeronautics indicates that if we make the requisite Revolutionary Technology Changes across the Board – From the ATC system through configuration changes and Functionalities to Discipline and sub-system technologies, the Civilian Aeronautical Future appears very bright indeed. Major new markets, especially for personal aircraft could be enabled and most of the present, emerging and serious

environmental, safety, security, and productivity problems successfully addressed. However, at this point real and major revolutions and sea changes in conceptualization are required. Lacking such, if the current evolutionary, fix-it-as-it-lies approaches continue the projected futures are far less bright-to-potentially fairly horrific. It has been a long and successful “run” for Civilian Aviation, but the number and seriousness of the gathering problems and an apparent inability to successfully address them going forward indicates it is now [or fairly soon] time for “re-invention. There are sufficient concepts and horizon technologies extant to consider doing such. Reinvention Goals include:

- Safe, affordable, fast, convenient, personal air mobility [door-to-door] providing huge societal/governmental cost avoidance for roads/bridges, airports etc. and major savings in travel time and human lives.
- Scalable, convenient, enjoyable, safe, on-time, quiet, non-polluting, scheduled Commercial Air Transport