Faster and Greener-- Pocket Airports

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ABSTRACT

The potential aeronautical, environmental and societal benefits of on-demand, distributed, Green air travel are examined along with the urgencies and opportunities that pertain. A proposal is presented to rapidly bring about these benefits by extending NASA's Centennial Challenge for Aeronautics, the Green Flight Challenge (GFC), into a sequence of two additional flight competitions, GFC II and III. The necessary performance requirements for small aircraft to compete in GFC II and III, namely safe and quiet operations from pocket airports, are defined with respect to their potential to transform surface and air transportation. Feasibility of achieving these performance requirements and a review of the emerging technologies that enable them are presented in the Appendix. The proposed extension of the Green Flight Challenge is shown to be aligned with the goals of the 2010 NARDP as well as being complementary to commercial aviation's existing system, stakeholders and infrastructure.

ABBREVIATIONS:

CAFE: The Comparative Aircraft Flight Efficiency Foundation
C.A.F.E.: Corporate Average Fuel Economy, the U.S. MPG standard for cars
CTOL: Conventional take-off and landing
dBA: The decibel level of sound on the A-weighted scale, the scale pertinent to human perception
DOD: Department of Defense
DOT 500: Dept. of Transportation Federal Motor Vehicle Safety Standard No. 500 (49 CFR 571.500), for low speed 4 wheel residential vehicles of $\leq$ 25 mph.
DtD: "Door-to-door", referring to a trip's complete surface and air path from origin to destination
G: The acceleration due to gravity
GA: General aviation
GFC or GFC I: Green Flight Challenge, NASA's Centennial Challenge for aeronautics
GFC II: A proposed GFC for GQ V/ESTOL aircraft
GFC III: A proposed GFC for GQ V/ESTOL aircraft with autonomous flight capabilities
GQ: Green and quiet, as applied to aircraft with those attributes
Green: Environmentally-friendly in terms of emissions and energy use
IC: Internal combustion, referring to engines
LSA: Light Sport Aircraft, a special class of low-performance, 1320 pound aircraft
pMPG: Passenger miles per gallon, i.e., vehicle MPG x # of seats
NARDP: National Aeronautics Research and Development Plan, Feb. 2010, by NSTC
NSTC: National Science and Technology Council
RC: Radio-controlled, as in hobbyists' models
SF: San Francisco, California
STOL: Short take-off and landing
TSA: Transportation Security Administration
UAS: Unmanned aircraft system
UCSF: University of California at San Francisco
U.S.: United States of America
Vc: Cruise velocity
VMT: Vehicle miles traveled
VTOL: Vertical take-off and landing
V/ESTOL: Either vertical or extremely short take-off and landing

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INTRODUCTION

The most basic purpose of aviation is to travel fast without need of roads. Yet, after America's first Century of Flight, our hub and spoke air transportation system fails to fulfill that purpose for the very trips that people most often make--trips of less than 200 miles. By converging current and emerging technologies with a well-aimed technology prize program, this failure can be rapidly remedied. The remedy enables drastic reductions in the time and distance traveled between airport and destination doorstep. In our current built environment, the only feasible way achieve such reductions is by bringing forth a new class of small Green, Quiet, vertical or extremely short take off and landing (V/ESTOL) aircraft—the "GQ V/ESTOL aircraft". GQ V/ESTOL aircraft will be uniquely capable of operating at very small "pocket airports" that are within walking distance of one's destination doorstep. Such aircraft will be both faster and "Greener" than any other mode of transportation on trips of less than 200 miles.

This paper explains how such aircraft, operating on-demand at a distributed network of pocket airports, will eliminate the wasteful and *uncertain* delays of road gridlock and bring many other benefits. The feasibility and rationale for the sequence of prize competitions necessary to bring forth the GQ V/ESTOL aircraft are presented as logical extensions of the NASA Green Flight Challenge. The GQ V/ESTOL aircraft can be appropriately named "Suburban Air Vehicle" or SAV for short, because their safe, ultra-quiet, ultra-short runway capabilities accord them unique, unprecedented acceptability for operations in suburban areas.

NASA articulated the need for such aircraft in 2003[1,2] as the natural sequel to its AGATE, GAP and SATS programs. Due to the continued worsening of road gridlock, along with global warming and the quest for Green, that need has become even more urgent and compelling today. The decline in the last 2 years' in America's general aviation industry (**APPENDIX**) and the increasing emergence of competitors to it abroad make support for developing GQ V/ESTOL aircraft more timely than ever before. Accordingly, NASA Langley Research Center held a Colloquium on this topic on May 4, 2010.[3]

In October 2010, NASA's Langley Research Center convened its Aviation Unleashed Conference in Hampton, Virginia to explore the cutting edge technologies that will shape

aviation's future and to predict what that future will look like in 30 years. On-demand, point-to-point air travel in quiet, small aircraft that use pocket airports was unanimously predicted to have a large future role for trips of under 500 miles. Additionally, there was broad consensus that the internet, and other networking accelerators would exponentially speed progress in new air vehicle technology.

Fortunately, NASA has already begun such a process. Its Green Flight Challenge (GFC) aims to bring forth the future Green aircraft with a $1.65M flight competition for quiet, 200 passenger mile-per-gallon (pMPG) aircraft. As of August 2010, 9 teams have registered to compete in this "Prius of the Sky" competition. Innovative Design Proposals from these 9 teams have already been approved and registered to fly in the GFC competition. This important first step[4] toward a future of sustainable mobility freedom needs to be extended with a GFC II and GFC III to fully realize its goals and bring forth the SAV.

GFC II should be held in 2013, 2 years after GFC I, and should require that, in addition to achieving GFC I requirements, competing aircraft demonstrate extremely low noise levels along with vertical or extremely short take-off and landing capability (V/ESTOL). These latter two capabilities, along with computerized flight controls that make them very safe and easy to fly, will be essential for SAVs to be allowed to take off and land at pocket airports and finally achieve point-to-point air travel.

GFC III should follow 2 years after GFC II, and should require all of the GFC II capabilities. In addition, GFC III should require SAVs to demonstrate both manual and autonomous pinpoint landing, envelope protection and sense and avoid capabilities. As required in GFC I, all aircraft in GFC II and III should have a vehicle parachute.

Experience suggests that, to be effective in attracting sophisticated citizen innovators and university teams, GFC II and GFC III should each offer at least a $2M prize, amounting to $4M of funding over a 4 year period. This funding should be drawn from the $50M budgeted for Centennial Challenges over the next 5 years. GFC II and III should be announced as soon as possible in order to maximize the preparation time available for teams. The feasibility of combining *all* of the requirements of GFC I, II and III into one aircraft, while still achieving high cruise speed, is presented in the **APPENDIX** below.

The pocket airport's absolute requirement for ultra-low noise is a special case. It constrains the size of aircraft that can compete in the GFC Program. Each year since CAFE hosted the first-ever Electric Aircraft Symposium in 2007, it has become increasingly clear that the heretofore missing crucial capability for V/ESTOL aircraft, i.e., ultra-quiet operation, is finally within reach thanks to the rapid advance of electrical energy storage technology and the near-silent operation of electric motors. However, because noise inherently scales with power, achieving neighborhood-compatible, ultra-low noise operation will be the domain of smaller aircraft of 1 to 6 seats that can operate with small amounts of power. Considering the highly distributed destinations and low occupancy rate (typically 1.4 persons per car) of most road vehicles, this obligatory size

limit for the GQ V/ESTOL aircraft seems appropriate to its role and means that it is not necessary or desirable to scale up small SAVs into regional airliners.

If pocket airports are implemented on or very nearby large air carrier hub airports, the door-to-door trip speed and overall travel experience on airliners can be dramatically improved by eliminating lengthy ground travel delays. In addition, use of pocket airports can save enormous amounts of fuel and time wasted by vehicles that are stuck in road gridlock, both for the passengers in the SAVs as well as for the road travelers whose gridlock is eased by wide-spread use of such aircraft.

Today's small market in GA, its lack of capital, and the "Innovator's Dilemma" that prevents market-dominant companies from investing in disruptive technologies, all impede the development of GQ V/ESTOL aircraft. Such development therefore must begin with a technology prize-induced demonstration of their functional capabilities. As typically happens in new product markets, the basis on which such aircraft will be chosen by early adopters and consumers will evolve from function to reliability to convenience to price. As this process proceeds to lower prices that enable high volume production, NASA's Chief Scientist has forecast that this can become **"a potential Trillion Dollar Market".** Accordingly, GQ V/ESTOL aircraft could revitalize aviation, transform our transportation system, grow thousands of new jobs and bring many other societal benefits as described below.

A large network of pocket airports with thousands more aircraft operating from them will demand a modernized and automated air traffic control system such as that envisioned by JPDO for NextGen. An air traffic study undertaken at the request of NASA by the Rhinocorps battlefield simulation company[5] demonstrated that airspace in the vicinity of New York City could safely accommodate several hundred times its current level of traffic while still using human pilots who operated with conventional sense and avoid separation strategies. It is anticipated that a fully automatic air traffic routing system capable of dynamic route restructuring and autonomous flight separation could increase by an *additional* 2 orders of magnitude the high-capacity safe air traffic scenario modeled by Rhinocorps.

Marshaling the resources and talents of a global network of citizen innovators and universities to bring forth GQ V/ESTOL aircraft can make the Green Flight Challenge the most practical, efficient and valuable of any NASA Centennial Challenge. It can be a strong and much needed stimulus for STEM education. Extending GFC to GFC II and GFC III can be a signature achievement for the Obama Administration, similar to what the Apollo Program was for JFK, and the GFC vehicles will benefit millions of Americans for everyday travel. Other comparisons of the proposed GFC Program to the Apollo Program are revealing:

Cost:	Apollo $24B	GFC $5.65M
Missions:	Apollo 17 missions	GFC 3 missions
Time:	Apollo 14 years	GFC 5 years.

NASA GOES GREEN

In summer 2009, visionary leaders at NASA launched a technology prize squarely aimed at Greening aviation. It is the 2011 CAFE Green Flight Challenge (GFC), the largest cash prize ever offered in aviation. In summer, 2011, NASA will award $1.65M cash to the highest scoring "Prius of the Sky". These will be aircraft that are Green and Quiet—GQ aircraft. There are currently 9 teams enrolled in the GFC, including 2 from universities and several led by highly regarded aircraft designers.

The GQ aircraft in the GFC must demonstrate 100+ mph while achieving at least 200 passenger MPG. They must take off and clear a 50 foot tall obstacle in less than 2000 feet while emitting no more than 78 dBA, as measured 250 feet to the side of the runway. For safety, these aircraft must be capable of maintaining level flight at or below 52 mph and each aircraft must be equipped with a ballistic parachute.

Indications are that the GFC-winning aircraft will far surpass the required 100 mph/200 pMPG performance threshold by combining the best of today's technology. That achievement will attract consumers as well as global media attention. But the inaugural GFC—GFC I—is just the beginning of the needed Green transformation of aviation.

The "Prius of the Sky" aircraft resulting from the GFC I will need to become immune to surface gridlock by becoming able to quietly take off and land within walking distance of most destinations. This is the ideal goal for GFC II—quiet, fast Green Flight with vertical or extremely short take-off and landing (V/ESTOL) capability. V/ESTOL capability can be defined as being able to take off or land over a 50 foot tall obstacle in no more than 400 feet. Achieving such V/ESTOL with little or no reduction in cruise velocity (Vc), quietness and "Greenness" is an unprecedented challenge that will produce a truly game-changing aircraft—the Suburban Air Vehicle or SAV.

GFC I, in keeping with NASA's mission, is designed to advance aviation for the benefit of all. GFC II would leverage the benefits of GFC I into further advances of these several technologies:
- High-lift devices, long overdue in General Aviation
- Circulation control
- "Roll-out curtain" fabric lift-enhancing surfaces
- Morphing wings
- Channel-wing technology
- Electric motors with tilt-rotor capability
- Vectored thrust technology
- Powered lift
- Ultra-quiet propellers and ducted fans
- Goldschmied propulsion
- Alternative and hybrid energy sources
- High Power density motors and batteries
- Distributed propulsion
- Motor-in-wheel propulsion and braking

- Computerized stability and low-speed control
- V/STOL safety and reliability
- Nano-materials
- Drag reduction

THE IDEAL TECHNOLOGY PRIZE

The Green Flight Challenge is one of several NASA Centennial Challenge technology prize competitions, a program authorized by the U.S. Congress to rapidly advance and converge important new technologies. The Centennial Challenge Program relies upon non-government organizations such as the CAFE Foundation to host and conduct its competitions and provides zero funding to those host organizations. Consequently, host organizations are expected to solicit private donations or sponsors in order to administer the competitions.

To maximally succeed, each Centennial Challenge should strive for the attributes of an ideal technology prize. An ideal technology prize can be defined as follows:

- Transformative—opens a new paradigm
- Converges cutting-edge technologies
- Attracts many teams and national media
- Delivers huge leverage of prize funding invested (v. "procurement")
- Rapidly delivers benefits to the nation and its public
- Impeccable fairness without loopholes or "Parlor-tricks"
- Grows a new industry and jobs via private funding
- Leapfrogs stagnated products that a depressed market cannot reinvent
- Indelibly links its sponsor's name to the achievement
- Darwinian: inclusively draws from a large gene pool of citizen innovators
- Rewards "best of breed' rather than 'first to demonstrate'
- Equitably circumvents the innovator's dilemma
- Stimulates education in science, technology, engineering and mathmatics
- If phased, publishes all rules for all phases at the outset
      (Teams hate rules changes)
- Aims to benefit the masses, not the elite
- Is funded just enough, not extravagantly
- Offers its funder risk-free investing: No result, no prize paid

To achieve all of the above, the ideal technology prize needs a synchronicity of need and opportunity. Societal and global environmental needs must coincide with an array of

emerging technological possibilities. Such a synchronicity exists today as global warming, population growth, road gridlock, the need for energy independence through Green energy and society's increasing demand for speed coincide with the technological possibilities of electric propulsion, nano-structures, extreme high-lift mechanisms and advanced flight decks with haptic control and autonomous flight capabilities.

The ideal technology prize must be astutely-designed by a dedicated team of well-informed contest designers. They must craft what can and needs to be done, on what time scale and how to measure it accurately. This has been a core skill and focus of the CAFE Foundation since 1981, when it designed the CAFE 400 series of fuel efficiency competitions. CAFE and NASA collaboratively designed the 2007 Personal Air Vehicle Challenge and the 2008 General Aviation Technnology Challenge. In accordance with the impeccable 30 year safety record of the CAFE Foundation, both the 2007 and 2008 flight competitions proceeded without any injury, accident or protest and they successfully primed the aeronautical design community for the GFC.

The GFC was formulated and approved only after a great deal of joint planning by CAFE and NASA. Formulating the GFC II will demand similar attentive care. This should begin immediately in order for GFC II to build upon GFC I's momentum and media attention as well as to provide maximal preparation time for teams and extend the value of its name sponsor's "Green branding".

GFC events can be planned so that they can be safely conducted, and have the advantage that each competing aircraft must have an FAA Airworthiness Certificate and 40 hours of flight time before it can compete.

The goals of GFC II, like any ideal technology prize, would be best achieved by setting required performance thresholds and then rewarding the competitor that surpasses them by the largest margin. This "Best of Breed" approach increases participation and the variety of innovations explored compared to a "First-to-Demonstrate" format. A Best of Breed competition is more attractive to the media and hence more valuable to the competition's sponsor than "First-to-Demonstrate". The diversity of advances brought forth by the Best of Breed format are not rewarded *unless and until* they meet the judiciously-set game-changing thresholds demanded by the competition organizers. New thresholds to win synergistic gains in capabilities can become successor prizes, if desired. For example, the GFC III should demand GFC II-qualified SAVs that are also capable of fully autonomous flight.

The NASA and CAFE Foundation experience with designing and hosting the 2007 and 2008 Centennial Challenges and the GFC has shown that prize amounts of $1.5M to $2.0M can attract several all-new prototype aircraft from highly regarded designers and universities.

"SPEED IS WHAT SELLS AIRPLANES"

—Roy LoPresti

Time is a non-renewable resource. Many members of the multi-tasking "X Generation" and Millenial "Texting Generation" place high importance on saving time, as evidenced by their constant quest for faster laptops and internet service. Saving time demands speed. In order to attract a mass market, SAVs must provide DtD trip speeds that are at least twice that of any other form of transportation, and the faster the better. To accomplish this, SAVs will need cruise speeds of over 100 mph. Accordingly, the GFC requires at least 100 mph average speeds and each aircraft's score based in part on the average speed it achieves during its 200 mile 'race' flight.

In **Graph I, II and III** are presented the impressive time savings that could be obtained with the use of GQ V/ESTOL aircraft in a typical setting of metro gridlock. The graphs are based upon a DtD speed of just 22 mph for gridlocked metro surface traffic, the speed predicted to apply for such travel in the Los Angeles basin[1]. As shown in **Graph II**, the unavoidably long delays of single file surface travel by car or bus to and from conventional take off and landing (CTOL) and metro hub airports make the speed and range of existing airliner and CTOL aircraft almost irrelevant for the trips most people want to make—trips of 200 miles or less. Ground travel delays are now endemic in our built environment and, along with other factors, have severely depressed the market for CTOL aircraft today. With all due respect to the great Roy LoPresti, we must recognize that in the 21st Century, it will be the *DtD trip speed* that sells airplanes.
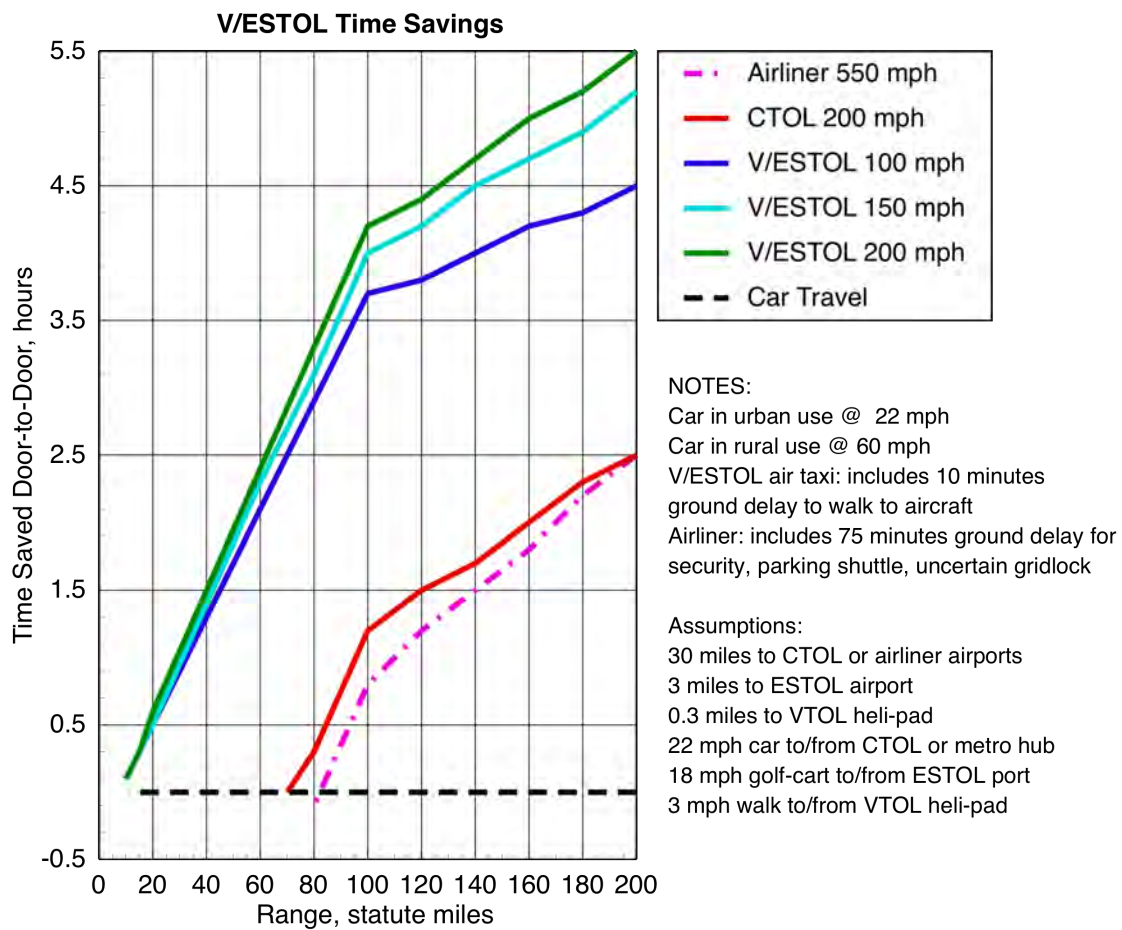
The only feasible way to enhance DtD trip speed is to develop aircraft suitable to operate at pocket airports. The fastest and best way to bring that about will be with a technology prize that extends the Green Flight Challenge to demand ultra-quiet GQ V/ESTOL aircraft. In order to seize and maintain the USA lead in aeronautics and the global market advantages that accords, these should be full scale aircraft that can carry people in reasonable comfort.

Accordingly, along with a stringent threshold requirement for ultra-low-noise (e.g. 60-65 dBA at 125 feet sideline distance at take off power), GFC II must reward Cruise Velocity (Vc) as one of its key metrics, with the other scoring metric being Take-off Distance. See **Graph IV**. The speeds and very low noise demanded in GFC II will demand aircraft with minimal drag and low power requirements and this may be more achievable in fixed-wing GQ ESTOL aircraft than in VTOL rotor-craft or powered lift vehicles. However, so as to not constrain innovation, all types that can meet the required qualifying metrics should be included and welcome in the GFC II.

GQ V/ESTOL BEATS CTOL

Graph I: (below) The Time Savings of V/ESTOL

A surprisingly large amount of time can be saved by V/ESTOL vehicles in air taxi service. The Time Saved Door-to-Door is highly dependent upon the ground travel time to and from the airport, both from one's departure doorstep and to one's destination doorstep. In the model presented in Graph I, V/ESTOL is the only aviation modality with substantial time savings relative to car travel on trips of less than 80 miles. Note that in a round-trip commute scenario, the amount of "Time Saved" shown on Graph I is doubled, such that on as short as a 50 mile commute, one can save over *3 hours per day*. If time is valued at $100/hour, that represents a $300 savings.

V/ESTOL Time Savings

Legend:
- Airliner 550 mph
- CTOL 200 mph
- V/ESTOL 100 mph
- V/ESTOL 150 mph
- V/ESTOL 200 mph
- Car Travel

NOTES:
Car in urban use @ 22 mph
Car in rural use @ 60 mph
V/ESTOL air taxi: includes 10 minutes ground delay to walk to aircraft
Airliner: includes 75 minutes ground delay for security, parking shuttle, uncertain gridlock

Assumptions:
30 miles to CTOL or airliner airports
3 miles to ESTOL airport
0.3 miles to VTOL heli-pad
22 mph car to/from CTOL or metro hub
18 mph golf-cart to/from ESTOL port
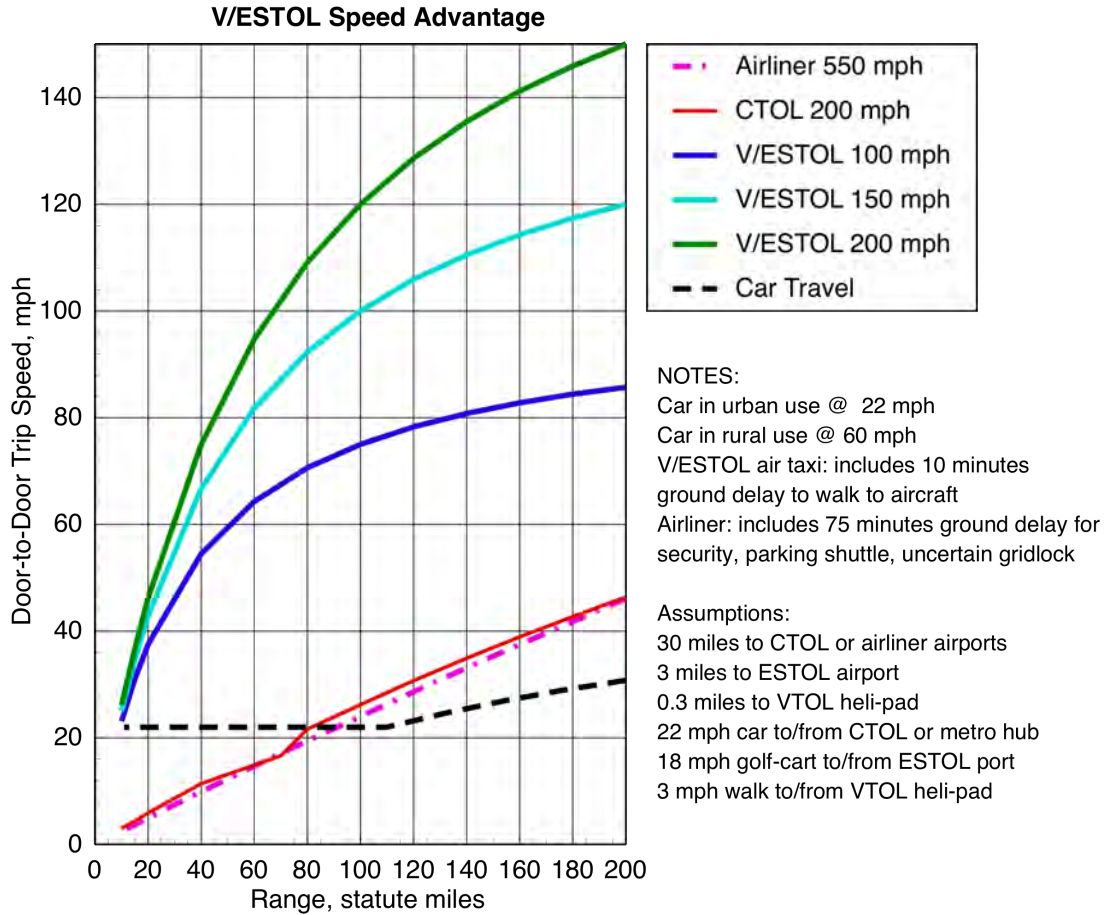3 mph walk to/from VTOL heli-pad

The time savings depicted in **Graph I** (above) varies according the type of airport being used. The typical conventional large airports for airliners and general aviation's conventional take-off and landing aircraft (CTOL) is presumed to be 30 miles distant. Future pocket airports are presumed to be < 3 miles distant if ESTOL and less than 0.3 miles distant if a VTOL helipad. Graph I is modeled upon a 22 mph freeway gridlocked car speed enroute to airliner or CTOL departure. It presumes an 18 mph golf cart on residential streets enroute to ESTOL departure and walking at 3 mph enroute to VTOL
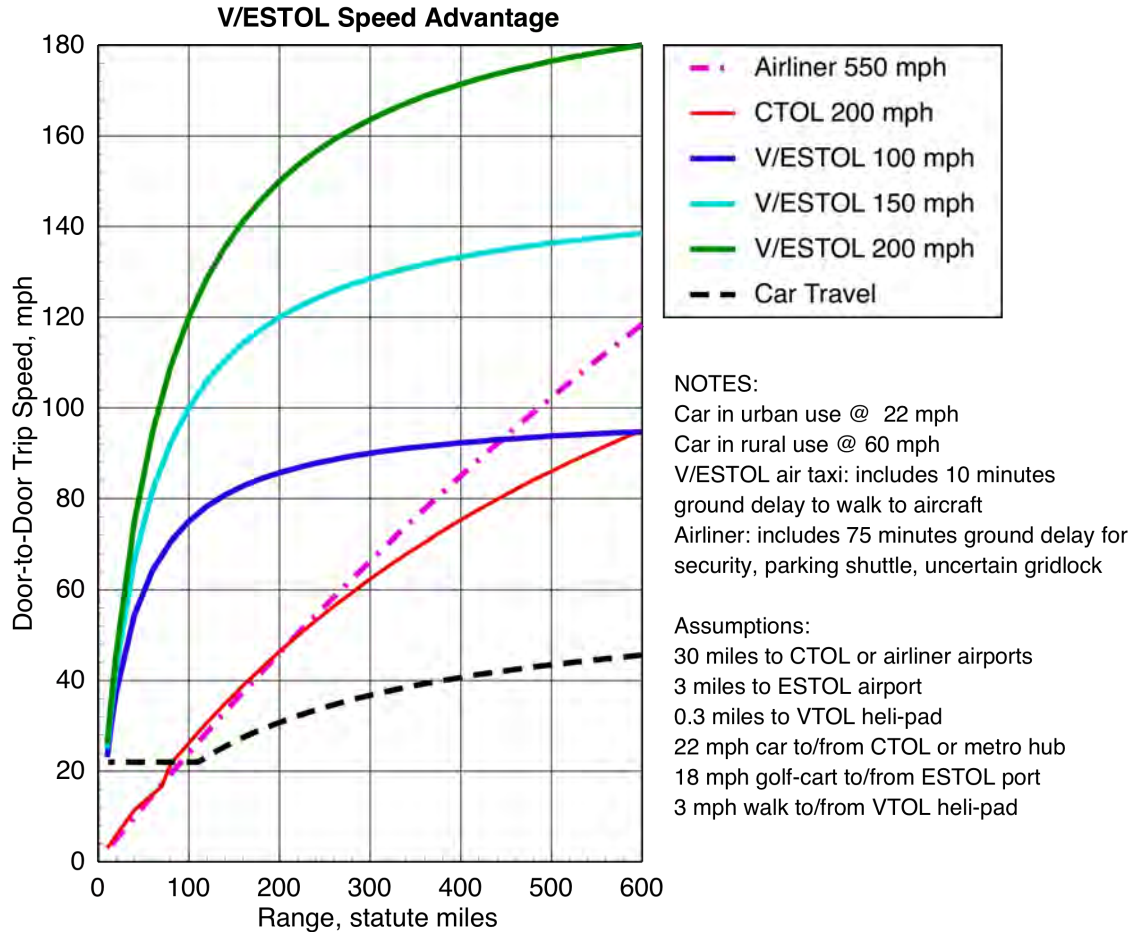
departure. The corresponding ground travel times will be 82 minutes for airliners and CTOL but only 6 minutes for both ESTOL and VTOL. Note that these times apply to both the ground travel trip to the airport as well as the one from the airport.

In **Graphs I, II and III**, the ground travel times are doubled to account for the travel to and from the airport involved in any *one-way trip* by air. This gives one-way ground travel times of 164 minutes for airliners and for CTOL and 12 minutes each for ESTOL and VTOL. The graphs also add an additional 75 minutes for each one-way flight by commercial airliner. This 75 minute delay does not apply to CTOL trips; it is due to airline baggage-check and shoes-off security check-in, park & fly shuttle, and the additional uncertain buffer time of 30 minutes for ground travel delays that one typically adds in order to assure not missing one's scheduled flight. Note that, with a *round trip* such as a daily commute by air, the ground travel time between the airport and one's doorstep must be *quadrupled*.

Graph II: (below) The Speed Advantage of V/ESTOL. Note that the Door-to-Door Trip Speed of the 100 mph V/ESTOL aircraft is *twice* that of cars, airliners and CTOL aircraft on trip lengths of between 40 miles and 160 miles. **Graph I** also shows that absence of advantage over a car for both airliner and CTOL travel on trips of less than 200 miles—the very length of trips that people most often make and the niche where the SAV can excel.

V/ESTOL Speed Advantage

NOTES:
Car in urban use @ 22 mph
Car in rural use @ 60 mph
V/ESTOL air taxi: includes 10 minutes ground delay to walk to aircraft
Airliner: includes 75 minutes ground delay for security, parking shuttle, uncertain gridlock

Assumptions:
30 miles to CTOL or airliner airports
3 miles to ESTOL airport
0.3 miles to VTOL heli-pad
22 mph car to/from CTOL or metro hub
18 mph golf-cart to/from ESTOL port
3 mph walk to/from VTOL heli-pad

Graph III: (below) The Speed Advantage of V/ESTOL. Note that the Door-to-Door Trip Speed of the 100 mph V/ESTOL aircraft surpasses that of cars, airliners and CTOL aircraft until trip length is more than 400 miles. The majority of all single and twin engine GA flights today are trips of under 400 miles.

V/ESTOL Speed Advantage

Legend:
- Airliner 550 mph
- CTOL 200 mph
- V/ESTOL 100 mph
- V/ESTOL 150 mph
- V/ESTOL 200 mph
- Car Travel

NOTES:
Car in urban use @ 22 mph
Car in rural use @ 60 mph
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30 miles to CTOL or airliner airports
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0.3 miles to VTOL heli-pad
22 mph car to/from CTOL or metro hub
18 mph golf-cart to/from ESTOL port
3 mph walk to/from VTOL heli-pad

(Axis labels: Door-to-Door Trip Speed, mph; Range, statute miles)

WHAT ABOUT FLYING CARS?

For decades, the dream of the flying car has attracted interest and yet failed to win a market. The criticism usually levied has been that flying cars have been mediocre cars and mediocre aircraft. Sadly, just when technology might enable a CTOL flying car to achieve satisfactory flight performance, the worsening gridlock that reigns between the CTOL airport and the destination robs its value as a time-saver. Creating Green, Quiet and V/ESTOL capabilities in a flying car imposes very difficult demands on a vehicle that is already burdened with the weight and performance penalties that attend automotive use. The GQ V/ESTOL capabilities are more valuable than the flying car capabilities because they enable the "last mile connectivity" for such aircraft to be achieved by walking, bicycle, golf cart, etc. rather than by a car that must use freeways and thus cannot escape the delays of gridlock.

Compromising the GQ V/ESTOL aircraft's performance in order for it to become a flying car is probably not necessary and should not be the primary goal of a technology prize. However, once the GQ V/ESTOL aircraft is proven, it may be valuable to add a subsequent prize for examples that can fold their wings and transform into DOT 500

compliant road vehicles that can drive 'the last mile' on residential streets at less than 25 mph.

WHY NOT ANOTHER CTOL PRIZE?

High fuel costs, high prices for new certificated aircraft, a global recession and increasing airspace/TSA restrictions have all added to the depressed market for CTOL aircraft. Cessna, Cirrus, Beech and Mooney have laid off thousands of workers. General aviation (GA) flight operations are down nearly 50% compared to the 1990s **(APPENDIX)** and there are nearly 50% fewer student pilots today than in the 1980s.

The GA market is nearly moribund. LSA sales have totaled only 1795 aircraft globally since their inception 4 years ago. GA sales are off 10% in the first half of 2010 compared to the abysmal sales volume of 2009.

A report by Thomas Frank in *USA Today* on September 17, 2009, entitled *"Feds keep little-used airports in business"* cited the large expenditures being made with tax funding to support under-utilized GA airports. GA advocacy groups had to defend small airports against Frank's attack, which in effect argued that such airports were no longer needed.

The public has recently expressed outrage at the use of private jets by CEOs of large companies that received government rescue funding. These jets are resented by the public as symbolic of a non-Green, privileged excess of luxury, expense and pollution. The public's sense of fairness expects that everyone should have to suffer the grind of gridlock as they do. If fast travel by air were affordably available to the general public, their resentment would likely subside. **But it cannot be truly fast unless it also becomes ultra-quiet V/ESTOL to reach close-by pocket airports.**

In the last 5 years, the emergence of CTOL Light Sport Aircraft (LSAs) and Very Light Jets (VLJs) have both failed to produce the hoped-for transformation of aviation. Despite expensive advertising hype for beautiful new small jets and innovative new LSAs, the annual sales of these aircraft number in the dozens instead of in the thousands. No matter how glitzy, these aircraft are not able to avoid the time wasted on ground travel to and from CTOL airports.

The adverse environmental footprint of CTOL aviation today is unsustainable. Its inefficient land-use, poor proximity to destination, toxic, lead-containing fuels, lack of pollution controls, high noise emissions and poor fuel efficiency all need to be remedied. The remedies need to come soon in order to avert loss of our nation's valuable network of CTOL airports. The GFC II can rapidly deliver such remedies.

HISTORICAL V/ESTOL SHORT-COMINGS

The game-changing new GQ aircraft must overcome the deficiencies that have prevented existing V/ESTOL aircraft from becoming popular. These deficiencies include:

- High noise emissions
- Unacceptably high cost
- Poor fuel economy, i.e., NOT Green
- Safety concerns
- Poor reliability
- High maintenance
- Low cruise speeds
- Resentment of perceived privilege
- The obstacle of flight training
- Lack of time savings

To solve the above deficiencies, the new breed of SAVs must correspondingly be very quiet, Green, ultra-efficient, accessible to most people and affordable. They must offer trip speeds that are substantially better than cars and must be easy to learn to fly. Their safety and runway requirements must be "neighborhood-compatible" for them to gain the crucially important close-in access to destinations. Global warming, peak-oil and our dependence upon foreign oil will increasingly demand that such future vehicles be Green.

This combination of vehicle capabilities is achievable with today's technology. See **APPENDIX.** However, creating such SAVs is beyond the means and market risk of small aircraft manufacturers. It is a highly challenging, breakthrough achievement that is ideal for a substantial, well-focused technology prize. A technology prize is far more cost-efficient than procurement funding as a way to bring forth such aircraft.

"Neighborhood-compatible" runway requirements mean ESTOL aircraft that can operate from airstrips that are ≤ 400-feet long, and VTOL aircraft that require less than 100-foot diameter landing sites. Mainly because of noise issues, small diameter VTOL landing sites have often been forbidden in residential areas. Due to local opposition, downtown San Francisco now has no active helipads. It has a few unused and former rooftop helipads that can only be used in emergencies.[6]

The opposition to VTOL landing sites means that, until VTOLs become much quieter, ESTOL and VTOL landing sites will continue to generally coincide and thus share equal proximity to destination. In addition, clearing a 50 foot obstacle after a take off distance of 250 feet and landing on a 100 foot diameter pad are essentially how helicopters operate today in order to stay out of the "dead-man's zone" of engine failure. Consequently, in the near-term future, it follows that VTOL capability be should accorded only slightly greater GFC II scoring value than ESTOL capability. See **Graph IV**, below.

Graph IV (below) A potential GFC II Scoring Formula

The formula for the simultaneous optimization of Speed and Take-off Distance needs to appropriately reward performance that is of practical value. Shortening the Take-off Distance to less than 100 feet offers very little practical advantage. Likewise, aircraft whose Take-off Distance over a 50 foot obstacle exceeds 400 feet will forfeit the benefit of pocket airports. The scoring formula must appropriately reward such attributes, as demonstrated in the **Graph IV** below. An aqua-colored vertical double-tipped arrow marks the 400 foot take-off scores. Note that all of these aircraft are required to achieve a very high passenger-MPG in order to qualify for GFC II, and this will make speeds above 160 mph difficult to achieve.

GFC II Proposed Scoring Formula:
Score rewards Cruise Speed (Vc) and Takeoff Distance (TD)

VTOL equivalent scores:
250 mph/400 feet
200 mph/300 feet
160 mph/200 feet
125 mph/100 feet
120 mph/50 feet

- Vc = 100 mph
- Vc = 120 mph
- Vc = 140 mph
- Vc = 160 mph
- Vc = 180 mph
- Vc = 200 mph
- Vc = 250 mph
- Vc = 300 mph

Lines of constant Vc

Notes:
Helipads are 50-100 ft diam.
Soccer fields are 350-400 ft long

STOL equivalent scores:
200 mph/900 feet
160 mph/700 feet
120 mph/500 feet
100 mph/400 feet

Takeoff Distance (TD) over a 50 foot obstacle, feet

$$1/((0.001*((TD/Vc)^3))+(1/Vc))$$

FIXED WING VERSUS POWERED LIFT V/ESTOLs

GQ V/ESTOL aircraft must be very lightweight and efficient. They must move a large mass of air downward at velocities that do not produce much noise. These demands for low thrust loading and light weight favor small, 1-2 seat electric-powered aircraft with transient high power density for take-off and low continuous power use during cruise flight. Since ground commuter vehicles typically carry an average of only 1.4 persons, a 1-2 seat aircraft can offer significant utility. Because of their suitability as "air taxis", heavier 4-6 seat V/ESTOL aircraft should be encouraged as well. These might deserve some allowance for greater noise due to the greater power needed for their increased gross weight.

As a DOD study has recently found[7], the quest for speed and the constraint of low thrust loading to limit noise mean that future V/ESTOL aircraft are likely to need to employ a hybrid design of fixed-wing plus some rotor lift. Such hybrids need a short runway rather than a helipad. The hybrid's fixed wing is needed to smoothly accelerate a large mass of air downward at a relatively low velocity, i.e., quietly, and its forward speed on the short runway provides the dynamic pressure necessary for such action. Ideally, the short runway can be built on a very small land parcel. Such a "pocket airport" could provide a short runway that is about 400 feet long, along with several spaces for aircraft parking and could occupy as little as 2 acres.

STABILITY AND CONTROL REQUIREMENTS

To use very short runways, aircraft must be able to accelerate quickly during take-off and then climb out at a steep angle. They must be capable of controlled flight during a slow-speed, steep glideslope on final approach to landing even in gusty conditions. To use a pocket airport, the landing touchdown must be precise without overshoot or undershoot. The hybrid of fixed-wing plus rotors that augment low-speed control, as well as wing spoilers, could achieve such performance. Small, RC models have demonstrated this[8]. Full-scale versions of such hybrids would almost certainly require computer-aided stability and control in order to handle strong gusts and crosswinds that, at low speeds, can rival dynamic pressure in magnitude. Such computer-aided control would give a valuable head-start toward precise, autonomous flight for these vehicles, a feature that they will need in order to become popularly accepted, and one that should be the goal of GFC III.

SURFACE GRIDLOCK: BOUND TO GET WORSE

Experts predict that ground travel delays due to surface gridlock will get substantially worse in the next 20 years. Door-to-door trip speeds in the Los Angeles Basin, for example, are predicted to be just 22 mph in the next 10 years.[1] Tom Vanderbilt, in *"Traffic"*, page 15, points out that "We (Americans) spend more on driving than on food or health care. There are more cars than citizens." He goes on to point out that "The average American, 2005, spent 38 hours annually stuck in traffic." Daniel Sperling,

Director of the Institute for Transportation Studies at UC Davis, states in his book "Two Billion Cars"[9]:

"Virtually all attempts to get Americans out of their cars have failed."

Due to the runway length requirements and noise footprint of today's GA and air carrier aircraft, large CTOL and metro airports are usually relegated to locations tens of miles outside town centers. This sentences most of today's air travelers to suffer the increasing delays of gridlocked commuter highways to reach their destinations.

Our interdependencies and continuing population growth make the trend to gridlock appear inexorable. Even when and if all cars become electric vehicles, the gridlock will remain. The growth in surface vehicles and VMT prominently outstrips the growth in population (See **Figure 2.5**, below). The rate of increase in the number of cars is likely to continue to outpace the capacity growth of our highways, whose average cost is $20M per mile.

38   TWO BILLION CARS
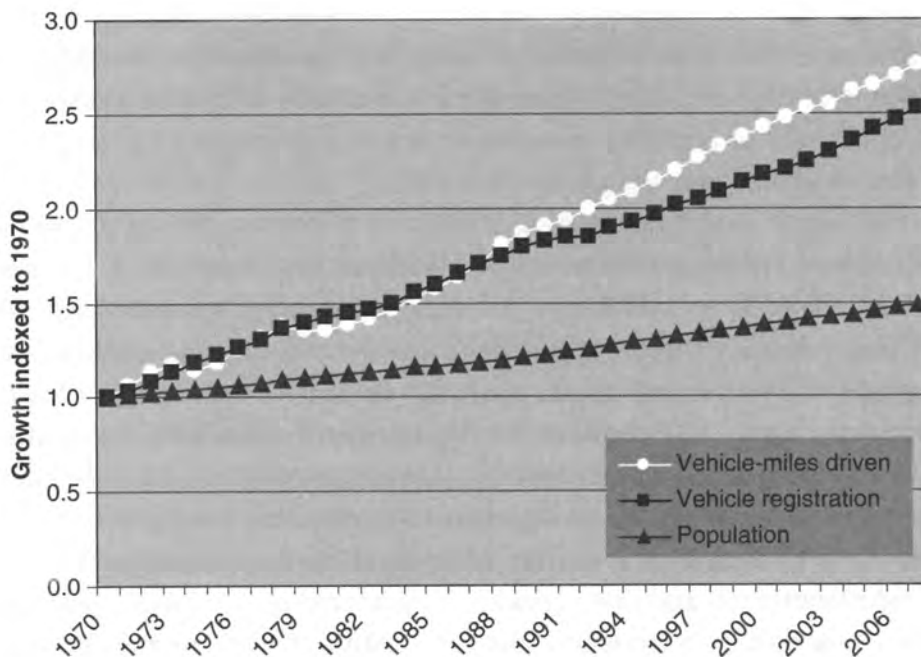
FIGURE 2.5 Growth of vehicle miles traveled (VMT), vehicle registration, and population in the United States since 1970. *Source*: Oak Ridge National Laboratory, *Transportation Energy Data Book: Edition 26*, tables 3.3, 3.4, and 8.1 (Washington, DC: U.S. Department of Energy), 2007.

Figure 2.5, above[8].

Planners find that the public is very resistant to giving up the security and autonomy of their cars. People place high value on privacy and personal space. Recent brain imaging

studies confirm that human brains have innate 'hard-wired' alarms that are activated when personal boundaries are violated. See: Dr. Daniel Kennedy et al. Personal space regulation by the human amygdala. *Nature Neuroscience*, 2009; DOI: 10.1038/nn.2381 (Report from Cal Tech).

The public resists using public transit for other reasons too. Buses and trains are inherently constrained to the limitations of two-dimensional, single-file surface travel and they impose the added delay of multiple stops. People deem the waiting, transfer maze, delays and limited distribution of transit stations to be unacceptable.

These factors cast doubt on the likelihood that public transit solutions to gridlock will succeed. Indeed, public transit ridership is declining. A study by the Madison Institute of the future impact of high speed rail on reducing road use has made a similar, pessimistic forecast.[10] See **Figure 2.7**, below.
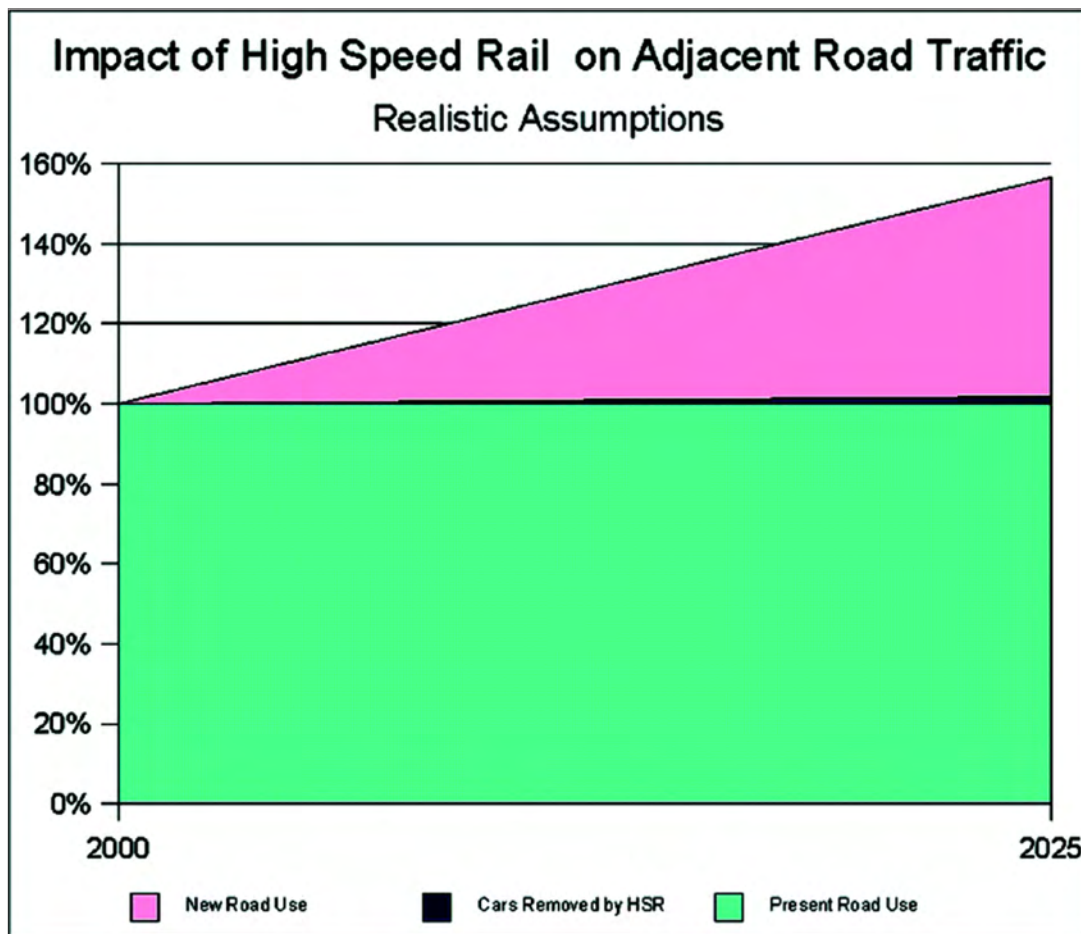
Figure 2.6

Unlike surface transportation, flying can provide highways in the sky with unlimited numbers of lanes and overpasses, off-ramps and merges. A highway in the sky is never blocked by accidents, toxic spills, "rubberneckers" or pedestrians. It can be dynamically reconfigured instantly and does not require public purchase of expensive land that must

be permanently removed from open spaces or any other use. Unlike paving with asphalt and the urban heat islands it creates, building aeronautical highways does not require millions of barrels of crude oil. The JPDO is already planning such pathways in America's NextGen air traffic system and similar efforts are underway in Australia.
http://www.jpdo.gov/nextgen.asp
http://www.smartskies.com.au/research/flighttrials/phaseone.jsp

THE POCKET AIRPORT CONCEPT

The transformation of aviation enabled by SAVs is predicated upon the concept of "pocket airports" and heliports, affordable parcels as small as 2 acres that can be situated within a very short distance from one's destination doorstep. That short distance, modeled here as just 3 miles or less, can be traveled by walking, biking, golf cart or DOT 500 vehicles on low-traffic residential streets.

The Pocket Airport
2 Acres, 418' x 208'
28 aircraft, 17 bikes, 14 golf carts

Runway 418' x 50'

14

Ground roll 236'

32

The stippled area represents the size of a standard football field
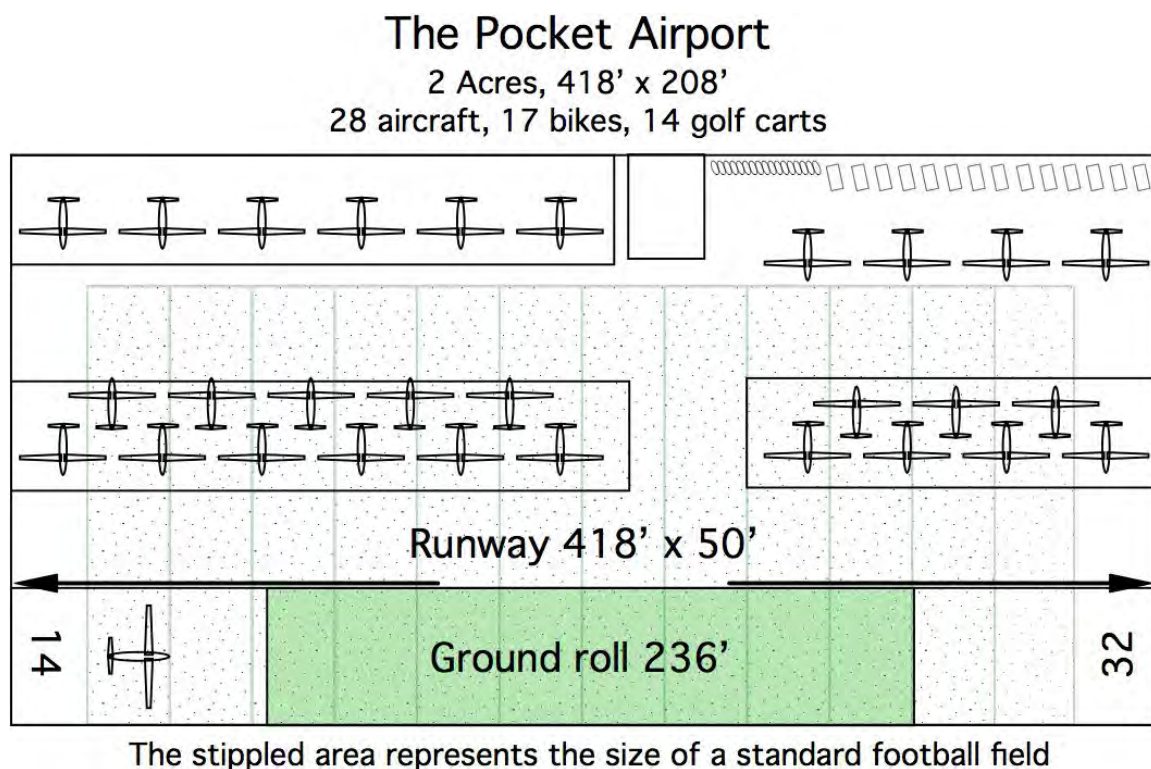
Figure 2.7 An idealized pocket airport.
Aircraft depicted are motor-gliders that have 50 foot wingspans

Pocket airports are designed exclusively for GQ V/ESTOL aircraft and will be built only after such future aircraft are created, proven safe and popularized. The popularization of GQ V/ESTOL aircraft will most likely begin with **air taxi** services into large corporate campuses and private residential airparks. This will demonstrate their great utility. Later, as flight deck automation and NextGen's air traffic control system matures and makes

flying easier, large numbers of non-professional pilots will personally adopt ownership and routine use of GQ V/ESTOL aircraft.

As shown in **Figure 2.7**, above, the air taxi pocket airport could be only slightly larger than a football playing field. The 236 foot ground roll shown above would give a 0.2 G deceleration to full stop from a touchdown speed of 38 mph. Such a small airport could be placed inside agricultural or urban greenbelt space, as depicted below in **Figure 2.8**.
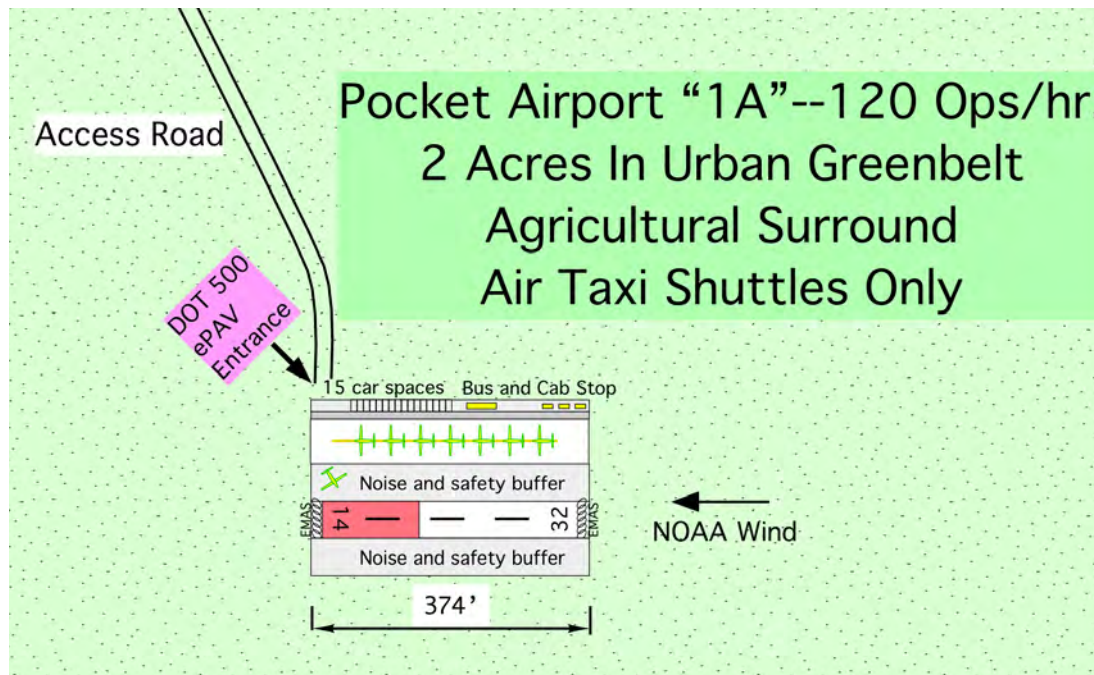

Figure 2.8 A small pocket airport inside a greenbelt.

Even with extremely quiet GQ aircraft, the 'downtown' pocket airport will need some amount of setback or noise buffer as well as runway clear zones. **Figure 2.9**, below, shows a 1200 foot long pocket airport that provides these extra features by having a take off runway and a landing runway that are in line but are separated by an overrun strip. This pocket airport could be a 2-story structure whose lower deck is an aircraft parking garage. It includes an entry 'driveway' for potential roadable DOT 500-compliant GQ aircraft that are able to fold their wings and drive on residential streets. The parking garage is an area suitable for 320 aircraft with folded wings. This 12 acre airport also provides 155 car parking spaces and a bus and cab curbside area.

Note that such a pocket airport would be 2 or 3 orders of magnitude smaller than other major airports listed in **Figure 2.9** and that it could provide 240 operations (i.e., take offs or landings) per hour. That could provide 480 operations during the 6 AM to 8 AM weekday commute hour.
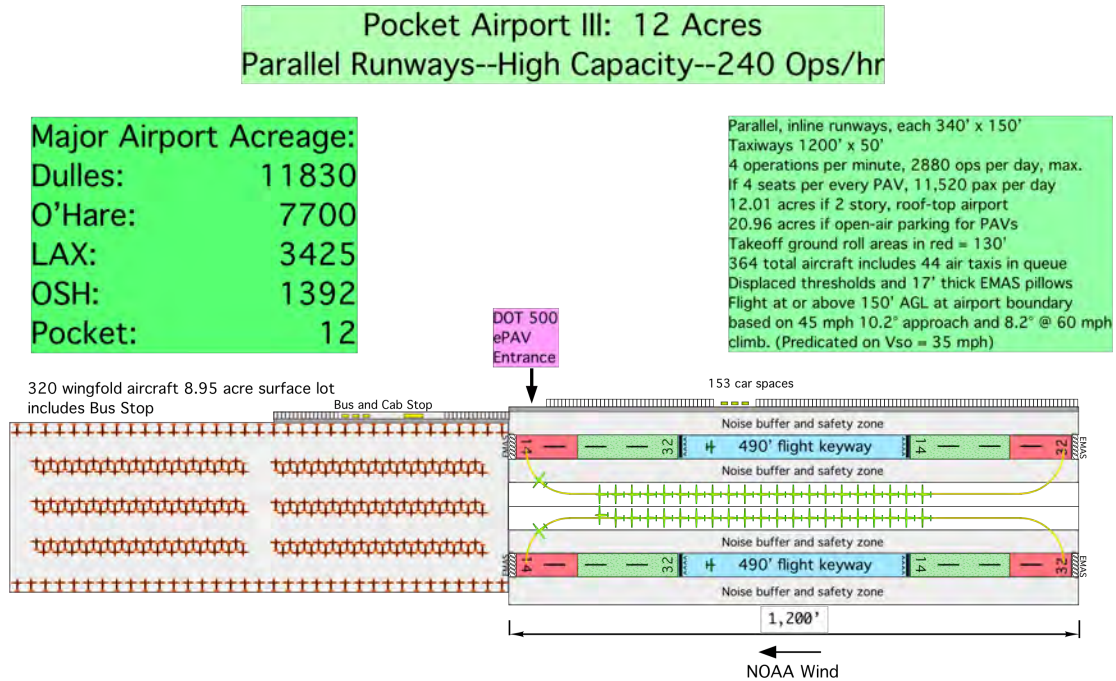
Pocket Airport III: 12 Acres
Parallel Runways--High Capacity--240 Ops/hr

Major Airport Acreage:
Dulles: 11830
O'Hare: 7700
LAX: 3425
OSH: 1392
Pocket: 12

Parallel, inline runways, each 340' x 150'
Taxiways 1200' x 50'
4 operations per minute, 2880 ops per day, max.
If 4 seats per every PAV, 11,520 pax per day
12.01 acres if 2 story, roof-top airport
20.96 acres if open-air parking for PAVs
Takeoff ground roll areas in red = 130'
364 total aircraft includes 44 air taxis in queue
Displaced thresholds and 17' thick EMAS pillows
Flight at or above 150' AGL at airport boundary
based on 45 mph 10.2° approach and 8.2° @ 60 mph
climb. (Predicated on Vso = 35 mph)

DOT 500 ePAV Entrance

320 wingfold aircraft 8.95 acre surface lot includes Bus Stop

Bus and Cab Stop

153 car spaces

490' flight keyway
490' flight keyway

Noise buffer and safety zone

1,200'

NOAA Wind

Figure 2.9. A high-capacity pocket airport

If desired and if space allows, an all-wind capable pocket airport could be designed using a triangular shape like that shown below in **Figure 2.9A**. This is a design that occupies 25 acres and is capable of 480 operations per hour. Its 490 foot flight keyway is a feature that helps assure that when aircraft fly across the airport's boundary, that they have achieved sufficient height above the ground to not disturb nearby residents. With the ultra low noise capability required in GFC II, a height above ground of 150 feet when crossing the airport boundary is likely to be sufficient to avoid noise complaints. For reference, the Matterhorn at Anaheim's Disneyland is 147 feet high.
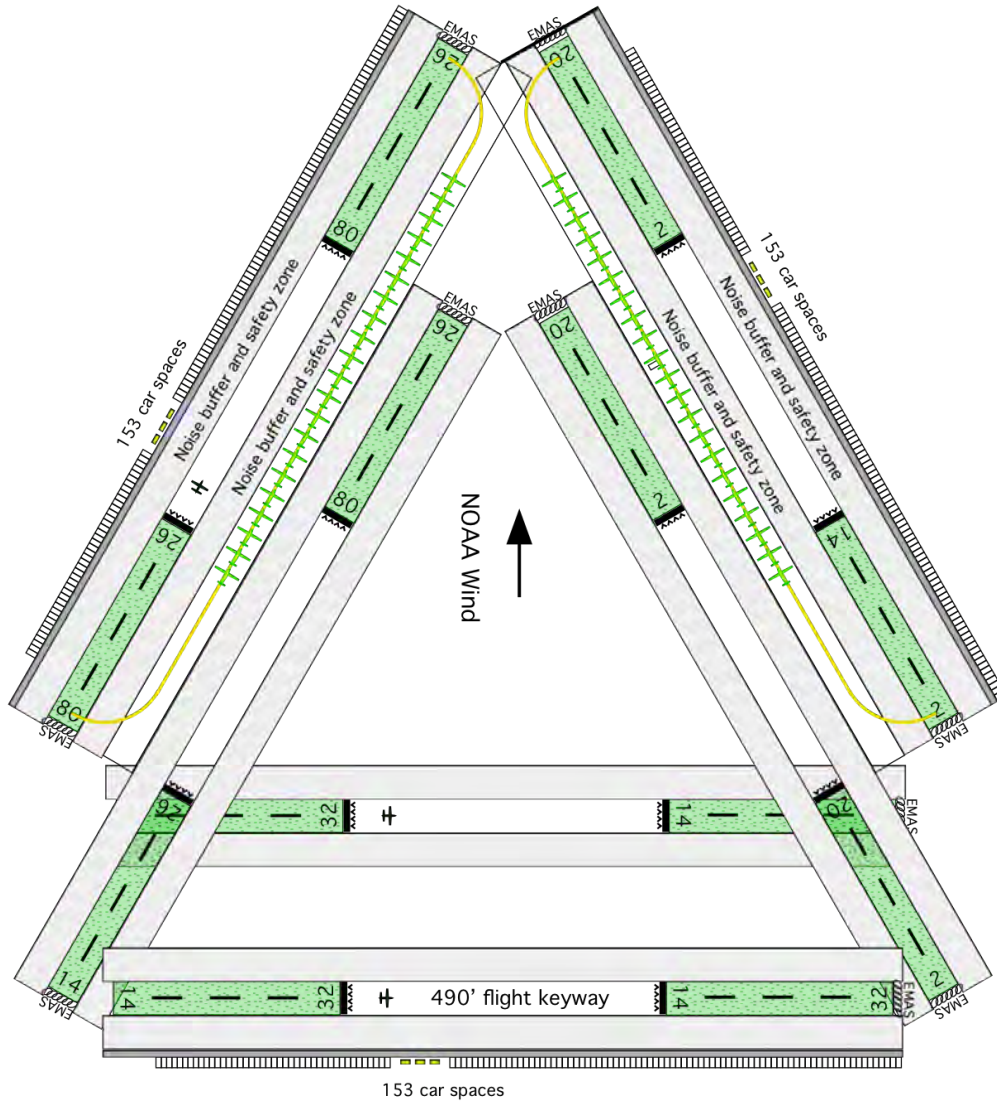
Figure 2.9A. A high-capacity, all-winds pocket airport

Figure 2.9B. A high-capacity pocket heliport of 7 acres.

Electric propulsion will soon enable vehicles that quietly perform vertical take off and landings using a heliport. A NASA version of this concept is shown above in **Figure 2.9B**. This heliport is designed for 120 operations per hour and includes adjacent

compatible businesses and aircraft storage. The photo below shows a NASA concept VTOL vehicle that could be used at such a pocket heliport.
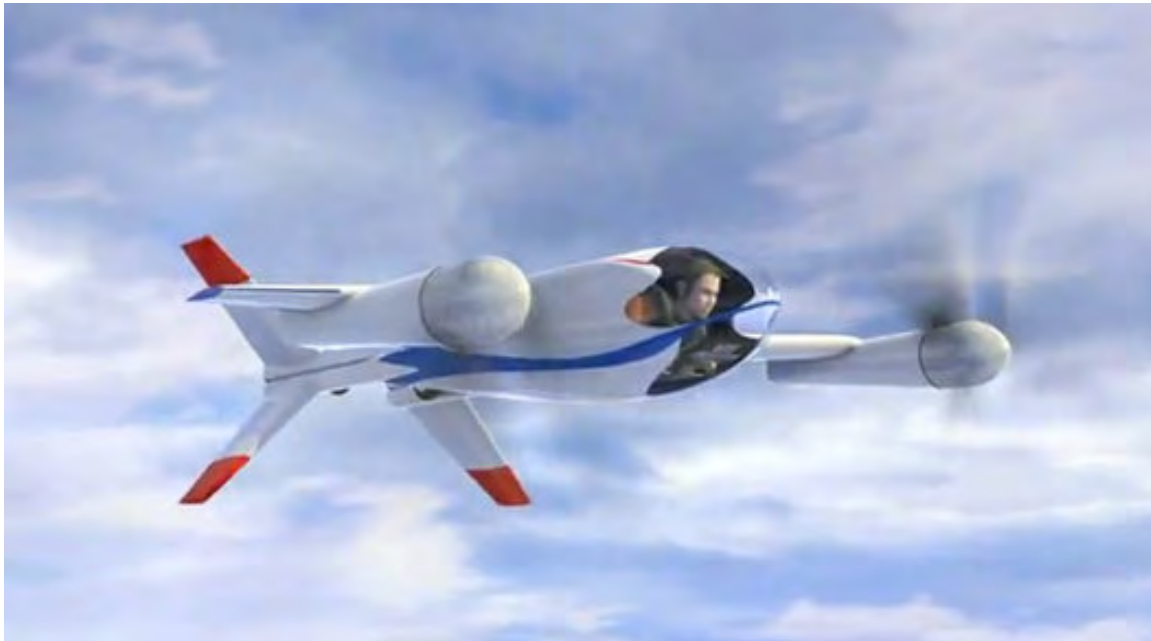
The pocket airport is analogous to the "pocket park" concept of the "New Urbanism"[11], where distributed small, walk-accessible neighborhood parks save having to drive to a more distant regional park. Once proven, pocket airports can sprout within walking distance of town centers. They will become the beacons of their neighborhoods, from which one could imagine, as one does standing on the shores of the Pacific Ocean, "from here, I could go anywhere".

Such opportunity for mobility freedom will help regional cities to preserve their urban growth boundaries by encouraging infill development. Pocket airports will also invite sustainable Green surface transportation such as low-speed, DOT 500-compliant electric vehicles, folding electric bikes, co-located mass transit stations, rentable bicycles as well as walking.[12, 13]

Walking and bicycling, epitomize "Green". They afford transportation, healthful exercise, and enjoyment while conserving fossil fuels, reducing toxic waste outputs, improving mind-body connection and physical vitality, and engaging people more fully in the experience of places. While human-powered travel modes are much slower than motorized travel, they are much more energy efficient, and their social, health, and especially environmental benefits make them now - more than ever – major Green. And adult human walking at 3 mph consumes energy at a rate equivalent to 290 MPG.

Walkable communities can address many of the nation's current public health concerns, including obesity, cardiovascular disease, diabetes, asthma, injury, depression, road rage, violence and social inequities. Walkability to bus/train transit, airport, market, shopping and job needs to become a priority. Land costs, existing development, tight government

budgets, limited open space and underutilization preclude building more large airports for conventional take-off and landing aircraft (CTOL). But 2-acre parcels where pocket airports could be affordably built can usually be found within 2 miles of most town centers. In the built environment of major metropolitan cities such as New York, Chicago, San Francisco and others, pocket airports could be implemented on the shore of the nearby bodies of water.

The absolute runway length needed by the SAV is an important parameter because of the inherent limitations on parcel size for pocket airports relative to their distance from 'downtown'. This is conceptualized in the graph below:

Airport Proximity and Noise

Generally,
people are willing
to walk 1/4 mile

Miles from airport to doorstep

Hours wasted in Gridlock, OR
Time Cost in hundreds of dollars

Available Parcel Size in Acres
(OR, 60 dBA noise footprint size)
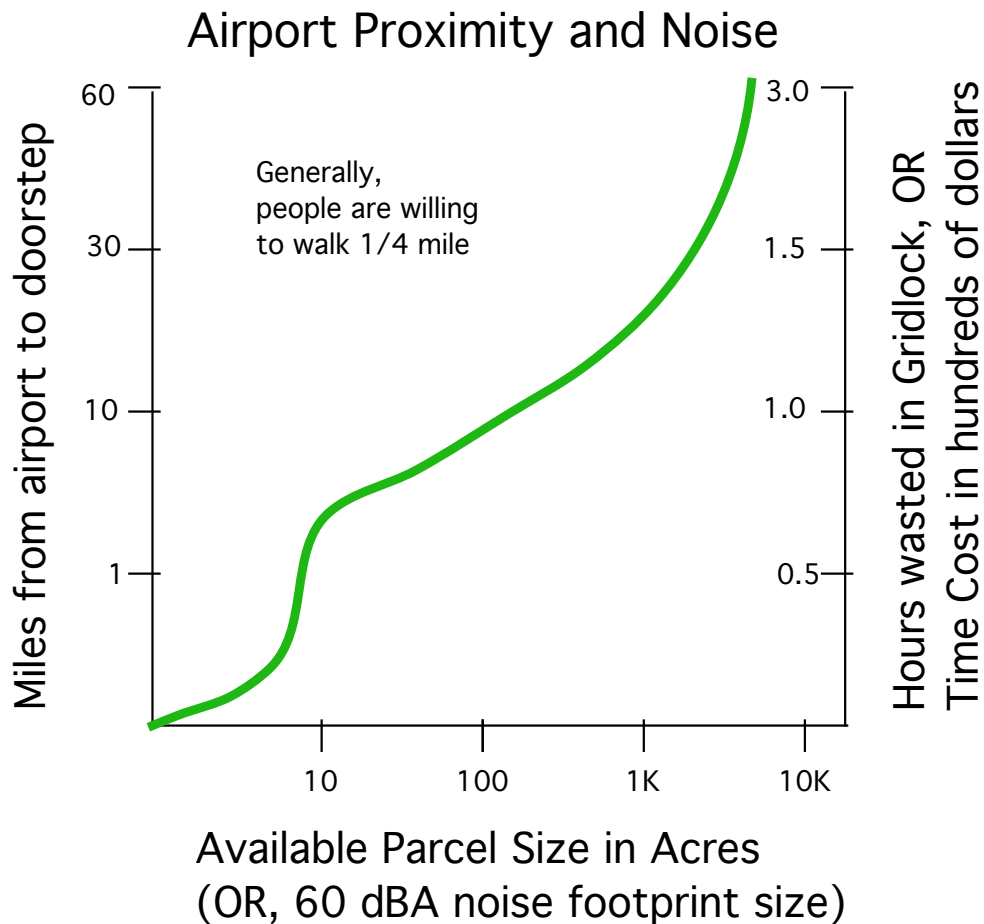
MAKING POCKET AIRPORTS SAFE

The pocket airport concept obviously will demand that the SAVs be extremely reliable and capable of precise spot landings. The electronic sensor, actuator and guidance hardware and software for such capabilities exist today and are becoming increasingly miniaturized and less expensive. (See **APPENDIX**). The operational safety of SAVs must surpass that of driving a car and should rival that of airline travel. Accident statistics and analysis ("The NALL Report" and NHTSB and NTSB) indicate that if the main

causes of small aircraft accidents, i.e., those due to pilot error, can be eliminated by advanced electronics, then the safety of SAVs could actually surpass that of the airline industry.

As our NextGen system becomes implemented, higher density operations at pocket airports could be enabled. One possible future operational model for the pocket airport is that of the virtual "portal". Each pocket airport could have both a departure and an arrival portal. Upon landing, an aircraft close to the airport would be flown by its human pilot through the arrival portal, at which point full automation would complete a pinpoint landing. Likewise, take off and climb out would proceed automatically until the aircraft passed through the departure portal, at which point the human pilot would assume control and fly a prescribed 4D trajectory (space plus time) to the destination airport's arrival portal. In the more distant future, as greater understanding of the ideal human-machine interface comes online, an alternative ratio of piloting and automation might supervene.

THE SONOMA-MARIN COUNTY COMMUTE MODEL

According to the Metropolitan Transportation Commission statistics, there are 88,500 road vehicles that cross either the Golden Gate Bridge or Richmond San Rafael Bridge every morning during commute hours in Northern California. Vehicles from Sonoma County comprise 13,500 of those morning bridge crossings. In accordance with traffic flow studies[14] that show gridlock to be relieved by as little as 4% reduction in vehicle traffic, it appears that removing 3500 of those 88,500 morning bridge crossings could undo the surface gridlock that plagues commuters there. That county's morning gridlock ranks as the second worst in all of Northern California.

Assuming the same average occupancy rate as surface traffic, 3500 commuting SAVs operating each morning from pocket airports in Sonoma County could undo the surface gridlock there. Simply put, this would entail 350 aircraft departures from each of 10 pocket airports. If those airports were like the 12 acre one drawn above (**Figure 2.9**) where 240 operations per hour are possible, each airport could depart its 350 aircraft in 1.5 hours, such as between 6:30 AM and 8:00 AM. Alternatively, a more distributed network of 20 smaller pocket airports could be used.

The already-existing 6 CTOL airports in Sonoma County, although somewhat remote from city centers, could make the county's future need for additional pocket airports more easily met.
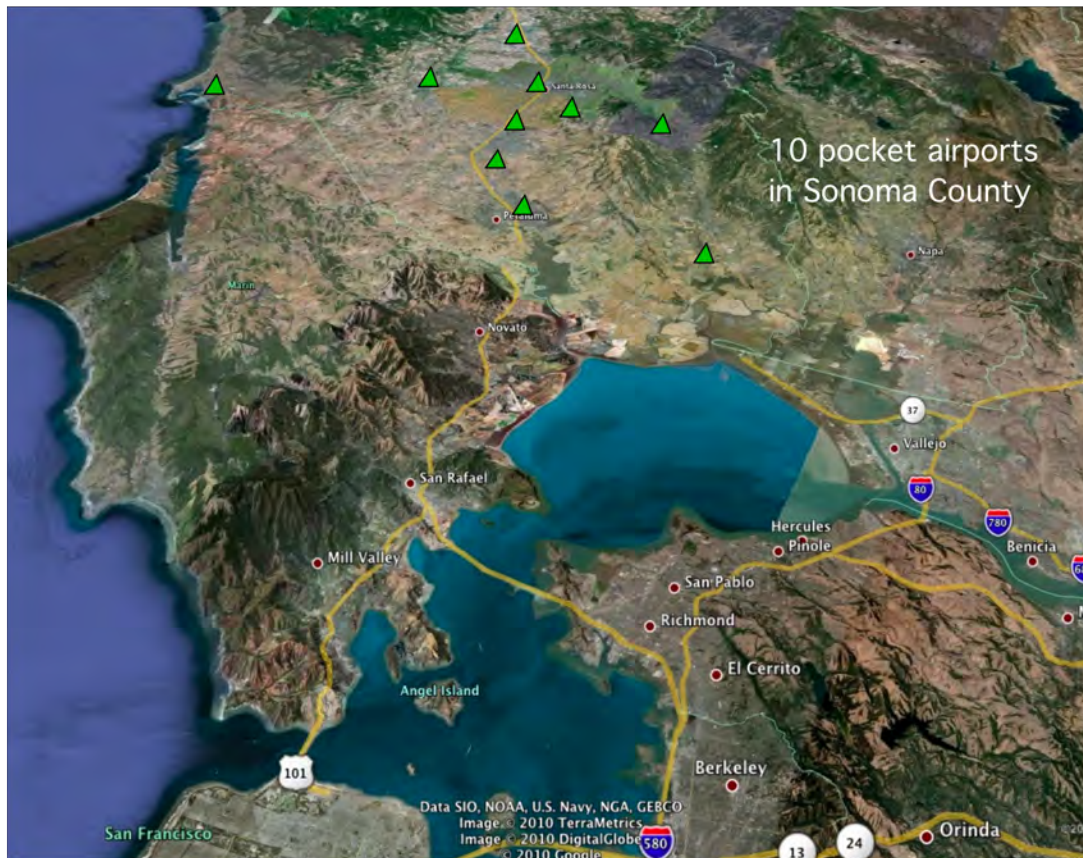
The network of pocket airport infrastructure necessary to realize this model would cost only a fraction of the cost of adding lanes to the existing freeways, which typically cost $20M per mile. These cost savings are even more impressive when compared to subsidized transit systems, as evidenced by the recent cost of a Bay Area Rapid Transit extension that cost $161M per mile. (http://sf.streetsblog.org/2010/06/22/bart-moves-ahead-with-oak-connecter-despite-civil-rights-violations/). Moreover, those traveling in the SAV would benefit with much faster, gridlock-free commutes compared to those traveling in cars. In addition, some of the airport construction costs could be offset by the revenue from renting SAV parking spaces.

In San Francisco, as shown in **Figure 3** below, the several sites at which pocket airports could be built would provide excellent walkable access to the city's major attractions.

Figure 3.

Potential Pocket Airports in San Francisco

1. Crissy Field, Exploratorium, Presidio	**6. Fillmore, Western Addition**
2. Ghirardelli Square, Fisherman's Wharf	**7. Kezar Stadium, UCSF Med Center**
3. Ferry Building, Financial District	**8. Sloat Blvd, SF Zoo**
4. SF Giants Stadium, China Basin	**9. Ocean Beach, Cliff House**
5. Cesar Chavez Street Wharf, Shipyard	**10. Baker Beach**

Note that most destinations on the above map of San Francisco lie within just 1 mile of a potential pocket airport and virtually no point lies more than 3 miles from a potential pocket airport.

Converting communities to pocket airports will in itself be powerfully Green. Eliminating nearly 2 hours and 60 miles of surface travel to metro airports, often involving fuel-wasting gridlock, could spare the need for more lanes on highways. It has been reported that in one year, Americans wasted 2.9 Billion gallons of gasoline while stuck in gridlock[13], much of it in metro areas near large hub airports. The value of the time wasted in traffic is incalculable but enormous. Pocket airports could greatly reduce such waste.

High energy efficiency and emission-free or bio-fueled aircraft will reduce carbon emissions. Distributed air travel, i.e., flying 'as the crow flies', shaves about 10% off of the trip miles a car or mass transit would entail.[15] These aspects of Greenness are independent of the actual MPG of the aircraft and might justify allowing SAVs to achieve less than the 200 pMPG demanded by GFC I.

Pocket airports offer a redundancy for airborne disaster relief and a more distributed system for Med-evac air ambulance. They are an ideal fit with Peter Calthorpe's[11] New Urbanism and its "transit-oriented development". The future of transportation is not more single file surface byways. It is not more cars or more lanes on the freeway.

GREEN FIELD AIRPORTS

Another iteration of Green Aviation is the "Green Field Airport", as conceived by Green Flight Challenge Team PC-Aero's Calin Gologan. This is a self-contained, small rural airport that is capable of producing the energy necessary for its aircraft using solar panels on the roof of its hangars. Its main purpose would be as a site for flight training, sport and recreational flying and as an access portal to remote areas. It could also serve as a reliever airport for the air traffic from pocket airports. An artist's conception of such an airport is given below:

SOCIETAL BENEFITS

Transforming our transportation system will produce many societal benefits, including growth in airspace capacity, greater mobility, faster trip speeds, enhanced safety, Green technology, jobs and manufacturing, along with inspiration for our next generation of young scientists, engineers and technology leaders. Pocket airports can make America more energy independent. SAVs could open a new market whose potential is predicted to approach $1 trillion[2]. This is perfectly aligned with NASA's mission of serving "for the benefit of all".

The GFC neatly aligns with the NSTC's 2010 National Aeronautics Research and Development Plan's (NARDP) stated goals to *"advance aeronautics research to improve aviation safety, air transportation, and reduce the environmental impacts of aviation; promote the advancement of fuel efficiency and energy independence in the aviation sector; and spur the development of innovative technologies that enable new products and services"*. It likewise fits with NASA's ERA project ("Environmentally Responsible Aviation") and with and the FAA's CLEEN Program. The single fastest way to achieve the NARDP goal to *"decrease the cost and time for the introduction of new aircraft"* will be by the mechanism of a technology prize that specifies the performance and capability requirements for such transformative aircraft and gets them flying as experimental prototypes rather awaiting fully certificated aircraft.

Landing site cost tends to be proportional to the square of the runway length. A CTOL airport with 5000 foot runways, though 10 times longer than a pocket airport with 500 foot runways, can cost 100 times more.

It is reported that in 1995 alone, the U.S. spent $95 billion on road building. Reducing the cost of road-building is a societal benefit that could enormously reduce the use of and dependency on fossil fuels. In 2004, NASA Chief Scientist Dennis Bushnell cited Arthur Clarke's 1984 quote that "The roads to support Autos cost as much as a small War and the casualties are on the same scale" as a reason to support future personal air travel. In that same presentation, he pointed to William Seifert's 1968 prediction that "Any form of transportation that offers the lowest door-to-door travel time will always drive out lower speed competing modes unless the economics of the higher speed system are grossly unfavorable".

V/ESTOL capability translates into safer aircraft whose very slow landing speeds allow them to land in very small spaces and thus find safe emergency landing sites nearly anywhere. These slower speeds also mean lower impact forces that result in fewer fatalities and less property damage from off-airport landings. It also means that emergency arresting devices (EMAS, giant pillows) placed at the ends of pocket airport runways can readily stop such vehicles with no harm. The small, light weight GQ aircraft are suitable for vehicle ballistic parachutes that can deploy and save occupants at heights as little as 200 feet above ground level. Belly mounted vehicle airbags are also possible with small vehicles. These benefits will enhance both consumer and neighbor acceptance of these vehicles.

Electric powered SAVs do not carry flammable liquid fuel and are thus less likely to involve fire in a crash.

GFC II PROPOSED REQUIREMENTS

GFC II can use much of the already NASA-approved team agreement of the Green Flight Challenge. It can eliminate its 52 mph stall speed requirement. It still must impose the 100 mph performance threshold and demand a high level of passenger MPG in order to rival future cars. Since 35.5 MPG for ostensibly 4 seat cars is the newest automotive U.S. C.A.F.E. Fleet Goal for 2016, GFC II could demand that all aircraft achieve at least 142 passenger MPG (4 x 35.5), for example.

To provide pocket airport compatibility, GFC II should require that all competing aircraft achieve a take-off distance over a 50 foot obstacle of ≤ 400 feet. The CAFE Foundation can measure Take-off Distance accurately and considers it a reasonably valid indicator of whether an aircraft can fulfill V/ESTOL requirements.

As mentioned above, a stringent low noise requirement must be applied in GFC II. The size of pocket airports would suggest that the expected distance from an aircraft to the neighboring residences will be as small as 125 feet. Since the FAA's guiding studies of noise levels considered tolerable by 90% of people indicate a need to keep noise below 60 dBA CNEL, It seems reasonable to require a noise limit of between 60-65 dBA at a 125 foot sideline distance for the GQ V/ESTOL that will compete in GFC II. See **Appendix, page 51.**

Winning GFC II will be more challenging, more expensive and more transformative than winning GFC I. Consequently, the cash prize for GFC II should be at least $2M. This size of award along with its "Best of Breed" format (as contrasted with "First to Demonstrate") incentivizes participation by a large number of teams, both private and from universities. In Best of Breed, all teams will get their chance to demonstrate, rather than becoming abortive efforts after a "First-to-Demonstrate" wins all. This increases the leverage and yield of the prize money invested as well as the diversity of innovations. Such diversity might be further enhanced by distributing the prize in diminishing amounts to the 2nd and 3rd place aircraft in the competition.

History teaches us that in technology prizes it is often the aspiring "amateur", non-corporate teams that make the most passionate and innovative efforts to win. Consequently, prize amounts of $10M or more are not needed or desirable.

To maximize the benefits of GFC II, it should be formulated and announced as soon as possible. By continuing the name "Green Flight Challenge", GFC II will increase the likelihood of major sponsorship support for both events, a key factor in their success. The lead time for GFC II should be at least 2 years in order to enable both GFC I and GFC II teams more time to modify, design and build ideal GQ V/ESTOL aircraft.

GFC II POSSIBLE DESIGNS

Some possible design concepts for the GFC II are pictured below:
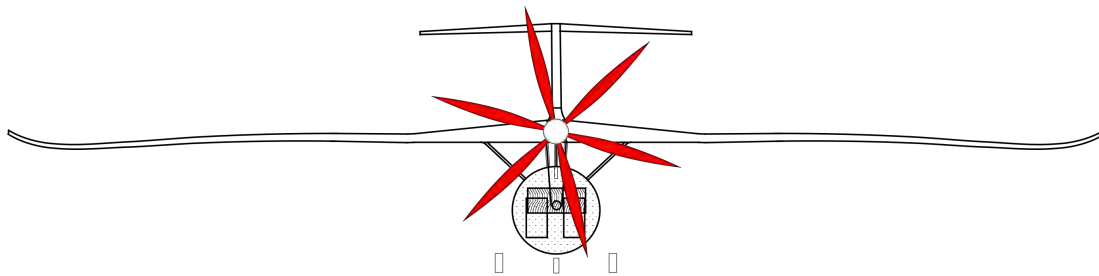
Such vehicles as these could achieve the extremely low noise, short take off and high fuel efficiency necessary to win the Green Flight Challenge II.

OTHER AERONAUTICAL CHALLENGES

The next aeronautical challenge, GFC II, should be for Green Quiet V/ESTOL aircraft that can achieve 200 mile range. Longer range (> 200 miles) for future affordable Green aircraft will evolve naturally from the market-driven advances in the energy storage density.

The ever-worsening and wasteful ground travel delays that attend all CTOL and hub airport use, combined with the high cost, high noise emissions, high carbon emissions and poor MPG of LSAs, VLJs and flying cars make these CTOL aircraft very unlikely to reach production volumes necessary to achieve the affordability requisite for societal impact. This makes it inappropriate to aim prize money toward any of those domains at this time.

The crucial importance of making SAVs safer and easier to use by adding robust computer-aided safety, reliability, pilot-assistance and precision landing capability should be the subject of a follow-on GFC III.

POLITICAL CONSIDERATIONS

The great promise of GQ V/ESTOL aircraft as a transportation solution is that they can **complement** commercial air travel by restoring its door-to-door trip speeds, by eliminating ground travel delays. The Green Flight Challenge program can efficiently promote such transformative aircraft as a path toward a potentially enormous new market. GFC can trump the Innovator's Dilemma that afflicts civil aviation today.

The purpose of a technology prize is to induce the most promising, urgent and transformative achievement that a risk-averse, capital-poor free market cannot otherwise produce. The ideal technology prize enhances networking and draws upon a large Darwinian 'gene pool' of knowledge that maximizes progress. Its result should be immediately recognizable by the public as game-changing and beneficial. It should recruit teams of talented individuals whose shared capabilities are synergistic and surpass those of any one innovator working in isolation.

The Green Flight Challenge can strengthen the lead in aerospace technology that America has held since the era of the Wright Brothers. That lead is clearly being threatened in today's global economy by the tremendous industrial growth in Asia. Three prominent "Sputnik" examples of this are the purchase by China of Superior Air Parts[16], the opening of a 260,000 square foot factory in Shanghai to produce the electric-powered Yuneec Aircraft[17] and the announcement of government sponsored technology prizes in several other countries.[18] Leaders in the White House, US Congress and at NASA should immediately recognize these trends and seize the opportunity to recapture America's lead by announcing the extension of the Green Flight Challenge into a 5 year program.

CONCLUSION

NASA's quest to make aviation Quiet and Green is embodied in the Green Flight Challenge (GFC). To maximize its benefits, the GFC should be extended to include both a GFC II that requires fast GQ V/ESTOL aircraft and a GFC III that requires such aircraft to demonstrate automated safe flight. These are the only aircraft that can have both the capability and the ***consent*** to land at pocket airports, very close to destination, and thereby eliminating the wasteful delays of road gridlock. These are the only aircraft that can fulfill aviation's fundamental purpose—fast travel without roads—on trips of less than 250 miles.

The popularization of SAVs can revitalize aviation, transform our transportation system and bring many other societal benefits. Harnessing the resources of a global network of talented citizen innovators and universities to bring forth such aircraft can make the Green Flight Challenge the most practical, efficient and valuable of any NASA Centennial Challenge.

Based upon the potential benefits described above, the GFC can be a signature achievement for the Obama Administration similar to what the Apollo Program was for JFK, though at a much lower cost.

Ironically, after aviation has conquered the sound barrier and soared high above the stratosphere, its most promising new frontier turns out to be that of mastering the ability to fly slowly, quietly, safely and close to the ground, like birds.

ABOUT THE CAFE FOUNDATION

The CAFE Foundation is an all-volunteer 501 (c)3 organization founded in 1981 in Santa Rosa, California for the purpose of advancing small aircraft efficiency. Its history is available at: http://cafefoundation.org/v2/aboutcafe_main.php

APPENDIX: CONVERGING TECHNOLOGIES

The Green Flight Challenge Program must have a realistic forecast of the maximum achievements that are possible for its new vehicles. To develop that forecast, it helps to examine the best performances achieved thus far in the diverse technologies that will enable pocket airport operation by GQ aircraft. These technologies include:

1. High lift devices including exotic flaps, circulation control and powered lift
2. Extremely low drag coefficients
3. High lift-to-drag ratio wings
4. Motor-in-wheel technology
5. Propeller noise reduction technology

6. Nano-structural weight savings
7. High energy density batteries or ultra-capacitors
8. High power density electric motors
9. 4th generation electronic guidance and control
10. Ideal human factors engineering and interfaces

1. High lift devices:

V/ESTOL capability exacts a high price in the form of drag due to large wing area or, alternatively, the cost and weight penalty that accompanies having complex high lift or powered lift devices. Powered lift VTOL capability has similar penalties in terms of potentially high noise and weight from its high power requirements. Today, advances in drag reduction, motors, batteries, actuators, high lift technologies, thrust vectoring, computerized stability and control and nano-material composites make the challenge of V/ESTOL more feasible. Even so, high lift technology is essential to the SAV. This includes circulation control, which NASA has demonstrated can achieve up to a maximum lift coefficient of 5-6. It also includes the channel wing, whose proponents have claimed can deliver a maximum lift coefficient of up to 13.

The 2 graphs below show that with the very high lift coefficients that have been attained in the past, fast, high MPG vehicles are indeed possible. These graphs presume a 1320 pound aircraft with 75 brake horsepower, a zero-lift drag coefficient of 0.018 and a propeller efficiency of 0.84. These specifications are modeled after proven prior aircraft design achievements.

Extreme High Lift
CLmax v. Ad and Vmax: 1320 lb, Cdo 0.018, 75 BHP, eta 0.84
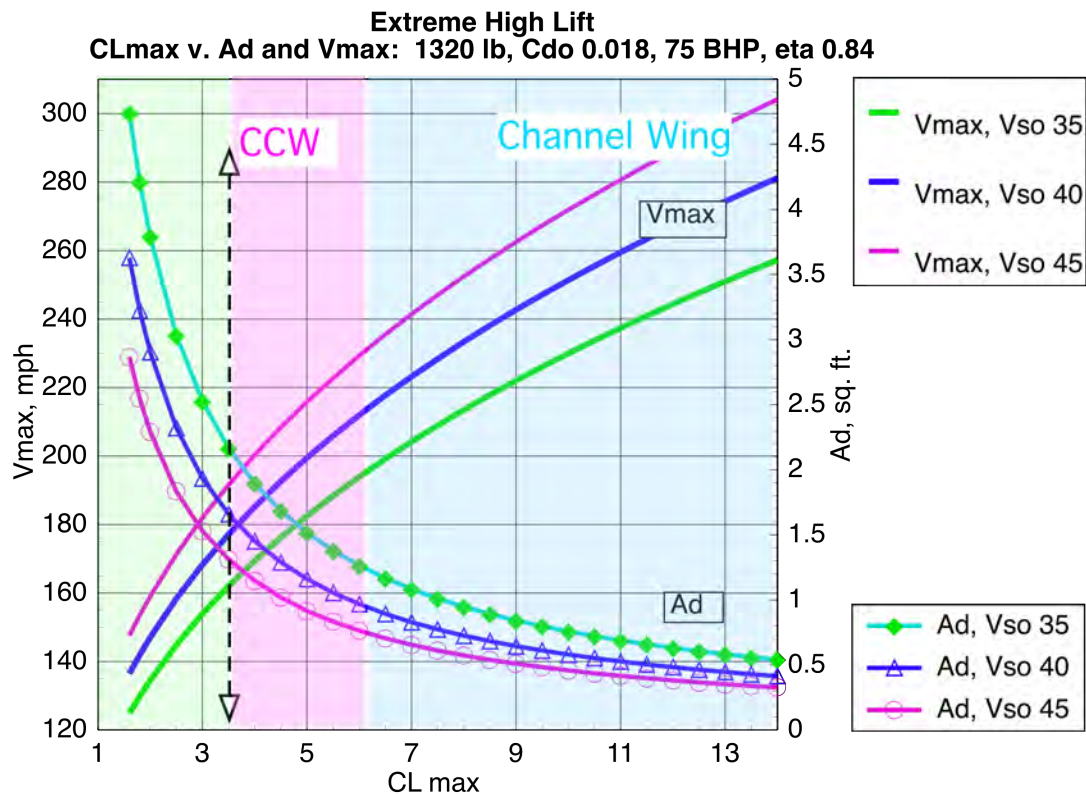
CLmax v. pMPG @ Vmax 1320 lb, Cdo 0.018, 75 BHP, eta 0.84, 2 seats
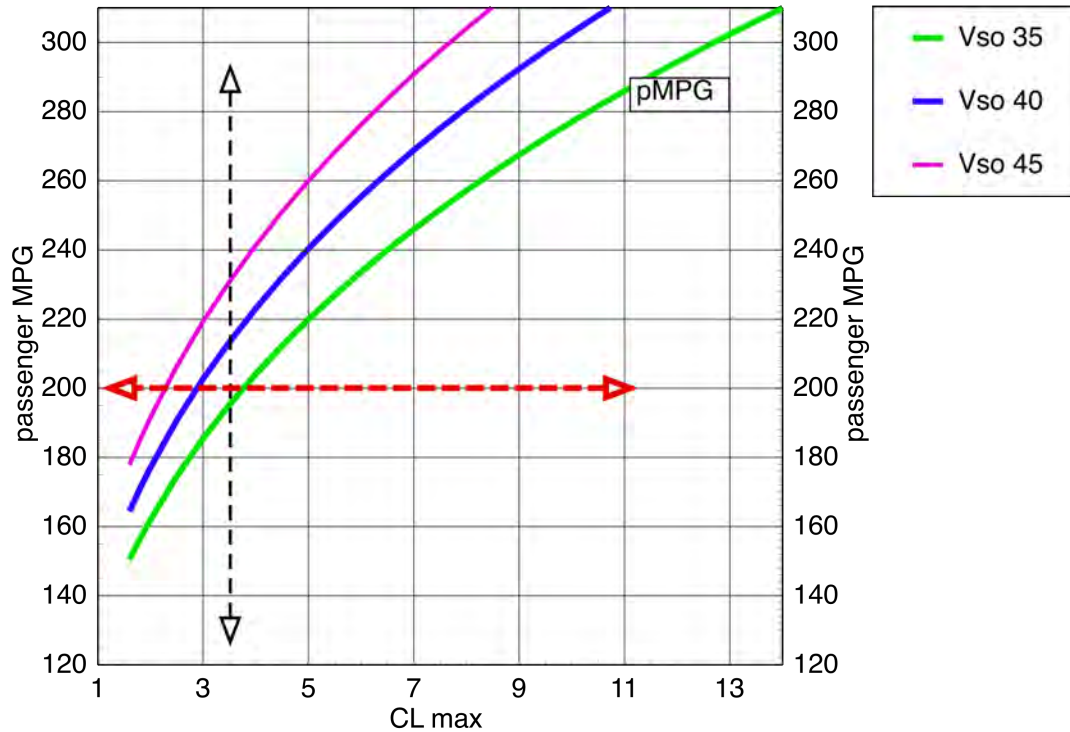
2. Extremely low drag coefficients:

NASA's research on "Goldschmied Propulsion", advances in smooth laminar flow composite surfaces and the marked reduction in cooling drag that attend electric motor propulsion are all enablers of lower drag future small aircraft. A wind-tunnel study of such advances has demonstrated an unprecedentedly low drag coefficient of just 0.0012, as shown in the photo below.

CDo = .0012 at Re = 7M

Extreme attention to reducing drag has resulted in aircraft such as the Sport Class Reno Racer called the Nemesis NXT, whose drag coefficient is just 0.0155. See photo below.

3. High lift-to-drag ratio:

The maximum lift-to-drag ratios being achieved with today's best sailplanes are over 70 to 1. Such aircraft require minimal power to fly and are pointing the way for quiet electric powered aircraft to achieve acceptable range. The Solair II (below), for example, was able to fly on just 755 watts of continuous power, and improvements to conformable solar panel efficiency will soon allow the sun's energy to add a significant boost to the range of such powered sailplanes.

4. Motor-in-wheel technology:

The 6 inch diameter Launchpoint pancake motor shown in the photo below delivers 7 horsepower and weighs only 1.4 pounds. It is scalable up to much larger power levels.

Such a motor can be used to replace main landing gear disc brakes with little or no weight penalty to a small aircraft. Replacing the disc brake with such a motor can provide unprecedented capabilities to the GQ aircraft, including:

- Near-silent taxiing
- Quieter acceleration
- Excellent horsepower to weight ratio (BMW Mini uses 160 BHP per wheel !!)
- Lessens the horsepower needed through noisy prop
- Anti-lock braking
- Anti-skid
- Steer-by-wire
- Self-retracting landing gear
- Tire Spool-up prior to landing touchdown
- Regenerative braking
- Golf cart-DOT 500 functionality if wings fold.

The benefit of motor-in-wheel acceleration on take off can be appreciated by the graphs below. The first of these (below) shows that the direct application of horsepower to where the 'rubber meets the runway' can produce excellent short ground roll distances for V/ESTOL aircraft. The second graph shows the very poor propeller efficiency that accompanies the initial part of the aircraft's ground roll, where forward speed is only 3 mph. This indicates that the motor-in-wheel can contribute a dramatic improvement to take off distance by its direct and highly efficient application of power to the pavement.

Takeoff Ground Roll for a 1320 lb ePAV to reach 35, 40 and 45 mph v. BHP and G
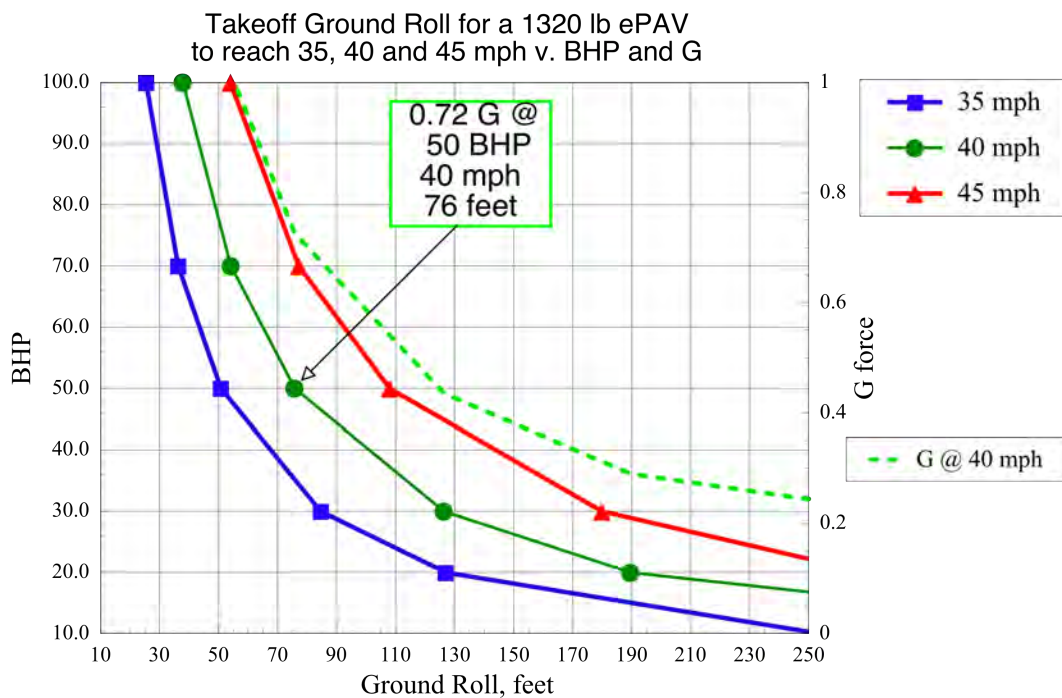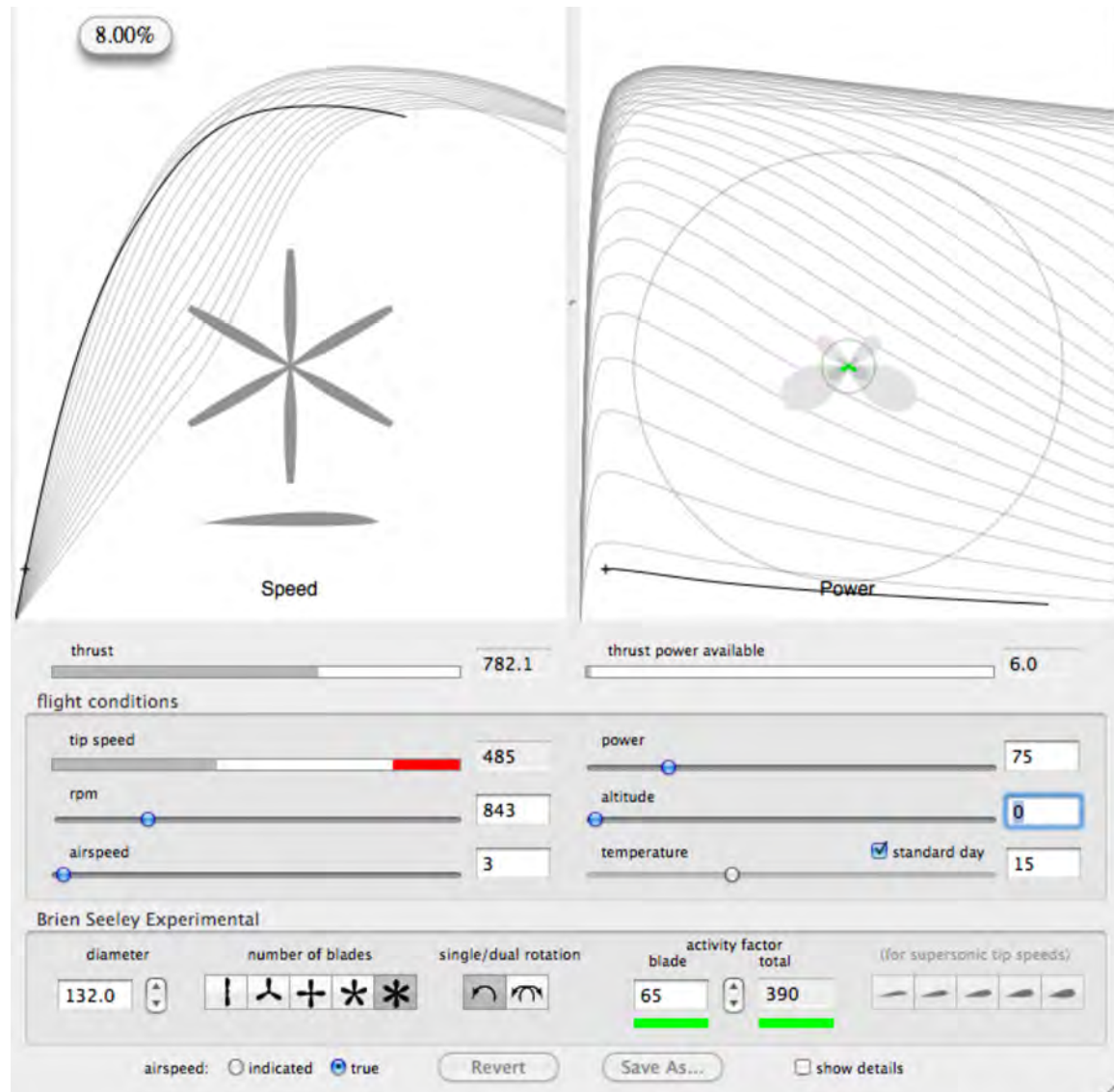
The eta value, or propeller efficiency, is given in the upper left corner of the Benchmark graph above as 8.00%. This low value is due to the lack of forward speed of the aircraft, shown in this example to be just 3 mph. These are the conditions that apply right at initial take off roll, and they emphasize how valuable will be the direct acceleration force obtained from rest by using motor-in-wheel technology.

5. Propeller noise reduction technology:

Extreme noise reduction for propellers presents a somewhat new quest in civil aviation because of the availability of near-silent electric motors as replacements for the previously difficult-to-quiet internal combustion engine. The new Benchmark software program enables one to pre-compute the noise footprint of a propeller. From that program, we can see that quiet propellers of good efficiency that offer the necessary low tip speeds can be created. Expert consensus is that the propeller blade tip speeds need to be kept below 400 fps. The graph below shows the convergence of ideal climb and cruise efficiency for a sample low power GQ aircraft to occur with a slow-turning propeller diameter of between 9 and 11 feet.
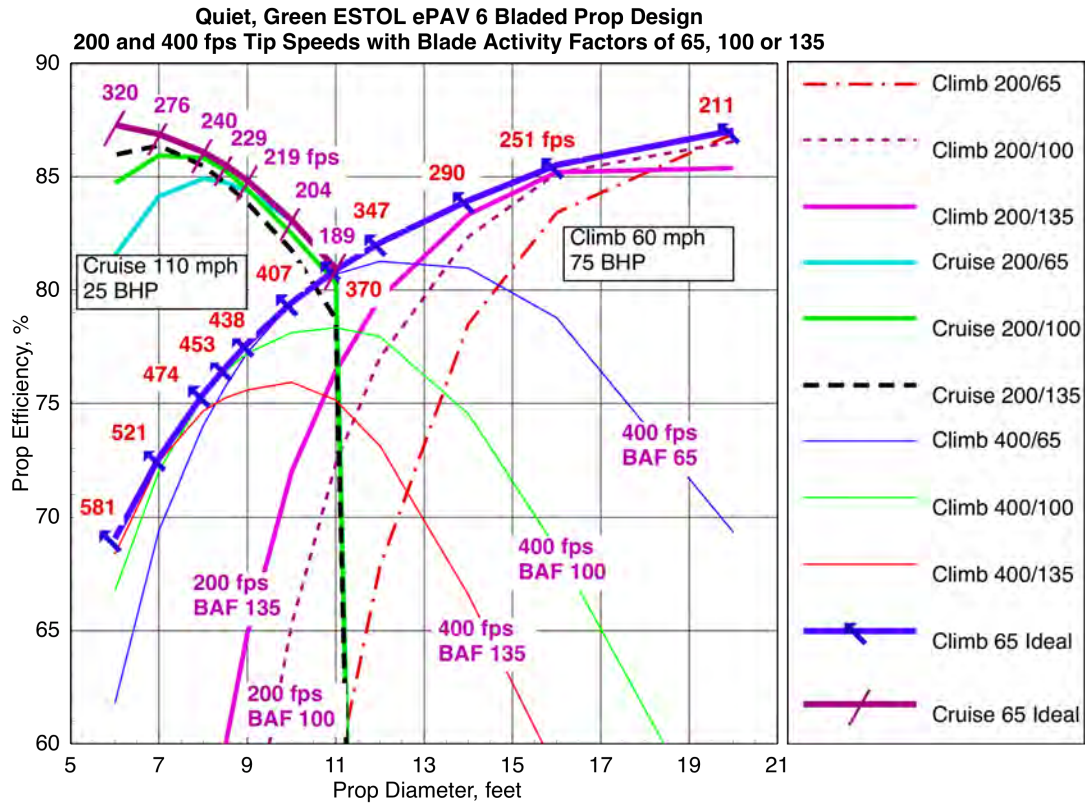
An 11 foot diameter slow-turning propeller with Blade Activity Factor 65
can provide 81% efficiency in both Climb and Cruise
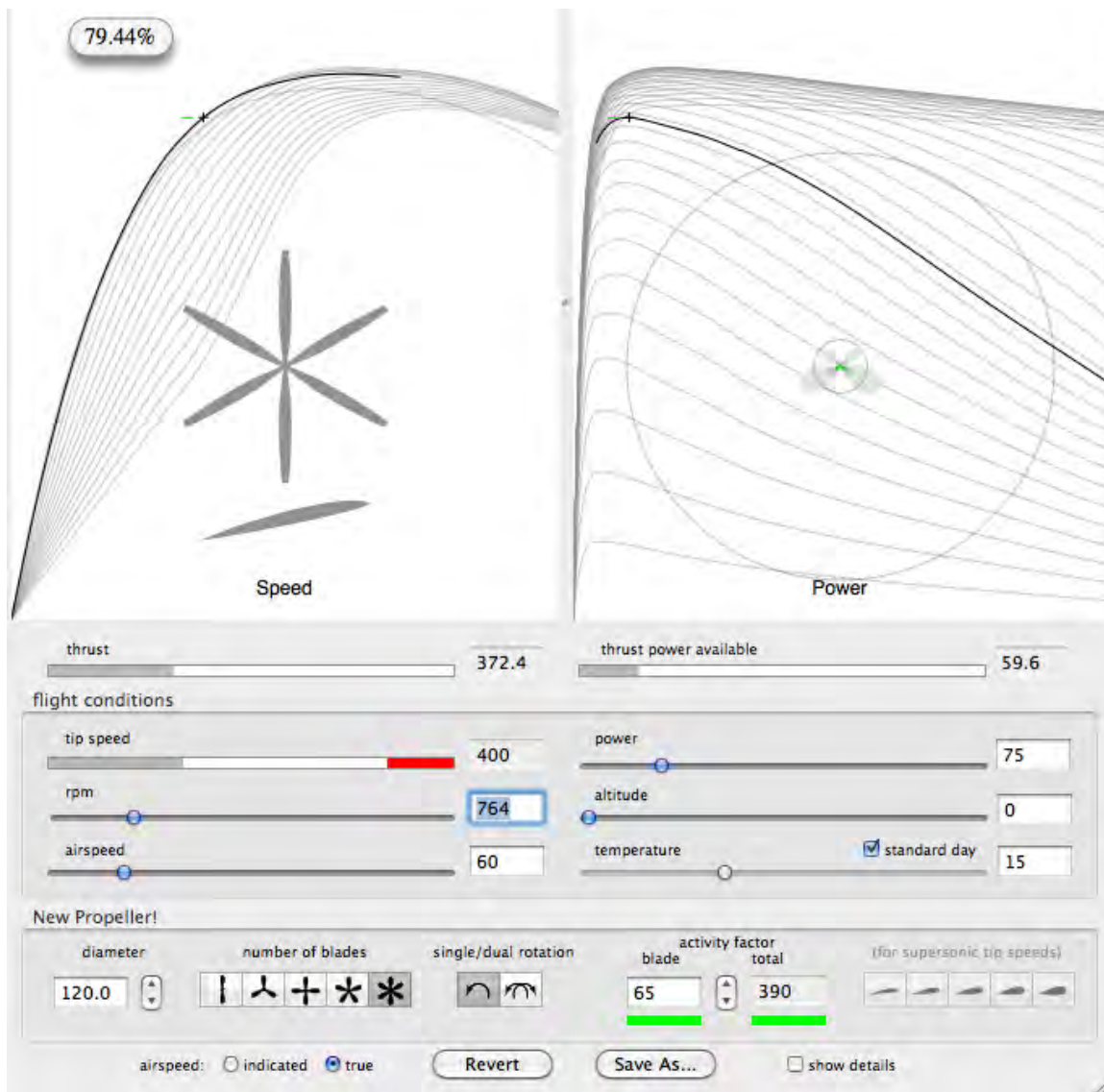
The graph above depicts the noise footprint of a 400 fps propeller of 10 feet diameter operating on 75 BHP in a 60 mph climb. On the right upper side of the graph are 2 concentric circles. Inside the inner circle, which represents a 125 foot radius, can be seen a tiny green noise footprint for this propeller. The green color indicates 60 dBA of noise. This extremely quiet propeller approximates the ambient noise level of a residential neighborhood and foretells reasonable compatibility for use of such low-powered electric aircraft at close-in pocket airports.

6. Nano-structural weight savings:

Nano structures can increase the strength to weight ratio of an aircraft and its components. Below, from NASA's Glenn Research Center, is pictured the concept of nano-composite fibers, whose coating with a Velcro-like surface makes their laminate much stronger than today's already strong carbon-fiber structures.

Detail of FFRP Microstructure
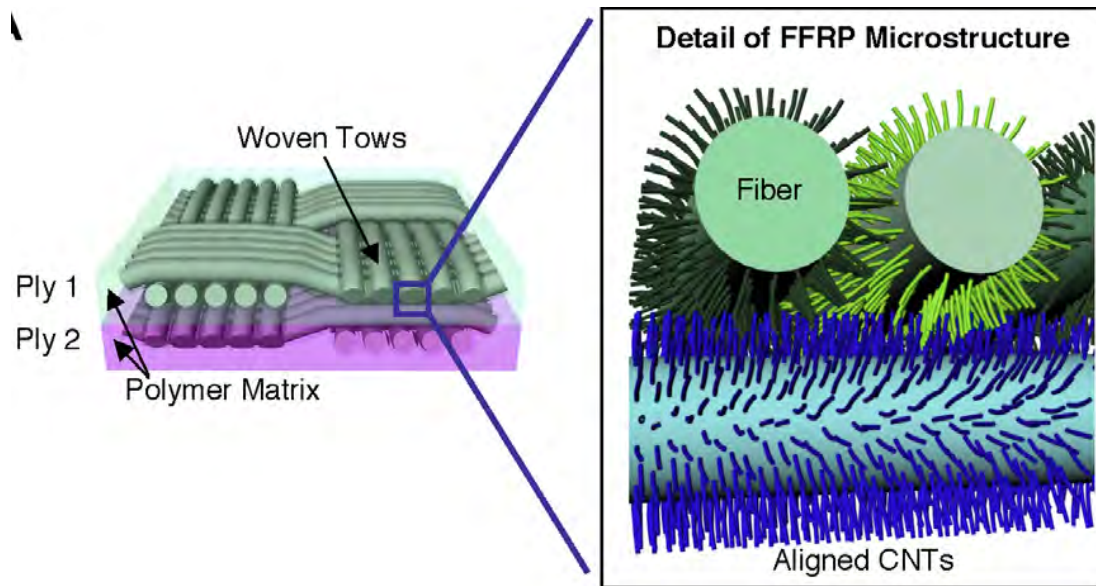
Below is a another depiction from NASA Glenn Research Center of nano-structural technology as applied to magnets, where magnetic field strengths are expected to double from such enhanced structure.

- Assembling a nanocomposite magnet from individual high-magnetization and high-coercivity nanoparticles critically depends on availability of anisotropic (single crystal) hard magnetic nanoparticles.
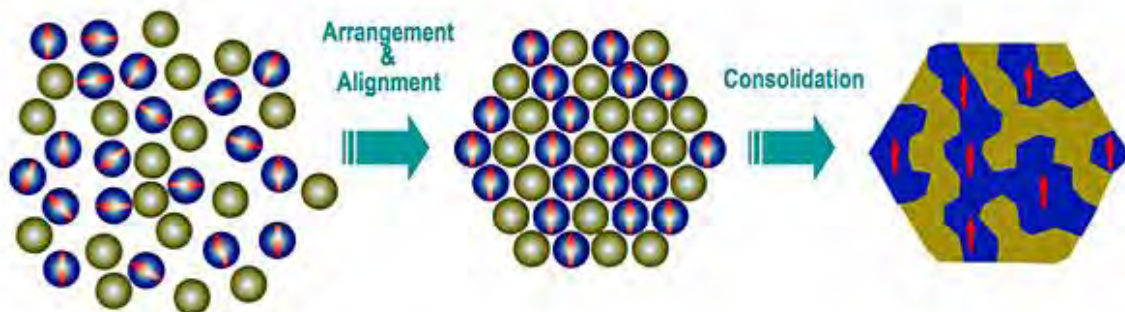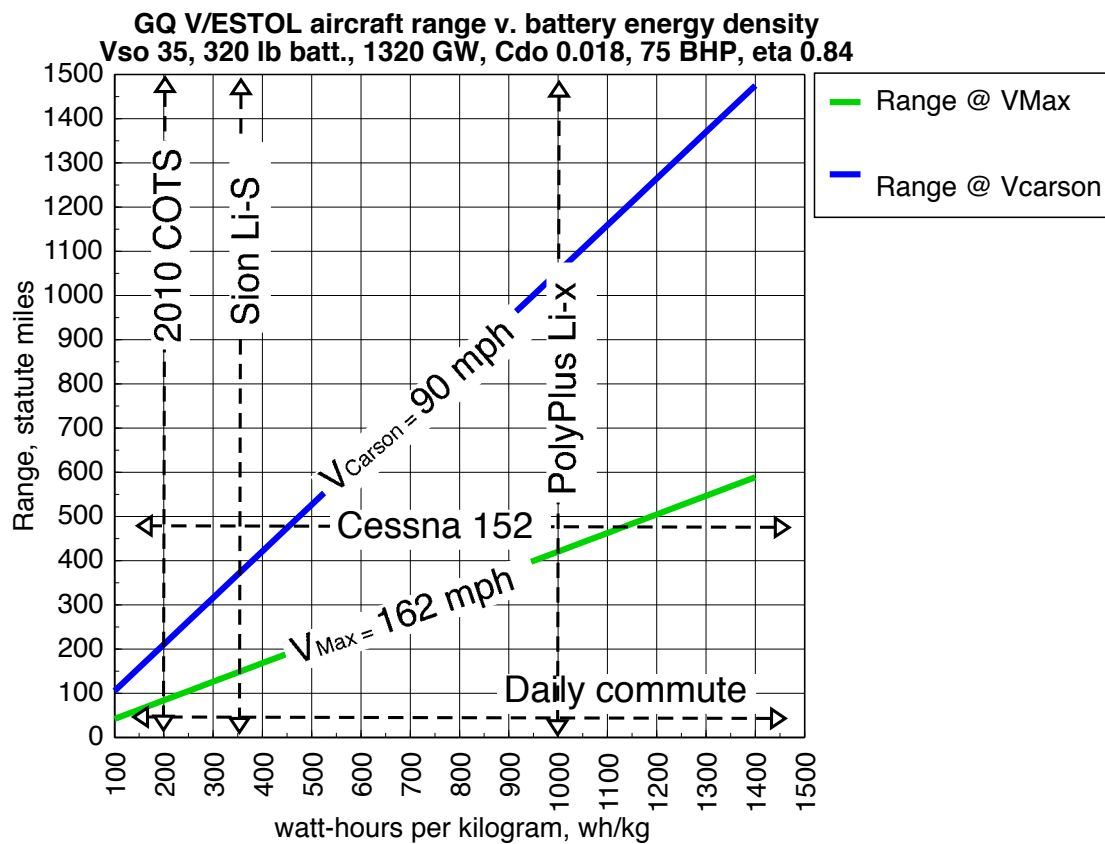
- Anisotropic RE-Co nanoparticles produced via surfactant-assisted HEBM satisfy the major requirements for this application.

- The next generation magnets are expected to have $(BH)_m$ >100 MGOe

7. High energy density batteries or ultra-capacitors:

Batteries and ultra-capacitors are making continuous improvement in the amount of energy that can be efficiently stored. Today's commercial off-the-shelf (COTS) available

batteries offer on the order of 200 watt-hours per kilogram (wh/kg). Sion Li-S batteries have achieved a claimed 350 wh/kg as of summer 2010. The future improvement in energy density is likely to render ultra-quiet, electric-powered flight feasible for trips of up to 500 miles range. Ultra-capacitor developers have recently been very secretive about their energy density predictions, but one has recently claimed a potential for a fifty-fold increase over today's best batteries.

With today's average daily surface commute distance of only 30 miles, commuting distances of 40-100 miles by air in GQ aircraft can be seen to be feasible even with today's batteries. See below:

GQ V/ESTOL aircraft range v. battery energy density
Vso 35, 320 lb batt., 1320 GW, Cdo 0.018, 75 BHP, eta 0.84

8. High power density electric motors:

Efficient electric motors with sufficient power for GQ aircraft exist today. These motors have excellent power to weight ratios and can be produced at a cost much lower than that of an equivalent internal combustion piston engine. The EMRAX 22 motor shown below can produce 187 horsepower for 30 seconds and weighs only 55 pounds. An equivalent reliable, low-rpm piston engine would weigh at least 4 times that weight. Nano-technology magnets may lead to motors with as much as 50% better power to weight

performance in the near future. The suitability of smooth, power-dense, reversible electric motors available today for vectored thrust is particularly promising:
See: http://www.youtube.com/watch?v=iyTKwTx_VdQ

Electric motors are favored in GQ aircraft because of their high-efficiency, high reliability, high power to weight ratios, smooth running (more suitable for slow-turning props and tilt-rotor), quiet, emission-free power and installation simplicity compared to internal combustion (IC) engines. However, the IC engine, if it can be quiet and Green enough, offers a clear advantage in range, re-fueling time and extant support infrastructure.
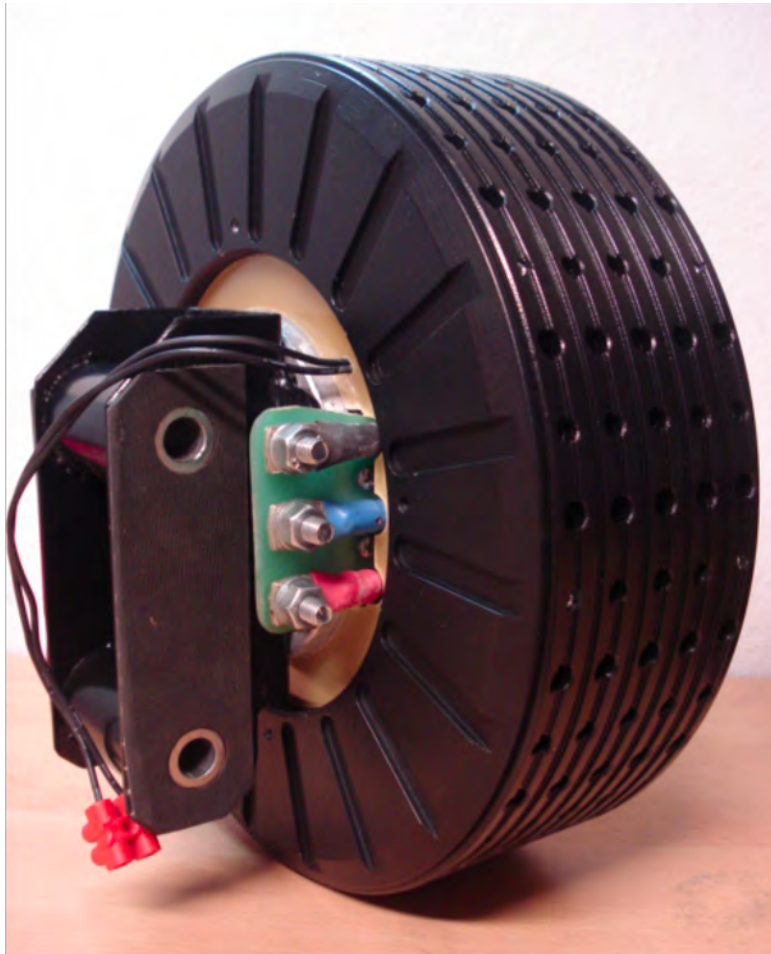
9. 4th generation electronic guidance and control:

Miniature guidance and control systems for small aircraft are already demonstrating remarkable new capabilities, as can be seen here:

http://techtv.mit.edu/videos/4149-indoor-autonomous-helicopter
shows a small electric helicopter that can use its on-board laser scanner to detect obstacles and avoid them. Such capabilities could be applied to GQ V/ESTOL aircraft that operated in "urban canyons".

http://techtv.mit.edu/videos/5789-voice-commandable-autonomousicopter
shows a similar helicopter that can navigate by voice commands.

http://xmb.stuffucanuse.com/xmb/viewthread.php?tid=6706
presents a small electric helicopter that is able to autonomously fly while maintaining an exact outdoor GPS location, even while experiencing a shifting payload.

Future advances in the automation of tracking and collision avoidance for aircraft in areas of high air traffic density will exploit understanding derived from the study of swarms of starlings (See photo below). Such swarms, often thousands of birds, operate without collisions using a tracking strategy that was recently modeled on computer in order to guide robotic flight traffic system design. http://www.telegraph.co.uk/science/science-news/3323488/Study-of-starling-formations-points-way-for-swarming-robots.html

In the event of a mid-air collision or other loss of control, the small GQ V/ESTOL aircraft can deploy a ballistic recovery parachute as a control measure of last resort.

The 2010 NARDP includes provisions for dynamically restructuring airspace as a means for increasing the capacity of the NextGen air traffic system. Such flexibility can and should be applied to GQ V/ESTOL routing and separation.

10. Ideal human factors engineering and interfaces:

High-resolution, sunlight-readable, flat-panel flight deck displays that can depict all-weather synthetic vision have already largely replaced the previous generation of round analog "steam gauges" in small aircraft. The future can anticipate these devices becoming faster, cheaper, more capable and portable, serving as familiar personalized human-machine interfaces and information stores that a pilot carries from aircraft to aircraft. As shown below, the iPad and its derivatives could begin this transformation soon.
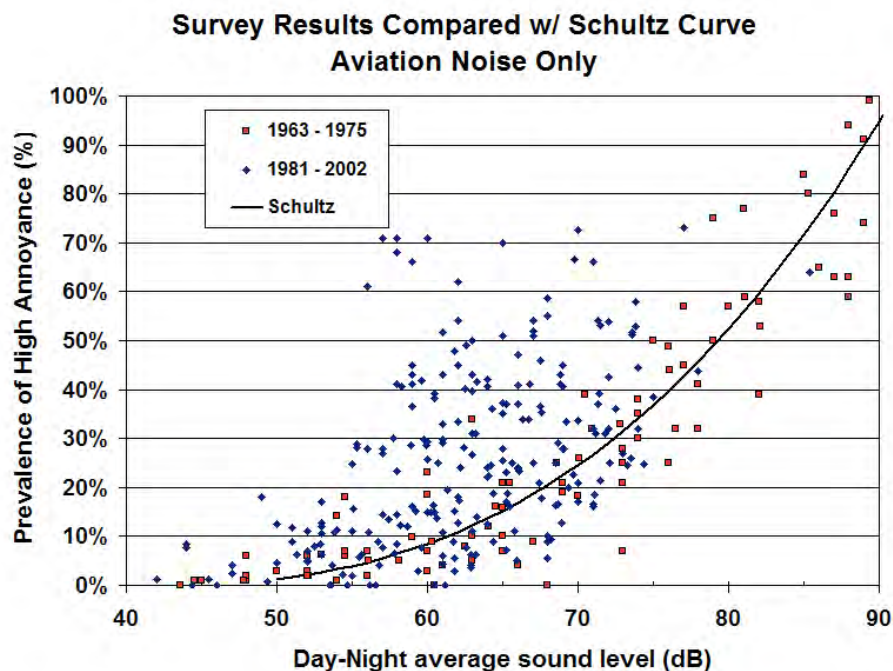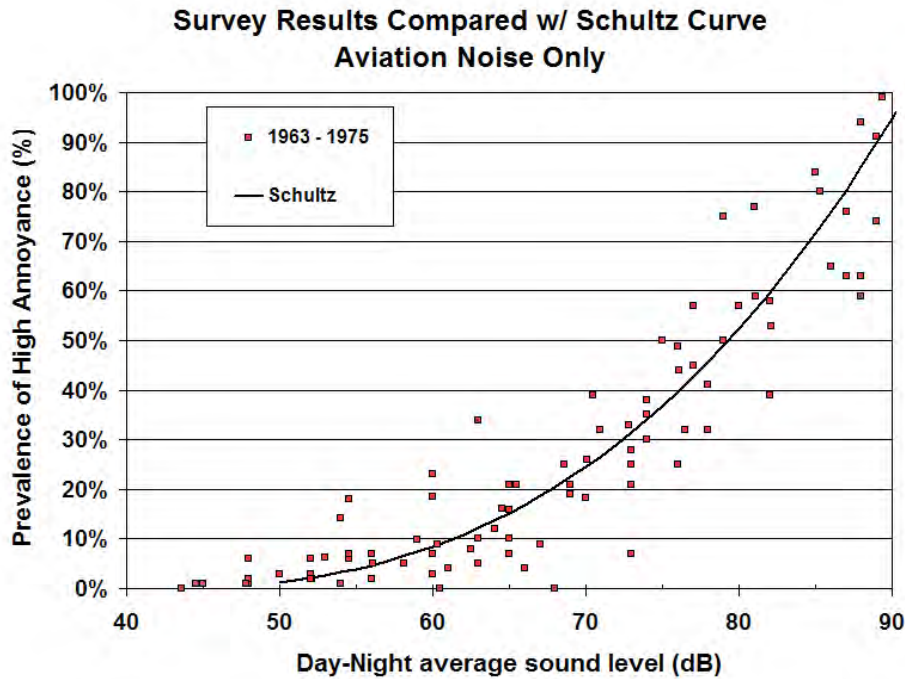

The Naturalistic Flight Deck with its haptic control system developed at NASA Langley has a force-feedback stick controller for the pilot. The machine intelligence built into this stick along with its complementary display system can provide both a mentoring and hazard avoidance function for pilots, easing their workload and greatly enhancing safety. The ideal division of tasks and command authority between the human pilot and the machine intelligence for a given situation is a work in progress that will evolve as experience and capabilities continue to rapidly advance.

Real-time weather depiction for pilots is now available as an application for the iPhone, as shown below. The collective detection of and response to such weather by humans and on-board automated systems will increase weather hazard avoidance.
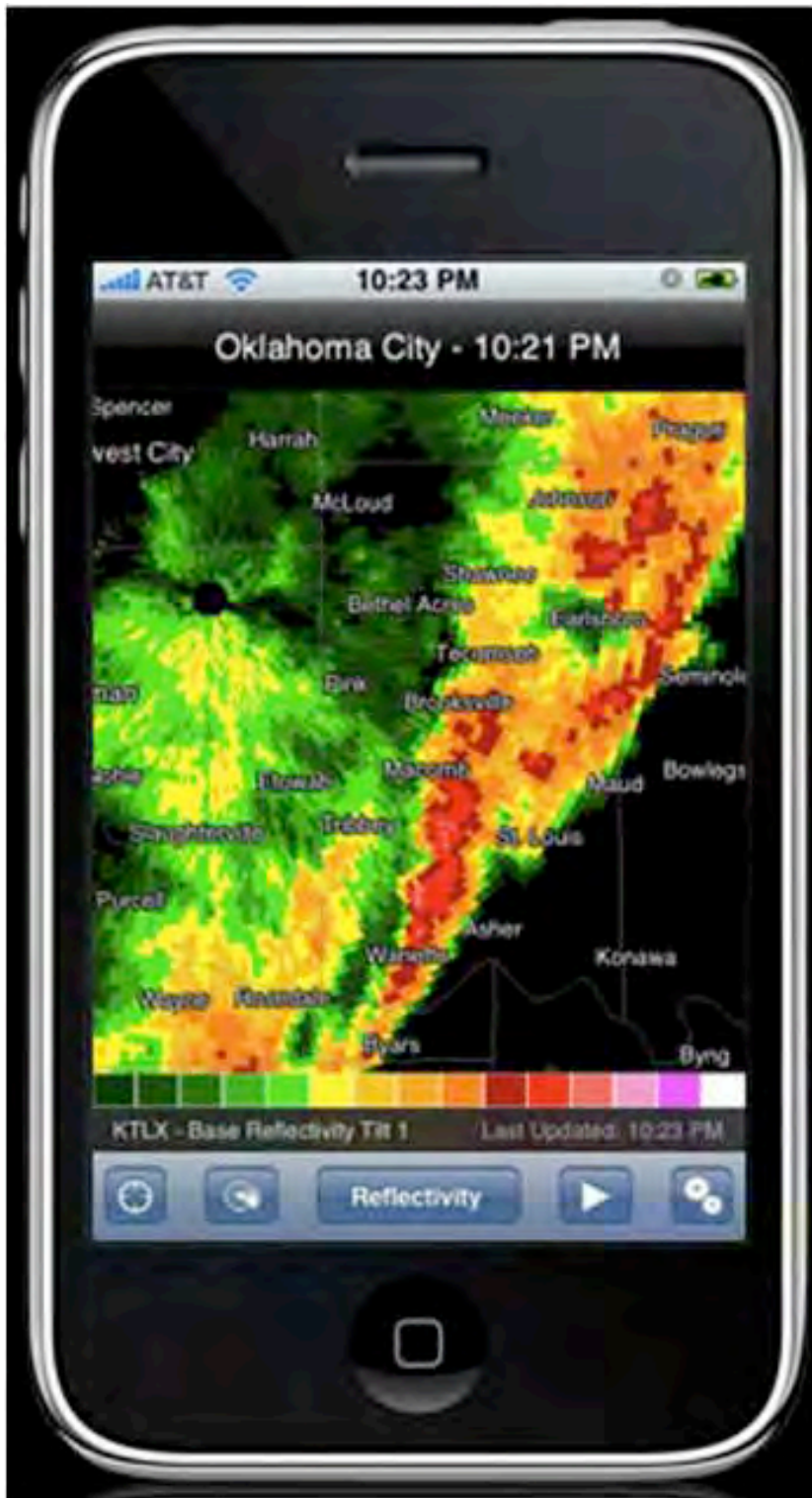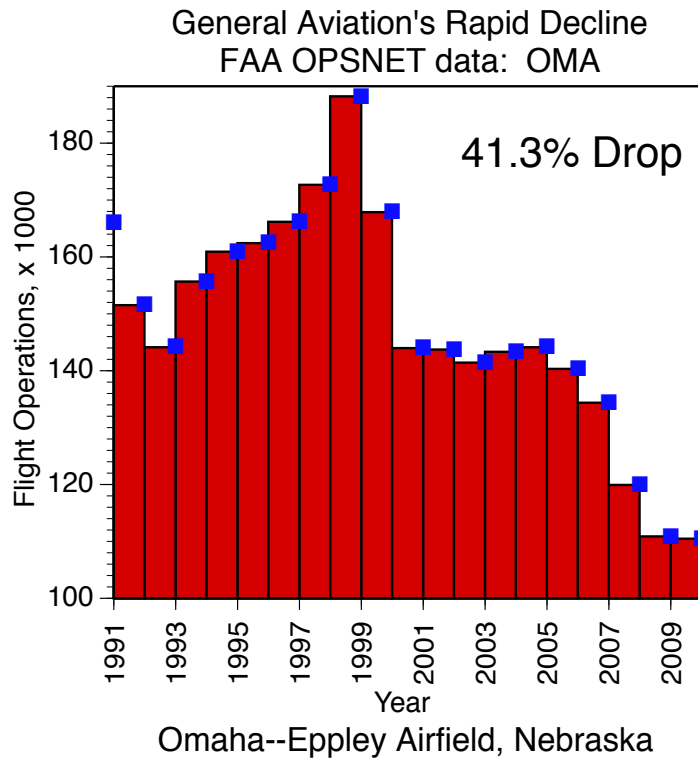
FAA NOISE CRITERIA

The FAA Part 36 guidelines for tolerable noise levels around airports have relied upon studies like the two graphs below. These indicate that a noise level of 60 dBA CNEL at the boundary of the pocket airport is likely to be an acceptable level to 90% of the residents nearby.

Survey Results Compared w/ Schultz Curve
Aviation Noise Only

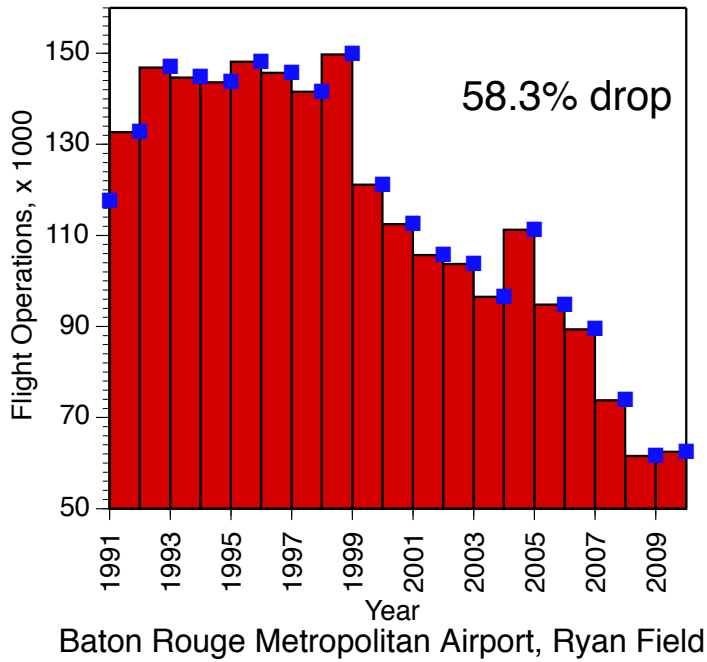Survey Results Compared w/ Schultz Curve
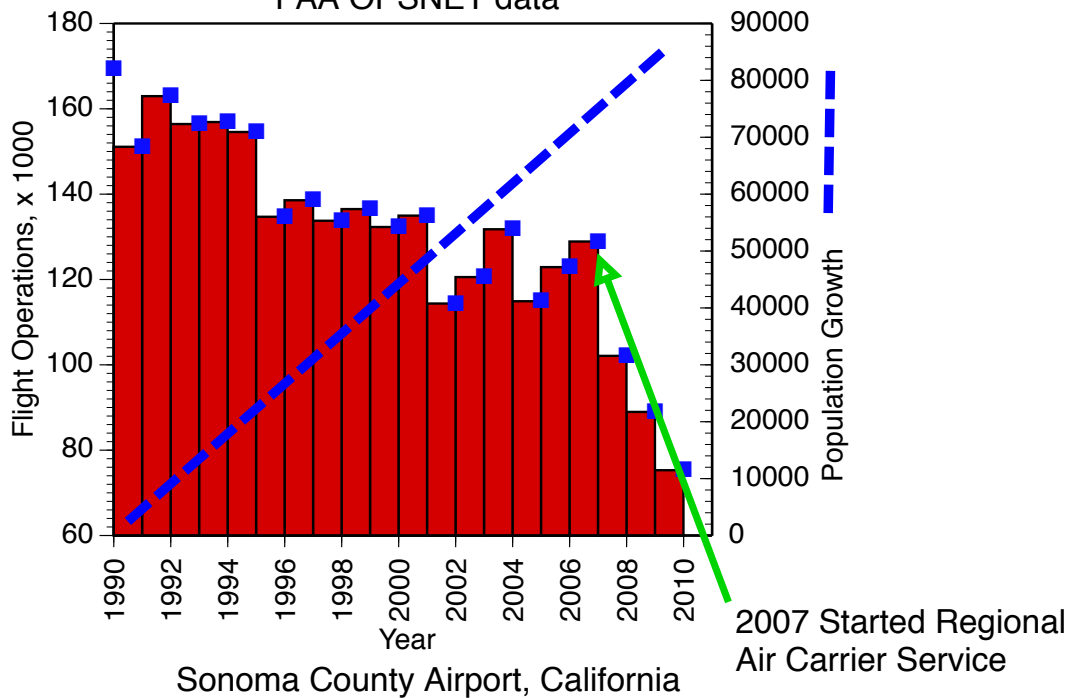Aviation Noise Only

GENERAL AVIATION IN MAJOR DECLINE

The following tables show the shocking decline in civil aviation operations across the USA during the last 20 years. The data are from the FAA.gov OPSNET website.
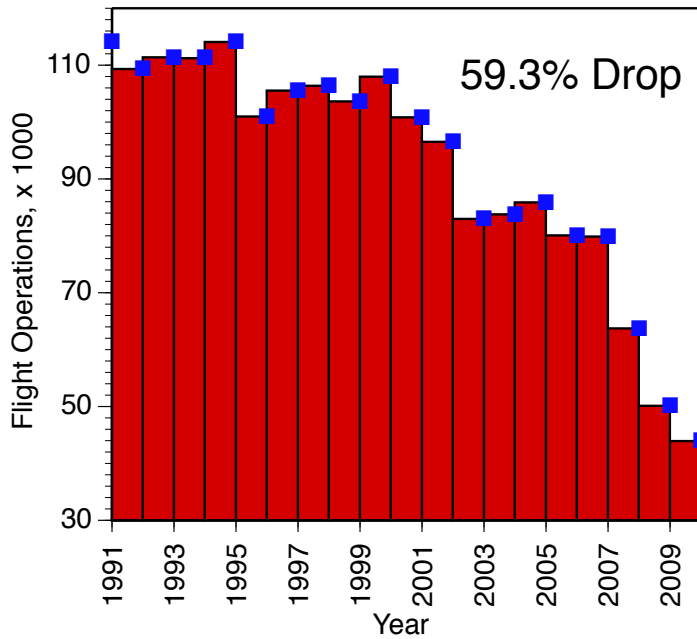
General Aviation's Rapid Decline
FAA OPSNET data: OMA

41.3% Drop

Flight Operations, x 1000

Year
Omaha--Eppley Airfield, Nebraska

General Aviation's Rapid Decline
FAA OPSNET data

58.3% drop

Baton Rouge Metropolitan Airport, Ryan Field

General Aviation's Rapid Decline
FAA OPSNET data

2007 Started Regional
Air Carrier Service
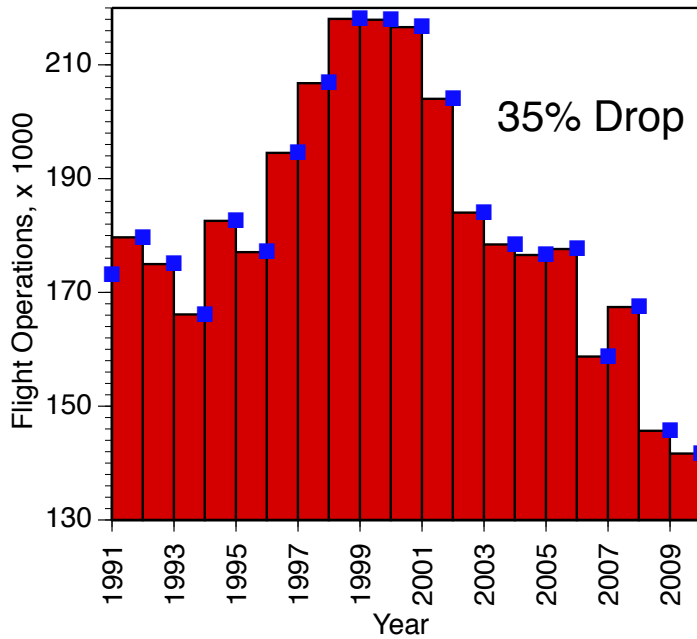
Sonoma County Airport, California

General Aviation's Rapid Decline
FAA OPSNET data: ROA

59.3% Drop

Roanoke Regional Airport, Virginia

General Aviation's Rapid Decline
FAA OPSNET data: ICT

35% Drop

Wichita Mid-Continent Airport, Kansas

REFERENCES:

Presentation by Dr. Seeley at NASA Langley:
http://www.nasa.gov/centers/langley/news/researchernews/rn_seeley.html

[1]AIAA paper 2003-264, entitled "PERSONAL AIR VEHICLES: A RURAL/ REGIONAL AND INTRA-URBAN ON-DEMAND TRANSPORTATION SYSTEM (available at: http://cafefoundation.org/v2/tech_lib.php then click on Title # 3 under the topic "NEXTGEN PAVs AND SATS")

[2]See: http://cafefoundation.org/v2/tech_lib.php Item # 11 under NextGen: PAVs and SATS

[3]http://shemesh.larc.nasa.gov/Lectures/OldColloq/c-100504.htm

[4]The United States Congress authorized and funded the NASA Centennial Challenge Technology Prize Program in 2005, a program that is now operated by NASA's Innovative Partnerships Program (IPP) under the direction of Doug Comstock. The GFC is NASA's Centennial Challenge for aeronautics.

[5]http://cafefoundation.org/v2/pdf_tech/SATS.demographs/PAV.RhinoCorps.Simulation.pdf

[6]http://stophelipad.org/helipads.shtml

[7]DOD study on V/STOL: http://www.acq.osd.mil/dsb/reports/2007-07-Future_Need_for_VTOL_STOL_Aircraft.pdf page ix.

[8]http://www.youtube.com/watch?v=4hZc-LVhsw8

http://technorati.com/videos/youtube.com%2Fwatch%3Fv=w68WRWBeWzU

http://technorati.com/videos/youtube.com%2Fwatch%3Fv=PTbkwgvxNDw

http://technorati.com/videos/youtube.com%2Fwatch%3Fv=PTbkwgvxNDw

[9]Sperling, Daniel, et al, *Two Billion Cars*, Oxford Press (2009).

[10]http://www.publicpurpose.com/21st-fl.htm

[11]Calthorpe, Peter, *The Regional City*, Island Press (2001).
http://books.google.com/books?id=qcwvvI0gfpoC&pg=PA53&lpg=PA53&dq=Peter+Calthorpe+walkability&source=bl&ots=dFBmoeGumf&sig=rNAZHqVJAYIMETxHV2KIquSdIvA&hl=en&ei=kL3MSohrhY60A8qzsaEB&sa=X&oi=book_result&ct=result&resnum=3 - v=onepage&q=&f=false
and
http://www.emich.edu/public/geo/557book/d373.calthorpe.html
and
http://en.wikipedia.org/wiki/New_Urbanism

[12]DOT 500 definitions: http://www.nhtsa.dot.gov/cars/rules/rulings/lsv/lsv.html

[13]http://www.rita.dot.gov/publications/transportation_vision_2030/html/passenger_transportation.html

[14]http://www.vtpi.org/tdm/tdm96.htm

[15]Air Miles are typically 10% shorter than car miles due to curves in roads. This 10% air travel advantage is included in the graphs I, II and III above.

[16]http://www.aopa.org/aircraft/articles/2010/100802superior_air_parts.html?WT.mc_id=100806epilot&WT.mc_sect=gan

[17]http://www.flyingmag.com/news/yuneecs-e430-electric-airplane-has-25-hours-endurance

[18]http://www.economist.com/node/16740639