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WNG01: P51 ACTUATOR CONTROLLER
Hardware Design Description (HDD)

For MICHAEL MALCOLM

Last Updated: *September 11, 2019,* ***Revision*** 1.1

Approvals for Rev 1.1

NUVATION ENGINEERING

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Revision History

Revision	Date	Description	By
0.1	2017-12-07	Initial Release for Client Review	Nuvation
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1.0	2019-06-18	Final release to client	Nuvation
1.1	2019-09-11	Add details for WOW detection	Nuvation

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1 Introduction

The North American P-51 Mustang has two thermostatic actuators that open and close the air outlet flaps (also called, "doors") of the coolant and oil radiators. These electrically-driven devices control the operating temperature of the engine. The thermostatic controllers for these actuators are no longer produced, and old stock of these controllers are dwindling and have aged to a point where they require extensive overhaul and are of poor reliability.

1.1 Purpose

The digital controller described below will solve the worst of these problems by replacing the actuator's electro-mechanical control system with a digital control system that uses a RTD (resistance temperature device) temperature sensor and modern computer control. It will give the pilot greater visibility into the operation of the actuator, the position of the outlet flap, and the temperature of the coolant/oil. It will provide a cockpit warning in the event that the temperature becomes unsafe, and it will maintain a complete record of operating temperatures and outlet flap movements.

1.2 Reference Documentation

AN 03-5CH-17, Handbook of Instructions with Parts Catalog, Models R-4250 and R4310 Thermostatic Actuators, 10 January 1945

1.3 Related Documentation

WNG01 Firmware Software Design Document (SDD)

WNG01 Mobile Software Design Document (SDD)

WNG01 Acceptance Test Plan (ATP)

2 Board Functional Overview

2.1 Actuator Interface and Replacement of Existing Thermostat

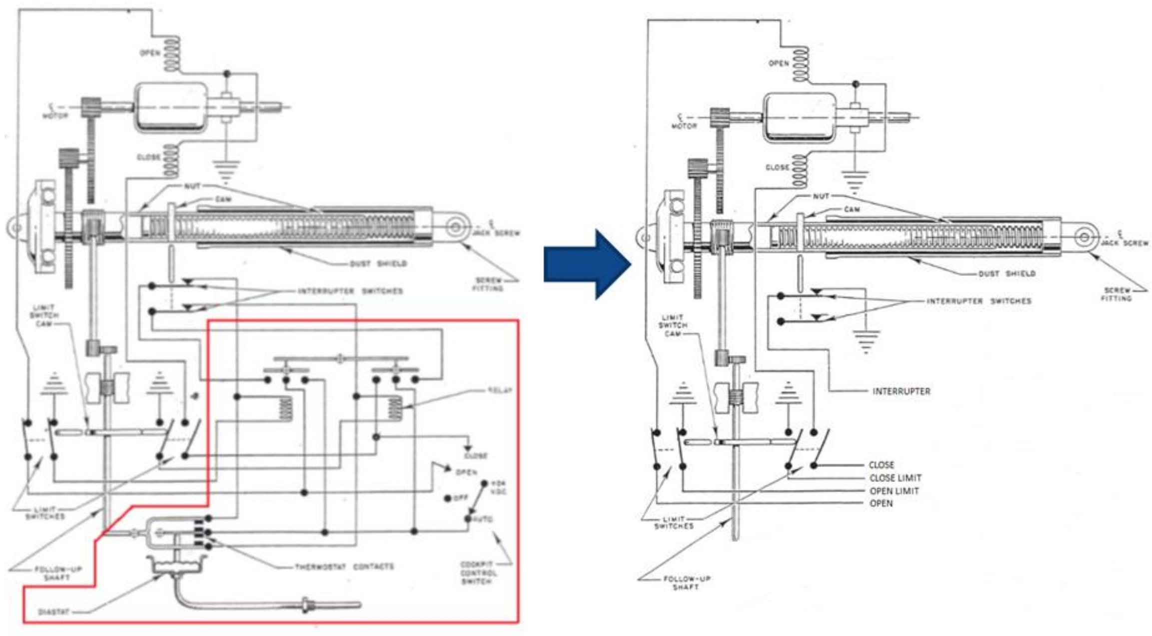

Figure 1: P51 Actuator and Thermostat Schematic

Figure 1 shows a schematic of the existing radiator door actuators (the schematic is identical for the oil and the coolant control systems) on the P51. The area highlighted in red is the OEM thermostat that will be replaced by the new digitally-controlled unit. The actuator itself has proven reliable over the years and will not be replaced. The image on the right shows the connections that will be made between the existing actuator/switches and the new control unit. The actuator itself runs off of nominally 24V supplied by a lead acid battery and DC generator that can exceed 28V when the aircraft is at operating RPM. All switches/contacts will maintain nominally 24V switch levels, and the motor will be driven directly from the new control unit as well. This will necessitate some protection on the controller PCB against automotive-type load dump, voltage spike, and reverse battery connection scenarios on the nominal 24V rail.

2.2 PCB Block Diagram

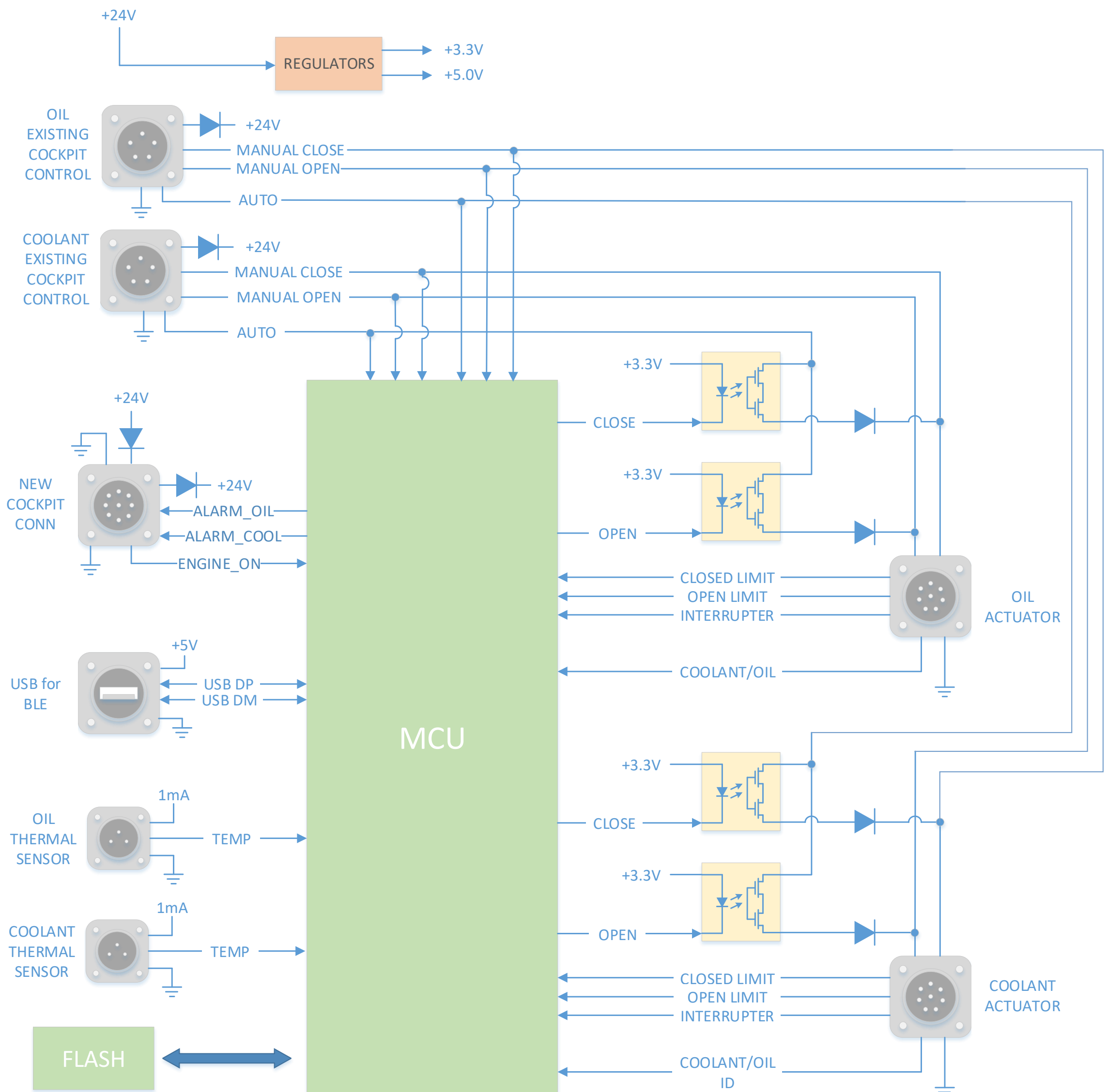

Figure 2: PCB Block Diagram

The PCB block diagram is shown in Figure 2. A single PCB is used to monitor and control both the oil and the coolant actuators.

Power enters the PCB via the "Existing Cockpit Control" connectors for the coolant and the oil (although not shown, protection will be included for load dump, transients, and reverse battery connection) and a small switching regulator is provided to power the digital portions of the PCB. This connector also provides the inputs from the existing oil and coolant controls in the cockpit to manually open/close the doors or place the systems in automatic mode.

A "USB to BLE" connector provides a USB connection for a Bluetooth transceiver mounted in the cockpit.

A “New Cockpit Connector” takes one input to indicate that the engine is running, and provides LED outputs for the cockpit in the form of alarm, malfunction, and system OK outputs designed to drive new warning indicators in the cockpit.

Two thermal sensor connections go to dipstick-type sensors mounted in the oil and coolant streams. Different connectors are used to avoid cross-plugging.

Two actuator connections go to the actuator units for the oil and coolant doors. Different connectors are used to avoid accidental cross-plugging.

3 External Connectors and Electrical Interfaces

3.1 Existing Cockpit Connector, Oil

Connector Part Number: MS3102R16S-8P

Manufacturer: ITT Cannon

Description: CONN RCPT 5 POS BOX MNT W/PINS, Normal Keying

PIN #	TYPE	Connection	Description	Connected to DEVICE
A	GND	GND	Ground Reference	
B	I, PWR	AUTO	Enables Automatic Control Mode, Battery +24V Power Input. Current can be drawn from this pin to drive actuators.	
C	I	MAN_OPEN_OIL	Manually opens the oil cooling door	
D	I	MAN_CLOSE_OIL	Manually closes the oil cooling door	
E	PWR	+24V_OIL	A +24V source that is diode-OR'd with the coolant +24V system to power the digital electronics on the controller	

Table 1: Pinout for Existing Cockpit Connector, Oil

3.2 Existing Cockpit Connector, Coolant

Connector Part Number: MS3102R16S-8PX

Manufacturer: ITT Cannon

Description: CONN RCPT 5 POS BOX MNT W/PINS, X Keying

PIN #	TYPE	Connection	Description	Connected to DEVICE
A	GND	GND	Ground Reference	
B	I, PWR	AUTO	Enables Automatic Control Mode, Battery +24V Power Input. Current can be drawn from this pin to drive actuators.	
C	I	MAN_OPEN_COOL	Manually opens the coolant door	
D	I	MAN_CLOSE_COOL	Manually closes the coolant door	
E	PWR	+24V_COOL	A +24V source that is diode-OR'd with the oil +24V system to power the digital electronics on the controller	

Table 2: Pinout for Existing Cockpit Connector, Coolant

3.3 New Cockpit Connector

Connector Part Number: MS3102R-18-1P

Manufacturer: ITT Cannon

Description: CONN RCPT 10POS BOX MNT W/PINS, Normal Keying

PIN #	TYPE	Connection	Description	Connected to DEVICE
A	PWR	+24V for Lamp Indicator	Battery +24V Power for Lamp Indicator (Output only, a diode prevents power from being fed to the PCB using this input)	
B	PWR	+24V for Lamp Indicator	Battery +24V Power for Lamp Indicator (Output only, a diode prevents power from being fed to the PCB using this input)	
C	GND	GND	Ground reference	

D	O	ALARM_OIL	Open drain output	
E	O	ALARM_COOL	Open drain output	
F	GND	GND	Ground reference	
G	I	ENGINE_ON	+24V level input, pulled up to +24V internally. An oil pressure switch must connect this input to frame/battery ground when the engine is running.	
H	GND	GND	Ground reference	
I	PWR	+24V_COCKPIT	An optional +24V source that is diode-OR'd with the actuator and oil +24V system to power the digital electronics on the controller.	
J	GND	GND	Ground reference	

Table 3: Pinout for New Cockpit Connector

3.4 USB to BLE Connector

The USB to BLE connector will used a MIL-DTL-38999 Series III style connector, but with a true USB type A connector in the center. This is a connector available from Amphenol in their USB Field harsh environment series.

Connector Part Number: USBFTV22G

Manufacturer: Amphenol PCD

Description: CONN USB SQ FLANGE RCPT-SLD GRN

PIN #	TYPE	Connection	Description	Connected to DEVICE
1	PWR	+5V	+5V Bus Power to run BLE dongle	
2	IO	D-	USB FS Data -	
3	IO	D+	USB FS Data +	
4	GND	GND	Ground reference	

Table 4: Pinout for USB to BLE Connector

3.5 Thermal Sensor Connector, Oil

Connector Part Number: MS3102R14S-2P

Manufacturer: ITT Cannon

Description: CONN RCPT 4 POS BOX MNT W/PINS, Normal Keying

PIN #	TYPE	Connection	Description	Connected to DEVICE
A	PWR	BIAS_OIL	1mA bias current for RTD temperature sensor	
B	I	TEMP_OIL_P	Output from RTD temperature sensor, Positive Kelvin Connection	
C	I	TEMP_OIL_N	Output from RTD temperature sensor, Negative Kelvin Connection	
D	GND	GND	Ground reference	

Table 5: Pinout for Thermal Sensor Connector, Oil

3.6 Thermal Sensor Connector, Coolant

Connector Part Number: MS3102R14S-2PX

Manufacturer: ITT Cannon

Description: CONN RCPT 4 POS BOX MNT W/PINS, X Keying

PIN #	TYPE	Connection	Description	Connected to DEVICE
A	PWR	BIAS_COOL	1mA bias current for RTD temperature sensor	
B	I	TEMP_COOL_P	Output from RTD temperature sensor, Positive Kelvin Connection	
C	I	TEMP_COOL_N	Output from RTD temperature sensor, Negative Kelvin Connection	
D	GND	GND	Ground reference	

Table 6: Pinout for Thermal Sensor Connector, Coolant

3.7 Actuator Connector, Oil

Connector Part Number: MS3102R16S-1P

Manufacturer: ITT Cannon

Description: CONN RCPT 7 POS BOX MNT W/PINS, Normal Keying

PIN #	TYPE	Connection	Description	Connected to DEVICE
A	O	CLOSE_ACT_OIL	High current drive to close door	
B	O	OPEN_ACT_OIL	High current drive to open door	
C	I	CLOSE_LIM_OIL	Logic input to indicate end of travel of actuator, closed door	
D	I	OPEN_LIM_OIL	Logic input to indicate end of travel of actuator, open door	
E	I	INT_OIL	A logic input activated once per screw revolution of the actuator	
F	O	ID/Presence Detect	• Open Circuit: Actuator not connected • 4.7kOhm resistor to GND: Actuator Present, WOW detected • 0 Ohm to GND: Actuator Present, WOW absent	
G	GND	GND	Ground Reference	

Table 7: Pinout for Actuator Connector, Oil

3.8 Actuator Connector, Coolant

Connector Part Number: MS3102R16S-1PW

Manufacturer: ITT Cannon

Description: CONN RCPT 7 POS BOX MNT W/PINS, W Keying

PIN #	TYPE	Connection	Description	Connected to DEVICE
A	O	CLOSE_ACT_COOL	High current drive to close door	
B	O	OPEN_ACT_COOL	High current drive to open door	
C	I	CLOSE_LIM_COOL	Logic input to indicate end of travel of actuator, closed door	
D	I	OPEN_LIM_COOL	Logic input to indicate end of travel of actuator, open door	
E	I	INT_COOL	A logic input activated once per screw revolution of the actuator	
F	O	ID/Presence Detect	10kOhm resistor to GND for presence detect/ID	
G	GND	GND	Ground Reference	

Table 8: Pinout for Actuator Connector, Coolant

3.9 SWD Debug/JTAG Header (Internal Use Only)

The PCB itself will only require test pads for the mating pogo-pin type connector. The connector and adapter that will have to be ordered is Tag-Connect TC2050-ARM2010 (cable) and TC2050-IDC (adapter), which will then mate directly to the ST-LINK/V2.

Connector Part Number: TC2050-IDC-NL

Manufacturer: Tag-Connect

Description: TC2050-ARM2010 adapter TC2050-IDC 10-pin Plug-of-Nails cables. Compatible with all ARM processors.

PIN #	TYPE	Connection	Description	Connected to DEVICE
1	O	VTREF	Target reference voltage	+3.3V
2	I	JTMS/SWDIO	JTAG Mode Select/SWD IO	MCU
3	GND	GND	Ground reference	MCU
4	I	JTCK/SWCLK	JTAG Clock/SWD CLK	MCU
5	GND/PWR	GND/3.3V	3.3V power for bench test, or GND to improve signal integrity. The selection is done by soldering jumpers on the Tag-Connect adapter. Provide 0-ohm jumpers to GND & 3.3V, but NC by default.	-
6	O	JTDO/TRACESWO	JTAG Data Out/TRACESWO	MCU
7	NC	NC	-	-
8	I	JTDI	JTAG TDI	MCU
9	I	JNTRST#	JTAG Reset	MCU
10	I	NRST#	System reset	Reset

Table 9: SWD Debug/JTAG Header

3.10 Debug UART Header (Internal Use Only)

A serial UART connection can be used for communication & control of the board for configuration and debug purposes. The PCB itself will only require test pads for the mating pogo-pin type connector. The connector will be Tag-Connect TC2030-FTDI-TTL-232R USB to TC2030 Serial Cable, containing the FTDI TTL-232RG-VREG3V3 USB-to-UART IC.

Connector Part Number: TC2030-FTDI-TTL-232R USB to TC2030 Serial Cable

Manufacturer: Tag-Connect

Description: TC2030-FTDI-TTL-232R USB to TC2030 Serial Cable, FTDI TTL-232RG-VREG3V3

PIN #	TYPE	Connection	Description	Connected to DEVICE
1	O	N/C	FTDI adapter +3.3V, 350mA (not connected)	-
2	I	RTS#	Connects to FTDI adapter CTS#	-
3	I	TXD	Connects to FTDI adapter RXD	MCU
4	O	RXD	Connects to FTDI adapter TXD	MCU
5	Gnd	GND	Ground reference	-
6	O	CTS#	Connects to FTDI adapter RTS#	-

Table 10: Debug UART Header

4 External User Controls, Sensors, Actuators

4.1 Cockpit Actuator Controls

The cockpit has one switch for coolant radiator air control (shown in Figure 3) and one for the oil radiator control. Both switches are normally in the “automatic” position, which allows them to be controlled by the device described in this design document.

Figure 3: Coolant Actuator Control Switch

Placing the switch into manual mode position disables the automatic controller, and allows the switch to be momentarily actuated in the “open” or “close” directions which manually open or close the radiator doors. The manual mode can be used to bypass the automatic controlled in the event of a failure, or for pre-flight inspections of the door actuator operation. The automatic mode should be used during normal flight conditions.

4.2 In-Cockpit Alarm Lights

Outputs for two alarm lights, one for oil and one for coolant, are provided by the controller. The alarms are open-drain outputs that will drive incandescent lights of a similar style and generation to the ones currently in the P51’s cockpit. A solid-state relay such as Diodes Inc ZXMS6004N8-13 self-protected load switch will be used to actuate these outputs. It is assumed the lights will be driven at a +24V level, although a +5V or other level would also be possible due to the open-drain nature of this interface.

The coolant light will come on if the coolant temperature exceeds the maximum normal temperature. The oil light will come on if the oil temperature exceeds the maximum normal temperature. If an alarm light illuminates, the system is not functioning correctly in AUTO mode, and the pilot should operate the door in manual mode.

4.3 BLE Connection with In-Cockpit Display

The Bluegiga BLED112 Bluetooth® Low Energy Dongle (Figure 4) is used to provide messaging to an attached device or tablet concerning current temperatures, door positions, and logging of temperature history.

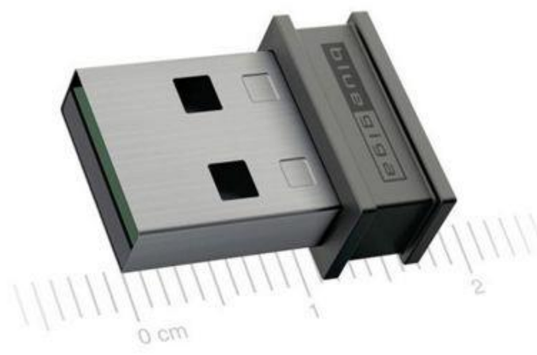

Figure 4: BLE Dongle

The USB dongle has a virtual COM port that enables seamless host application development using a simple application programming interface.

4.4 Thermal Sensors for Oil and Coolant

The PCB will be designed to accept any 3-terminal PT100 probe (platinum wire resistive temperature device, calibrated to 100 Ohms of resistance at 0 degrees Celsius).

Figure 5: Omega PT100 RTD Device

Figure 5 shows some example RTD measurement devices available from Omega Engineering. This particular example shows a PR-26 series connector that is available in ¼” diameter with 6” length (can be custom ordered down to 2” length), with 1/2NPT, 3/8NPT, and 1/4NPT mounting thread options.

If possible a probe compatible with the existing oil and coolant wells should be selected, but if a special adapter is required a generic wand-style probe can be selected and an appropriate fixture designed to retain it in the P51’s coolant and oil streams.

4.5 Door Actuators for Oil and Coolant

A schematic of the door actuator is shown in Figure 6. The coolant actuator is rated at 1/10th horsepower (which is 3A @ 24V input), and the oil actuator is rated at 1/30th horsepower (1A @ 24V input).

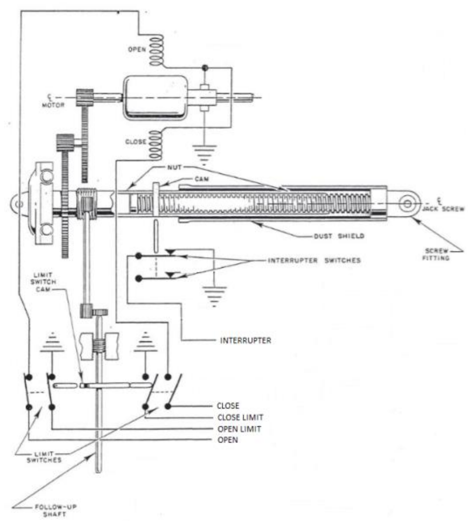

Figure 6: Door Actuator Schematic

In the automatically-controlled operation, OPEN and CLOSE outputs will be driven through an automotive-rated high side switch, Infineon BTT60501EKAXUMA1. Hardware logic will prevent both open and close circuits from being driven at the same time in case of software malfunction, to prevent permanent damage to the actuators. T

When MANUAL mode is selected using the cockpit controls, these high side switches can be bypassed and the OPEN and CLOSE outputs driven directly from the momentary action of the cockpit control switch.

The INTERUPT, CLOSE LIMIT, and OPEN LIMIT inputs will be filtered and ESD-protected on the PCB before the signals are passed to the main processor.

5 Internal Interfaces

5.1 Battery Input Protection

The +24V power rail is supplied by a combination of the plane's battery and the engine's DC generator. It will require filtering against typical automotive/avionic noise, load dump, and reverse battery connection.

The LT4356MP-1 surge stopper will be used to isolate low voltage circuitry from damaging spikes and surges found in automotive, avionic and industrial systems. The LT4356 also guards against overloads and short circuits, and withstands input voltage reversal due to a reversed-battery condition.

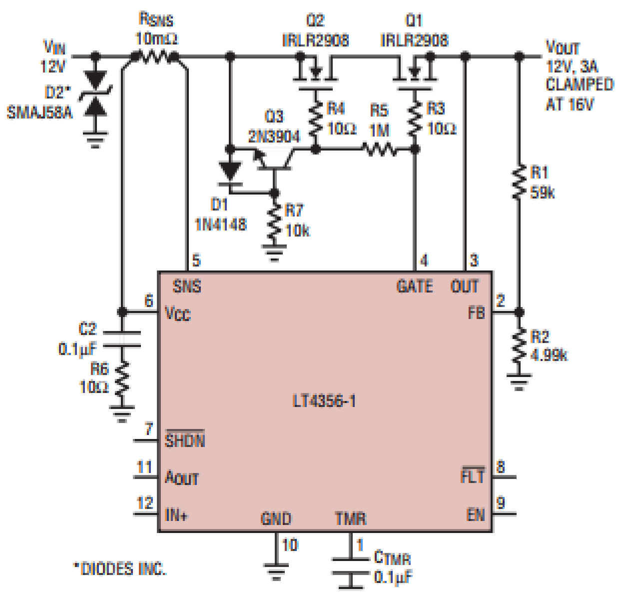

Figure 7: LT4356MP-1 Surge Stopper

The configuration shown in Figure 7 shows a typical configuration for a 12V battery connection. The circuit used here will be very similar but the voltage doubled for 24V operation, 32V clamp, and a 1A current limit.

5.2 Main Processor

The selected microprocessor is ST Electronics STM32F412VET3. It comes in a 100-pin LQFP package with -40C to 125C range, 100 MHz ARM Cortex-M4 processor, and additional peripherals as shown in Figure 8.

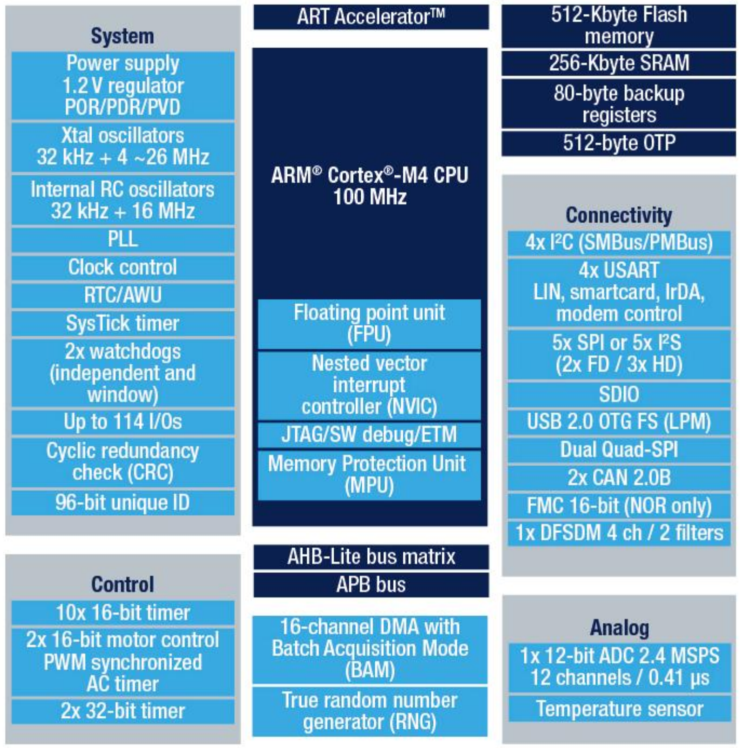

Figure 8: STM32F412xE Series Microcontroller

External crystals will be provided to clock the 32.768 kHz RTC and the main processor.

The development board that will be used to support this project is 32F412GDISCOVERY.

5.3 Flash Storage for Logging

256Mbits (32 Mbytes) of storage is provided by a single part, the Cypress Semiconductor S25FL256LAGMFN000. This size is anticipated to be more than sufficient for data logging purposes. The flash chip is temperature rated from -40C to 125C, operates at 3.3V logic level, and supports a SPI or Quad-SPI interface to the main processor. The device package is 16-SOIC.

5.4 Temp Sensor Conditioning Circuits

A 4-terminal PTD100-type RTD sensor will be used externally, and will require some signal conditioning prior to being read by the onboard ADC. An example of such a circuit (but for a 3-terminal device) is shown in Microchip Inc.'s App Note 687 in Figure 9.

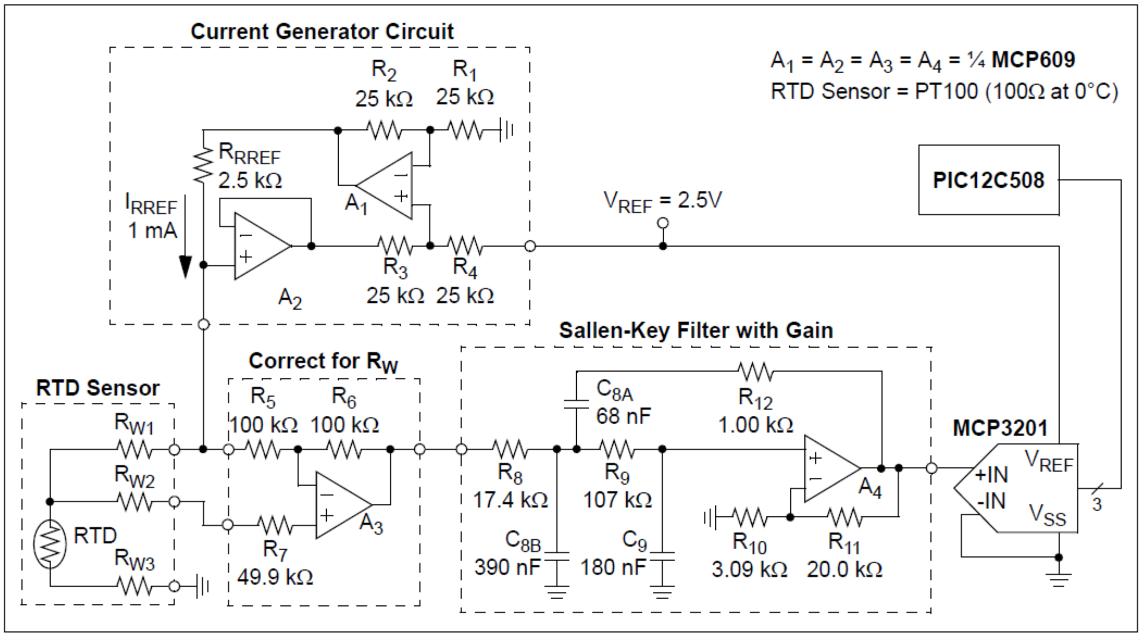

Figure 9: RTD Measurement Circuit (Microchip AN687)

A floating 1mA constant-current source will feed each of the RTD devices, and the ground connection of each RTD will return via the wiring harness and terminate on the PCB.

In this figure, one op-amp stage is then used to cancel the resistance of the wiring that leads to the sensor (this is important as the resistance of the wiring will vary with temperature and can introduce both constant and temperature-dependent error). With a 4-terminal RTD sensor arrangement Kelvin connections are provided from both the top and bottom of the RTD, and an instrumentation amplifier cancels out any common mode (not shown in the figure, but fulfilling the same purpose as the "Correct for Rw" section). An instrumentation amplifier with a gain of 2 will be used for this application.

A final op-amp stage provides low-pass filtering to reduce noise and provide anti-aliasing, and gain to increase the temperature resolution of the ADC. In the case shown a 2nd order 10Hz cutoff filter was selected, and a gain of 7.47. With the first stage instrumentation amplifier gain of 2x, the total gain is 14.94. Over a temperature range of -20 C to 175C the RTD resistance will vary from approximately 90 Ohms to 167 Ohms, giving an output reading of 1.345 V to 2.494 V at the ADC, with a resolution of approximately 0.11 degrees C/LSB for a 12-bit converter referenced to 2.5 V.

Adjustments to the above circuit both in terms of component values and component selection may be required, but the circuit provides a reference point for the design.

6 System Support

6.1.1 Reset

The STM32 microcontroller implements internal power-on reset (POR), power-down reset (PDR), and brownout reset (BOR). An external pushbutton will be provided for debug use during software development to manually trigger the reset of the system. The pushbutton will not be exposed for use in the field.

6.1.2 Clocking

The main processor will have two clocks provided by external crystals.

The main crystal, NDK NX3225GD-8MHZ-STD-CRA-3, will operate at 8 MHz. It will connect to the processor's PLL to generate an internal 100 MHz clock to operate the processor. The processor will then use that to derive clocks to drive any peripherals as necessary.

The second crystal, NX3215SA-32.768K-STD-MUS-2, is a 32.768 kHz real-time-clock (RTC) oscillator. It supplies the internal timekeeping hardware on the processor, which will aid in logging of data recorded by the system. The RTC sub-system will not be battery-backed, meaning only relative passage will be recorded in the logs.

6.1.3 JTAG/Debug

The ST-LINK/V2 in-circuit debugger/programmer for STM32 will be used for debug and programming of these units.

Figure 10: ST-LINK/V2 Debugger/Programmer

To that end, a Tag-Connect TC2050-ARM2010 PCB footprint, with a cable and adapter to mate directly to the ST-LINK/V2 will be provided.

7 Power

7.1 System Power

Power is provided to the system from the aircraft's nominally +24V system. It is filtered through a LT4356MP-1-based load dump/reverse battery protection circuit to prevent damage to the digital circuits in case of issues with the +24V system.

A Linear Tech LT8608 1.5A synchronous regulator generates a precise +5V0 from the input voltage, which is used to drive the BLE transmitter and also fed to an LDO for powering the main processor.

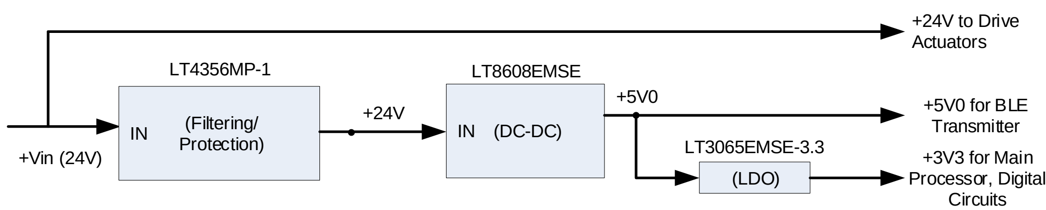

Figure 11: Power System Block Diagram

7.2 Sequencing

The microprocessor and all on-board peripherals are powered from a single 3.3V supply so no special sequencing is required.

The BLE functionality is supplied by an external USB-based dongle powered off the 5V rail. A suitable time delay may be required before the USB device can be enumerated, but no power sequencing will be required.

7.3 Power Consumption

An estimate of the total power draw in worst case (all peripherals turned on and running) is shown in Table 11. This allows sizing of the power supplies and wiring for the unit.

Table 11: Actuator Controller PCB Power Consumption

	+3V3	+5V0	+24V Bus				
	3.3	5	24				
Main Processor	70.0			0.23 W			
Op-amps, misc	20.0			0.07 W			
NOR Flash	60.0			0.20 W			
USB-BLE Dongle		44		0.22 W			
Actuator - Oil			1000.0	24.00 W			
Actuator - Coolant			3000.0	72.00 W			
					Regulat	Efficie	Loss
Regulator +3V3	150.0 →	150.0			LDO	66%	255.0 mW
Regulator +5V0		194.0 →	44.9		DCDC	90%	22.5 mW
		Total:	4044.9	mA			0.3 W
		Total:	97.1	W			

The majority of the power consumed is dissipated outside of the unit, in the actuators. Approximately 1 W from the 5 V bus and regulators will be dissipated on board the PCB in worst case. Assuming 0.06 Ohms on resistance for the actuator relays, the oil actuator relay would dissipate 0.06 W, and the coolant relay dissipates 0.54 W. The total peak PCB dissipation is then around 1.6W when actuators are active, with probably less than 1 W average since actuators do not see 100% duty cycle and neither does the NOR flash which logs data.

8 Mechanical Requirements

8.1 Board Mechanical Diagram

The product enclosure will consist of an aluminum box with holes drilled to accept the circular Milspec connectors. A proposed part number is Hammond Manufacturing 1550WHBK, as shown in Figure 12 and Figure 13.

Figure 12: Enclosure Image

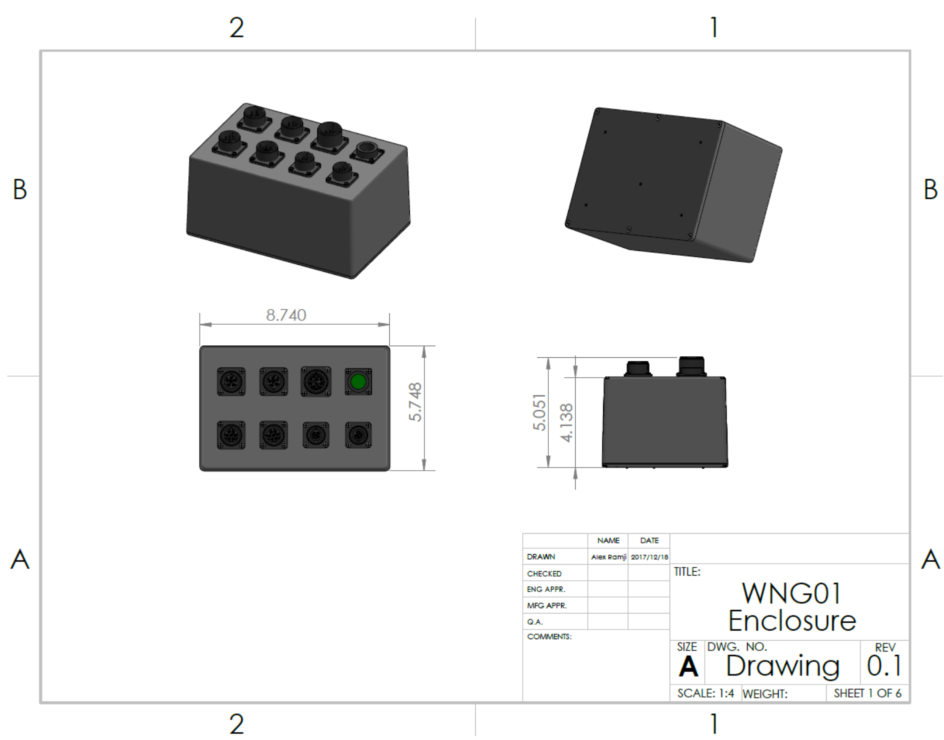

Figure 13: Enclosure Drawing

8.2 Layout

The PCB size can be at most 5" x 8" based on an examination of typical enclosures that might be suitable to hold the number of circular mil-spec connectors required. A PCB of that size would be more than required for the electrical components; however, a larger PCB might ease the component placement and routing effort so the final dimension can be expected to be around that maximum size.

8.2.1 PCB Information

Board Criteria	Description
Schematic name	WNG01 Actuator Controller
Schematic number	SCH-WNG0101-0101
PCB name	WNG01 Actuator Controller PCB
PCB fab number and rev	PCB-WNG0101-0100
PCB assy number and rev	ASY-WNG0101-0101
PCB fab vendor name	TTM Toronto
PCB fab vendor contact	
Estimated pin count	
Layout Approximate Start date	
Layout Approximate End date	
Schematic capture tool	Altium
Layers count	6 layers
Board Thickness	0.062"
PCB target impedance	50Ω single-ended, 90Ω differential (USB)
Finish	ENIG
Tented vias	Yes, Plugged and Filled
Minimum trace width	4 mil
Minimum via drill size	8 mil
ICT Test Points	NO
Place ICs	PRIMARY SIDE
Place discretes	BOTH SIDES
EMI (FCC) Requirements	

Table 12: PCB Information

8.2.2 Proposed PCB Stack up

The proposed stack-up is a 6 layer design as detailed below. Contact will be made with the final PCB vendor prior to commencing layout activities to tweak any parameters as necessary.

Imp	Lyr	Type	Image	Foil	Plt (Mil)	Thk (Mil)	Er	MATERIAL	Vendor	Family
	smt					0.7				
	Drill1									
3xΩ	L1	Signal		0.5oz	1.1		0.00	Hoz - 0.7 mil	Gould	Foil
						2.52	3.70	1080	Panasonic	R-1650
 3xΩ	L2 L3	Power / Ground Signal		1oz 1oz	0	4	3.77	Core 4 mil 1/1	Panasonic	R-1755
							4.00	2116	Panasonic	R-1650
						7.82	4.00	2116	Panasonic	R-1650
						21	4.28	Core 21 mil 0/0	Panasonic	R-1755
							4.00	2116	Panasonic	R-1650
						7.82	4.00	2116	Panasonic	R-1650
3xΩ	L4 L5	Signal Power / Ground		1oz 1oz	0	4	3.77	Core 4 mil 1/1	Panasonic	R-1755
						2.52	3.70	1080	Panasonic	R-1650
3xΩ	L6	Signal		0.5oz	1.1		0.00	Hoz - 0.7 mil	Gould	Foil
	Drill1									
	smb					0.7				

Impedance Report

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Layer model	Trace (design)	Differential Spacing *-not pitch-* (design)	Coplanar Spacing (design)	Ref. Plane Top	Ref. Plane Bot.	Desired Imp. (Ω)	Imp. Tolerance	Calculated Imp.(Ω)
L01 coated_microstrip_1b	5.00				L2	50.0	+/-10%	49.0
L01 edge_coupled_coated_microstrip_1b	4.00	9.00			L2	100.0	+/-10%	99.8
L01 edge_coupled_coated_microstrip_1b	4.30	5.50			L2	90.0	+/-10%	90.3
L03 offset_stripline_1b1a	5.50			L5	L2	50.0	+/-10%	49.8
L03 edge_coupled_offset_stripline_1b1a	4.50	13.00		L5	L2	100.0	+/-10%	99.9
L03 edge_coupled_offset_stripline_1b1a	4.30	5.50		L5	L2	90.0	+/-10%	89.7
L04 offset_stripline_1b1a	5.50			L2	L5	50.0	+/-10%	49.8
L04 edge_coupled_offset_stripline_1b1a	4.50	13.00		L2	L5	100.0	+/-10%	99.9
L04 edge_coupled_offset_stripline_1b1a	4.30	5.50		L2	L5	90.0	+/-10%	89.7
L06 coated_microstrip_1b	5.00				L5	50.0	+/-10%	49.0
L06 edge_coupled_coated_microstrip_1b	4.00	9.00			L5	100.0	+/-10%	99.8
L06 edge_coupled_coated_microstrip_1b	4.30	5.50			L5	90.0	+/-10%	90.3

8.3 External Engine Running Indicator

An external engine running indicator is to be provided on the new cockpit connector. It will require a normally open oil pressure switch, which is grounded to the aircraft frame (battery negative, or “GND”) when the engine is running.

9 Environmental & Regulatory Compliance

9.1 Environmental

Component selection should be targeted to an industrial/automotive range (-40C to 85C), with extended industrial/automotive under-the-hood (-40C to 125C) selected whenever possible.

9.2 EMC

This design uses engineering best practices to meet FCC and CE requirements, although Nuvation is not responsible for testing or meeting these requirements.

A commercial off-the-shelf (COTS) BLE USB dongle is used to ease the burden of any radio testing that may be required.

External interfaces are ESD protected using engineering best practices.