Endurance Test Procedure

Rev. 1.0

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I. TEST OVERVIEW

A. Applicability

This document describes a procedure to test the lifetime endurance capability of small UAV engines. The procedure is for UAV engines driving a propeller in pusher or tractor configuration on a static test stand. Prior to testing, it is assumed that the engine has undergone initial development iterations and design review to meet physical requirements, and is at a point where it can be run in a more-or-less frozen design state.

Because the size of the engine dictates the details of the physical test setup, such specifics were omitted from this document. It is left to the test facility to provide all necessities to properly execute the test, including fuel, engine mounts, cooling air, noise mitigation, safety provisions, data acquisition and engine control.

B. Test Summary

The test is at least 150 hours long to achieve a specified number of cycles as described below. During this time an engine is run on a stationary test stand under predefined loads and operating temperatures while being monitored by personnel for performance changes and component failures. When running, the engine is commanded to various speeds that are representative of what it is likely to experience in flight. The test is broken up into daily 450-minute cycles which follow an engine speed profile. The profile commands a range of RPM set points which are based on a specified percentage of the engine’s maximum continuous power.
II. TEST OBJECTIVES

A. Top level goals

Design of the test procedure was framed by the following objectives:

1. Determine upper limits of stress under which the engine can operate in a specified period of time and identify items that need improvement

2. Provide customers with endurance data to meet engine selection requirements

3. Increase airworthiness confidence by qualifying engine reliability against known FAA standards

4. Monitor fuel consumption

5. Collect data to be used in determining product operating limits, maintenance schedules and, ultimately, hourly operating cost with respect to product life cycle

B. Why an endurance test?

The longevity of an engine plays heavily in its lifecycle cost and overall reliability. For the purpose of this study, lifetime durability was of primary concern because regardless what conditions an engine may operate in, time is always the enemy and is the variable that TBOs and maintenance schedules are measured against. Other aspects such as resistance to shock or harsh environmental exposure are also life-limiting but it would not be practical to test such impacts until the engine demonstrates that it can withstand its own wear and tear.

C. Airworthiness Standards

At the time of writing, there are no formal airworthiness standards pertaining to engines specific to unmanned aircraft, commercial or otherwise. The Federal Aviation Regulation (FAR), Part 33, while not intended for unmanned applications, is currently the closest set of regulations related to aircraft engine reliability. Subpart D, relating to reciprocating aircraft engines, is commonly selected by UAV engine manufacturers as a realistic airworthiness requirement to measure their product against. This procedure follows this convention.

A detailed wording of the Part is not included herein, but the key points are summarized below along with notes describing which details are included and excluded from the test procedure.
§33.41 Applicability – Included. This section identifies the subpart as relating to block tests and inspections for reciprocating aircraft engines.

§33.42 General – Included. Requires that anything having an adjustment, calibration, setting or configuration independent of test stand installation be established (with noted limits) and recorded.

§33.43 Vibration Test – Excluded. Outlines tests to compare vibration characteristics in the crankshaft, due to torsion and bending or the stress resulting from peak amplitude, to the endurance stress limit of the crankshaft material. The successful completion of the endurance test itself would be used as a demonstration that the endurance stress limits are not exceeded.

§33.45 Calibration Tests – Included. Requires baseline calibration tests to establish the power characteristics and test conditions of the test engine. The power characteristics of the test engine need to be established before the endurance test using shaft power output and maximum RPM as metrics. This requirement defines the engine’s maximum take-off power, maximum continuous power, and partial-power speed references. The requirement is also used in determining power degradation.

§33.47 Detonation Test - Included. Requires that the engine can operate throughout its range without detonation (i.e. undesired ignition of end-gas after the primary combustion event). It is assumed that the engine type has been tested early in its development for detonation.

§33.49 Endurance Test
a) General – Majority included. Specifies endurance length, order of test intervals, power references, temperature set points, propeller thrust loads and accessory loads.

b) Unsupercharged engines – Included. This section outlines the individual run phases in the endurance program, and includes 6 runs totaling 20 hours each plus one run lasting 30 hours. The runs are divided into various intervals of maximum continuous power, rated takeoff power, and lower specified power settings. See Section IV for graphical depictions of the runs as described in 33.49 (b). In the case of this procedure, the runs are not completed in uninterrupted 20 or 30 hour intervals but are divided into shorter but more numerous intervals such that the speed transitions intended by 33.49 (b) and the total hourly requirements of each phase are satisfied.

(c) – (e) Calls out endurance phases for different engine classes; not applicable.

§33.51 Operation Test – Excluded. This test does not receive Administrator involvement and thus did not undergo a formal Operation Test. However, the example items mentioned in this section (e.g. starting, idling and acceleration) should be
characterized early in the engine development process and checked during individual engine acceptance procedures.

§33.53 Engine System and component tests – Excluded. Requires additional testing for those components and systems that were not verified adequately by the endurance test to demonstrate functionality in all declared operating and environmental conditions, including temperatures at the rated temperature limit of the component. This catch-all requirement is not addressed herein; such tests would be component-specific and beyond the scope of this document.

§33.55 Teardown inspection – Majority included. This section requires the engine be disassembled and each component checked that it maintains settings and functioning characteristics within the limits established in Section 33.42.

§33.57 General conduct of block tests – Included. This requirements states that a) separate engines may be used for the various tests in this subpart; b) minor repairs are permitted without requiring retest; and c) all test facilities and personnel must be provided by the applicant.

D. Additions to FAR Part 33

With respect to the test objectives, data may be gathered not only to establish airworthiness confidence but also to support future test procedure improvements and product development efforts such as exhaust design, fuel flow reporting, or noise studies.

III. TEST SETUP

A. Engine Configuration

The engine selected for the endurance test, along with any components subject to the test, should be provided with all-new hardware except in the cases where aged hardware is used in an effort to increase the chance for component failure. Aged hardware is permitted in examples where the chance for component failure is increased during the test cycle. (i.e. an older or used component does not make the test easier to complete the full test mode) The engine and its installed components, specifications, adjustments and settings should be recorded prior to the test so that replacements and changes can be tracked.
B. 33.49 (b) Run Profiles

The endurance runs are defined in FAR 33.49 (b) as follows.

Run 1: 30 hour run consisting of alternate periods of 5 minutes at rated takeoff power with takeoff speed, and 5 minutes at maximum best economy cruising power.

Runs 2 – 6: 20 hour runs each consisting of alternate periods of 1-1/2 hours at rated maximum power with maximum continuous speed and ½ hour at 91% maximum continuous speed (Run 2); 89% maximum continuous speed (Run 3); 87% maximum continuous speed (Run 4); 84.5% maximum continuous speed (Run 5); and 79.5% maximum continuous speed (Run 6).

Run 7: 20 hour run consisting of alternate periods of 2-1/2 hours at maximum continuous speed, and 2-1/2 hours at maximum best economy cruising power.

These runs are depicted graphically in Section IV.

C. AMRDEC Adaptation

To make the endurance intervals manageable in a given work day, the run intervals defined in 33.49 (b) were reorganized into daily runs derived by the US Army AMRDEC (Aviation & Missile Research Development & Engineering Center). This allows one to operate the engine through all the power settings specified in 33.49 (b) in a 7.5 hour cycle, which can be accomplished in one working day allowing time for setup and inspection. A total of 20 cycles is required to reach the full 150 hour requirement, so each of the runs defined in 33.49 (b) is truncated to 1/20\textsuperscript{th} of the interval specified. The accumulated time the engine spends at each power setting is the same as the original profile in 33.49 (b). The 5-minute transitions in Run 1 remain at 5 minutes each (rather than being scaled down) in order to preserve the objective of testing engine transients.

5-minute warm-up and cool-down periods are added at idle (3000 RPM) at the beginning and end of each cycle.

The end result, shown in Figure 1, shows the AMRDEC profile for one 7.5-hr test cycle applied to sample reference speeds, plus the startup, shutdown and idle periods discussed above.
Figure 1: AMRDEC Test Cycle

Time (min)

Shutdown

450 minutes (7.5 hrs) per cycle

Official Test Mode

Cruise

MCTE MCNE MCNE MCNE MCNE MCNE MCNE MCNE MCNE MCNE MCNE MCNE MCNE MCNE

Cruise

MCTE MCNE MCNE MCNE MCNE MCNE MCNE MCNE MCNE MCNE MCNE MCNE MCNE MCNE

Startup
D. Overall test plan

The daily process of testing the engine consists of the following:

1. Check fuel level and record fuel weight and any fuel calibration values.
2. Check all hardware and electrical connections.
3. Set a throttle or RPM command.
4. Start engine and note the time.
5. Adjust the cooling air volume as necessary to maintain your rated WOT temperature.
6. On shutdown, note the time and conduct post-run inspection per the checklist.
7. Address any repairs or replacements as required.
IV. FAR §33.49B PROFILES

Note: Rated Takeoff Speed = Maximum Continuous Speed (MCNe), both at wide-open throttle (WOT).

**Figure 2: §33.49 (b) (1) – 30 hours**

**Figure 3: §33.49 (b) (2) - 20 hours**
Figure 4: 33.49 (b) (3) - 20 hours

Figure 5: 33.49 (b) (4) - 20 hours
Figure 8: 33.49 (b) (7) - 20 hours