Teaching Maintenance and Inspection Aspects of the Rotax 900 Series Aircraft Engine at a Traditional Part 147 Airframe and Powerplant Technician School

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Abstract

The Rotax 912 series Aircraft Engine is a 4-cylinder, 4-stroke, high RPM, liquid cooled, lightweight power unit used in a host of recreational experimental and special light sport aircraft. The non-certified 912 ULS 100 horsepower visual flight rules (VFR) only version is the most common. Since the Rotax is substantially different from typical light aircraft reciprocating engines in several respects, additional training above what is offered in a typical Airframe and Powerplant (A & P) curriculum is recommended and in some case required to perform various levels of maintenance on the engine. Rotax approved maintenance courses at several levels are available through a number of factory approved providers. Due to the popularity of these power plants and the recent emergence of the experimental light sport aircraft (E-LSA) and special light sport aircraft (S-LSA) markets, familiarization with these engines and/or addition of factory approved maintenance courses may be viable additions to traditional Part 147 A & P programs. This paper examines some of the engine's characteristics and provides some suggestions for inclusion of Rotax engine familiarization material in such a program.

Background

Rotax 912 series engines are manufactured by BRP Powertrain GmbH, an Austrian company which was acquired by Bombardier in 1970. Originally designed for Sea- doo® Watercraft and BMW motorcycles and all terrain vehicles (ATVs), the engines may more closely resemble motorcycle rather than aircraft types in some respects. While the first Rotax designed for aircraft use was certified in 1975, development of the 912 series began in 1984 with the 912F type certified 10 years later and the increasingly popular 912 ULS light 4-stroke light sport aircraft engine more recently (Rotax, 2009). During the course of its evolution to the modern light sport aircraft power plant marketed today, the Rotax endured some growing pains (Cox, 2007), however, the present day series exhibit few problems when properly maintained (Hamilton, 2007). The Rotax 912 ULS currently is in use in a large number of experimental and special light sport aircraft (E-SLAs and S-LSAs), the latter including the popular Remos and Tecnam lines.

Characteristics of the Rotax 912 include 4-cycle operation, liquid cylinder head cooling, use of balance tube connected twin Bing carburetors with embedded starting carburetors (perhaps inaccurately called chokes), a dry sump oil lubrication system, a propeller speed reduction gear box and a magneto type generator for accessory operation and ship's battery charging. While some of these characteristics mirror what is common in motorcycle engines, similarities to typical aircraft engines include battery independent redundant solid state magneto driven ignitions, dual spark plug cylinders and automatic fuel mixture metering for efficient operation at altitude. The engines operate to a service ceiling of around 12,000 feet and at a considerably higher RPM than conventional reciprocating aircraft engines.

The FAA, Rotax and LSA manufacturers collectively have developed guidelines on engine servicing and inspections. In addition to the conditional requirements that the Federal Aviation Administration (FAA) and primarily Rotax may impose for individuals to service and inspect its engines, the light sport aircraft manufacturer may also have specific guidelines as to qualifications for performance of maintenance and inspections on its products. These are generally specified in the manufacturers' maintenance manuals for a particular engine/aircraft and must be adhered to. Certain items may be approved for inspection by the aircraft owner and other generally more complex or airworthiness related ones, by a certificated airframe and/or powerplant technician or a light sport aircraft repairman with the proper training and/or experience. Any modifications to the airframe or its components must be approved and specified by the manufacturer as to what can be performed and how the procedure is to be accomplished. Unlike conventional aircraft in which major alterations or modifications require an approved FAA form 337 Major Repair and Alteration (Airframe, Powerplant, Propeller, or Appliance) form, both major and some cases minor alterations require the manufacturer's, but not necessarily the FAA's approval. Certain repairs may also require manufacturer's approval and documentation as specified in the aircraft maintenance manual or via direct communication with the manufacturer. In any case, a thorough understanding of the applicable aircraft and engine maintenance manuals is paramount to performing required maintenance and inspections properly (FAA, 2006). The intention of this paper is to assist interested FAA Part 147 Airframe and Powerplant Maintenance Schools in the addition of Rotax engine maintenance and inspection familiarization procedures to their programs. It is not intended as an empirical paper or literature review and by no means is a guide to practical application of any maintenance or inspection procedure or a substitute for any material contained in the various manuals published by the engine or airframe manufacturer. The information contained in this paper is not endorsed by Bombardier, BRP Powertrain GmbH & Co, Rotax or any of its subsidiaries.

What Part 147 A & P Schools Can Do

Part 147 airframe and powerplant mechanic schools are a primary source of entry level aircraft maintainers in the U.S. (GAO, 2003). While these schools are governed in the topics they must include in their curriculum by the FAA, there is some latitude for adding instruction beyond specified topics included in the regulations. The topics are arranged in Appendices B - D to Part 147.2 and include material that must be taught in the general, airframe and powerplant curricula respectively. Although certain topics are specified, the regulations do not limit the inclusion of ancillary material where time permits (FAA, 2009). It is in this realm and under these guidelines that material relating to unconventional aircraft power plants such as the Rotax 900 series may be introduced. This being said, it should be noted that a revision of the Part 147 curriculum requirements is presently under review by the Aviation Rules Advisory Committee in conjunction with the FAA and revision of the topics and contact instructional time allotted to each of the three categories is subject to change. Specifically, the contact hours of instruction required for the FAA power plant mechanic certification may be reduced from the present 750 to 650 although a total of 1900 hours for the sum of all three categories of instruction is expected to remain (Thompson, 2010).

In the power plant curriculum at Southern Illinois University Department of Aviation Technologies, five courses deal directly with power plant maintenance, repair and inspections. These are the Reciprocating Power Plant; Carburetion, Lubrication and Fuel; Power Plant Testing; and Powerplant Inspection classes. Additionally, the Ignition Systems, Electrical Systems and Propellers classes offered provide additional venues wherein Rotax related material may be covered. The five primary and three secondary power plant courses occupy 21 and 13 credit hours and make up over 600 and 300 semester contact hours respectively.

What to Add and Where to Put It

Using a typical A & P curriculum as an example, a discussion of the appropriate areas of instruction to place the additional material follows.

Most of our students begin their power plant courses in the second year of the program. The first of the engine related classes in which the students participate is a Reciprocating Powerplant course. This class teaches construction, operation and timing mechanisms as well as cleaning and inspection of typical aircraft engines. Basic concepts as well as adherence to manufacturer's guidelines are stressed. It is in this course that the characteristics of the Rotax engine could be introduced. Approximately two hours of instructor led discussion and demonstration may be adequate for a basic overview. Included in the instruction could be a discussion of the close tolerances of manufacture including the engine's liquid cooled, high compression, high RPM and twin carburetor distinctiveness permitting the development of 100 horsepower in a 130 lb package. Use of a large graphic of the engine and a typical installation as depicted below in Figures 1 and 2 would afford the instructor the opportunity of teaching the highlights of its construction and operation while giving the students a proper visual overview.

Figure 1. Rotax 912 ULS

Figure 2. Typical Rotax 912 Installation

With permission from the producer, the inclusion a one hour video entitled *Rotax 912 Engine Introduction* produced by Paul Hamilton and featuring Phil Lockwood and Dean Vogel of Lockwood Aviation describing aspects of Rotax 912 operation and maintenance would be appropriate in this course (Hamilton, 2007). Once initial introduction to the engine is accomplished in the Reciprocating powerplant course, details of its line maintenance can be covered in the various component courses such as carburetors, ignitions, propellers, etc. and inspections covered in the Powerplant Inspection course.

The details of the twin top mounted carburetors can be examined in a carburetors class. These units consist of two Bing-64 constant depression float type carburetors connected by a balance tube at the intake manifolds. They are mounted to the intake manifold body of the engine with a flange secured with clamps that facilitate easy removal. Most installations do not employ filter screens in the carburetor bodies making installation of a gascolator on the airframe firewall and a course particulate filter at the fuel tank-fuel line connection advisable. Installations can be made with or without an airbox; however, for the benefit of a carburetor heat control its inclusion in the installation is recommended (Rotax, 2009). In the Rotax, the cold starting sequence consists of operating a "choke" rather than priming the engine or pressurizing the fuel system as in injector type systems. The "choke" is actually a starting carburetor which injects additional fuel when activated to enrich the fuel-air mixture for cold starts. The throttle must be in the full idle position and the "choke" at full activation for the system to operate properly. As the "choke" lever also increases engine starting RPM, Rotax recommends that the "choke" lever be backed off and the throttle increased to 2200 RPM for warm-up after the engine starts (Rotax, 1998). Part of the installation and inspection process consists of balancing and checking the two carburetors such that the two throttle valves open equally and an equal vacuum level throughout the throttle travel path is achieved on both carbs. This is a multi-step process which consists of an initial mechanical setting of the cables and linkages followed by a pneumatic balancing wherein fine adjustments are made ultimately achieving a smooth idle and run condition. The process is delineated in the Rotax Line Maintenance Manual (Rotax 2009) and several other sources including the article *Looking After Your Rotax 912 Series Engine* (Beale, 2009) and *Reaching Smooth Idle, Parts 1 & 2* (Lockwood, 2004). As the Rotax actually functions as two 2-cylinder engines connected to a common crankshaft, it is imperative this aspect of engine installation and maintenance be carried out (Lockwood, 2004). Additionally, according to the Rotax 912 Line Maintenance Manual, carburetor balance must be inspected, checked, and corrected if necessary at each annual/100 hour inspection and at the initial 25 and 50 hour engine inspections (Rotax, 2009) reinforcing the importance of performing this operation.

It should be mentioned that the Rotax 900 series runs very well on automobile gasoline, 91 octane or above, as well as 100 low lead (LL) avgas, however, there are some caveats which apply to each fuel type usage. As the Rotax is partially liquid cooled, the engines normally do not run as hot as a typical Lycoming or Continental aircraft power plant. When using 100 LL, lead deposits accumulate on the cylinder heads, valves, connecting rods, etc. as well as spark plugs and a pasty lead residual will accumulate in the sludge and particulate catching area at the bottom of oil reservoir. Rotax recommends that use of 100 LL more than 30% of the time requires a shorter interval between spark plug and oil changes (Rotax, 1998). The shorter intervals are generally at one-half the normal plug change interval and every 50 hours for an oil and oil filter change. While Rotax does not comment on the use of lead scavenger additives such as TCP, some of the other literature suggests that its use may decrease problems associated with the use of leaded fuels (Aircraft Spruce, 2009). Rotax does conclude that field experience has shown that no detriment to the engine occurs with their use (Rotax, 2009). Use of unleaded automobile fuels with gasohol added may create some problems if the percentage of ethanol in the fuel is high enough. Since ethanol has a tendency to absorb water, condensation in fuel tanks may tie up some of the ethanol, which while good to eliminate water from the fuel can lower its octane rating below the minimum of 91 required for proper operation of the engine (Hamilton, 2007). This can also lead to a condition called phase separation of the fuel, which could cause further degradation of fuel system components. One of this paper's authors noted through an unfortunate personal experience with high (93) octane unleaded automotive fuel not containing ethanol, degradation of some composite fuel tank slosh coatings and adhesives on the inside surfaces of the fuel tanks. It appeared possible that this damage may have been caused by the effects of unknown additives in the fuel. Providentially the degradation was noticed early and repairs affected before serious damage threatening the integrity of the fuel tanks occurred. While the octane rating and presence or absence of ethanol in automotive fuels is easily determined, the presence of other additives which may damage particular systems may not be evident until damage is done. As the federal Environmental Protection Agency and others push for replacement of leaded aircraft fuel with an acceptable standardized unleaded, non-ethanol containing substitute (Douglas, 2010), caution is appropriate in the usage of automotive fuels as they may cause damage to the fuel system.

Additional information regarding lubricants for instruction relates to crankcase oil. As indicated previously, the Rotax 900 series engine resembles a motorcycle engine in many aspects. One aspect is the use of a gearbox similar to what constitutes a motorcycle engine transmission to reduce the high engine RPM to a rate appropriate to drive a propeller. Because of both the tight mechanical tolerances utilized in manufacture of the engine and the use of a lubrication system common to both the crankcase and gearbox, regular aviation engine oil is not recommended for use in the Rotax power plant. Instead a non-synthetic petroleum oil, high quality multigrade motorcycle oil (10W 40 or 10W 50) or specially formulated semi-synthetic (Hamilton, 2007) such as Aeroshell Sport Plus 4 is recommended (Aircraft Spruce, 2010).

Oil level check and change procedures in the Rotax also require a different approach than in conventional aircraft engines. The Rotax uses a dry-sump type system wherein the oil is contained in a separate reservoir rather than the engine crankcase. The system does, however, use an oil cooler, a mechanical engine driven oil pump and a fiber filter with a pressure bypass as is the case in typical aircraft engines. Rotax recommends the oil reservoir be mounted on the firewall and the oil cooler mounted in the air stream with the intake and output ports facing upward. The Hamilton Rotax Introduction video also recommends exclusive use of Rotax brand oil filters due to their bypass pressure characteristics and manufacturer's assurance of quality (Hamilton, 2007).

Prior to checking the oil level in the reservoir, the engine needs to be hand cranked in the counterclockwise direction of normal rotation (when facing the power take off or propeller side of the engine) with the oil reservoir filler cap removed until a gurgling sound is heard. This procedure assures any engine oil remaining in the crankcase is returned to the reservoir and to also prevent the introduction of air into the oil lubrication system. The process may take up to 10 or more rotations. When performing an oil change or servicing the system, care should be taken not to permit engine rotation in the direction opposite of normal rotation. Should the lubrication system require service necessitating disconnection of the oil lines at areas other than the top of the reservoir tank, removal or replacement of oil lines, changing of the oil cooler, or total draining of the oil system, the system must be purged as oil is added, again to prevent introduction of air which may become trapped into the system. Procedures for accomplishing these tasks are outlined in the Rotax engine Line Maintenance Manual (Rotax, 2009) and the purging procedure is also demonstrated by a video posted on the Rotaxowners.com web site. Additional procedural Rotax “E-learning” and instructional videos relating to oil and filter changes as well as other maintenance and inspection procedures are also available there (Rotax, 2010).

Although not actually part of the fuel and lubrications topic, a magnetic plug inspection should be performed at specific intervals as described in the line maintenance manual and instruction videos. The Rotax engine has a single magnetic plug which is located on the left side of the engine above the oil filter flange. As is the case in any engine, an excessive amount of metal filings (greater than a 3 mm [0.125 in] clump in the case of the Rotax) adhering to the magnetic plug is an indication of possible internal engine damage or malfunction and should be promptly investigated. As with conventional aircraft engines, the oil filter should be cut open and the element examined for metal filings or other particulates at the change cycle (Rotax, 2009).

The Rotax uses a liquid cooling system for the cylinder heads while conventional air cooling is used for the balance of engine temperature regulation. As is the case in automobiles and liquid cooled motorcycle engines, a radiator, expansion and overflow bottle are employed and all need periodic checks and maintenance. The liquid coolant may be a typical 50/50 (50 percent distilled water and 50 percent antifreeze) antifreeze solution or a waterless coolant such as Evans® may be employed. The coolant type used is designated by the manufacturer. The Rotax cylinder head gauge temperatures generally range between around 160° to 300° F (150° C maximum) and the oil temperature between 120° and 285° F (50° – 140° C). In the event a change is the coolant type is made, the system must be thoroughly flushed and treated in accordance with the manufacturers’ directions. Waterless coolants and 50/50 coolants are generally not compatible. Engines will typically run somewhat hotter when waterless coolant is used (Hamilton, 2007).

An ignitions class would be a good venue to discuss the redundant dual magneto solid state ignition while an electrical systems class may be more appropriate to discuss the DC power system. In the ignition system, there are no mechanical contact points to wear out. However, a study of the mechanism is important as an adjunct in proper maintenance and inspection of the system. The energy for the ignition spark is generated in a magneto coil which is co-mounted in the ignition housing at aft end of the engine along with a “light coil” circuit. The 8 light coils generate an alternating current that is rectified and filtered to provide the 12 – 14 volts direct current (DC) to run the aircraft radios, instruments and accessories as well as keep the ship’s battery charged. Rotating magnets on the flywheel induce voltages in both the light and ignition coils. There is also a take off to power an electronic tachometer. The AC power from the redundant ignition coils is sent to the electronic ignition module for spark energy processing and that from the light coils to a rectifier-regulator-filter unit to achieve the 12 volt, 250 watt DC energy for battery charging and accessory power. Figures 3, 4 and 5 below reveal the external components of the electrical and ignition systems (Lockwood, 2004).

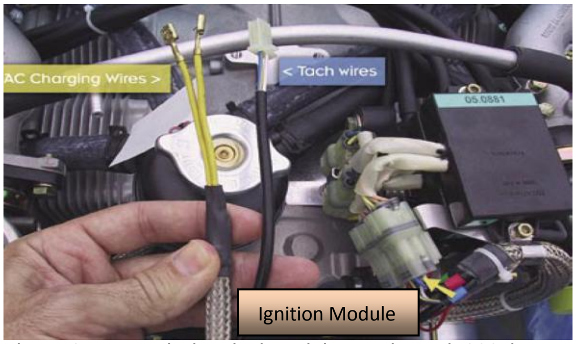

Figure 3. External Electrical Modules Lockwood, 2004)

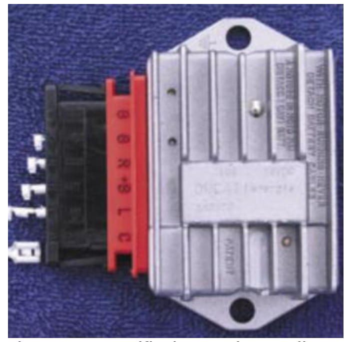

Figure 4. Rectified-Regulator-Filter Module (Lockwood, 2004)

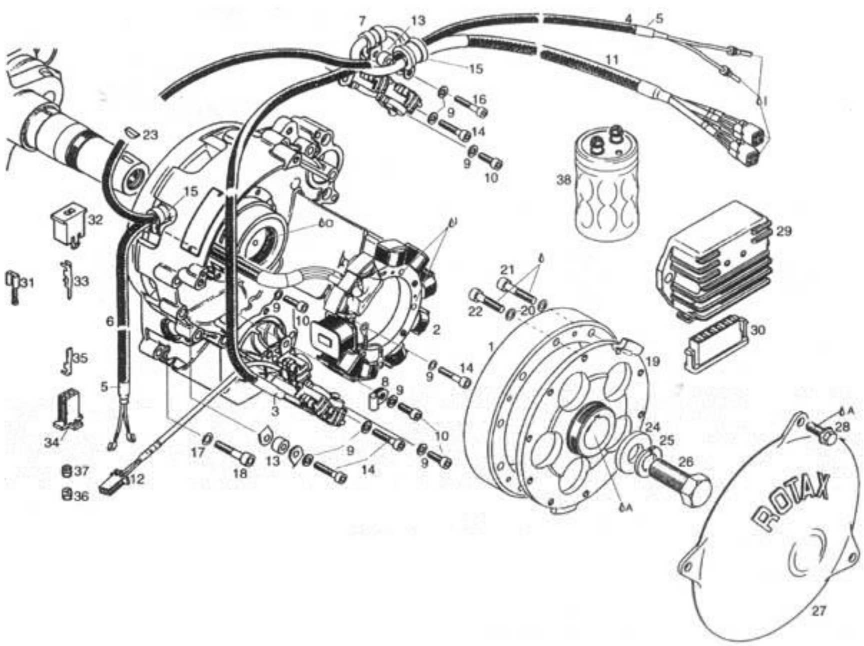

Figure 5. Rotax Magneto-Generator and Associated Parts (Rotax, 2009)

As is the case in a typical reciprocating aircraft engine, the Rotax uses redundant spark plugs, two per cylinder. Plug electrode gaps should be checked and set during replacement or cleaning and at inspection intervals (Beale, 2009). The spark plug heat rating is important, and the plugs should be changed with a direct replacement type typically every 100 hours or every 50 hours if 100 LL fuel is used (Rotax, 2009). Spark plugs for the Rotax are sold at a cost comparable to automotive plugs so frequent changes are an inexpensive portion of maintenance costs. Rotax recommends a heat conductive silicon based paste be applied to the plug threads taking care not to permit the paste to contact the bottom 3 threads or electrode area. Disabling of the ignition system subsequently shutting down the engine is accomplished by grounding appropriate pins on the 6-pin connectors to the ignition modules. Typically this is controlled through a set of toggle switches or a conventional OFF-MAG 1 ON-MAG 2 ON-BOTH ON-START ignition switch. If it becomes necessary to test the ignition system, removal of a plug to check for spark at the electrode while cranking over the engine is not advisable. According to the Hamilton Rotax video, the engine must rotate at about 250 RPM to produce a usable spark of sufficient magnitude to be visible. Hand cranking of the engine by turning the propeller, even with the effect of the gearbox, does not provide sufficient rotation speed to accomplish this. Further, if a plug is not adequately grounded, damage to the ignition coils may occur as the energy generated has to be dissipated somewhere. If this energy does not have a suitable path, it can cause an overload, burning out the excitation coil necessitating an expensive repair. If ignition testing becomes necessary, use of a timing light or other appropriate testing device is recommended (Hamilton, 2007).

A number of types of propellers are suitable for the Rotax engine although usage of different types and manufacturers call for a particular RPM idle setting (Lockwood, 2004). A benefit some three blade composite prop types is a single blade can be changed out in the event of chips or damage rather than replacement of the entire propeller assembly (Warp Drive, 2010). In most cases the airframe and or propeller manufacturer defines how the process is to be performed and it should be followed precisely. Because of the Rotax' high RPM characteristic, a gearbox with a reduction rate of 2.43:1 is required to ensure the propeller tip speed is not excessive. Maintaining the engine idle RPM between 1800 and 2200 is recommended in any case although extremely light weight propellers may permit speeds as low as 1400 RPM. An idle speed lower than 1400 will damage the torsion damper system in the gearbox and would probably result in a rough idling engine in any case (Rotax 1998). The gearbox shares its lubrication oil with the rest of the engine, necessitating the use of somewhat specialized oils as described above. The gearboxes in newer engine models are equipped with an overload clutch to mitigate damage in the event of a prop strike, however, should one occur appropriate inspections of the crankshaft and other engine components are necessary prior to return to service. Checking the amount of torque required to engage the overload clutch is part of the maintenance and inspection procedure (Rotax, 2009).

Putting it all together

The final areas to combine and review the Rotax maintenance and inspection material together are Powerplant Testing and Powerplant Inspection classes. It is here that students use the knowledge and experience they have gained in the 2.5 to 3 year airframe and powerplant technician program to complete their training.

A powerplant testing class can provide the students with knowledge of the correct procedures and precautions to be observed during engine installation, ground operation and fuel and oil servicing in addition to culmination of the material they have learned in previous training. Troubleshooting and interpretation of instrument readings is also taught in this class. Particularly applicable to the Rotax, the manufacturer recommends a number of installed monitoring instruments to assure the health and well being of its engines during normal operation. In addition to the typical fuel quantity, oil pressure, temperature and hour-meter gauges, two cylinder head temperature gauges and an oil temperature gauge is advised as well as fuel pressure, exhaust gas temperature and electrical system DC voltage output indicators. Provisions are made in the new glass cockpit engine monitoring systems designed for light aircraft such as the Dynon EMS-D120 (pictured below) in installations where electronic monitor system has replaced the older analog steam gauge type instruments (Dynon 2008). Whichever method is used, continued familiarization with the Rotax Engine operators' and installation manuals as well as the line maintenance manual can be stressed here.

Figures 6 and 7. Depiction of Dynon EMS-D120 display with engine off and engine running (Hannon and Harrison, 2009)

In a powerplant inspections class, students can demonstrate their knowledge of Federal Aviation Regulations relating to engines, applications of Federal Aviation Administration Airworthiness Directives, Service Bulletins and proper use of inspection equipment. Generally, Rotax engine installations fall under the FAA Special Light Sport or Experimental Light Sport rules which would include demonstration of adherence to both the engine and airframe manufacturers' guidelines, service directives and maintenance procedures as well as any directives imposed by the FAA. Below is an example of an engine inspection check list portion developed by one of the authors for a Rotax 912 engine (Figure 6).

Inspection Description	Hours			
Task	50 hr	100 hr	other	Performed by
1. Clean engine	X	X	200	owner
2. Visual engine check	X	X	200	owner
3. Engine leak check	X	X	200	owner
4. Check engine mounts	X	X	200	owner
5. Check engine external parts	X	X	200	A & P
6. Reduction gear check	X	X	200	A & P
7. Check oil level	X	X	200	Owner
8. Change oil and filter	X	X	200	A & P
10. Check cooling system	X	X	200	A & P
11. Change coolant (every two years or)			200	A & P
12. Replace coolant reservoir pressure cap			200	A & P
13. Check and regulation of carburetors	X	X	200	A & P
14. Check control cables	X	X	200	Owner
15. Change spark plugs			200	A & P
16. Check compression			200	A & P
17. Check engine electrical parts	X	X	200	A & P
18. Change rubber parts			200	A & P
19. Check overvoltage relay			200	A & P
20. Overhaul engine (15 years)			1500	A & P

Figure 6. Typical engine inspection checklist in an LSA Airplane

As is generally the case under light sport rules, the manufacturer is at liberty to determine maintenance tasks and who should perform them. In this case, some of the inspection items may be performed by the owner (owner) and others by a qualified airframe and powerplant technician (A&P). The inspection lists and maintenance items generally have one or more caveats advising that FAA or appropriate regulatory agency and/ or engine manufacturer's regulations and guidelines be followed with respect to individuals considered qualified to perform the maintenance and inspection tasks (Figure 7). It is recommended that a separate engine logbook be kept (Beale, 2009) and Rotax actually supplies one with its engines. The Rotax Line Maintenance manual contains a section on performance of inspections and an inspection checklist (Rotax, 2009).

IMPORTANT :

As far as ROTAX 912 engine installation, inspections and maintenance are concerned, carefully follow the instructions of the engine manual supplied with the engine.

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For maintenance and inspections of parts with finished materials or supplied by other manufacturers, such as: propeller, hubs, wheels, brakes, pumps, filters, pulleys, cables, pipes, bolts, rivets, extrusions, fusions, etc., follow the suggestions of the manufacturer, if supplied.

Figure 7. Manufacturer's Caveat Concerning Installations and Maintenance (Rotax, 2009)

Per Special Light Sport Rules, the aircraft manufacturer is the last word in aircraft maintenance and repair. It is reiterated that the FAA 337 Major Alteration form is not required in performing special light sport aircraft repairs and maintenance, however, manufactures approval along with a method of compliance is.

Summary

Addition of Rotax engine training material would be an enhancement to any A & P school curriculum. There is a wealth of information available on the Rotax web site and also through a variety of other sources. Depending on the needs and desires of the institution, a greater or lesser degree of material can be introduced. Several organizations offer the factory approved courses in the form of 2 day service and maintenance courses as well as a Rotax technical instructions course (Rotax-Owners, 2010). These courses may be of value for Part 147 A & P instructors in preparing instructional materials.

In the case of institutions certificated by the Federal Aviation Administration under Part 147, integration of Rotax engine familiarization material into systems courses where engine repair and maintenance is covered where desired, may become easier as a result of suggested revisions to Part 147 by the Maintenance Technician Schools Curriculum and Operating Requirements Working Group of the Aviation Rules Advisory Committee (ATEC, 2009). In such cases, FAA guidance as well as curriculum committee or other approval depending on local practice should be undertaken prior to implementation of any course revisions. As these materials are taught, the end result will be better informed and educated airframe and powerplant technicians available to service a popular aircraft engine in the emerging light sport category.

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