



Regional Sky Transit IV: Pocket Airpark Design Constraints

Brien A. Seeley M.D.*

Sustainable Aviation Foundation, Santa Rosa, California, 95404

By providing affordable, accessible, fast, and safe flights distributed across urban/suburban mega-regions using electrically-powered small aircraft (Sky Taxis), Regional Sky Transit^{1,2,3} (RST) aims to reduce CO₂ emissions and the cost of surface infrastructure while preserving people's strong preference for on-demand travel in personal vehicles. In its fullest expression, RST could become aviation's largest market in terms of number of flights because it could serve a large share of the billions of daily trips of less than 160 kilometers. As such, RST promises to be both economically and environmentally sustainable. That fullest expression of RST would require an extensive network of community-acceptable, high-proximity "pocket airparks" in order to minimize ground travel time (GTT). These airparks would face fundamental design constraints that would depend upon whether they were located in a downtown, high-rise urban area or a suburban residential area, and both these areas would need to be served in order to maximize market size and profitability. High proximity would require that airparks be as small as practicable while still providing the efficiency of a high duty cycle of shared use as a form of public transit. Pocket airparks would need to fulfill community noise constraints and have sufficient area to enable a high capacity of passenger throughput. Airparks would need to comply with pertinent building codes and meet the regulations of the Americans with Disabilities Act (ADA). They would need to fulfill applicable present and future FAA regulations and standards, including the integration of their traffic into the ATM system. Provisions for near-all weather operations, electrical charging stations, on-site solar panel arrays, service bays, transit connections, security, lighting, perimeter fencing, etc., would all be needed. Uniform, realistic standards for airpark size and acceptable noise limits will be fundamental to successfully implementing pocket airparks close by to where people live. From these and other requirements it is possible to distill the range of reasonable and definable design limits for both the airpark and the small Sky Taxis that will serve RST. This paper explores those requirements, compares them to what might pertain at alternative types of take off and landing sites and presents a rational plan for the implementation and operation of an RST system.

Nomenclature

<i>4D</i>	= a three-dimensional path along which each point has a defined specific clock time
<i>AGL</i>	= above ground level (height or altitude)
<i>ATC</i>	= air traffic control
<i>ATM</i>	= air traffic management
<i>BHP</i>	= brake horsepower
<i>CAS</i>	= calibrated airspeed
<i>CL_{max}</i>	= maximum lift-coefficient
<i>CNEL</i>	= community noise equivalent level
<i>CO₂</i>	= carbon dioxide
<i>CTOL</i>	= conventional take-off and landing

*President, Sustainable Aviation Foundation, 4370 Raymonde Way, brienseeley@gmail.com, Senior Member AIAA.

<i>dba</i>	= decibel noise level, A-weighted scale
<i>DNL</i>	= day night level in dBA, a metric for noise measurement
<i>DtD</i>	= door-to-door
<i>ESTOL</i>	= extremely short take-off and landing
<i>eta</i>	= propeller efficiency
<i>fps</i>	= feet per second
<i>G</i>	= the acceleration due to gravity at sea level on Earth
<i>GA</i>	= general aviation
<i>GPS</i>	= global positioning system
<i>GTT</i>	= ground travel time, the total of non-airborne time in a Sky Transit trip
<i>GVW</i>	= gross vehicle weight
<i>HPA</i>	= high-proximity aviation
<i>IFR</i>	= instrument flight rules; e.g., flying with instrument rather than visual guidance (see VFR)
<i>kg</i>	= kilogram
<i>kph</i>	= kilometers per hour
<i>kWh</i>	= kilowatt hour
<i>kW</i>	= kilowatt
<i>last mile</i>	= the distance from a transit station or airpark to one's destination doorstep
<i>lb</i>	= pound
<i>L_{den}</i>	= level in dBA, day evening and night, a metric for noise measurement
<i>m</i>	= meter
<i>m/sec</i>	= meters per second
<i>mph</i>	= miles per hour
<i>MSL</i>	= above mean sea level, describing elevation or altitude on a standard day
<i>NHTS</i>	= National Household Travel Survey
<i>RPM</i>	= revolutions per minute
<i>RST</i>	= Regional Sky Transit
<i>sec</i>	= second
<i>sq ft</i>	= square feet
<i>STEM</i>	= science, technology, engineering and mathematics education
<i>TAS</i>	= true airspeed
<i>VESTOL</i>	= vertical or extremely short take-off and landing
<i>VFR</i>	= visual flight rules, flying in mostly clear skies using vision to see and avoid traffic
<i>VMT</i>	= vehicle miles traveled
<i>VTOL</i>	= vertical take-off and landing
<i>V_{so}</i>	= minimum velocity at 1 G at which an aircraft in landing configuration stalls

I. Introduction

There is a growing awareness in the aerospace industry that using electrically powered aircraft to extend on-demand passenger air travel across urban mega-regions to locations that are close to where people live and work could greatly improve door-to-door trip speeds. It could also largely eliminate the uncertainty in trip time that affects those trips during daily commute hours. Such high proximity aviation (HPA) has been called Regional Sky Transit (RST) and it represents an entirely new domain for aviation. When fully implemented, RST promises to substantially ease surface gridlock, reduce the cost of highway and bridge infrastructure and reduce greenhouse gas emissions. Both business and operational models of RST have been presented at AIAA's AVIATION 2015 and 2016, respectively.^{4,5} These models forecast that fully implemented RST could be both affordable and profitable without government subsidies. These favorable attributes suggest that RST could be economically and environmentally sustainable by using a distributed network of very small, use-permitted "pocket airparks". The main barriers to the realization of RST as a mass market will be the creation of the ideal high-capacity but very small airparks and the development of Sky Taxis that can fulfill community acceptable noise levels while operating there. Consequently, this study attempts to design both the smallest possible high-capacity pocket airpark and a Sky Taxi quiet enough to operate there.

II. Parameters of Influence

The success of RST, defined as an air transit system that achieves a *meaningful* level of ridership, will depend upon two main factors. The first is the proximity of pocket airparks to where people live and work, which in the main will depend upon their land parcel size. The second, which will itself affect land parcel size, is the throughput capacity of those airparks in terms of passengers per hour. The proximity is essential to minimizing ground travel time and making RST competitive relative to car travel in both time and cost on the shortest trips possible. The throughput capacity is essential to generating sufficient fare revenue as to enable affordability and to warrant public support as a democratized system.

The factors that will affect the size of a pocket airpark are these:

1. The noise footprint of the aircraft that will operate there
2. The take off, climb, taxiing and landing speeds and accelerations of those aircraft
3. The ramp footprint of the aircraft—its length and span and parking space requirement
4. The adjacent terrain, structures, obstacles, and land uses nearby
5. The adverse weather conditions that could apply at that airpark
6. The elevation of the airpark
7. The prevalent ambient noise level at the airpark's location
8. The [future] standards and regulations that define and control the size of pocket airparks

Each of these 8 factors will be discussed in turn:

1. To be practical and efficient, each Sky Taxi operating in the Regional Sky Transit system should fulfill the noise requirements that apply at the most stringent case of low ambient noise—which will be those airparks that serve quiet, serene residential settings. In those settings, low ambient noise levels, especially those after 7 PM and before 7 AM, will exacerbate the perceived level of Sky Taxi noise and annoyance to people who live nearby. There are at least two aircraft noise levels that will be perceived near the airpark. One is the noise emitted while on the ground during high power operations. The second is the noise of flying overhead on either approach or departure from the airpark. Both of these can be estimated using software such as Benchmark.⁶

The noise footprint of the Sky Taxi in use will be a critical determinant of airpark size. By regulatory precedent with the FAA, to be community acceptable the airpark must be large enough to contain the noise of take offs and landings such that it 'highly annoys' less than 10% of the airpark neighbors. The flight path of the Sky Taxi during approach and climb out will also need to be designed so that its noise is nearly imperceptible to the airpark neighbors. These requirements will be especially difficult to meet at airparks in serene residential areas where frequent evening operations are occurring. Reducing noise to a minimum will also free Sky Taxis from the constraint of having to fly only above noisy freeways.

Numerous FAA, DOT and European surveys of annoyance levels from aircraft noise, including the more stringent noise levels found in the DOT Volpe Center studies of noise in National Parks performed by Rapoza et al.⁷, indicate that it will be necessary to maintain a noise level below about 48 dBA CNEL at the airpark boundary in order to achieve community acceptability in quiet residential areas. For a busy airpark that operates at the maximum predicted capacity of one take off every 10 seconds, the single event SENEL will need to be very near to this 48 dB CNEL level. It would be ideal to achieve even lower than 48 dBA at the airpark boundary if this were possible, and future technologies may enable this.

2. The dimensions of the airpark must be large enough to allow safe take offs and landings at airspeeds that fit with the other mission requirements of the Sky Taxi, such as its cruise speed and stall speed. The operational speeds and accelerations of the Sky Taxi affect both the size of the airpark as well as its throughput capacity. Since economic sustainability favors maximizing both cruise speeds and the throughput at each airpark, the Sky Taxi speeds, both in the air and on the ground, must be high enough to provide expeditious movement of people and cargo while not being so high as to demand longer runways. This means that there will be a just-right landing speed that offers sufficient margin above stall speed, rapid cadences of touchdown, braking and turning off the landing strip and yet without a long ground-roll-out after touchdown. There will also be a just right take off acceleration and lift off speed. It is anticipated that for these requirements and for those of rapid short take offs, wheel motors in the landing gear will likely be required on both VTOL and ESTOL aircraft. Precision autonomous flight controls in future Sky Taxis are

likely to enable the airpark to be sized with tighter margins around these airspeeds than are used for Sky Taxis with human pilots.

3. The size of the Sky Taxi in terms of its wingspan, length or diameter affects how many parking spaces can be fitted along the airpark's loading dock, which in turn affects the cadence of operations to launch and recover the aircraft. Preliminary assessments suggest that 13 parking spaces could enable a cadence of one launch and one recovery every 10 seconds.

4. The smallest airparks can obviously be those that have unobstructed approaches and departure paths. Sky Taxis that have steep approach capabilities can help overcome this influence. In many metropolitan areas, there are available waterfronts on which small airparks with high proximity to downtown areas could be built onto piers over the water.

5. Airparks in regions with adverse weather, particularly those subject to snow or icing will likely have to have some margin of larger parcel size in order to accommodate the decrease in runway traction these entail, even though small airparks will likely have heated runways. Anti-lock and anti-slip wheel technologies can minimize the traction problems of wet pavement.

6. Airparks at higher elevations will naturally need to be larger due to the higher true airspeeds that obtain during take offs and landings at those density altitudes.

7. Airparks that are in very quiet residential areas, where ambient noise levels can approach 35 dB, will likely need somewhat larger airparks in order to contain the noise. Alternatively, these ultra-quiet areas could have curfews that prevent flight operations between 7 PM and 7 AM.

8. Obviously, ASTM, FAA, EASA and others will develop and implement regulations regarding both the allowable noise levels and the airpark size, in accordance with the emerging demonstrated performance of future electrically powered Sky Taxis. That process would be greatly facilitated by the early demonstration of the limits of achievement in both low noise and short runway performance, which could be accomplished with an appropriately designed technology prize.

III. The Smallest Airpark Possible

In an effort to model the extremes for a high capacity airpark that could be as small as possible, this paper examines the reasonable limits of performance for a 2-seat 600 kg fixed-wing Sky Taxi. These limits include the Sky Taxi's noise footprint, speed, acceleration, glide slope, separations, parking spot size and power required and their effect upon airpark size. See Figure 1., which shows the results: a pocket airpark of just 1.216 hectares (3.0 acres) at which both take offs and landings can occur at a 10-second cadence. The performance and dimensional specifications that enable this extremely small airpark are as follows:

For this airpark model, the shortest conceivable take off ground roll was determined by assuming that small, efficient wheel motors could provide sufficient low-RPM torque and power for a very brief period sufficient to provide brisk acceleration of 0.8 G's for the 600 kg Sky Taxi to accelerate from brake release to its lift off speed of 24 m/sec (53.69 mph). This computed to be a peak power of 56.5 kW at 94% efficiency for each of the 2 wheel motors with a duration of just 4.335 seconds. These take offs were computed with adherence to a jerk limit of 3.2 m/sec³, and yielded a take off ground roll of just 38.7 m (127 feet). It is assumed that this performance, on dry pavement, is performed precisely and repeatedly by autonomous control software. It is also assumed that the landing roll can reverse this process, although the landing Sky Taxi will turn off the runway at a taxiing speed of 4.9 m/sec (11 mph), shortening the pavement needed for landing to just 35.9 m (117 feet).

The model included the goal of completing the climb out to a substantial height above ground level at which the Sky Taxi's noise would become nearly imperceptible and doing so in a reasonably short distance over the ground that would fit inside the airpark boundaries. It became obvious that this is best accomplished with a curved flight path using a bank angle to lengthen the distance traveled over the airpark property. As a compromise, a bank angle of 25° was chosen, resulting in a climb distance of 131.9 m (433 feet) at a rate of climb of 6.97 m/sec (1371 fpm) in order to reach a height of 40 m (131.232 feet) at the airpark boundary. Steeper climbs are possible, but would entail a larger noise footprint and larger parcel.

The model calculated the best propeller/motor to achieve the 6.97 m/sec climb rate with the lowest possible noise. This computation was made using multiple iterations in the Benchmark noise footprint prediction software based upon the Gutin noise formula. The result was to use two 6-bladed propellers, each of 3.048 m diameter (10 feet) and each consuming 39.8 kW 53.34 BHP at 550 RPM, with tip speed of 91.1 m/sec (299 fps) and assuming 95% motor and controller efficiency along with the predicted 79.34% prop efficiency at 24 m/sec airspeed, 114 activity factor, and at sea level conditions. See Figure 2. Each of

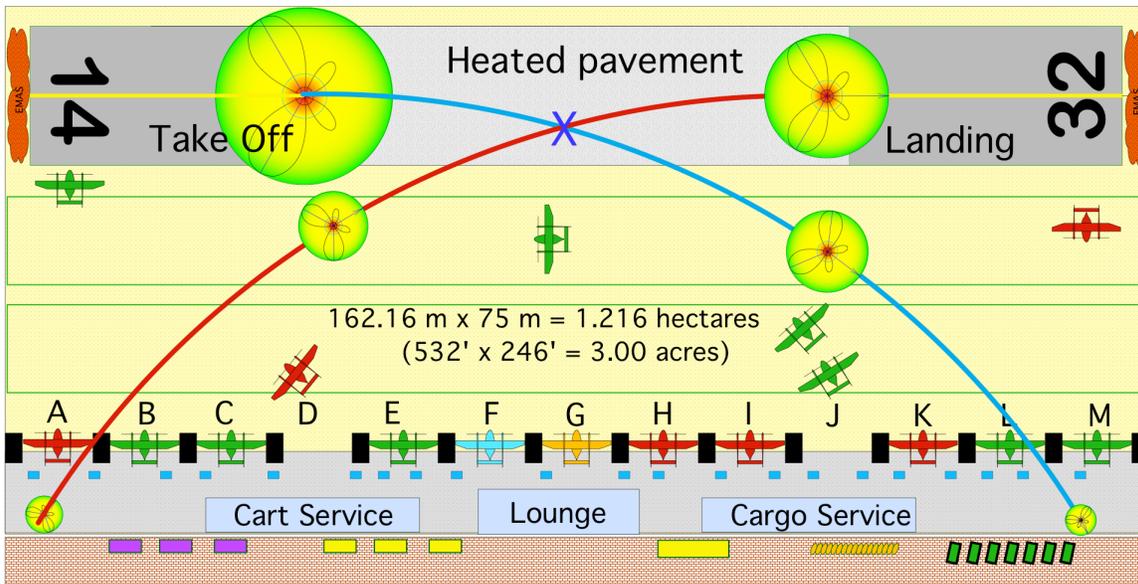


Figure 1. Above: A very small, high capacity pocket airpark with 13 docking stations. Below: The heights and times of the take offs and landings at this airpark.

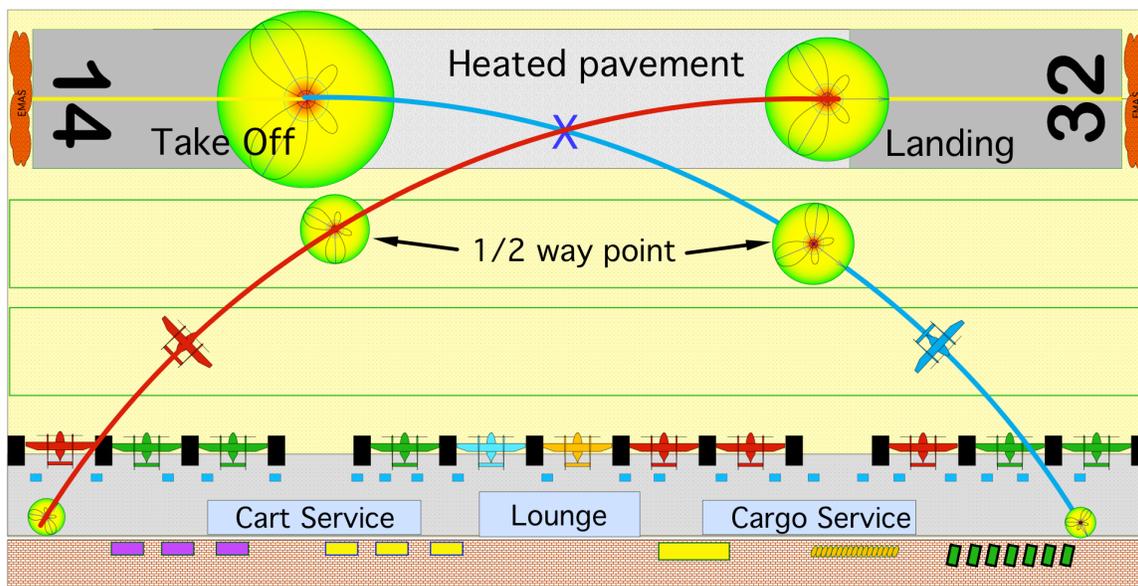
Climb to 40 m and descent from 30 m @ 24 m/sec

Take off height at X = 11.34 m (37.2 ft)

Take off height at 1/2 way = 20 m (65.6 ft)

Landing height at X = 3.27 m (10.73 ft)

Landing height at 1/2 way = 10.36 m (34 ft)



Climb out duration (blue arc) = 5.74 sec

T.O. Ground roll/climb to "X" = 4.335/1.62 sec

Descent duration (red arc) = 5.62 sec

Landing roll/Descent to "X" = 2.535/3.97 sec

these propellers is predicted to generate 35 dB at a 40 m sideline distance. The sum of those two noise emissions would be 38 dB at 40 m. This would be equivalent to 48 dB at a 12.65 m sideline, so a noise radius of 12.65 m at the point of lift off on take off was used as the noisiest case for this Sky Taxi. This is depicted in Figure 1. as a 12.65 m radius "noise rainbow" on the lift off area of runway 14 in the figure. As

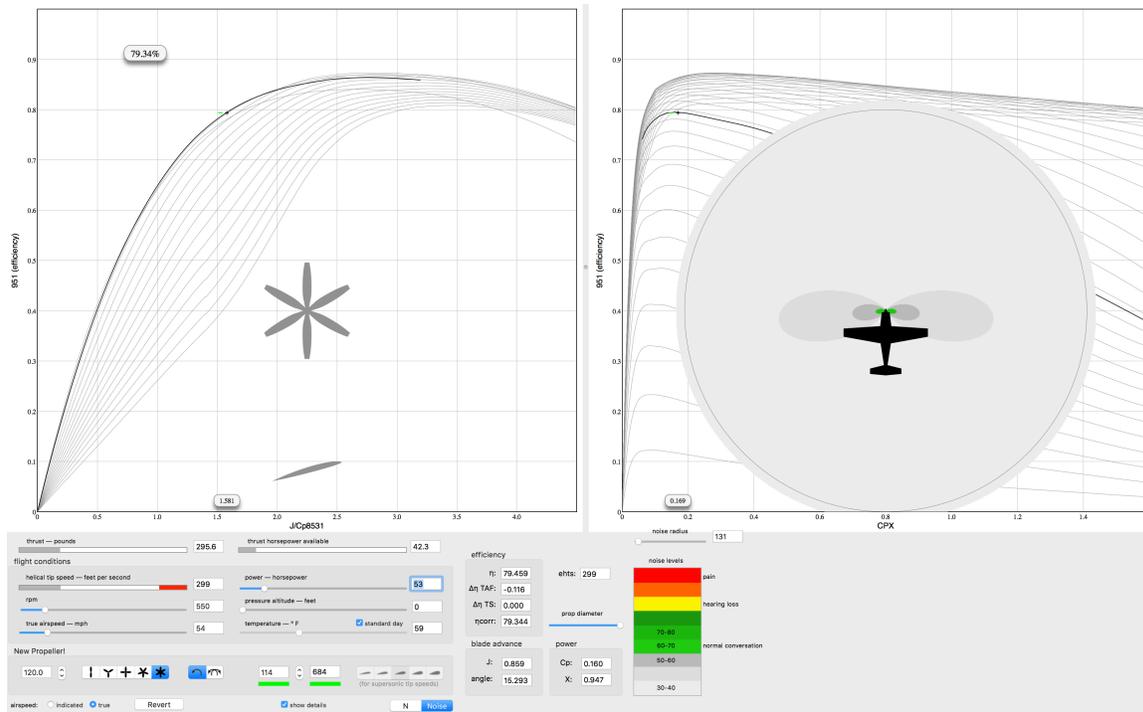


Figure 2. The Benchmark software noise footprint result for a 3.048 m (10 feet) diameter propeller at 53.69 mph and 550 RPM shows only 35 dB at 40 m (131 feet). This amounts to just 38 dB with both props operating on a twin motored Sky Taxi. This 38 dB noise level would result in 48 dB at a sideline radius of just 12.65 m.

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the Sky Taxi climbs along the blue arc shown, its noise rainbow diminishes in size and is shown to become a tiny circle as it reaches the end of that arc at a 40 m height above the ground. At that point, the noise of the departing Sky Taxi would be less than 48 dB on the ground at the boundary of the airpark.

A similar sizing process is shown for the landing approach in Figure 1. Here, the Sky Taxi enters the airpark boundary in a steep power-off descent at a height of just 30 m. It continues its steep descent along the red arc shown, and, as it nears the ground, its noise rainbow increases in diameter. At the point shown with the blue “X”, the landing and take off paths cross, however the Sky Taxis never pass that point at the same time due to 4D flight path planning. Note that the noise rainbow of the landing Sky Taxi increases substantially in size right at its touchdown point on the landing runway, due to a blast of propeller thrust over the high lift flap system at that moment that helps smoothly arrest its sink rate. This red arc of descent to touchdown is carefully scripted to fit achievable sink rates and tolerable jerk rates. It presumes that a brisk control authority over aircraft drag and lift will be possible using the large propellers alternately as either drag brakes and lift enhancers by blowing onto the Fowler flaps.

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Figure 1., in its lower half, presents the values for height above ground and time intervals that pertain to the take off and landing operations at this extremely small pocket airpark. Note that the height of the landing and departing Sky Taxis at point “X” differ by nearly 8 m (27 feet) and that the landing Sky Taxi is more than 10 m (32 feet) above the parallel taxiway during its descent. These separations are much larger than those used for cars with human drivers traveling at freeway speeds.

Figure 3. shows the relative size of a helicopter landing facility superimposed upon the small pocket airpark. The small size of this helipad is deceptive because of both the operational constraints that apply to rotorcraft and their noise footprint. The operational constraints include the need for rotorcraft to adhere to a “height-velocity diagram”, like that shown in Figure 4. That diagram shows how a rotorcraft must fly close to the ground as it changes speeds in order to safely avert a crash in the event of a propulsion failure.

Figure 5. shows the additional limitations on rotorcraft that pertain to making low noise approaches and avoiding operations that would cause the high noise condition of “blade slap”. These operational constraints increase the actual size of the landing facility or Vertiport necessary to handle rotorcraft operations. However, the single largest factor that will affect the size of the landing facility for VTOL aircraft is likely to be the inherently larger noise footprint that occur with powered lift aircraft.

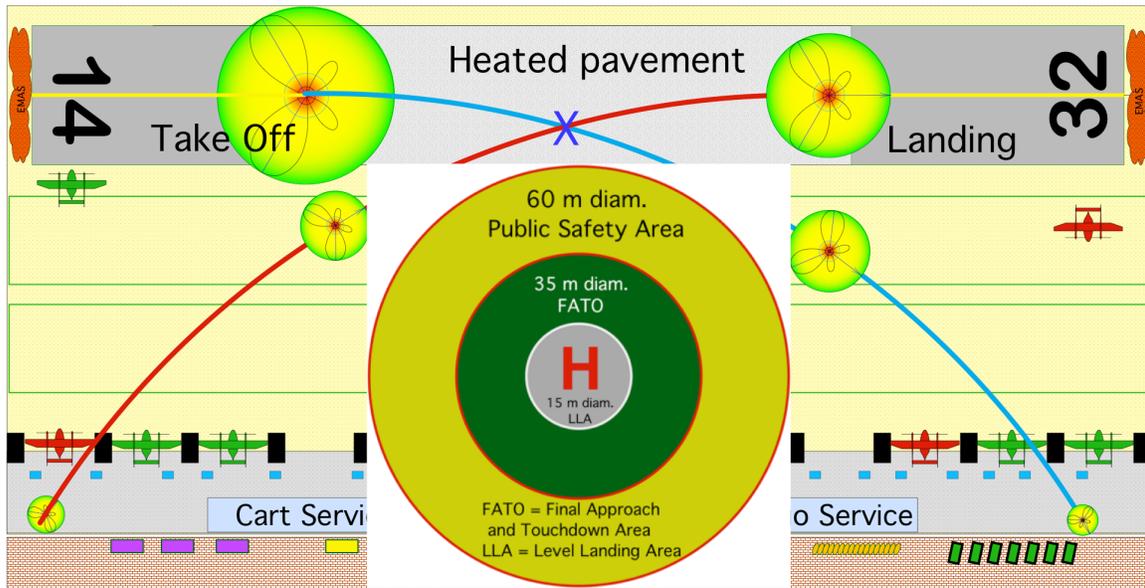


Figure 3. A standard helicopter landing facility superimposed on a very small airpark.

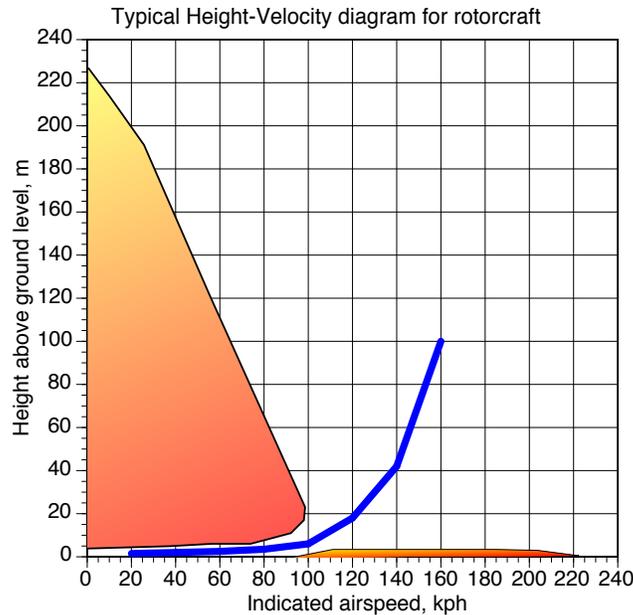


Figure 4. The Height-Velocity diagram for a medium helicopter. Operation in the orange-colored areas must be avoided. The blue line shows the acceptable path. Rotorcraft must ensure that in the event of engine, motor or rotor failure, that there will be available a sufficient combination of kinetic (velocity) and potential (height) energy to enable the rotorcraft to make a controlled landing using auto-rotation. This results in these VTOL aircraft having to hover low to the ground until they build up sufficient forward airspeed to safely execute their take off climb out. Excepting rooftop Vertiports, that flight profile effectively increases the required size of the Vertiport well beyond that of a 15 m level landing area (LLA) helipad. In general, fixed-pitch rotor-equipped VTOL aircraft, such as many multi-copter designs, cannot perform auto-rotation; they rely instead on either a ballistic recovery system (parachute) or propulsion system redundancy to avert crashes.

Initial industry efforts to realize Regional Sky Transit are focusing on electric VTOL powered lift aircraft with a vision for them to operate at small “Vertiports” located in both urban and suburban areas. The limiting case for such VTOL operations will be the quiet suburban areas with low ambient noise in serene neighborhoods. In this study, 2 VTOL 600 kg Sky Taxi designs, Models “D” and “E” from an earlier study⁸ are examined to determine the size of airpark necessary for them to operate in or near residential areas. The power, RPM and other details of the propulsors in these 2 VTOL aircraft are given in that reference and they are shown schematically in Figure 6. The noise footprint of these two designs was determined using Benchmark software. For Model D, the quad-copter design, the sideline distance (noise radius) at which 48 dB would be heard (while generating the 7351 N of thrust necessary for climb) was calculated to be 1007 m during initial lift off at a vertical speed of 1.6 kph and 1507 m during a steady climb at a vertical speed of 11 kph. For Model E, the tilt-wing design, these sideline distances for 48 dB at 7351 N of thrust were found to be 3578 and 4014 m, for the 1.6 kph and 11 kph vertical speeds, respectively. If, as experience and survey data suggest, there will be a need to keep the noise of high capacity take off operations below 48 dBA all along the Vertiport’s boundary, it would appear that these distances would demand a Vertiport of at least $2 \times 1507 = 3014$ m diameter for Model D and $2 \times 4014 = 8028$ m diameter for Model E type aircraft to operate there. Figure 8. shows this size to scale with its diameter of 3.014 km (1.87 miles), which dwarfs the small pocket airpark shown. A 1.87 mile Vertiport is very unlikely to fit anywhere near to the residential areas that RST must serve. Further analysis shows that such very large diameter Vertiports face more demands; they would actually have to be even larger in order

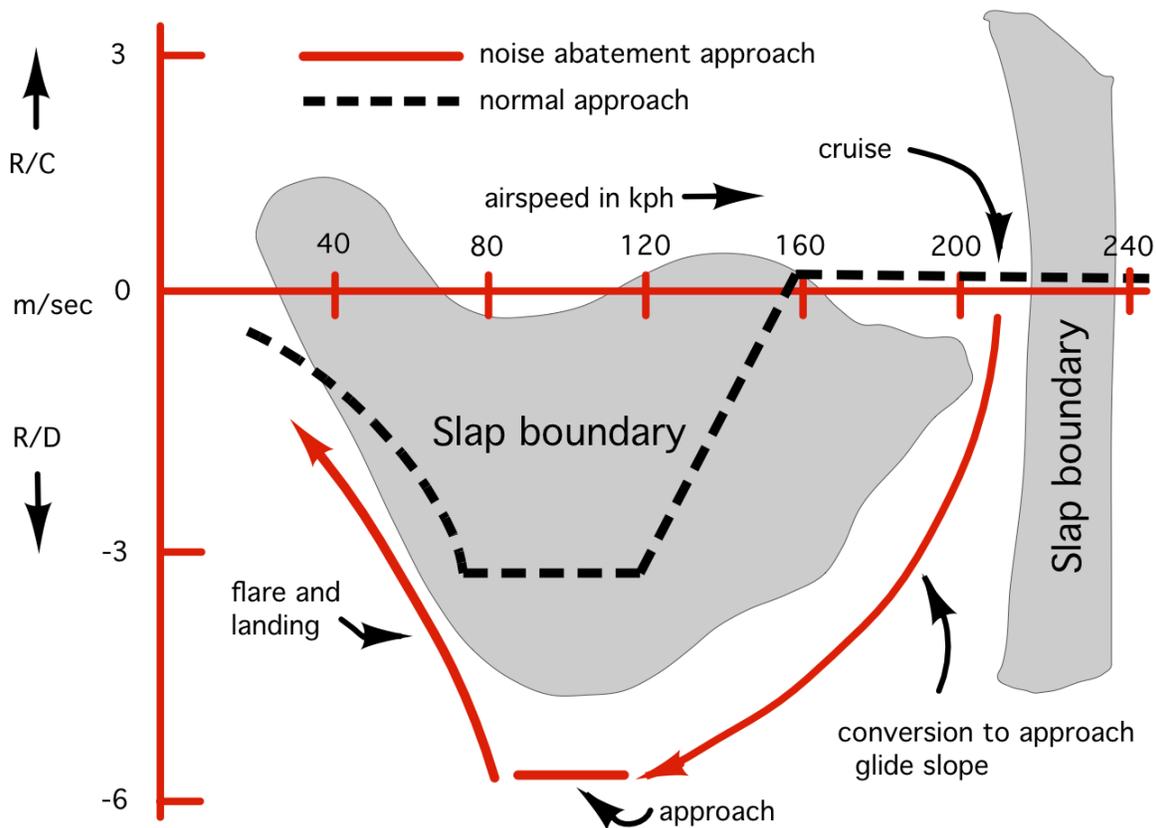


Figure 5. Derived from Bell Helicopter data for a medium helicopter flying the required H-V diagram with the lowest noise result, this graph from Leverton⁹ shows the operational boundaries for avoiding blade slap noise. This shows a need for a steep increase in the descent rate (R/D) as one reduces airspeed to begin a noise abatement landing approach (red arrows), followed by a rapid reduction in rate of descent as one slows toward hover mode, flare and landing.

to contain the noise of these VTOL aircraft if their flight operations were to include crossing the Vertiport boundary at any altitude above ground level that was below their noise radii of 1507 m (4944 feet) and 4014 m (13,169 feet), respectively. Such required distances make it untenable that VTOL aircraft with the noise footprints of Models D and E could be acceptable to operate close to quiet residential communities. It should also be noted that Model D and E are predicated on a 600 kg GVW, which is far below the 2268 kg (5000 lb) GVW 4-seat VTOL aircraft that some propose for use in RST. The larger weight aircraft would entail much greater thrust and would result in an even larger noise footprint.

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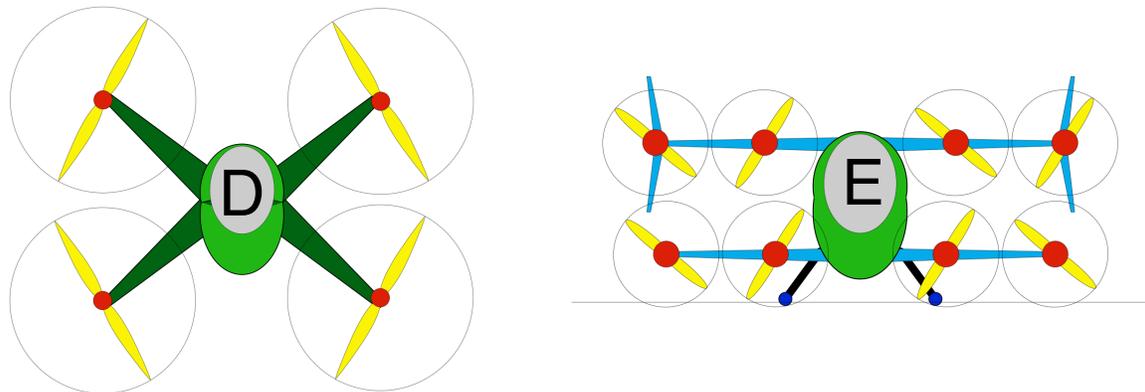


Figure 6. Two conceptual 600 kg VTOL Sky Taxis with 1.25 thrust to weight ratios examined in this study. Model “D”, the quadcopter, has a 2-seat people pod and 4 rotors, each of which are 2.44 m (8 foot) diameter and have 2 blades. Model “E”, a 2-seat tilt-wing and tilt-canard VTOL Sky Taxi uses eight 2-bladed propellers each of 1.219 m (4 foot) diameter.

The factors that disfavor VTOL solutions for RST include the relative and inherent penalties in power, range, weight and efficiency that attend powered lift designs. Other disfavoring factors are the demands imposed by hover mode, the virtual noise penalty that the public applies to rotorcraft, the increased complexity and empty weight fraction that apply with tilt-rotor, tilt-wing or tilt duct designs, and the low L/D that attends most VTOL designs. There also can be anticipated a greater cost in time and money for certifying autonomous electric tilt-mode VTOL aircraft compared to conventional fixed-wing designs. In addition, and perhaps even more disfavoring are the operational demands (optimal flight profile) that attend minimizing noise. These will further penalize VTOLs, requiring them for noise abatement to not descend until above the destination and then to descend in inefficient and time consuming ways that entail high energy use. Such descents must observe the VTOL’s height-velocity H-V diagram requirements if these apply, and also must avoid the vortex ring state condition (settling with power). These H-V and vortex ring state operational profile constraints could adversely affect the size of the land parcel that must be allocated for a Vertiport.

The generic H-V diagram shown in Figure 4, will change with aircraft weight and density altitude, but conveys the general idea that rotorcraft, unlike fixed-wing aircraft, must carefully avoid situations in which a loss of engine or motor power would result in an uncontrollable crash. Uncontrollable is defined as any situation of power loss in which the kinetic (airspeed) or potential (height) energy of the rotorcraft was insufficient to allow either a controlled flare or auto-rotation to a safe touchdown. What is apparent in all such diagrams is that the “land anywhere” attribute hoped-for in rotorcraft must be qualified by, for safety assurance, them having to approach the landing spot with a nearly horizontal flight at a very low altitude during which they decelerate their airspeed to near zero or to hover to enable the touchdown.

A high passenger throughput capacity at Vertiports will be essential to enabling affordable fares and thereby attracting a large enough ridership to have a meaningful effect on the transportation system. Economic success will depend upon minimizing the time consumed by each Sky Taxi in making a safe approach and landing, along with minimizing the time spent taxiing to the de-boarding area, de-boarding, re-boarding, battery charging or battery swapping, repositioning for take off and then departing the Vertiport or airpark on its next flight. One could apply a metric of passengers per hour per acre of land at the Vertiport or airpark to better assess the comparative economic results of VTOL Sky Taxis versus fixed-wing Sky Taxis.

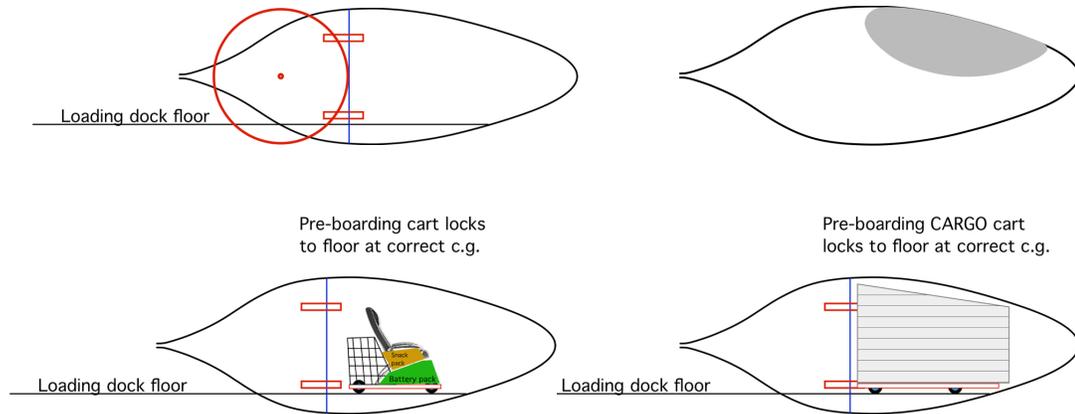


Figure 7. The 600 kg Sky Taxi could use a low-drag laminar flow body of revolution—the Sky Pod—as a fuselage with a panoramic flush windscreen. The Sky Pod could provide a standard sized container whose rear 1/3 opened as an entry door for either passenger or cargo loading carts. These self-powered, autonomous carts could be pre-loaded on the dock with 2 passengers or several parcels of cargo to enable very rapid boarding and de-boarding. Each cart could carry a freshly charged battery pack onto the Sky Taxi for each flight.

IV. Loading Dock Carts for Passengers and Cargo

A fast turnaround time for RST operations will require that the processes at the loading dock—boarding, de-boarding, battery swap, pre-flight inspection, provisioning—all be done expeditiously. To facilitate that, a fast-loading fuselage concept has been devised based upon a very low drag laminar flow body of revolution. This body, as shown in Figure 7., would have a rear hatch opening that allowed a cart containing either pre-boarded passengers or a standardized cargo container to be rolled into the fuselage cabin and securely clamped onto its floor at an ideal c.g. location. Sky Taxis equipped in this way could also disgorge their passengers or cargo container very quickly, perhaps in under 5 seconds, upon arrival at the dock. The carts could contain a freshly charged battery pack for the next flight and they could even double as small ‘last-mile’ golf cart-like vehicles to transport passengers to their residential destinations from the airpark. This generic laminar “Sky Pod”, 1.52 m (5 feet) wide and commodious for 2 people seated side-by-side, could be incorporated on any number of different Sky Taxi designs, including low, mid-, or high wing variants. It could even be used in VTOL variants.

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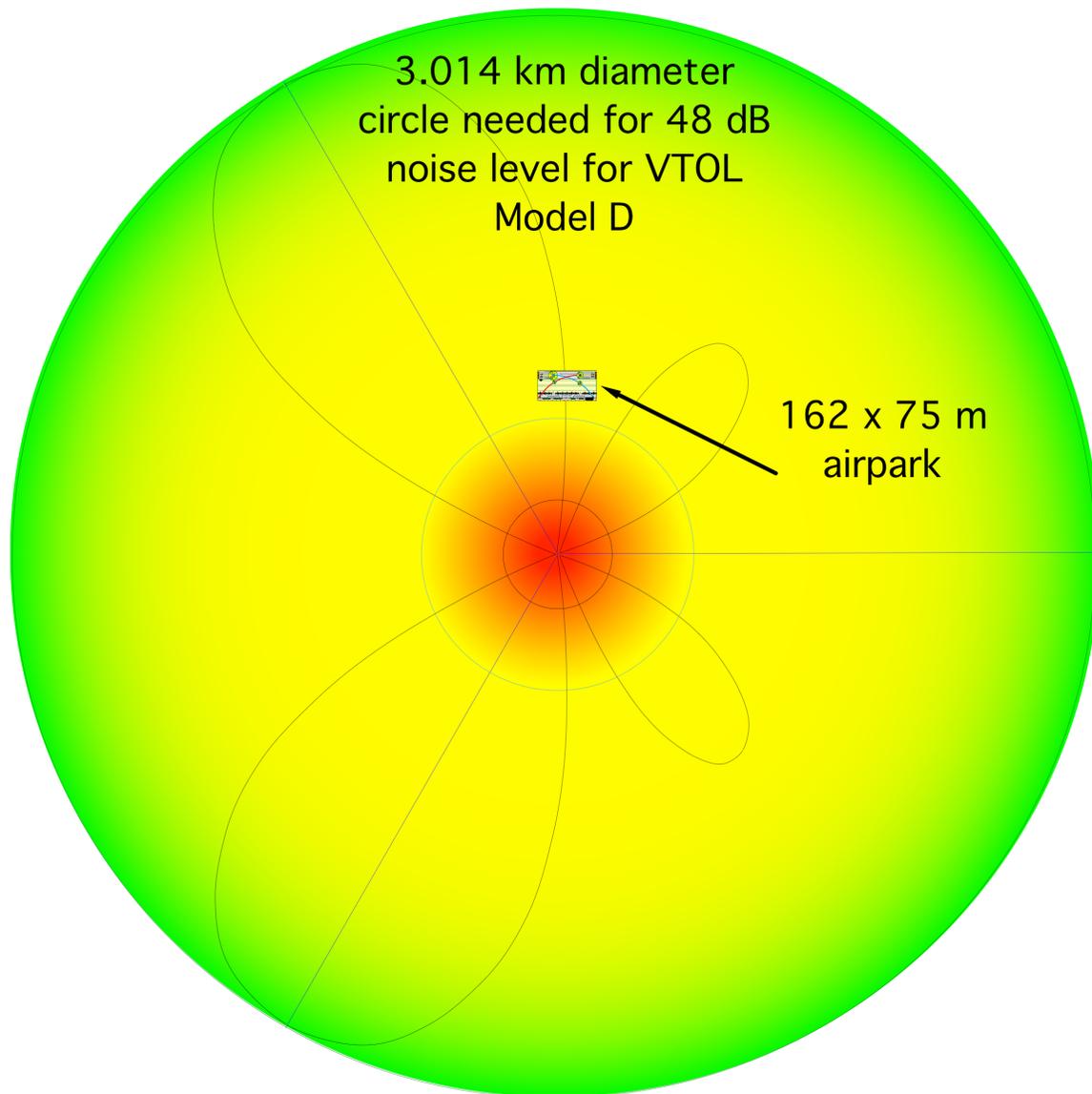


Figure 8. The 600 kg VTOL quad-copter Sky Taxi “D” take off noise footprint requires this 3.014 km diameter circle of land for its Vertiport to contain a perimeter noise level of 48 dB. With the ultra-quiet fixed-wing Sky Taxi, the 48 dB would be contained inside the much smaller 162 x 75 m airpark shown here in scale for comparative purposes.

V. Scripted Approaches

Noise abatement, obstacle avoidance and community acceptability will demand that Sky Taxis make extraordinarily steep landing approaches. These are generally within the capabilities of VTOL aircraft and in fixed-wing aircraft they can be made possible by adding large amounts of drag through the use of either drag brakes or by the effect of large, electrically-controlled windmilling propellers.

A fixed-wing Sky Taxi, by adding lots of drag can perform a landing from a 30 m height at the airpark boundary in just 443 feet or less, while maintaining tolerable jerk rates and touching down at 24 m/sec. Then, using strong wheel motor regenerative braking, that Sky Taxi can turn off the landing runway at just 5 m/sec in just 117 feet beyond touchdown. This entire landing, from crossing the airpark boundary at 24

m/sec at a height of 30 m to touch down to turning off the runway at 5 m/sec can be completed in just 8.2 seconds while keeping the jerk rate below 3.2 m/sec^3 . If equipped with a TAG landing gear¹⁰ these times and distances could be even shorter. The 4D path used in such approaches, with defined time and positions, will need to be executed autonomously by successive landings at 10-second intervals and in appropriate synchrony with the other aircraft movements at the airpark (take offs, taxiing, etc.). This synchrony will help maximize the efficient use of the small airpark for high capacity passenger throughput.

Note that the fixed-wing Sky Taxi, unlike a VTOL one, must for controllability reasons fly its approach and touch down with a substantial forward speed and then must seamlessly transition into taxiing toward the loading dock. The VTOL Sky Taxi, on the other hand, is designed to fly its steep noise abatement approach in accordance with a scripted height-velocity diagram, while avoiding a too rapid vertical descent that might produce the dreaded ‘vortex ring state’ or settling under power. This scripted VTOL approach must include avoiding combinations of airspeed and sink rate that would place that Sky Taxi in the realm of blade slap, as shown in Figure 5. In addition, the VTOL will require some period of seconds spent in hover at high power settings prior to touching down vertically with zero forward speed. From that touchdown point, the VTOL Sky Taxi must then re-accelerate to some taxiing speed to move from the center of the touchdown pad to a nearby loading dock that is a safe distance away. The total time spent by the VTOL Sky Taxi on approach, hover, touchdown and taxiing will depend upon the size and layout of the Vertiport and will add to the total turnaround time for that Sky Taxi to get back in the air. The turnaround time is a very important factor in determining the average trip length, the daily number of trips possible, the market size and the annual net profit of the RST system.

VI. Taking Off

The turnaround time includes the aforementioned time spent on approach, landing and taxiing to the loading dock as well as the time spent boarding and de-boarding and getting the Sky Taxi readied for its next flight. To this is added the time spent getting from the loading dock to the take off area, the take off run and the climb-out to the boundary of the airpark or Vertiport. The portion of the pocket airpark or Vertiport dedicated to taking off must therefore have no delays in getting the aircraft launched. It should be kept continuously busy.

For fixed-wing Sky Taxis that use wheel motors for take off acceleration, just 10.08 seconds are needed for the entire process of a jerk-limited take off ground roll to reach lift off at 24 m/sec and the subsequent climb-out to reach a height of 40 m (131 ft) at the airpark boundary. These are accomplished while keeping the jerk rate below 3.2 m/sec^3 and the acceleration below 0.8 G’s, with a climb rate of 6.97 m/sec (1371 fpm). The take off ground roll is 38.7 m (127 ft) and the climb segment, confined within the airpark boundaries and shown as the blue arc in Figure 1., is just 132 m (433 ft) in ground length. If the ambient noise level in the neighborhood of the airpark is 50 dB, then the 38 dB noise level of the departing Sky Taxi that is heard on the ground as it climbs out across the airpark boundary will be imperceptible.

VII. Airpark Costs

The cost of land necessary for a pocket airpark will depend upon the property values at its location and the size of the airpark. Obviously, the total system cost to implement RST will favor keeping the airpark size as small as possible while still meeting noise, safety, community acceptability and capacity requirements. If small enough, the airpark runways can be heated to ensure no icing conditions. There will be significant costs for the installation of high powered charging stations and, ideally, for co-located solar panel arrays to cover the loading dock area. As a magnet for business, some airparks may obtain additional revenue by leasing part of their property to commercial businesses such as FedEx, Starbucks, etc.

VIII. Airpark Standards

From the foregoing it should be clear that a system of RST cannot operate effectively without standards for both aircraft performance and for airpark design. All forms of transportation have evolved standards that are essential to the smooth operation of the system and its vehicles; setting the nation’s standard for the width of railroad tracks is a prime example. In the same vein, uniform standards for RST should set the size and operational design of pocket airparks as well as the minimum performance requirements and separations for the Sky Taxis that operate in that system. In order for the closely spaced regimented cadence of operations outlined in this study to be realized, we must discard conventional thinking and

regulations about aircraft separations. We should imagine the Sky Taxis as if they were cars operating in dedicated lanes or on freeway overpass ramps with the same kind of proximities that are used with cars. The blue and red curved arcs of departing climb out and descending landing Sky Taxis depicted can thus be thought of as freeway on-ramps. The rapid cadence necessary to high capacity operations and thereby to profitability and sustainability demands this and it will ultimately demand fully autonomous operations. The many examples of precision control demonstrated in autonomous vehicles suggest that these closer separations can be accurately and safely conducted.

Future airport standards should ensure that Sky Taxis can safely, quietly and efficiently operate at their airports in near all weather and without annoyance to the neighbors who live nearby. The setting of such standards must be informed by, among other things, realistic, known or demonstrated performance capabilities of the future Sky Taxis, foremost among these being their runway requirements and take off noise footprints. Such performance can be predicted with software, but would best be actually demonstrated at full scale. Such demonstration could be facilitated by use of one or more astutely designed technology challenge prizes for which a large monetary award was offered. Once the realistic performance capabilities had been publicly demonstrated then a set of consensus standards, such as those used by ASTM, could be better defined.

IX. The Perils of Gentrification

The pent-up demand for fast, safe travel is very large in urban mega-regions across the globe. This offers an enormous potential market size for RST—one that could ultimately far surpass the typical ridership level of about 5% in urban transit systems. The challenge will be for RST to offer accessible, affordable, ubiquitous travel by Sky Taxi. The affordability of RST hinges upon a logical progression that starts with the volume of passengers carried, which in turn, will hinge upon safely serving very short trip lengths by having quiet enough Sky Taxis to enable ubiquitous small, affordable, high-proximity airports at which operate a large fleet of Sky Taxis whose price could be radically reduced thanks to mass production. The numbers of passengers using RST will determine its contribution to easing traffic congestion and improving air quality. Those numbers will be much higher with a \$20 fare than with a \$130 fare.

X. Discussion

This paper enumerates the rationale for and categories of standards that will be crucial to implementing RST. It also proposes a realistically imaginable range of values that could fulfill those standards in an effort to road map how RST could best work. The noise footprint of the Sky Taxi that will ultimately be allowed to operate at high proximity airports will be the key determinant of airport size and will also become a regulated performance requirement for other Sky Taxis. Although noise footprints can be estimated using various types of software and known values for power, RPM, airspeed, altitude, number of blades, etc., the actual full scale demonstration of a Sky Taxi's noise footprint will best inform airport design. A technology prize competition to evince the lowest possible take off noise in a full-scale air vehicle with the short-runway and other key features necessary for a Sky Taxi has been designed by the Sustainable Aviation Foundation, Inc. This competitive prize will greatly accelerate the emergence of RST and its many societal benefits.

XI. Conclusion

Abundant evidence suggests that confining Sky Taxi noise to within the boundaries of the airport will be necessary in order to satisfy community acceptance of this new mode of transportation, Regional Sky Transit. Using software to estimate the noise footprint and runway length requirements of various Sky Taxi designs for RST suggests that fixed-wing designs could best enable the smallest possible airport. Low noise requirements impose absolute constraints upon the design of a noise-compliant Sky Taxi and designers who ignore such inconvenient constraints run the risk of having their aircraft either banned from operation in the RST system or made obsolete by quieter ones. An extreme example of the smallest possible airport is presented and its size suggests that high proximity aviation can indeed become a future mass market.

Appendix

The level of accelerations shown below are from The Physics Hypertextbook, 1998-2017 by Glenn Elert and are found at: <http://physics.info/acceleration/> These support as acceptable the use of the Sky Taxi accelerations modeled in this paper.

Automotive accelerations (g)

event	typical car	sports car	F-1 race car	large truck
starting	0.3–0.5	0.5–0.9	1.7	< 0.2
braking	0.8–1.0	1.0–1.3	2	~ 0.6
cornering	0.7–0.9	0.9–1.0	3	?

Acknowledgments

B.A.S. author is particularly indebted to the following Sustainable Aviation Board members for their ideas, research, advice and innovations that contributed to this paper: Tyler MacCready and Wayne Cook, and to his son, Damon B. Seeley for assistance with graphic design and depictions. Astute editing was provided by Anne E. Seeley. Significant additional contributions were made by David Calley of Planet-Rider, Tim Seeley and the esteemed faculty and participants at the Sustainable Aviation Symposia of 2016-17.

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