Antique Aircraft Avionics Modernization

Process and System Design for A Transponder Installation in a 1946 Luscombe 8A

By: Nicholas Camacho

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Abstract

The general aviation population is full of vintage aircraft. Built in the heyday of personal aviation, these machines embody the spirit of aviation; freedom afforded from the everyday monotony of earthbound people. As technology advanced and air traffic became more congested, new requirements were set forth by governing bodies to ensure the safety of aircraft. These regulations limited the capability of vintage general aviation aircraft. This report was commenced to understand the necessary steps required to add modern technology to old aircraft, as well as design a system that would enhance the capability of vintage aircraft while keeping their antique personality intact. This system was achieved with a Sandia 165 transponder and a Tenergy lithium polymer battery pack. Regulations research showed that biennial, in-depth inspections would be required to maintain compliance in the national air traffic system. There were also operation requirements, including a requirement to operate the transponder at all times when the aircraft was flying. These regulations were secondary, however, to the freedom regained by the pilot to be unencumbered with any airspace concerns. The cost of the system would be approximately $2,500. Based on a study of rerouting procedures, an estimate of a 10% increase in efficiency was determined. This indicates that the investment would be recouped after approximately 780 cross country hours in congested airspace.

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1 Introduction

Aviation ushered in a new era once World War II ended. With the G.I. Bill aiding servicemen, as well as the influx of military aviators back into the civil airspace, general aviation manufacturing boomed in the mid to late 1940s. Utilizing designs from the prewar years, such as the Piper Cub, Aeronca Champ, and Luscombe 8 series, people were able to learn to fly in affordable two person sport planes with minimal complexity.

Figure 1: 1946 Luscombe 8A, Subject Aircraft

1.1 Problem Statement

As the air traffic control system increased in complexity, the fleet of small aircraft struggled to keep up. Manufacturers went out of business, limiting support for maintenance. Air traffic volume increased in metropolitan areas, requiring new equipment to allow for proper separation of such traffic. One way safe traffic flow was achieved was by marrying ground based radar with vehicle based transponders. With a programmable transponder aboard an aircraft, a radar operator can not only discern individual aircraft from one another, but also be provided with valuable altitude information that previously wasn't available from the ground station. While this was a giant leap forward in the safe operation of the air traffic system as a whole, it became an aggravation for many antique sport airplane owners. Not only was the new equipment costly, but it required a full support system that most of the aircraft were not equipped with. With ignition systems that featured magnetos, many of the light aircraft didn't even have a source of electrical power. To implement such luxuries as a transponder would also entail a vast systems overhaul to include a battery and generator or alternator. For the Continental A-65-8 engine, original equipment in Luscombes, Champs, and Cubs, this was not even an option, as there were no provisions on the engine to drive an accessory such as an alternator. What began as a simple avionics requirement turned into a full system overhaul, including an engine upgrade. As battery technology and transponder size and power requirements continued to advance and improve, more options for these systems became available. Transponders were designed to be smaller, and include the encoders in the box, minimizing their size and footprint in the instrument panel. Battery chemistry also evolved, increasing the energy density and output of rechargeable batteries. This project was undertaken to research the available options for battery and transponder combinations that would have minimal impact on a vintage aircraft, both in appearance and performance. This would require a system that is small in physical size and weight, as well as inconspicuous.

This project was also initiated to provide a quick reference guide for owner/operators of these classic airplanes. The FAA rules over certified aircraft and the alteration of them with an iron fist. With the large quantity of regulatory and advisory paperwork published by the Federal Aviation Administration, wading through each and every document and determining its applicability to a specific model or instance becomes a large and undesirable task. By delving into the giant FAA library, this report will provide an owner/operator a starting point when they consider making their aircraft safer and more useful by installing a modern transponder.

1.2 Scope

This project will focus on designing a transponder system for a 1946 Luscombe 8A with no electrical system. An in depth literature review will provide insight on the regulatory aspect of the alteration, and the process involved in completing such an alteration. A system design will also be completed to determine the most appropriate transponder and battery equipment to install in the aircraft. An installation guide will provide insight on the location and mounting of the new hardware in the airplane. The goals of the completed system are twofold: performance and appearance. The system should increase the empty weight of the aircraft by no more than 1% of its current configuration. The weight and balance of the aircraft should not be affected in any direction. Also, the appearance and character of the airplane should remain intact. No permanent cutting or modification should occur to the current panel that would render it obsolete if the aircraft was ever returned to it primitive, non-electric state. The transponder and the battery should be placed in inconspicuous locations, as to not take away from the antique persona of the aircraft.

2 Literature Review

The literature review focused on the regulatory aspects of installing new equipment on old aircraft, in which factory provisions for such equipment are not available. A vital aspect of designing a system to be installed on a FAA certified aircraft is fulfilling all of the regulatory requirements. An important characteristic of this report is to complete the requisite background research to insure that all FAA requirements are met.

Transponders are important not only because they are seen by air traffic controllers on the ground, but also in the air. Many modern airliners utilize TCAS systems that rely on transponders in all aircraft, GA or commercial, to inform them of impending collisions with nearby aircraft. To insure that this function is accurate enough to safely operate in the National Airspace System, the Federal Aviation Regulations set forth mandatory inspection periods. As per FAR 91.413(a): *No person may use an ATC transponder that is specified in 91.215(a), 121.345(c), or 135.143(c) of this chapter unless, within the preceding 24 calendar months, the ATC transponder has been tested and inspected and found to comply with Appendix F of part 43 of this chapter.* Appendix E to Part 43 provides the details of the necessary testing to maintain compliance in the National Airspace System. These tests include static systems tests, to ensure that the data arriving to the tranponder is accurate, as well as altimeter tests to ensure that no critical errors are present in the reporting aspect of the box. The FAA goes on to specify who is allowed to administer such tests and maintenance in FAR 91.411(b), as seen in Appendix A. The manufacturer and qualified radio shops are allowed to repair and maintain transponders, while certified mechanics can administer the tests required for the static system only.

This regulation provides a couple of key points. First, part 1 gives the manufacturer of the aircraft jurisdiction to complete all transponder maintenance. In the case of Luscombes, this option is negated by the fact that the manufacturer is no longer available. While the type certificate has live on through many business incarnations, the Luscombe Aircraft Company closed its doors in 1950. Owners still have many options, however. Certified repair stations, found at most regional or larger airports, are allowed and often equipped to perform inspections and repairs. Airframe and powerplant mechanics, the most prevalent repair resource available, are also allowed to do testing and inspection of the static system. Advisory Circular 43-6B provides recommended testing procedures to fulfill the FAA requirements. The Federal Aviation Regulations set forth the certification procedures for aircraft, equipment, and pilots. Part 23 is the section of the FARs that govern the certification of normal, utility, aerobatic, and commuter aircraft. In other words, all modern general aviation aircraft are certified under part 23. Within these regulations, procedures for aerodynamic characteristics, flight test tasks, equipment requirements, and more are set forth. However, these regulations were enacted by the FAA, which was formed in 1958. Prior to the enactment of the FAA, the national aviation system was regulated by the Civil Aeronautics Administration. The analog to current day FARs were the Civil Air Regulations. CAR-04A covered all aircraft airworthiness issues, similar to FAR 23. Along with performance requirements, CAR-04A provided guidelines for equipment. According to CAR-04a.5821; *Battery shall be easily accessible and adequately isolated from fuel, oil, and ignition systems. Adjacent pats of the aircraft structure shall be protected with suitable acidproof paint if the battery contains acid or other corrosive substance and is not completely enclosed. If the battery is completely enclosed, suitable ventilation shall be provided. All batteries shall be so installed that spilled liquid will be suitably drained or absorbed without coming into contact with the airplane structure.* This paragraph provides appropriate mounting and positioning restrictions on various types of batteries. Battery type and chemistry will be discussed later in the literature review. CAR-04A also necessitates the installation of a master switch. According to CAR-04A.5828: *Electrical installations shall incorporate a master switch easily accessible to a member of the crew.* This dictates the additional piece of equipment that must be included in the system.

Rules regarding operations of aircraft that are transponder equipped are important to pilots not familiar with such requirements. The two main operating directives available to pilots are the FARs and the

Airman Information Manual (AIM). The core difference between the two documents is that the FARs are regulations mandated by the FAA whereas the AIM is a document that is *designed to provide the aviation community with basic flight information and ATC procedures for use in the National Airspace System of the United States.* The AIM provides worthwhile information to pilots that are suggested procedures, such as radio terminology, while the FARs are set in stone requirements dictated by the FAA. The airspace system and procedures are set forth in the FARs. The main restriction set forth by the modern airspace system is the Mode C transponder requirement in FAR 91.215(b). This paragraph calls out the regions requiring the use of a transponder. Airspaces around large airports are shaped like upside down wedding cakes, with circular layers propagating out from the center of the airport, to allow large aircraft to be under positive control as the approach the airport from high altitudes. Additionally, a 30 nautical mile circle, or veil, surrounds selected high traffic commercial airports. Operation within this veil is limited to aircraft that are equipped with mode C transponders. However, vintage aircraft are relieved of this burden by part 3 of FAR 91.215. All aircraft manufactured with Continental A65-8 engines fell within this category, due to the lack of accessory capabilities of the engine case. 91.215(c) provides guidelines for aircraft operating with transponder installations:

> *While in the airspace as specified in paragraph (b) of this section or in all controlled airspace, each person operating an aircraft equipped with an operable ATC transponder maintained in accordance with §91.413 of this part shall operate the transponder, including Mode C equipment if installed, and shall reply on the appropriate code or as assigned by ATC.*

This is notable because it removes the right of any transponder equipped aircraft from operating in controlled airspace, whether it requires a transponder or not. With a battery powered system that could be discharged over numerous flights, an aircraft could theoretically be grounded by having a transponder installed, when it is not required for operation otherwise. The AIM reiterates the requirements for operation with a transponder installed in an aircraft. 4-1-20(a), basically saying that by allowing other radar stations and aircraft to see the transponder equipped aircraft in the sky, it is safer for everyone. 4-1-20(c) restates the necessity to have the transponder in operation whenever the aircraft is in the air:

> *Civil and military transponders should be adjusted to the "on" or normal operating position as late as practicable prior to takeoff and to "off" or "standby" as soon as practicable after completing landing roll, unless the change to "standby" has been accomplished previously at the request of ATC. IN ALL CASES, WHILE IN CONTROLLED AIRSPACE EACH PILOT OPERATING AN AIRCRAFT EQUIPPED WITH AN OPERABLE ATC TRANSPONDER MAINTAINED IN ACCORDANCE WITH 14 CFR SECTION 91.413 SHALL OPERATE THE TRANSPONDER, INCLUDING MODE C IF INSTALLED, ON THE APPROPRIATE CODE OR AS ASSIGNED BY ATC. IN CLASS G AIRSPACE, THE TRANSPONDER SHOULD BE OPERATING WHILE AIRBORNE UNLESS OTHERWISE REQUESTED BY ATC.*

Battery behavior was also looked at. DOT/FAA/AR-09/55 was a report on the behavior of lithium polymer battery cells in less than stellar environmental conditions, notably fire. LiPo batteries are notorious for catching on fire, but while the report found that they were susceptible to explosions and fires, it was only when they were introduced to extremely hot or fiery situations. Attempts to cause internal combustion by shorting resulted in no fireworks. Also, the report noted that halon fire extinguishers were effective in dousing the lithium polymer fires (Summer). This initiated a quick search into halon extenguishers, which determined that there were models available that were small enough to add to the aircraft without significantly or adversely affecting performance.

The FAA also researched transponder performance in the late 90's to survey general aviation equipment. The research was done at the national EAA convention, with airplanes that serve a similar purpose to the subject aircraft: pleasure flying. The report found that only 4 percent of the transponders selected passed every test in a battery of 31 measurements. Many of the altitude systems associated with the transponders were found to fail due to warm-up issues. While no solution was set forth, this implied that overheating would not be an immediate or major issue with the transponder. (Talotta)

3 Design

The design of the system would have three major components; transponder selection, battery selection, and implementation in the aircraft. Transponder and battery selection would both utilize market research to determine what units would best fulfill the needs of the system, while maintaining the goals of small lightweight components that are inconspicuous in their installation. Implementation in the aircraft would include a study of possible locations and mounting methods for the components, and a solution that includes position and mounting information.

3.1 Transponder Selection

The transponder is obviously the heart and soul of the project. Choosing the right transponder and locating it appropriately would be vital to the success of the project. Market research provided background on all of the applicable transponder options. The first step in the market research was a study of all readily available general aviation transponders. There were 2 broad classes of transponders when it came to size; "avionics stack" transponders, and small transponders. The majority of the transponders on the market are designed to fit in an avionics panel, along with radios and audio panels. This entails a set width of approximately 6.25". While this was not a debilitating characteristic for the transponder, it would make it more difficult to unobtrusively place the box in the aircraft. The small class of transponders ranged in width from 2.4" to 3.5". This made the task of tucking away the modern piece of equipment in the vintage cockpit much more manageable, therefore the "avionics stack" transponders were excluded from the search.

The selection was made using a weighted figure of merit table. The characteristics used as the figures of merit were: physical size, weight, cost, encoder location, and power requirements. Physical size and weight were characteristics, so they were weighted accordingly. Cost was a major factor, due to the exorbitant cost of all the transponders in contention. Encoder location was an issue because of the logistical issues that arise with the requirement to locate a secondary piece of equipment, such as a remote encoder. Additionally, some of the transponders weren't marketed with encoders, requiring an additional expenditure. Finally, power requirements drove the battery selection, which was the other main component of the system. If any of the transponders required excessive amounts of power, any weight savings would be offset by the battery needs. The following data was collected and categorized:

Brand	Model	Height (in)	Width (in)	Length (in)	Weight (oz)	Input Voltage	Current Req'ts	Cost	Altitude Encoder
Sandia	165	1.78	3.5	7.34	20.8	11-33 Vdc	500 mA (28 Vdc)	1700	Yes
Micro Air	T2000	2.4	2.4	6.3	21.1	10-33 Vdc	100-150 mA (28 Vdc)	2161	No
Trig	TT21	1.73	2.48	5.55	16	9-33 Vdc	280 mA (14Vdc)	2195	Yes
Becker	ATC 4401	2.413	2.413	8.031	25.6	9.5-32.2 Vdc	250 mA (28 Vdc)	1995	No
Garrecht	VT-01	2.55	2.55	1.77	28.16	10-32 Vdc	450 mA	3617	Remots, incl.

Table 1: Transponder Options

Figure 2: Transponder Options, in order of table

With the market research complete, the figure of merit table was constructed and populated to determine which transponder would best fulfill the mission required for this system.

Figure of Merit	Weight	Sandia 165	Micro Air T2000	Trig TT21	Becker ATC4401	Garrecht VT-01
Physical Size	0.20	2	3	1	4	5
Weight	0.20	2	3	1	4	5
Cost	0.30	1	3	4	2	5
Altitude Encoder	0.20	1	3	1	3	2
Power Req'ts	0.1	5	1	3	2	4
Total	1.0	1.8	2.8	2.2	3.0	4.3

Table 2: Figure of Merit Table, Transponder

The physical size characteristic was judged on the height and width of the avionics, with the depth not being as important due to the abundance of space behind the panel. The transponders were ranked from one to five in each category, with the exception of the altitude encoder. There were only three different conditions for the altitude encoders; the transponder had a built in encoder, a remote encoder was included, but would have to be installed, or a remote encoder would have to be purchased. Based on these guidelines, the transponder of choice is the Sandia 165. It provides a small footstep with a built in encoder at a reasonable price. While it required more current than most of the other options for transponders, the power requirement turned out to be fairly insignificant due to the low current requirements of the whole class of micro transponders.

Figure 3: Sandia 165 Transponder

3.2 Battery Selection

Battery selection would also be critical to the success of the transponder system. With a goal of 1% increase in the empty weight of the airplane, both the transponder and battery would need to be optimized. To determine the power required and duration of the battery, some simple calculations were run. Using Ohm's Law, once can determine the resistance in the transponder in the following manner

$$V = I \times R \rightarrow \frac{28\ V}{0.5\ A} = 56\ \Omega$$

Now, considering a 12 volt battery to operate the system, and using the same logic, the current requirement would be 210 milliamps to operate for one hour. A 12 volt battery is desirable because it is prevalent in both general aviation as well as many other commercial ventures.

With the requirements set, the battery selection process can begin. There are two main types of batteries used in general aviation: flooded cell batteries, and sealed batteries. Flooded cell batteries are similar to the units used in cars, where lead plates submerged in acid provide the chemical reaction. Sealed batteries immobilize the acid component through the use of a gelling agent or glass fiber mat (Busch). Sealed batteries have many advantages over flooded cell batteries. The liquid electrolyte solution in flooded cell batteries is perpetually fluctuating, and required periodic inspections and maintenance when the liquid falls below a certain level. Provisions must also be made (as mentioned earlier from CAR-04a.5821) to ensure that the structure supporting an acid filled battery is protected against any spills. The can be achieved with acidproof paint. The flooded cell batteries are also heavier, which leaves them at a distinct disadvantage in a weight driven system. Due to these factors, sealed batteries were chosen over flooded cell batteries. Another option that was considered was lithium polymer batteries, popular in consumer electronics. Lithium polymer (LiPo) chemistry batteries have been advancing greatly, as cellphone and laptop industries push the envelope of what is possible to gain from a small battery. LiPo batteries achieve a much greater energy density than standard flooded cell or dry cell batteries, allowing them to provide similar energy at fractions of the size and weight required out of an older style battery. As mentioned in the literature review, lithium polymer batteries do have less than desirable characteristics in fire or other high temperature environments, but they are not susceptible to explosion from short circuits, and can be extinguished with halon.

To begin comparing batteries, a duration requirement had to be set. Without lights, the aircraft is limited to daylight flying only. While this could mean up to 16 hours or more of legal flying time, 10 hours can be considered a practical maximum, based on the aircraft’s undesirable interior and the mental taxation of hand flying an aircraft with single axis trim. With the idea of recharging the battery in mind, the duration constraint was set at 12 hours, to include a safety margin. This easily surpasses the maximum single flight capability of the aircraft, which is approximately 6 hours of flying with a full allotment of fuel. To operate the Sandia transponder at 12 volts for 12 hours, 2.52 amp-hours would be required.

3.2.1 Sealed Battery

The smallest sealed battery marketed by Concord Battery Corporation is the RG-12LSA. Concord was chosen because they are an industry leader in aviation batteries, and they specialize in sealed batteries. This 13 pound battery was rated at 11 amp-hours, which translates to 52.4 hours of operation. While this would decrease the workload for the operator by minimizing charging cycles required, the weight of the battery is still an issue. To achieve the goal of a 1% increase in empty weight, the installed system is limited to 8.6 pounds. If the Concord sealed battery was utilized, this would push the weight increase to near 2% of the empty aircraft weight. The outer dimensions of the RG-12LSA are 7.5” x 4.6” x 5.2”

Figure 4: Concord RG-12LSA Sealed General Aviation Battery

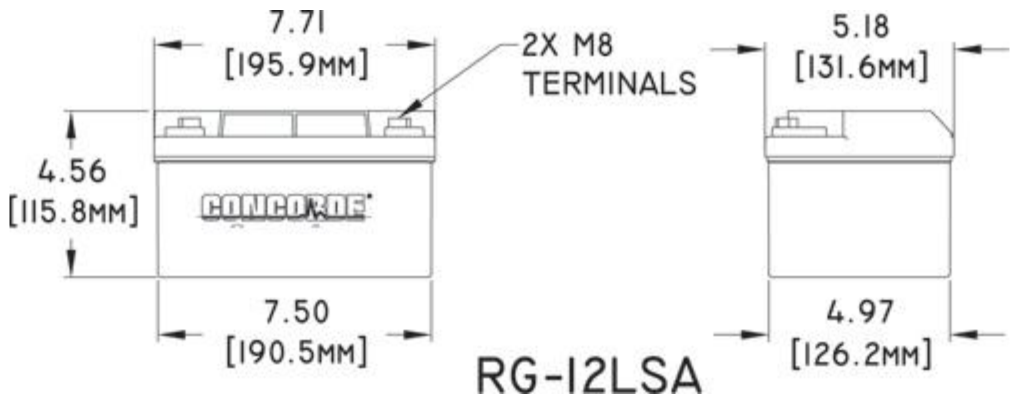

Figure 5: Physical Specifications, Concord RG12-LSA

3.2.2 Lithium Polymer Battery

Like the Concord selection, Tenergy LiPo batteries were chosen based on their rigorous testing, track record of quality, and wide selection of cells to tailor a system around. The Tenergy 30138 cell provides 2700 mA at 3.7 volts per cell. To achieve 12 volts, four cells can be connected in series to create a battery pack. With each cell weighing 0.15 pounds, a pack with 4 cells and wiring and connectors can still be safely expected to weigh in under a pound. The pack's physical dimensions would be 3.93" x 1.97" x 1".

Figure 6: Tenergy 30138 Lithium Polymer cell

Based on the overwhelming advantage seen by the LiPo battery in both physical size and weight, it was chosen over the sealed battery, despite the minimal safety concerns. The LiPo battery not only allows the weigh objective to be achieved, but provides a much easier mounting solution as well, due to its much smaller footprint.

3.3 Installation

A key aspect of the project was the installation of the transponder and battery. As noted in CAR-04a, a master switch easily operated by the pilot in flight. There were four possible scenarios to mount the transponder. The first, and most common, is in the panel. The illustration below shows the current instrument panel in the subject aircraft, and the logical location for the transponder is highlighted with a red box. Many aircraft that have been modified with transponders, radios, and intercoms utilize this area to build a small avionics stack. However, this location would require significant modification to the panel, as well as a tray structure to support the transponder. Modifications this severe are not desirable because it severely limits the airplane’s capability to be returned to a stock configuration.

Figure 7: Luscombe Panel, installation location #1

The second scenario would involve building a tray structure to mount the transponder below the panel. This option, while desirable considering the minimal modification to the current structure that would occur, is not preferred because of the limited space already available in the cockpit. For pilots over 6' tall, legroom is at a premium, and hanging a box 2 inches below the panel would further reduce comfort and enjoyment of the airplane.

Figure 8: Luscombe Panel, installation location #2

The third scenario would involve modifying the glove box located on the right side of the instrument panel to include the transponder and possibly the battery. This option is desirable on many levels; it allows the transponder to be hidden from sight when not in operation, there is already structural support built into the panel for the glove box, and no permanent modification would be required. By simply designing a new glove box to bolt into the existing structure, the airplane could easily be converted back to its original state by simply swapping glove boxes. The big detriment for this location is the distance from the pilot. While the box is within acceptable reach of the pilot, it would be difficult to monitor the instrument regularly in flight. Since the transponder requires minimal attention during operation, this issue was minimized.

Figure 9: Luscombe Panel, installation location #3

The final option for transponder placement is behind the pilot, below the fuel tank. There is a headboard above the seat rest that covers the main fuel tank , which is behind the pilot. The fuel tank Is oval shaped, leaving significant space behind the headboard for modifications. This location would bring up similar issues with pilot workload, but would also require additional structure to be designed to support the transponder. While the headboard could be replaced fairly cheaply and easily, the work required to support the installation makes this undesirable. The image below shows the fuel tank area, with the headboard removed.

Figure 10: Luscombe Fuselage, installation location #4

3.4 Solution

The final solution for the transponder system was to use a Sandia 165 transponder with a built in encoder to minimize installation hassles. Power would be provided by a Tenergy 4 cell 30138 LiPo battery pack. The advantages of the lithium polymer set up far outweigh the minimal risks associated with the battery chemistry. If there are any further worries, a small halon fire extinguisher can be carried in the aircraft in case of any incidents. Halon was shown to extinguish LiPo fires, and small extinguishers can be found for less than 3 pounds, so the additional equipment would still weigh less that the sealed battery solution. The glove box installation required the least amount of work, and provided the most inconspicuous location for the equipment, so it was a win-win situation. The transponder and battery fit nicely in the glove box next to each other. With a shelf and divider assembly to separate the components, there was still 3” of space to be utilized for charts, books, or other accessories that live in the glove box. This resulted in a loss of 40% of storage space. A JBT AN3021-2 toggle switch would provide the appropriate on-off functionality to the pilot. The transponder will have an approximate duration of 12 hours, and must be operated at all times when the aircraft is in operation. The installation will require a Form 337 Major Alteration and appropriate manufacturer’s data for the transponder and battery to be submitted to the FAA, due to the additional capability being provided by the new equipment, which was not available at the time of manufacture of the aircraft. The transponder will need to be inspected every 24 months to remain in compliance, and the inspections must be done by an appropriately equipped maintenance shop.

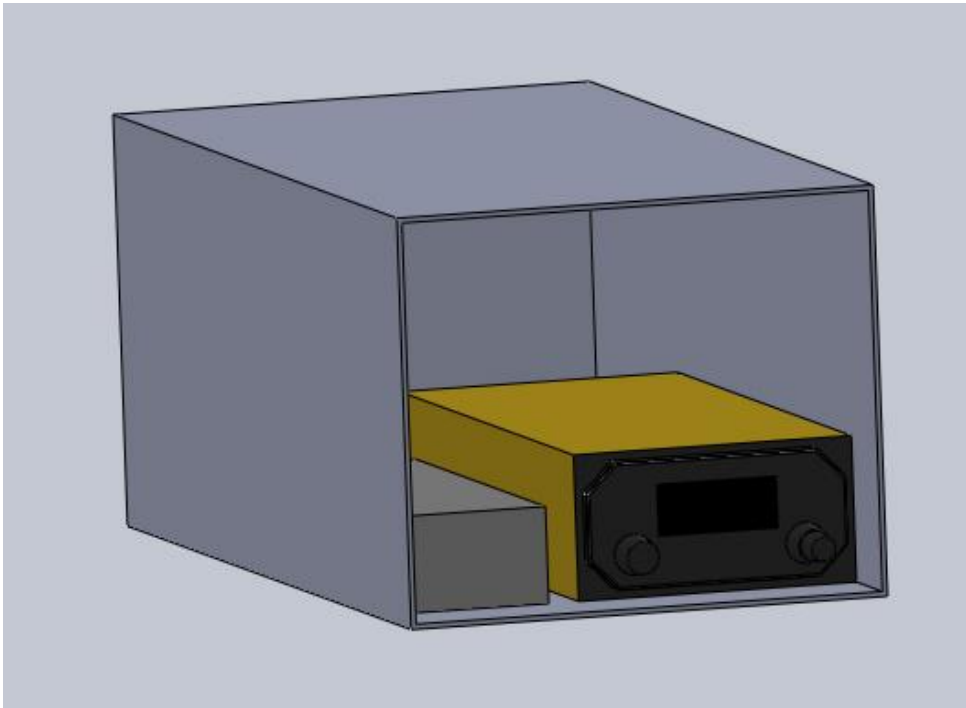

Figure 11: Transponder and battery test fit in CAD model

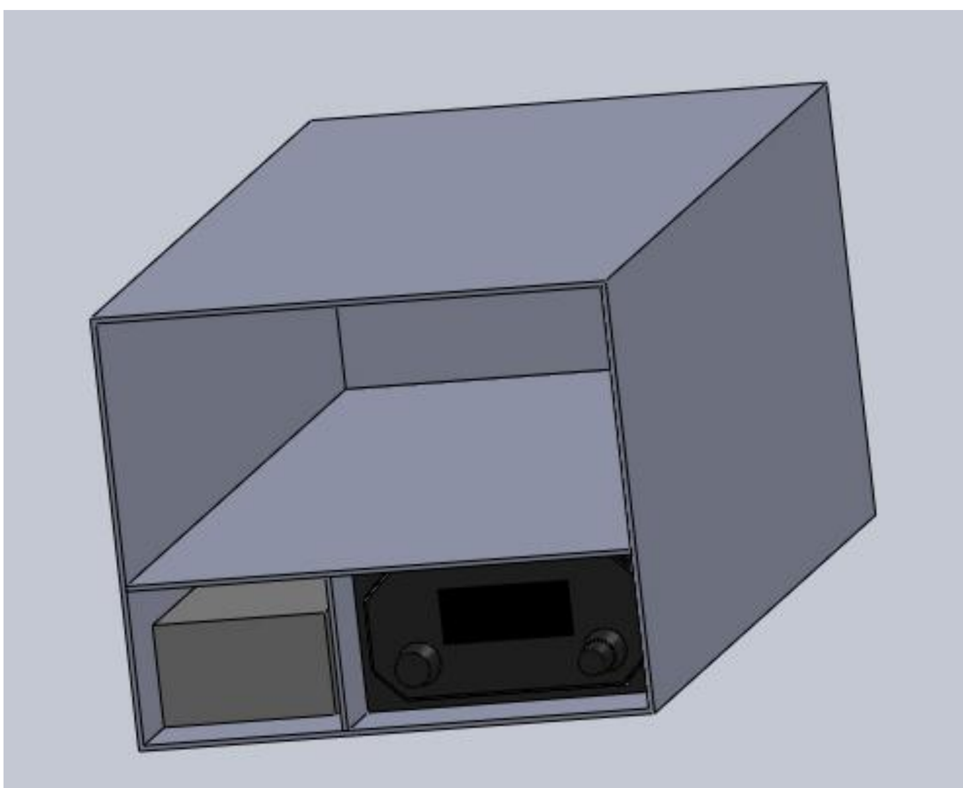

Figure 12: Full CAD assembly showing tray and divider for transponder and battery

4 Economic Justification

Cost for the whole system is estimated at $2500-$3000, depending on the cost of approvals from the FAA. The system components will cost $2100. The difficulty in executing an economic justification comes into play when the value added to the airplane is determined. The amount of airplanes available for sale is small, due to many aspects, including the challenging nature of taildraggers, as well as the fact that none of these aircraft have been manufactured since the 1950's. When dealing with airplanes or anything of an antique nature, straight comparisons are difficult to achieve due to the various damage histories, restoration efforts, or missing data. The capability that the airplane gains is varying based on the usage by the pilot. One pilot might put a transponder in an airplane for peace of mind while flying around in his local area. There is no significant change in operational style or cost of operation, but the pilot enjoys the additional measure of safety afforded by being visible in the air traffic control system. A rough estimation in added cost of operation can be estimated by looking at a cross country example that is affected by transponder required areas. A flight from San Luis Obispo to San Diego's Gillespie Field is 231 nautical miles when flown on a straight line. However, due to airspace restrictions, an aircraft without a transponder would have to fly around the airspace, resulting in a route length of 253 nautical miles, or an increase of 9.5%. Based on an airspeed of 80 nautical miles per hour in standard conditions, this deviation would result in an additional 17 minutes per flight. The operating cost of the aircraft is $25/hr (based on a fuel burn of 4.2 gal/hr, fuel cost of $5.50/gal, an oil burn of 1 quart every 5 hours, and oil costing $9/quart). On top of this is the cost of the hours on the engine. With an 1800 hour suggested time between overhaul, and an estimated overhaul cost of $12,000, every hour flown on the engine costs $6.66, bringing the total cost to $31.66 per flight hour. Based on an estimated 10% increase in cross county flight time in the congested California airspace, it would take 780 hours of cross country flying to see a direct justification economically in terms of saving $2500 in operational expenses by utilizing the transponder.

5 Conclusion

A lightweight, inconspicuous battery powered transponder system can be designed to improve the capability of vintage sport aircraft. The advancements in battery technology was the biggest contributor to this accomplishment. The Sandia 165 transponder combined with Tenergy LiPo cells would fulfill all of the technical requirements at a weight of 2.5 pounds. The transponder was stashed neatly inside the glove box, totally hidden from sight, and only costing the pilot 40% of his in-flight storage space. By the addition of this equipment, the airplane would gain greater capability by being able to enter more congested, popular airspace, as well as provide the pilot with a sense of safety based on the increased visibility afforded him in the air traffic control system. While these abilities aren't quantifiable economically, they do add a limited financial value to the airplane. To recoup the investment in the avionics, the airplane would have to fly approximately 780 hours in congested airspace. With the new equipment, the pilot has to obey additional requirements of the FAA. With the transponder installed in the aircraft, it must be operating anytime the aircraft is operating. The pilot must be familiar with all of the terminology associated with transponder operations, as well as squawking procedures. To accomplish all of this, a major alteration must be approved by the FAA, utilizing data from the manufacturers of both the transponder and the battery.

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7 Appendix A

7.1 Part 43, Appendix E:

Each person performing the altimeter system tests and inspections required by 91.411 shall comply with the following:

(a) Static pressure system:

(1) Ensure freedom from entrapped moisture and restrictions.

(2) Determine that leakage is within the tolerances established in §23.1325 or §25.1325, whichever is applicable.

(3) Determine that the static port heater, if installed, is operative.

(4) Ensure that no alterations or deformations of the airframe surface have been made that would affect the relationship between air pressure in the static pressure system and true ambient static air pressure for any flight condition.

(b) Altimeter:

(1) Test by an appropriately rated repair facility in accordance with the following subparagraphs. Unless otherwise specified, each test for performance may be conducted with the instrument subjected to vibration. When tests are conducted with the temperature substantially different from ambient temperature of approximately 25 degrees C., allowance shall be made for the variation from the specified condition.

(i) Scale error. With the barometric pressure scale at 29.92 inches of mercury, the altimeter shall be subjected successively to pressures corresponding to the altitude specified in Table I up to the maximum normally expected operating altitude of the airplane in which the altimeter is to be installed. The reduction in pressure shall be made at a rate not in excess of 20,000 feet per minute to within approximately 2,000 feet of the test point. The test point shall be approached at a rate compatible with the test equipment. The altimeter shall be kept at the pressure corresponding to each test point for at least 1 minute, but not more than 10 minutes, before a reading is taken. The error at all test points must not exceed the tolerances specified in Table I.

(ii) Hysteresis. The hysteresis test shall begin not more than 15 minutes after the altimeter's initial exposure to the pressure corresponding to the upper limit of the scale error test prescribed in subparagraph (i); and while the altimeter is at this pressure, the hysteresis test shall commence. Pressure shall be increased at a rate simulating a descent in altitude at the rate of 5,000 to 20,000 feet per minute until within 3,000 feet of the first test point (50 percent of

maximum altitude). The test point shall then be approached at a rate of approximately 3,000 feet per minute. The altimeter shall be kept at this pressure for at least 5 minutes, but not more than 15 minutes, before the test reading is taken. After the reading has been taken, the pressure shall be increased further, in the same manner as before, until the pressure corresponding to the second test point (40 percent of maximum altitude) is reached. The altimeter shall be kept at this pressure for at least 1 minute, but not more than 10 minutes, before the test reading is taken. After the reading has been taken, the pressure shall be increased further, in the same manner as before, until atmospheric pressure is reached. The reading of the altimeter at either of the two test points shall not differ by more than the tolerance specified in Table II from the reading of the altimeter for the corresponding altitude recorded during the scale error test prescribed in paragraph (b)(i).

(iii) After effect. Not more than 5 minutes after the completion of the hysteresis test prescribed in paragraph (b)(ii), the reading of the altimeter (corrected for any change in atmospheric pressure) shall not differ from the original atmospheric pressure reading by more than the tolerance specified in Table II.

(iv) Friction. The altimeter shall be subjected to a steady rate of decrease of pressure approximating 750 feet per minute. At each altitude listed in Table III, the change in reading of the pointers after vibration shall not exceed the corresponding tolerance listed in Table III.

(v) Case leak. The leakage of the altimeter case, when the pressure within it corresponds to an altitude of 18,000 feet, shall not change the altimeter reading by more than the tolerance shown in Table II during an interval of 1 minute.

(vi) Barometric scale error. At constant atmospheric pressure, the barometric pressure scale shall be set at each of the pressures (falling within its range of adjustment) that are listed in Table IV, and shall cause the pointer to indicate the equivalent altitude difference shown in Table IV with a tolerance of 25 feet.

7.2 AC 43-6B

8. RECOMMENDED TEST PROCEDURES. *The following test procedures provide one way, but not the only way, of demonstrating altitude reporting and transponder system performance and the testing of individual components. In noted instances, these procedures are adequate to demonstrate compliance with the maintenance requirements of §§ 91.411 and 91.413.*

a. Static Pressure System Test. *Performance of this test on all instruments that rely on* *connected static air will ensure component leak integrity and that no leaks have been introduced while making connections to the encoding altimeter, blind encoder, or other instruments. This procedure is one method of demonstrating compliance with the requirements within § 91.411(a)(2). Persons authorized to perform this test are listed in § 91.411(b).*

NOTE: Damage may occur to other aircraft instruments, such as the vertical speed indicator, if the altitude rate is changed faster than the limit of the installed instruments.

(450) *Visually inspect the ports, tubing, accessories, and instruments connected to the static system and repair or replace those parts that are defective (e.g., broken "B" nuts, cracked flare sleeves, deteriorated flexible tubing, bad valves, etc.). Purge the system, if necessary, to remove foreign matter that may have accumulated in the tubing.*

CAUTION: Be sure to remove all pitot pressure and static air connections to every instrument that is connected before purging the system tubing.

(2) Check the static port heater, if so equipped to ensure proper operation by noting either ammeter current or that the pitot tube or static port becomes hot to the touch.

(3) When an aircraft has more than one static system, test each system separately to ensure their independence and that the leak rate for each system is within tolerances established in 14 CFR §§ 23.1325, 25.1325, 27.1325 or 29.1325, whichever is applicable.

(4) Connect the test equipment directly to the static ports, if practicable. Otherwise, connect to a static system drain or tee connection and seal off the static ports. If the test equipment is connected to the static system at any point other than the static port, it should be made at a point where the connection may be readily inspected for system integrity after the system is returned to its normal configuration. Remove all static port seals after completion of the static system test.

(5) Test the alternate static system at field elevation to ensure the selection valve functions, if installed. If the reading of the altimeter when on the alternate static pressure system differs from the primary system by more than 50 feet, a correction card should be provided for the alternate static system in accordance with §§ 23.1325, 27.1325, and 29.1325.

(6) For unpressurized aircraft, conduct the static pressure system proof test to the standards prescribed in §§ 23.1325(b)(2)(i) or 25.1325(c)(2)(i), as applicable (see paragraph 9).

b. Altimeter Certification Test. *This test ensures that an altimeter is calibrated and acceptable for use in the NAS. This procedure is adequate to ensure proper operation, but may* *not fulfill all the requirements of a manufacturer's minimum performance test required after maintenance of an altimeter.*

(450) *Persons authorized to conduct the altimeter test are listed in § 91.411(b). A certificated mechanic is only authorized to perform static leak testing and is not authorized to perform altimeter testing.*

(2) Perform the test procedure in part 43, appendix E(b). This procedure demonstrates compliance with the maintenance requirements of § 91.411. Altimeters which are the air data computer type with associated computing systems, or which incorporate air data correction internally, may be tested in a manner and to specifications developed by the manufacturer which are acceptable to the Administrator.

(3) The altimeter should be tested on the bench to the maximum altitude of its design specification. The date of the actual altimeter test and maximum in-tolerance altitude should be recorded on the altimeter. An altimeter found to have a lower maximum in-tolerance altitude than its design specification may be put into service provided that the in-tolerance altitude is at least that of the maximum certificated altitude of the aircraft it will be installed in, or if an operational limitation is placed on the aircraft and noted by placard.

c. Altimeter Field Elevation Verification. *Normal installation of an altimeter or encoding altimeter should not alter its calibration or certification basis. A field elevation verification of performance is adequate after installation to ensure safe operation within the NAS.*

(450) *Persons authorized to conduct the altimeter test are listed in § 91.411(b). A certificated mechanic is only authorized to perform static leak testing and is not authorized to perform altimeter testing. The Altimeter Field Elevation Verification is an observation made at the time of installation and in the context of § 91.411(b), not a test of the altimeter.*

(2) Compare the altitude displayed on the subject altimeter when referenced to 29.92 inches of mercury (1013.2 millibars) with that of a calibrated reference altimeter (as described in paragraph 9a or b) and ensure agreement within ± 20 feet.

d. Pressure Altitude Correspondence Test. *Ensures that the altitude reporting equipment associated with a radar beacon transponder is calibrated to transmit altitude data corresponding within 125 feet (on a 95 percent probability basis) of the indicated or calibrated datum of the* *altimeter normally used to maintain flight altitude, as required by § 91.217(b). This procedure is adequate to ensure proper operation of a pressure altitude encoding device installed in a transponder system but may not fulfill all the requirements of a manufacturer's minimum performance test required after maintenance of an encoder. The following test procedure (in part 43, appendix E©) demonstrates compliance with the maintenance requirements of § 91.411.*

7.3 FAR 91.411b

The tests required by paragraph (a) of this section must be conducted by—

(1) The manufacturer of the airplane, or helicopter, on which the tests and inspections are to be performed;

(2) A certificated repair station properly equipped to perform those functions and holding—

(i) An instrument rating, Class I;

(ii) A limited instrument rating appropriate to the make and model of appliance to be tested;

(iii) A limited rating appropriate to the test to be performed;

(iv) An airframe rating appropriate to the airplane, or helicopter, to be tested; or

(3) A certificated mechanic with an airframe rating (static pressure system tests and inspections only).

© Altimeter and altitude reporting equipment approved under Technical Standard Orders are considered to be tested and inspected as of the date of their manufacture.

(d) No person may operate an airplane, or helicopter, in controlled airspace under IFR at an altitude above the maximum altitude at which all altimeters and the automatic altitude reporting system of that airplane, or helicopter, have been tested.

7.4 FAR 91.215B

Unless otherwise authorized or directed by ATC, no person may operate an aircraft in the airspace described in paragraphs (b)(1) through (b)(5) of this section, unless that aircraft is equipped with an operable coded radar beacon transponder having either Mode 3/A 4096 code capability, replying to Mode 3/A interrogations with the code specified by ATC, or a Mode S capability, replying to Mode 3/A interrogations with the code specified by ATC and intermode and Mode S interrogations in accordance with the applicable provisions specified in TSO C–112, and that aircraft is equipped with automatic pressure altitude reporting equipment having a

Mode C capability that automatically replies to Mode C interrogations by transmitting pressure altitude information in 100-foot increments. This requirement applies—

(1) All aircraft. In Class A, Class B, and Class C airspace areas;

(2) All aircraft. In all airspace within 30 nautical miles of an airport listed in appendix D, section 1 of this part from the surface upward to 10,000 feet MSL;

(3) Notwithstanding paragraph (b)(2) of this section, any aircraft which was not originally certificated with an engine-driven electrical system or which has not subsequently been certified with such a system installed, balloon or glider may conduct operations in the airspace within 30 nautical miles of an airport listed in appendix D, section 1 of this part provided such operations are conducted—

(i) Outside any Class A, Class B, or Class C airspace area; and

(ii) Below the altitude of the ceiling of a Class B or Class C airspace area designated for an airport or 10,000 feet MSL, whichever is lower; and

(4) All aircraft in all airspace above the ceiling and within the lateral boundaries of a Class B or Class C airspace area designated for an airport upward to 10,000 feet MSL; and

(5) All aircraft except any aircraft which was not originally certificated with an engine-driven electrical system or which has not subsequently been certified with such a system installed, balloon, or glider—

(i) In all airspace of the 48 contiguous states and the District of Columbia at and above 10,000 feet MSL, excluding the airspace at and below 2,500 feet above the surface; and

(ii) In the airspace from the surface to 10,000 feet MSL within a 10-nautical-mile radius of any airport listed in appendix D, section 2 of this part, excluding the airspace below 1,200 feet outside of the lateral boundaries of the surface area of the airspace designated for that airport.