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Regional Sky Transit

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Future, on-demand, electrically-powered "Sky Taxi" aircraft must be able to deliver both people and packages at high proximity "pocket airparks" that minimize the length of 'last mile' surface travel for the short-range trips that people most often make. These are sub-100 mile trips that stay within metropolitan 'mega-regions'. Such a regional "Sky Transit" system would serve a vastly larger user base than that for trips that exceed 160 km (100 miles) in length. Sky Transit would necessarily operate with a very different type of aircraft than the conventional take-off and landing (CTOL) type used on longer range, higher speed general aviation (GA) flights. Ultra-quiet, V/ESTOL Sky Taxis, by having a much higher duty cycle than GA, would also be much more affordable. Fortunately, electrically-powered aircraft whose range is somewhat limited by present day battery technology could still fulfill the Sky Transit mission requirements if designed for robotic battery swap. A prospective business model for such regional Sky Transit using various cost scenarios and market penetrations shows its potential for strong profitability as well as numerous societal benefits. The San Francisco metropolitan region is analyzed with respect to its inter-county and major corridor surface traffic volumes in order to project realistic ridership for a fully implemented regional Sky Transit system. The analysis includes actual trip distances that account for direct flight path versus tortuous surface road path lengths. The subjective aspect of 'crowding of the skies' is examined by projections of a sky image simulated during peak operations. Partitioning of the region's airspace by assignment of altitudes is used as a means to estimate such projections and the attendant separation distances. Fast tempo take-off and landing operations are examined for their effect upon profitability and system capacity. Peak capacity at locations with the greatest number of daily travelers is examined in terms of operational intervals and safe aircraft separations. The relationship between land parcel size and availability with high proximity for the most popular traveler destinations is examined as a means to define the limiting case of short runway operations. Trip fares and their effect upon ridership and profitability are explored relative to alternative modes of surface travel and on a cost per km basis. The total regional electrical energy demand that would attend a full-fledged, electrically-powered Sky Transit system is estimated. The effect of Sky Transit in easing surface gridlock is estimated, along with its effect in reducing greenhouse gas emissions.

Nomenclature

4D	=	a three-dimensional path along which each point has a defined specific clock time
6'	=	6 feet, with apostrophe indicating feet
AFS	=	autonomous flight system
AGL	=	above ground level (height or altitude)
ATC	=	air traffic control
BMS	=	battery management system
CAFE	=	CAFE Foundation, Inc., an all-volunteer, 501c3 non-profit educational foundation
CAS	=	calibrated airspeed
CCW	=	circulation-controlled wing
CFD	=	computational fluid dynamics
CFJ	=	co-flow jet, a specialized high lift airfoil system

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CLmax = maximum lift-coefficient
CNEL = community noise equivalent level
CO2 = carbon dioxide
CTOL = conventional take-off and landing
dBA = decibel noise level, A-weighted scale
DNL = day night level in dBA, a metric for noise measurement
DtD = door-to-door
EAA = Experimental Aircraft Association
ESTOL = extremely short take-off and landing
eta = propeller efficiency
G = the acceleration due to gravity at sea level on Earth
GA = general aviation
GFC I = the 2011 Green Flight Challenge sponsored by Google and prize-funded by NASA
GPS = global positioning system
GTT = ground travel time, the total of non-airborne time in a Sky Transit trip
HPA = high-proximity aviation
IFR = instrument flight rules; e.g., flying with instrument guidance while immersed in clouds (see VFR)
kg = kilogram
kph = kilometers per hour
kWh = kilowatt hour
kW = kilowatt
last mile = the distance from a transit station to one's destination doorstep
lb = pound
L_{den} = level in dBA, day evening and night, a metric for noise measurement
m = meter
mic = microphone
MPG = miles per gallon, typically referenced to 87 octane unleaded auto fuel
mph = miles per hour
MSL = above mean sea level, describing elevation or altitude on a standard day
NAS = National Airspace System
NHTS = National Highway Travel Survey
OSTP = Office of Science and Technology Policy
pkmPL = passenger kilometers per liter
psi = pounds per square inch
ROI = return on investment
RPM = revolutions per minute
RST = regional Sky Transit
sq ft = *square feet*
STEM = science, technology, engineering and mathematics education
STS = Charles M. Schulz Sonoma County Airport
TAS = true airspeed
V = volt
V/ESTOL = vertical or extremely short take-off and landing
VFR = visual flight rules; i.e., flying with visual guidance and not immersed in clouds
VMT = vehicle miles traveled
VTOL = vertical take-off and landing
Vmax = maximum velocity
Vso = minimum velocity at 1 G at which an aircraft in landing configuration stalls
6MR = the 6 minute rule, describing the ideal of 6 minutes to reach a pocket airpark

I. Introduction

Regional Sky Transit (RST) is the term that describes a consensus future for civil aviation: that of a public, on-demand, ubiquitous, accessible, affordable, high-volume system that safely transports people and goods point-to-point by small, ultra-quiet, electrically-powered, autonomous, 2-seat, V/ESTOL aircraft across a metropolitan mega-region using high-proximity pocket airparks that are roughly the size of a soccer field. The potential future market for such an *all-electric*, regional Sky Transit and Sky Cargo civil aviation system, driven by its superior speed, convenience, value and sustainability, appears by this research to exceed that of all other forms of civil aviation (Appendix). RST would, for the first time in history, extend personal flying to everyone. As a form of 'green' mass transportation, RST would also create large environmental, governmental and societal benefits. With the exception of ultra-low noise propulsion, the technologies necessary to RST already exist. This paper will explore RST as a system, its operational characteristics, benefits, sustainability and requirements and conclude with a plan by which it can be realized.

II. Background

People make an enormous number of short trips everyday. The vast preponderance of these is still made by car. Despite earnest and informed efforts, public transit has consistently failed to take enough cars off the road to eliminate surface gridlock. Public transit is very expensive to build and requires fare subsidies in order to win meaningful ridership.

In March, 2015, Secretary of the Department of Transportation, Anthony Foxx lamented that the transportation system is "in a huge ditch" due to unfunded and deferred infrastructure maintenance. He stated publicly on March 16, 2015 that "In the next 30 years, 75% of the population will live in metro mega-regions . . [and] mega-regions will have worsening traffic at hubs. Multi-modal systems are going to be needed in the future . . technology is going to play a productively disruptive role here. For example, the airplanes on NextGen with GPS can be spaced closer together".[1]

This paper presents a 'productively disruptive role' for technologic advances in aviation to create a transformational, multi-modal transit solution. However, that solution will not include today's civil aviation paradigm. The sustainability of the general aviation market using conventional take-off and landing aircraft (CTOL) is in serious doubt based upon its recent market performance and value proposition (Appendix). The high costs of a pilot's license and personal aircraft ownership limit single engine aircraft sales to just a few hundred per year, and are these are very expensive, mainly hand-built aircraft that are affordable to only a small percentage of the population. GA flight operations are markedly reduced nationwide. Most privately owned aircraft are unused for 99% of their lives, parked either on the ramp or in a hangar. See Figure 1.

Figure 1. Most GA aircraft are parked and unused for 99% of their life, as schematically depicted here for the "Nob Hill" hangars at STS.

High noise levels have typically banished the necessarily huge hub airports to low land-cost open spaces that are tens of miles from metro centers, causing commercial air carrier service to exacerbate the congestion of surface transportation rather than reducing it. This, in turn, causes air carriers to suffer abysmally slow door-to-door (DtD) trip speeds due to that surface congestion. Even supersonic aircraft suffer major reductions in DtD trip speeds by the inherently low-proximity CTOL aviation paradigm.

Todd Litman, Executive Director at the Victoria Transport Policy Institute, found that, on average, every car in America required on the order of 250 sq meters of combined road-bed and parking lot hardscape.[2] This proportion is represented in Figure 2., below. If we apply this proportion to the total number of new vehicles that are manufactured each year, we discover an alarming burden in terms of new hardscape required by those vehicles. If that burden is extrapolated year over year, the picture becomes one of an unsustainable trend. This is depicted in Figure 3., below. The trend can be reduced by a variety of strategies, such as ride-sharing, driverless cars summoned by cell phone, living within walking distance of work, increased use of transit, bicycles and telecommuting. But

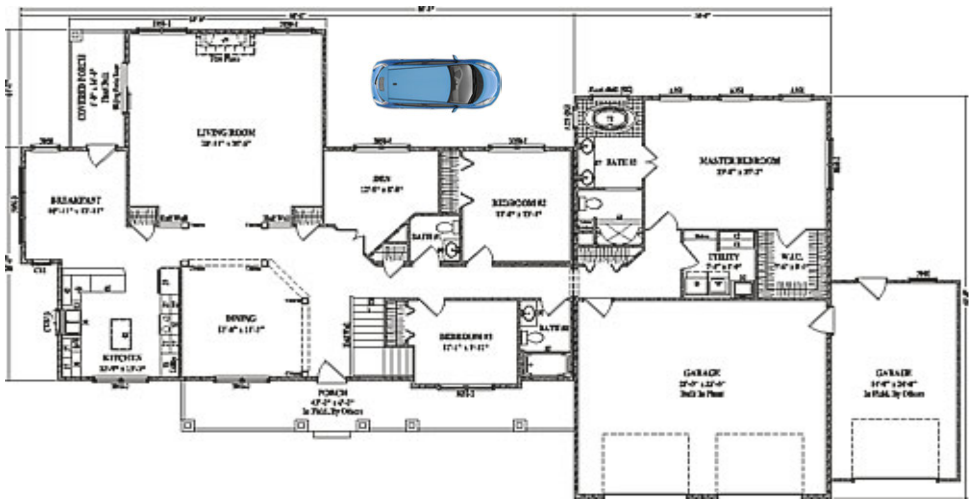


Figure 2. This scaled drawing shows a 250 sq m home with a Nissan Leaf superimposed.

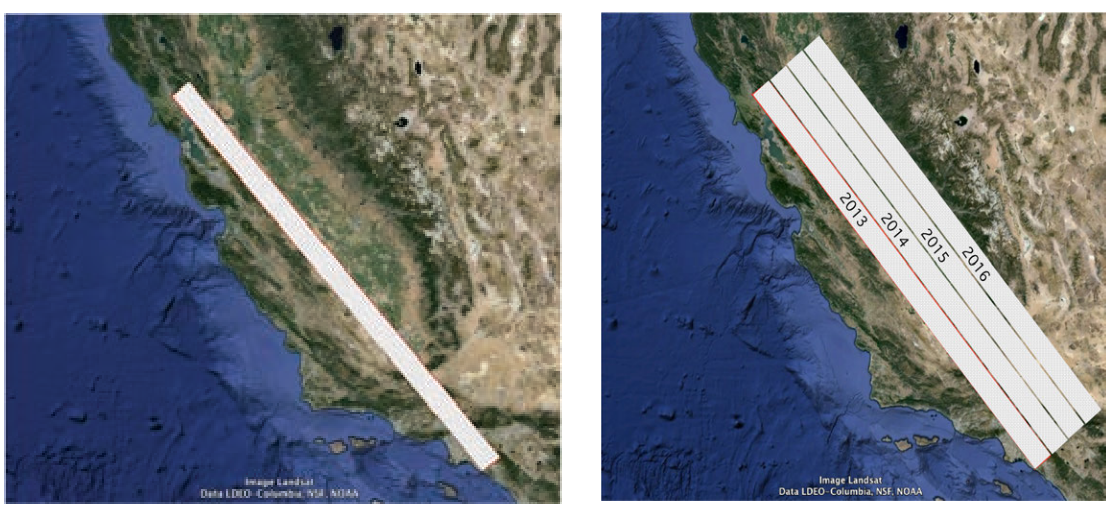


Figure 3. The left side figure shows a satellite image of California with an overlay of concrete 32 by 680 km, extending from Rohnert Park to Newport Beach. That represents the average total hardscape required for the 87 million new vehicles that were manufactured in 2013. The right side figure shows the area affected when that 2013 hardscape is reapplied over succeeding years.

these all require a push to accomplish. Public transit, in particular, has proven to be a difficult push. Figure 4., below reveals that transit ridership over many decades has remained at about 5% of workers. This is true in spite of substantial government subsidies and fare discounts, including seniors riding for free. The reasons for the low ridership include lack of privacy, violation of personal space boundaries, slow DtD trip speeds, limited distribution of stations and difficult 'last-mile' connections. With just 5% ridership on transit, and the ever-growing numbers of cars being produced, road congestion continues to worsen despite massive expenditures on new lane miles of road. Indeed, annual person hours of traffic delay in very large urban areas in 2011 was 52 hours.[3]

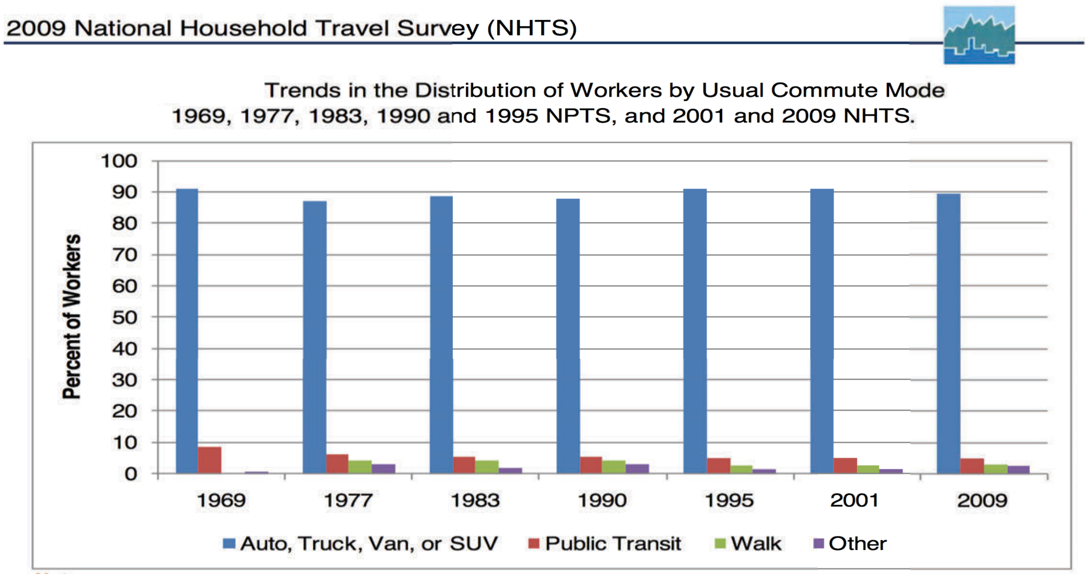


Figure 4. This graph reveals that Public Transit ridership has remained about 5% of workers for the last 40 years.

In light of the above, it is clear that a new modal solution is urgently needed, both for air travel and to relieve worsening surface congestion. Regional Sky Transit can be that solution.

III. A New Frontier in Aviation

Of all the great achievements in aeronautics in terms of range, speed, altitude, etc., perhaps the only one that remains an unexplored frontier is that of combining ultra-quiet with V/ESTOL capabilities in a safe, practical aircraft. When this inherently conflicted combination is achieved, it will enable an enormous new mass market in civil aviation—regional Sky Transit. RST will be the closest that humans have come to the miraculous flight capabilities of birds—that is, flying to and from any location one desires. This "high proximity aviation" (HPA) will be the main embodiment of transformational flight and will save enormous amounts of time and fuel.

To understand the momentousness of RST, imagine being able to use your cell phone to reserve at your local pocket airpark a safe, autonomous, electrically-powered 2-seat Sky Taxi that could fly you in quiet comfort with better than airline safety to anywhere within 100 miles. You would simply select your destination on a touch-screen map. Imagine completing your trip with a DtD speed 4 times greater than could be done in a car and at the same cost, with virtually no uncertainty about the amount of traffic congestion or the mental status of the pilot and crew. Visualize a panoramic forward view of the landscape below you, with no instrument panel in the way and with free high-speed wi-fi onboard if you should need it. RST would operate from 6 AM to 10 PM and could fly in fog, drizzle and rain, but not in thunderstorms or icing conditions. Its flight would be point-to-point 4D flight paths that were coordinated by NextGen, but were resilient in case of re-routings needed 'on-the-fly'. Low altitudes routes would avert the need for oxygen or cabin pressurization.

Sky Taxis would be certificated by the FAA as essentially pilotless air vehicles with full autonomous controls that eliminate pilot error. This would make them available to nearly the entire population rather than the very small and shrinking cohort of licensed private pilots. As with military UAVs, there would be 'bunker pilots' who could intervene with some degree of remote control if needed. For safety, Sky Taxis would have very slow landing speeds, a near 20:1 glide ratio, a vehicle parachute, passenger and vehicle airbags and an automatic vehicle life raft.

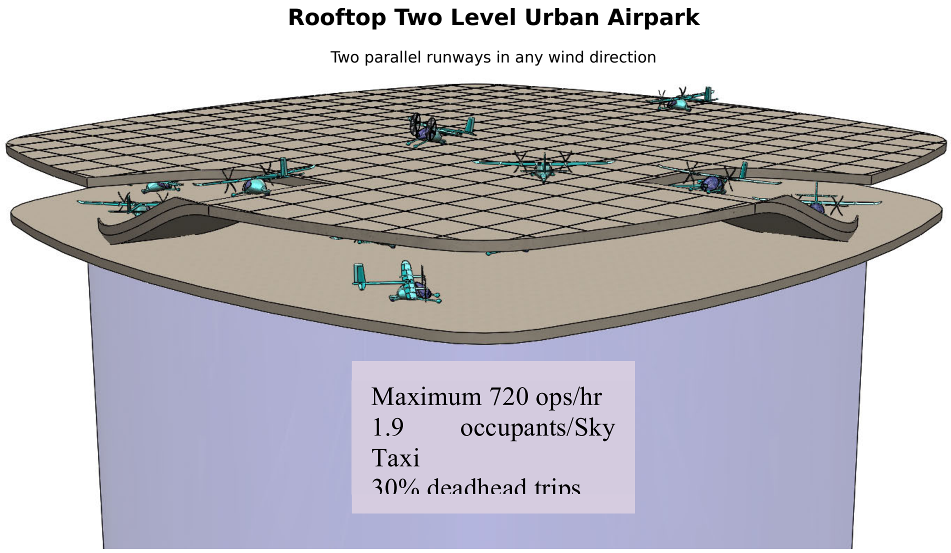


Figure 5. A rooftop pocket airpark could provide HPA to downtown areas.

Pocket airparks, about the size of a soccer field, would be conveniently located within 6 minutes of where most people live and work and would have no TSA security lines. Busy pocket airparks at hubs would have a queue of Sky Taxis waiting for their passengers, and upon reaching the curbside electronic entry gate at its deer & dog fence, you would walk directly from there to climb into your designated Sky Taxi and buckle up. From that point, the Sky Taxi would you get airborne in only 90 seconds, lifting off in about 100 feet or less, and climbing out steeply with noise emissions so far below ambient levels as to be imperceptible by airpark neighbors.

Rooftop pocket airparks 80 meters square could enhance HPA in the densest metro areas, like the San Francisco downtown financial district. Being atop buildings of 12 or more floors (or higher as needed) would insulate street level pedestrians from perceptible Sky Taxi noise and ensure that landing and take-off operations on their parallel runways were consistently 'into-the wind'. Loading and unloading along with robotic battery swap would occur on the floor below the upper deck runway, accessible by a taxiing ramp, somewhat like an aircraft carrier. The rooftop pocket airpark would offer the ultimate in DtD trip speed to that building's tenants, who, using the building's elevator to get to the boarding floor, could get airborne in under 3 minutes. Such rapid, easy access would justify a significantly higher rent in that building, and calculations indicate that, over time, that increased rent would be sufficient to pay for the construction of the rooftop pocket airpark. See Figure 5.

If, as shown in Figure 6., two pocket airparks were built atop the terminal building at SFO, they could provide

Figure 6. Yellow rectangles show pocket airparks atop the terminal building at SFO.

RST service for about 1/3 of the average of 5,300 airline passengers per hour flying to and from that hub airport. This would substantially reduce the parking lots needed and unburden the surface transportation system to and from SFO. Commercial airline trips would enjoy a marked improvement in DtD trip speeds by eliminating on the order of 2 hours of ground travel time (GTT) to and from the hub airport.

The RST traveler would enjoy a discounted fare in return for doubling up randomly with another passenger who sought the same destination. Exclusive, single-person use of Sky Taxis would be allowed but discouraged by a surcharge on the fare. An online networking app would match-up users and minimize empty 'deadhead' flights. A centrally located dispatch/maintenance facility at a site with low-land-cost such as a surplus military base would

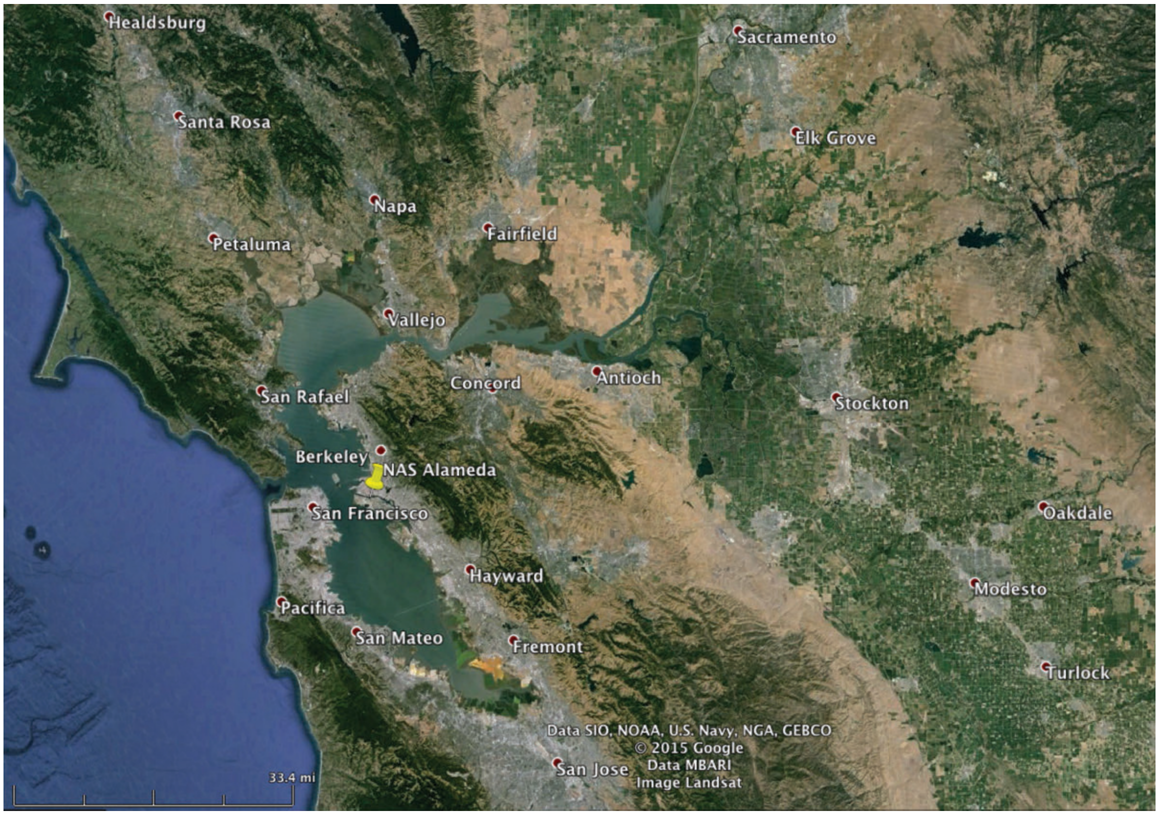


Figure 7. The yellow pin indicates the surplus field at Naval Air Station Alameda, an ideal low-land-cost location for the centralized Sky Transit maintenance/repair station just a short 6 km flight from the downtown San Francisco financial district.

serve as the home nest for Sky Taxis to have freshening service, tires and battery packs replaced during off-peak hours. See Figure 7.

Note that RST would solve the main problems with surface transit. It would ensure un-crowded, seated privacy, offer very fast DtD speeds with highly distributed destinations and walk-up on-demand service with no headway waiting time, and would do so with potentially emission-free vehicles. As a result, ridership could be expected to reach 10%, far surpassing the 5% of surface transit, and could eventually well exceed 20% of those who were making inter-county trips in the region.

For the highly beneficial societal, economic and environmental benefits that RST would produce, communities and private interests within the San Francisco Combined Statistical Area could be expected to cooperate in cost-share agreements with state and federal government to designate pocket airpark locations and then build and maintain the pocket airparks. Pocket airparks would enhance tourism and be business magnets whose business tenants (FedEx, Starbucks, etc) would pay rent as well as enhance local sales tax revenue. The increase in productivity for those who rode RST would be diffused as a benefit across the region. The potential reduction in road, rail and bridge infrastructure costs that could result from RST is difficult to calculate, but could be enormous.

RST would serve the existing hub and spoke transportation system by allowing people to fly the radial spokes. However, it would also serve a large number of daily trips that go from spoke to spoke. The result would eventually be a much-expanded reach for residents throughout the region. Where people live and work would redistribute. Urban greenbelts would make more sense as people sought to live and work closer to centrally located pocket airparks. The resulting in-fill of town centers would help limit sprawl, reduce surface VMT and reduce the need for new road construction. RST would be available to all segments of the population, workers, students, the elderly, the disabled, the inebriated and even the blind.

In Figure 8., below, the 56.2 billion car trips of between 15 and 99 miles length in the USA in 2009 represents an enormous untapped market for Sky Transit. By serving such trips, a fully developed RST system could serve 35 fold more trips than the current CTOL GA market, whose focus is on the small market of trips of 100+ miles.

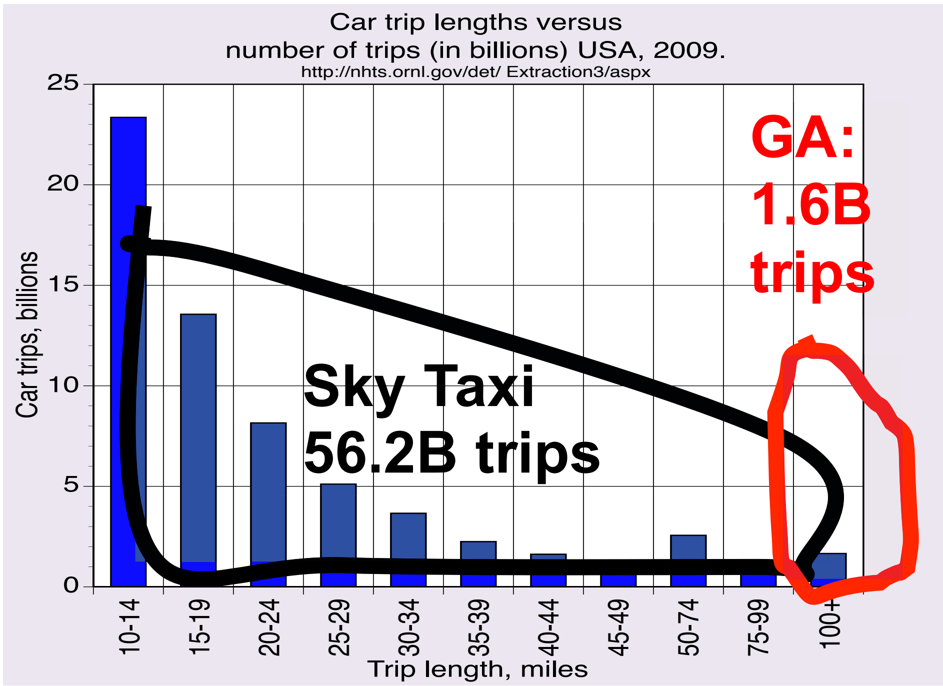


Figure 8. Car trip length versus number of trips for USA in 2009.

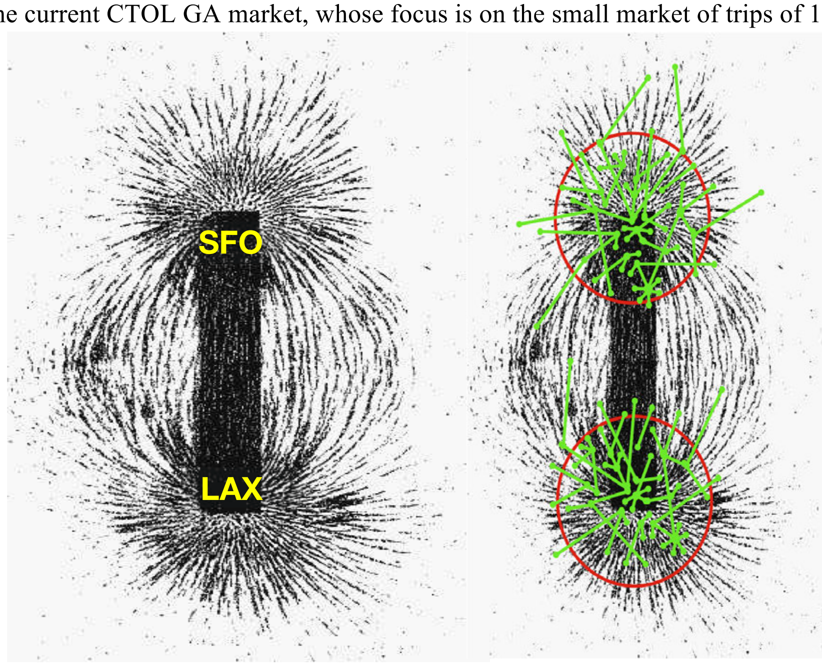


Figure 9. In the hub and spoke system, RST will fly both the radial spokes and their myriad other local network connections, shown in green.

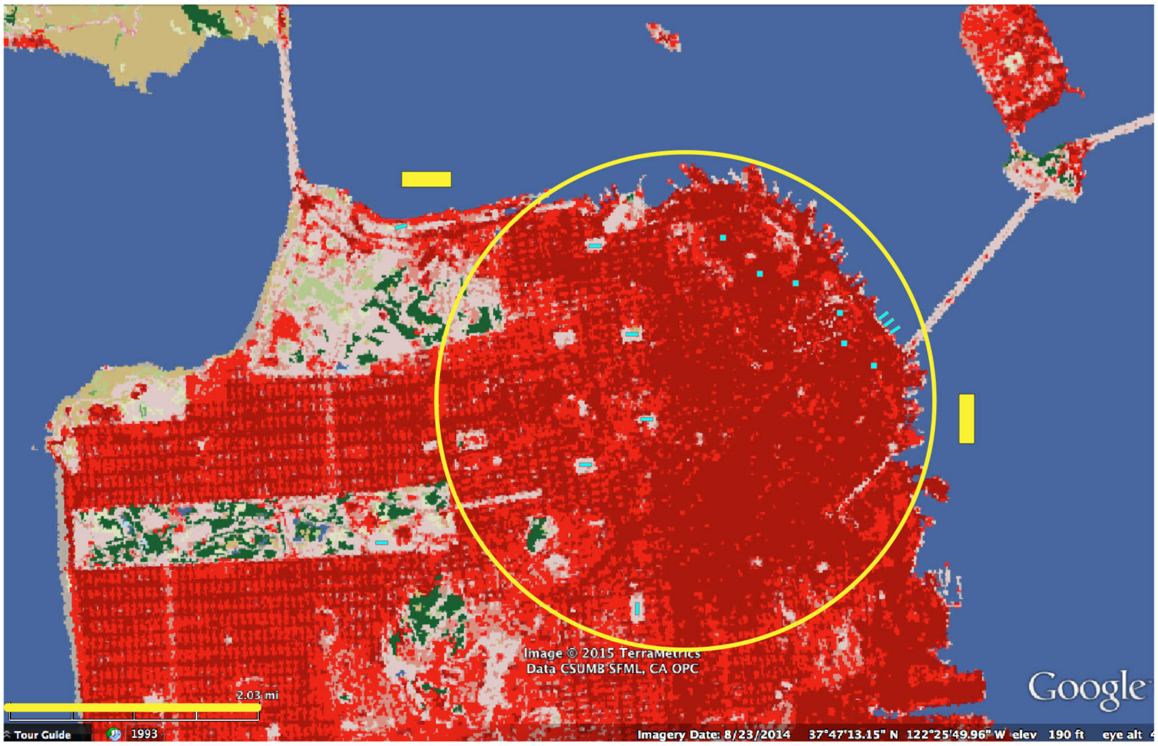


Figure 10. USGS Map of San Francisco's dense urban area shows built hardscape in shades of red. Despite such extensive land cover, there are at least 10 suitable open-space locations for street-level pocket airparks of 160 x 80 meters, as shown by the tiny aqua-colored rectangles. This includes 3 placed atop piers near the Bay Bridge. Six tiny square rooftop airparks of just 80 x 80 meters are also shown in aqua color in the downtown financial district. The 2 large yellow rectangles on the water represent outlines of airports that are 640 x 320 meters—and there is no non-built land parcel large enough to fit these within the yellow circle of 3.22 km (2 miles) radius that encircles the city's core. These large yellow airports are the size necessary if Sky Taxi noise levels were 12 dBA louder than the acceptable level at the 160 x 80 meter aqua-colored pocket airparks.

In Figure 10., above, we see how the extensive hardscape in San Francisco would limit HPA. A pocket airpark of 160 x 80 meters is seen to have a close-to-ideal size that allows its placement in good enough proximity to keep most areas of San Francisco within 6 minutes of a takeoff or landing location. Larger pocket airparks simply do not fit. Smaller airparks, i.e., smaller than the rooftop airparks of 80 x 80 m and surface airparks of 160 x 80 m, would be unlikely to offer any significant improvement in GTT, capacity, or cost and, most importantly, would demand unattainable levels of noise reduction from the air vehicles.

IV. Climate Change and Sustainability

The burden on the environment from human-caused greenhouse gas emissions is now well recognized. Numerous federal and state initiatives seek to mitigate that burden through enormously costly initiatives. The extensive conversion to electric propulsion in surface vehicles and the development of clean energy sources will help in reducing transportation's adverse effects on climate change. However, absent the political means to limit population growth, those favorable trends in electric surface vehicles will not limit the increase of hardscape nor the increase in surface congestion with its waste of time and fuel. Regional Sky Transit, on the other hand, could greatly help limit those increases because Sky Taxis will use virtual "highways in the sky" that do not congest.

The potential savings in infrastructure cost that would occur with a fully implemented RST system are difficult to calculate due to uncertain future trends. However, it is plausible that moving 10% of the Bay Area's inter-country travelers by RST could undo surface gridlock and spare the need for building extra lanes on surface byways. The potential savings on infrastructure could be enormous simply because the cost of adding a lane to a regional freeway is about $20M per mile and the cost of adding track to regional systems like BART is $1B per mile, while that of adding a "highway in the sky" for Sky Transit is essentially zero. Assuming each pocket airpark costs $3M to build, the entire network of 354 pocket airparks for 10% ridership would cost $1.1B. Compare this to the MTC-proposed $7.6B cost of building the planned 800 additional miles of Express Lane freeway in the San Francisco Bay Area by 2035.[4] Yet these new Express Lanes have a very limited distribution compared to the routings of RST. Moreover, the very large and ongoing costs of maintaining roads and freeways is non-existent for pot-hole-free "highways in the sky", which also exert no heat-island effects.

Sky Taxis could operate as zero fossil fuel (ZFF) vehicles if they did so on electricity produced by wind, solar, and geo-thermal sources. The size of the potential 2025 reduction in CO2 emissions from 10% ridership across the US computes to be more significant than that of either the NASA ERA (Environmentally Responsible Aviation) program or that obtained by eliminating *all* of the fuel wasted in surface gridlock. See Figure 11., below.

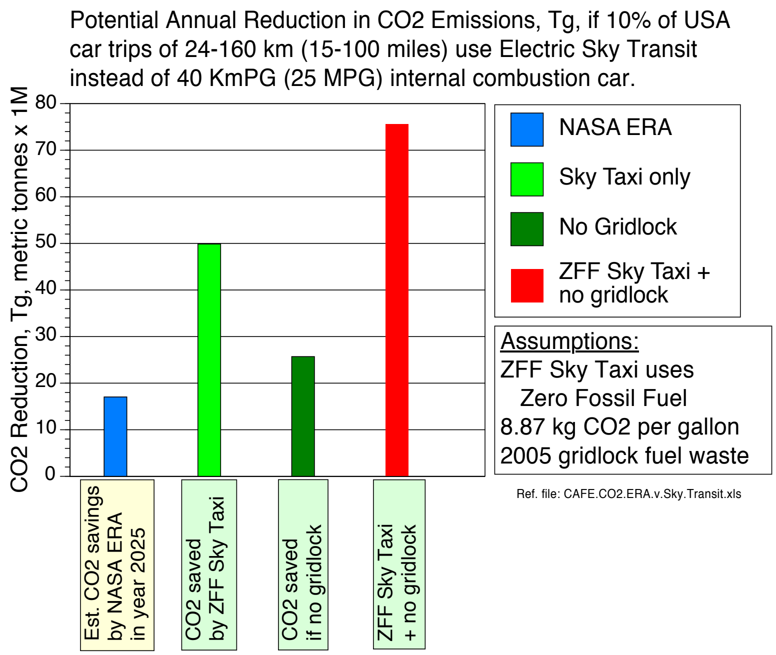


Figure 11. Potential savings in US annual CO2 emissions from a full-fledged Regional Sky Transit system and the potential elimination of fuel wasted in surface gridlock.

V. Noise Rules

RST can only be realized if future Sky Taxis can be made ultra-quiet relative to today's notions of quiet aircraft. "Ultra quiet" will require specific definition in terms of both the level of dBA and the sideline or radius distance at which it is measured. People's intolerance of noise is well documented, is increasing and, according to this RST model, will absolutely dictate the success or failure of future Sky Taxi aircraft designs used in Sky Transit.

Rules and regulations that set noise limits will impose the fundamental technologic challenge to HPA. In addition to the noise rules imposed by the FAA for both aircraft and airports, local municipalities have the authority to impose their own noise ordinances, and these will surely be applied to neighborhoods accessed by RST..

The city of Berkeley, California, for example, limits long duration residential neighborhood noise to a maximum of 60 dBA from 7 AM to 7 PM.[5] The city of Seattle lists a level of 60 dBA as the beginning of "intrusive" noise and affirms that a continuous exposure to 65 dBA carries a "bad risk of heart circulation disease".[6] In California, airport noise is closely regulated and a limit of no more than 65 dBA CNEL at the airport noise impact area is prescribed. The CNEL "community noise equivalent level" metric is the same as L_{den}, which is the level "day-evening-night". These are similar to DNL, the day-night level. These metrics are all averages of the noise over a 24 hour period and all include a 10 dBA penalty for the quiet period during nighttime. The CNEL or L_{den} also include a 5 dB penalty during the period from 7 PM to 10 PM.

Despite numerous and ongoing efforts to specify the subjective character of noise in terms of its annoyance, the current consensus metric for quantifying annoyance remains the long-accepted dBA scale. The existing noise rules imposed by the FAA and by state and local jurisdictions vary somewhat in their allowable dBA levels. A new FAA noise survey will be conducted in summer of 2015 at 20 major airports. Existing dBA-based noise survey data reveal two important phenomena relevant to RST. One is that people's sensitivity to noise is found to be increasing over the last several decades. The other is that the frequency of flight operations has a substantial effect on people's noise tolerance, with increased frequency demanding much quieter single flight events, whether those be flyovers or take-offs. RST will necessarily involve an unprecedentedly high frequency of take-offs and landings.

In addition to its high frequency of operations, RST will have Sky Taxis operating simultaneously at pocket airparks. For example, one will be initiating take-off roll while another is climbing out and another is taxiing. The summation of such multiple separate noises will increase the noise according the logarithmic formula, as shown in Figures 12. and 13., below. This formula affects the summing of loud noise with quieter noise in a non-intuitive way:

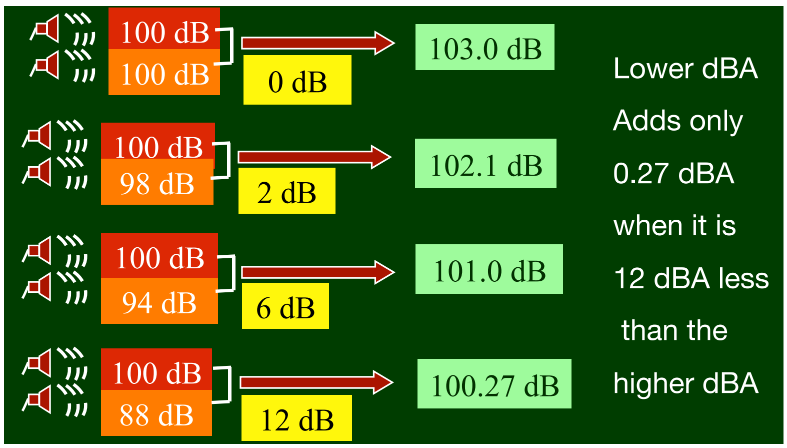


Figure 12. The summing of separate but very close together noise sources, dBA_1 , dBA_2 , dBA_3 obeys the formula:

$$dBA = 10 \times Log_{10} ((10\hat{}(dBA_1/10)) + ((10\hat{}(dBA_2/10)) + ((10\hat{}(dBA_3/10)) + \ldots)$$

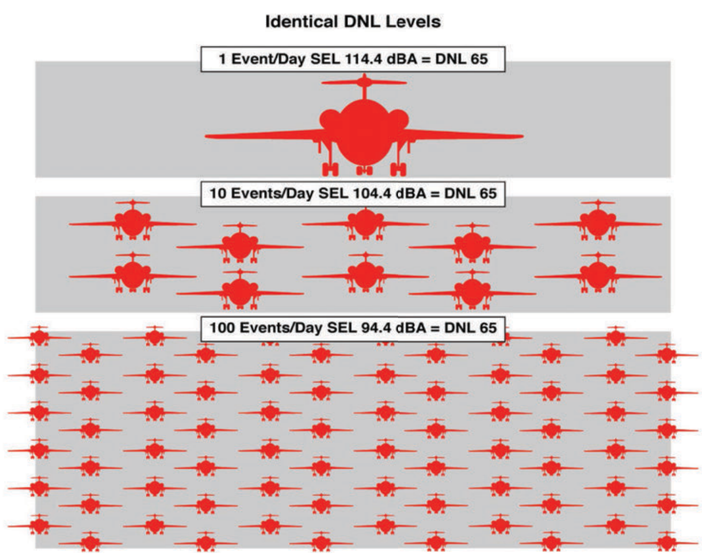


Figure 13. A given DNL of noise can be produced by a variety of different single noise events.[7]

Accordingly, the result of summing the noise of 5 separate Sky Taxis operating in very close proximity, each emitting 48 dBA, would be 55 dBA. Similarly, 5 separate Sky Taxis, each emitting 65 dBA, would sum to 72 dBA.

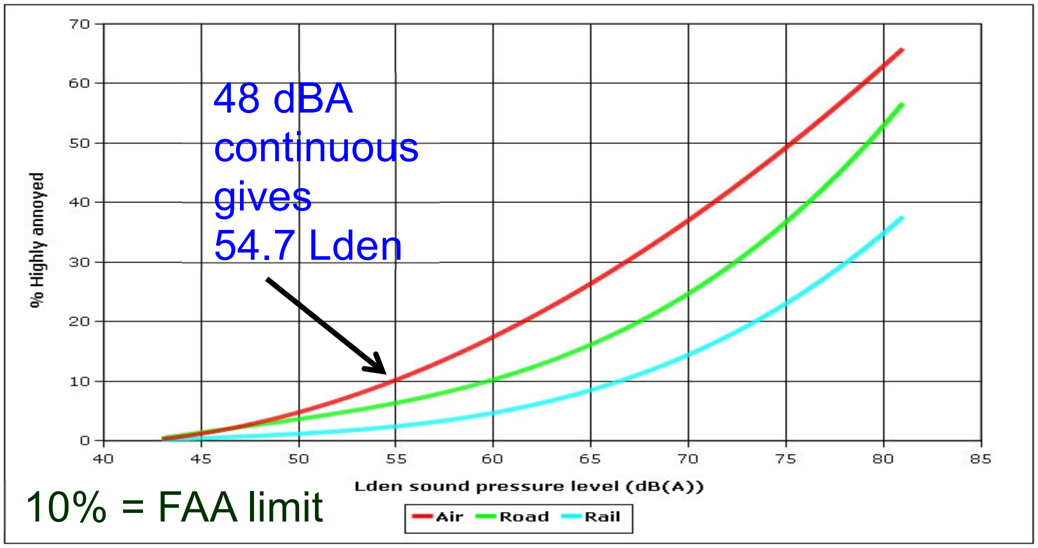


Figure 14. Compliance with the FAA limit of 10% highly annoyed demands Lden noise levels below 55 dBA. For the near-continuous noise levels of Sky Taxis departing every 10 seconds, each Sky Taxi's single event noise level must be below 48 dBA.

The varying separation distances from the observer relating to separate runways and departure sequencing would reduce these summed values by 2-3 dBA. The summed noise of 2 propellers on one aircraft, each emitting 45 dBA, will be 48 dBA. Importantly, in the presence of a continuous ambient noise level of 60 dBA, a noise level of 48 dBA will be imperceptible. Figure 14. reminds us that the 10 dBA night penalty with L_{den} requires a continuous noise level of 48 dBA to fulfill the 55 dBA L_{den} limit for aircraft.

Figures 15. and 16. both show that people's sensitivity to noise appears to be increasing. While in 1972 a level of 65 dB annoyed 10% of people, that 10% annoyance level has dropped to just 55 dB in 2002 and is trending in Europe toward just 47 dB in 2005. This trend must be respected, for the voting populace in every community has consistently exerted absolute veto power over airport sitings and operations that violate their noise tolerance.

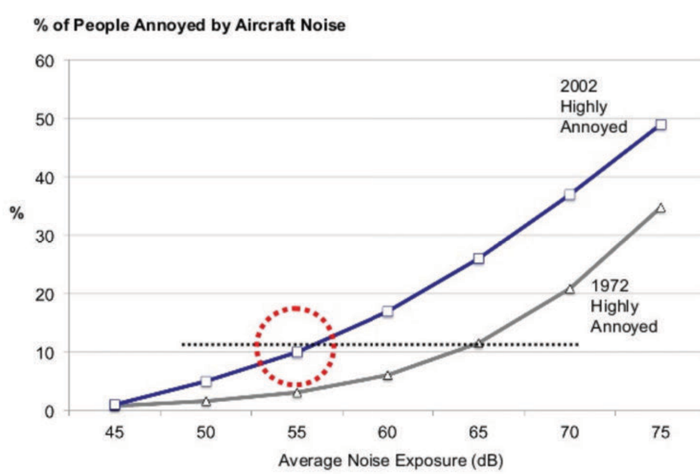


Figure 15. In the 30 years from 1972 to 2002, it appears that the 10% annoyed noise tolerance level for aircraft noise decreased by nearly 10 dB.

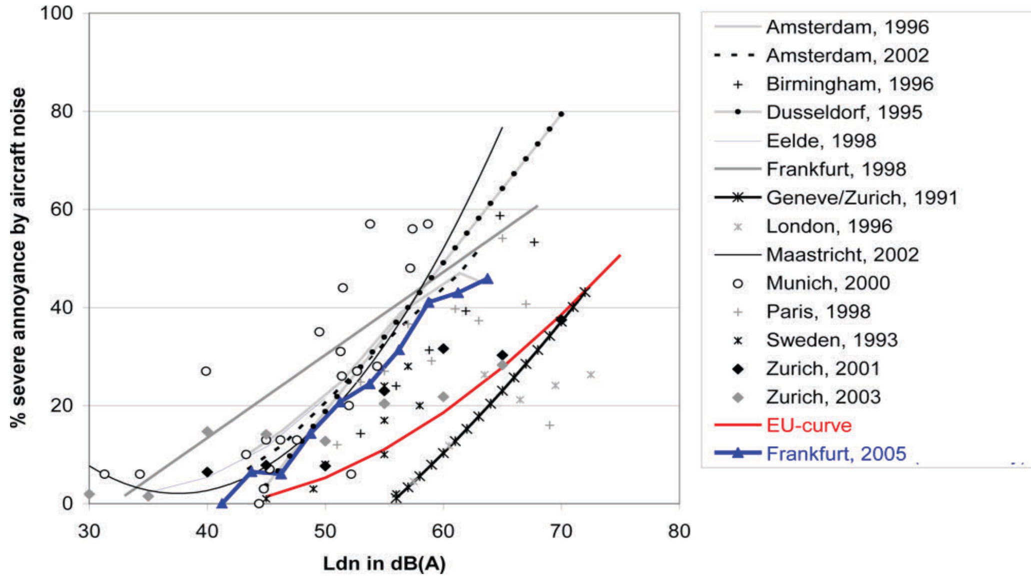


Figure 16. The experience in Europe corroborates the increase in stridency with regard to noise annoyance, when comparing the data for Geneve/Zurich in 1991 with that of Frankfurt in 2005.

In a laboratory with a direct A:B comparison we can detect about a 1 dB change in sound level. In a normal environment, a 3 dB change is generally the threshold of detectability. A 3 dB increase represents two times the sound energy and a change of 6 dB is clearly perceptible in normal ambient levels. A 6-dB increase requires four times the sound energy.[8]

While Sky Taxis that emit less than 48 dBA at 40 m during take off can be called "ultra-quiet" by conventional standards, the summing of noise from several Sky Taxis, along with the heightened annoyance trend in recent surveys and the marked sensitivity to be more annoyed by frequent take-offs will demand that RST comply with even lower noise levels in order to be publicly acceptable. The quieter the better. Figure 17. shows an FAA report

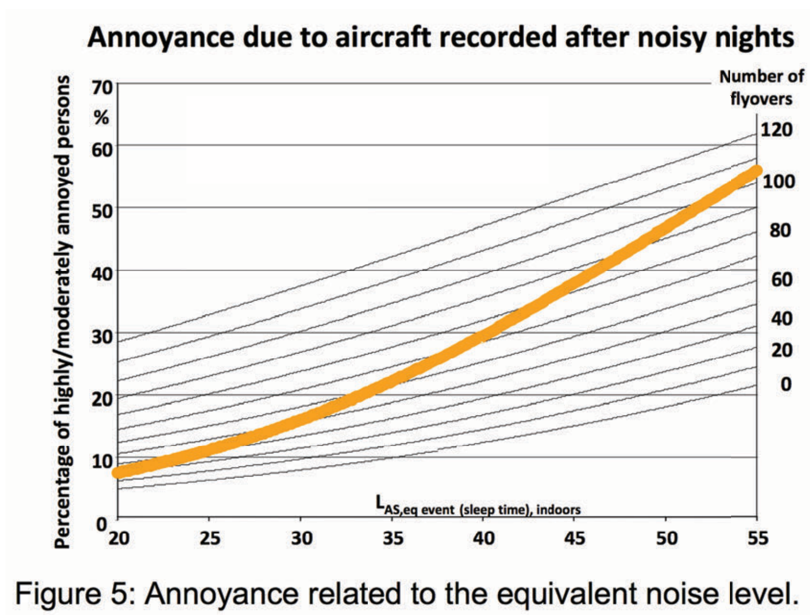


Figure 17. More frequent flyovers at night dramatically increases the percentage of those highly annoyed. The single event noise level tolerable at night is much lower than during daytime. From FAA.gov, Quehl and Basner[9]

revealing a markedly increased annoyance threshold with frequent nighttime flyovers. Another study at the Karolinska Institute in Sweden revealed that aircraft traffic frequency exceeding roughly 50 take-offs per 24 hours triggered increased noise annoyance sensitivity on the order of 20 dBA. These shockingly low noise tolerance levels emphasize the extreme importance of creating ultra-quiet Sky Taxis if the great promise of RST is to be realized.[10]

Power affects noise according to the "Power Formula": dBA reduction = 10 x Log (kW_1 / kW_0)   For example, the noise reduction for an aircraft that takes off with 100 kW instead of 200 kW would be:

dBA reduction = 10 x Log (200/100) = 3.0 dBA

The Power Formula suggests that Sky Taxis will need to be aircraft with a small amount of power required. Such aircraft will necessarily be small and of limited payload. Fortunately, the statistics on US travel habits, shown in Figure 18., indicate that 2 seats will be enough for the vast majority of trips with RST. It shows that the vast majority of car trips carry 2 people or less. This reflects the highly distributed destinations that people have in their daily travel, a distribution that is poorly served by public transit due to its limited number of stations. This also shows that 4 and 6-seat Sky Taxis would not only be unnecessary, but would be wasteful of seat occupancy. A 2-seat aircraft will need less power than one of 4 or 6 seats and thereby will inherently make less noise.. *If quiet enough*, 2-seat Sky Taxis will be allowed to provide HPA to a very large number of destinations, ones that are much closer to the highly distributed destinations that fulfill most people's travel purposes. (Appendix).

The compulsory noise constraints inferred by the Power Formula favor the low power requirements conferred by the higher L/D ratios of fixed-wing type aircraft rather than the typically much lower L/D ratios of purely vertical powered-lift versions. A high-aspect ratio fixed-wing Sky Taxi that is a sailplane-like aircraft with high L/D and low power requirements will likely make less noise than one with a low-aspect ratio. However, the quest to minimize power for the sake of reducing noise must be tempered by the need for Sky Taxis to deliver cruise airspeeds of 193 kph (120 mph) or above.

. Average Vehicle Occupancy for Selected Trip Purpose 1977, 1983, 1990, and 1995 NPTS, and 2001 and 2009 NHTS (Person Miles per Vehicle Mile).

Trip Purpose	1977	1983	1990	1995	2001	2009	95% CI
To or From Work	1.3	1.29	1.14	1.14	1.14	1.13	0.01
Shopping	2.1	1.79	1.71	1.74	1.79	1.78	0.05
Other Family/Personal Errands	2	1.81	1.84	1.78	1.83	1.84	0.04
Social and Recreational	2.4	2.12	2.08	2.04	2.03	2.20	0.06
All Purposes	**1.9**	**1.75**	**1.64**	**1.59**	**1.63**	**1.67**	**0.03**

Figure 18. According to the NHTS[11], the average vehicle occupancy in 2009 for all trip purposes was 1.67 persons per vehicle. Sky Taxis with 2 seats can fulfill that requirement.

The design guidelines for minimizing propeller or fan noise generally favor 5 or more blades, large diameter, low RPM (low tip speed), short chord, thin, laminar-flow blade sections with slight forward sweep and a planform that delivers elliptical lift distribution. If two propellers are used, autonomous precision synchro-phasing shows great promise to reduce noise. The ultimate degree of noise reduction that could be achieved with the ideal combination of all of these propeller design guidelines, while still producing a level of thrust sufficient for a 2-seat Sky Taxi, has never been determined. The stringent noise rules and relationships described above make it clear that if the many benefits of Sky Transit are to be realized, that determination must be made as a high priority. Such a determination could be made by an astutely designed, full-scale technology prize for quietest take-off.

VI. The Transformational Approach

When taking off, the Sky Taxi should achieve a height AGL of at least 40 meters at the boundary of a surface pocket airpark in order to meet the necessary noise and proximity constraints. Such steep departures can be achieved by aircraft that have a high power to weight ratio and low span-loading. Fortunately, electric motors can supply very high power-to-weight ratios that far exceed their rated power, if applied for just a few seconds during take-off.

The boundary of busy rooftop pocket airparks will likely already be more than 40 meters above street level. Sky Taxis there could make more shallow take-offs or approaches without excessive noise at street level, enabling the rooftop runway to be 80 m in length instead of the 160 m of a surface pocket airpark. Sky Taxis landing at surface pocket airparks will need to perform a new "transformational landing approach" of nearly 20° glide slope. The development of high-lift/high sink rate devices, smart, long-travel active landing gear and high-speed closed-loop autonomous controls will enable such landings. With electric motors that can almost instantly reverse torque and large diameter variable pitch propellers that can almost instantly become very effective drag brakes, extremely accurate steep glide path control should be achievable by fast-acting, closed loop autonomous sensor suites.

The concept of RST operations at the busiest pocket airparks, such as those proposed on the waterfront in large cities like San Francisco, Chicago and New York, is one whose capacity crucially depends upon having minimum delay between take-offs or landings. A maximum of 6 operations per minute per runway is projected for Sky Transit as compatible with safe separation distances. With brisk take-offs and climb-outs, this can be achieved. However, such high tempo operations will also require nimble Sky Taxis that are capable of rapidly approaching, touching down and clearing the pocket airpark's landing area with no delay.

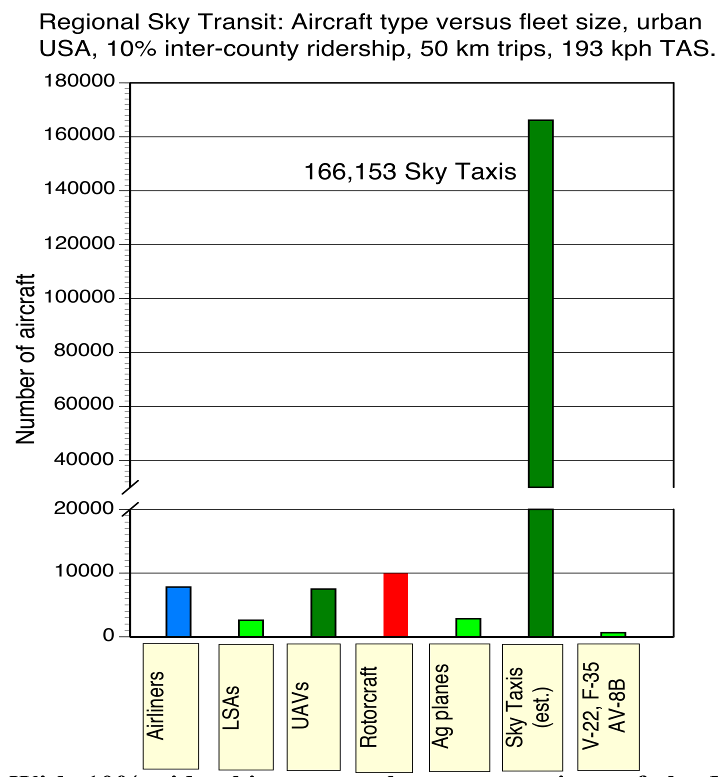


Figure 19. With 10% ridership across the metro regions of the USA, regional Sky Transit would need over 166,000 Sky Taxis. At a price of $800,000 per unit, that amounts to over $133 billion.

VII. Hand-Made vs. Mass-Production

Current single engine certificated aircraft are built in very small numbers. These include the Cirrus SR22 and Mooney Acclaim Type S. In effect, they are hand-made and do not enjoy the economy of scale that would apply if mass production methods could be justified. According to reliable sources, the new Cirrus SR22 with a complete avionics package has a list price of $663,000. The new Mooney Acclaim Type S list price is $734,000. Even considering the high cost of certification, it seems reasonable that an electrically-powered Sky Taxi with a much lower parts count than either the Cirrus or Mooney could be produced in mass quantities approaching hundreds of thousand of aircraft for less than $800,000 each, and quite possibly as little as $400,000 each. For the purposes of this RST model, we shall use the more conservative $800,000 as a nominal value for aircraft price, though $400,000 may be achievable with mass-production economies of scale.

Extrapolating to large urban areas across the US the ratio of the Sky Transit fleet of 7250 aircraft necessary to serve 10% of the inter-county trips made by the San Francisco Bay Area's 8.5 million people reveals a potential market for over 166,000 Sky Taxis. If each Sky Taxi sold for $800,000, that would be over $133 billion in sales volume. Figure 19. shows this volume of production to dwarf that of all other types of aircraft.

VIII. Cooperation and Collaboration

Civilized societies organize by a social contract in which personal freedoms are limited for the greater good of all. For example, communities have agreed that certain areas of the community provide a shared-use facility. When sand-lot baseball or street stick-ball games were found to obstruct traffic or break neighbor's windows, communities decided to provide civic parks where these games could be safely played at a nicer facility. Other examples of communities collaborating in shared-use facilities abound--everything from farmer's markets to public restrooms. The same will be true of pocket airparks. The notion of randomly landing and taking off in passenger aircraft in sand-lots or residential back-yards would likely be neither community-acceptable nor manageable by ATC. Use permits, appropriate land zoning and transportation mode changes adjacent to pocket airparks will be essential.

Communities will be active participants in the implementation of Sky Transit. Its early adoption will likely be in the form of Sky Cargo. The first pocket airparks will likely be placed in industrial parks or on large high-tech campuses such as Google's. Some will likely be built on the rooftop of Amazon.com's enormous fulfillment center warehouses in Tracy, to enable same hour freight delivery. As trust in autonomous vehicles increases beyond early adopters, some more affluent communities will seek and cost-share in the placement of convenient pocket airparks for their residents. As the awareness of the benefits of using pocket airparks grows, more airparks will be added, and communities will likely become increasingly receptive to RST and develop their own regulations with respect to pocket airpark land use, noise and overflight paths.

The major societal and environmental benefits of regional Sky Transit will justify its support by various levels of government. The US government will need to have a major role in regional Sky Transit, just as it does in both highway and commercial air travel. That role will involve the certification of Sky Taxis, the establishment of standards for pocket airparks, the building of pocket airparks, the design, and construction and operation of the NextGen air traffic management system, and the regulation of Sky Transit operations.

Well-targeted measures to increase the ridership of Sky Transit could improve its efficiency and profitability as well as remove cars from gridlocked highways. Though regional Sky Transit, unlike all other forms of transit, does not appear to need a fare-box subsidy, it might benefit the entire transportation system to offer substantial fare reductions to qualifying senior citizens, students, and even low-wage earning commuters for whom the $/km metric is the go-no-go determinant of use. It may be beneficial to offer a discounted "aero-rail pass" for frequent fliers in order to grow ridership Such subsidies must be carefully applied so as to not impair ridership on other forms of surface transit, unless the surface transit system is saturated and needs relief by some alternative other than roads.

IX. The Value of Time and Money

The attractiveness to the general public of travel by Regional Sky Transit (RST) will be mainly determined by its value in saving both time and money. Time and money each have different values to different segments of the population. For example, pensioners (retired people on fixed incomes) have been known to say that they 'have all the time in the world'. Their fixed incomes afford them very little money. In contrast, busy and highly paid company CEOs have very limited time and an abundance of money. The potential mass market for RST includes these extremes and everyone in-between, distributed according to the value that they place on time and money.

A recent advertisement for the Good Jet company announced that its pricing for on-demand business jet service was available for as little as $500/person/hour. This figure is of interest to people who earn several hundred dollars per hour, and emphasizes the extreme importance that some place on the value of time. But $500/person/hour is largely untenable for the mass market of RST. Unlike pensioners and CEOs, most of the public value time according to their hourly wages and how much they perceive that they have to do on a given day. They value money according to its abundance in their lives. Interestingly, an informal survey of rank and file wage-earners regarding their dollar value for an hour of their leisure time given up to perform some obligation for hire was an impressive $204/hr. This hints that RST may be exceptionally popular for future weekend trips.

In travel, time in the USA can be valued by the "doorstep-to-doorstep" kilometers per hour for an entire trip, expressed as "DtD" trip speed. In travel, money irrespective of time can be expressed as "dollars per kilometer" ($/km). Currently, the IRS assigns a national average value of $0.575 as the $/mile that attends all-inclusive business travel by car. In metric terms this is $0.357/km. Another cost benchmark is that made to the fares charged by taxi cabs. In San Francisco, travel by conventional taxi ('yellow cab') costs $0.55 per 1/5 mile, which is equivalent to $1.71 per km, on top of a base fare of $3.50 for all trips. In Figure 25., Sky Transit costs are compared to values of $0.357/km for commute car and $1.71/km for taxi cab.

If the values of time and money are to be combined, then the term dollars per kph ($/kph) may be used. However, note that a given value in $/kph of, say $0.10/kph, could represent a DtD speed by air travel of 200 kph for $20 or, equivalently, a DtD speed by car travel of 20 kph for $2. For a trip of 20 km, the air travel example would make the trip for $20 and consume just 6 minutes, while the car travel example would make the trip for just $2 in 1 hour. The car trip would thus save $18 but consume 54 minutes of extra time, delivering $0.10/km cost. The aircraft trip would save 54 minutes of time and would cost $1.00/km. So while the aircraft and car were identical in their $/kph, the aircraft trip cost 10 times more than the car trip. The absolute 'out-of-pocket' cost is crucial to the majority of people.

The spectrum of travelers in the USA, from pensioners to CEOs, can choose which travel mode to use according to either its absolute $/km (pensioners) or its relative $/kph (CEOs). In order to win the largest segment of the potential user spectrum, RST must compete favorably in both $/km and $/kph. It would be helpful to operators of Sky Transit to have a single metric by which to evaluate its value compared to car travel. Fortunately, such a metric can be devised.

During the 1980's, the CAFE Foundation designed and conducted an annual aviation technology prize known as the "CAFE 400". To determine its winners, CAFE derived a scoring method, the "CAFE Formula", to measure aircraft flight efficiency. The formula was "Speed times miles-per-gallon x payload", or V x MPG x Wp. If the payload term, Wp, is discarded because virtually all Sky Taxis have the same payload of 2 fare-paying passengers, then this formula simplifies to just V x MPG. We can restate the MPG term as km/$, which is easily calculated for RST from the trip length and the fare price. Then, the CAFE Formula can become kph x km/$, a term for which larger is better. The reciprocal of this term, would be hours/km x $/km. This is equivalent to $/km/kph, the metric used to compare the DtD speed and cost of RST DtD to that of IRS business car use in Figure 20., below.

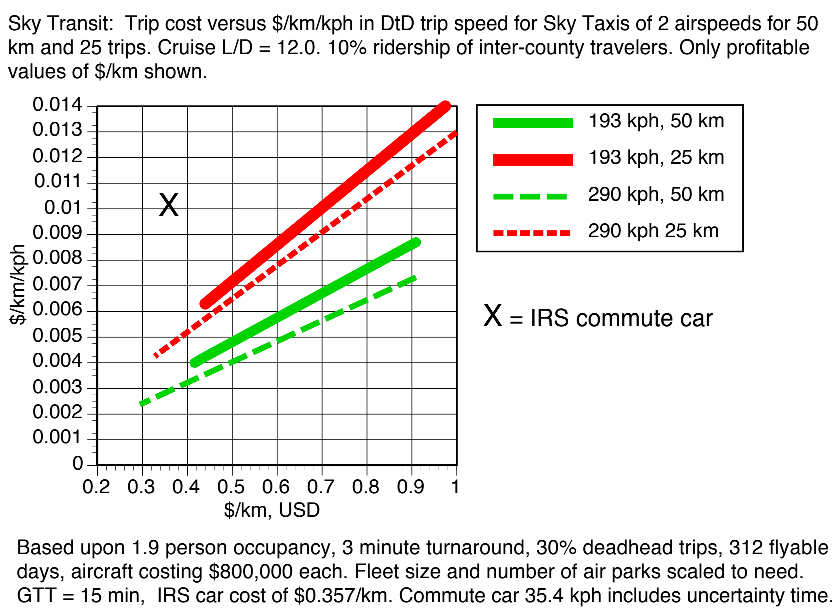
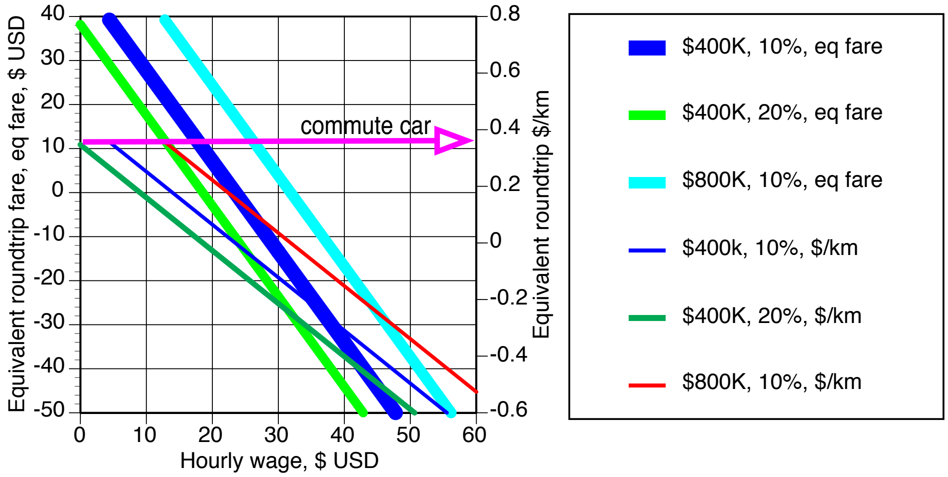


Figure 20. Sky Transit's combined cost of time and money shown in $/km/kph.

RST, 50 km flights: Hourly wage versus Equivalent roundtrip fares and $/km if total DtD time savings are included, compared to DtD time of 35.4 kph commute car at cost of $0.357/km.



Actual fares are those giving $1B net profit/yr for Sky Taxis that cost $400K or $800K. Riderships are 10% or 20%. TAS = 193 kph. GTT = 15 min. $/km calc. uses car trip distances of 55 km.

Figure 21. For one-way trips of 50 km, the equivalent roundtrip fares are computed to include the value of time saved, based upon the traveler's hourly wage level.

The Y-axis figure of merit in Figure 20., reflects the inherent interdependence of $/km and $/kph. When plotted against the potentially profitable range of values for $/km on the X-axis, the term $/km/kph shows how well RST can compete with travel by car. Here, the car speed is fixed at 35.4 kph, which is the national average car DtD speed reduced by the NHTS average of 43% uncertainty time that attends commuting by car. At $0.40/km, for example, the fare for a 50 km trip in a 193 kph Sky Taxi will be $0.40 x 50 = $20. Thus, that fare must be at least $20 in order to make a profit. At that fare, the figure of merit in $/km/kph is seen to be nearly 5 times better than that of the commute car. At a much more profitable RST cost of $0.90/km, the fare would be $45 and the $/km/kph would still be 2 times better than that of the commute car.

Income distribution in the USA can provide an important basis for assessing potential ridership. Employment data from 2010 indicate that 93.4% of US workers earn less than $100,000 per year, which can nominally be represented as wages of $50.00 per hour or less.[12] The vast majority of these workers earn less than $50,000 per year or about $25.00 per hour. The comparative cost of using Sky Transit needs to make sense to as large a portion as possible of wage earners. When that comparative cost accounts for the value of the time saved by using RST compared to commuting in a car, its mass-market potential is seen to be very large. Arguably, workers who make $25.00 per hour should value their time to be at least worth $25.00 per hour. If making a trip by RST can save that person 1 hour, then the price of the Sky Transit fare could be considered to be reduced by $25.00. This accounting method can reveal what can be called the "equivalent fare" for regional Sky Transit.

This analysis of Sky Transit fares as "equivalent fare" simply factors in the value of the time saved relative to travel by commute car using a person's hourly wage level. See Figure 21. By this measure, the potential of RST to reach a public mass-market becomes more understandable; it becomes remarkably affordable to nearly everyone. In the nominal case of $800,000 Sky Taxis with 10% ridership, a person earning just $12.80/hour can ride RST for an equivalent $/km cost that matches the IRS car use allowance of $0.357/km. In the best case shown of $400,000 Sky Taxis with 20% ridership, it can be seen that for those making just $14/hour, a 100 km trip can be made for an equivalent fare of just $10. These figures are all based upon a Sky Taxi whose cruise airspeed is 193 kph (120 mph). If the Sky Taxi speed were higher, then the cost of using RST becomes even more attractive relative to car use.

For those making higher wages, Figure 21 shows that the time savings become so large as to produce equivalent fares that are below zero. The practical aspects of a negative equivalent fare would be that one's employer would pay for one to ride RST on business travel rather than to use one's car. This would compel employers to rethink the need for 'company cars' and would strongly encourage all inter-county commuters to use RST rather than their cars.

Table 1., below reveals the remarkably low wage levels that could have RST equivalent fares that rivaled the cost of traveling by commute car. This would also extend RST to seniors and others who do not drive cars.

Cost of Sky Taxi	% users	Ave. km	Cruise kph	$1B profit, fare	$/km	$/hr wage for $0.357/km
$400,000	10	25	193	$17.45	$0.6345	$20.00
$400,000	10	25	290	$15.50	$0.5636	$13.50
$400,000	**10**	**50**	**193**	**$24.14**	**$0.4389**	**$4.40**
$400,000	10	50	290	$20.08	$0.3651	$0.40
$400,000	20	25	193	$12.40	$0.4509	$6.80
$400,000	**20**	**50**	**193**	**$19.09**	**$0.3471**	**-$0.55**
$800,000	10	25	193	$22.02	$0.8007	$32.00
$800,000	10	25	290	$18.88	$0.6865	$21.60
$800,000	**10**	**50**	**193**	**$32.79**	**$0.5962**	**$12.80**
$800,000	10	50	290	$26.17	$0.4758	$5.90
$800,000	20	25	193	$16.97	$0.6171	$18.75
$800,000	20	50	193	$27.75	$0.5045	$7.90
$800,000	1	50	193	$123.60	$2.2473	$101.00
$800,000	1	50	913	$24.25 if $0 profit	$0.4409	$4.50

Table 1. Fares that would generate $1B in annual profit, their direct $/km user cost and the $/hr wage level of a user whose time savings on RST would make those direct costs equal to $0.357/km, which is the IRS business allowance for car travel.

X. The Six-minute Rule

There are 590 high schools distributed within a 160 km radius of San Francisco, an area of 40,212 square km. That distribution of high schools can represent a template of societally acceptable shared land use and proximity. Each high school has dedicated a parcel of land as a football field that is about the size of a pocket airpark. If we were to use 60% of that distribution to determine the number of pocket airparks needed to serve the region's Sky Transit system, it would amount to 354 pocket airparks. This number, when distributed with careful attention to population density and the traveling habits of the area's residents, should be sufficient to largely fulfill the "Six-

Figure 22. For the sake of minimizing GTT (ground travel time), Sky Transit superiority requires its surface mode of travel to avoid using congested freeways.

minute rule" (6MR). The 6MR refers to the ground travel time (GTT) consumed in surface travel to or from a pocket airpark. If the airpark can be reached in the span of just 6 minutes or less, and the final destination doorstep can be reached in just 6 minutes or less after landing at the destination airpark, then an acceptably short GTT can obtain. The total GTT will include 90 seconds from curbside to lift-off at the pocket airpark and another 90 seconds from touchdown to leaving curbside at the pocket airpark. That means that the overall GTT is 6 + 6 + 1.5 + 1.5 = 15 minutes. A GTT of 15 minutes based upon the 6MR is the standard generally applied to the DtD trip speeds in this RST model. The 6MR means that if one's proximity to a pocket airpark is within 3.22 km (2 miles), a 32 kph EV cart or scooter can reach it in about 6 minutes without having to use a congested freeway. A person can walk about 0.5 km in 6 minutes. See Figure 22.

The 15 minute GTT ensures that the door-to-door (DtD) trip speed of Sky Transit, even at modest airspeeds, can substantially surpass that of car travel for very short trips, as shown in Figure 23. This fact will help Sky Transit attract the maximum user base. Attracting the maximum user base is essential to an economically successful and environmentally significant size for RST. In Figure 24., below, the powerfully beneficial effect of having minimal GTT is apparent in determining the shortest Sky Transit trip on which one can save 30 minutes of time. Note that

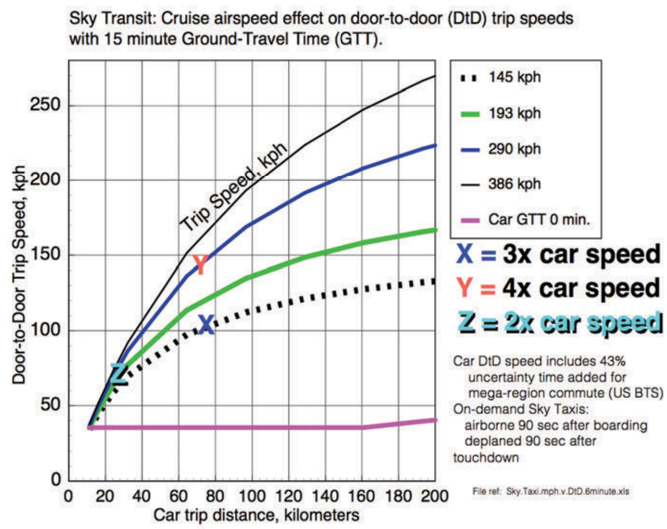


Figure 23. With the 6MR keeping GTT to just 15 minutes, even very short-range trips by Sky Taxi can offer 2X speed advantages.

the cruise airspeed has remarkably little effect on the time saved on such short trips.

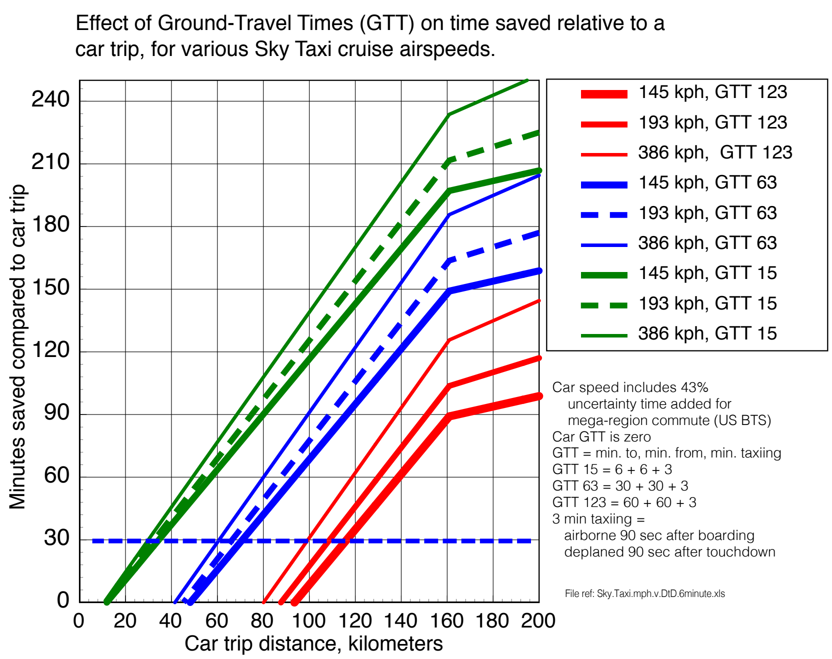


Figure 24. Short GTT enables RST to save 30 minutes on even very short trips.

According to the US NHTS 2009 commute data, DtD trip speed averages in the US are 46.5 kph for cars, 18.4 kph for public transit (including headway times), and 5.9 kph for walking (for distances of 1.6 km). However, during the daily commute congestion, there is, on average, an additional 43% "uncertainty time" that must be applied to car

DtD speeds, making them slightly less than 35.4 kph (22 mph) in metro mega-regions. For the purposes of this RST study, a speed of 35.4 kph is used for the DtD speed of a commute car.

XI. The Business Model of RST

The CAFE Foundation is an all-volunteer educational tax-exempt non-profit foundation mainly concerned with promoting aircraft efficiency through technology prize competitions, educational symposia and flight-testing. Though CAFE has no plans to create a Sky Transit business or to build Sky Taxi aircraft, it became clear that creating a preliminary business model of Sky Transit was essential to understanding its prospects. The business model was also deemed a responsibility to alert the aviation community to the opportunity to use aviation technology to help mitigate climate change, pollution, and surface gridlock.

CAFE studied the economic prospects of the implementation of Regional Sky Transit to the San Francisco Bay region using reliable data from the Metropolitan Transportation Commission.[13] This RST model necessarily involves assumptions about operating expenses and how the system will work. It is presented mainly in a series of graphs that reveal the interrelationships of key metrics as predictors of economic sustainability.

The model uses a potential service area of a 160 km radius outward from the downtown financial district of San Francisco. For this area, the total of daily inter-county person trips was taken from the MTC dataset as the denominator of potential future Sky Transit users, and a ridership of between 1% and 20% percent was applied to define the number of daily person trips that would be serviced by RST. The percent ridership, in turn, determined the number of aircraft necessary for the RST fleet. By this model, 1% ridership can be serviced by a fleet of 725 Sky Taxis. The fleet would need to be 7250 Sky Taxis to serve 10% ridership.

The total number of inter-county person trips per year estimated by MTC for 2025 for the 9 San Francisco Bay Counties is 1,021,447,314. That 9 county area now has about 8.5 million inhabitants, but that does not include the substantial additional population in the other 9 counties that fall within a 160 km radius of San Francisco. These other counties are Mendocino, Yolo, Lake, Sacramento, San Joaquin, Stanislaus, Santa Cruz, Colusa and Monterey and their combined population is estimated at 3,536,000. The number of inter-county person trips of more than 25 km that are made each weekday from these more remote counties is not known and those trips are not included in this RST model. That number would be likely to dramatically increase when RST became fully available as a travel mode option across the region. The radically reduced DtD trip time with RST will surely enable many other new types of long-distance trans-regional day trips that are otherwise impossible without it. Thus, the number of person trips in this model is likely to be an underestimate and these economic prospects are therefore conservative.

With for example 251 working days in 2015, minus those eliminated by weather and including about half the remaining 114 holidays and weekend days, we can assume that there will be 312 flyable days per year. Then, taking 10% of the total number of trips gives 327,387 daily person trips that could be made if Sky Transit wins 10% ridership of those who daily make inter-county trips in the 9 counties of the San Francisco Bay area. Multiplying by 312 days gives a total of over 102 million person trips per year. If the RST vehicle occupancy is 1.9 persons per flight, then that amounts to 53.7 million flights per year in just the San Francisco region. Compare that volume with the US total of 9.4 million commercial air carrier flight departures per year in 2012 to gain a sense of the enormity of the Sky Transit market.

Sky Transit ridership was further dissected to determine the number of weekday person trips being made to and from downtown San Francisco from the region. For this data, the inter-county trips to and from adjacent counties of San Mateo, Marin and Alameda were discarded since their close proximity to San Francisco would obviate the need to use a Sky Taxi. The result was that 728,000 weekday person trips to or from San Francisco and to or from its non-adjacent counties are predicted for the year 2025. If Sky Transit ridership captured 10% of that number, then 72,800 weekday person trips would have to be flown. If Sky Transit operates with 30% deadhead flights and occupancy of 1.9 person per flight, with peak operations of 6 landings (or take-offs) per minute during the 6 peak hours and half of that (3 landings per minute) during the 10 off-peak hours, then 10 dual-runway pocket airparks in San Francisco could accommodate 105,000 weekday person trips. See Figure 10., which depicts these airparks. For comparison, the average number of weekday person 'exits' in 2015 combined from the 6 Bay Area Rapid Transit (BART) Stations in San Francisco, including all the local traffic, is 157,219 in 2014. Due to its freedom from bridge tolls, parking space scarcity and fees, the number of future centripetal RST trips to downtown San Francisco in this model is likely an underestimate.

The largest operating expense to RST would be the four-year leases on its fleet of aircraft, which for 7250 aircraft at $800,000 each would cost $1,746M per year. Figure 25., below, shows the effect of aircraft cost on the

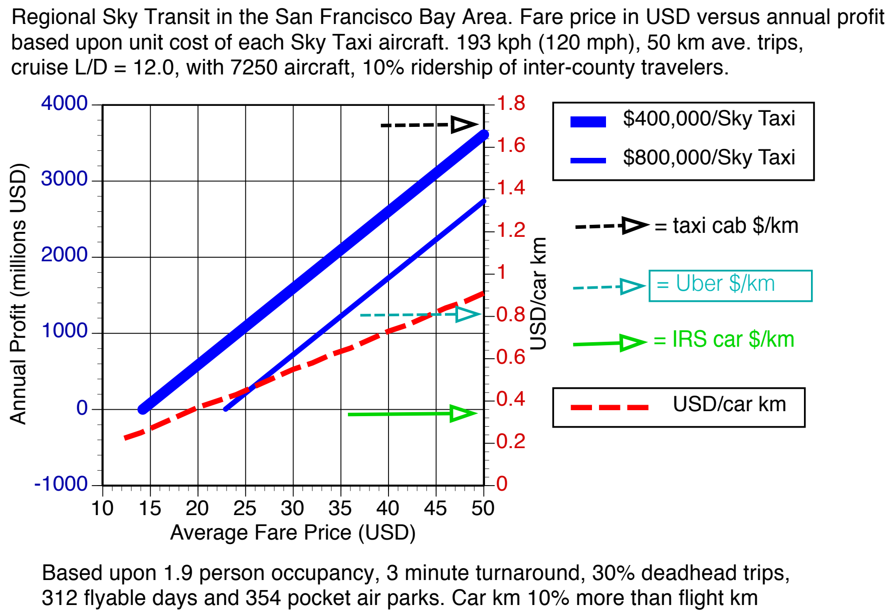


Figure 25. The unit price of each Sky Taxi aircraft strongly affects the fare necessary to achieve profitability. Sky Transit fare cost versus its cost in $/km (red dashed line) competes well with benchmark car travel costs.

dollar amount of a one-way fare necessary to achieve profitability at 10% ridership. A one-way fare of $20 for a $400,000 Sky Taxi is seen to yield $600M in annual net profits (the thick blue line on the graph) while equaling the IRS-accepted cost of business car use (the dotted red line). Given the great advantage in speed, the freedom from parking lot fees and bridge tolls, the absence of "congestion uncertainty", and the expected much higher level of safety, Sky Transit could even reach 20% ridership.

The fuel or energy cost for the entire RST system is only 2-3% of total operating expenses due to the extreme

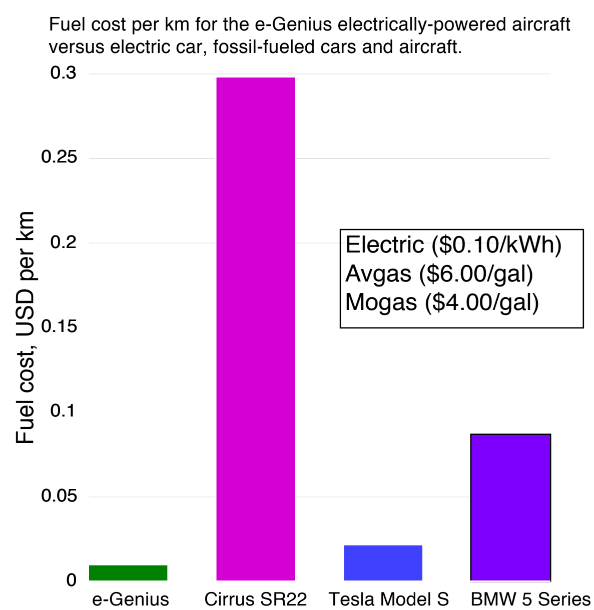


Figure 26. The 2011 Green Flight Challenge (GFC I) demonstrated the extraordinary comparative fuel efficiency of electric aircraft.

energy efficiency of electrically-powered aircraft, as shown in Figures 26 and 29..

The Sky Transit model assumes that Sky Taxis will be extremely reliable and will require only routine parts replacement. A main cost is for tires, due to the very frequent take-offs and landings per day. Allowance is also made for replacing the propellers at 1500-hour intervals. In order to control costs, the high volume level for maintenance is assumed to be highly efficient, using automated robotic equipment where possible.

The annual expenses for 7250 aircraft at 10% ridership include $20.9M for replacement tires, $174M for battery pack replacements, $131.6M for propeller replacements and $54.4M for electricity priced at $0.10 per kWh.

The business model for 10% ridership includes expenses for each of its 354 pocket airparks to have 6 employees per shift and 2 shifts per day. The maintenance/repair facility on the low-cost land at the surplus NAS Alameda would have 44 employees for each of its 2 shifts. The business office headquarters in an outlying suburb would have 19 full-time employees including the CEO. The bunker pilot facility, also at NAS Alameda, would have 20 pilots per each of 2 shifts. Five mobile field crews of 2 mechanics each would add 10 employees, making 4,405 total employees.

See **Table 2.**, below, for a summary of the operating expenses for a 10% ridership with 193 kph Sky Taxis.

Item:	**Cost per year**
Sky Taxi Fleet cost, 4 year lease, $800,000 each	$1,745,800,000
Pocket Airpark employee salaries/benefits	$127,440,000
Insurance	$10,250,000
Legal Services	$2,000,000
Service Center staffing	$4,200,000
Field Repair crews salaries/benefits	$500,000
Home office HQ staff salaries/benefits	$2,080,000
Tires	$20,880,000
Propellers	$131,607,273
Battery pack replacements	$174,000,000
Electricity cost/year	$54,360,453
Promotion and Advertising	$39,915,577
Office Supplies	$440,500
Misc parts	$14,500,000
Rent	$8,856,000
Robotic arms, battery swap equipment	$3,740,000
Bunker pilot salaries	3,200,000
	Total annual expenses: **$2,343,769,803**

Table 2. The projected operating expenses for 10% ridership RST.

The cruise airspeed of Sky Taxis, by affecting how many fares per day that they can generate, is a significant factor in the profitability of RST. A cruise airspeed of above 193 kph is shown in Figure 27, below, to allow profitable operations with fares as low as $23 for a 50 km trip. No matter the airspeed, the linear slope of the increase in profitability with rising fares is the same.

The percent ridership has a very large role in determining the profitability of RST. As shown in Figure 28., below, the slope of the increase in profitability with rising fares is much steeper when ridership is high. This graph indicates that everyone benefits by increases in ridership because profits can be higher at lower fares. Inevitably, the fares that achieve the best balance between increased ridership and acceptable profit margins will be determined by the operator of the RST system. However, the significant societal and environmental effects that RST will have by reducing greenhouse gas emissions, easing surface gridlock and saving on road and bridge infrastructure costs, along with reducing pollution and improving productivity and land use—these all would justify a stakeholder role for local, state and federal government in helping to ensure high ridership levels on RST. It would not serve the public or environment if RST were allowed to be an elite, exclusive or gentrified system though the initial start-up of RST may necessarily involve higher fares and the very limited ridership of 'early adopters' who can afford those higher fares. As stakeholder, it is hoped that the government would mandate fare pricing that would provide fairness toward both the operator of RST as well as to the public users.

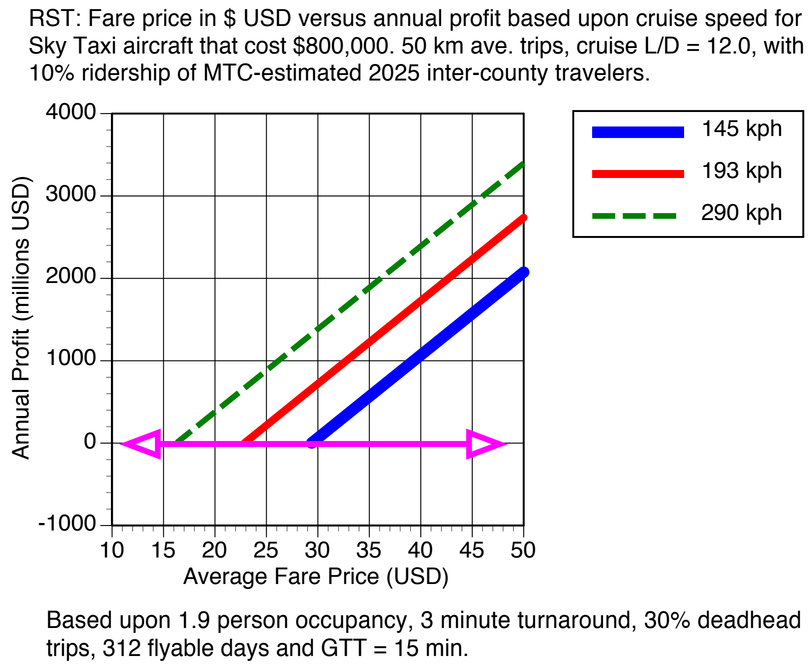


Figure 27. The affordability of Sky Transit fares will depend upon the cruise airspeed of the aircraft. To achieve good profitability at reasonable fares, Sky Taxis should cruise above 193 kph TAS (120 mph).

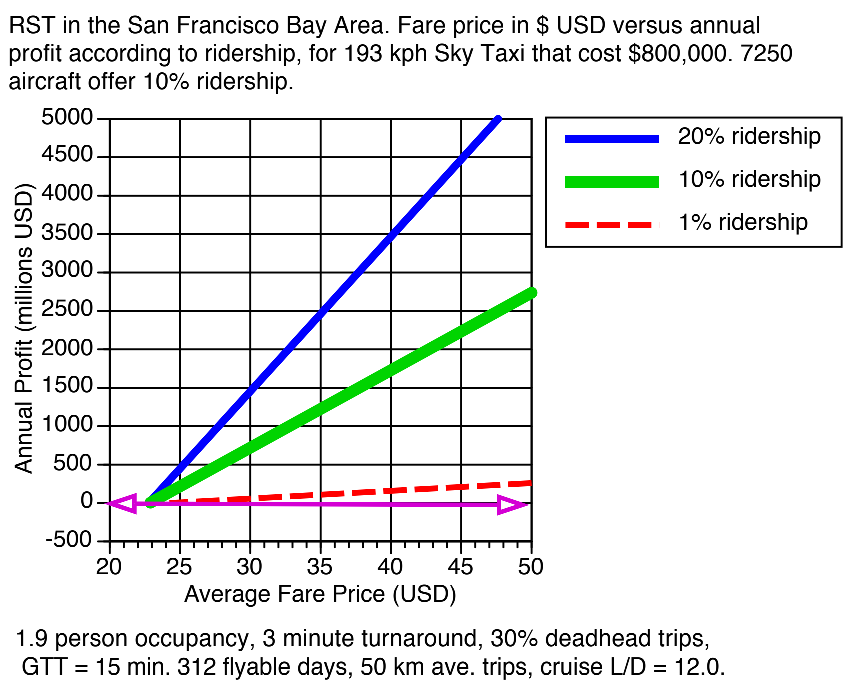


Figure 28. The profitability of Sky Transit will depend upon the size of its ridership, which will, in turn depend upon its fare pricing.

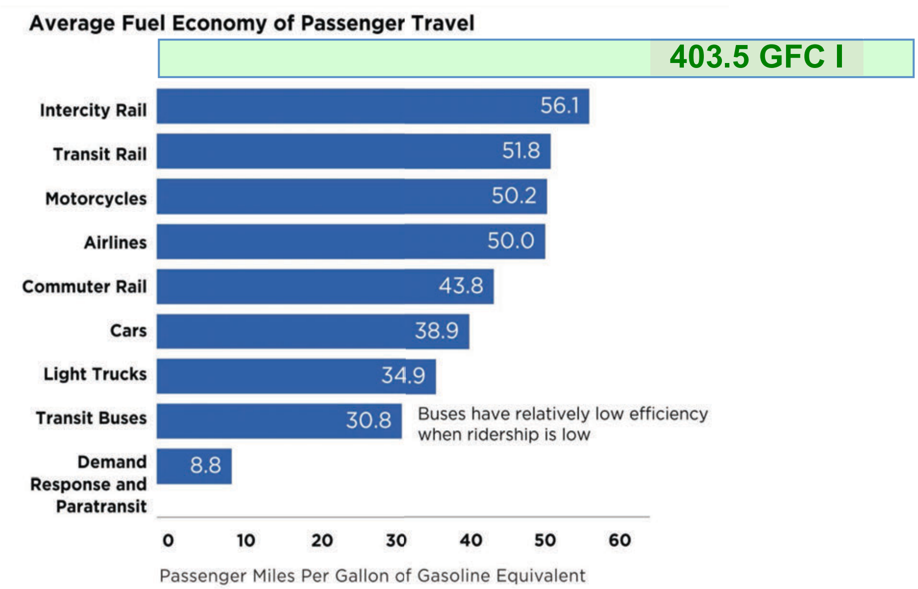


Figure 29. The GFC I achievement of 403.5 pMPG by a 4-seat electrically-powered aircraft far surpassed the energy efficiency of all other forms of transportation.

Figure 30 shows national data for the periods during which trips are most frequent. This data guided the choice of peak RST operations hours of 6-9 AM and 5-8 PM used in this RST study. Off-peak hours extend to 10 PM.

In the calculation of net profits, the salary expenses for pocket airparks were scaled in proportion to the fleet size, with a ratio of 354 pocket airparks for 7250 aircraft. Replacement parts costs were also scaled to fleet size.

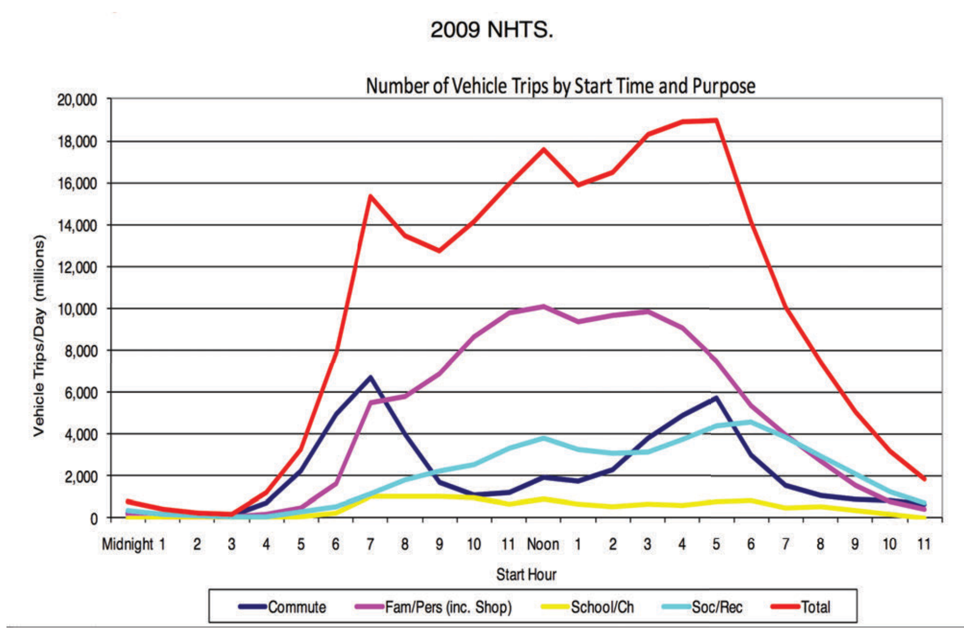
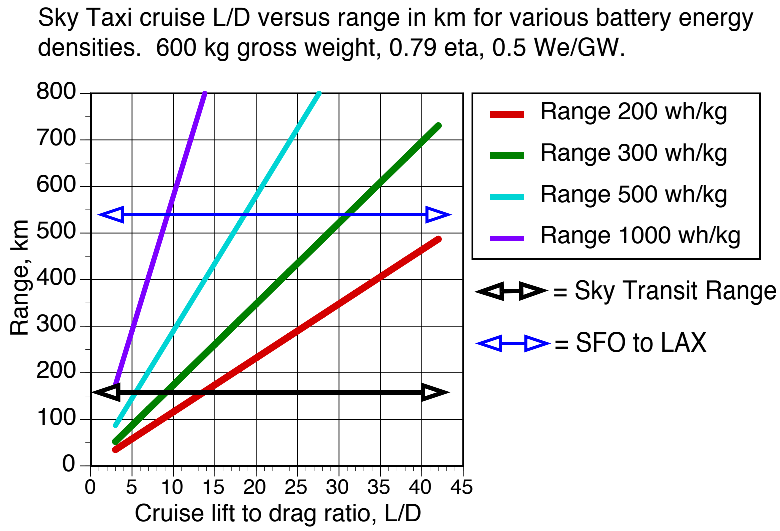


Figure 30. Before 6 AM and after 6 PM the number of commute vehicle trips drops by about 50%. Most midday trips are of shorter length. This RST model operates from 6 AM to 10 PM. It uses 6 peak hours at 6 runway operations per minute and 10 off-peak hours with 3 runway operations per minute. There are 3 peak hours in the AM and 3 peak hours in the PM.

XII. Range Anxiety of Electric Aircraft

In Figure 31., the range in km is shown for a 600 kg Sky Taxi plotted as a function of its L/D ratio for 4 different battery energy densities. The empty weight to gross weight ratio used is 0.5 and the overall propulsive efficiency (motor/controller/propeller) used is 0.79. Figure 31. shows that today's 200 2wh/kg batteries are sufficient for a 160 km range with an achievable cruise L/D of about 13:1. In the Hepperle version of the Breguet Range Equation, the terms are given below the graph.



Martin Hepperle's modification of the Bregeut equation:

$$\text{Range} = E_d \times \eta_{total} \times (1/g) \times (L/D) \times (M_{batt}/GW)$$

Figure 31. Sky Transit Range is 160 km. SFO to LAX is 540 km.

For the Hepperle equation for range, the following are used:

- Range is in meters
- E_d is energy density of batteries in Nm/kg
- η_{total} is total combined efficiency from battery to thrust generated
- g is the acceleration due to gravity in m/sec^2
- L/D is the cruise value for lift to drag ratio
- $M_{battery}$ is the weight of the battery pack in kg
- GW is the gross weight of the aircraft in kg.

Several reputable faculty members at the annual CAFE Electric Aircraft Symposia have stated that the gains that could be made in battery energy density in the future may reach 1000 wh/kg. Such gains could be purely translated in at least 4 different ways. At a fixed gross weight, the gains could be used to shorten take-off distance, enhance range (fewer robotic battery swaps), enhance payload (more fare-paying passengers per trip) or speed (more fare trips per hour, greater advantage over cars). Alternatively, the gains could be distributed into enhancements of both range and speed.

The operational characteristics of regional Sky Transit will affect how the gains are best distributed. For example, using improved energy density to reduce take-off weight and enable shorter take-offs would offer minimal benefit if the Sky Taxi's short field capabilities were already sufficient for the length of a standard pocket airpark. Similarly, a Sky Taxi's range need only span the diameter of the urban mega-region in order to serve 90+% of the trips being made. Extremely long-range flights of more than 3 hours may test the limits of people's bladder capacity. The payload carried need only be 2 people per flight in order to fulfill the great majority of trip needs. Figure 27., clearly shows that enhancing the speed of the Sky Taxi would provide substantial increases in profit, affordability and system capacity. There could evolve a variety of Sky Taxis, with most built for higher speed and routinely short trips but with others of lower span-loading built for greater range at lower speeds. No matter the mission, all Sky Taxis will still need to fulfill the mission requirements of ultra-quiet V/ESTOL in order to use pocket airparks.

XIII. Autonomous Flight---Essential to Sky Transit

The enormous number of flights to be made in a fully developed RST system will require that the vehicles fly autonomously on assigned 4D flight paths. The number of pilots that would otherwise be required is an untenable scenario. By eliminating pilot error, autonomous flight should deliver a several fold enhancement to the flight safety of general aviation. The ever-improving technology for autonomous flight that is being concurrently developed in drones by both the military and hobbyists will be a rich source for developing safe autonomous Sky Transit.

Sky Taxis will need to have onboard, self-sufficient autonomous systems as well as ground and satellite dependent ones. For example, routine navigation by precision GPS will be augmented by onboard inertial navigation equipment. Deployment of the rooftop vehicle ballistic parachute by occupants will be augmented by the capability for remotely activated deployment by a bunker pilot, etc.

The array of sensors, microprocessors and actuators on a Sky Taxi will give it the capability for unprecedentedly rapid and precise flight path control, including gust and ride-quality mitigation. This is owing to the fact that human sensori-motor neural conduction velocities are limited to on the order of 100 m/sec and electronic signals and energy travel at about 100,000,000 m/sec or 1/3rd the speed of light. Even factoring in the time necessary for its microprocessors, the information and actuation speeds of the autonomous system will be at least 100 fold faster than those of a human pilot. It can be anticipated that ultimately, such an electronically sentient autonomous Sky Taxi will be able, even in gusty conditions, to consistently perform a precision spot-landing within a 20 foot circle.

The level of safety required in RST will be very high, and any fatality in the early adoption phase would be a major setback to its implementation and growth. At present, humans are more willing to trust human cab drivers and charter pilots than they trust fully autonomous vehicles. But as the statistics inevitably emerge to show that autonomous vehicles have become much safer than those driven by humans, the trust in autonomy will grow. That trust will need to approach the level that people place in using autonomous high-rise hotel elevators or airport trams.

As mentioned, RST may begin as Sky Cargo, and that could involve using “optionally pilot aircraft” (OPAs) in which a pilot can operate the otherwise fully autonomous controls. OPAs could be an excellent way to build trust in autonomy as it matures and is successfully demonstrated in millions of hours of Sky Cargo use.

XIV. Airspace and Sequencing

If all 7250 Sky Taxi were distributed equally across the region’s sky at any one time and all at the same altitude,

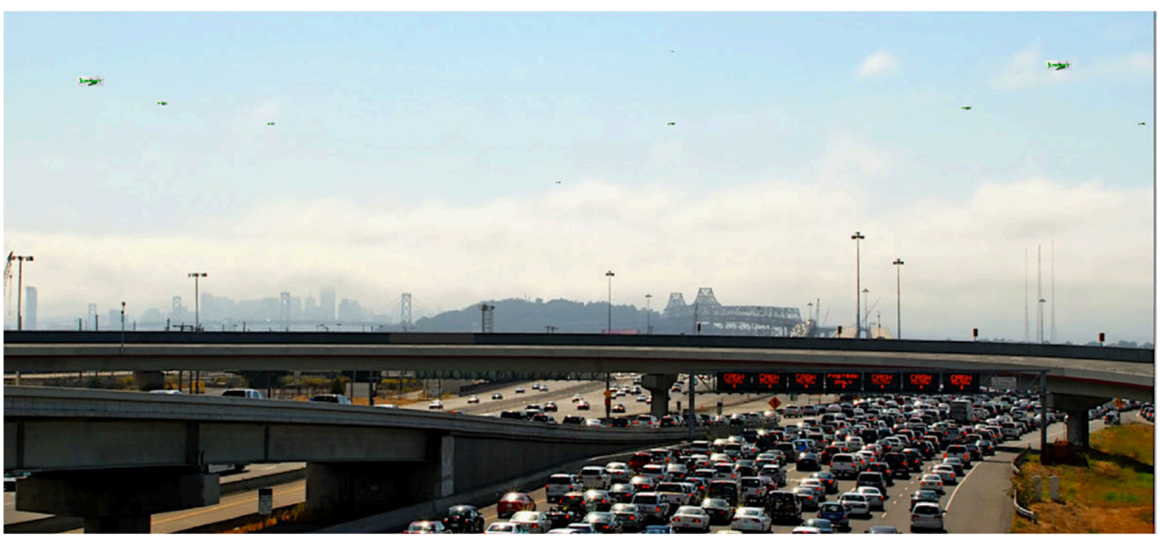


Figure 32. A photographic simulation of 9 Sky Taxis flying over the MacArthur maze approach to the Bay Bridge during commute hour in Oakland, California. This density is a rough approximation of that needed to serve 10% of inter-county trips.

they would each be separated from the other by at least 1138 meters or about 0.75 miles. However, that separation ignores the fact that the Sky Taxis will operationally be flying in several different layers of altitude. This fact, along with the fact that there will always be several Sky Taxis on the ground at pocket airparks, would increase the calculated 1138 meter separation more than 8 fold, to nearly 10 km. The tight separations that would temporarily exist at busy pocket airparks would be on the order of 180 meters if take-offs were spaced 10 seconds apart and Sky Taxis climbed at 88 kph. A 180 meter separation is much greater than the 74 meters separation recommended between cars that are traveling 88 kph on the freeway.[14] With brisk autonomous control, 180 meter separations should easily ensure manageable spatial conflicts. As the steep climb-outs transitioned to cruise climb and the Sky Taxis fanned out to their diverse destinations, these tight separations would loosen several fold toward that mentioned above.

XV. Total Electrical Demand

The electrical demand of RST will depend mainly upon the size of its ridership. That demand in the San Francisco Bay Area RST model presented here was calculated using a 10% ridership level for a fleet of 7250 Sky Taxis operating 16 hours per day. The assumptions for computing electrical demand are based upon Sky Taxis that have a cruise L/D of 12:1 and a cruise TAS of 193 kph. They each perform 34 vehicle trips per day and operate 312 flyable days per year. For trips that average 50 km in length, the energy consumption is 7.064 kWh per trip. This computes to a total electrical demand for the entire RST system of 1742 megawatts per day. It is noteworthy that California in 2012 installed a total capacity of 1000 megawatts of new solar energy capture devices. A proposal to install a wind-energy farm of 800 megawatts capacity near Tehachapi is nearing approval. The rate of growth in both solar and wind energy is increasing each year in California and in the next 10 years that growth could enable all RST flights to be essentially fossil-fuel-free.

XVI. Sky Taxi Mission Requirements

From the foregoing discussions the mission requirements of a Sky Taxi have become somewhat better defined. These include the following:

1. ultra-low noise emissions (likely < 50 dBA @ 40 m) compatible with small airpark size; and
2. safety: 'zero pilot error' autonomy, a risk comparable to that of airline travel; and
3. electric propulsion; and
4. payload of at least 2 large people, each with an average carry-on bag; and
5. V/ESTOL operations with steep approaches and climb-outs at small airpark parcels ≤ 160 x 80 meters; and
6. expeditious operations; ≥ 6 operations per minute per landing site
7. cruise speed: at least 193 kph
8. range: at least 160 km on one battery charge

XVII. Sky Cargo

Sky Cargo will be a key part of the initial implementation of Regional Sky Transit. Sky Cargo will serve as the proving ground for the safety of autonomous flight operations for Sky Taxis that carry passengers. For rapid implementation, the initial Sky Cargo aircraft will likely be designed as optionally-piloted aircraft that can be re-configured to also carry passengers as Sky Taxis. A separate preliminary study of the business model for Sky Cargo with 'same-hour' delivery indicates that it will have strong and sustainable profit potential.

XVIII. Sky Taxi Technologies

The many technologies that will enable safe Sky Taxi development include:

1. electric motors—quiet, reliable, lightweight, regenerative and vibration-free;
2. precise, near-instantaneous and reliable motor control technology;
3. wheel motors that efficiently integrate tire and brake in a small, lightweight package;
4. energy density increases with good cycle life and burst power capability;
5. battery management systems that ensure safety;

6. battery chemistries that will not ignite
7. solar energy capture, photovoltaics;
8. ideal traction—tires with low-noise compounding, profile, and grip;
9. advanced structures including nano-technologies;
10. ultra-quiet propulsion including active noise reduction (ANR) and synchrophasing;
11. high lift devices including vectored thrust, blown flaps, CFJ and CCW;
12. high L/D and high pMPG sailplane technology;
13. CFD guided drag reduction, laminar flow, and Goldschmied propulsion;
14. vehicle parachutes, airbags and life rafts;
15. wheel motors that perform acceleration, braking, steering, and navigating;
16. autonomous controls with machine intelligence, both onboard and remote;
17. advanced sensor systems and wireless communication/navigation;
18. fast-acting servo flight controls effective at low flight speeds—"stability and ride enhancers."
19. autonomous steep approaches and glide path control using drag brakes/spoilers
20. gust and turbulence detection and alleviation by smart tabs
21. fast-charging of batteries and robotic battery swap
22. smartphone apps to make easy advance reservations for Sky Taxi services
23. robust system redundancy throughout.

XIX. Advantages of Technology Prizes

Technology prizes have many advantages as an effective method to bring forth new capabilities. The Obama Administration has recently recognized this. Its OSTP report in March 2012 authorized the use of technology prize competitions by all Cabinet agencies, and cited the 2011 Green Flight Challenge (GFC I) designed by the CAFE Foundation as a prime example of such advantages.[15]

The information-accelerating effects of the Internet, the urgency to find solutions to global problems such as energy needs, traffic congestion and climate change and the increasing demand for greater return on investments in research all favor the technology prize methodology. The GFC I demonstrated that technology prizes can safely and rapidly bring forth a diversity of new vehicle capabilities that far surpass the required performance thresholds.

The foremost advantage of the technology prize is its inducement of simultaneous diverse competing approaches to the goal. Such diversity enhances the evolution of ideal solutions. That diversity is inherently lacking in single point development or procurement projects by a single entity, government agency or corporation.

A second advantage of the technology prize is its leverage. Several teams will invest large amounts of time and money toward winning a single prize purse. Such teams will use the Internet to recruit talent and expert consulting from around the globe. Competiveness compels teams to apply passionate dedication and determination to their efforts, greatly increasing the effective leverage beyond mere expenditure of funds. The current shortage of funding for transportation solutions demands such leverage. This leverage and the diversity advantage are maximized when all teams are assured a chance to compete for the prize, a feature that is lost if the prize were offered as a "first-to-demonstrate" competition.

A third advantage of technology prize competitions is that, unlike cloistered proprietary efforts, the tech prize can grow the public and entrepreneurial awareness of the demonstrated breakthrough capabilities. This speeds the investment in ventures that will apply those breakthroughs into useful products. This deliberate transparency of technology prize competitions greatly enhances their potential to stimulate STEM education and grow new jobs in both research and manufacturing. It also provides added incentive to teams to win on the 'global stage'.

A fourth advantage is that technology prizes can be tailored to induce exactly the performance capabilities necessary to open up new markets, frontiers, industries or paradigms of utility. Astute calculation of the known physical limits on materials and their potential performance must inform such tailoring. The hurdle must not be set too high relative to the timeline offered for its achievement.

The measurements of performance in prize competitions must be accurate and verifiable and should be entrusted to organizations with well-established reputations for integrity, safety and freedom from bias.

The size of the prize must respect the costs necessary for each team to create the breakthrough innovation.

XX. The Green Flight Challenge II

The 2011 Green Flight Challenge sponsored by Google proved the concept of practical cross-country flight in electrically-powered aircraft. It also demonstrated that electrically-powered aircraft could be extraordinarily quiet when the e-Genius aircraft demonstrated a full-power take-off noise level of just 65 dBA at a 125 feet sideline distance. As explained in this report, achieving the major societal, economic and environmental benefits of RST will demand specialized aircraft that can get airborne ultra-quietly. Such ultra-quiet noise levels will be particularly challenging to achieve in V/ESTOL aircraft that must exert larger amounts of power during take-off.

To date, there has been no concerted effort by either government or industry to combine ultra-quiet with V/ESTOL capabilities on a practically-sized aircraft. There has been an ultra-quiet helicopter that was human powered and was 58 m. (190 feet) wide, operating indoors in no wind. There have been decades of V/ESTOL research and its current iterations that have succeeded with aircraft that fulfill military uses or that fulfill the more lenient noise limits at very large CTOL airports. However, excessive noise, fear and downwash issues have largely prohibited these from use in civil HPA. San Francisco prohibits heli-pads in its downtown area, for example. To reach mass production, a V/ESTOL Sky Taxi will need to have its take-off noise level well below 55 dBA at 40 m. This is an enormous challenge that encompasses fundamental aero and electrical physics and is crucial to the realization of RST.

The CAFE Foundation has designed the Green Flight Challenge II (GFC II) as a technology prize to combine ultra-quiet with V/ESTOL capabilities in a practically-sized aircraft. This challenge would reward the quietest air vehicle of 600 kg gross weight and of less than 14 m diameter (46 feet) that could get airborne and sustain flight over a series of horizontal laser beam 'hurdles' that are 3 m high above the pavement. The vehicle must clear the first hurdle in less than 8 seconds and do so within a horizontal distance of 58 m (190 feet). With a prize purse of $2M USD, this prize would recruit the world's best innovators into an R&D effort to solve the main technological barrier to RST. Judging from the extraordinary results in the first Green Flight Challenge, CAFE considers it virtually certain that a team would create an ultra-low noise vehicle that would far surpass the e-Genius's record for quiet take-off. It is even conceivable that a team in this GFC II could achieve a noise level of below 40 dBA at a 40 m sideline distance and that would comprise a valuable, practical and game-changing achievement in aviation.

XXI. Conclusion

The potential economic, operational and environmental aspects of a system of regional Sky Transit are explored and found to be very promising. The ultimate market for Sky Transit in terms of passengers, sales and aircraft production could exceed that of any other form of aviation. The potential environmental benefits of a fully implemented system of RST in terms of reducing greenhouse gas emissions, air pollution, hardscape/heat islands and noise could be of enormous value. RST could greatly improve the DtD trip speeds of commercial air carriers as well as providing a community-acceptable means for same-hour regional delivery of freight. The technologic challenges that attend RST appear surmountable with present day capabilities. The principal design frontier that must be championed before the great benefits of RST can be realized is that of combining ultra-low noise emissions with V/ESTOL capabilities in a 2-seat autonomous air vehicle. This design frontier can best be championed by a focused, full-scale technology prize competition aimed at those performance capabilities. The CAFE Foundation presents a framework for that competition.

Any practical 2-seat electrically-powered air vehicle that can safely and reliably fulfill Sky Transit's necessity for combined ultra-quiet V/ESTOL capabilities as described in this study will most likely have its entire configuration and design dictated by those requirements. The concurrent and rapidly advancing capabilities in autonomous flight are anticipated to not require a technology prize in order to develop products for specific use in Sky Taxis. The promise of future, multi-fold improvements in battery energy densities could soon enable RST to expand to offer distributed, direct, on-demand *inter-regional* service to the public. Future small passenger aircraft design projects that aim to achieve the large production volumes sufficient to pay for the cost of FAA certification should aim to fulfill the fundamental design requirements for regional Sky Transit in order to maximize their potential market.

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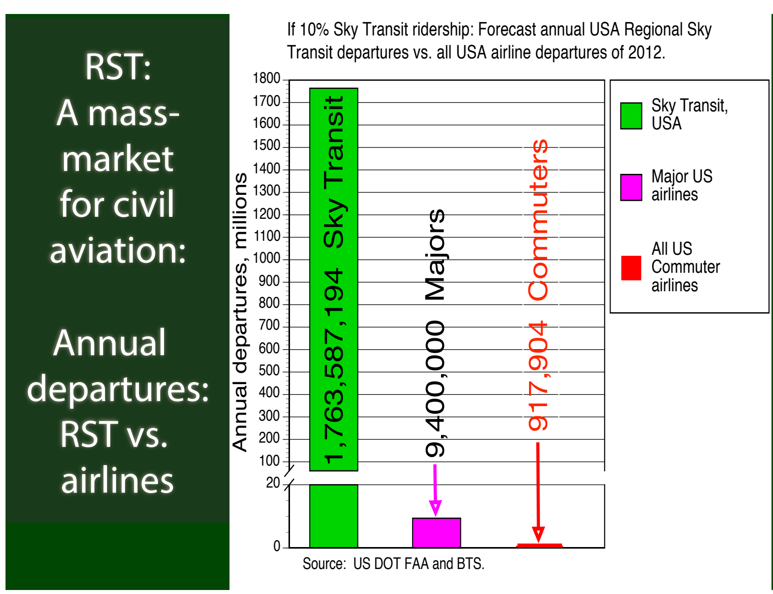
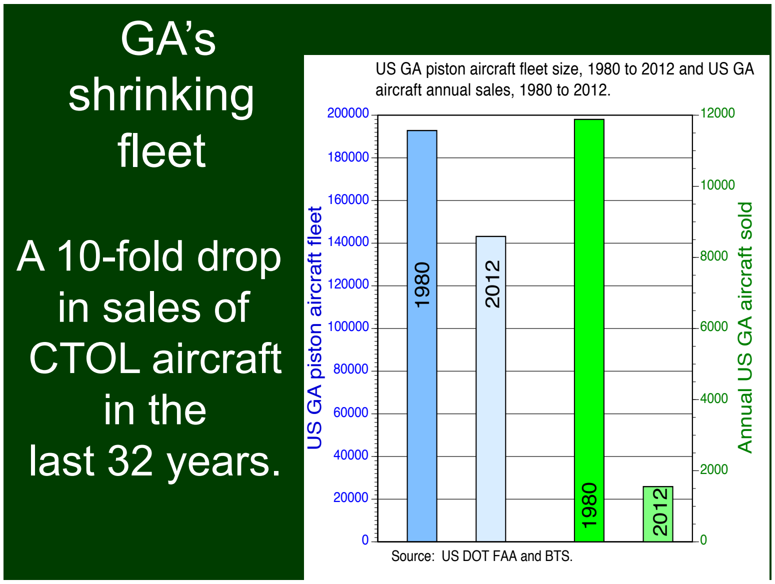
Appendix

Statistics affirming the potential market size for regional Sky Transit and the major decline in CTOL aircraft sales.




GA's shrinking fleet
A 10-fold drop in sales of CTOL aircraft in the last 32 years.
US GA piston aircraft fleet size, 1980 to 2012 and US GA aircraft annual sales, 1980 to 2012.
US GA piston aircraft fleet
Annual US GA aircraft sold
0
20000
40000
60000
80000
100000
120000
140000
160000
180000
200000
0
2000
4000
6000
8000
10000
12000
1980
2012
1980
2012
Source: US DOT FAA and BTS.