A33N Endurance Testing

Rev. 1.2.1

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EXECUTIVE SUMMARY

Propulsion systems on unmanned aerial vehicles (UAVs) need to provide reliable, continuous power. Although engines are the most mission-critical component on a UAV, they are also known to be the least reliable. In response to this trend, the Cobra Aero team tested the 33cc fuel-injected A33N engine to demonstrate endurance and reliability using a high-stress run profile. After a 150-hour test period, the A33N engine successfully completed the test with no overhaul and no perceptible power denigration.

This report documents the test background, setup, criteria and results used to qualify the A33N engine.

Contents

I. Introduction

A. The Engine

The A33N engine is an air-cooled, 2-stroke, single-cylinder reciprocating engine with a displacement of 33 cubic centimeters (cc). The engine utilizes an ECU-driven electronic fuel injection (EFI) system provided by Currawong Engineering to regulate ignition and fuel delivery. The engine runs on unleaded gasoline at a 50:1 oil premix ratio. Power output with a quiet exhaust is rated at 2.1 kW (2.82 hp) with a dry weight of 2.35 kg (5.2 lbs.). The engine is designed for a direct-drive propeller in pusher or tractor configuration. It also drives a generator to provide up to 250 W continuous power (400 W intermittent) to the user's aircraft electrical busses.

B. Test Summary

The A33N was set up on a static propeller test stand and run per a specified max temperature and speed profile for 19 separate test segments until the test period of 150 hours was complete. Some days, a single segment was run, while on others the engine was run around the clock. The maximum continuous run during this test was for 27 hours. Component hours, engine telemetry, environmental conditions, fuel consumption and any other noteworthy events were recorded. Noninvasive inspections were conducted at the end of each daily test cycle against a checklist, and any anomalies were noted and addressed. The same engine serial number was used for the duration of the test. At the end of the test, the engine was removed from the stand and a full teardown was conducted on the top-end and exhaust.

II. Test Objectives

A. Top level goals.

Design of the test procedure for the A33N 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. Calibrate reporting of fuel consumption from the ECU
5. Collect data to be used in determining product maintenance schedules and, ultimately, hourly operating cost with respect to product life cycle.

Section III provides a detailed description of the test setup. In Section IV.G, results are evaluated against these objectives.

B. Why an endurance test?

Endurance and durability both play significant roles in engine reliability. For the purpose of this study, engine longevity 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 official airworthiness standards pertaining to engines specific to unmanned aircraft. The Federal Aviation Regulation (FAR), Part 33, while not intended for unmanned applications, is the closest set of regulations related to aircraft engine reliability. Subpart D, relating to reciprocating aircraft engines, is commonly used by UAV engine manufacturers as a “standard” to compare against. A detailed wording of the Part is not included in this report, but the key points are summarized below along with notes describing which details are included and excluded from the A33N test objectives.

33.41 Applicability – Included. This section clarifies that subpart relates 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 crank shaft material. Vibration characteristics and peak amplitudes were not recorded for the A33N, however the objective of preventing fatigue failure was met within reasonable doubt based on previous data of the subject engine's crank shaft. It is known that the crank shaft material and design can withstand fatigue without failure in similar applications for over 5 million cycles, far above the 2.2 million cycles that the endurance test engine would spend at full power when the crankshaft stresses are highest. 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 were established before the endurance test using shaft power output and maximum RPM as metrics. The requirement allows the final portion of the endurance test to be used as part of the data set to determine 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). The engine type has been tested early in its development for detonation. The relatively small bore diameter (39mm) allows rapid advancement of the flame front across the chamber, and thus does not provide much dwell time for the end-gasses to auto ignite. No signs of detonation were visible in the combustion chamber upon inspection at any time during the test.

33.49 Endurance Test

a) General – Majority included. Specifies endurance length, order of test intervals, speed variability, temperature set points, propeller thrust loads and accessory loads. The engine ran for the specified endurance length and RPMs were maintained within 3% of their rated speed except the maximum continuous power. For the test engine, such a power setting occurs at WOT, so the throttle can open no more to correct for deviation from the rated max continuous power. Run order was not defined by an Administrator. See Section III.E for run order. A limiting temperature as measured at the cylinder head was established and maintained throughout the test. A propeller was fitted which applied thrust loads to the engine, although these loads were not the maximum thrust loads that the engine was designed to resist. A belt-driven generator was installed during the test, but the generator was not loaded.

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 Appendix Section V.A for graphical depictions of the runs as described in 33.49 (b). In the case of the A33N maximum continuous power and rated takeoff power both occur at the same engine speed. The runs were not completed in uninterrupted 20 or 30 hour intervals but were further 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 were satisfied.

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

33.51 Operation Test – Excluded. This test did 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, acceleration) are 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. An example component would be the integrated ECU / fuel pump assembly, which was mounted on the test stand in such a way that it was not exposed to the same vibration or heat as it might on an airframe. While the A33N components were not subjected to further durability or environmental tests, the same components had been tested through extensive and high-stress use on other systems in lab and field environments.

33.55 Teardown inspection – Majority included. This section requires the engine disassembled and each component checked that it maintains settings and functioning characteristics within the limits established in Section 33.42. The crank case was not disassembled at the end of the endurance test. Such disassembly could invalidate testing beyond 150 hours by increasing the risk of damage to the bearings, which can be checked for grinding and slipping without disassembly.

33.57 General conduct of block tests – Included. This requirement 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. Only one engine serial number was used for the duration of the test.

D. Additions to FAR Part 33

With respect to the test objectives, data was gathered not only to establish airworthiness confidence but also to support future product development efforts and test procedure improvements.

Exhaust Design – The exhaust is the focus of substantial engineering effort because of its impact on engine efficiency and noise. It is also one of the highest risks for test failure when one considers its exposure to temperature, pressure and vibration stresses.

Fuel Flow – Because fuel starvation is the leading cause of engine failure in UAVs, fuel consumption and the ability to measure it are subject to continuous calibration and scrutiny. The fuel-used calculation of the ECU can be reported to the operator on the ground and used in determining the range of a given mission. Although other methods are recommended for maintaining a safe fuel reserve margin, it helps if this reported fuel-used figure is as accurate as possible.

Noise – Knowing the noise signature of the test itself is useful in determining the feasibility of future tests. It is also helpful for making relative comparisons between different engine configurations, such as exhaust or propeller changes.

III. Test Setup

A. Engine Configuration

The engine selected for the endurance test was a A33N as provided by Cobra Aero with all-new hardware. The engine and its installed components are collectively serialized as a Build according to the crank case serial number, 006. Specifications, adjustments and settings are listed below.

Cylinder	Cobra Aero ECAX0039P3 39mm bore
Case	Cobra Aero ECAX0043
Crankshaft	Cobra Aero EAAX0004
Piston	Cobra Aero ECAX0019

Spark Plug	NGK CM-6, 0.018” gap
Reeds	Cobra Aero ECAX0048 – Fiberglass 0.20mm thick
Exhaust	Cobra Aero XAAM0033 AXS Quiet Manifold
Intake Manifold	Cobra Aero ECAX0051
Throttle Servo	Futaba BLS173SV
Injector	CE646-002 SN A04299, 21.4 g/min @ 4.0 bar
Ignition	CE432-01A SN 126
CHT Sensor	CE214B SN 778
MAT Sensor	CE215-001B SN 792
Static Timing	63° BTDC pusher (CW)
CHT Max	160°C at WOT
Propeller	APC 16x14 2-blade in pusher (CW) rotation
Generator	Not operational during this test
ECU	CE367 SN 1009
Fuel Pump	CE 464-008

All fasteners were torqued per current build instructions and torque-striped with the exception of the spinner screw, which required removal at the end of every cycle to inspect the prop screws inside.

B. Test Stand

The engine was mounted to the test stand via a Currawong Engineering engine mount. All four isolators had a Shore A durometer of 40. The crankshaft was horizontal with the cylinder perpendicular to the ground plane. The propeller spun inside a steel guard allowing starter access to the spinner. See Figure 1.

The test stand was placed under a roof in an outdoor environment. Power cables were fed in from Cobra’s adjacent plant, and the communication and control computer was local to the test. Ambient temperatures varied from -9C to nearly 20C. Cooling air was driven by a centrifugal fan mounted to the test stand. The air was ducted to the engine head via a damper (to control CHT) and flex ducts. See Figure 2.

All materials required to run the engine were located on the test cart and secured as needed.

C. Fuel

Engine fuel was unleaded 98 Octane Sunoco 260GTX premixed with Ultra Blue 2-stroke aviation oil at a 50:1 ratio. Fuel was fed into a 10-micron fuel filter which in turn was fed to the fuel pump attached to the ECU. The fuel pump, which duty-cycles based on pressure feedback from the ECU, fed to the injector on the engine in a dead-head configuration. Just before the injector, a T-fitting was added to provide a vent line back into the fuel tank for purposes of relieving pressure and priming air out of the fuel lines. See Figure 3.

Figure 1: Front of engine test stand

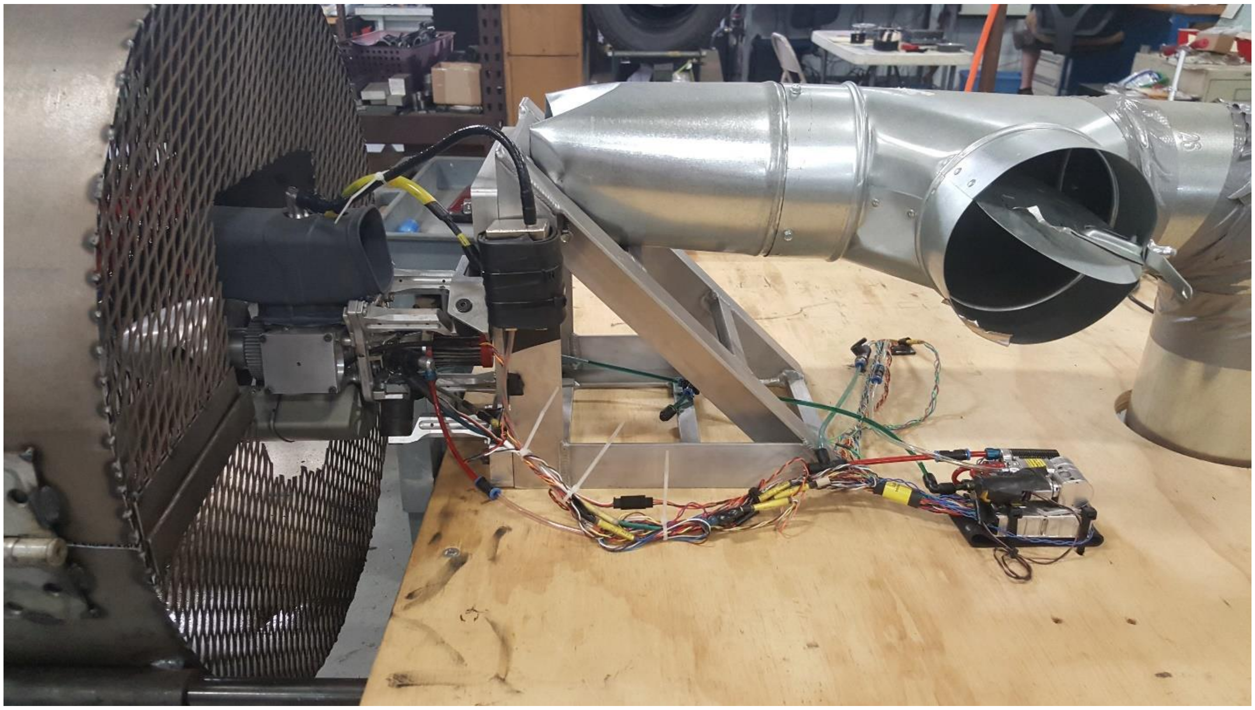

Figure 2: Side of engine stand

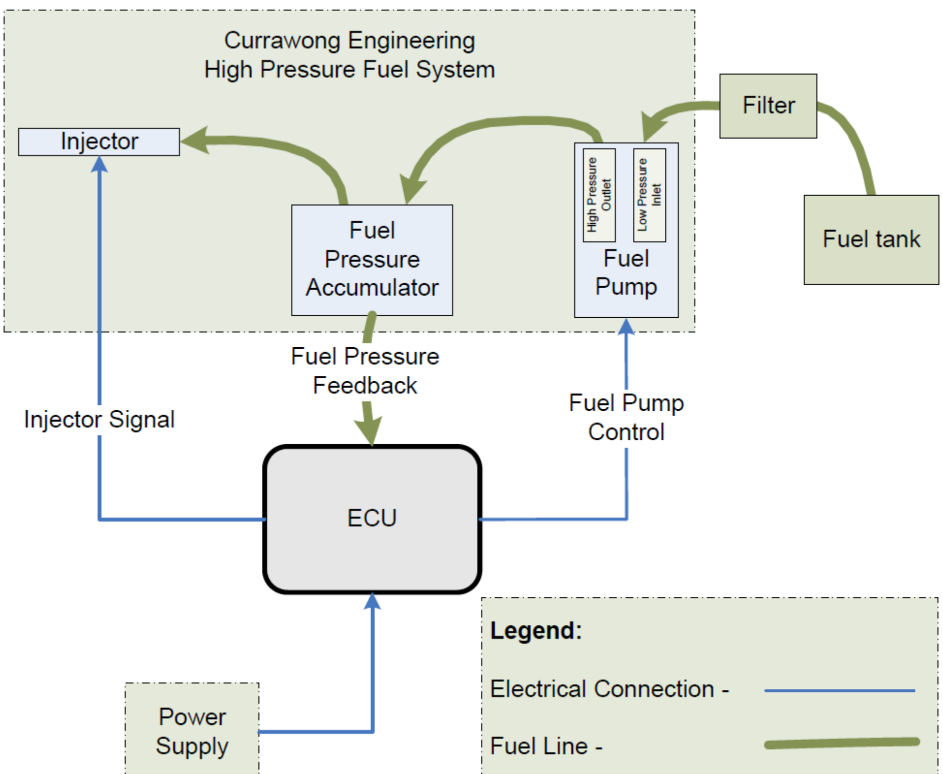

Figure 3: Fuel system schematic (vent line not shown)

D. Test conditions

Cycle 1 began on April 10, 2018 and ended on April 30, 2018. Of primary concern is manifold air temperature (MAT) and humidity, because these provide supporting data to explain engine performance anomalies. Otherwise, environmental data is of little concern to a durability test and therefore was not scrutinized. However, the following values were recorded each day. In summary, no weather phenomena were observed worthy of invalidating any portion of the test.

Cycle Number	High Temp, °C	Starting Relative Humidity %
1	8	19.5
2	11	62
3	12	63
4	14	47
5	8	71
6	9	46
7	12	34
8	9	43
9	9	55
10	10	40
11	12.4	33
12	16	29
13	13.3	29
14	11.7	32
15	17	60
16	11.1	91
17	10.8	98
18	12	63
19	20.1	34

Table 1: Weather conditions

E. 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.

A graphical depiction of these runs are shown in Appendix Section V.A .

For the A33N, the following speeds were selected for each speed or power setting called out in 33.49 (b).

Condition	**Engine Speed**
Rated Takeoff Speed	8100 RPM
Maximum Continuous Speed (MCNe)	8100 RPM
Cruise	5000 RPM
Idle	3000 RPM
87% MCNe	7052 RPM
85% MCNe	6897 RPM
81% MCNe	6548 RPM
76% MCNe	6161 RPM

Table 2: A33N profile Reference Speeds

F. 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 run profiles 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 including additional 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 $1/20^{th}$ 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 were added at idle (3000 RPM) at the beginning and end of each cycle.

The end result, shown in Figure 4, shows the AMRDEC profile for one 7.5-hr test cycle applied to the reference speeds in Table 2.

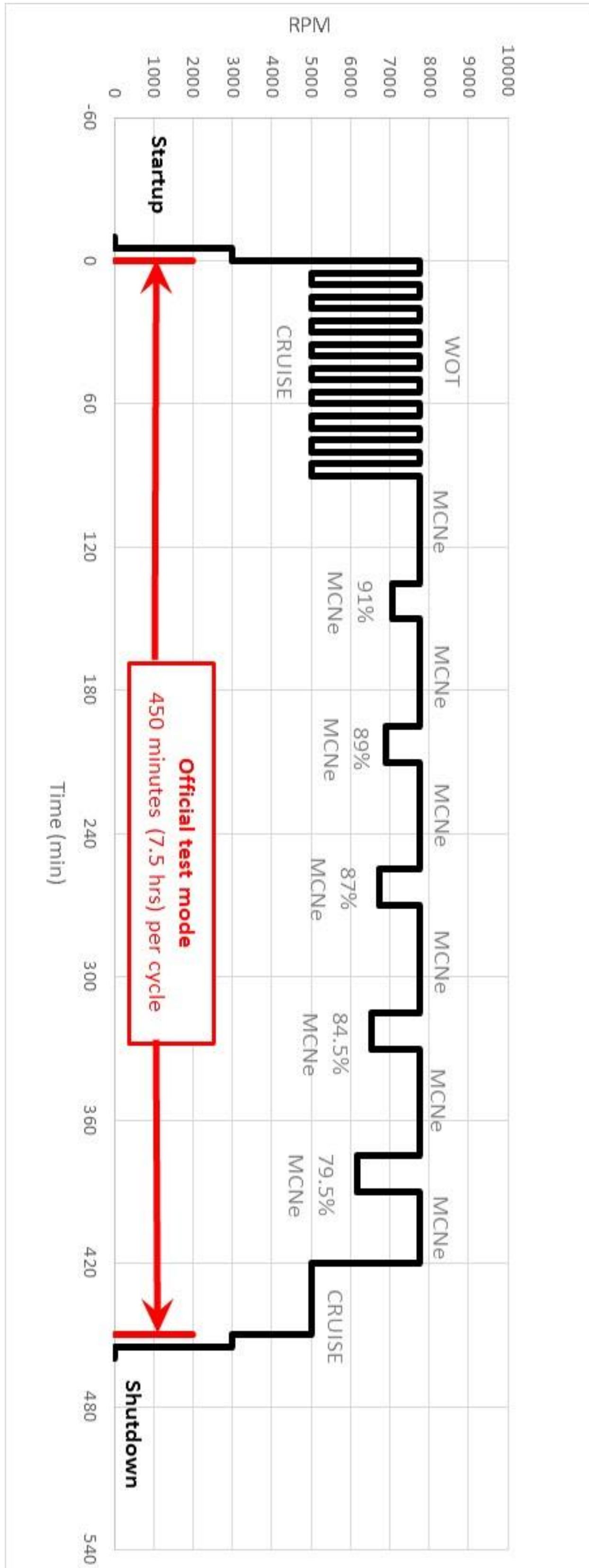

Figure 4: AMRDEC Test Cycle

G. Engine Control

The test engine maintained the speed references in Table 2 via an RPM control feedback which adjust throttle servo position as required for a particular speed target. The commanded RPMs were generated on an operator's PC which was connected to the ECU via CAN. Once the AMRDEC profile and associated speed references were decided, an RPM profile was loaded on the PC and executed so that the PC could control engine RPM in

For WOT cases (i.e. takeoff speed and MCNe), an arbitrary RPM was selected that was higher than the engine could achieve, thus keeping the throttle commanded to 100%.

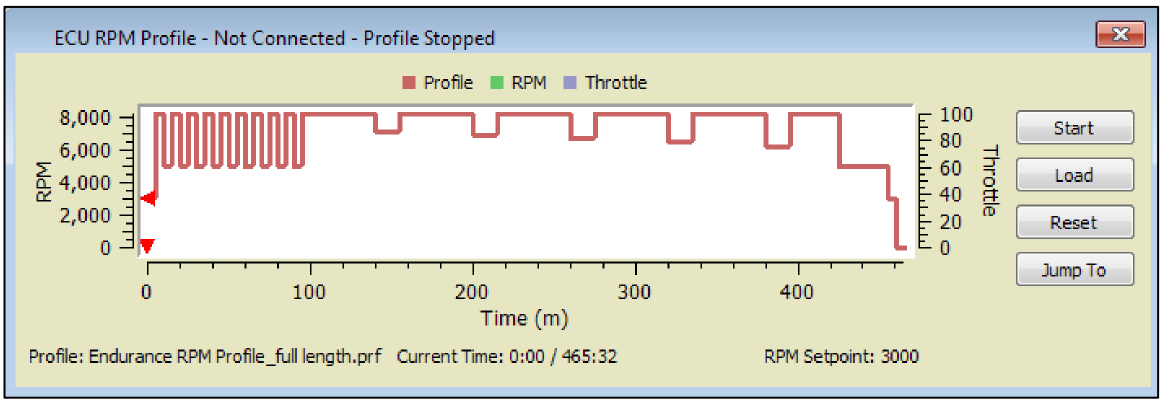

Figure 5: The actual RPM profile for one cycle

H. Overall test plan

The test was conducted with the goal of running one profile each day, start to finish. The daily process of testing the engine consisted of the following:

1. Record fuel weight and ECU fuel calibration value.
2. Load RPM profile and establish communications with the ECU.
3. Check all hardware and electrical connections per the checklist.
4. Set a throttle or RPM command.
5. Start engine and note the time.
6. Adjust the cooling air volume as necessary to maintain 160°C at WOT.
7. On shutdown, note the time and conduct post-run inspection per the checklist.

8. Address any repairs or replacements as required.

9. Fill the fuel tank and reset ECU fuel-used value.

IV. Test Results

A. Engine updates prior to achieving full FAR33 test sequence

The A33 went through four distinct updates prior to successfully completing the FAR33 sequence. All of these improvements were focused on crank train durability, and each Configuration outlined below was tested separately prior to us determining that a change was necessary. During this process, we utilized a variety of tools and expertise to land upon our final, robust solution. The final Configuration (D) is the one that ultimately passed the test and will be launched with our initial customers.

1. Configuration A

a) After Cycle 4, we noted that the bottom-end rod bearing was showing signs of failure. We re-tooled the bearing increasing its width from 9.8mm to 10.8mm.

2. Configuration B

a) After Cycle 6, it was noted that the crank bearings were rough feeling. Upon closer inspection, there were clear signs of brinelling and of material transfer from the balls to the race. We employed the services of a bearing specialist (through NSK Corporation), and he determined that we were overloading the main bearing. A re-design of the case was necessary, and we incorporated a larger main bearing with a load rating 40% higher than our previous design. See Figure 6.

3. Configuration C

a) After Cycle 4, the engine was inspected, and it was discovered that the outer crank bearing was loose in its bore. We determined that the propeller loads were overcoming the hoop strength of the engine case, and we improved the structure in that area (see Figure 6).

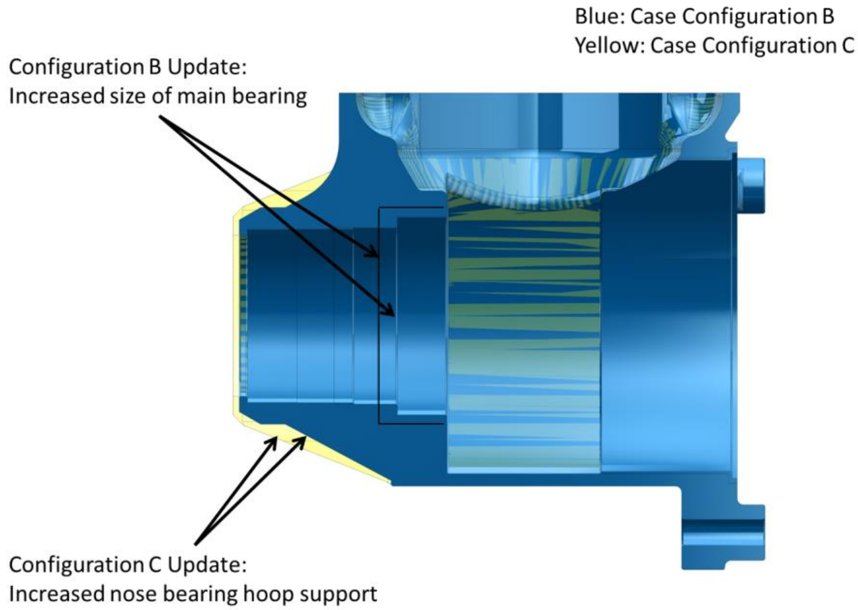

Figure 6. CAD depiction of design updates.

4. Configuration D

a) After Cycle 4, we noticed a 'notchy' feeling while rotating the crankshaft. After closer inspection (and a consultation by our NSK bearing expert), we determined that our bearings required a different fit to mitigate the effect of thermal shock that the engine was undergoing during its transitions from extended wide open throttle to near idle in very cold conditions (-12C) with an undamped cooling fan, and that we needed to ensure that our main bearing bores were machined to a higher degree of roundness. Figure 7 illustrates this process improvement.

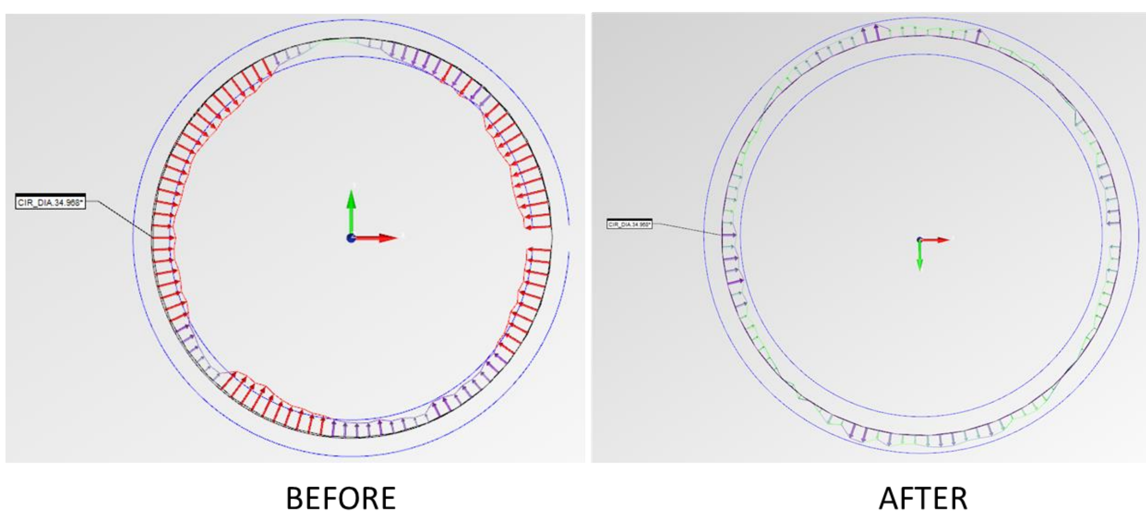

Figure 7. BEFORE: Out of round and out of tolerance. AFTER: within spec. Note, true position tolerance is ±0.0003".

The bearing fits recommended by NSK are shown in Figure 8, and they are set to achieve the following goals:

- Eliminate shaft creep
- Maintain interference between bearing and with housing at operating temperature
- Keep clearance reasonable at installation to maintain a good torque
- Don't sacrifice bearing life with too little clearance at operation

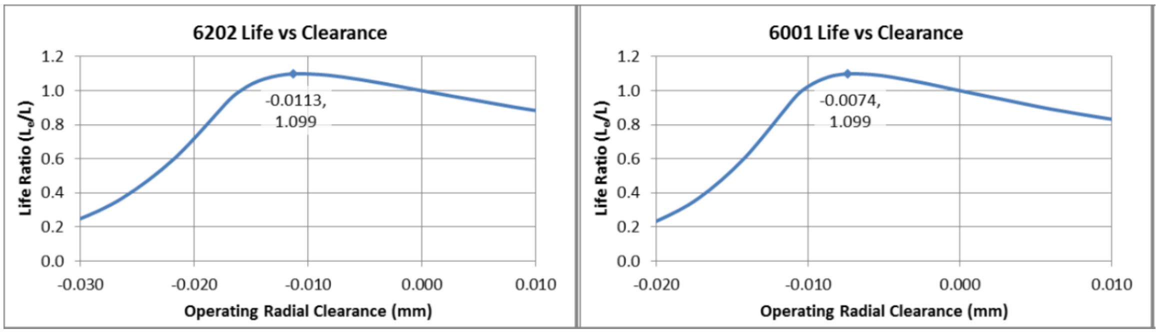

Figure 8. Recommended operating radial clearance for the main crank bearing (left) and the output bearing (right).

B. Timeline

The following time line summarizes all noteworthy events. Implications and "lessons learned" follows this section. Captions below indicate hours for that particular component, not the cumulative test hours.

0.5 hours (Cycle 1): Wire harness

- Lost CHT. Wire broke on harness side. Repaired and restarted.

23.4 hours (Cycle 3): Post-run adjustment

- Engine was surging at low throttle and RPM settings. Adjusted fuel table at these points to stop surge.

86.2 hours (Cycle 11): Engine Out

- Engine would not restart. Noted that Hall pickup was 12 degrees out of adjustment. Re-adjusted Hall sensor, but still no restart. Swapped ignition modules, and engine fired immediately. We also had to replace paper air filter element as it was deteriorating badly.

150.4 hours (Cycle 19) Post run inspection

- The top-end, muffler and reeds were disassembled and inspected.
- The piston was found to be in very good overall condition. Note that the top-end had approximately 30 hours on it prior to the start of this test. Machining marks are still clearly visible on both the front and back (thrust) sides of the piston.

Some top ring land coking is visible near the ring gap, however, the piston ring was still free as it appears that the semi-keystone ring shape was effective in shedding excess carbon buildup. The ring gap was set at 0.004” when it was installed, and at the end of the test it measured 0.006”.

Figure 9: Piston views (150.4 hours + previous ~30 hours)

- The crankshaft assembly was in good condition after the test. We did witness some leakage of grease from the sealed bearings, but the bearings felt smooth and tight. The ‘tri-spline’ (where the prop hub rides) was in good condition as well (Figure 10).

Figure 10: Crankshaft Assembly.

- The top and bottom-end rod bearings finished the test with no issues. (Figure 11).

Figure 11: Top and bottom-end rod bearings with rod guides and crankshaft. All components finished the test with no sign of excessive wear. (150.4 hours)

- The exhaust port showed signs of closing off on the top side with carbon buildup.

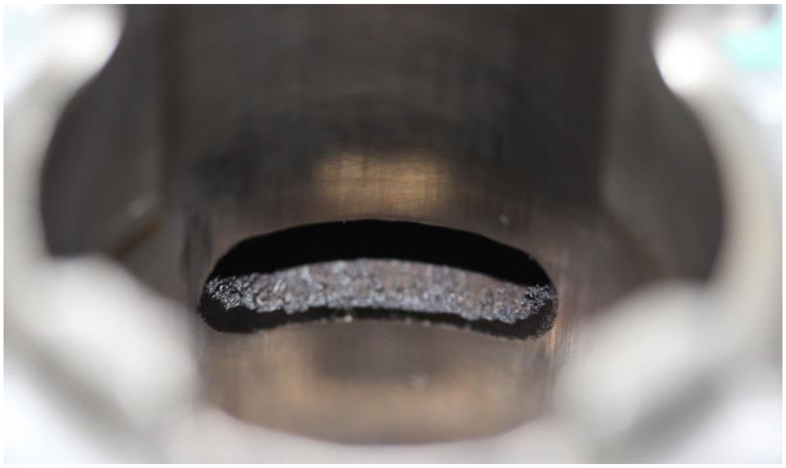

Figure 12: Exhaust port. (150.4 hours)

- The reeds showed no signs of cracking or chipping over the duration of the test.

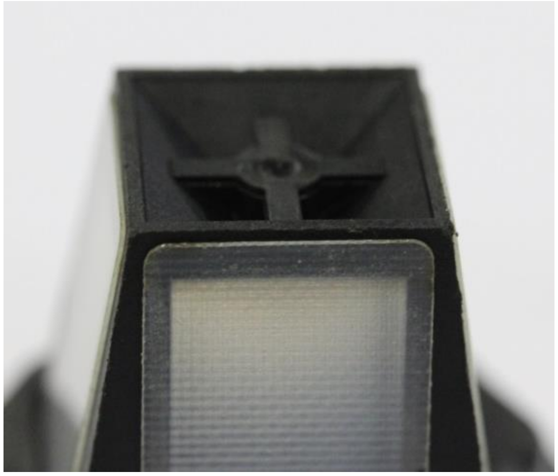

Figure 13: Reeds (150.4 hours)

- The spark plug shows signs of coking. The plug gap start: 0.018", end: 0.024".

Figure 14: Spark Plug (150.4 hours)

- The exhaust outlet shows small amounts of carbon buildup on the outlet holes.

Figure 15: Exhaust outlet (150.4 hours)

- The main bearing bore in the cases shows some signs of fretting on the bottom side (power stroke). The bearing fit into the case was still tight during teardown.

Figure 16. Main bearing bore (150.4 hours)

- The cowl shows signs of fretting where the cylinder fins come in contact with the inner surface. The cowl is material is Nylon 12.

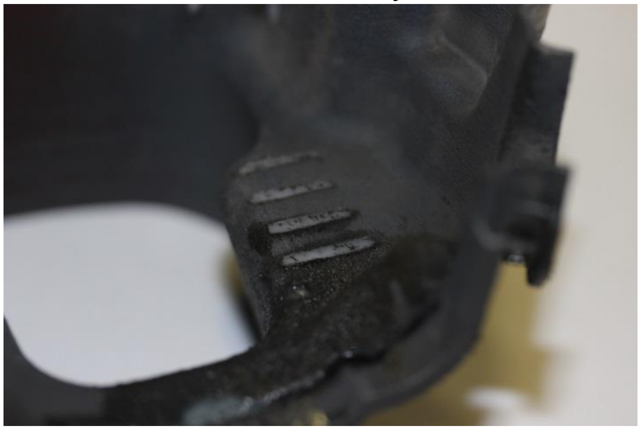

Figure 17. Cowl (outlet side).

C. Deviations

1. Cycle Count

Although the test ran for 150.37 hours, only 19 of 20 cycles were completed. The length of each daily cycle was usually longer than the exact length of the AMRDEC profile. This allowed the engine to accumulate hours faster than the cycle count would imply. Thus, fewer cycles were required to complete the 150 hour requirement.

Daily cycles were longer for a number of reasons:

a) Two 5-minute intervals were added to each cycle for warm-up and cool-down, which are not included in the AMRDEC profile. Thus a 7.5-hour cycle is really 7.67 hours (460 minutes).

b) Occasional communications errors between ECU and PC would cause the engine to run independently of profile control. Once communication was reestablished by the test operator, some guesswork was required to resume the RPM profile at the correct point in time.

2. Logger

The PC logger, with which all engine telemetry history was recorded, was not able to capture data for more than half the cycle until a software update after Cycle 11. (This coincides with the software bug discussed in (c) above.) The logger shows time advancing but all data after a certain point shows up as frozen. For this reason, only the first portion of cycle data is available for review from Cycles 1 through 11. From Cycles 12 on, the logger was able to record live data for the duration of the cycle.

3. Cycle 12-15

In order to speed up the completion of this test, we decided to run the engine around the clock for several cycles. Starting with Cycle 12, and ending mid-way through cycle 15, we ran the engine for just over 28 hours straight.

D. Fuel consumption

Although real-time fuel flow was not logged, the total fuel consumption of each cycle was estimated by the ECU using known injector duty cycle and a calibration constant called the *fuel used divider*. A decrease in this value increases the reported fuel used value. This constant was adjusted to match the difference in fuel tank weights from the beginning of the cycle to the end.

E. Power degradation

The A33N was checked out with an RPM of 8100. Thus 8100 RPM was the basis for all partial-speed phases of FAR 33.49 (b) and the AMRDEC profile. The maximum engine speed during the test 7900 RPM observed during Cycle 19. During the final cycle, the maximum speed observed had dripped to 7820 RPM.

F. Implications, conclusions, lessons learned.

1. Air Filter

The average life of the air filter was 44 hours. The current air filter, even when brand new, suffers from inconsistent durability and restriction issues, both which could be remedied by a filter of a different design or type. The filter will be updated to an open-cell foam design that will be much more robust to engine vibration.

G. Test validation

The results of this test are validated below against the (5) objectives in II.A.

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

- The primary stress imposed by the endurance test were the CHT set point at WOT and the timeframe of the test itself. All key crank train components looked very good after the 150 hour test, therefore the we are comfortable with suggesting a peak CHT of 165C.
- Weaknesses with the air filter design and its effects on the engine have been demonstrated.
- The results of this test can be applied to tests of subject engines of similar configuration.

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

- This test represents initial results for a 150-hour endurance program. This is a first step in making longer endurance tests feasible. The data gathered from this testing and the methods to gather that data have been refined.

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

- The FAR33 endurance requirement for reciprocating aircraft engines has been heavily referenced in the course of setting up and executing the endurance test.

4. *Calibrate reporting of fuel consumption from the ECU*

- As provided above, ECU fuel calibration has been refined based on recorded fuel weights for the AMRDEC profile. A further refinement can be made by recording the reported ECU fuel used while running a different RPM profile.

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

    - The length of time an engine can be run depends on how one approaches the system components: At what point is the engine proper "dead" and what components can be considered valid LRUs? This test helps to paint clues into which components have the most risk in terms of failure consequence (exhaust, piston) as well as probability (air filter). The data in this test is not fully conclusive but it meets the objective in that it can be used as part of a larger study in determining maintenance and operating requirements. A full system TBO will require more tests which continue to accumulate time on specified components such as the piston, cylinder, and crank shaft.

V. Appendix

A. FAR 33.49b profiles

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

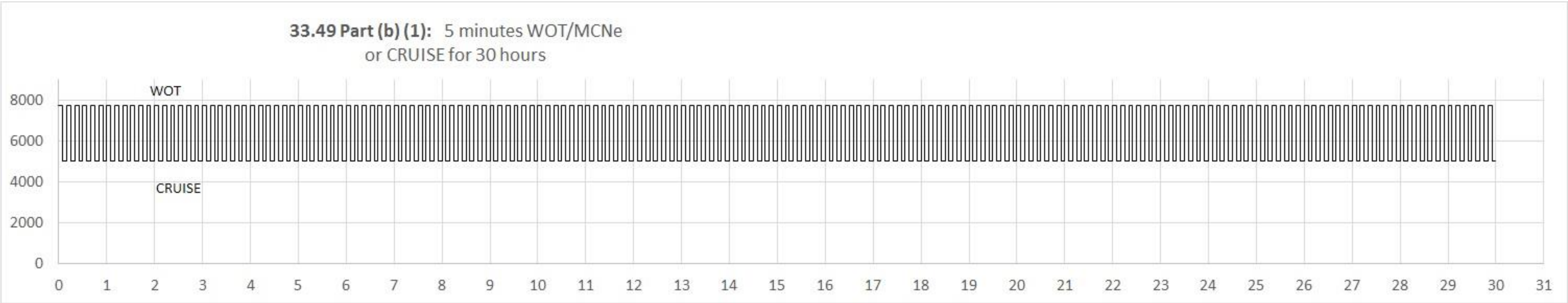

Figure 18: 33.49 (b) (1) – 30 hours

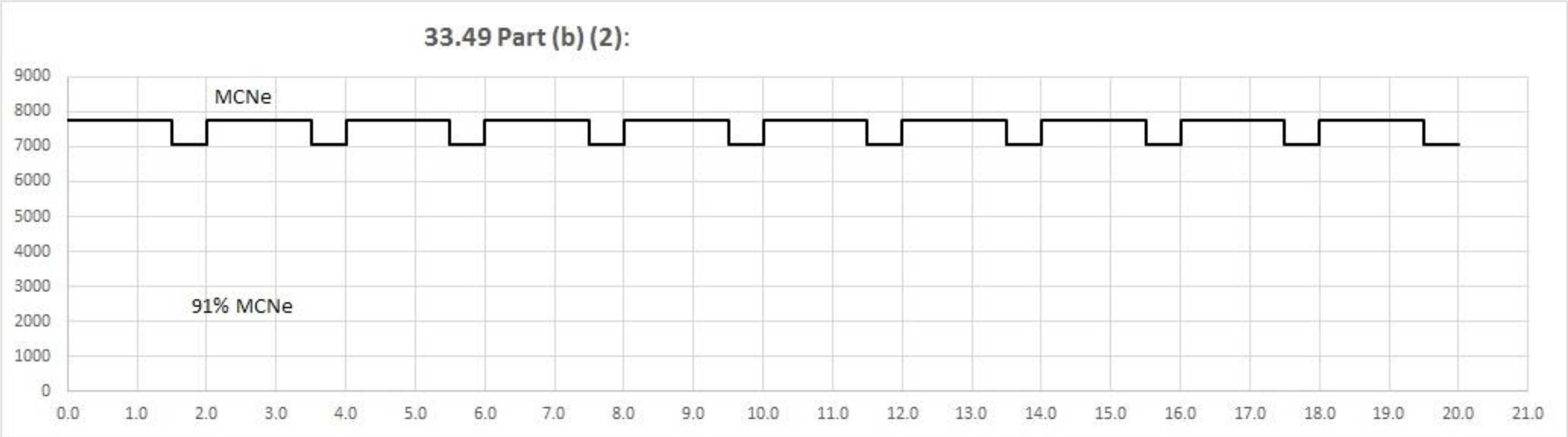

Figure 19: 33.49 (b) (2) - 20 hours

Figure 20: 33.49 (b) (3) - 20 hours

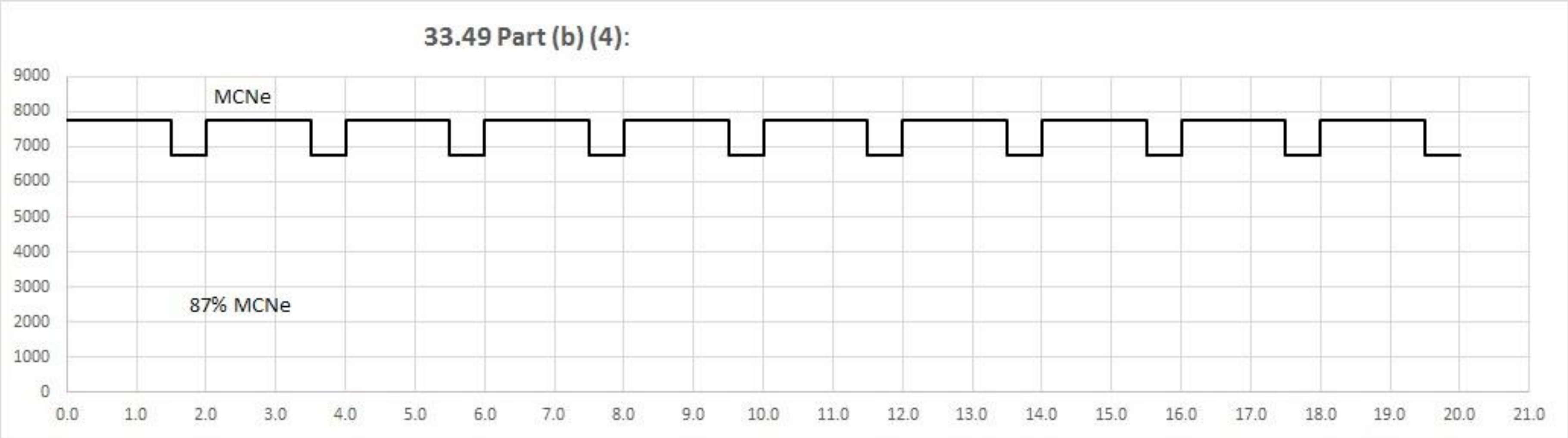

Figure 21: 33.49 (b) (4) - 20 hours

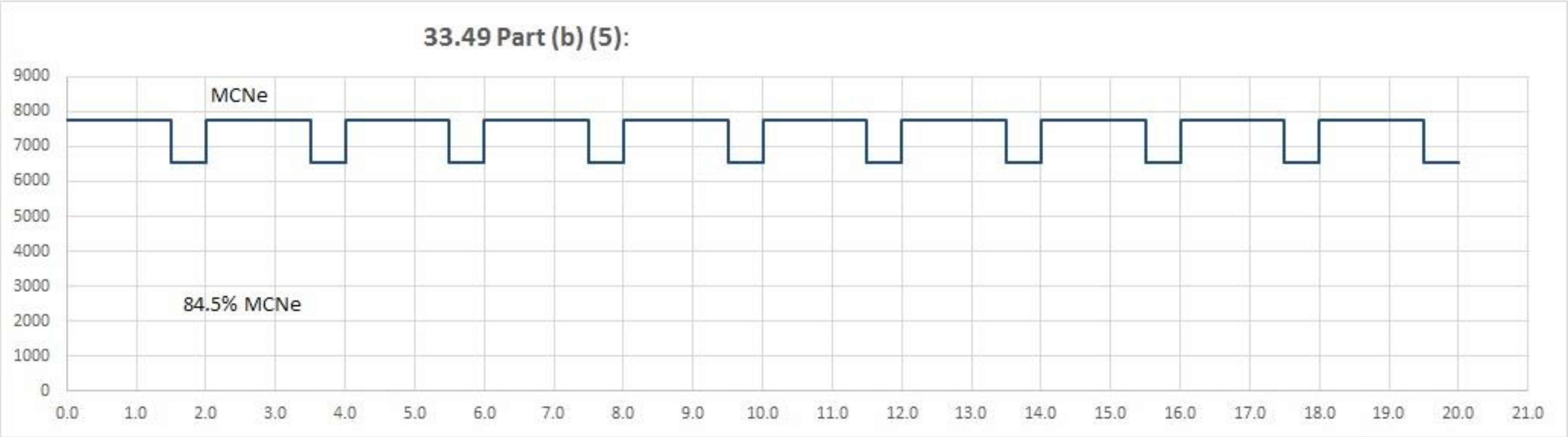

Figure 22:33.49 (b) (5) - 20 hours

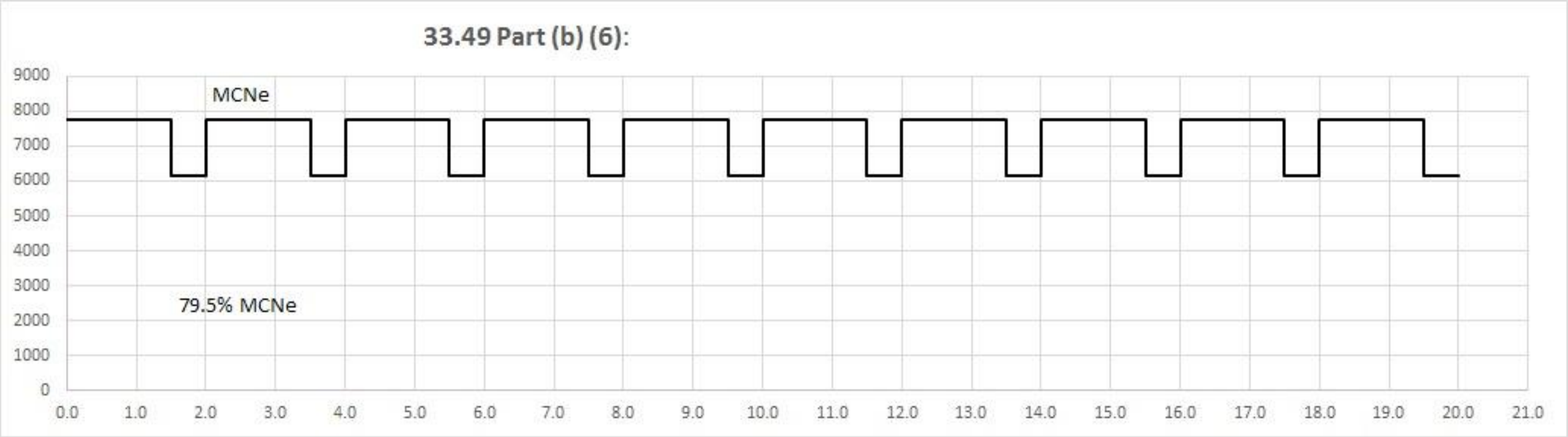

Figure 23: 33.49 (b) (6) - 20 hours

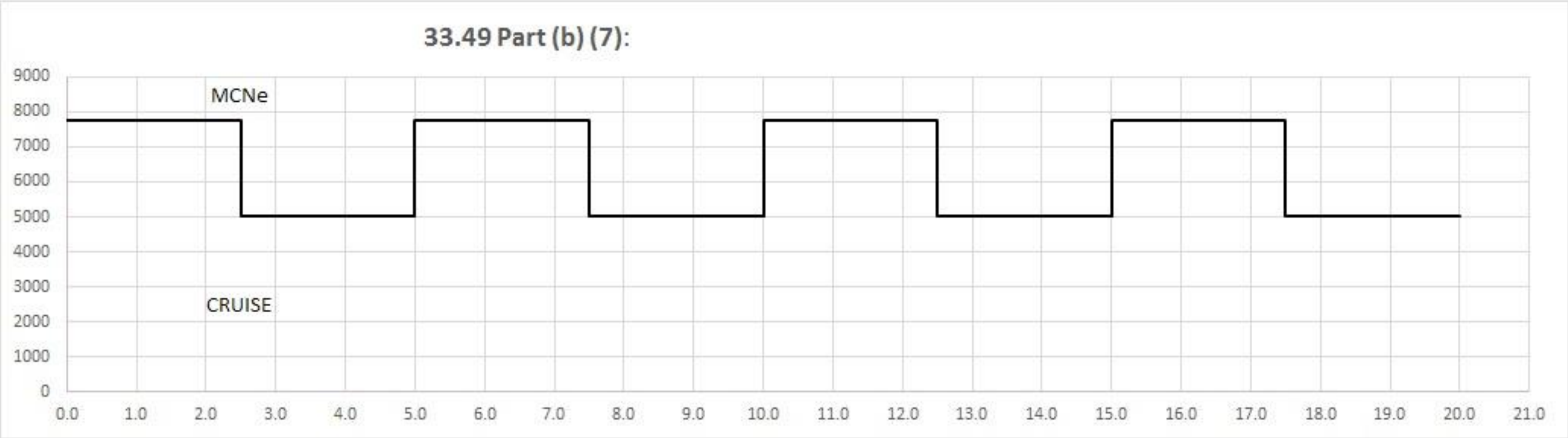

Figure 24: 33.49 (b) (7) - 20 hours

Engine daily run checklist form

First Name		**Engine #:**		**Location:**		**Date (m/d/y):**	
Fuel Tank Start Weight (kg)		**Humidity (%)**					
Start-up Checklist	Disable ECU	Fuel tank (2.5 kg + tank)	Header bolts torque check	Check engine/prop/mount/spark bolt	Check all fasteners on cart	Inspect prop	Crank sensor abrasion
Prop cage wing nuts	ECU/Fuel pump mounts (1/2")	Check fuel lines (kinks/leaks)	Blower hose secure	Air filter secure	Secure the cart wheels	Fire extinguisher handy	Set up perimeter cones
Plug in power strip	Clear blower intake	Power cord for blower ready	Reset fuel used on CE interface	Eye/ear protection ready	Connect laptop to ECU	Clear cart of unnecessary	Purge fuel line
Start data logging/aux mode	Enable ECU/Start engine	Stabilize engine to 160 deg C at WOT					
Start-up notes							
Start time		End time		Profile run		Reason for stop	
Engine comments:							

Prop stand comments:							
Fuel tank final weight (kg)		**ECU reported fuel used (kg)**					
Shut-Down Checklist	Disable ECU	Check fuel used divider	Check for fuel leaks	Check engine/prop/mount/spark bolt paint	Check all fasteners	Prop bolts (4mm, inside spinner)	Motor mounts (11mm)
Ecu/Fuel pump mounts (1/2")	Prop cage wing nuts	Crank sensor abrasion	Blower hose secure	Air filter secure	Unplug power strip	Torque seal header bolts	
Shut-down notes							