

Tactile Active Gear (TAG) For V/ESTOL Electrically Powered Aircraft

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Electrically-powered, V/ESTOL aircraft that carry a high capacity battery pack in order to have a useful range could use that pack to operate a new type of electric landing gear system—the tactile active gear (TAG). The TAG concept is that of a smart system whose position, strain, motion and acceleration sensors detect and provide input for a software-guided precise positioning control of its long-travel landing gear legs. The long-travel TAG could enable smooth, consistently acceptable accelerations and jerk rates during steep landings with touchdowns at relatively high sink rates. This could significantly enhance the V/ESTOL performance of the TAG-equipped aircraft, particularly when programmed in concert with near-instantaneous electric autonomous modulation of the aircraft's thrust, lift, drag and tire braking. This paper presents the TAG concept as an advantage that could be developed in electrically powered autonomous aircraft and that could provide them with ultra-short runway capabilities that could otherwise not be achieved by conventional mechanical landing gear systems.

Nomenclature

<i>AGL</i>	=	above ground level (height or altitude)
<i>CAS</i>	=	calibrated airspeed
<i>CL_{max}</i>	=	maximum lift-coefficient
<i>CTOL</i>	=	conventional take-off and landing
<i>dBA</i>	=	decibel noise level, A-weighted scale
<i>EAA</i>	=	Experimental Aircraft Association
<i>ESTOL</i>	=	extremely short take-off and landing
<i>G</i>	=	the acceleration due to gravity at sea level on Earth
<i>GA</i>	=	general aviation
<i>HPA</i>	=	high-proximity aviation
<i>jerk</i>	=	change in acceleration in m/sec ³
<i>kg</i>	=	kilogram
<i>kph</i>	=	kilometers per hour
<i>kWh</i>	=	kilowatt hour
<i>kW</i>	=	kilowatt
<i>lb</i>	=	pound
<i>LSA</i>	=	light sport aircraft, a consensus standards licensing category for FAA Airworthiness
<i>m</i>	=	meter
<i>mph</i>	=	miles per hour
<i>RPM</i>	=	revolutions per minute
<i>RST</i>	=	regional Sky Transit
<i>sq ft</i>	=	<i>square feet</i>
<i>TAS</i>	=	true airspeed
<i>V</i>	=	volt
<i>V/ESTOL</i>	=	vertical or extremely short take-off and landing
<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

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I. Introduction

Previous work¹ explored the potential future mass market for an *all-electric*, regional Sky Transit and Sky Cargo civil aviation systems that offer superior speed, convenience, value and sustainability. Such Regional Sky Transit (RST) could extend a new and special mobility freedom--the personal, on-demand flying privilege of private pilots--to everyone. In order to accomplish this, such systems must rely upon taking off and landing at very small pocket airparks that offer unprecedentedly high proximity to destination. Such pocket airparks demand special short runway capabilities for vertical or extremely short take off and landing (V/ESTOL). Those capabilities can be achieved by the development of a new type of landing gear system known as the "Tactile Absorptive Gear" or TAG. This paper will explore the concept of TAG, its operational characteristics and benefits, and conclude with some suggestions for its implementation.

II. Background

Pilots devote extensive training to learning how to land smoothly. This typically involves executing a landing flare in which the goal is to touchdown with no perceptible jolt to passengers. To achieve this, the flare tends to be a prolonged, very gradual reduction to a near zero sink rate coinciding with a touchdown speed that is perhaps 10 or more kph above stall speed. For most GA aircraft, such a landing flare consumes a sizeable length of runway, since the aircraft is typically traveling at around 110 kph (100 fps). A 3-second flare thus consumes 300 feet of runway.

For electrically-powered aircraft, whose distinguishing advantage is their capability for combining ultra-low noise with V/ESTOL performance, a 3-second landing flare would seriously increase their otherwise short runway requirements. To realize extreme V/ESTOL performance, such as will be essential at pocket airparks, a no-flare landing would be very helpful, but only if it could be accomplished without excessive Gs and impact forces on the aircraft and its occupants.

One strategy for controlling Gs and impact forces is to have a long-travel landing gear system that absorbs the sink rate over a large dimension. This same idea is used with the front fork shock absorbers of off-road 'dirt-bike' motorcycles that need to perform jumps over rough terrain. Such a long-travel cushioning landing gear was designed for use on the CarterCopter, and it exhibited an impressive ability to absorb vertical sink rate. Using SR/C™ Technology, the Carter Aviation Technologies website describes this landing gear as follows:

"Carter has developed a smart mechanical landing gear that can determine the impact velocity in the first inch of deflection and then apply a constant pressure/de-acceleration over a large stroke to provide safe 24 – 36 ft/sec impact landings. The gear can be light weight since the loads are nearly constant, spread over the entire stroke."

The CarterCopter landing gear was demonstrated in a drop test available for viewing as a YouTube video online at: <https://www.youtube.com/watch%3Fv=MntCeJRI2YE>

A purely mechanical passive system that uses hydraulic fluid shocks to absorb the energy of the touchdown, the very promising CarterCopter landing gear inspired the author to consider using the large reservoir of electrical energy in the battery pack that is already on-board each electrically-powered aircraft as a means to control its landing gear movement during landings. It seemed reasonable that the same reservoir of energy that is used for propulsion in flight and for wheel motors in taxiing and take off, could be used to exert very large forces in absorbing the energy of landing gear loads. The forces involved appeared manageable if the landing gear travel was long enough.

III. TAG ideas

It became apparent that an electrically powered active landing gear would need to operate with a closed loop software-guided control system that 'knew' the position and velocity of the landing gear and aircraft at every instant. It would have to sense and 'know' when it touched down on landing and at what sink rate. Once the sensor suite necessary to that kind of 'sense and act' capability was in place, the actively controlled landing gear could be re-purposed to do even more than just intelligently soak-up landings. It could also be used to change the pitch angle and perhaps, in high winds, even the roll angle of the aircraft. Changing the pitch angle would allow the fixed-wing aircraft on take off to rapidly change gear leg position so as to tilt the aircraft's nose upward to increase its wing's angle of attack just before lift off. Likewise, the change in pitch angle could deliberately tilt the aircraft into a nose-

down attitude after touching down on landing, to increase the down force on its tires and enable more aggressive braking. The nose down attitude could also help stabilize the parked aircraft in high wind conditions, as was done with the Rutan Varienze and Longeze.

The promising prospects of such a “tactile active gear” (TAG) seemed to merit a closer look. An Excel spreadsheet was used to study its possibilities. From preliminary calculations, in which the landing gear total travel is modeled as being 1 m, it appears that a sizeable sink rate can be smoothly absorbed by such landing gear without producing excessive Gs and without exceeding tolerable jerk rates. In the model studied, a touchdown sink rate of 1.93 m/sec (380 fpm) was used with a forward velocity of 23.98 m/sec and an acceleration of 1.12 Gs. This represents a 4.6° glide slope. The spreadsheet calculated the changing sink rate, Gs, jerk and horizontal distance traveled every 0.02 seconds (20 milliseconds) over the course of 1.02 seconds. In that time, the aircraft’s path was programmed to travel the full 1 m vertical distance while steadily and smoothly reducing the sink rate to near zero. Throughout this descent path, the jerk rate was kept to within the limit of 3 m/sec³ that is a commonly accepted level of tolerable jerk for amusement park standards. In addition, throughout the path the acceleration was kept below 1.25 positive Gs.

This exercise quickly revealed that the same kind of polynomials that are becoming popular for calculating and executing agile quadcopter flight maneuvers that conform with “minimum snap trajectories” could also be applied to the TAG. When this is done, the program can place limits on the allowable Gs and the tolerable jerk rates to keep these acceptable to the passenger public. This process is very similar to the programming of a tall hotel’s express elevator, which in modern times can be relied upon to consistently perform a very smooth vertical acceleration-deceleration maneuver. For the TAG, the software can also readily show what the safe structural and never exceed limits are for a particular TAG system.

What is special about the TAG is that, unlike passive systems, it should theoretically be able to deliver the same ‘feel’ to passengers on every landing. In addition, the TAG should be able to arrange the resistance to the landing impact such that at the moment when the sink rate has been smoothly reduced to zero, the landing gear travel is at exactly its full 1 m excursion and the Gs have settled back to 1.0. This would be the ‘zero bounce’ landing and it could be accomplished with decent passenger comfort, even at remarkably high sink rates at touchdown.

There is also the possibility that the TAG could help ensure that the down force on the tires was modulated such that the aircraft could effectively apply maximal regenerative braking through its wheel motors as early after touchdown as possible.

IV. TAG mechanicals

The mechanical system necessary to enable TAG could take many forms. One such form is offered here. It would seem prudent in a small aircraft, such as an autonomous ESTOL Sky Taxi, to carry the large landing gear loads into a sturdy hard point on the fuselage. Likewise, the progressive dissipation of those large loads by the moving parts of the TAG would need to be focused into a suitable strong point in the fuselage.

Figure 1 shows a basic concept for how this might be done. Both the front and rear landing gear legs are actually long-armed bell-cranks, whose motion by the portion inside the fuselage is harnessed to some load dissipating mechanism. That mechanism could consist of a cable that pulled on a motor’s clutched capstan, a ball-screw whose shuttle spun a shaft, a linear rail-motor, or a magneto-rheologic shock absorber. An alternative, drawn from biomimicry, could be the mechanism used by the jumping spider *Hyllus Giganteus* in which controlled rapid pumping of fluid (blood) at high pressure into or out of a closed hydraulic actuator effects the movement². In any case, the load dissipating mechanism would need to meet 2 requirements: It must be strong enough to control the peak loads of a hard landing and it must allow precise control of positioning throughout its travel and rotational speed range.

One mechanism that may work adequately for this is the ball screw, Figure 2. A ball-screw could be tailored to spin its shaft at a high enough RPM to facilitate precise control. The restraint could be by having the shaft connect to a strong motor and by having the shaft spin a large disc brake whose caliper squeeze action could be precisely modulated. Fixed positioning could be by a wrap spring clutch.

V. TAG electricals

Electrically-powered small aircraft will need to carry a large battery pack. We may expect something on the order of 40 kWh capacity. If that pack had a high enough “C” rate to deliver 20 times its capacity for a very short (1 sec) period, then that would be an instant power of 800 kW or 1072 BHP. In English units, that is about 590,000 ft-lb/sec. That should be more than enough power to control the touchdown forces of a 1322 lb LSA.

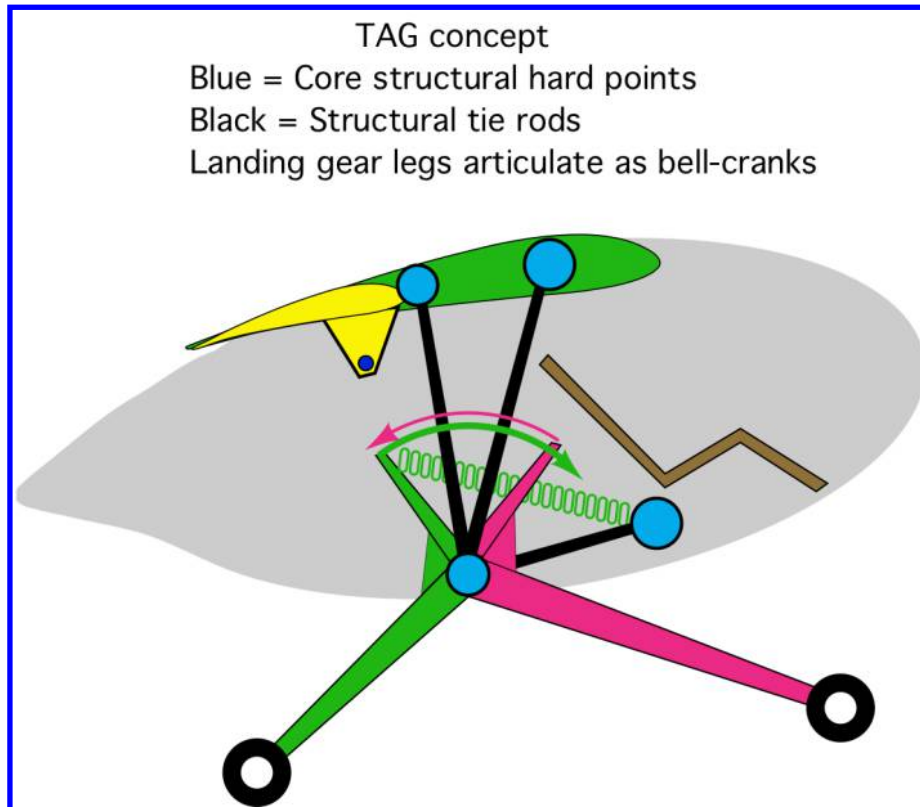


Figure 1. A schematic view of the TAG. Both the front and rear landing gear legs are bell-cranks that pivot at a shared hard point. The green spring represents a shock absorbing element whose mechanism details involve powerful electric control of position and rate and whose loads are dissipated at the blue hard point under the reclining seat.

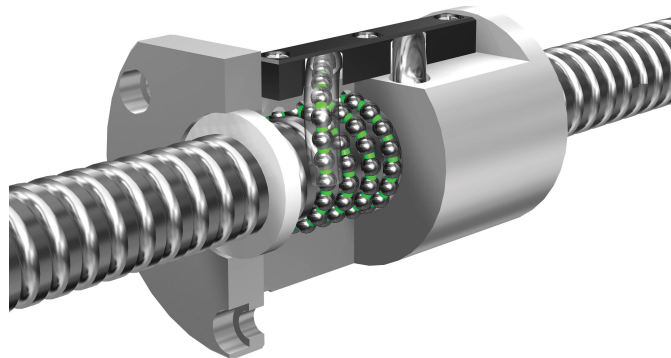


Figure 2. A representative sample of a high quality ball-screw, the THK SBN. Such a device can be used to dissipate linear motion of the landing gear into controllable shaft rotation amenable to precise modulation by electrical power.

XXI. Conclusion

The potential for a transformative innovation in aircraft landing gear design awaits electrically powered aircraft. Such an innovation is described in this paper. Using the “all-at-once” power available in a large on-board battery pack to precisely control the absorption of landing gear impacts with the ground can enhance V/ESTOL capabilities and reduce the size of land parcel necessary for a pocket airpark. It can also enable useful changes in the aircraft’s pitch attitude during ground operations, including take off rotation and a ‘curtsey’ to facilitate boarding of passengers. The creation and testing of the software and hardware necessary to enable a practical 2-seat electrically-powered air vehicle with such features, and one that can also safely and reliably fulfill the mission requirements of Regional Sky Transit, should be prioritized industry and government support.

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References And Bibliography

¹Seeley, B., Regional Sky Transit, AIAA AVIATION 2015, June 2015, URL: <http://arc.aiaa.org/doi/abs/10.2514/6.2015-3184>

²BBC, video of jumping spider, Jan 29, 2016, URL: <http://www.bbc.com/earth/story/20160129-watch-the-worlds-biggest-jumping-spider-make-a-dramatic-leap>