

ALTERNATIVE ENGINES

OPTIMIZING THE EJ25 FOR AIRCRAFT USE BY DOMINIC ACIA, MAXWELL PROPULSION SYSTEMS

Choosing a powerplant that meets personal needs and airframe requirements can be challenging. In the current marketplace, there is a wide variety of powerplant options ranging from fully FAA-certified engines to builder-designed experimental systems. For years the industry standards have been the Continental and Lycoming engines. While these companies offer options that work in most applications,

Developed by Fuji Heavy Industries, the EJ Series engine is the newest four-cylinder, four-stroke internal combustion engine in the Subaru line.

Most folks understand that you wouldn't take a standard production car engine, install it in a race car, and expect to win the race. In fact, you may not even finish the race! Production automotive engines, with their standard oil and cooling

don't realize that you shouldn't take a standard production car engine, put it in an airplane and expect its performance, longevity and reliability to match that of the production automobile. A lot of kitplane builders have done this, some have succeeded, and others have failed, sometimes with unfortunate consequences. That is the bad news; the good news is that converting a production automobile engine to a reliable aircraft engine does not require drastic changes. Making just a few critical modifications can result in an automotive engine ready to fly safely.

ENGINE OIL FUNCTION

To increase engine reliability, the most important mechanical changes involve the bearing and piston-to-wall clearances. In order to understand the importance of a proper clearance, it is essential to understand the many functions of engine oil. The engine oil's primary function is to provide lubrication to reduce engine friction losses and wear. Since no lubricant is perfect, there is still some friction and heat produced, and another very important function of engine oil is to help carry that heat away. In fact, oil carries off up to 40% of the heat generated by an engine. Corrosion control, cleaning and sealing are also secondary functions of engine oil.

Bearing heat load depends on several factors, with the two largest heat producers being operating rpm and power density. In an automotive application, where it only requires 15 to 35 hp to cruise at 60 mph and the rpm is generally around 2400, the heat load is significantly less than in an aircraft. Typically, in an aircraft setting, the Subaru engine operates at upwards of



THE SUBARU EJ25 ENGINE BLOCK IS BEEFY. MPS USES ONLY THE FINEST INGREDIENTS, LIKE THE BLOCK INTENDED FOR SUBARU'S TURBOCHARGED APPLICATIONS.

some builders are interested in exploring the more modern powerplants.

In this article, we hope to provide background information, describe relevant information on bearing clearances, discuss the modifications that MPS incorporates into their engines to ensure their reliability, and clarify some of the misconceptions and myths about Subaru aircraft conversions that have become the equivalent of urban legends.

systems, simply are not designed for continuous use at high speeds and high loads. The next time you are in your car, check out the engine rpm. I know in my cars—I have five Subarus—I usually cruise down the highway and through town at less than 3000 rpm. In contrast, a race car engine spends most of its life above 4000 rpm and many race car engines produce up to twice the horsepower of a production car.

In the same way, many airplane builders

4000 rpm and 140 hp continuously for hours at a time. As a result, managing an engine's heat load requires more capable oil and cooling systems than those found in most production automobiles.

BEARING CLEARANCE AND TOLERANCE

Loaded with excellent data, system operation descriptions, and inclusive troubleshooting sections, the Subaru service manuals are extremely complete and comprehensive. They also provide detailed information on the factory-defined tolerances and clearances. Of interest is that in an automotive application, larger tolerances are acceptable because the engines are not run very hard. On the other hand, bearing clearance is a critical issue in an aircraft application. For example, according to the Subaru Manual, the acceptable range for the connecting rod oil clearance is 0.0007-0.0018 inches. While a tolerance of 0.0011 inches might not seem significant, it actually allows an oil volume difference of 264%.

In other words, the larger clearance of 0.0018 inches allows 2.6 times more oil to pass through the bearing and thereby accomplish one of its primary functions—removing heat. This is a dramatic increase in terms of bearing heat load management. At the lower end of the Subaru production engine clearance scale, 0.0007 is woefully inadequate for providing effective heat removal in an aircraft engine.

During the blueprinting process at Maxwell Propulsion Systems, all bearing clearances are set to allow a maximum of 30% difference in oil flow volume. Thus, not only do the bearings in the MPS engines get more flow, the flow is more balanced than the Subaru standard.

FLOW BALANCE AND OIL PRESSURE

A stable oil film or cushion is the layer of oil between the components of a bearing. In addition to keeping two surfaces from contacting each other and welding themselves together, this oil pressure wedge helps cushion vibration energy that would



THE EJ25 ENGINES ARE TORN DOWN AT MPS TO BE BLUEPRINTED AS PART OF AIRCRAFT-SPECIFIC MODIFICATIONS. THESE ARE IMPORTANT FOR LONGEVITY.

otherwise be directly translated into the stationary portion of the machine. An unstable oil film is unable to establish a continuous pressurized wedge of oil to separate the stationary and rotating surfaces. Instead, the oil wedge builds and collapses in an erratic manner. This fluid instability potentially results in a variety of mechanical problems.

The flow path of oil through an EJ series Subaru engine demonstrates that the #2 and #3 rod journals get their oil from the same port on the crankshaft (#3 main journal) while the other rods have their own independent supply. To expand on the example above, if the #2 bearing clearance is 0.0018 and #3 is 0.0007, #2 gets 2.6 times more oil. In real-world conditions, oil pressure depends on demand—as demand increases with a steady supply,

pressure decreases. In this example the oil's ability to lubricate is compromised. Not only does #3 get less oil, but it also has a lower pressure oil wedge.

This situation produces premature wear on the bearing even in the low horsepower, low rpm automotive application. In order to further accommodate the higher oil demands in the high horsepower, high rpm, race or aircraft installations, MPS-blueprinted engines use a Subaru oil pump that provides higher flow and higher pressure than that originally available in the normally aspirated 2.0-, 2.2- and 2.5-liter engines.

ENGINE BLUEPRINTING

Engine blueprinting is always an interesting topic for discussion. Let's take a look at the Motorsport industry standard for engine blueprinting. As described in

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Car Craft magazine's article World Guide for Blueprinting, the basic rule of thumb for setting rod bearing clearance is 0.001 inches for every inch of journal diameter + 0.0005 inches. In other words, a 2-inch journal would have a clearance of 0.0025 inches.

The EJ25 engines have a journal diameter of 2.05 inches. By the Motorsports industry standard, the Subaru specified clearance of 0.0018 inches is a little on the tight side, and 0.0007 is well below the acceptable range. MPS experience with both aircraft and race engines has shown that 0.0016- to 0.0020-inch clearance is appropriate for producing a reliable and safe engine.

SUBARU MYTHS AND FACTS

Over the past several years working with both automobile engine clients and aircraft customers, I have had multiple conversations about a variety of Subaru issues.

While there is always at least a grain of truth surrounding each concern, a more complete examination of the specifics reveals some interesting information. The three most common concerns and beliefs are described below.

Subaru's factory-established bearing tolerances should never be modified.

This article describes the potential for bearing failures, but how many Subaru engines are affected? If you talk to any Subaru car dealership or repair shop, all will tell you that rod-bearing failures are the number one cause of Subaru engine failures. In fact, it has become so common that Subaru very recently changed the rod-bearing materials and modified the acceptable clearances.

While we have not yet seen the actual details in print, in late November 2008 we disassembled a new EJ257 short block and discovered that the bearings were made from a new, stronger bearing material. In addition, the tolerances on this

engine were within the specifications that MPS has been using in their blueprinting procedures.

Subaru engines blow head gaskets.

The Phase 1 EJ25 Dual Overhead Cam (DOHC) and early Phase 2 EJ25 DOHC engines were well known for their leaking head gaskets. Subaru has addressed this issue by releasing a newly designed MLS head gasket that eliminates this problem. That said, the specific models with this problem are generally not used by manufacturers building FWF packages. All Maxwell Propulsion System FWF packages use the EJ25 Single Overhead Cam (SOHC) heads coupled with the Subaru MLS head gasket designed for the STI turbo. This combination provides a lighter assembly and eliminates the observed failure mode associated with the Phase 1 EJ25 DOHC heads.

Subaru Pistons Fail and/or Create Excessive Piston Noise.

| Fable | Facts | MPS Approach |
|--|--|---|
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| Subaru Pistons Fail and/or Create Excessive Piston Noise | This is true in some situations: The current Subaru production specifications for all engine blocks allows for up to .0004" interference between the piston and cylinder wall. This tolerance was established by Subaru to minimize the engines that fail assembly line-inspection. In an automotive application this is viewed as acceptable since the occasional short block replacement under warranty can be deemed a reasonable cost of doing business. | To address this issue, during the blueprinting process, MPS establishes a piston to wall clearance that is appropriate for an aircraft engine. |



SPECIFIC BLUEPRINTING ENSURES THAT CRITICAL CLEARANCES ARE MAINTAINED WITH AN EYE TOWARD MAKING THE ENGINE RELIABLE AND DURABLE IN AN AIRCRAFT.

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When searching for an appropriate short block on which to base our packages, MPS conducted extensive research into the EJ25D and EJ251 normally aspirated and EJ257 Turbo blocks. The EJ257 has extra webbing and reinforcements on the exterior and ligaments on the block deck. These features provide a stronger, more reliable block with minimal increased weight, and help support the cylinder liner and prevent head gasket erosion at high power levels. Our assessment was that the advantages offered by the WRX/STi EJ257 block in terms of strength and reliability outweighed the minimal cost increase, weight and, in the normally aspirated configuration, an approximate eight horsepower loss.

As a result, the EJ257 platform now serves as the basis for the entire MX series of Firewall Forward (FWF) engine packages. These packages range from the normally aspirated 165 hp to the fully intercooled turbo 240-hp system. The process used

to build an aircraft system uses the methods described above. When MPS receives a new EJ257 short block, we perform a blueprint and balance on the engine. All rotating engine components are balanced to 0.10 gram. Following reassembly of the engine and addition of the various support components, every system is installed on the dynamometer where it undergoes a controlled break-in, all operating parameters are evaluated and adjusted as required and a power run is conducted.

During discussions with potential customers, we often have questions regarding the reliability of the MPS turbo packages. Once again, the best analogy and experience issues from the automotive setting where, equipped with a turbocharger pushing 14.5 psi of boost, the stock Subaru WRX STi produces 300 hp. In the aftermarket setting when coupled with a larger turbocharger it y can routinely produce in

excess of 450 hp. This shows us that the strength is adequate. However, running the factory engine at full power for 10 minutes (simulating a climb) will surely result in engine failure from inadequate oil and coolant system heat capacity. The turbocharged MX2 and 3 engine packages have the modifications and support systems necessary to handle the heat load at their horsepower ratings.

Since its beginnings, the MPS goal has been to bring a safe and reliable alternative engine package to the experimental aircraft marketplace. We believe that our current products meet or exceed these goals. In addition, beyond the issues of performance and reliability we believe that our products, when compared to the Continental and Lycoming engines, offer significant cost advantages from initial purchase, extending through normal operating expenses and beyond to the cost of overhaul.

Further, the MPS packages use components and manufacturing practices that address the reliability issues of the factory standard Subaru engine. As proven in the performance automotive market, the Subaru's inherent strengths are significantly improved by using these processes. The end result is an increase in reliability and longevity of the engine...exactly what members of the aviation community interested in flying behind a modern powerplant want and need. •

A promotional graphic for Firewall Forward Systems. At the top, it says "Discover the MPS Difference" in large, stylized yellow and orange letters. Below this, there are three bullet points: "PSRU and Propeller", "Professionally Engineered", "Solid Model Design", and "Scientifically Tested". In the center, there are several engine parts, including a red piston, a blue cylinder head, and various bolts and nuts. To the right, there is a section for "FWF System Testing" with three bullet points: "Vibration Analysis", "FAA Certification-Equivalent Ground Test", and "60-day Flight Test with N787MX Sportsman 100 hours - 11,500 nm". At the bottom, it says "FIREWALL FORWARD SYSTEMS", "RV - SPORTSMAN - GLASTAR", and "Engine Balanced & Blueprinted In-Flight Adjustable Propeller". There is also a logo for Maxwell Engineering in the top right corner.