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Regional Sky Transit II

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Regional Sky Transit (RST) is the name applied to a proposed system of ubiquitous, short-range, on-demand, affordable, point-to-point delivery of people by electrically-powered, autonomous, ultra-quiet Sky Taxis. The RST system relies upon easily accessible small, "pocket airparks" adequate for vertical or extremely short take off and landing (V/ESTOL) that allow the public to minimize ground travel time (GTT) on short trips within a highly populated mega-region. Regional Sky Transit was first presented in an AIAA paper at AVIATION 2015[1]. That seminal paper has generated intense interest and inquiries leading to a number of follow-on explorations regarding RST's viability, operational details, design requirements and implementation plan. This paper presents those explorations along with an analysis of their significance.

Nomenclature

4D	=	a three-dimensional path along which each point has a defined specific clock time
AGL	=	above ground level (height or altitude)
ATC	=	air traffic control
BMS	=	battery management system
CAS	=	calibrated airspeed
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
ESTOL	=	extremely short take-off and landing
eta	=	propeller efficiency
fps	=	feet per second
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
m/sec	=	meters per second

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mph	=	miles per hour
MSL	=	above mean sea level, describing elevation or altitude on a standard day
NHTS	=	National Household Travel Survey
RPM	=	revolutions per minute
RST	=	Regional Sky Transit
sec	=	second
sq ft	=	square feet
STEM	=	science, technology, engineering and mathematics education
TAS	=	true airspeed
V/ESTOL	=	vertical or extremely short take-off and landing
VMT	=	vehicle miles traveled
VTOL	=	vertical take-off and landing
Vso	=	minimum velocity at 1 G at which an aircraft in landing configuration stalls

I. Introduction

People in modern societies are increasingly aware of the value of saving time. We live in an age of fast-food, sound bites, 30-second elevator pitches and microwave dinners. Twitter limits messages to 140 characters. To save time, texters invent a plethora of new abbreviations, including TLDR for "too long, didn't read" to describe a message that delved deeper than the recipient's time budget or attention span allowed. Car commuters use software apps like "Waze" to try to circumvent surface traffic jams to save a few minutes enroute.

In this fevered context, a system that could reliably and affordably save the time-starved traveler 30 minutes or more, even on one-way trips as short as 30 km, could be expected to win a large user market. Regional Sky Transit (RST) could be such a system. When fully implemented across a mega-region such as the San Francisco Bay Area, a high capacity system of RST could win a large enough ridership to substantially ease surface gridlock, and thus create major reductions in both wasted time and wasted fuel. Such benefits, if applied to all of the mega-regions in the USA, could also substantially reduce the nation's greenhouse gas emissions and, by taking a substantial number of cars off the roads, its costs for the nation's highway system. To be realized, such benefits demand that the aircraft serving RST fulfill definable performance capabilities that are radically different from those of conventional take off and landing aircraft (CTOL). The recent steady and abysmal shrinking of the GA market for CTOL aircraft, the dependency of the thin haul market on subsidy, the very high cost of FAA certification and the enormously larger mass market for RST compared to thin haul would all suggest that further private or public investment in CTOL aircraft is a doubtful proposition.

This study finds that economically sustainable Regional Sky Transit is not only technologically feasible, but that, given appropriate governmental support, it could become aviation's largest market and thereby confer important and urgently needed environmental and societal benefits. These findings also indicate that setting future uniform standards for both pocket airpark size and Sky Taxi mission capabilities will be as essential as setting the gauge of a nation's railroad's tracks. To set those standards the aeronautical physics, applicable human physiology and foreseeable market conditions that pertain to RST must be delineated. Once delineated, those standards can inform the metrics for the design of a useful Sky Taxi aimed at the potentially enormous future market of RST. Those metrics, in turn, can inform a pragmatic technology prize that will substantially advance the design of future, mass-market aircraft that are uniquely suited to operate in RST as safe, autonomous Sky Taxis.

II. Standards needed

The standards necessary for a high capacity system of RST fall into these general categories:

- Pocket airpark size
- Pocket airpark flight and ground operations
- Profiles for steep descent and climb-out—tolerable jerk limits
- Allowable levels of aircraft noise
- Range requirements
- Acceptable aircraft speed envelope
- Energy efficiency

- Realistic and feasible new vehicle cost of each shared-use Sky Taxi relative to certification cost
- Autonomous flight capabilities of extreme precision and reliability and suited to all situations
- A demonstrated level of safety and on-board standard safety equipment
- UTM—the unmanned aircraft traffic management system and its RST requirements

There are identifiable RST system characteristics that can define reasonable limits for the above standards. These are explored in the following sections.

III. Pocket airpark size

Pocket airpark size is a crucial component of RST. The evidence so far indicates that the minimum size standard for a pocket airpark should be 168 x 99 m (550 x 325 ft). This just-right 'Goldilocks' size is neither too small nor too large. Shrinking this size by half may work for rooftops above urban canyons where a steep, noise-abating climb-outs and landing descents are obviated because the aircraft's noise footprint is kept more than 40 m above street level. However, expanding the size from this minimum of 168 x 99 m when the airpark is built in more open suburban areas would be fruitless and lavishly wasteful of cost because all Sky Taxis must still be mission capable in terms of low noise and V/ESTOL for the smallest airpark in the system. Pocket airpark size is thus a denominator.

Downsizing pocket airparks once their size has been set to a workable minimum standard would not make sense, even if there miraculously emerged future generations of aircraft capable of making imperceptibly quiet take offs and landings in people's backyards. To merit a use-permit as a shared community asset, and to fit into a workable air traffic system, the land allocated for each pocket airpark must make sense in terms earning its keep. It must have a minimum number of flight operations and passenger throughput to justify its presence, else the land would be better allocated as a park or community garden. We are already evolving beyond the unsustainable land-use model of having a two-car garage at every residence and the unsustainable hardscape growth that attends having everyone own and park a car. To then aspire to an extreme case in which every residence needs a 60 m diameter helipad for an owner flown Sky Taxi seems an untenable and unnecessary future model.

Downsizing airpark size would also not significantly improve DtD trip speeds and time savings on short trips because the short, six-minute average ground travel times (GTT) in RST are already sufficient to provide a 30-minute time-savings for a mass market of very short trips. Shorter GTT (e.g., by halving airpark size) would offer diminishing returns for DtD speed and would, according to today's outlook, place unrealistic demands on both the noise footprint and short runway capabilities required of Sky Taxis. Increasing airpark parcel area 16-fold, as would occur if its noise levels were 12 dBA above the level needed at a community-acceptable pocket airpark, is also untenable. It would more than double the GTT, preventing the required time-savings on short trips. This would mean that the trip length for which RST would save 30 minutes would increase from 30 km to 70 km, resulting in a nearly 10- fold reduction in the number of flights. Reducing RST ridership 10-fold, from 10% to 1%, would cause a ruinous loss in profits, as shown in Figure 10. This loss of profit would likely disqualify RST from making sense in light of the huge certification costs, estimated at $1B by NASA, that will be required of future fully autonomous Sky Taxis.

Defining pocket airpark size also poses the challenge of minimizing land parcel size while preserving realistic

Figure 1. This general aviation airport faces chronic threat of closure due to noise complaints from neighbors living near the runway, where jet aircraft land over backyard pools. In Regional Sky Transit, the goal will be for ultra-quiet Sky Taxis to be able to land and take off over such residences without being heard at all. Such imperceptibility needs to be the main quest of initiatives to bring about RST.

dimensions for the high-capacity flight and ground operations that must take place there. Figure 2. shows a drawing of a high-capacity pocket airpark of 168 x 99 m, populated with 13 docking stations and a schematic representation of its operational sequence with location numbers depicting aircraft at various stages of movement. This airpark is designed for ultra-quiet aircraft with V/ESTOL performance.

The black and white diagonally cross-hatched portions shown on each runway in Figure 2. represent the general area of take off ground roll. The "Take Offs" runway is placed closer to the center of the airpark, farther from the airpark boundaries because aircraft typically generate more noise on take off than on landing. The red "X" marks the nominal touchdown point on the "Landings" runway, shown as Runway 14. The blue "Z" marks the planned point of lift-off for aircraft taking off on the "Take Offs" Runway 14. Both "X" and "Z" locations are shown for the no-wind condition. A passenger lounge containing bathrooms and vending machines, etc. is shown along the street adjacent to the airpark. Also on that street are depictions of transient loading zones for yellow taxicabs, a yellow bus, a bicycle rack and 7 diagonally parked golf-carts. Each airpark needs room for these essential amenities. In addition to walking, users want the ready means for ground transportation on the very short trips needed from pocket airpark to doorstep destinations. To minimize hardscape and land parcel size/cost, pocket airparks should have an absolute minimum of car parking spaces and this can be facilitated by users employing smartphone apps to summon and pre-pay for their means of ground transportation. In the near future, such ground transportation service will likely be provided by shared-use self-driving cars that do not require parking spaces.

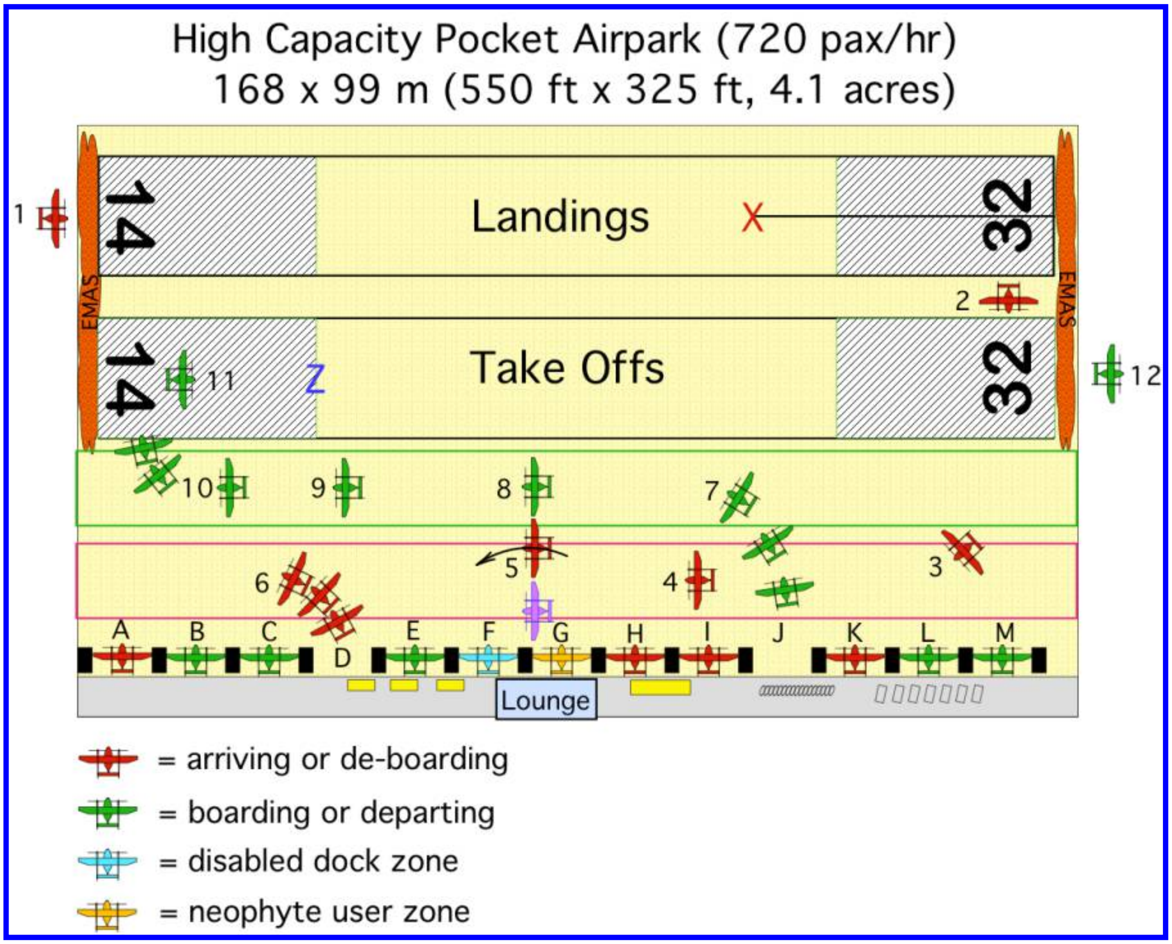


Figure 2. With a rapid cadence of 6 landings and 6 take offs per minute, this high capacity pocket airpark could move a maximum of 720 passengers per hour if there were an occupancy of 2 passengers in every Sky Taxi.

IV. Pocket airpark flight and ground operations

The sky has plenty of room for its Sky Taxis, but the airparks of RST must be carefully choreographed to ensure high capacity movement of people. Time saving is the raison d'etre for RST users. True on-demand service must have no headway or waiting time. This demands a high tempo, rapid cadence of operations at pocket airparks.

Figure 2. shows a pocket airpark at which a red aircraft depicted at location #1 is entering the pocket airpark property at 30 m (98.4 ft) AGL on its approach to landing. In the 10 seconds consumed by its steep descent to touchdown, landing roll-out and turning off the landing runway, the aircraft reaches location #2. In so doing, note that this aircraft must travel more than the full runway distance of 168 m (550 ft) in 10 seconds, a feat that requires a horizontal speed of at least 80.5 kph (50 mph or 73 fps) in order to land, slow to a suitably slow taxiing speed, turn off and clear the active runway in that distance. Fortunately, 80.5 kph is a just-right 'Goldilocks' level of speed that is also enough above most gust speeds that the Sky Taxi could anticipate adequate control effectiveness during landing. If this 80.5 kph landing speed, as is often the case for preserving gust margins, were set as 1.4 times the minimum stall speed of the fixed-wing aircraft (Vso), then that stall speed could be expected to be 57.5 kph (35.7 mph). An ESTOL fixed-wing aircraft with a 57.5 kph stall speed could, according to common GA experience with the ratio of cruise speed to stall speed, be expected to achieve a cruise speed of 3.4 x 57.5 = 195.5 kph or 121.5 mph. As will be shown below in Figure 11., 195.5 kph is a more than sufficient cruise speed for a Sky Taxi to deliver time savings in the RST system. The relationship of landing speed to cruise and stall speed in a purely VTOL or powered lift aircraft is a different challenge because its landing approach is likely to be much different. These differences will be discussed below in the section on **"Profiles for steep descent and climb-out"**.

Passenger throughput capacity has a profound effect upon the sustainability and affordability of RST. Capacity is essential to making its many benefits sizeable and meaningful, and therefore justifying public support for its infrastructure. Capacity is tied to a cascade of causality that goes like this: Capacity requires high proximity airparks which require operations in rapid succession from very small land parcels which require autonomous aircraft with the combination of ultra-low-noise with V/ESTOL performance which require an entirely new aircraft design that does not yet exist---the Sky Taxi. An outline of such a design is provided in this paper.

In order to achieve and maintain a high capacity of passenger movement at pocket airparks, the ground operations there will need to proceed with the fastest cadence possible. For the purposes of this exploration, a 10-second cadence is studied. This will require a precisely coordinated choreography for continuous flight and ground operations. A detailed description of that choreography is as follows:

Figure 2. depicts operations when the wind direction is favoring landing and taking off on Runway 14. The red aircraft that has just completed its landing roll-out is shown at location #2 in Figure 2. It will employ its autonomous landing gear to automatically adjust the aircraft's pitch attitude to reduce its susceptibility to gusts during taxiing. That aircraft is expected to use its wheel motors, without any propeller or rotor rotation, to smoothly continue its taxiing from location #2 to the next vacant loading dock position. According to commonly accepted standards[2] a reasonable taxiing speed of 7.6 m/sec (27 kph or 17 mph or 25 fps) could be used.

From location #2 the Sky Taxi will taxi for up to 40 seconds to reach the next available vacant docking station. This 40 seconds includes an allotted 2.5 seconds for acceleration at 0.306 G from 0 kph to 27 kph which will move 9.14 m (30 ft) as well as an additional 2.5 seconds for deceleration from 27 kph to 0 kph, which will also move a distance of 9.14 m (30 ft). Those 5 seconds of acceleration and deceleration fall within tolerable jerk limits and produce 18.28 m of distance in addition to the 266 m distance covered in 35 seconds of taxiing at 7.6 m/sec. Thus, this Sky Taxi can taxi a distance of 266 + 18.28 = 284.28 m in 40 seconds. That distance is large enough to easily allow the just-landed Sky Taxi at location #2 to reach even the most distant docking station on the pocket airpark, shown in this case as docking station "A". Most such taxiing movements will require much less than 40 seconds because the docking station will be much closer to location #2. An additional 10 seconds is allotted for the autonomous Sky Taxi to use its wheel motors to precisely back into and stop at a vacant docking position. Thus, the worst-case time required for a landing Sky Taxi to arrive and park in the most distant docking station for de-boarding is 10 + 40 + 10 = 60 seconds. During those 60 seconds, a freshly boarded Sky Taxi has taken off every 10 seconds from location #11. Also during those 60 seconds, 6 more Sky Taxis have landed on the "Landings" runway to begin, in turn, their taxiing to the docking stations successively vacated by green departing Sky Taxis. The locations #3, 4, 5 and 6 in Figure 2. show these additional arriving Sky Taxis spaced at 10-second intervals along the red-outlined taxiway for arrivals. Location #5 shows a red arriving Sky Taxi being just able to taxi past a disabled Sky Taxi shown in purple near the lounge.

Upon parking at its docking station, robotic battery swap, if needed, would occur in less than 10 seconds concurrently with the 30 seconds allotted for the de-boarding of passengers. It should be noted that, the continuous bustle of Sky Taxis at the airpark will have a very low noise level, on the order of 50 dBA or less at the airpark fence. This is because the Sky Taxis will be electrically powered and use wheel motors for their ground operations.

In Figure 2., the Sky Taxis shown each have a 9.75 m (32 ft) wingspan. Parking these so that their wingtips are 2.44 m (8 ft) apart in the docking stations, provides room for 13 separate docking stations, depicted as stations "A" through "M". One docking station is allocated for disabled and handicapped people, who require more time to de-board and board, and this is shown by the blue Sky Taxi at docking station "F". Here, a conductor would assist the elderly, infirm, blind or wheelchair dependent person to complete their boarding in whatever time was required. Likewise, the gold colored Sky Taxi at position G represents a loading dock position intended for the occasional neophyte or rookie user of the system who requires more time and instruction regarding how to board, buckle-up, etc.

Of the 13 docking stations, 12 are for users of normal agility. At any one moment in time, each of those 12 docking stations corresponds to a Sky Taxi that is in a different 10-second phase of its ground operations. These successive ground operations phases at the 12 stations can be listed as follows:

1. Just arrived and parked by backing into the vacant docking station to begin de-boarding
2. 10 seconds into de-boarding
3. 20 seconds into de-boarding
4. 30 seconds into de-boarding and thus has begun boarding
5. 10 seconds into boarding
6. 20 seconds into boarding
7. 30 seconds into boarding and thus departing the dock to begin taxiing for take off
8. 10 seconds into taxiing for take off, providing a vacancy into which next arriving Sky Taxi backs in

9. 20 seconds into taxiing for take off, providing 10 seconds into de-boarding the next arrived Sky Taxi
10. 30 seconds into taxiing for take off, providing 20 seconds into de-boarding the next arrived Sky Taxi
11. 40 seconds into taxiing for take off, providing 30 seconds into de-boarding and thus has begun boarding
12. 50 seconds after dock departure, providing 10 seconds into boarding the next arrived Sky Taxi

Every 10 seconds, the ground operational phase listed above for each of these 12 stations shifts to the next phase listed immediately below it. From the moment it parks in the docking station, it requires 60 seconds for each Sky Taxi to de-board, board and be ready to depart. Notice that the operational phase at station number 5 above (10 seconds into boarding) is identical to that at station number 12. These 2 stations with identical phases of boarding, along with the boarding that is occurring at station "F" for disabled people, proceed along parallel paths that offer redundant sources of departing aircraft and a steady 10-second cadence of vacated docking stations. Notice also that there are other pairs of stations whose phases are identical and thus redundant. These are station pairs 1 + 8, 2 + 9, 3 + 10, 4+ 11, along with 5 + 12. The total time it takes from the moment of departing the docking station to exiting the airpark on climb-out at location #12 is nominally 60 seconds. That 60 seconds is comprised of 40 seconds of taxiing to the "Take Offs" runway, 10 seconds additional time to taxi into take off position and 10 seconds to take off, climb and reach location #12. In Figure 2., those 40 seconds of taxiing are represented by the 4 green departing Sky Taxis shown spaced 10 seconds apart at locations #7, 8, 9 and 10 on the green-outlined departing taxiway.

There is thus a take-off queue at the airpark, from which a Sky Taxi departs every 10 seconds. Its operation proceeds at that cadence like the metering lights to a freeway on-ramp, except that there are no human pilots involved. Of the 10 seconds elapsing during take off and climb-out, 4.6 seconds would be consumed in rapidly accelerating on the runway at 0.6 G with wheel motors to reach 96.5 kph (60 mph), at which point lift off would occur, 62 meters from brake release. The remaining 106 meters of runway would be flown at or above a speed of 27 m/sec in just 3.9 seconds. Thus, the Sky Taxi taking off would reach the airpark fence in about 8.5 seconds in no wind conditions. Crossing that fence and continuing its climb-out for another 1.5 seconds would place this Sky Taxi about 195 m downrange from where it began its take off. The next departing Sky Taxi would thus begin its take off roll when the previously departed Sky Taxi had achieved a separation distance of 195 m (640 ft or nearly 1/8 mile).

Though much closer in separation than required in current FAA regulations, it is anticipated that 195 m separation will be deemed sufficient and allowable for well-coordinated, sentient autonomous Sky Taxis departing from a pocket airpark. It should be noted that the rapid cadence necessary to high capacity movement of passengers requires that Sky Taxis be able to expeditiously conduct each phase of their operations at pocket airparks. This demands that the Sky Taxi fulfill threshold levels of alacrity in airspeeds, sink rate, taxiing speed, take off acceleration and rate of climb. If too slow, the airpark capacity is diminished. If too fast, the force and jerk rates become excessive or the airpark must increase the size of its land parcel, threatening its valuable proximity.

This cog-wheeling cycle of coordinated movement for each Sky Taxi at the airpark can thus be summarized as 60 seconds to land and park at the dock, 60 more seconds to de-board and board in readiness to leave the dock, and 60 seconds to leave the dock, take off and get airborne out to the edge of the airpark. This comprises a nominal 3 minute turnaround time for each Sky Taxi, which is the time used in modeling Regional Sky Transit's DtD trip time. These efficient operational sequences and times presuppose that there be no TSA security delays at pocket airparks, just as there are none at yellow taxi-cab boarding zones at major hotels. Clearly, it is untenable to expect human pilots to be able to maintain the high frequency and precise timing of the flight and ground operations described above.

At less busy pocket airparks, this turnaround time could be shortened substantially by agile users who board and de-board much faster than the nominal 30 seconds allotted. In addition, again at the less busy airpark, Sky Taxis from phase stations 10, 11 and 12 above, which are 30, 40 or 50 seconds, respectively, into their taxiing toward take off, could, depending upon the proximity of their docking station to the departure end of the active runway, have already reached the take off position shown as location #10 in Figure 2. At less busy airparks, this would allow them to get airborne more quickly and to shorten their turnaround time by another 10 seconds or more.

Though uneven timings could upset the smooth continuous cadence of a take off occurring every 10 seconds, the high capacity pocket airpark could occasionally accumulate additional Sky Taxis on the field beyond those accounted for in Figure 2. These additional Sky Taxis could be already moving in queue on the taxiways in either the take-off queue (e.g., location #7 in Figure 1.) or the taxiing queue of arriving Sky Taxis (e.g., location #4 in Figure 2.). It is expected that the operation of these moving queues would be resilient enough to reset its cadence to standard in the course of a few take offs and arrivals. Similarly, if there were an imbalance in the number of arriving and departing Sky Taxis, then some dead-heading Sky Taxis with no passengers could be made to either arrive or depart to make up the difference. A large nearby service maintenance center, such as the former Alameda Naval Air

Station surplus ramp area just 4 miles away from San Francisco, could serve as the overflow buffer for such flow adjustments.

There is also the issue of 'wave-offs'. If a steady stream of landing Sky Taxis had to be diverted due to a disabled Sky Taxi on the runway, or other exigency such as weather or equipment failure, then those diverted Sky Taxis would need to be redirected to another nearby airpark. In the case of the San Francisco Bay Area model of Regional Sky Transit, it is anticipated that the alternate airpark of choice for overflows at the high capacity airparks could be the capacious former Alameda Naval Air Station, which is a short distance from the city centers.

As mentioned, the nominal time from when a Sky Taxi crosses the airpark fence to its docking, de-boarding, boarding, refueling, taking off and exiting the airpark on climb-out is thus 10 + 40 + 10 + 30 + 30 + 40 + 10 + 10 = 180 seconds. It is instructive to examine the extreme case of hurry-up that might apply at less busy airparks where the cadence was not locked. For example, highly experienced, agile users could board in just 10 seconds. If their docking station were relative close to the departure end of the runway, they could start their take off roll in just 20 seconds and be airborne in just 10 + 20 + 4.6 = 34.6 seconds. Likewise, if descent to landing took 10 seconds and an expeditious taxiing of just 20 seconds reached the docking station, an experienced, agile user who de-boarded in just 5 seconds could leave his or her Sky Taxi just 35 seconds after reaching the airpark.

To fulfill the 10-second departure and arrival cadence requires that there be enough Sky Taxis available at the loading dock to have at least one in each phase of the step-wise sequence of operations. It is noteworthy that the 13 loading dock spaces shown in Figure 1. are predicated on parking Sky Taxis with a wingspan of 9.75 m (32 ft) with 2.44 m separation between wingtips. Larger wingspans (or vehicle diameters), though perhaps attractive as a means to reduce power required and noise, would reduce the number of loading dock spaces and thus would reduce the possibility of having enough Sky Taxis waiting at the dock to ensure continuously fulfilling the 10-second cadence of operations. Thus, Sky Taxis whose diameter is more than 9.75 m (32 ft) would impose limitations on the system's cadence and thereby on its passenger throughput capacity, ridership and profitability.

V. Profiles for steep descent and climb-out

Pocket airparks will require steep descents for landing and steep climb-outs in order to limit noise to the airpark neighbors. The steep climb-out requires a short period of very high excess thrust, which can be achieved in electric aircraft.

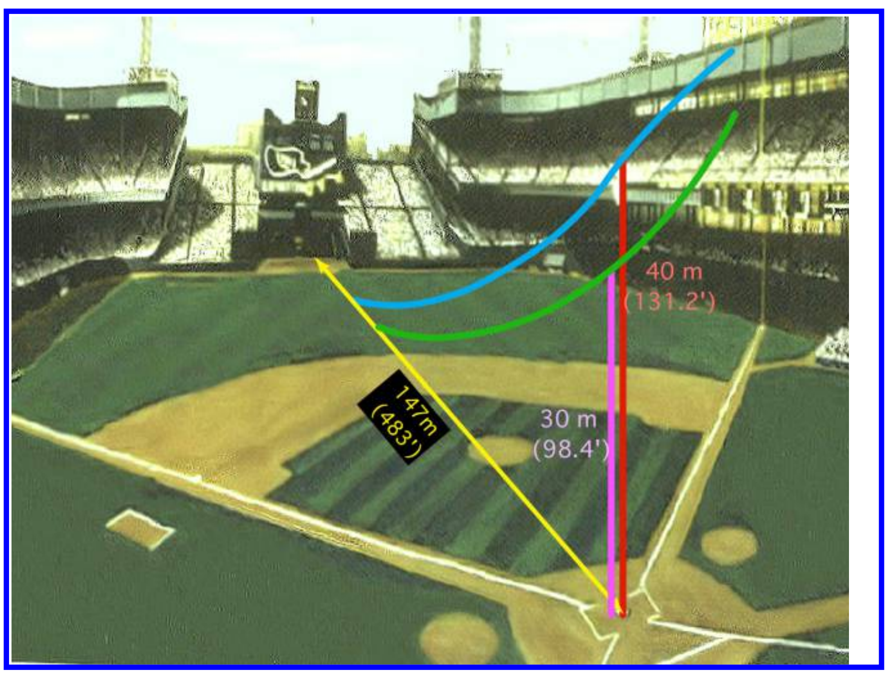


Figure 3. In and out at pocket airparks: With a 483 foot distance to center field, the NY Giants' former home at the Polo Grounds provides perspective on the sizing necessary. A steep final approach 'over the fence' at 30 m AGL (green) as well as the steep climb-out to 40 m AGL (blue), can each be performed so as to fit the short field length of a 168 m (550 ft) pocket airpark with enough ground roll to spare.

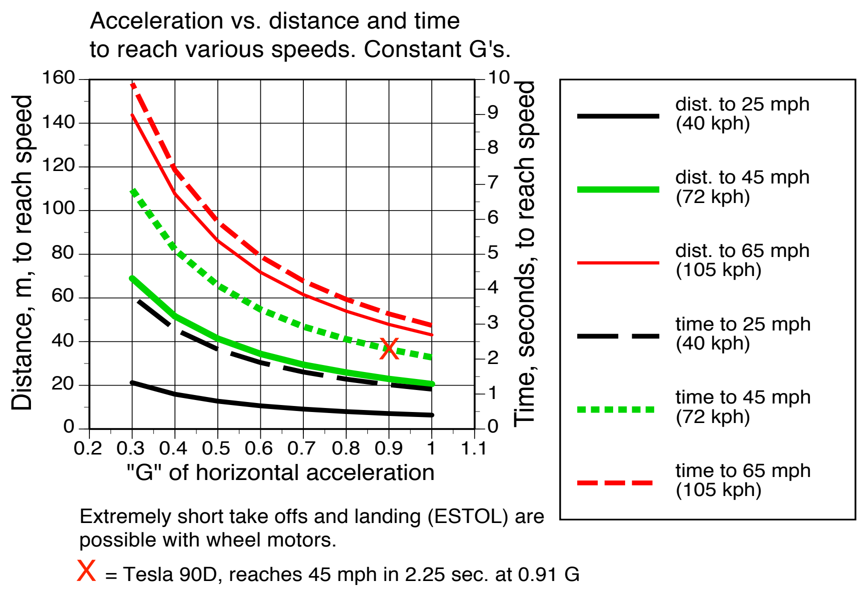


Figure 4. At a constant and tolerable 0.6 G of acceleration, wheel motors could enable Sky Taxis to reach 72 kph (45 mph) in just 35 meters (115 ft).

The noise constraints at pocket airparks will demand that Sky Taxis cross the airpark fence, both on landing approach and on climb-out, at heights above ground level that sufficiently reduce the noise levels heard by airpark neighbors on the ground. The Sky Taxi height at the airpark fence when landing must be low enough to allow the aircraft to perform an approach to touchdown with adequate runway pavement remaining for touchdown, braking and turn-off. Likewise, the Sky Taxi height at the airpark fence when departing must be achievable during climb-out with a realistic rate of climb. These height requirements that reconcile noise abatement with realistic steepness of flight path can be fulfilled by specialized aircraft if such aircraft are designed for this purpose.

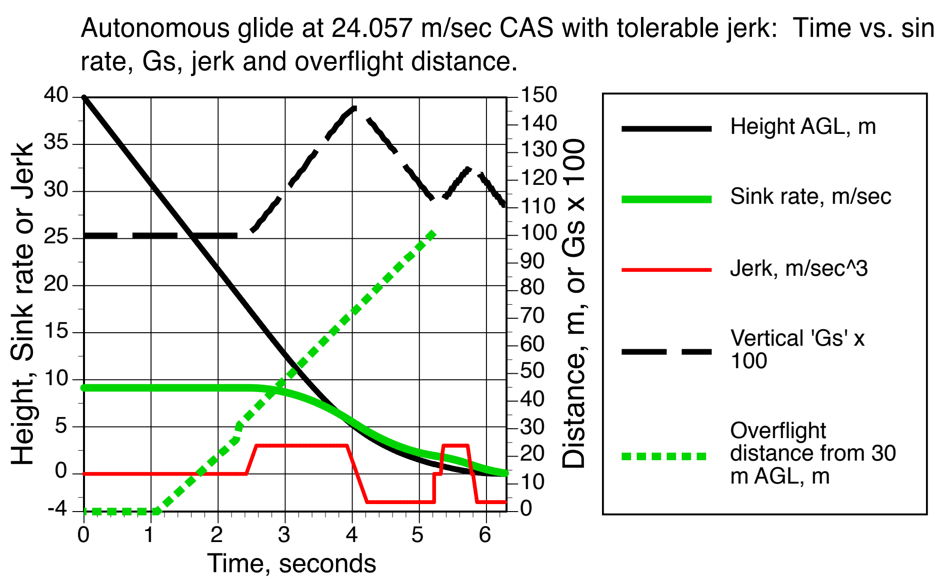


Figure 5. Autonomous control of drag and thrust can enable very steep, precision landing glides that maintain tolerable jerk and Gs while minimizing the distance of runway pavement overflown. This is crucial for operations at very small pocket airparks and ensures final approaches that consistently minimize noise for airpark neighbors.

Figure 3. depicts a size reference based upon a major league baseball field for the kind of steep descent and climb-out that will be necessary at pocket airparks. The blue curved line represents the path during climb-out to a height of 40 m AGL, and the green curved path shows the steep descent from 30 m AGL.

The actual ground roll for both take off and landing roll-out can very short for Sky Taxis with the appropriate speed envelope and wheel motor equipped landing gear. As shown in Figure 4., powerful wheel motors can enable a Sky Taxi to rapidly accelerate to reasonable lift-off speeds in a very short distance.

Figure 5. shows the characteristics of a very steep descent from 40 m AGL to touchdown. A detailed analysis of the aircraft height, sink rate, horizontal velocity, overflight distance, Gs and jerk rate was made to determine if it were possible to execute the maneuver while keeping within the tolerable jerk limit of 3 m/sec^3. In this case, the touchdown was deliberately made while still at a significant sink rate, in order to model the absorption of that final sink rate by a long travel landing gear system.

It can be seen that the high sink rate begins to diminish at a height of about 17 m AGL about 1.5 seconds after the aircraft has crossed the airpark fence at 30 m AGL. The sink rate diminishes smoothly with a steady increase in Gs from 1.0 up to a peak of 1.46 Gs. The overflight distance ends at just over 100 m of runway when touchdown occurs at a height of 1 m at 1.12 Gs with a sink rate of 1.93 m/sec. This 1 m height represents the 1m long travel of the autonomous landing gear. The jerk rate is held throughout to its limit of ± 3 m/sec^3. The entire descent and no-flare touchdown are accomplished in 5.3 seconds from the moment of crossing the airpark fence. As shown in the rapid cadence of ground operations at the high capacity airpark, this 5.3 seconds helps achieve the high volume of operations. After touchdown, there remains 66.5 m (218 ft) of runway in which to apply braking to slow to 27 kph for turning off. This can easily be accomplished within that distance from the touchdown speed of 24 m/sec.

This landing is modeled for a fixed wing aircraft that is capable of generating very high drag on command using large propellers. To duplicate a similar 5.3 second, steep approach and touchdown from 30 m AGL in a VTOL aircraft or powered-lift aircraft would likely pose a challenge in terms of staying within its HV diagram and staying out of a vortex ring state. Because, the expeditious 5.3 seconds for a landing enhances the airpark's capacity for passenger throughput and thereby the profitability of RST, this kind of steep and rapid approach will be a valuable performance capability for a Sky Taxi.

It is here worth reviewing FAA regulation FAR 91.119, whose text is as follows:

§ FAR 91.119 Minimum safe altitudes: General.

Except when necessary for takeoff or landing, no person may operate an aircraft below the following altitudes:

(a) *Anywhere.* An altitude allowing, if a power unit fails, an emergency landing without undue hazard to persons or property on the surface.

(b) *Over congested areas.* Over any congested area of a city, town, or settlement, or over any open air assembly of persons, an altitude of 1,000 feet above the highest obstacle within a horizontal radius of 2,000 feet of the aircraft.

(c) *Over other than congested areas.* An altitude of 500 feet above the surface, except over open water or sparsely populated areas. In those cases, the aircraft may not be operated closer than 500 feet to any person, vessel, vehicle, or structure.

(d) *Helicopters, powered parachutes, and weight-shift-control aircraft.* If the operation is conducted without hazard to persons or property on the surface—

(1) A helicopter may be operated at less than the minimums prescribed in paragraph (b) or (c) of this section, provided each person operating the helicopter complies with any routes or altitudes specifically prescribed for helicopters by the FAA; and

(2) A powered parachute or weight-shift-control aircraft may be operated at less than the minimums prescribed in paragraph (c) of this section.

[Doc. No. 18334, 54 FR 34294, Aug. 18, 1989, as amended by Amdt. 91-311, 75 FR 5223, Feb. 1, 2010]

This FAR thus provides no minimum safe altitude or height above the surface at which a person may perform a take off or landing. This means that Sky Taxis could legally make landing approaches over private property at lower than the 30 m AGL described in this section and they could likewise depart the airpark property at less than the 40 m AGL described here during their climb-out after taking off. However, for decades, such low flight over private property has been a cause for complaint from airport neighbors. Their objections have been reasonable. They have been principally about the loud noise emitted by the aircraft, but they include expressed fears that an aircraft will crash on their property. If future Sky Taxis can be quiet enough to be unheard above ambient noise levels in their take offs and landings, and can demonstrate a level of reliability and safety with autonomous electric propulsion that makes the public fears of crashes unreasonable, then we could expect wide public acceptance of the kind of take offs and landing described here. This would facilitate the development of the large network of pocket airparks that is essential for RST to win a large ridership. In terms of political will, a community's acceptance of pocket airparks in residential areas will also depend upon the proportion of residents who want to enjoy the transportation advantages that it offers relative to the much smaller numbers of people whose property adjoins a pocket airpark. It is clearly going to be extremely important that the industry prioritize the development of extremely reliable, ultra-quiet, autonomous Sky Taxis in order to grow an RST system.

VI. Allowable levels of aircraft noise

There are numerous reputable survey studies that measured the percent of people highly annoyed by aircraft noise versus the noise level exposure in dBA. These were presented in the original Regional Sky Transit paper. Taken together, these many studies suggest that in order to serve residential communities, the noise emissions from the flight and ground operations at pocket airparks will need to be nearly imperceptible to those communities. What passes as imperceptible depends upon the ambient noise level that exists at the pocket airpark. But the recent additional findings of Leverton[3] regarding "virtual noise" and of Rapoza[4] from DOT regarding very high noise sensitivities in National Parks, both echo the axiom that "there is no such thing as 'too quiet'". Virtual noise is the term for the increased annoyance reported for noises that are highly impulsive, i.e., characterized by a rapid rise in dB. Such noise, especially if perceived as originating from a helicopter, is more resented than steady tone noise by about 5 dBA. The current regulatory limit in 36 CFR Ch. 1 (7-1-10 Edition) for machine noise in National Parks is 50 dBA at 50 ft. This is equivalent to 41.6 dBA at a 40 m sideline. It is a fairly rigorous requirement that can serve as a benchmark for preserving the serenity in quiet residential neighborhoods. The tolerance for noise during sleeping hours at night becomes even more stringent; 24 dBA measured indoors is the level that 10% of respondents found highly annoying. Annoyance also rises substantially if there are many flights passing overhead during sleep time.

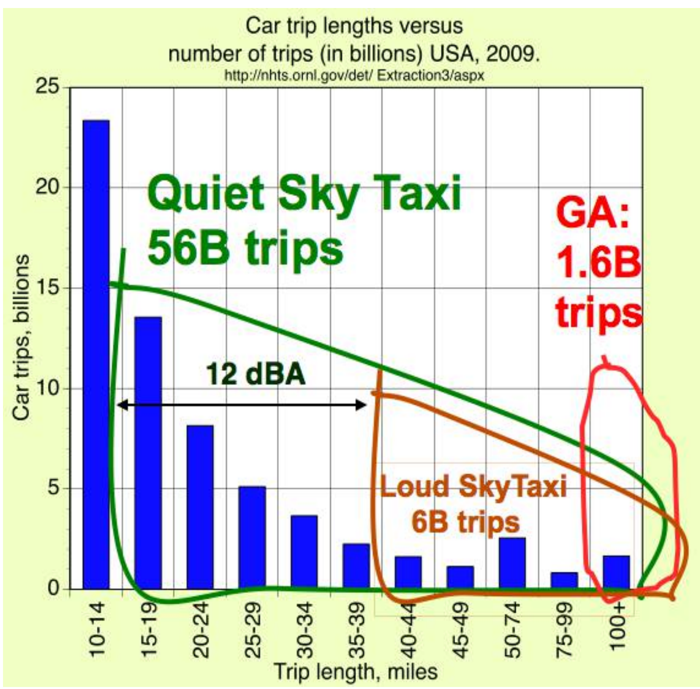


Figure 6. If a Sky Taxi is 12 dBA too loud for a pocket airpark, and thereby can only use airparks that are 4 times larger and more remote than pocket airparks, then its much longer GTT causes it to lose its ability to provide time-savings on very short trips. This could shrink ridership 10-fold, from 10% down to just 1%, with a dramatic reduction in profits. The market for 100+ mile GA trips using CTOL airports is 35 times smaller than the RST market.

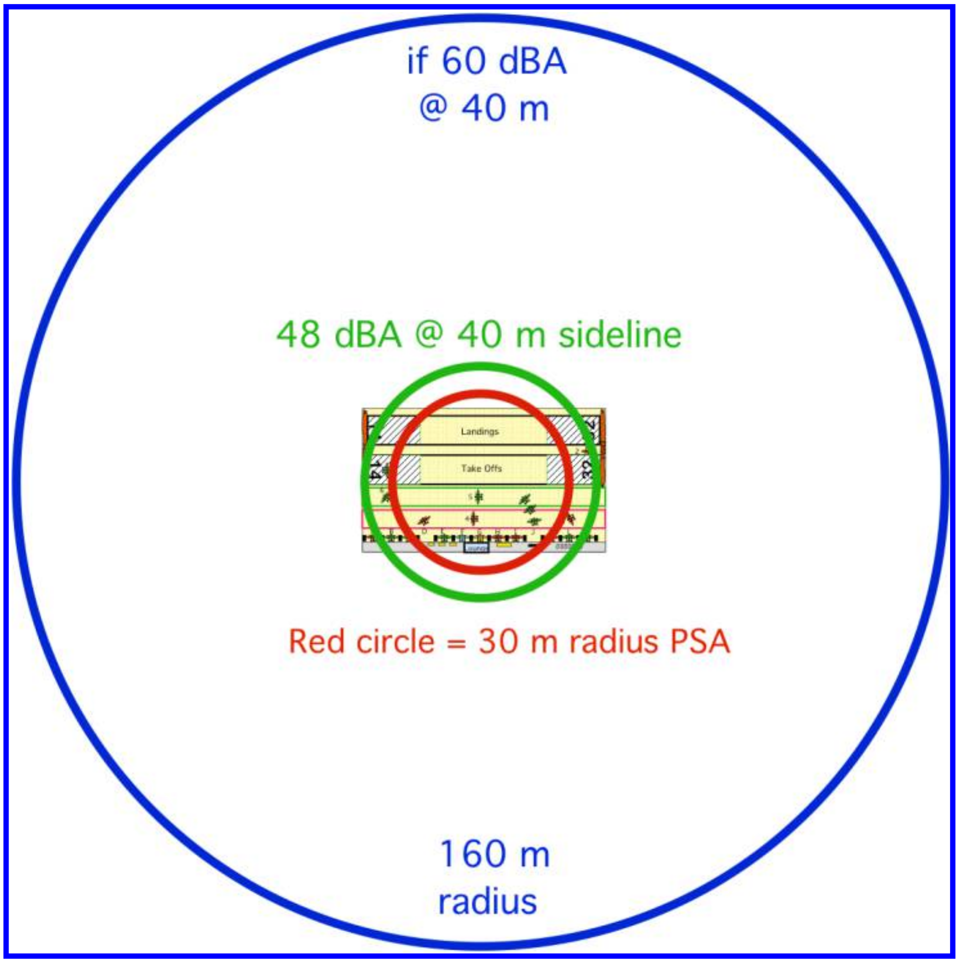


Figure 7. The crucial importance of noise: If 48 dBA at a 40 m sideline is the noise standard for a pocket airpark, then an aircraft whose noise emissions were 60 dBA at 40 m would require a land area 16-fold larger in order to achieve 48 dBA at the airpark fence (blue circle). The red inner circle is the standard sized Public Safety Area used at heliports.

VII. Range requirements

The RST market focuses on short trips of 100 miles or less because these are the most numerous by far. The use of robotic battery swap can enable such short ranges to be manageable by pure battery electric aircraft without need of hybrids that use fossil fuel or hydrogen fuels. Even with the 200 wh/kg batteries that were available in NASA's 2011 Green Flight Challenge sponsored by Google, the competing battery-electric aircraft were able to fly 200 miles on one battery charge. Range is a metric that favors small electric aircraft, as shown in Figure 8.

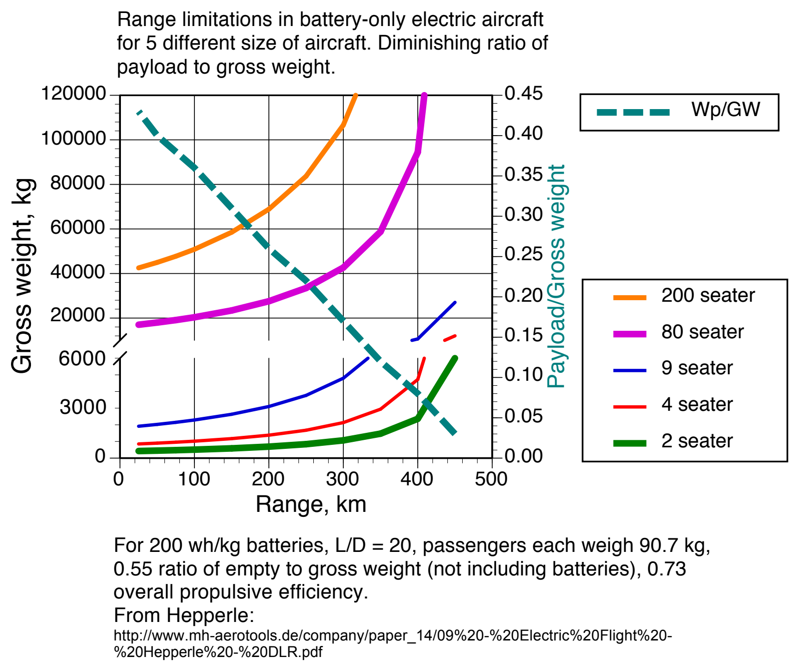


Figure 8. For 200 wh/kg batteries, 160 km range is more readily achievable at an acceptable gross weight for small, 2-seat Sky Taxis than for larger aircraft. It can be seen that a range of just 300 km is untenable for 80- and 200-seat airliners.

VIII. Acceptable aircraft speed envelope

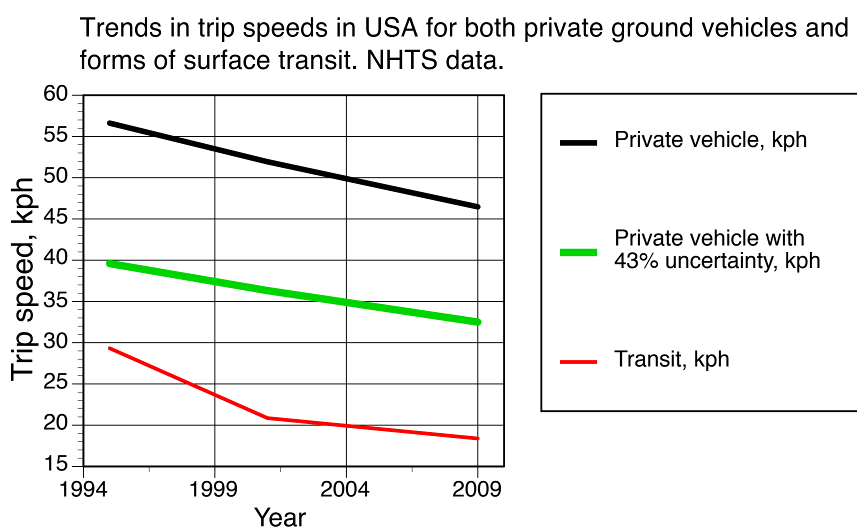


Figure 9. Increasing surface gridlock. A Sky Taxi with a 193 kph cruise speed could be 10 times faster than public transit.

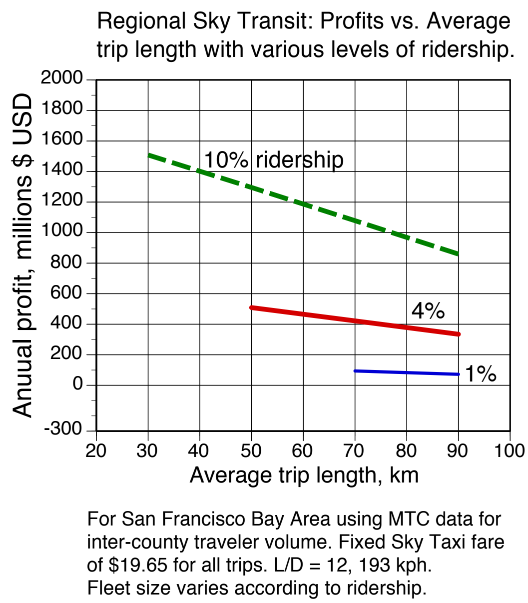


Figure 10. Servicing very short trip lengths is crucial to economic sustainability for RST. That requires HPA, ultra-low noise V/ESTOL Sky Taxis of 2 seats.

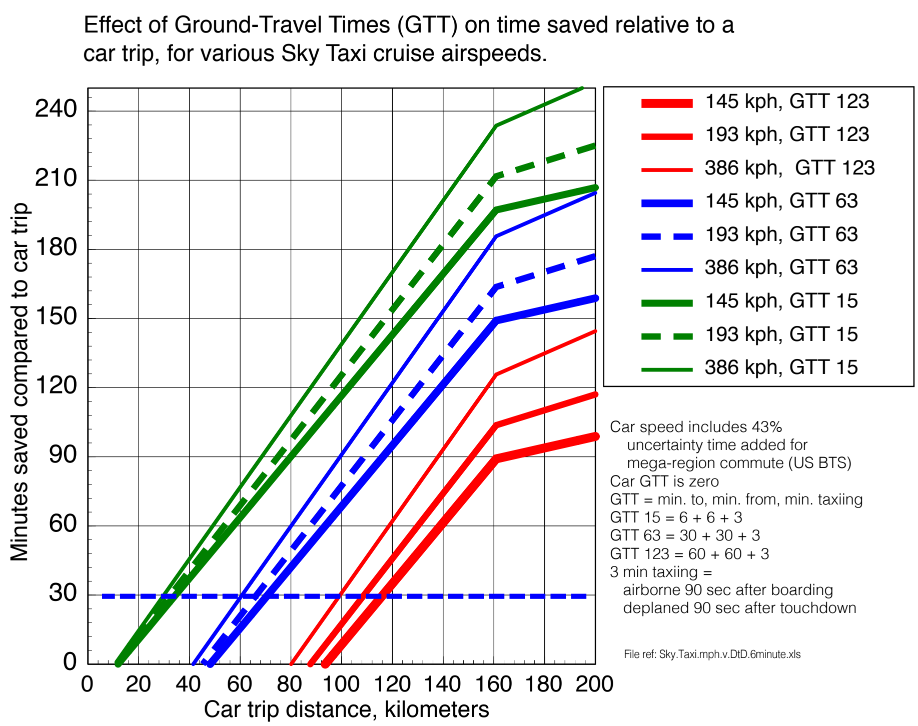


Figure 11. Brief GTT enables RST to save 30 minutes on even very short trips. On such short trips, the cruise airspeed has minimal effect on minutes saved relative to car travel.

In order to favorably compete with ground transportation on very short trips, the foremost requirement for a Sky Taxi is to be ultra-quiet, which is what enables it to operate at high proximity pocket airparks. If high proximity is assured, such that ground travel time (GTT) can be kept to just 15 minutes per trip, then the threshold of worthwhile time savings of 30 minutes can be fulfilled on very short trips. What is most impressive, as shown in Figure 11., is that cruise airspeed has little effect on the amount of time saved when the trips are very short.

IX. Energy efficiency

The previous paper on Regional Sky Transit presented a business model in which the costs for the electricity to operate the entire fleet of Sky Taxis comprised only about 3% of the total operational expenses. That study was modeled on an $800,000 Sky Taxi whose cruise L/D was 12:1. Figure 12. shows how the percent of total overhead

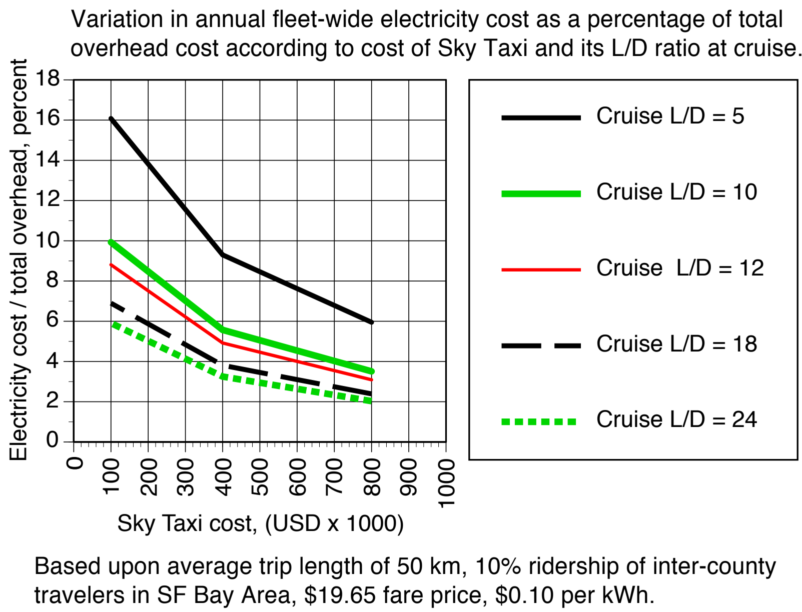


Figure 12. Except for Sky Taxis with cruise L/D below 10:1, the percent cost of electricity to total overhead cost for an RST fleet is below 10% across the range of expected new vehicle cost for each Sky Taxi.

cost that is attributable to fleet-wide consumption of electricity is affected by L/D ratio and new vehicle cost.

It is apparent that new vehicle cost, as the preponderant expense in RST, is the main driver of the ratio of the cost of electricity to total overhead costs. The implications appear to be that, across the range of realistic new vehicle costs for a mass-produced small aircraft, the L/D ratio, once above 10:1, is relatively unimportant in determining overhead costs. Achieving mass production of Sky Taxis is thus the crucial factor in lowering system operating costs.

X. New vehicle cost of each Sky Taxi

A realistic and feasible estimate of the new vehicle cost of each Sky Taxi will depend upon its size, complexity, the volume of its production, and its certification costs. Some portion of the new vehicle cost must be allotted to the cost of product liability. The largest determiner of vehicle cost will be its volume of production. That volume, in turn, will depend upon the public acceptance of RST and its level of ridership. A high percentage of ridership can only be achieved if the Sky Taxi proves useful and popular on very short trips, and this will only be possible if they are quiet enough to be allowed to operate at very high proximity pocket airparks.

XI. Autonomous flight capabilities

The high volume of operations, the rapid cadence of vehicle movements at pocket airparks and the much closer airspace separation distances attendant to RST will demand that the Sky Taxis be fully autonomous. To what extent their initial use at low ridership levels will employ human pilots, whether on-board or in remote bunkers, is an unknown at this time. However, both the extant experience in air safety with piloted vehicles and the extraordinary emerging capabilities in autonomous flight both point to a relative rapid transition to fully autonomous RST.

XII. Standards for safety

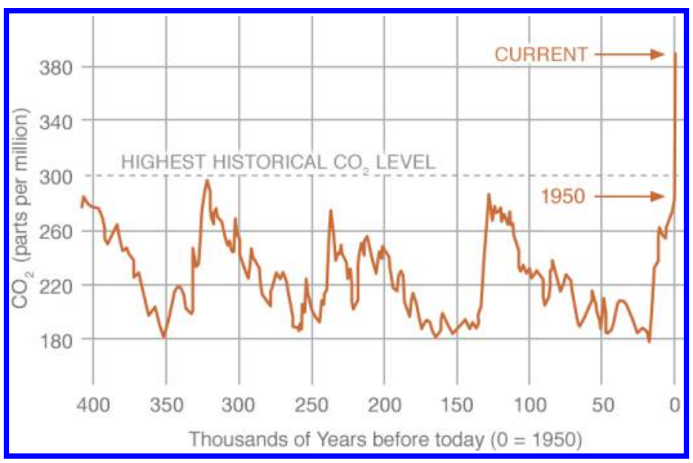
Electrically powered aircraft are anticipated to be inherently safer and more reliable than those propelled by internal combustion or even turbine powerplants. The high reliability of electric motors combined with the absence of a highly flammable on-board fuel both contribute to this. The small size and relatively slower landing speeds of Sky Taxis will also reduce the severity of damage to people and property in crashes. Fully autonomous flight should eliminate pilot error, pilot incapacitation, pilot incompetence and depressed pilots intent on suicide. Having each Sky Taxi equipped with standard equipment including a ballistic vehicle recovery parachute, ELT, airbags and, perhaps, a flotation device that automatically deploys in water landings should also drastically improve the air safety of RST.

Pocket airparks will have dog/deer fences, engineered materials arresting systems (EMAS), surveillance video cams, electronic identification of users at the gate, and a human security guard.

XIII. UTM—the new air traffic system

The integration of the anticipated high volume of unmanned and autonomous air vehicles into civil airspace will be essential to the operation of RST. The design and implementation of unmanned aerial systems traffic management (UTM) must balance the concerns and capabilities of both central control authorities and the ever-improving sentient capabilities that will be on-board each autonomous Sky Taxi. A detailed discussion of UTM is beyond the scope of this paper. NASA is well underway with UTM and anticipates demonstration of the advanced autonomy, "Capability 4" in March 2019.

XIV. Climate Change and Sustainability



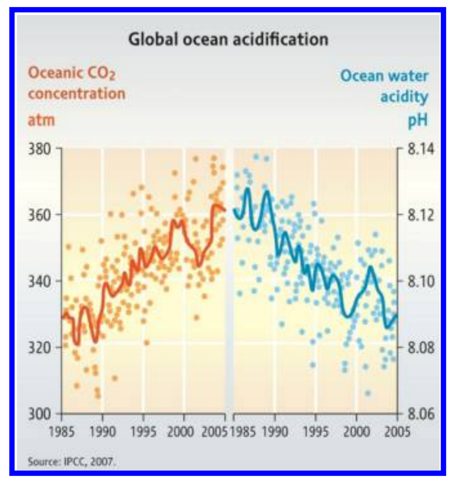


Figure 13. A broad consensus agrees that the increasing level of CO2 is causing climate change and harmful ocean acidification. Transportation is a main emitter of CO2. Graph on left from climate.nasa.gov. Graph on right from IPCC.

The concurrent urgencies of climate change and worsening surface gridlock should compel the aerospace industry and governments to actively and rapidly pursue efforts to bring about RST. Due to small and shrinking market size, efforts to improve or rejuvenate GA with emission-free conventional take off and landing commuter aircraft will not produce the magnitude of benefits necessary to relieve surface gridlock or meaningfully reduce CO2 emissions. RST, if implemented across the USA at 10% ridership, could produce substantial benefits as shown in Figure 14.

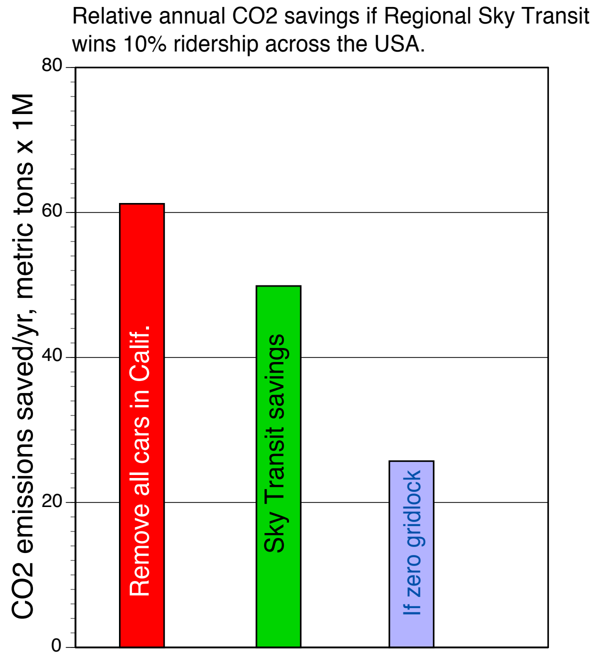


Figure 14. At 10% ridership across the mega-regions of the USA, Regional Sky Transit could save enormous amounts of CO2 emissions. Such savings would further increase in accordance with the reductions in surface gridlock that RST could engender.

XV. Designing a mission-capable Sky Taxi

From the foregoing outline of the standards necessary to RST, one can design a Sky Taxi that could fulfill its mission requirements. JOB ONE in that process is to create a 2-seat vehicle that can provide a combination of ultra-low noise emissions with V/ESTOL capability that fits a pocket airpark. It must also reach 120 mph in cruise, and be capable of steep climb-outs and descents at expeditious airspeeds. It will need a 100-mile range with an L/D of more than 10:1. To limit new vehicle cost and enable reasonable size for docking stations, it should be as simple as possible and as small as possible. We can target its gross weight to be that of Light Sport Aircraft, 600 kg. It must also be fully autonomous.

Most of these mission requirements have already been fulfilled by the aerospace industry. Several of these, including pure battery electric aircraft with 120 mph cruise, 100-mile cross-country range and high L/D were demonstrated in NASA's 2011 Green Flight Challenge sponsored by Google. Autonomous air vehicles with increasing levels of sophistication in sense and avoid, envelope protection and precision navigation seem to be hatching everywhere these days. Impressive V/ESTOL capabilities were demonstrated decades ago in a variety of aircraft, though never combined with ultra-low noise emissions. Steep climb-outs and descents are essentially just a matter of high power and high drag, respectively. The singular mission requirement that stands out as heretofore unconquered by the aerospace industry is that of ultra-low noise emissions. Electric propulsion finally offers the opportunity to conquer that one.

Fortunately, mathematical tools and understanding in aero-acoustics can assist in designing for ultra-low noise emissions as JOB ONE in a Sky Taxi design exercise. A principle purpose of this paper is to emphasize the overdue primacy of doing so, if we are to realize the benefits of RST and create aircraft that actually reach production.

Alfred Scott of Sequoia Aircraft and his team of mathematicians including Matt Emerson, James Petty, Jack Amos and Richard Thompson, have crafted a valuable software tool called Benchmark in which a calculator of propeller or rotor noise is included. This calculator is a free download and is Mac-based. It is based upon the Boeing Propeller Chart and uses a modified Gutin noise formula. It presents an actual color-coded noise footprint for various propeller designs showing dBA at specified sideline distances. It does not yet include all of the latest sub-routines and conditions, such as off-nominal angle of attack, blade thickness and section characteristics, blade flex, etc, that have been incorporated in the newer NASA ANOPP noise calculating software.[5] Consequently, the

Benchmark Gutin software may underestimate the noise profile of some propellers. Nevertheless, it provides an accessible tool with which to begin exploring how to create an ultra-low noise aircraft.

The Benchmark propeller tool shows that a 3.048 m (10 ft) diameter propeller of 6 blades and activity factor = 100, driven by a 15.7 kW motor at 380 RPM at an calibrated airspeed of 185 kph (115 mph CAS, 120 mph TAS) at a Standard Day altitude of 914.4 m (3000 ft MSL) could produce 55 lb of thrust with eta = 80.14%, while making the ultra-low noise of just 35 dBA at a 40 m sideline. With 2 such propellers and motors delivering 110 lb of thrust for cruise, and making a summed noise of 38 dBA at a 40 m sideline, we find that such a Sky Taxi could cruise at 193 kph (120 mph) TAS with 31.4 kW. Doing so for 1 hour would deliver over 160 km (100 miles) of range while consuming 31.4 kWh of energy from the battery pack.

The Benchmark tool also shows what those same propellers could do during take off and climb. Here, the design requirement is to take off and reach a height of 40 m (131.2 ft) in a runway distance of 168 m (550 ft). If we use a best angle of climb speed (Vx) of 90.2 kph (56 mph), a gross weight of 600 kg, an overall propulsive efficiency of .722 (Martin Hepperle suggests .73 [6]), then we need a rate of climb of 7.45 m/sec (1466 fpm) from these two large propellers being each driven with 41.92 kW of motor power and producing a combined total thrust of 2415 N (543 lbf).. This can be achieved. According to Benchmark, each motor of 41.92 kW would, with its propeller turning at 550 RPM with eta = 80% and climbing out steeply at better than 7.45 m/sec, deliver 1334 N of thrust while making only 36 dBA of noise at a 40 m. sideline distance. See Figure 15.

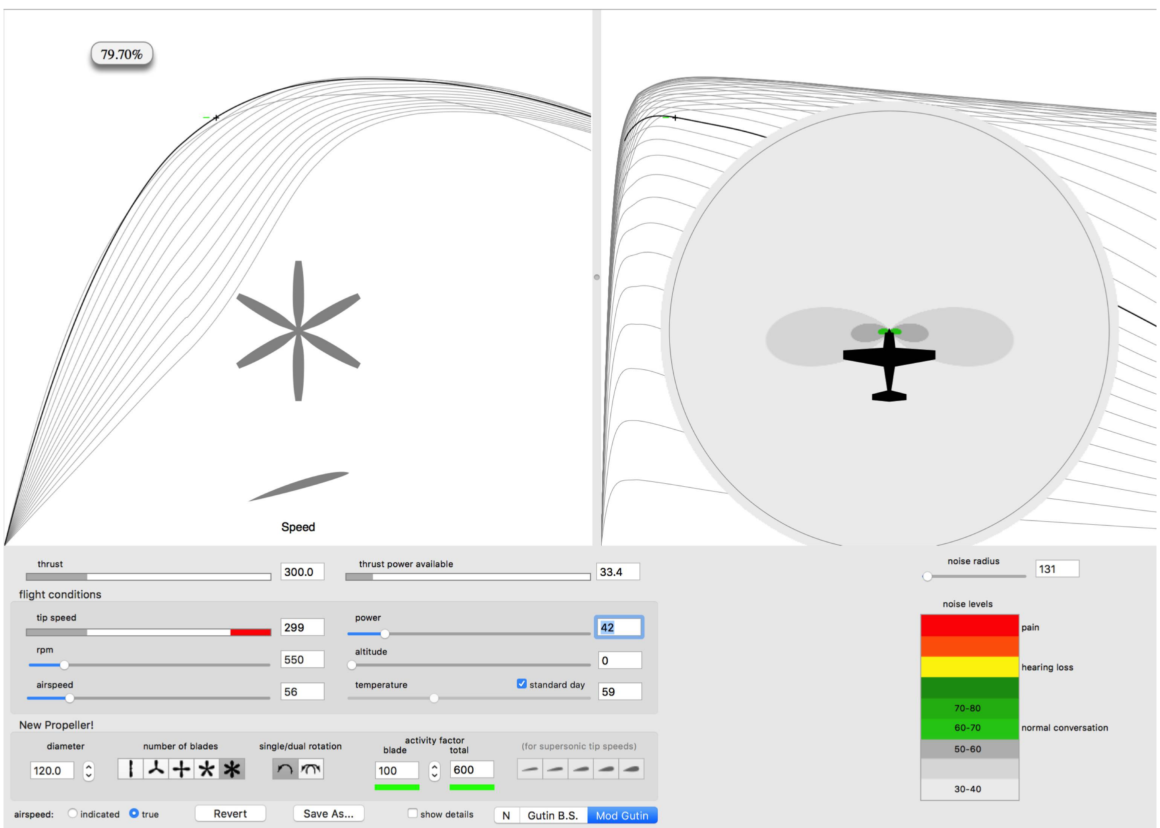


Figure 15. Alfred Scott's Benchmark software provides excellent prospective scenario modeling for propeller noise footprint, blade activity factor, number of blades, prop diameter, power, thrust, airspeed, etc. Here is a 36 dBA at 40 m propeller scenario.

That would mean a noise level of 39 dBA at 40 m from this aircraft during its full power take off, an unprecedentedly quiet passenger plane. This would qualify the aircraft to operate at pocket airparks, if it were *also* capable of making steep landings at low enough airspeeds to fit a pocket airpark.

As mentioned above, the steep landings necessary demand a large increase in airframe drag in order to have the necessary sink rate. Again there is a narrow, just-right "Goldilocks" airspeed range that offers the combination of dynamic pressure, runway overflight distance and braking distance after touchdown necessary to fit the pocket airpark. Happily, the large diameter 3.048 m diameter propellers can offer help in producing the necessary drag. The dynamic pressure at during a steep descent at 24.056 m/sec airspeed (53.8 mph) times the area of the 2 large propeller discs could produce a potential drag of at least 5169 N (1162 lb). This is more than enough to modulate the necessary steep glide at the pocket airpark. Starting from a height of 30 m (98.4 ft) AGL at the airpark fence, the Sky Taxi could descend autonomously at 24.056 m/sec and execute a precisely controlled reduction in sink rate to touchdown with adequate runway remaining for braking and turning off. The sink rate reduction would be accomplished by software that would change the propellers from windmilling drag to thrust mode for blown flap effect, in just the right amount at just the right moment. The result would be a smoothly tailored maneuver. This strategy largely avoids the need for a landing flare and the large amount of runway consumed by it.

It may even be possible, with smart software that provides just-right, very fast, electrically-controlled propeller blade angle adjustment, to alter the net thrust axis of these large propellers as a means to augment pitch and yaw control.

It is assumed that the noise level of the landing aircraft will be much less than that of its take off, so that an over-the-fence height of 30 m AGL on landing would be permissible. Note that this 30 m height is higher than that legally allowed by FARs for the backyard overflights of landing bizjets at some GA airports.

In order to accomplish such a short landing, the proposed Sky Taxi would employ a long travel landing gear system known as the Tactile Active Gear or TAG. This system's 1 m of travel would actively and precisely absorb the impact of landing touchdowns at vertical speeds on the order of 1.93 m/sec (380 fpm) while constantly maintaining a tolerable jerk of less than 3 m/sec^3. This landing gear is depicted in the bottom right image of Figure 16. By exploiting the electric aircraft's asset of having a large powerful battery pack, the TAG could offer more than just smart shock absorption. It could also rapidly change and adjust the pitch attitude of the fuselage and wing as needed during take off rotation, during taxiing in high winds and when parking to perform a 'curtsey' that facilitated de-boarding and boarding. The TAG is the subject of this author's separate AIAA paper for AVIATION 2016.

The proposed Sky Taxi would need an adequate gust margin for controllability at very low airspeeds. This would be facilitated by having blown flaps of a double-slotted Fowler type, as shown in Figure 16. Based upon prior studies of blown flaps in the Breguet 941[7], blown flaps can produce actual installed CLmax values as high as 6.5 or higher. For comparison, in order to achieve a pocket-airpark compatible stall speed (V_{so}) of 57.4 kph (35.7 mph), the 600 kg Sky Taxi with a wing area of 10.22 sq m (110 sq ft) would only need a CLmax of 3.68.

A summary of the proposed Sky Taxi characteristics is as follows:

- Gross weight: 600 kg (1322 lb)
- Wingspan: 9.75 m (32 ft)
- Wing area: 10.22 sq m (110 sq ft)
- Aspect ratio: 9.31
- Stall speed, Vso: 57.5 kph (35.7 mph)
- CLmax (blown flaps): 3.68
- Cdo: 0.0238
- L/D at cruise: 12.03
- Vx: 90.2 kph (56 mph)
- Propeller diameter: 3.048 m (10 ft)
- Take off noise level: 39 dBA at 40 m sideline
- Installed power: 2 each, 42 kW motors
- Wheel motors x 4
- Long-travel "TAG" landing gear

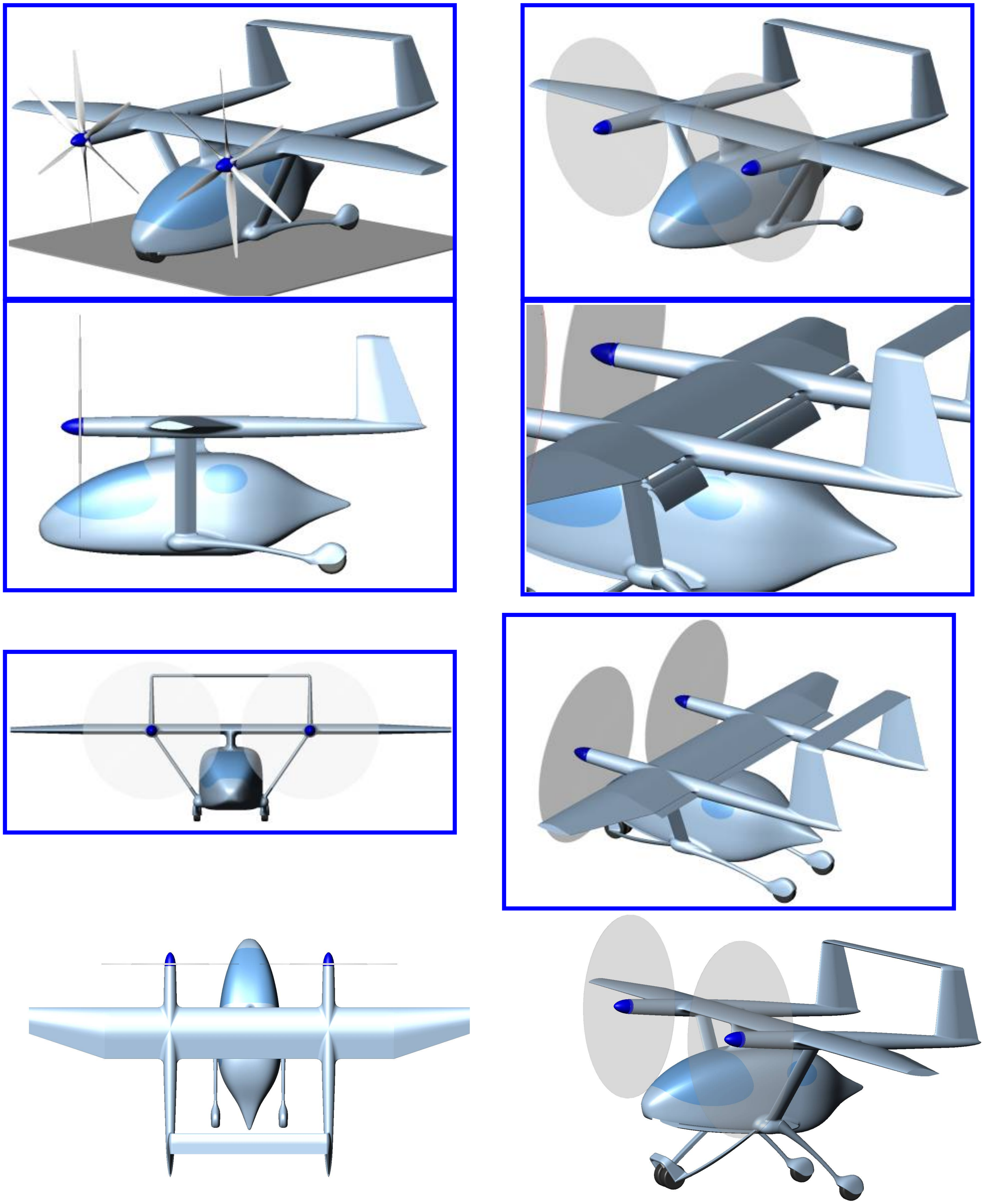


Figure 16. Two-seat Sky Taxi design drawn by Cris Hawkins has 3.048 m (10 ft) diameter propellers, long-travel autonomous landing gear ('TAG'), blown Fowler flaps, and a panoramic field of view for its occupants.

The direct drive motors for the proposed Sky Taxi would each be capable of 50 kW for 30 seconds and, according to estimates by motor expert David Calley, would each weigh only 10 kg including bearing housing and propeller flange. The cabin would offer commodious seating for 2 including room for baggage. The battery pack would be mounted in the belly of the Sky Taxi to enable rapid robotic battery swap through an underneath service bay below ramp level in the docking station. The occupants of the Sky Taxi would enjoy a panoramic view of the world below them. Each would wear a safety harness that contained an airbag. The top of the Sky Taxi would carry a ballistic recovery parachute. The nose landing gear would consist of 2 tires that retracted into the nose after take off. All 4 tires on the Sky Taxi would be equipped with wheel motors to enable very rapid take off acceleration and precision positioning and taxiing on the ramp.

Figure 17. shows the dramatic reductions in noise and power required that can be obtained by using large diameter slow-turning propellers.

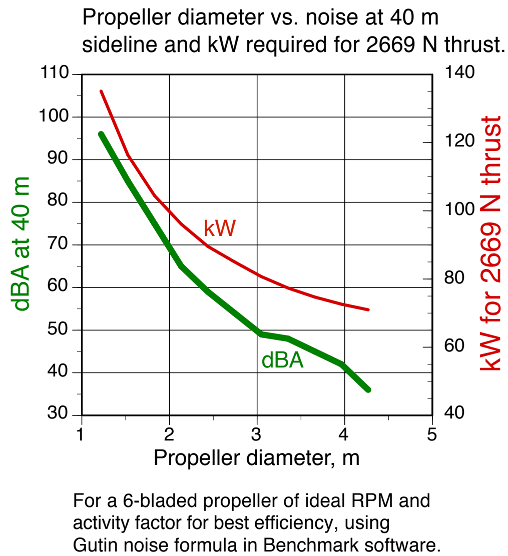


Figure 17. For a given thrust requirement, optimizing ultra-low noise and propeller efficiency favors the use of fewer large diameter, low RPM propellers rather than numerous small diameter high RPM ones.

XVI. No headway please

The concept of on-demand aviation emerges from the frustrations and increasingly onerous time costs that one encounters with scheduled commercial airline service. These include having to wait as much as 2 hours to pass through TSA security lines, suffering through baggage/ticketing lines and boarding times that last more than 30 minutes, having to walk more than a quarter mile to reach a boarding gate, etc. It is the goal of private bizjet ownership to circumvent such delays, and to be able to come and go when and where one chooses, to destinations that are not served by commercial airlines. However, even bizjets and chartered flights impose delays on their elite users. Their flights are always scheduled in the sense that a highly trained pilot as well as several passengers must be alerted to a time certain that the aircraft will depart. This means they must plan their ground travel to the CTOL jetport to be certain to be there well before the aircraft leaves. Having that 'time certain' imposes a time cost because of the inescapable 43% (national average) uncertainty time that attends using a congested freeway in the USA. And any CTOL airport large enough to handle bizjets is going to be remote, on the outskirts of town, and therefore likely to require use of a freeway. If one leaves work early enough to ensure allowance for that 43% uncertainty time and yet, due to lighter than usual surface traffic, arrives at the jetport in plenty of time to catch the flight, the time spent standing around waiting for the other passengers and corporate pilot to arrive at the appointed time is like the time between trains in transit systems--headway. It is fundamental to organizing any trip that the more people who are going in the vehicle, the more time it will take to round them up and get underway. The several passengers on a chartered, so-called 'on-demand' 9-seat commuter liner all face this same ground travel time penalty as they plan their arrival and boarding of the aircraft. The adverse effect of this on DtD trip speed is exaggerated; the shorter the trip, the worse its time penalty. The penalty is so severe that it disqualifies short charter flights from making sense, time-wise. Yet short flights are the mass market that can provide an economically sustainable RST system and overcome the need for the revenue guarantees, grants and subsidies that are required by thin-haul carriers.

The RST system should have ZERO headway. In RST, the user can travel a short distance of under 2 miles on un-gridlocked residential or city streets instead of freeways, to arrive at any desired time at curbside at a high proximity pocket airpark. The user can then walk a short distance to the docking station. From there, he or she can climb into a Sky Taxi and get airborne in as little as 40 seconds. This difference, the absence of any headway, is what will give RST unique access to the enormous mass-market of "short-trip takers" for whom other forms of aviation do not make sense.

XVII. Stay off the freeway

The possibility of using the vacant space inside the on-ramps of freeway cloverleafs for take offs and landings of pure VTOL aircraft has been recently studied at NASA. Though tempting as a means to increase the allowable noise emissions of the VTOL aircraft operations that could occur there, such operations would worsen freeway gridlock rather than easing it. This is because, unless expensive tunnels were dug, these operations would necessitate the use of the freeway (with its 43% uncertainty time) by every air traveler in order to reach any destination. This would essentially forfeit the basic reason for flying—fast travel without the constraint of roads. Freeways only go to certain places. Landing inside cloverleafs would ruin the 'on-time guarantee' of RST. Using the freeway for every RST trip would increase the GTT needed and would thereby shrink its market severely. Such a cloverleaf transit system would also face a very limited capacity of passenger throughput due to the space limitations inside cloverleafs and the gridlocked on-ramps surrounding the aircraft there. In addition, the constraints imposed by the inherent VTOL issues of the HV diagram and avoidance of the "vortex ring state" ('settling with power') would substantially slow the sequence of take off and landings used in operations in and out of these locations. The cloverleaf idea, when an adequate public safety area is applied, would have little or no room for docking stations, ground vehicle transient parking or passenger lounges with amenities. Expeditious access for summoned ground vehicles would hampered due to gridlocked on-ramps at the cloverleaf. That gridlock itself would be worsened rather than eased by the

Figure 18. Blue high-capacity RST airpark is 168 x 99 m, 1.7 hectares (550' x 325') and is roughly 1/4 mile from San Francisco's Financial District. The Red areas are Embarcadero and Montgomery St. BART Stations, which sum to 1.8 hectares. The passenger capacity of the airpark rivals that of the BART stations, but BART roadbed costs $1B per mile while the flight paths are free.

arriving Sky Taxis.

XVIII. RST compared to other forms of transit

The Bay Area Rapid Transit (BART) system delivers an average station to station trip speed of 21 mph, including waits for headway. Compare this to the roughly 100 mph trip speeds of RST. The prospective business model of RST presented at AVIATION 2015[8] estimated that its fares could generate 200% of overhead while BART's generate only 68% and require large subsidies. The BART system offers a narrow string of destinations while RST could deliver users across a widely distributed area. BART's daily ridership is 423,000. RST's, at 10 % ridership, would be 344,000. These comparisons, along with its enormous savings on roadbed cost, justify RST as a worthwhile public expenditure for regional transit systems.

XIX. The Sustainable Aviation Challenge

Single point design exercises, even though targeted on mission requirements, can never be optimal or ultimate in fulfilling their niche requirements in their first iteration. The principle of "survival of the fittest" is what can make a diverse array of better vehicle designs evolve from early design ideas and prototypes. The fastest way to evolve that fittest survivor is with "selection pressure". Selection pressure is what technology prizes create. The Sustainable Aviation Challenge (SAC) is a multi-year global technology prize for real aircraft that aims to speed the evolution and emergence of a mission-capable Sky Taxi that can help aviation meet the urgencies of climate change and transportation gridlock. This challenge prioritizes the breakthrough achievements in combining ultra-low noise with V/ESTOL performance in vehicles that can also go on to fulfill the other mission requirements of a Sky Taxi. It is open to teams from both industry and academia, both fixed-wing and rotor-craft, ESTOL and VTOL. Due to the comprehensive vehicle performance it demands, the SAC will be a technological feast that attracts many a wide array of STEM disciplines. It will kick-start the Sky Transit domain by providing venture capitalists with the all-important proof of concept vehicle and, importantly, it will inform the setting of realistic standards for RST.

For more details about this Challenge, please contact the Sustainable Aviation Foundation, Inc., an all-volunteer, tax-exempt, non-profit organization, at contact@sustainableaviation.org.

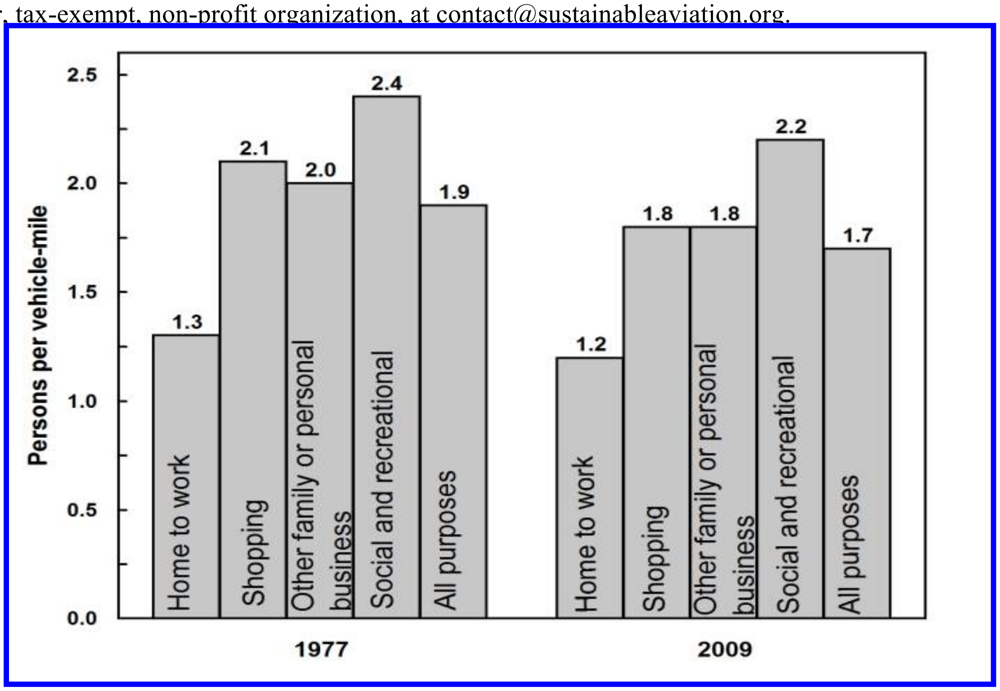


Figure 19. The NHTS of 2009 shows a significant trend toward fewer people per vehicle, suggesting that 2 seats are sufficient for the vast majority of trips. [9]

XXI. Barriers to implementation

In 2016, aviation finds itself at the intersection of technology with the commonwealth of our planet. The aerospace industry has already proven that it has the technologic capabilities necessary to create Regional Sky Transit. Now it must recognize and fulfill its social responsibility to do so. To not pursue what is inevitable because it is "hard to do" or "will take a long time" does not address our increasingly urgent problems of surface gridlock and climate change. Because RST is unique as the aviation domain that can make a substantial contribution to solving those problems, the aviation industry should extend its proven capabilities to rapidly implement projects that fit its mission requirements. Where the planet's well-being is at stake, the responsibility rests not with a single individual or company, but with government. In that domain, the zero sum budgetary process requires that we must be willing to set aside our obsolete projects, processes and practices in order to take on new ones. We must redirect our efforts to what will clearly be meaningful—what will lead to both a sustainable market and a sustainable planet. The most efficient and effective way to accomplish this in today's wired world is with a well-designed, multi-year technology prize whose goal is not bombast or spectacle nor a dumb-downed oversimplification of what is needed, but rather practical and relevant breakthroughs in the key aircraft capabilities identified as necessary to RST. General George Patton famously said, "A good plan today is better than a perfect plan tomorrow." Roads cost trillions of dollars; emission-free flight has a tiny environmental footprint. Government and industry need to steer us all towards planetary stewardship and away from mindless extraction of non-renewable resources--away from continuing to treat the air we all breathe as an open sewer. To paraphrase FDR, "The only thing we have holding us back is holding ourselves back."

XXI. Conclusion

A detailed examination of the operational and performance requirements of Regional Sky Transit indicates that it could become a sustainable and valuable adjunct to the transportation system of urban mega-centers. Its potentially large benefits to the environment, to productivity, and to the quality of life in general merit it receiving substantial support by government and industry. A highly efficient, leveraged means to initiate such support would be through a well-designed technology prize to evince the ultra-quiet, V/ESTOL autonomous Sky Taxis necessary to RST.

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