Penn State Lunar Lion Team

Test Readiness Review Package

Tuesday, July 21, 2015

The Pennsylvania State University
Lunar Lion Team

Version 2.0

Date: 7/21/2015

OVERALL TABLE OF CONTENTS

PENNSTATE

Puma Flight Testing – Operational Readiness

The Pennsylvania State University
Lunar Lion Team

Operational Readiness Signature Page

<u>Instructions</u>

The following signatures indicate the approval of the undersigned of this document(s) and/or procedure(s) to be used for testing as described within. Once signed, the document is locked in its current form. If any updates or revisions are made, a formal revision must be produced and reapproved.

Submitted by:

____ **Date:** ________________

John Targonski
Integration and Test Lead

Program Approval:

____ **Date:** ________________

Michael Paul
Mission Director

____ **Date:** ________________

TBD
Research and Development Engineer

____ **Date:** ________________

Kevin Myers
Occupational Safety and Environmental Health Specialist

REVISION DESCRIPTION and HISTORY			
Rev	**Issue Date**	**Description and History**	**Initiator**
2.0.3	07/21/2015	New Operational Readiness Plan for Puma Flight Testing Campaign at Larson Test Track	John Targonski

1. Introduction

The Lunar Lion Team's Puma craft test program employs graduate and undergraduate students in the design, assembly, integration and operation of a rocket propelled craft to test the systems that have been created by the students on the team.

The students executing this work are required to receive training and satisfactorily demonstrate proficiency to the Test Director on H2O2 handling, usage, material compatibility, as well as general lab and fire safety prior to receiving certification for a specific test team role.

Different students fill different roles over time, so each role is defined below, and the necessary training required identified for each role. Periodic re-training is required for all positions.

Only trained students are allowed to fill these roles and actively participate in testing once their certification has been entered in this document. Proper and up-to-date training must be confirmed for each team member prior to testing. Role authorization must be indicated in this binder by completion of Personnel Training Checklist, signed off by Integration & Test Lead or Deputy.

Version Tracking

Description	Version
Puma P&ID	2.0
LabVIEW Layout	2.0
Test Day Supplies Check List	2.0
Personnel H2O2 Fill Layout	2.0
Personal Test Layout	2.0
Puma Static Test Setup Diagram	2.0.1
Puma Flight Test Setup	2.0
Pump Fitting Assembly Diagram	2.0
Auxiliary Box Functional Block Diagram	2.0

DOCUMENT OVERVIEW

Sheet	Description
Change Log	List of changes per version, things needed to be changed, and notes
H2O2 Usage Log	Documents peroxide used to fill tank, monitors peroxide in waste drum.
Component Nomenclature	Table of the Common Name, Short Name, and Description of each component
LabVIEW Display	Screenshot of LabVIEW GUI
P&ID	Drawing of Pluming and Instrumentation in relative to each component
Personnel H2O2 Fill Layout	Diagram of the locations of personnel during a H2O2 fill
Personnel Test Layout	Diagram of the locations of personnel during flight
Pre-Test Briefing	Summary of topics to touch on for pre-test briefing
Test Day Supply Checklist	List of all supplys needed to complete a full day of testing
SOP	Standard Operating Procedures - Short overview of required PPE and general information
Abridged Test Start Up & Initial Test Checklist	Checklist of critical processes that must be completed prior to testing. Intended to compliment Start up & Initial Test Procedure
Abridged Recycle & Re-Test Checklist	Checklist of critical processes that must be completed prior to testing. Intended to compliment Recycle & Re-Test Procedure
Battery Swap Procedure	Details the procedure for replacing depleded batteries with fully powered batteries for continued operation
N2 Fill Procedure	Details the procedure for refilling Puma with N2 for a powered, safe to approach state
Startup & Initial Test Procedure	Details the procedure for readying the system for testing
Recycle & Re-Test Procedure	Details the procedure for readying the system for testing again after a previous successful test or aborted test
Recycle & Shutdown Procedure	Details the procedure for flushing Puma and storing Puma
Puma Static Test Diagram	Diagram of setup for a static test
Puma Flight Test Diagram	Diagram of setup for a flight test
Pump Fitting Assembly Diagram	Schematic of Puma pump setup and visual indcators of locations to be assembled and disassembled during proceedures
Auxillary Box Diagram	Funcational block diagram of the auxiliary box that powers Puma and pump during procedures
Power Connector Locations and Soft Kill Abort Values	List of electronic sensors with corresponding location on power box and operating valve that triggers abort.
Contingency Procedures	List of actions to take in the event of an anomaly.
Aborts Record	Documentation of all aborts triggered
Emergency Reporting Form	Contact Information and form in case of emergency

Who	Title	Abv	Role
Systems Personal	Test Controller	TC	Follows the steps of a single sequence section with permission from TD
Integration & Test Lead	Test Director	TD	Gives TC permission to advance to next sequence section
Trained Inspector and Safety Authority	Inspector and Safety Authority	ISA	Verify that all testing is following the safety protocols as defined in the Unit Specific Safety Plan. Inspector and Safety Authoritys will have the ability to stop testing if any unsafe activities are observed.
Larson Test Track Full Time	Technician	Tech	Gives TD permission to prepare for testing and begin Procedure or Sequence (except automatic shutdowns)

Change Log

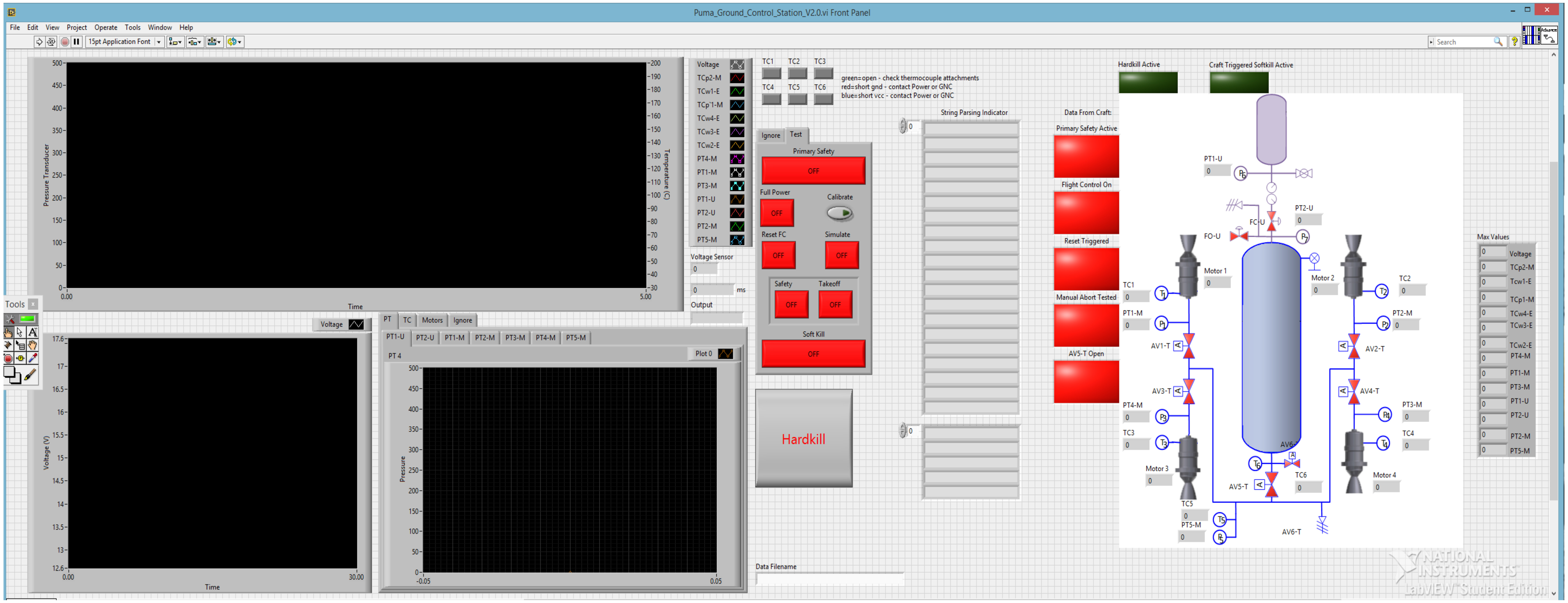
Change Made	Date	Initials	Version

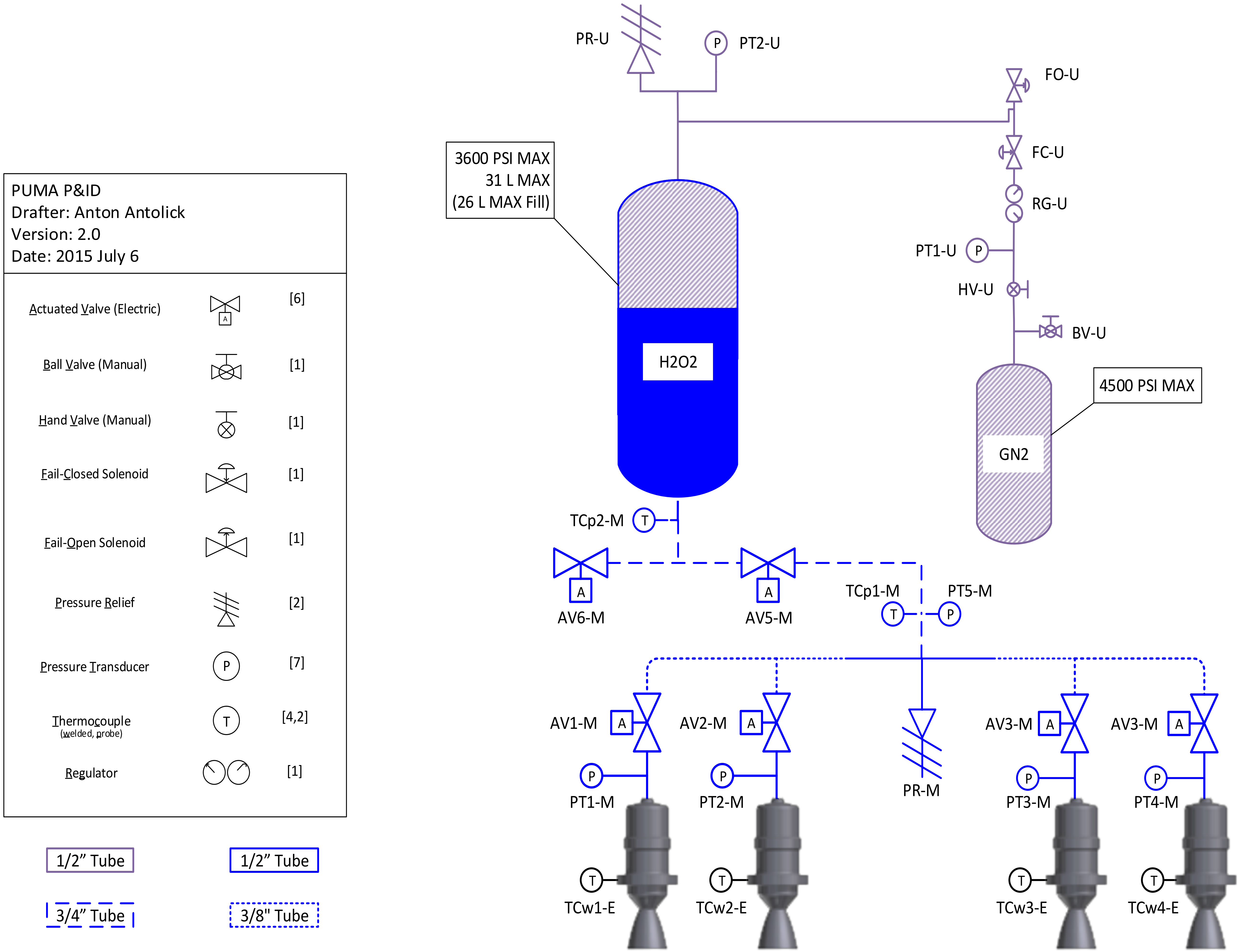
H2O2 Usage Log

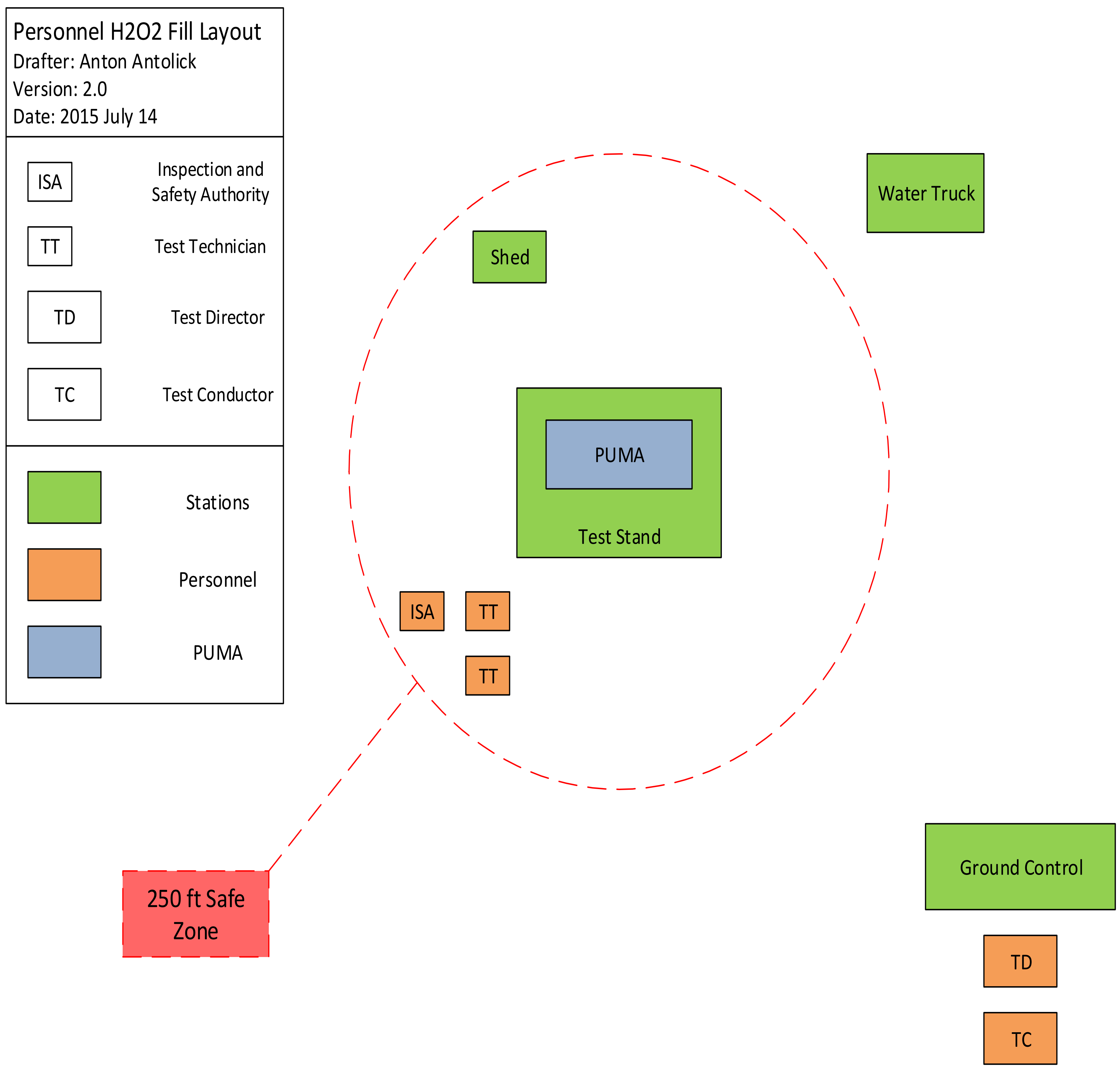
Date	Test Number	Volume in propellant tank (gal)	Estimated waste from fill (gal)	Additional waste from abort triggered or other event (gal)	H2O2 volume in collection drum (gal)	Concentration (mass)

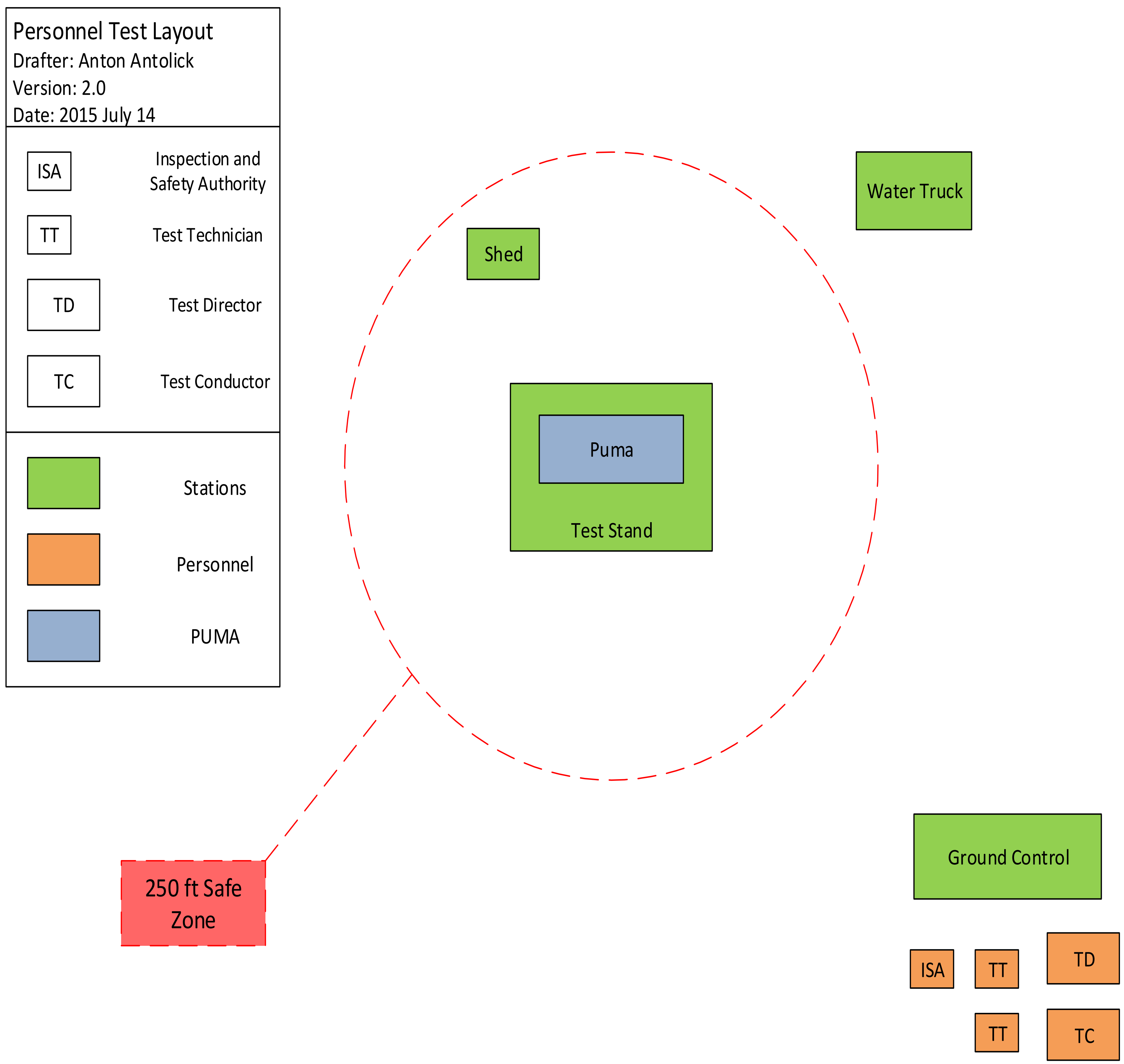
Component Nomenclature		
Common Name (Goes in Action)	**Component Name**	**Description (Long Name)**
Ullage		
Pressurant Tank Pressure Transducer	PT1-U	Pressurant Tank Pressure Transducer
Propellant Tank Pressure Transducer	PT2-U	Propellant Tank Pressure Transducer
Pressurant Vent Valve	FO-U	Pressurant Fail Open Vent Valve
Pressurant Iso Valve	FC-U	Pressurant Fail Close Isolation Valve
Pressurant Fill Valve	BV1-U	Pressurant Fill Vent Ball Valve
Pressurant Hand Valve	HV-U	Pressurant Hand Valve
Same as description	RG-U	Pressurant Regulator
Same as description	PR-U	Pressurant Pressure Relief
Manifold		
Engine Throttle Valve	AV1-M	Throttle Actuated Valve
Engine Throttle Valve	AV2-M	Throttle Actuated Valve
Engine Throttle Valve	AV3-M	Throttle Actuated Valve
Engine Throttle Valve	AV4-M	Throttle Actuated Valve
Propellant Tank Remote Isolation	AV5-M	Iso Actuated Valve
Propellant Tank Fill/Dump	AV6-M	Dump Actuated Valve
Same as description	PR-M	Manifold Pressure Relief
Plumbing Lines Thermocouple	TCp1-M	Manifold Probe Thermocouple Midsteam of Plumbing Lines
Propellant Tank Thermocouple	TCp2-M	Manifold Probe Thermocouple Downstream of Propellant Tank
Engine 1 Pressure Transducer	PT1-M	Manifold Pressure Transducer Upstream of Engine 1
Engine 2 Pressure Transducer	PT2-M	Manifold Pressure Transducer Upstream of Engine 2
Engine 3 Pressure Transducer	PT3-M	Manifold Pressure Transducer Upstream of Engine 3
Engine 4 Pressure Transducer	PT4-M	Manifold Pressure Transducer Upstream of Engine 4

Plumbing Lines Pressure Transducer	PT5-M	Manifold Pressure Transducer Midstream of Plumbing Lines
Engine		
Engine 1	E1	Peroxide Engine 1
Engine 2	E2	Peroxide Engine 2
Engine 3	E3	Peroxide Engine 3
Engine 4	E4	Peroxide Engine 4
Same as description	TCw1-E	Engine 1 Weld-On Thermocouple
Same as description	TCw2-E	Engine 2 Weld-On Thermocouple
Same as description	TCw3-E	Engine 3 Weld-On Thermocouple
Same as description	TCw4-E	Engine 4 Weld-On Thermocouple


Puma_Ground_Control_Station_V2.0.vi Front Panel
Pressure Transducer
Temperature (C)
Time
Voltage (V)
Pressure
Primary Safety
Full Power
Calibrate
Reset FC
Simulate
Safety
Takeoff
Soft Kill
Hardkill
green=open - check thermocouple attachments
red=short gnd - contact Power or GNC
blue=short vcc - contact Power or GNC
String Parsing Indicator
Data From Craft:
Primary Safety Active
Flight Control On
Reset Triggered
Manual Abort Tested
AV5-T Open
Hardkill Active
Craft Triggered Softkill Active
Voltage Sensor
Output
Data Filename
Max Values


PUMA P&ID
Drafter: Anton Antolick
Version: 2.0
Date: 2015 July 6
Actuated Valve (Electric) [6]
Ball Valve (Manual) [1]
Hand Valve (Manual) [1]
Fail-Closed Solenoid [1]
Fail-Open Solenoid [1]
Pressure Relief [2]
Pressure Transducer [7]
Thermocouple (welded, probe) [4,2]
Regulator [1]
1/2" Tube
1/2" Tube
3/4" Tube
3/8" Tube
PR-U
PT2-U
FO-U
FC-U
RG-U
PT1-U
HV-U
BV-U
3600 PSI MAX
31 L MAX
(26 L MAX Fill)
H2O2
4500 PSI MAX
GN2
TCp2-M
AV6-M
AV5-M
TCp1-M
PT5-M
AV1-M
AV2-M
PR-M
AV3-M
AV3-M
PT1-M
PT2-M
PT3-M
PT4-M
TCw1-E
TCw2-E
TCw3-E
TCw4-E


Personnel H2O2 Fill Layout
Drafter: Anton Antolick
Version: 2.0
Date: 2015 July 14
ISA
Inspection and Safety Authority
TT
Test Technician
TD
Test Director
TC
Test Conductor
Stations
Personnel
PUMA
Water Truck
Shed
PUMA
Test Stand
ISA
TT
TT
250 ft Safe Zone
Ground Control
TD
TC


Personnel Test Layout
Drafter: Anton Antolick
Version: 2.0
Date: 2015 July 14
ISA
Inspection and Safety Authority
TT
Test Technician
TD
Test Director
TC
Test Conductor
Stations
Personnel
PUMA
Water Truck
Shed
Puma
Test Stand
250 ft Safe Zone
Ground Control
ISA
TT
TD
TT
TC

Pre-test Briefing

At the start of each test session, the Test Director will gather all participants for a pre-test briefing, including test personnel and any observers or visitors. The Test Director will inform the assembled:

- That they must follow the instructions of the Test Director at all times
- Of the role of each person on the test team
- The personnel layout during critcal phases of testing procedures
- That the test team must adhere to the signed and approved test procedures
- Of the goals of the day's testing including number and expected duration of each test firing
- That safety comes first
- Refresh how to operator Puma's regulator and review that Pressurant Fill Valve will vent tank if opened
- That anyone and everyone must speak up if they see anything out of order, regardless of their area of responsibility, and regardless of the impact a delay

The Test Director will also:

- Confirm that the test team's training certifications are current and valid
- Remind the team that handling H2O2 is challenging and hazardous
- Refresh the procedures on how to use water truck
- Indicate the location for personnel assembly in the case of a fire
- Instruct any observers and visitors that they are to immediately clear the area and go to the emergency assembly point if told by any member of the test
- Walk through the contingency procedures with the test team

Test Day Supplies Checklist	Check Mark
Fill out everyday before testing	
Stored in Van	
Walkie-Talkies to communicate between GC and test area	
Wallkie-Talkie to communicate with test track personnel	
Extension cord for control center	
Power strip for control center	
Safety Glasses	
Nitrile Gloves	
Three Tyvek coverall Suits	
Three 22 mil Nitrile Gloves	
Three Face Shields	
Folding chairs	
Canopy tent	
Health Monitoring SD card	
Flight Controller SD card	
Stored in Shed	
Puma on Cart	
5 one-gallon DI jugs	
10 gallon DI carboy	
2 five-gallon DI carobys	
2 five gallon empty DI waste containers	
Trickle changer for tractor battery	
Multimeter	
Grey tote for rinsing/storing H2O2 clean components	
4 come along wrenches	
Steel Wagon	
Secondary container for steel wagon	
10 gallon carboys with H2O2(stored in seprate shed)	
Nitrogen canister	
Blue Bucket	
Pump setup	
Auxillary box	
1 Torque wrench	
2 variable wrenches	
Aluminum honeycomb sheets	
Small waste container for peroxide	
4 Static testing brackets	
8 Static testing 8inch bolts	
3 foot step ladder	
4 LiPo batteries	
Mag probe	
Auxillary outlet connector	
Auxillary to Puma connector	
Extension cord for auxillary box	

Standard Operating Procedure

Caution: This system uses corrosives, high pressure, and oxidizers

Personal Protective Equipment (PPE) required:
• Basic PPE is to be worn by all personnel within the test zone (250 feet of the test stand) when performing DI fill or manipulating pressurant tank
• Full PPE is to be worn by all personnel within the test zone when H_2O_2 is out of the shed.
• Basic PPE: Closed Toe Shoes, Long Pants, powder free gloves and goggles.
• Full PPE: Tyvek coverall suit, boots, and splash shields (over goggles) when handling H_2O_2.
General Considerations:
• No untrained or unauthorized personnel are allowed within the test zone at anytime.
• Any test participant or bystander has the authority and responsibility to announce any seen unsafe conditions.
• It is important to notify all Test Track personnel of testing status. Ensure the test area is clear and remains so throughout the day.
• H_2O_2 Storage Tank will remain in secondary containment in designated storage shed when not filling propellant tank on test stand
• The **Start Up & Initial Test, Recycle & Re-test,** and **Recycle & Shutdown Procedure** forms should be completed for each test and kept for our records to identify exact testing steps/procedures that were performed for a particular test
Pre-Testing:
• Preform a communications check with walkie-talkies.
• Notify necessary personnel that system will be turned on.
• Follow actions from **Start Up & Initial Test Procedure**. System is ready for testing.
Testing:
• Commence testing via LabVIEW by executing *Test Script*
1. If test is successful, continue monitoring *System Standby Aborts* until next test begins. Follow **Recycle & Retest Procedure** if need to re-fill tank.
2. If test is unsuccessful and *Soft Kill Script* will be executed.
Shutdown:
• Follow actions from **Recycle & Shutdown Procedure**.
• Once test zone is safe to enter (propellant lines depressurized), notify all necessary personnel that testing has completed.
Note: For serious emergencies that could result in injury (fire, failure to depressurize, H_2O_2 liquid spill, etc.), follow emergency procedures will be followed and no students will be let into the test zone until the area is cleared by the TD and ISA.
• Power, control or valve failure, pressure leak, H_2O_2 spill, and abort triggered -- Follow the procedures outlined in **Contingency Procedures**.
• The Hard Kill command de-powers the entire system. All fail safe valves go to their intended configuration.

Abridged Test Startup & Initial Test Checklist

PPE required:	Saftey glasses when maniupulating pressurant tank Closed-toe shoes Long pants without cuffs Powder-free gloves when handling any components during assembly/ disassembly and DI water fill Full PPE: Tyvek coverall suit, boots, 22 mil nitrile gloves, and splash shields (over glasses) when handling H2O2
Supplies Needed:	Walkie-Talkie, Two 4 Cell LiPo Batteries, Mag Probe, Health Monitoring SD Card, Flight Profile SD Card, Auxillary Box with Connectors, Extension Cord, Honeycomb, Static Setup Materials, Flight Setup Materials, 3' Step Stool, Torque Wrench, Adjustable size wrench, H2O2 carboy in wagon
Test Purpose:	

Action	Completed	Notes
Review day's objectives and fill out Test Purpose above		
Review contingency procedures		
Make sure all necessary PPE for testing (as prescribed above) is clearly laid out		
Fill out Supply Check List		
Install Health Monitoring and Flight Profile SD card		
Simulate the Flight Profile to ensure it is correct		
Cycle and visually confirm that all valves respond when told		
If static test, bolt all four of Puma's arms to test stand		
Attach all three cable guides onto Puma		
Fill propellant tank and propellant lines with DI, then drain tank		
Run Flight Profile to flush DI through lines		
Insert batteries on Puma		
Fill propellant tank with H2O2 using pump setup		
Set delivery pressure to desired Testing Pressure		
Remove any non-critical items from Test Area		
Confirm all personnel is beyond 250 ft test zone		
Close FO-U and open FC-U and AV5-M		
Verify there is enough battery to perform test		
Test		

Testing Pressure	
Flight Profile #	
Test Duration	
Max Height	

Test Number ____________________
Test Date ____________________
Test Conductor ____________________
Test Director ____________________
ISA ____________________
Test Technicians ____________________

Abridged Recycle & Re-Test Checklist

PPE required:	Saftey glasses when maniupulating pressurant tank Closed-toe shoes Long pants without cuffs Powder-free gloves when handling any components during assembly/ disassembly and DI water fill Full PPE: Tyvek coverall suit, boots, 22 mil nitrile gloves, and splash shields (over glasses) when handling H2O2
Supplies Needed:	Walkie-Talkie, 3' Step Stool, Pump Setup, Auxillary Box with connectors, Adjustable size wrench, small waste container, two 5-gal DI carboys, 2 1-gal DI jugs, 1 10-gal H2O2 carboy in wagon
Test Purpose:	

Action	Completed	Notes
TD approval to proceed with Recycle & Re-Test Procedure		
Check Battery Level is enough for an additional test		
Check for enough N2 for an additional test		
Refill H2O2 if necessary		
Set delivery pressure to desired Testing Pressure		
Remove any non-critical items from Test Area		
Confirm all personnel is beyond 250 ft test zone		
Close FO-U and open FC-U and AV5-M		
Verify there is enough battery to perform test		
Test		

Testing Pressure	
Flight Profile #	
Test Duration	
Max Height	

Test Number ____________________
Test Date ____________________
Test Conductor ____________________
Test Director ____________________
ISA ____________________
Test Technicians ____________________

Section BS: Battery Swap Procedures

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
All Personnel handling Puma must be wearing appropriate PPE									
BS.01	If craft has H2O2, personnel handling Puma MUST apply following PPE: **Safety glasses, Tyvek coverall suit, boots, face shield, 22 mil nitril gloves**								
BS.02	If craft has H2O2, personnel handling Puma MUST have previously completed following training: **Lab Safety, H2O2 Safety, and be approved to perform H2O2 fill ***								List of trained personnel is available in Personnel Readiness
BS.03	Retrieve grounding strap and two replacement 4-cell LiPo batteries and check voltage with multimeter*								Check voltage is within +/- 0.2 V of 14.8 Volts
BS.04	Click "Full Power" button to off position		Light indicator should turn green on bottom right corner of power box						
BS.05	Close pressurant vent valve	**FO-U**							
BS.06	Click "Primary Safety" button to *off* position								
BS.07	Place 3' stool next to test stand								
BS.08	Connect grounding strip to Puma's Chassis								
BS.09	Turn switch to *off* position located on right side of Puma power box		Light indicator should turn off on bottom right corner of power box						
BS.10	Press stop button on LabVIEW*								Located at top left corner of LabVIEW
BS.11	Unlach and open battery compartment door slowly								
BS.12	Release battery guard and remove batteries from compartment								
BS.13	Replace depleded batteries with fully charged batteries*								Must replace both batteries
BS.14	Close and lach battery compartment door slowy*								Close slowly to avoid pitching wires
BS.15	Turn switch to *on* position located on right side of Puma power box		Light indicator should turn green on bottom right corner of power box						
BS.16	Disconnect ground strip and return batteries to be charged								
BS.17	Name test file under "Test Filename"								
BS.18	Press Run Arrowon LabVIEW*								Located at top left corner
BS.19	Name test file under "Test Filename"*								If shutdown procedures follow name accordingly
BS.20	Click "Calibrate" button on LabVIEW								
BS.21	Verify calibration and click "Ok" to proceed								
BS.22	Ensure all six Thermocouple boxes on LabVIEW are colored grey*								If not, get Test Directors Attention

BS.23	Verify data is nominal								
BS.24	Click "Primary Safety" button to *on* position								
BS.25	Verify battery voltage level on LabVIEW and record in data column at right*								Check voltage is within +/- 0.2 V of 14.8 Volts
BS.26	Open pressurant vent valve	**FO-U**							
BS.27	Click "Full Power" button to on position		Light indicator should turn red on bottom right corner of power box						
BS.28	Please Proceed with the procedures PRIOR to Battery Swap Procedures								

KEY	
Verify operating conditions are satisfactory	(yellow)
Action * indicates a reference to Notes column	

SECTION NF: N2 FILL PROCEDURE

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
All Personnel handling Puma must be wearing appropriate PPE									
NF.01	If craft has H2O2, personnel handling Puma MUST apply following PPE: **Safety glasses, Tyvek coverall suit, boots, face shield, 22 mil nitril gloves**								
NF.02	If craft has H2O2, personnel handling Puma MUST have previously completed following training: **Lab Safety, H2O2 Safety, and be approved to perform H2O2 fill ***								List of trained personnel is available in Personnel Readiness
NF.03	If craft does not have H2O2, all personnel in test area MUST apply following PPE: Safety glasses and nitrile gloves								
NF.04	Verify pressurant iso valve is closed	**FC-U**							
NF.05	Verify pressurant vent valve is open	**FO-U**							
NF.06	Retrieve N2 canister and wheel it over next to test stand								
NF.07	Verify pressurant regulator reads 0 psi, record in data column at right	**RG-U**							
NF.08	Open pressurant hand valve completely	**HV-U**	PT1-U should raise as it is pressurant tank pressure						
NF.09	Record pressure from pressurant tank pressure transducer in data column at right*	**PT1-U**	Value should match left side of regulator						This value is the pressure level of pressurant tank
NF.08	Adjust N2 canister regulator delivery pressure to 0 psi*								Turn counter clockwise until no resistance
NF.09	Verify N2 canister vent needle valve is completely closed								
NF.10	Attach head of N2 canister pressure delievery system to Puma's pressurant fill valve	**BV-U**							
NF.11	Open N2 canister ball valve completely		Left side of N2 canister regulator should increase						
NF.12	Open Puma's pressurant fill valve	**BV-U**							
NF.13	Set N2 canister delivery pressure to 4500 psi	**RG-U**	Puma's pressurant tank pressure should rise						
NF.14	Once Puma's pressurant tank reads 4500 psi, close Puma's pressurant fill valve and record pressure reading in data column at right	**BV-U**							
		PT1-U							
NF.15	Close pressurant hand valve completely	**HV-U**							
NF.16	Adjust Puma's regulator to a delivery pressure of 100 psi	**RG-U**							
NF.17	Adjust N2 canister regulator delivery pressure to 0 psi*								Turn counter clockwise until no resistance
NF.18	Open N2 canister vent needle vavle		Pressure should briefly vent						
NF.19	Reomove head of N2 canister pressure delievery system to Puma's pressurant fill valve	**BV-U**							

NF.20	Wheel and chain N2 canister back in shed								
NF.21	When personnel is in shed, open pressurant iso valve	**FC-U**	Pressurant should vent out of FO-U and PT1-U pressure level should drop to 0 psi						
NF.22	Adjust delivery pressure to 0 psi*	**RG-U**							Turn counter clockwise until no resistance
NF.23	Close pressurant iso valve	**FC-U**							
NF.24	Please Proceed with the procedures **prior** to N2 Fill Procedures								

KEY	
Verify operating conditions are satisfactory	
Action * indicates a reference to Notes column	

START UP & INITIAL TEST PROCEDURE

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *

Testing Info

	Date	Test Number
	Time	Test Technicians
	Test Track Technician	
	Test Conductor	
	Test Director	
	Inspector and Safety Authority	

PPE required:	Saftey glasses when maniupulating pressurant tank
	Closed-toe shoes
	Long pants without cuffs
	Nitrile gloves when handling any components during assembly/ disassembly and DI water fill
	Full PPE: Tyvek coverall suit, rubber boots, 22 mil nitrile gloves, and splash shields (over glasses) when handling H2O2

Supplies Needed:	Walkie-Talkie	Two 4 Cell LiPo Batteries	Mag Probe
	Health Monitoring SD Card	Flight Profile SD Card	Auxillary Box with Connectors
	Extension Cord	Honeycomb	Static Setup Materials
	Flight Setup Materials	3' Step Stool	Torque Wrench
	Blue Bucket	Two Adjustable Wrenches	Pump Setup

	Two 9/16" Wrenches	H2O2 Carboy in Wagon	
Test Purpose:			

Who	Title	Abv	Role
Integration & Test Lead	Test Director	TD	Final operational authority. Gives TC permission to advance to next sequence section.
Personnel trained by TD	Test Controller	TC	Follows the steps of a single sequence section with permission from TD
Personnel trained by TD	Inspector and Safety Authority	ISA	Verify that all testing is following the safety protocols as defined in the Unit Specific Safety Plan. Inspector and Safety Authoritys will have the ability to stop testing if any unsafe activities are observed.
Personnel trained by TD	Test Technician	TT	Supports TC and TD in testing operations. Authorized to change and clean hardware and execute line-item specific actions (except H2O2 fill) as directed by TC.
Larson Test Track Technician	Technician	Tech	Gives TD permission to prepare for testing and begin Procedure or Sequence (except automatic shutdowns)

Note: If any personnel notice an unsafe condition, they have the authority and responsibility to stop the procedures.

SECTION 1: STARTUP SAFETY

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
1.01	Review **Pre-Test Briefing**								
1.02	Review **Contingency Procedures**								
1.03	Fill out **Test Day Supply Checklist**								

1.04	Review days' objectives and fill out Test Purpose above								
1.05	Fill in TBD value of amount of H2O2 for test in **Step 10.11** at data column at right.								
1.06	Notify test track personnel that testing will soon commence								
1.07	Perform a communications check with walkie-talkies between the test stand and the ground control station								
1.08	Turn on ground control computer								
1.09	Retrieve multimeter, two batteries, mag probe, Health Monitoring SD card, Flight Controller SD card, auxillary box, auxillary outlet connector, auxillary to Puma conector, and extension cord								
1.10	Check battery voltage with multimeter*								Check voltage is within +/- 0.2 V of 14.8 Volts
1.11	Place multimeter and batteries back in shed								
1.12	Uncap all four engines								
1.13	Verify that none of the seals on Puma's bolts have been compromised								

SECTION 2: PUMA'S COMMUNICATION VERIFICATION

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
2.01	All personnel in within 250 ft Test Zone MUST apply following PPE: Long pants, closed-toe shoes								
2.02	Place Puma on ground next to test stand with cart								

2.03	Ensure all power cables are attached on Puma								
2.04	Insert Health Monitoring SD Card in Puma								
2.05	Insert Flight Profile SD Card in Puma								
2.06	Ensure that pressurant hand valve is completely closed	**HV-U**							
2.07	Plug battery connectors into auxiliary connector inside power box								
2.08	Press down on auxiliary box red button*		Auxiliary box cant receive power when this button is in down position						This button is located on outlet cord between outlet and auxiallary box
2.09	Plug auxiliary connector into wall outlet								
2.10	Plug auxiliary connector labed "Puma" into Puma								
2.11	Twist red button on auxiliary box clockwise*		This powers the auxilary box. Fan on box should be audible						Fan on auxiliary box should be audible
2.12	Turn switch labed "Puma" to *on* postion located on auxiliary box		Red light imminates						
2.13	Launch LabVIEW								
2.14	Open PUMA_Ground_Control_Station_V2.0.vi								
2.15	Ensure hard kill button is in up position located on ground control								
2.16	Plug in two Ground Control USB cables into computer*								Located on ground control hard kill button

2.17	Turn switch to *on* position located on right side of Puma power box		Light indicator should turn green on bottom right corner of power box							
2.18	Press Run Arrowon LabVIEW*									Located at top left corner
2.19	Click "Calibrate" button on LabVIEW									
2.20	Verify calibration and click "Ok" to proceed									
2.21	Ensure all six Thermocouple boxes on LabVIEW are colored grey*		Grey boxes correspond that all thermocouples are plugged in							If not, get Test Directors Attention
2.22	Verify all Pressure Transducers are reading nominal pressure		All pressure transducers should read ~ 0 psi							
2.23	Verify all thermocouples are reading nominal temperature		All thermocouples should read ~ current temperature outdoors							
2.24	Click "Primary Safety" button to *on* position		LabVIEW "Primary Safety" button should turn green							
2.25	Click "Full Power" button to on position		'Light indicator should turn red on bottom right corner of power box LabVIEW "Full Power" button should turn green							
2.26	Click "Motor" tab									
2.27	Click "Reset FC" button to *on* position		LabVIEW "Reset FC" button should turn green							
2.28	Once "Reset triggered" turns green under Data From Craft, click "Reset FC" button to off position		LabVIEW "Reset FC" button should turn red							
2.29	Click "Simulate" button to *on* position		LabVIEW "Simulate" button should turn green Flight Profile should be displayed under "Motor" tab							
2.30	Verify displayed flight profile is desired flight profile									

2.31	Click "Simulate" button to *off* position								
2.32	Click "Reset FC" button to *on* position		LabVIEW "Reset FC" button should turn green						
2.33	Once "Reset triggered" turns green under Data From Craft, click "Reset FC" button to off position		LabVIEW "Reset FC" button should turn red						
2.34	Cycle and visually inspect function of propellant dump valve	**AV6-M**							
2.35	Cycle and visually inspect function of propellant iso valve	**AV5-M**							
2.36	Cycle and visually inspect function of pressurant vent valve	**FO-U**	Valve will light up when in open state						
2.37	Open pressurant vent valve	**FO-U**	Mag probe light should power on if valve is powered						
2.38	Cycle and visually inspect function of pressurant iso valve with mag probe	**FC-U**	Mag probe light should immuniate if valve is powered						
2.39	Click "Safety" button to *on* position		LabVIEW "Safety" button should turn green						
2.40	Click "Takeoff" button to on position		LabVIEW "Takeoff" button should turn green Flight Profile should run						
2.41	Once flight profile ends, click "Takeoff" button to off position								
2.42	Click "Safety" button to *off* position								
2.43	Click "Reset FC" button to *on* position		LabVIEW "Reset FC" button should turn green						
2.44	Once "Reset triggered" turns green under Data From Craft, click "Reset FC" button to off position		LabVIEW "Reset FC" button should turn red						

2.45	Visually inspect Puma structure and plumbing components for signs of corrosion								

SECTION 3: CHECK PRESSURANT TANK LEVEL

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
3.01	"All personnel in within 250 ft Test Zone MUST apply following PPE: Long pants, closed-toe shoes"								
3.02	Verify pressurant iso valve is closed	**FC-U**							
3.03	Verify pressurant vent valve is opened	**FO-U**							
3.04	Verify pressurant regulator reads 0 psi, record in data column at right	**RG-U**							
3.05	Verify pressurant hand valve is completely closed*	**HV-U**							Turn counter clockwise until no resistance
3.06	Record pressure from pressurant tank pressure transducer in data column at right	**PT1-U**	Should be ~ 0 psi and match left side of regulator						
3.07	Open pressurant hand valve completely	**HV-U**							
3.08	Record pressure from pressurant tank pressure transducer in data column at right*	**PT1-U**	Value should match left side of regulator						This value is the pressure level of pressurant tank
3.09	Close pressurant hand valve completely	**HV-U**							
3.10	Adjust delivery pressure to 100 psi*	**RG-U**							
3.11	All personnel take a step back from Puma								

3.12	Open pressurant iso valve	**FC-U**	Pressurant should vent from pressurant vent valve						Pressure at PT1-U should equal pressurant regulator pressure
3.13	Once all pressurant vents and pressurant tank pressure transducer reads 0 psi, reapproach the craft	**PT1-U**							
3.14	Adjust delivery pressure to 0 psi*	**RG-U**							Turn counter clockwise until no resistance
3.15	Close pressurant iso valve	**FC-U**							
3.16	If pressure value recorded in Step 3.08 is below TBD psi, stop Startup Procedure and proceed with **N2 Fill Proceedure**								

SECTION 4: STATIC TESTING SETUP

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
4.01	All personnel in within 250 ft Test Zone MUST apply following PPE: Long pants, closed-toe shoes"								
4.02	If test is a flight test, please proceed to **Section 5: Flight Setup**								
4.03	Click "Full Power" button to off position		Light indicator should turn green on bottom right corner of power box						
4.04	Close pressurant vent valve	**FO-U**							
4.05	Click "Primary Safety" button to *off* position								
4.06	Turn switch to *off* position located on right side of Puma power box		Light indicator should turn off on bottom right corner of power box						
4.07	Press stop button on LabVIEW*								Located at top left corner of LabVIEW

4.08	Turn switch labed "Puma" to *off* postion located on auxiliary box								
4.09	Disconnect power connector from Puma's power box								
4.10	Press down on auxiliary box red button*								This button is located on outlet cord between outlet and auxiallary box
4.11	Place Puma in center of marked square on test stand								
4.12	Retrieve static setup equipment, three foot step stool, and torque wrench from shed								
4.13	Bolt all four engine arms to test stand according to *Static Tie-down diagram v2.0*								
4.14	Verify left side of engine arm 1 is properly torqued to 43 ft-lbs								
4.14	Verify right side of engine arm 1 is properly torqued to 43 ft-lbs								
4.15	Verify left side of engine arm 2 is properly torqued to 43 ft-lbs								
4.16	Verify right side of engine arm 2 is properly torqued to 43 ft-lbs								
4.17	Verify left side of engine arm 3 is properly torqued to 43 ft-lbs								
4.18	Verify right side of engine arm 3 is properly torqued to 43 ft-lbs								
4.19	Verify left side of engine arm 4 is properly torqued to 43 ft-lbs								
4.20	Verify right side of engine arm 4 is properly torqued to 43 ft-lbs								

4.21	Retrieve flight setup equipment and two 9/16" wrenches from shed								
4.22	Verify that all cable guides are sufficiently tensioned								
4.23	Bolt cable arms on to Puma according to *Cable Arm diagram v2.0*								
4.24	Verify cable arm 1a is fully tightened								
4.25	Verify cable arm 1b is fully tightened								
4.26	Verify cable arm 2a is fully tightened								
4.27	Verify cable arm 2b is fully tightened								
4.28	Verify cable arm 3a is fully tightened								
4.29	Verify cable arm 3b is fully tightened								
4.30	Plug auxiliary connector labed "Puma" into Puma								
4.31	Twist red button on auxiliary box clockwise*								Fan on auxiliary box should be audible
4.32	Turn switch labed "Puma" to *on* postion located on auxiliary box								
4.33	Turn switch to *on* position located on right side of Puma power box		Light indicator should turn green on bottom right corner of power box						
4.34	Name test file under "Test Filename"								

4.35	Press Run Arrowon LabVIEW*								Located at top left corner
4.36	Click "Calibrate" button on LabVIEW								
4.37	Verify calibration and click "Ok" to proceed								
4.38	Ensure all six Thermocouple boxes on LabVIEW are colored grey*								If not, get Test Directors Attention
4.39	Verify all Pressure Transducers are reading nominal pressure		All pressure transducers should read ~ 0 psi						
4.40	Verify all thermocouples are reading nominal temperature		All thermocouples should read ~ current temperature outdoors						
4.41	Click "Primary Safety" button to *on* position								
4.42	Open pressurant vent valve	**FO-U**							

SECTION 5: PUMA FLIGHT SETUP

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
5.01	"All personnel in within 250 ft Test Zone MUST apply following PPE: **Long pants, closed-toe shoes"**								
5.02	If test is static test, please proceed to **Section 6: DI WATER FILL**								
5.03	Retrieve 20.5" x 20.5" size honeycomb from and place on center of test stand								
5.04	Click "Full Power" button to off position		Light indicator should turn green on bottom right corner of power box						

5.05	Close pressurant vent valve	**FO-U**							
5.06	Click "Primary Safety" button to *off* position								
5.07	Turn switch to *off* position located on right side of Puma power box		Light indicator should turn off on bottom right corner of power box						
5.08	Press stop button on LabVIEW*								Located at top left corner of LabVIEW
5.09	Turn switch labed "Puma" to *off* postion located on auxiliary box								
5.10	Press down on auxiliary box red button*								This button is located on outlet cord between outlet and auxiallary box
5.11	Disconnect power connector from Puma's power box								
5.12	Retrieve Flight setup equipment, three foot step stool, and torque wrench from shed								
5.13	Place Puma on top of honeycomb								
5.14	Verify that all cable guides are sufficiently tensioned								
5.15	Bolt cable arms on to Puma according to *Cable Arm diagram v2.0*								
5.16	Verify cable arm 1a is fully tightened								
5.17	Verify cable arm 1b is fully tightened								
5.18	Verify cable arm 2a is fully tightened								

5.19	Verify cable arm 2b is fully tightened								
5.20	Verify cable arm 3a is fully tightened								
5.21	Verify cable arm 3b is fully tightened								
5.22	Plug auxiliary connector labed "Puma" into Puma								
5.23	Twist red button on auxiliary box clockwise*		Fan on auxiliary box should be audible						
5.24	Turn switch labed "Puma" to *on* postion located on auxiliary box								
5.25	Turn switch to *on* position located on right side of Puma power box		Light indicator should turn green on bottom right corner of power box						
5.26	Press Run Arrowon LabVIEW*								Located at top left corner
5.27	Click "Calibrate" button on LabVIEW								
5.28	Verify calibration and click "Ok" to proceed								
5.29	Ensure all six Thermocouple boxes on LabVIEW are colored grey*								If not, get Test Directors Attention
5.30	Verify all Pressure Transducers are reading nominal pressure		All pressure transducers should read ~ 0 psi						
5.31	Verify all thermocouples are reading nominal temperature		All thermocouples should read ~ current temperature outdoors						
5.32	Click "Primary Safety" button to *on* position								

5.33	Open pressurant vent valve	**FO-U**							

SECTION 6: DI WATER FILL

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
6.01	"All personnel in within 250 ft Test Zone MUST apply following PPE: Safety Glasses, nitrile Gloves								
6.02	Retrieve pump setup, 10-gal DI carboy, 3' step stool, adjustable wrentch, and blue bucket. Place on ground next to test stand								
6.03	Determine marked volume level corresponds to 8 gallons and record in data column at right*								
6.04	Place pump on 3' step stool								
6.05	Set up pump setup according to Pump Setup Diagram v2.0								TT1 will attach and dettach pump setup and monitor flow rate during fill
6.06	Insert unswaged end of fill line into filled 10-gal DI carboy								
6.07	Close pump needle valve	**NV-P**							
6.08	Connect pump to auxiliary power box								
6.09	Verify pressurant iso valve is in closed position	**FC-U**							
6.10	Verify pressurant vent valve is in open position	**FO-U**							
6.11	Open propellant iso valve	**AV5-M**							

6.12	Open propellant dump valve	**AV6-M**							
6.13	TT2 place hand over pump and monitor carboy level during fill								
6.14	Plug auxiliary connector labed "Pump" into Pump								
6.15	Open pump needle valve 5 revolutions*	**NV-P**							Tape on handle is for visual aid
6.16	ISA turn switch labed "Pump" to *on* postion located on auxiliary box								
6.17	Visually monitor volume level on carboy until carboy is 0.5 of a gallon from desired level marked in 6.03		Should be around 1 minute						
6.18	Once volume is 0.5 gallon's away from desired level, close pump needle valve by 4 revolutions								
6.19	Quickly close pump needle valve when desired level is reached	**NV-P**							
6.20	ISA turn switch labed "Pump" to *off* postion located on auxiliary box								
6.21	Close propellant dump valve	**AV6-M**							
6.22	Close propellant iso valve	**AV5-M**							

SECTION 7: DRAIN TANK AND FLUSH LINES

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
7.01	Disconnect hose from upper side of pump and place in blue bucket*								Refer to *Pump Setup Diagram v2.0* for visual aid

7.02	Open pump needle valve completely	**NV-P**							
7.03	Open propellant dump valve	**AV6-M**	DI should flow into blue bucket						
7.04	Once DI stops flowing , close pump needle valve compeletly	**NV-P**							
7.05	Reattach hose to upper side of pump								
7.06	Remove blue bucket from test area								
7.07	Verify pressurant iso valve is closed	**FC-U**							
7.08	Verify pressurant vent valve is open	**FO-U**							
7.09	Verify pressurant regulator reads 0 psi, record in data column at right	**RG-U**							
7.10	Open pressurant hand valve completely	**HV-U**	PT1-U should raise as it is pressurant tank pressure						
7.11	Set presurrant delivery pressure to 100 psi	**RG-U**							
7.12	Record pressure from pressurant tank pressure transducer in data column at right	**PT1-U**							
7.13	Close pressurant vent valve	**FO-U**							
7.14	Open pressurant iso valve	**FC-U**							Pressure at PT1-U should equal pressurant regulator pressure
7.15	Open propellant tank iso valve	**AV5-M**							

7.16	Record data from propellant tank and propellant iso pressure transducers*	**PT2-U**							PT2-U & PT5-M should be within 10 psu of 100 psi
		PT5-M							
7.17	Click "Full Power" button to on position		Light indicator should turn red on bottom right corner of power box						
7.18	Click "Reset FC" button to *on* position								
7.19	Once "Reset triggered" turns green under Data From Craft, click "Reset FC" button to off position								
7.20	Click "Safety" button to *on* position								
7.21	Click "Takeoff" button to on position		Water should flow through engines						
7.22	Once flight profile ends, click "Takeoff" button to off position								
7.23	Click "Safety" button to *off* position								
7.24	Click "Reset FC" button to *on* position								
7.25	Once "Reset triggered" turns green under Data From Craft, click "Reset FC" button to off position								
7.26	Close pressurant iso valve	**FC-U**							
7.27	Open pressurant vent valve	**FO-U**							
7.28	Wait 30 seconds for pressurant to vent		PT2-U & PT5-M should drop to 0 psi						

7.29	Close propellant iso valve	**AV5-M**							
7.30	Record pressure from pressurant tank pressure transducer in data column at right*	**PT1-U**							This value is the pressure level of pressurant tank
7.31	Once PT2-U reads 0 psi, close pressurant hand valve completely	**HV-U**							
7.32	Open pressurant iso valve	**FC-U**	Pressurant should vent from pressurant vent valve. Left & Right gague on RG-U should drop to 0 psi						Pressure at PT1-U should equal pressurant regulator pressure
7.33	Verify all pressurant vented and pressurant tank pressure transducer reads 0 psi	**PT1-U**							
7.34	Adjust delivery pressure to 0 psi*	**RG-U**							Turn counter clockwise until no resistance
7.35	Close pressurant iso valve	**FC-U**							
7.36	If pressure value recorded in Step 7.26 is below TBD psi, stop **Start Up & Initial Test Procedure** and proceed with **N2 Fill Proceedures**								

SECTION 8: SET UP CAMERAS/DAQ

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
8.01	Mount and position cameras to correct angle								
8.02	Wirelessy connect cameras to TVs and bring up live feed on TV screen								
8.03	Plug cameras in to power source, ensure data cards are installed, and turn on WiFi on Hero3s*								Blue WiFi indicator light is on and WiFi symbol is visible on TV

BEGINNING INTIAL TEST PROCEDURE

SECTION 9: CHANGE PUMA POWER SUPPLY FROM AUXILIARY TO BATTERIES

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
9.01	If test is a **static test**, to **Section 10: H2O2 Tank Fill**								
9.02	"All personnel in within 250 ft Test Zone MUST apply following PPE: **Long pants, closed-toe shoes**"								
9.03	Retrieve two 4-cell LiPo batteries measured in step 1.10 and grounding strap from shed and bring to test stand								
9.04	Click "Full Power" button to off position		Light indicator should turn green on bottom right corner of power box						
9.05	Close pressurant vent valve	**FO-U**							
9.06	Click "Primary Safety" button to *off* position								
9.07	Place 3' stool next to test stand								
9.08	Connect grounding strip to Puma's Chassis								
9.09	Turn switch to *off* position located on right side of Puma power box		Light indicator should turn off on bottom right corner of power box						
9.10	Press stop button on LabVIEW*								Located at top left corner of LabVIEW
9.11	Turn switch labed "Puma" to *off* postion located on auxiliary box								
9.12	Press down on auxiliary box red button*								This button is located between outlet and auxiallary box

9.13	Disconnect power connector from Puma's power box									
9.14	Unlach and open battery compartment door slowly									
9.15	Disconnect connectors from auxillary slot and attach both batteries									
9.16	Close and lach battery compartment door slowy*									Slowly to avoid pinching wires
9.17	Turn switch to *on* position located on right side of Puma power box		Light indicator should turn green on bottom right corner of power box							
9.18	Disconnect ground strip and return batteries to be charged									
9.19	Turn on power switch located on Puma's power box		Light indicator should turn green on bottom right corner of power box							
9.20	Name test file under "Test Filename"*									Name file according for deisred name for test
9.21	Press Run Arrowon LabVIEW*									Located at top left corner
9.22	Click "Calibrate" button on LabVIEW									
9.23	Verify calibration and click "Ok" to proceed									
9.24	Ensure all six Thermocouple boxes on LabVIEW are colored grey*									If not, get Test Directors Attention
9.25	Verify data is nominal									
9.26	Click "Primary Safety" button to *on* position									

9.27	Verify battery voltage level on LabVIEW and record in data column at right*								Check voltage is within +/- 0.2 V of 14.8 Volts
9.28	Open pressurant vent valve	**FO-U**							

SECTION 10: H2O2 TANK FILL

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
ALL PERSONS HANDLING H2O2 MUST BE WEARING APPROPRIATE PPE									
10.01	Persons handling H2O2 MUST apply following PPE: Safety glasses, Tyvek coverall suit, rubber boots, face shield, 22 mil nitril gloves								
10.02	Persons handling H2O2 MUST have previously completed following training: **Lab Safety, H2O2 Safety, and be approved to perform H2O2 fill ***								List of trained personnel is available in Personnel Readiness
10.03	*Make announcement, beginning H2O2 filling procedure*								
10.04	Verify that propellant tank pressure transducer reads 0 psi	**PT2-U**							
10.05	Retrieve pump, pump power cable, 3' set stool, small waste container, 5-gal DI carboy, 1-gal DI jug, and empty-5 gal carboy. Place on ground next to test stand								
10.06	Place pump on 3' step stool								
10.07	Set up pump setup according to Pump Fitting Assembly Diagram v2.0*								TT1 will attach and dettach pump setup and monitor flow rate during fill
10.08	ISA verify that all fiitings are tight								
10.09	Place small waste container on test stand*								Should be placed under pump between propellant dump valve and pump needle vavle

10.10	Pour TBD of DI into small waste container								
10.11	Place 10-gal H2O2 carboy on wagon and wheel it next to pump								
10.12	Determine marked volume level corresponds to desired fill volume and record in note column at right*		Desired volume of H2O2 should be in data column at right (from Step 1.04)						Calculated carboy volume level to stop fill: _______________
10.13	Insert unswaged end of fill line into 10-gal H2O2 carboy								
10.14	Close pump needle valve	**NV-P**							
10.15	Connect pump to auxiliary box								
10.16	Ensure pressurant iso valve is in closed position	**FC-U**							
10.17	Verify pressurant vent valve is in open position	**FO-U**							
10.18	Verify propellant iso valve is in closed position	**AV5-M**							
10.19	Open propellant dump valve	**AV6-M**							
10.20	TT2 place hand over pump and monitor carboy level during fill								
10.21	Open pump needle valve 5 revolutions*	**NV-P**							Tape of handle is for visual aid
10.22	ISA turn switch labed "Pump" to *on* postion located on auxiliary box								
10.23	Visually monitor volume level on carboy until carboy is 0.5 of a gallon from desired level marked in 10.11		Should be around 1 minute						

10.24	Once volume is 0.5 gallon's away from desired level, close pump needle valve by 4 revolutions								
10.25	Quickly close pump needle valve when desired level is reached	**NV-P**							
10.26	Turn switch labed "Pump" to *off* postion located on auxiliary box								
10.27	Close propellant dump valve	**AV6-M**							
10.28	Monitor propellant tank pressure thermocouple for thirty seconds for signs of pressure increase, indicating peroxide decomposition in propellant tank*	**TCp1-M**							If temperature increases above **TBD**, get TD attention
10.29	Verify that small waste container is placed under head of pump setup*								Reference Pump Fitting Assembly Diagram v2.0 if necessary
10.30	TT1 detach pump set up from Puma and let residue H2O2 fall into small waste container		Some H2O2 should flow into small waste container						
10.31	Place head of pump setup into empty 5-gal carboy								
10.32	Insert unswaged end of pump setup into 5-gal DI carboy								
10.33	Open pump needle valve 5 revolutions*	**NV-P**							Tape of handle is for visual aid
10.34	ISA verify setup is done properly								
10.35	ISA turn switch labed "Pump" to *on* postion located on auxiliary box		DI should flow through pump and into empty 5-gal carboy						
10.36	Once all DI has flowed through pump, close pump needle valve	**NV-P**							
10.37	All personnel must throughly rinse gloves								

10.38	Turn off pump located on auxilary box								
10.39	Disconnect pump power connector to auxiliary box								
10.40	Press down on auxiliary box red button*								This button is located on outlet cord between outlet and auxiallary box
10.41	Disconnect auxiliary connector into wall outlet								
10.42	Remove pump setup, auxiliary box with connectors, wagon with H2O2 carboy, 5-gal DI waste carboy, 5-gal emtpy garboy, 1-gal DI jug, and TBD size wrenches from test area								
10.43	Remove any items from test area that are not critical to testing								
10.44	Announce transfer process is complete								

SECTION 11: PRESSURIZE PROPELLANT TANK

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
11.01	Verify pressurant iso valve is closed	**FC-U**							
11.02	Verify pressurant regulator reads 0 psi, record in data column at right	**RG-U**							
11.03	Open pressurant hand valve completely	**HV-U**	PT1-U should raise as it is pressurant tank pressure						
11.04	Set presurrant delivery pressure to TBD psi	**RG-U**							
11.05	All personnel exit test zone (radius of 250 ft), according to **Personnel Test Layout Diagram**								

NO PERSONNEL TO ENTER WITHIN TEST ZONE BEYOND THIS POINT NO PERSONNEL TO ENTER WITHIN TEST ZONE BEYOND THIS POINT

11.06	Record pressure from pressurant tank pressure transducer in data column at right	**PT1-U**							
11.07	Click "Full Power" button to on position		Light indicator should turn red on bottom right corner of power box						
11.08	Open propellant tank iso valve	**AV5-M**							
11.09	Close pressurant vent valve	**FO-U**							
11.10	Open pressurant iso valve	**FC-U**	PT2-U rises to pressure in 11.03						Pressure at PT1-U should equal pressurant regulator pressure
11.11	Compare propellant tank pressure to delivery pressure and record in data column to right*	**PT2-U**							values should match within 10 psi. If not, consider replacing PT1-U.
11.12	Record data from pressure transducers*	**PT2-U** **PT5-M**	PT2-U & PT5-M should be within 10 psi of TBD psi						

SECTION 12: FINAL TEST READINESS VERIFICATION

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
12.01	Click "Reset FC" button to *on* position								
12.02	Once "Reset triggered" turns green under Data From Craft, click "Reset FC" button to off position								
12.03	Fill out Abridged Start up Test Checkout								

12.04	Obtain final Go/No-Go from TD								
12.05	Notify staff members via walkie-takie that testing is in progress								
12.06	Start recording all cameras								
12.07	Click "Safety" button to *on* position								
12.08	Click "Takeoff" button to on position								

KEY	
Verify operating conditions are satisfactory	
Action * indicates a reference to Notes column	

RECYCLE & RE-TEST PROCEDURE

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *

Testing Info

	Date	Test Number
	Time	Test Technicians
	Test Track Technician	
	Test Conductor	
	Test Director	
	Inspector and Safety Authority	

PPE required:	
	Closed-toe shoes
	Long pants without cuffs
	Powder-free gloves when handling any components during assembly/ disassembly and DI water fill
	Full PPE: Tyvek coverall suit, boots, 22 mil nitrile gloves, and splash shields (over glasses) when handling H_2O_2

	Walkie Talkies	3' Step Stool
	Pump Setup	Adjustable Wrench

Supplies Needed:	Small Waste Container	2 5-gal DI Carboys
	2 1-gal DI jug	10- gal H2O2 carboy
	Wagon	
Test Purpose:		

SECTION 1: HEALTH VERIFICATION

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
1.01	**If flight soft kill or hard kill was triggereded, proceed according to Contingency Proceudres. Do not recycle until approved by TD**								
1.02	Click "Takeoff" button to off position								
1.03	Click "Safety" button to *off* position								
1.04	Click "Reset FC" button to *on* position								
1.05	Once "Reset triggered" turns green under Data From Craft, click "Reset FC" button to off position								
1.06	Close pressurant iso valve	**FC-U**							
1.07	Open pressurant vent valve	**FO-U**							
1.08	Wait 30 seconds for pressurant to vent		PT2-U & PT5-M should drop to 0 psi						

1.09	Close propellant iso valve	**AV5-M**							
1.10	Record pressure from pressurant tank pressure transducer in data column at right*	**PT1-U**							This value is the pressure level of pressurant tank
1.11	Confirm max temperature is within material and component limits. Record max temperature and corresponding sensor in data column at right								
1.12	Confirm max pressure is within material and component limits. Record max temperature and corresponding sensor in data column at right								
1.13	Visually inspect system from cameras for leaks or damage								
1.14	Have **TD** confirm that the craft is safe to approach								
All Personnel handling Puma must be wearing appropriate PPE									
1.15	Personnel handling Puma MUST apply following PPE: **Safety glasses, Tyvek coverall suit, boots, face shield, 22 mil nitril gloves**								
1.16	Personnel handling Puma MUST have previously completed following training: **Lab Safety, H2O2 Safety, and be approved to perform H2O2 fill ***								List of trained Personnel is available in Personnel Readiness
1.17	Once PT2-U reads 0 psi, approach craft and close pressurant hand valve completely	**HV-U**							
1.18	Visually inspect honeycomb integrity								
1.19	Open pressurant iso valve	**FC-U**	Pressurant should vent from pressurant vent valve						Pressure at PT1-U should equal pressurant regulator pressure
1.20	Once all pressurant vents and pressurant tank pressure transducer reads 0 psi, reapproach the craft	**PT1-U**							
1.21	Adjust delivery pressure to 0 psi*	**RG-U**							Turn counter clockwise until no resistance

1.22	Close pressurant iso valve	**FC-U**							
1.23	View battery voltage level from LabVIEW and record data in column at right								
1.24	Determine if sufficent propellant in tank to perform another test*								No accurate method for calculating. Estimates can be made based on test duration, thrust level, and initial propellant volume
1.25	If not a sufficent amount of propellant in tank, fill in TBD value of amount of H2O2 for test in Step 3.12 at data column at right.								
1.26	Determine if sufficent battery voltage in tank to perform another test. If so, stop **Recycle & Re-Test Procedure** and proceed with **Battery Swap Procedures***								TD makes final descision. Batteries must be replaced if below TBD V
1.27	If pressure value recorded in Step 1.10 is below TBD psi, stop **Recycle & Re-Test Procedure** and proceed with **N2 Fill Proceedure**								
1.28	Press stop on LabVIEW								
1.29	Name test file under "Test Filename"*								Name file according for deisred name for test
1.30	Press Run Arrow on LabVIEW*								Located at top left corner
1.31	Click "Calibrate" button on LabVIEW								
1.32	Verify calibration and click "Ok" to proceed								
1.33	Ensure all six Thermocouple boxes on LabVIEW are colored grey*								If not, get Test Directors Attention
1.34	Verify data is nominal								
1.35	Continue with recycle only with TD approval								

SECTION 2: FLUSH REMAINING H2O2

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
2.01	If there is enough propellant for additional test was determined in 1.24, please proceed to **Section 4: Pressurize Propellant Tank**								
2.02	Close pressuant iso valve	**FC-U**							
2.03	Open pressurant vent valve	**FO-U**							
2.04	Close propellant iso valve	**AV5-M**							
2.05	Verify that propellant tank pressure transducer reads 0 psi	**PT2-U**							
All Personnel handling Puma must be wearing appropriate PPE									
2.06	Personnel handling Puma MUST apply following PPE: **Safety glasses, Tyvek coverall suit, boots, face shield, 22 mil nitril gloves**								
2.07	Personnel handling Puma MUST have previously completed following training: **Lab Safety, H2O2 Safety, and be approved to perform H2O2 fill ***								List of trained Personnel is available in Personnel Readiness
2.08	Verify pressurant regulator reads 0 psi, record in data column at right	**RG-U**							
2.09	Open pressurant hand valve completely	**HV-U**	PT1-U should raise as it is pressurant tank pressure						
2.10	Place 3' stool next to test stand								
2.11	Stand on stool and adjust delivery pressure on regulator to 100 psi								

2.12	All Personnel proceed past safe zone radius of **250** ft radius, according to *Personnel Test Layout Diagram*								
NO PERSONNEL TO ENTER WITHIN SAFE ZONE BEYOND THIS POINT				**NO PERSONNEL TO ENTER WITHIN SAFE ZONE BEYOND THIS POINT**					
2.13	Record pressure from pressurant tank pressure transducer in data column at right	**PT1-U**							
2.14	Close pressurant vent valve	**FO-U**							
2.15	Open propellant tank iso valve	**AV5-M**							
2.16	Open pressurant iso valve	**FC-U**							
2.17	Compare propellant tank pressure to delivery pressure and record in data column to right	**PT2-U**	PT2-U and PT5-M should both be around 100 psi						
		PT5-M							
2.18	Click "Reset FC" button to *on* position								
2.19	Once "Reset triggered" turns green under Data From Craft, click "Reset FC" button to off position								
2.20	Click "Safety" button to *on* position								
2.21	Click "Takeoff" button to on position								
2.22	Once flight profile ends, click "Takeoff" button to off position								
2.23	Click "Safety" button to *off* position								

2.24	Click "Reset FC" button to *on* position								
2.25	Once "Reset triggered" turns green under Data From Craft, click "Reset FC" button to off position								
2.26	Close pressurant iso valve	**FC-U**							
2.27	Open pressurant vent valve	**FO-U**							
2.28	Wait 30 seconds for pressurant to vent		PT2-U & PT5-M should drop to 0 psi						
2.29	Close propellant iso valve	**AV5-M**							
2.30	Record pressure from pressurant tank pressure transducer in data column at right*	**PT1-U**							This value is the pressure level of pressurant tank
2.31	If pressure value recorded in Step 2.30 is below TBD psi, stop **Recycle & Retest Procedure** and proceed with **N2 Fill Proceedure**								

SECTION 3: FILL PROPELLANT TANK

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
3.01	If there is **NOT** enough propellant for additional test was determined in 1.25, please proceed to **Section 4: Pressurize Propellant Tank**								
All Personnel handling H2O2 must be wearing appropriate PPE									
3.02	Personnel handling H2O2 MUST apply following PPE: Safety glasses, Tyvek coverall suit, boots, face shield, 22 mil nitril gloves								
3.03	Personnel handling H2O2 MUST have previously completed following training: Lab Safety, H2O2 Safety, and be approved to perform H2O2 fill *								List of trained Personnel is available in Personnel Readiness

3.04	*Make announcement, beginning H2O2 filling procedure*								
3.05	Verify that propellant tank pressure transducer reads 0 psi	**PT2-U**							
3.06	Retrieve pump, pump power cable, 3' set stool, small waste container, 5-gal DI carboy, 1-gal DI jug, and empty-5 gal carboy. Place on ground next to test stand								
3.07	Place pump on 3' step stool								
3.08	Set up pump setup according to Pump Fitting Assembly Diagram v2.0*								TT1 will attach and dettach pump setup and monitor flow rate during fill
3.09	Place small waste container on test stand*								Should be placed under pump between propellant dump valve and pump needle vavle
3.10	Pour TBD of DI into small waste container								
3.11	Place 10-gal H2O2 carboy on wagon and wheel it next to pump								
3.12	Determine marked volume level corresponds to desired fill volume and record in note column at right*		Desired volume of H2O2 should be in data column at right (from Step 1.26)						Calculated carboy volume level to stop fill: _______________
3.13	Insert unswaged end of fill line into 10-gal H2O2 carboy								
3.14	Close pump needle valve	**NV-P**							
3.15	Connect pump to auxiliary box								
3.16	Ensure pressurant iso valve is in closed position	**FC-U**							
3.17	Verify pressurant vent valve is in open position	**FO-U**							

3.18	Verify propellant iso valve is in closed position	**AV5-M**							
3.19	Open propellant dump valve	**AV6-M**							
3.20	Have TT2 place hand over pump and monitor carboy level during fill								
3.21	Open pump needle valve 5 revolutions*	**NV-P**							Tape of handle is for visual aid
3.22	ISA verify that all fiitings are tight								
3.23	ISA turn switch labed "Pump" to *on* postion located on auxiliary box								
3.24	Visually monitor volume level on carboy until carboy is 0.5 of a gallon from desired level marked in 3.12		Should be around 1 minute						
3.25	Once volume is 0.5 gallon's away from desired level, close pump needle valve by 4 revolutions								
3.26	Quickly close pump needle valve when desired level is reached	**NV-P**							
3.27	Turn switch labed "Pump" to *off* postion located on auxiliary box								
3.28	Close propellant dump valve	**AV6-M**							
3.29	Monitor propellant tank pressure thermocouple for thirty seconds for signs of pressure increase, indicating peroxide decomposition in propellant tank*	**TCp1-M**							If Tcp1-M exceeds TBD degrees, exit test and follow according contingency******
3.30	Verify that small waste container is placed under head up pump setup								

3.31	TT1 detach pump set up from Puma and let residue H2O2 fall into small waste container		Some H2O2 should flow into small waste container						
3.32	Place head of pump setup into empty 5-gal carboy								
3.33	Insert unswaged end of pump setup into 5-gal DI carboy								
3.34	Open pump needle valve 5 revolutions*	**NV-P**							Tape of handle is for visual aid
3.35	ISA verify that setup is done currectly								
3.36	ISA turn switch labed "Pump" to *on* postion located on auxiliary box		DI should flow through pump and into empty 5-gal carboy						
3.37	Once all DI has flowed through pump, close pump needle valve	**NV-P**							
3.38	Turn off pump located on auxilary box								
3.39	Disconnect pump power connector to auxiliary box								
3.40	Remove pump setup, wagon with H2O2 carboy, 5-gal DI waste carboy, 5-gal emtpy garboy, 1-gal DI jug, and TBD size wrenches from test area								
3.41	Remove any items from test area that are not critical to testing								
3.42	Announce transfer process is complete								

SECTION 4: PRESSURIZE PROPELLANT TANK

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *

4.01	Verify pressurant iso valve is closed	**FC-U**							
4.02	Verify pressurant regulator reads 0 psi, record in data column at right	**RG-U**							
4.03	Open pressurant hand valve completely	**HV-U**	PT1-U should raise as it is pressurant tank pressure						
4.04	Set presurrant delivery pressure to TBD psi	**RG-U**							
4.05	All Personnel proceed past test zone radius of 250 ft radius, according to *Personnel Test Layout Diagram*								
NO PERSONNEL TO ENTER WITHIN TEST ZONE BEYOND THIS POINT					**NO PERSONNEL TO ENTER WITHIN TEST ZONE BEYOND THIS POINT**				
4.06	Record pressure from pressurant tank pressure transducer in data column at right	**PT1-U**							
4.07	Click "Full Power" button to on position		Light indicator should turn red on bottom right corner of power box						
4.08	Open propellant tank iso valve	**AV5-M**							
4.09	Close pressurant vent valve	**FO-U**							
4.10	Open pressurant iso valve	**FC-U**	PT2-U should rise to value in 4.06						
4.11	Compare propellant tank pressure to delivery pressure and record in data column to right*	**PT2-U**							
4.12	Record data from pressure transducers*	**PT2-U**							PT2-U & PT5-M should be within 10 psi of TBD psi
		PT5-M							

SECTION 5: FINAL TEST READINESS VERIFICATION

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
5.01	Click "Reset FC" button to *on* position								
5.02	Once "Reset triggered" turns green under Data From Craft, click "Reset FC" button to off position								
5.03	Fill out *Abridged Recycle & Re-Test Checkout*								
5.04	Obtain final Go/No-Go from TD								
5.05	Notify staff members via walkie-takie that testing is in progress								
5.06	Start recording all cameras								
5.07	Click "Safety" button to *on* position								
5.08	Click "Takeoff" button to on position								

KEY	
Verify operating conditions are satisfactory	(yellow)
Action * indicates a reference to Notes column	

RECYCLE & SHUTDOWN PROCEDURE

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *

Testing Info

	Date	
	Time	Test Technicians
	Test Track Technician	
	Test Conductor	
	Test Director	
	Inspector and Safety Authority	

	Safety glasses when in test area
	Closed-toe shoes
PPE required:	Long pants without cuffs

	nitrile gloves when handling any components during assembly/ disassembly and DI water fill		
	Full PPE: Tyvek coverall suit, boots, 22 mil nitrile gloves, and splash shields (over glasses) when handling H2O2		
Supplies Needed:	Walkie Talkie	Auxiliary Box with connectors and extension cord	Static Setup Materials
	Flight Setup Materials	3' Step Stool	1 10-gal DI Carboy
	Adjustable Wrench	Empty 10-gal Recycled DI Carboy	1 1-gal DI Jug
	Grounding Strap	Battery Charger	Extension Cord

SECTION 1: HEALTH VERIFICATION

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
1.01	If flight soft kill or hard kill was triggereded, proceed according to Contingency Proceudres. Do not shutdown until approved by TD								
1.02	Click "Takeoff" button to off position								
1.03	Click "Safety" button to *off* position								
1.04	Click "Reset FC" button to *on* position								

1.05	Once "Reset triggered" turns green under Data From Craft, click "Reset FC" button to off position								
1.06	Close pressurant iso valve	**FC-U**							
1.07	Open pressurant vent valve	**FO-U**							
1.08	Wait 30 seconds for pressurant to vent		PT2-U & PT5-M should drop to 0 psi						
1.09	Close propellant iso valve	**AV5-M**							
1.10	Record pressure from pressurant tank pressure transducer in data column at right*	**PT1-U**							This value is the pressure level of pressurant tank
1.11	Confirm max temperature is within material and component limits. Record max temperature and corresponding sensor in data column at right								
1.12	Confirm max pressure is within material and component limits. Record max temperature and corresponding sensor in data column at right								
1.13	Visually inspect system from cameras for leaks or damage								
1.14	Have **TD** confirm that the craft is safe to approach								
All Personnel handling Puma must be wearing appropriate PPE									
1.15	Personnel handling Puma MUST apply following PPE: **Safety glasses, Tyvek coverall suit, boots, face shield, 22 mil nitril gloves**								

1.16	Personnel handling Puma MUST have previously completed following training: **Lab Safety, H2O2 Safety, and be approved to perform H2O2 fill ***								List of trained personnel is available in Personnel Readiness
1.17	Once PT2-U reads 0 psi, approach craft and close pressurant hand valve completely	**HV-U**							
1.18	Open pressurant iso valve	**FC-U**	Pressurant should vent from pressurant vent valve						Pressure at PT1-U should equal pressurant regulator pressure
1.19	Once all pressurant vents and pressurant tank pressure transducer reads 0 psi, reapproach the craft	**PT1-U**							
1.20	Adjust delivery pressure to 0 psi*	**RG-U**							Turn counter clockwise until no resistance
1.21	Close pressurant iso valve	**FC-U**							
1.22	View battery voltage level from LabVIEW and record data in column at right								
1.23	Determine if sufficent battery voltage in tank to perform shutdown procedure. If so, stop **Recycle Procedures** and proceed with **<u>Battery Swap Procedures</u>***								TD makes final descision. Batteries must be replaced if below TBD V
1.24	Press stop on LabVIEW								
1.25	Name test file under "Test Filename"*								Use extension **.txt** Only enter file if you are interested in the data
1.26	Press Run Arrowon LabVIEW*								Located at top left corner
1.27	Click "Calibrate" button on LabVIEW								

1.28	Verify calibration and click "Ok" to proceed								
1.29	Ensure all six Thermocouple boxes on LabVIEW are colored grey*								If not, get Test Directors Attention
1.30	Verify data is nominal								
1.31	Continue with shutdown only with TD approval								

SECTION 2: FLUSH REMAINING H2O2

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
2.01	Close pressuant iso valve	**FC-U**							
2.02	Open pressurant vent valve	**FO-U**							
2.03	Close propellant iso valve	**AV5-M**							
2.04	Verify that propellant tank pressure transducer reads 0 psi	**PT2-U**							

All Personnel handling Puma must be wearing appropriate PPE

2.05	Personnel handling Puma MUST apply following PPE: **Safety glasses, Tyvek coverall suit, boots, face shield, 22 mil nitril gloves**						

2.06	Personnel handling Puma MUST have previously completed following training: **Lab Safety, H2O2 Safety, and be approved to perform H2O2 fill ***								List of trained personnel is available in Personnel Readiness
2.07	Verify pressurant regulator reads 0 psi, record in data column at right	**RG-U**							
2.08	Open pressurant hand valve completely	**HV-U**	PT1-U should raise as it is pressurant tank pressure						
2.09	Place 3' stool next to test stand								
2.10	Stand on stool and adjust delivery pressure on regulator to 100 psi								
2.11	All Personnel proceed past safe zone radius of **250** ft radius, according to *Personnel Test Layout Diagram*								
NO PERSONNEL TO ENTER TEST AREA BEYOND THIS POINT				**NO PERSONNEL TO ENTER TEST AREA BEYOND THIS POINT**					
2.12	Record pressure from pressurant tank pressure transducer in data column at right	**PT1-U**							
2.13	Close pressurant vent valve	**FO-U**							
2.14	Open propellant tank iso valve	**AV5-M**							
2.15	Open pressurant iso valve	**FC-U**							
2.16	Compare propellant tank pressure to delivery pressure and record in	**PT2-U**	PT2-U and PT5-M should both be						

2.16	to delivery pressure and record in data column to right	**PT5-M**	around 100 psi						
2.17	Click "Reset FC" button to *on* position								
2.18	Once "Reset triggered" turns green under Data From Craft, click "Reset FC" button to off position								
2.19	Click "Safety" button to *on* position								
2.20	Click "Takeoff" button to on position								
2.21	Once flight profile ends, click "Takeoff" button to off position								
2.22	Click "Safety" button to *off* position								
2.23	Click "Reset FC" button to *on* position								
2.24	Once "Reset triggered" turns green under Data From Craft, click "Reset FC" button to off position								
2.25	Close pressurant iso valve	**FC-U**							
2.26	Open pressurant vent valve	**FO-U**							
2.27	Wait 30 seconds for pressurant to vent		PT2-U & PT5-M should drop to 0 psi						

2.28	Close propellant iso valve	**AV5-M**							
2.29	Record pressure from pressurant tank pressure transducer in data column at right*	**PT1-U**							This value is the pressure level of pressurant tank

SECTION 3: DI WATER FILL

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
All Personnel handling Puma must be wearing appropriate PPE									
3.01	Personnel handling Puma MUST apply following PPE: **Safety glasses, Tyvek coverall suit, boots, face shield, 22 mil nitril gloves**								
3.02	Personnel handling Puma MUST have previously completed following training: **Lab Safety, H2O2 Safety, and be approved to perform H2O2 fill ***								List of trained personnel is available in Personnel Readiness
3.03	Retrieve pump setup, pump power cable, auxililary box, auxilary box outlet cable, small waste container, extension cord, 10-gal DI carboy, 3' step stool, XX size wrentch, and 10-gal empty carboy. Place on ground next to test stand								
3.04	Determine marked volume level corresponds to 8 gallons and record in data column at right*								
3.05	Place pump on 3' step stool								
3.06	Set up pump setup according to Pump Setup Diagram v2.0								TT1 will attach and dettach pump setup and monitor flow rate during fill
3.07	Insert unswaged end of fill line into 10-gal DI carboy								

3.08	Close pump needle valve	**NV-P**							
3.09	Press down on auxiliary box red button*								This button is located on outlet cord between outlet and auxiallary box
3.10	Plug auxiliary connector into wall outlet								
3.11	Plug auxiliary connector labed "Puma" into Puma								
3.12	Connect pump to auxiliary box								
3.13	Twist red button on auxiliary box clockwise*								Fan on auxiliary box should be audible
3.14	Verify pressurant iso valve is in closed position	**FC-U**							
3.15	Verify pressurant vent valve is in open position	**FO-U**							
3.16	Open propellant iso valve	**AV5-M**							
3.17	Open propellant dump valve	**AV6-M**							
3.18	TT2 place hand over pump and monitor carboy level during fill								
3.19	Plug auxiliary connector labed "Pump" into Pump								

3.20	Open pump needle valve 5 revolutions*	**NV-P**							Tape on handle is for visual aid
3.21	ISA turn switch labed "Pump" to *on* postion located on auxiliary box								
3.22	Visually monitor volume level on carboy until carboy is 0.5 of a gallon from desired level marked in 3.04		Should be around 1 minute						
3.23	Once volume is 0.5 gallon's away from desired level, close pump needle valve by 4 revolutions								
3.24	Quickly close pump needle valve when desired level is reached	**NV-P**							
3.25	ISA turn switch labed "Pump" to *off* postion located on auxiliary box								
3.26	Close propellant dump valve	**AV6-M**							
3.27	Close propellant iso valve	**AV5-M**							

SECTION 4: DRAIN TANK AND FLUSH LINES

Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
4.01	Disconnect hose from upper side of pump and place in empty 10-gal carboy*								Refer to Pump Setup Diagram v2.0 for visual aid
4.02	Open pump needle valve completely	**NV-P**							

4.03	Open propellant dump valve	**AV6-M**	Recycled DI should flow into empty 10-gal carboy						
4.04	Once 10-gal recycled DI carboy reaches **7** gallons, close pump needle valve compeletly*	**NV-P**							This leaves around one gallon in Puma
4.05	Reattach hose to upper side of pump								
4.06	Press down on auxiliary box red button*								This button is located on outlet cord between outlet and auxiallary box
4.07	Verify small container is under propellant dump valve								
4.08	Disconnect plug auxiliary connector labed "Pump" from auxillary box								
4.09	Disconnect auxiliary connector into wall outlet								
4.10	Remove 10-gal recycled DI carboy, pump setup, auxililary box, XX size wrench, small container, 3' step stool, and small container from test area								
4.11	All personnel with 250 Safe Zone MUST apply following PPE: Safety glasses and nitrile gloves								
4.12	Verify pressurant iso valve is closed	**FC-U**							
4.13	Verify pressurant vent valve is open	**FO-U**							
4.14	Verify pressurant regulator reads 0 psi, record in data column at right	**RG-U**							

4.15	Open pressurant hand valve completely	**HV-U**	PT1-U should raise as it is pressurant tank pressure						
4.16	Record pressure from pressurant tank pressure transducer in data column at right	**PT1-U**							
4.17	Close pressurant vent valve	**FO-U**							
4.18	Open pressurant iso valve	**FC-U**							Pressure at PT1-U should equal pressurant regulator pressure
4.19	Open propellant tank iso valve	**AV5-M**							
4.20	Record data from propellant tank and propellant iso pressure transducers*	**PT2-U**	PT2-U & PT5-M should be within 10 psu of 100 psi						
		PT5-M							
4.21	Click "Full Power" button to on position		Light indicator should turn red on bottom right corner of power box						
4.22	Click "Reset FC" button to *on* position								
4.23	Once "Reset triggered" turns green under Data From Craft, click "Reset FC" button to off position								
4.24	Click "Safety" button to *on* position								
4.25	Click "Takeoff" button to on position								

4.26	Once flight profile ends, click "Takeoff" button to off position									
4.27	Click "Safety" button to *off* position									
4.28	Click "Reset FC" button to *on* position									
4.29	Once "Reset triggered" turns green under Data From Craft, click "Reset FC" button to off position									
4.30	Close pressurant iso valve	**FC-U**								
4.31	Open pressurant vent valve	**FO-U**								
4.32	Wait 30 seconds for pressurant to vent		PT2-U & PT5-M should drop to 0 psi							
4.33	Close propellant iso valve	**AV5-M**								
4.34	Record pressure from pressurant tank pressure transducer in data column at right*	**PT1-U**								This value is the pressure level of pressurant tank
4.35	All personnel with 250 Safe Zone MUST apply following PPE: Safety glasses and nitrile gloves									
4.36	Once PT2-U reads 0 psi, approach craft and close pressurant hand valve completely	**HV-U**								
4.37	All personnel step 10 feet from test stand									

4.38	Open pressurant iso valve	**FC-U**	Pressurant should vent from pressurant vent valve						Pressure at PT1-U should equal pressurant regulator pressure
4.39	Once all pressurant vents and pressurant tank pressure transducer reads 0 psi, reapproach the craft	**PT1-U**							
4.40	Adjust delivery pressure to 0 psi*	**RG-U**							Turn counter clockwise until no resistance
4.41	Close pressurant iso valve	**FC-U**							

SECTION 5: SHUTDOWN AND SAFETY

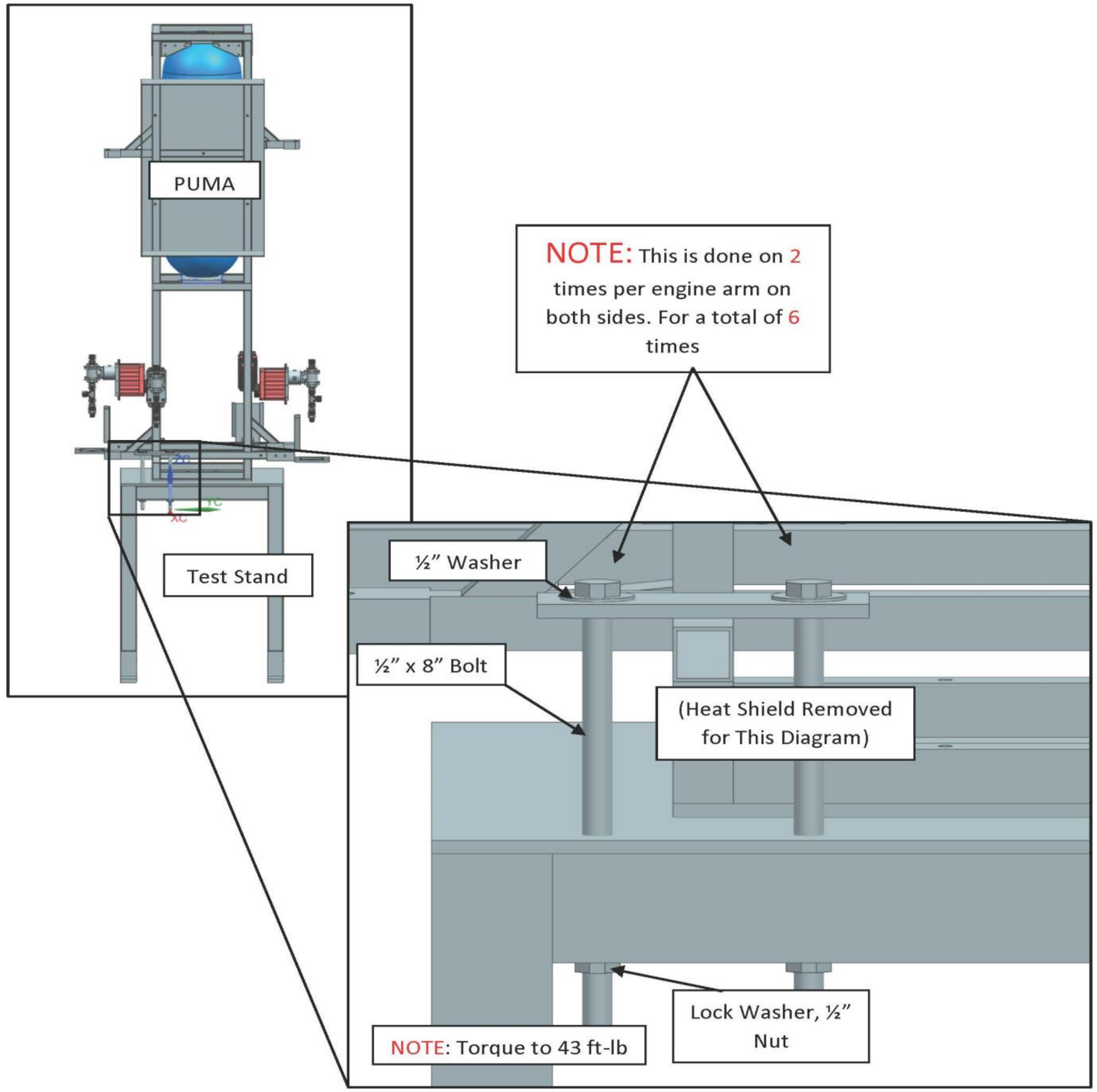
Step Number	Action	Component Name	Expected Behavior	TC	Data	Time	ISA	TD	Notes *
5.01	All personnel in within 250 ft Test Zone MUST apply following PPE: **Long pants, closed-toe shoes**								
5.02	Close pressurant vent valve	**FO-U**							
5.03	Visually verify that all valves are in their closed states*								**All acuated valves should show red tape**
5.04	Click "Full Power" button to *off* position		Light indicator should turn green on bottom right corner of power box						
5.05	Click "Primary Safety" button to turn off								
5.06	Retrieve 3' step stool, grounding strap, engine caps, and XX wretches from shed								

5.07	Connect grounding strip to Puma's Chassis								
5.08	Turn switch to *off* position located on right side of Puma power box		Light indicator should turn off on bottom right corner of power box						
5.09	Press stop button on LabVIEW*								Located at top left corner of LabVIEW
5.10	Unlach and open battery compartment door slowly								
5.11	Release battery guard and remove batteries from compartment								
5.12	Remove Health Monitoring SD Card in Puma								
5.13	Remove Flight Profile SD Card in Puma								
5.14	Close and lach battery compartment door slowy*								Close slowly to avoid pitching wires
5.15	Disconnect ground strip and return batteries to be charged								
5.16	Make annocement that testing is complete								
5.17	If static tests were performed disable all 4 engine arm mounts								
5.18	Unbolt all six cable guides from Puma								

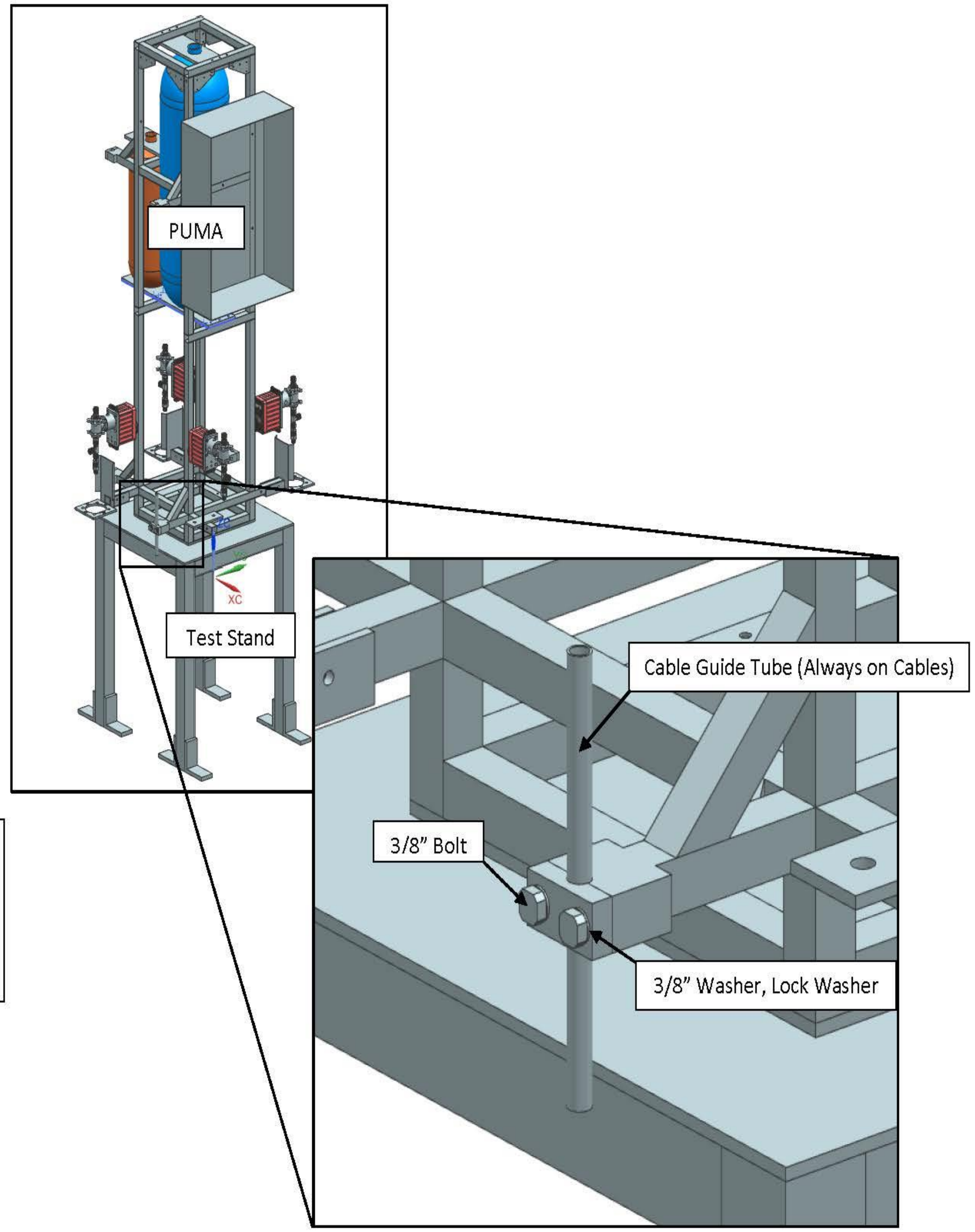
5.19	Attach bolts and washers solely on Puma to serve as storage of bolts								
5.20	Cap all four rocket engine nozzles								
5.21	Remove and place Puma in shed via cart								
5.22	Remove honeycomb from the test stand								
5.23	Rinse the test area off with DI								
5.24	Shutdown and place ground station equipement in van								

KEY	
Verify operating conditions are satisfactory	
Action * indicates a reference to Notes column	

PUMA Static Test Setup Diagram
Drafter: Anton Antolick
Version: 2.0.1
Date: 2015 July 20

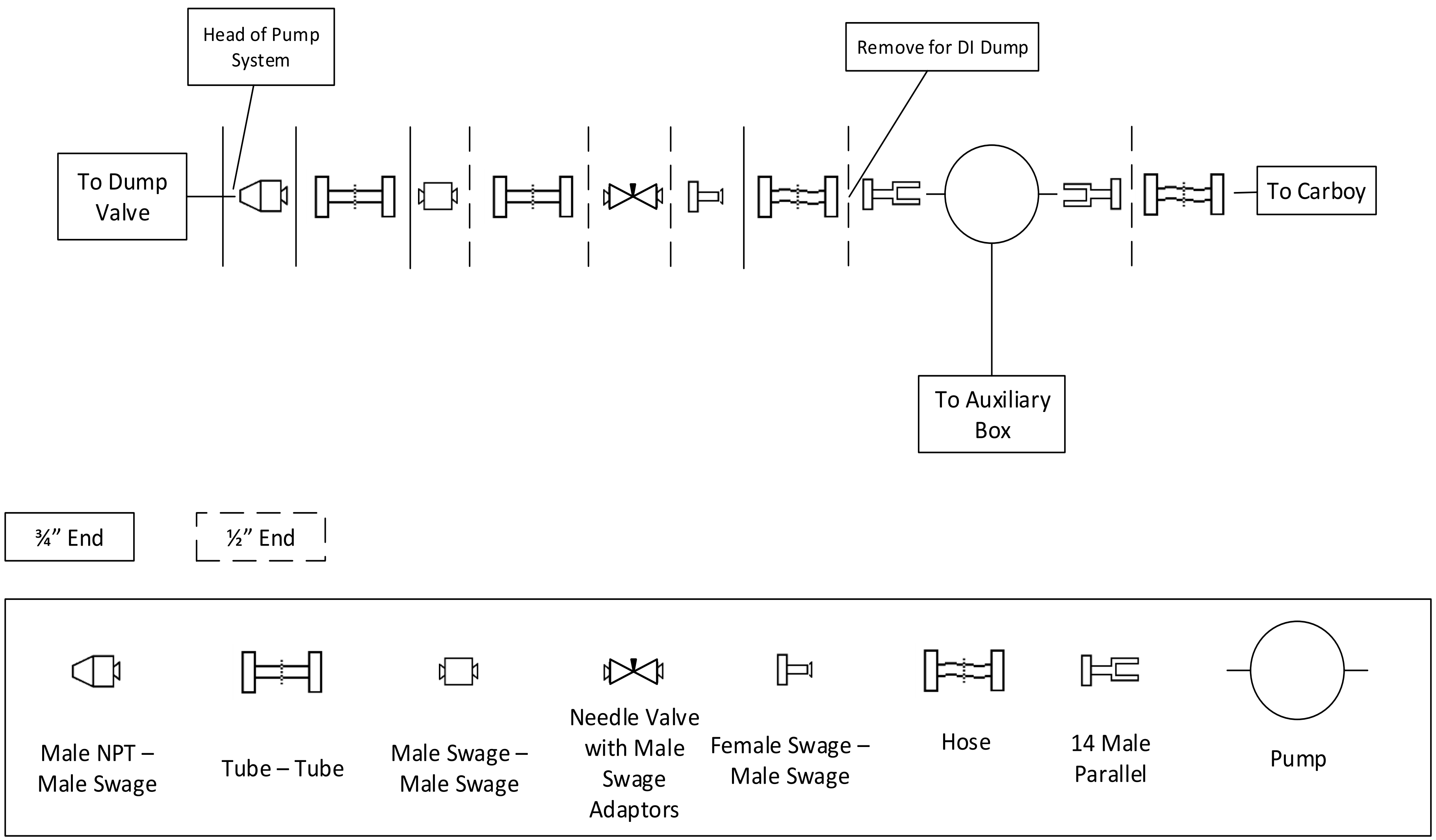


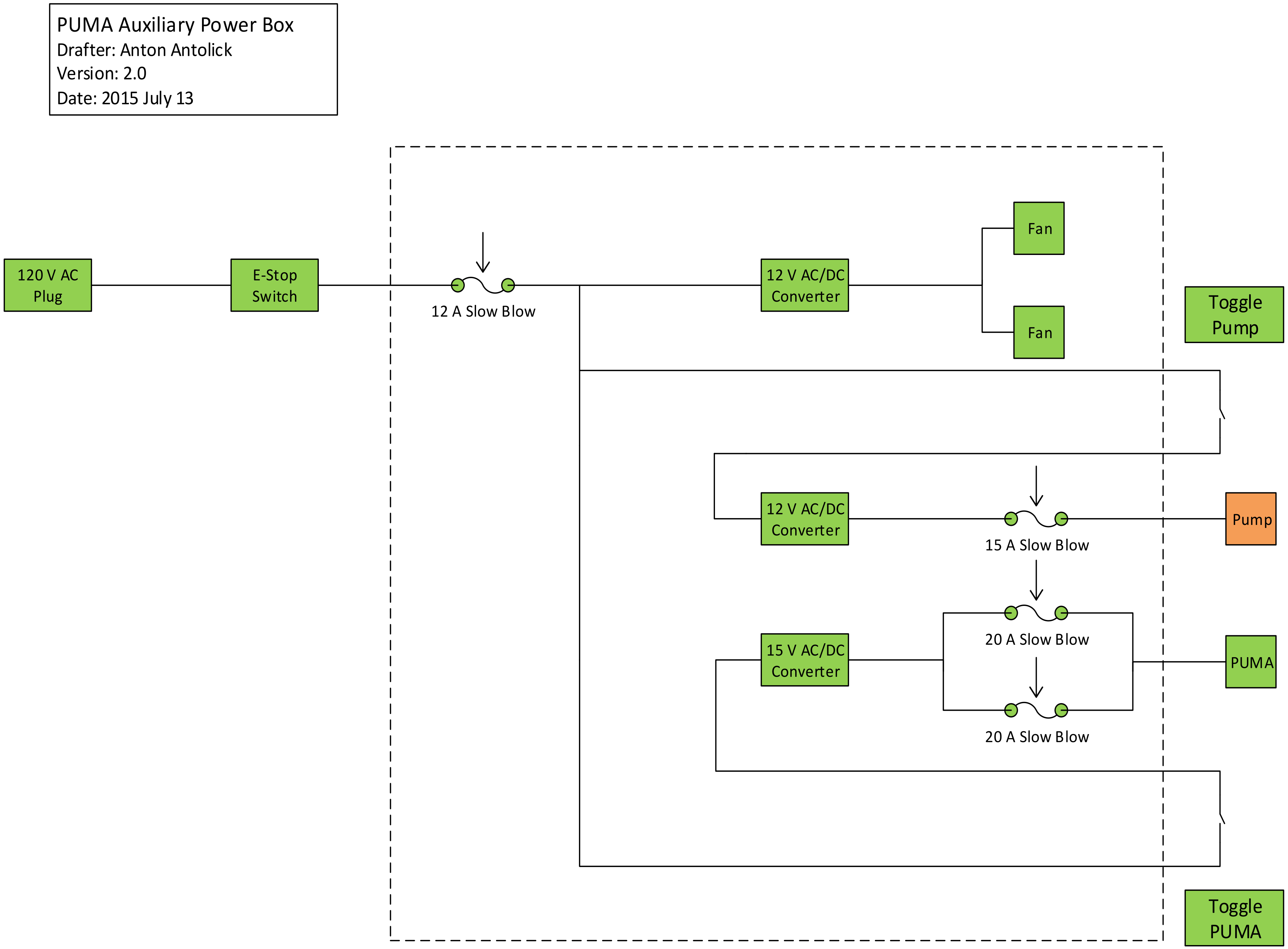
PUMA Flight Test Setup Diagram
Drafter: Anton Antolick
Version: 2.0
Date: 2015 July 17



NOTE: This setup is done 2 times per cable guide in a total of 6 locations

PUMA Pump Fitting Assembly
Drafter: Anton Antolick
Version: 2.0
Date: 2015 July 13




PUMA Auxiliary Power Box
Drafter: Anton Antolick
Version: 2.0
Date: 2015 July 13
120 V AC Plug
E-Stop Switch
12 A Slow Blow
12 V AC/DC Converter
Fan
Fan
Toggle Pump
12 V AC/DC Converter
15 A Slow Blow
Pump
20 A Slow Blow
15 V AC/DC Converter
PUMA
20 A Slow Blow
Toggle PUMA

Power Connector Locations and Soft Kill Abort Values					
Component Name	**Common Name (Goes in Action)**	**Power Box Layout Number**	**Range**	**Units**	**Soft Kill Abort Value**
TCp1-M	Plumbing Lines Thermocouple	Available when next power box is intergrated	-328 +2200	˚F	TBD
TCp2-M	Propellant Tank Thermocouple	Available when next power box is intergrated	-328 +2200	˚F	TBD
TCw1-E	Engine 1 Weld-On Thermocouple	Available when next power box is intergrated	-328 +2200	˚F	TBD
TCw2-E	Engine 2 Weld-On Thermocouple	Available when next power box is intergrated	-328 +2200	˚F	TBD
TCw3-E	Engine 3 Weld-On Thermocouple	Available when next power box is intergrated	-328 +2200	˚F	TBD
TCw4-E	Engine 4 Weld-On Thermocouple	Available when next power box is intergrated	-328 +2200	˚F	TBD
PT1-U	Pressurant Tank Pressure Transducer	Available when next power box is intergrated	0-5000	PSI	TBD
PT2-U	Propellant Tank Pressure Transducer	Available when next power box is intergrated	0-1000	PSI	TBD
PT1-M	Engine 1 Pressure Transducer	Available when next power box is intergrated	0-1000	PSI	TBD
PT2-M	Engine 2 Pressure Transducer	Available when next power box is intergrated	0-1000	PSI	TBD
PT3-M	Engine 3 Pressure Transducer	Available when next power box is intergrated	0-1000	PSI	TBD
PT4-M	Engine 4 Pressure Transducer	Available when next power box is intergrated	0-1000	PSI	TBD
PT5-M	Plumbing Lines Pressure Transducer	Available when next power box is intergrated	0-1000	PSI	TBD
AV1-M	Throttle Actuated Valve	Available when next power box is intergrated			
AV2-M	Throttle Actuated Valve	Available when next power box is intergrated			
AV3-M	Throttle Actuated Valve	Available when next power box is intergrated			
AV4-M	Throttle Actuated Valve	Available when next power box is intergrated			
AV5-M	Iso Actuated Valve	Available when next power box is intergrated			
AV6-M	Dump Actuated Valve	Available when next power box is intergrated			
FO-U	Pressurant Fail Open Vent Valve	Available when next power box is intergrated	0-2000	PSI	
FC-U	Pressurant Fail Close Isolation Valve	Available when next power box is intergrated	0-1500	PSI	
PR-U	Pressurant Pressure Relief		401-1000	PSI	
PR-M	Manifold Pressure Relief		401-1000	PSI	

NOTE: Checklists/procedures for safing craft to approach (purging system) and a corresponding checklist are attached

A - Abort Triggered When Not in Flight	
1	If personnel within 250 ft test zone, have personnel exit immediately
2	Press "Reset FC"
3	Once "Reset Triggered" turns green under Data craft, Press "Reset FC" to turn off
4	If Pressurized:
	(a) Open FO-U
	(b) Close FC-U
5	Determine what triggered abort
6	Determine if any sensors have been damaged
7	Visually inspect the craft for any damages via cameras
	If Pressurized:
	(a) Once TD and ISA determine if it is safe to approach, approach craft and close HV-U
	(b) Open FC-U
	c) Once pressure vents close FC-U
8	TD determines if it is safe to continue testing for the day
B - Abort Triggered When in Flight	
1	Click "Takeoff" to turn to *off* position
2	Click "Safety" to turn to *off* position
3	Once craft lands:
4	Click to Open FO-U
5	Click to Close FC-U
6	Click "Reset FC"
7	Once "Reset Triggered" turns green under Data craft, Press "Reset FC to turn off
8	Determine what triggered abort
9	Determine if any sensors have been damaged
10	Visually inspect the craft for any damages
11	Once TD and ISA determine if it is safe to approach, approach craft and close HV-U
12	Open FC-U
13	Once pressure vents close FC-U
14	TD determines if it is safe to continue testing for the day
C - Total Power Failure	
If Pressurized: The expected behavor of a power lost is that communication will be lost with craft and FO-U starts	
1	Visuallly inspect state of the craft via cameras
2	Verify that craft is in its default safe state to aproach
3	Record issue on Test Check List
4	Await TD for further direction
D - Communication Failure	
1	If craft is pressurized, personnel within 250 ft test zone, exit immediately

2	If Flight Profile is being exectued:
	(b) determine if craft behavior looks nominal
	(i) If craft looks nominal, wait for the flight profile to be completed
	(ii) if craft doesn't look nominal, click LabVIEW "hardkill button"
	(iii) If (ii) fails, press Big Red "Hardkill button"
	(iv) If (iii) fails, wait 5 minutes for command lost time to be executed
3	Wait for communication to come back online
4	If 5 minutes pass without communication, communication lost timer (Hard Kill) should autonmous be executed
5	Try trouble shooting USB cables
6	Await TD for further direction
E - Pressure Loss	
1	1a) Press "Soft Kill" button on LabVIEW
	1a) If (1) fails, click "Hardkill Button" on LabVIEW
	1b) If (1a) fails, press Big Red "Hardkill Button"
2	Determine where pressure loss has occurred
3	Verify craft safe to approach
4	Inspect craft
5	Determine if pressure loss can be fixed
F - H2O2 Leak (not spill)	
1	Place craft in a safe state (Depressurized, isolate N2 and H2O2)
2	Wait for H2O2 Leak to stop
3	If H2O2 leak is a high volume use Water Truck to Diloute H2O2
G - H2O2 Spill During Fill	
Concentrated H2O2 spill occurs. Person handling spill MUST wear appropriate H2O2 PPE, all other persons must clear the area. Announcement will be made to notify all personnel that spill area is restricted. Spill will be delt with by heavily diluting the propellant with water.	
H - Actuated Valve Failure	
AV1:4-M	
1	Click "Hardkill Button" on LabVIEW
2	If 1) fails, press Big Red "Hardkill button"
3	If 2) fails,:
3a	Close AV5-M
3b	Close FC-U
3c	Open FO-U
AV5-M	
1	Click "Soft Kill" on LabVIEW
2	Close FC-U
3	Open FO-U
AV6-M Failure in Open Position During Fill	
1	Drain and dilute fuel
2	Attempt to diagnose issue, if successful restart fuel fill
AV6-M Failure in Closed Position	
1	Attempt to diagnose and fix issue, if unsuccessful proceed with Step (2)

3	Close AV5-M
4	Close FC-U
5	Open FO-U
6	Verify AV1:4-M are closed
7	Unpower the craft
8	Approach craft, remove actuator on AV6-M
9	Attach hose leading to waste container to AV6-M outlet
10	Manually open and drain AV6-M
I - Rapid Unscheduled Disassembly of Engine(s) or Craft	
	Soft kill script executed automatically
1	If Soft kill isn't executed automatically, Press "Soft Kill" button on LabVIEW
1a	If (1) fails, click "Hardkill Button" on LabVIEW
1b	If (1a) fails, press Big Red "Hardkill Button"
J - Fire in Test Area	
1	If personell within 250 ft safe zone, exit immediately
2	Call 911
3	Notify Test Track Personnel
4	Open FO-U
5	Open FC-U
6	Proceed to Fire Drill
K - Camera Malfunction/Loss of Signal	
1	Attempt to regain connection
2	If (1) fails, attempt to fix or replace camera manually
3	If (2) fails or cannot occur, determine if camera is essential to conduct test
4	If camera is essential to conduct test, proceed with Shutdown Procedure
L - Peroxide Decompositon in System	
Decomposition in system can be indicated by steadily increasing temperatures in TCp1:2-M, or pressures in PT2-U or P	
1	Press Red "Abort" Button
2	Open FO-U
3	Close FC-U
4	Close AV5-M
5	Wait until Decompostion is finished
M - Loss of Thermocouple Data	
In the event data from a thermocouple is lost, the labview program will highlight the thermocouple with the cause of the fault. An abort will not be triggered.	
1	If TCw1:4-E is affected, continue test.
2	Proceed as if Abort Triggered (Section A)
N - Loss of Pressure Transducer Data	
In the event data from a transducer is lost, it will display as 0. No indication will be given in labview. No abort will be	
1	Proceed as if Communication Lost (Section D)

ABORTS RECORD					
Test Number	**Channel**	**Time Elapsed**	**High**	**Mean**	**Notes**

Emergency Reporting Form

NOTE: If an injury occurs, contact The Pensylvania State Univeristy Safety Office (EHS) and fill out their Post-Incident Investigation Form.

EHS Office Number: (814) 865-6391

Emergency		**Date**	
TC		**Test #**	
ISA		**Time**	
TD			
Tech			

Was anyone hurt? If so, how? Who reported it to ARL and when?

What happened?

Why? What can be done to prevent this in the future?

Puma Flight Testing – Personnel Readiness

The Pennsylvania State University
Lunar Lion Team

Author: Max Winn and John Targonski Version 2.0 Date: 7/9/2015

Personnel Readiness Signature Page

<u>Instructions</u>

The following signatures indicate the approval of the undersigned of this document(s) and/or procedure(s) to be used for testing as described within. Once signed, the document is locked in its current form. If any updates or revisions are made, a formal revision must be produced and reapproved.

Submitted by:

______________________________ **Date:** ______________

John Targonski
Integration and Test Lead

Program Approval:

______________________________ **Date:** ______________

Michael Paul
Mission Director

______________________________ **Date:** ______________

TBD
Research and Development Engineer

______________________________ **Date:** ______________

Kevin Myers
Occupational Safety and Environmental Health Specialist

REVISION DESCRIPTION and HISTORY			
Rev	**Issue Date**	**Description and History**	**Initiator**
2.0	07/21/2015	New Personnel Readiness Plan for flight testing campaign at the Larson Test Track	John Targonski

1. Introduction

The Lunar Lion Team's Puma craft test program employs graduate and undergraduate students in the design, assembly, integration and operation of a rocket propelled craft to test the systems that have been created by the students on the team.

The students executing this work are required to receive training and satisfactorily demonstrate proficiency to the Test Director on H2O2 handling, usage, material compatibility, as well as general lab and fire safety prior to receiving certification for a specific test team role. Different students fill different roles over time, so each role is defined below, and the necessary training required identified for each role. Periodic re-training is required for all positions.

Only trained students are allowed to fill these roles and actively participate in testing once their certification has been entered in this document. Proper and up-to-date training must be confirmed for each team member prior to testing. Role authorization must be indicated in this binder by completion of Personnel Training Checklist, signed off by Integration & Test Lead or Deputy.

2. Description of Roles

Title	Abbreviation	Role
Test Technician	TT	Supports TC and TD in testing operations. Authorized to change and clean hardware and execute line-item specific actions (except H2O2 fill) as directed by TC.
Inspector and Safety Authority	ISA	Verify that all testing is following the safety protocols as defined in the Unit Specific Safety Plan. Inspector and Safety Authoritys will have the ability to stop testing if any unsafe activities are observed.
H2O2 Fill	NONE	Authorized to perform H2O2 fill procedure under the direction of TC
Test Conductor	TC	Follows the steps of a single sequence section with permission from TD
Test Director	TD	Final operational authority. Gives TC permission to advance to next sequence section
Test Track Technician	NONE	Gives TD permission to prepare for testing and begin Procedure or Sequence (except automatic shutdowns)
Integration and Test Lead	I&T	Integration and Test Lead
Deputy Integration and Test Lead	DI&T	Deputy Integration and Test Lead

Note: *If any personnel notice an unsafe condition, they have the authority and responsibility to stop the procedures.*

3. Description of Training

Role	Trained By	Training Required
TT	I&T or DI&T	• Lab Safety Training Course • H2O2 Safety Training Course • Participation in Test Track Fire Drill • Participation in Test Track H2O2 Spill Drill • Draw entire Puma P&ID • Explain the purpose of each component • Walk through the test stand at the test track and explain the purpose of each part • Walk through static/flight test stand and set ups • Walk through auxiliary power box operation and battery swaps • Identify primary H2O2 compatible and hazardous materials • List basic PPE required when working in test range • List full PPE required for handling H2O2 • Explain what determines Puma as "safe to approach" • Walk through DI fill • Walk through GN2 fill • Walk through water truck operation • Shadow DI fill 2 times • Walk TC through valve operation for DI fill. • Demonstrate proper pressure regulator operation • Identify fitting types and demonstrate proper installation • Shadow TT on test day at least once • Discussion of basic mechanism for H2O2 rocket engine operation
ISA	I&T or DI&T	**All training required of TT**
H2O2 Fill	I&T or DI&T	**All training required of TT and:** • Perform a dry run of the DI fill process, with a discussion of the order of steps • Perform DI fill process 10 times, under the supervision of the TD • Observe H2O2 fill process 10 times • Perform 3 dry runs of H2O2 fill process under supervision of TD
TC	I&T or DI&T	**All training required of TT and:**

		• Completion of Data Channels and Aborts sheet, listing NI modules, current data channel, and abort values for all test stand components, along with validation of those values • Discussion of Standard Operating Procedures • Discussion of Contingency Procedures
TD	I&T Lead and Mission Director Paul	**All training required of TC and H2O2 Fill and:** • Serve as Test Conductor • Fully walk-through entire Design Documentation material • Full walk-through of Operating Procedures Binder

4. Personnel Training Record

Provided below is an overview of the training that the personnel listed have completed. Blue columns corresponded to safety training courses and drills. Green columns correspond to authorized roles. Safety training refresher courses must be completed yearly.

Note: *Only persons listed below are authorized to participate in flight testing, in accordance with their authorized roles per their level of trained as specified below. Final authorization must come from current Integration and Test Lead. (In the event of a change in leadership roles, the new Integration and Test Lead must re-authorize ALL personnel prior to testing)*

Current Integration and Testing Lead (as of July 2015): John Targonski

First Name	Last Name	Lab Safety	H2O2 Safety	TT	H2O2 Fill	TC	TD	ISA
Vincent	Pesce	8/25/2014	6/30/2015					
Kara	Morgan	12/19/2014	7/9/2015					
Max	Winn	1/6/2015	1/8/2015					
John	Targonski	5/5/2015	12/17/2014					
Yeyuan	Xin	11/9/2014	2/23/2015					

Puma Flight Testing –Training Guide

The Pennsylvania State University
Lunar Lion Team

1. Introduction

1.1. Training Overview

The Lunar Lion Team's Puma craft test program employs graduate and undergraduate students in the design, assembly, integration and operation of a rocket propelled craft to test the systems that have been created by the students on the team.

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Different students fill different roles over time, so each role is defined below, and the necessary training required identified for each role. Periodic re-training is required for all positions.

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Integration and Test Lead	I&T	Integration and Test Lead
Deputy	DI&T	Deputy Integration and Test Lead

Integration and Test Lead		
Note: *If any personnel notice an unsafe condition, they have the authority and responsibility to stop the procedures.*		

Table 2: Description of Required Training

Role	Trained By	Training Required
TT	I&T or DI&T	• Lab Safety Training Course • H2O2 Safety Training Course • Participation in Test Track Fire Drill • Participation in Test Track H2O2 Spill Drill • Draw entire Puma P&ID • Explain the purpose of each component • Walk through the test stand at the test track and explain the purpose of each part • Walk through static/flight test stand and set ups • Walk through auxiliary power box operation and battery swaps • Identify primary H2O2 compatible and hazardous materials • List basic PPE required when working in test range • List full PPE required for handling H2O2 • Explain what determines Puma as "safe to approach" • Walk through DI fill • Walk through GN2 fill • Walk through water truck operation • Shadow DI fill 2 times • Walk TC through valve operation for DI fill. • Demonstrate proper pressure regulator operation • Identify fitting types and demonstrate proper installation • Shadow TT on test day at least once • Discussion of basic mechanism for H2O2 rocket engine operation
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		• Perform 3 dry runs of H2O2 fill process under supervision of TD
TC	I&T or DI&T	**All training required of TT and:** • Completion of Data Channels and Aborts sheet, listing NI modules, current data channel, and abort values for all test stand components, along with validation of those values • Discussion of Standard Operating Procedures • Discussion of Contingency Procedures
TD	I&T Lead and Mission Director Michael Paul	**All training required of TC and H2O2 Fill and:** • Serve as Test Conductor • Fully walk-through entire Design Documentation material • Full walk-through of Operating Procedures Binder

1.2. The Test Stand Plumbing & Instrumentation Diagram (P&ID)

1.2.1. P&ID Overview

A P&ID illustrates a general layout for all plumbing components (i.e. valves, pressure releases and filters) as well as monitoring components (i.e. pressure gauges, thermocouples) within the system.

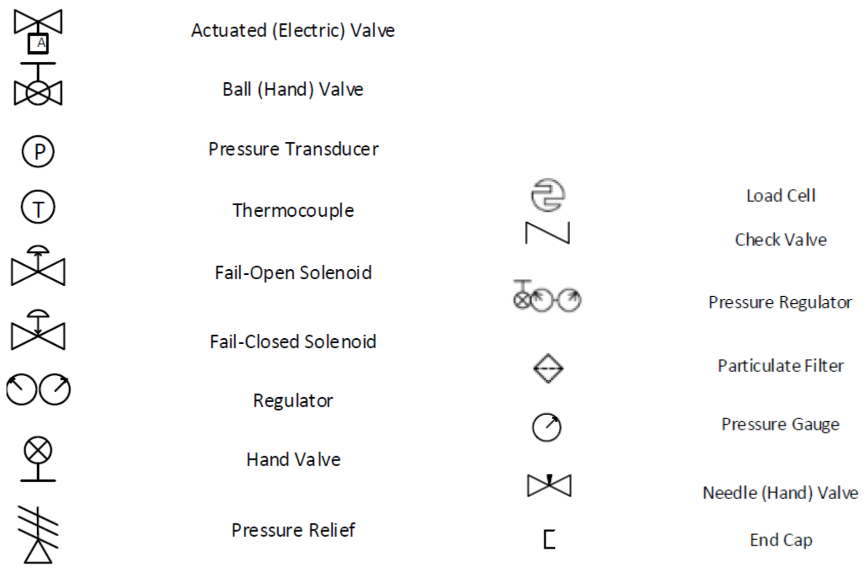
The purpose of this system is to monitor and regulate the flow of fuel (H2O2 in this case) through the system, ultimately allowing it into the engine and outputting a thrust force. The system also regulates the flow of inert gases (in this case, Gaseous Nitrogen – GN2) for the purpose of pressurizing the system.

The schematic does not attempt to represent where each component and circuit is to be placed onto Puma, only the layout of components within each circuit and relative to one another. Placement of each circuit onto Puma is up to the assembler of the physical system.

Once constructed, the propulsion system is integrated on Puma for the whole system to be tested.

1.2.2. Reading the P&ID

Abbreviation format is: XX#-L
-XX is component abreviation
-# is the number (if applicable)
- L is the location (ENGINE, PURGE, STAND, TANK, ULLAGE, MANIFOLD)



1.2.3. Component Functions

1.2.3.1. Valves

Use of valves is a primary way of regulating flow throughout the system. They are generally given their name by either location within the plumbing system, construction of the orifice or how operation is induced (opening and closing of the orifice).

Valve classifications commonly used in engine plumbing:

Bleed Valve: Placed in such a way that it allows fluid to bleed from the system on command. The opening of a bleed valve is usually for the purpose of relieving pressure in the system and is therefore commonly placed in a circuit with a pressure relief. It is also used to safely drain propellants from the lines.

Isolation (iso) Valve: Isolates fluid and prevents it from reaching a specific location in the plumbing system.

Ball Valve: A spherical shape seals the orifice

Needle Valve: Orifice is needle-shaped to significantly slow down and allow for fine control of the flow rate (e.g. kitchen faucet)

Check Valve: Limits the flow of a fluid to just one direction; prevents backflow. Every check valve has an arrow indicated flow direction. Be careful to install check valves with the arrow pointing downstream.

Actuated Valve: A motor operates the valve. Used when precise valve control is necessary (e.g. a 30° orifice opening within 4 seconds vs just having an immediate open or close). Can also be used in binary (on/off) operation.

Throttle Valve: A specific type of actuated valve which is located just upstream of the engine. It's used to control flow of propellant to the engine which will result in different levels of thrust.

Solenoid Valve: Will open or close when energized by an electric current. Fail-open solenoid valves close when energized and fail-closed solenoids open when energized. In the event of a system failure (e.g. a max pressure limit is reached), power is killed and each valve goes into the default state. This is used as a mitigation technique to avoid damage to the system as well as injury.

Solenoid Considerations

- Gems valves are prone to crack/leak if NPT fittings are over-tightened or the stem isn't torqued according to specs.
- Do not disassemble unless necessary.
- If disassembly is necessary:
    - Handle seals carefully. Remove with Teflon (e.g. floss picks) and replace if required.
    - Leak check reassembled valve with pressure before reinstalling on stand.

Hand Valve: Refers to a manually operated valve. The handle always points in the direction of flow when the valve is open; it is perpendicular when the valve is closed.

1.2.3.2. Pressure monitoring and control

Pressure Regulator: Monitors and regulates tank pressure; commonly referred to as a reg. We will be using a regulator to control the delivery pressure out of a gas cylinder. The reading on the right portion of the regulator displays the tank pressure while the left side displays the pressure being delivered into the system. The horizontal bar between the two gauges acts as a needle valve, allowing fine control of how much pressure from the tank to allow into the line. If too much pressure is allowed into the line, pressure cannot be returned through this valve. In this case, pressure entering the line from the tank must first be sealed off and then existing pressure in the line can be vented to the air through a second needle valve (not shown in figure).

Figure 2 - pressure regulator http://lhpressuregauge.en.ec21.com/offer_detail/Sell_gas_welding_regulator_pressure--10083482.html?gubun=S

Pressure Relief: This is a specialized valve used to relieve pressure from the system. It is a mechanical component where an inner spring is released once a maximum pressure is reached, thus allowing pressure to be reduced

Pressure Transducer: Monitors pressure throughout the system by using a set of resistors, similar to the working principal of a strain gauge.

Pressure Gauge: General term for a pressure reading device, usually analog

1.2.3.3. Other Plumbing Components

Thermocouple: An electronic measuring device that measure temperature through gradients.

2. Test Technician Requirements

Outlined below is the material that must be covered before being considered a trained Test Technician for Puma Flight Testing.

2.1. Draw the Puma P&ID

Be able to draw the schematic from memory. *(See Puma P&ID v)*

2.2. Why Are Those Components There?

Explain the purpose of each component on the stand.

2.3. Common Types of Hazardous Material with H2O2

- Organics(cotton, wool, etc.): will catalyze H2O2 and, as heat and oxygen is generated, will combust
- Transition metals: will catalyze H2O2

2.4. Primary H2O2 Compatible Materials Used on System

- Stainless steel (316, 304)
- Aluminum (pure, no alloys)
- PVC
- Teflon (PTFE)
- Polyethylene (LDPE, HDPE)

2.5. Three Steps for Material Treatment and Passivation

The three steps involved with MTP and briefly explain the purpose of each.

- LOX cleaning – clean all components with a degreasing solution (Simple Green) to remove and residual dirt and oil leftover from manufacturer
- Passivation – soak all metal components in a 70% nitric acid bath for 5 hours to "passivate" the material. Surface impurities are removed and a protective oxide layer is formed.
- Propellant Conditioning – soak all components in a dilute, 30% H2O2 bath for a minimum of 48 hours to identify any troublesome spots

2.6. Explain the limits of the test range

Once operational procedure have begun, there are to be no persons in the test range (within 250 feet of the test stand) unless they are at least Test Technician trained or otherwise authorized by the Test Director. All persons within this area should be wearing proper Personal Protective Equipment (PPE). When hydrogen peroxide is out of its main storage shed, only those authorized to perform the hydrogen peroxide fill and wearing full PPE (as outlined below) are allowed in the test range.

2.7. Basic PPE Required When Working in Test Range (<250 feet of the stand)

- Safety glasses
- Close-toed shoes
- Long pants
- Nitrile gloves

2.7.1. PPE General Considerations

- Always wear basic PPE when working on the system.
  - Gloves should be worn when handling any passivated/LOX clean parts, on the system or off. Protects skin from residual peroxide and the components from finger oils and dirt.
- Always cap or cover exposed piping or components on the test stand or any other passivated/LOX cleaned parts.
- Bag components after removal. Ensure parts have been properly cleaned and passivated before installing on stand. If unsure, do not use.

2.8. PPE required when handling H2O2 (Full PPE)

- Tyvek coverall suit
- Rubber boots
- Safety glasses
- 8" face shield
- 22 millimeter thick nitrile gloves

2.9. Demonstrate Proper Pressure Regulator Operation

- The left gauge indicates delivery pressure. The right gauge indicates tank pressure.
- When opening the stem or main tank valve, open completely.
- Set delivery pressure while stem valve is closed and main valve is open.
  - An increase in delivery pressure will immediately be indicated on the gauge, but pressure must be bled through the stem to read a decrease in delivery pressure.
- When depressurizing lines, close tank supply but open stem valve to avoid trapping pressure in regulator. Vent through hand valve just downstream of regulator.
- Close stem valve and hand valve downstream of regulator after line is depressurized.

2.10. Identify Fitting Types and Demonstrate Proper Installation

The main three fitting types we use on this system are Swagelok, NPT, and AN. TTs should be able to identify these types, as well as demonstrate proper installation in the system.

2.10.1. Fitting Considerations

- This system uses three types of fittings—Swagelok, AN, and NPT—know the difference.
- Male NPT threads must be taped, Swagelok and AN should not be.
- Wrap the NPT fitting with Teflon tape in the direction of the threads, coming close to but not covering the face of the fitting.
- Be careful not to over-tighten NPT fittings. General rule of thumb: 1½ turns past "hand tight."
- Use two wrenches to install fittings—one to tighten the fitting, and another to hold the fitting to which it is being installed, to avoid putting torque on the system.
- Swagelok females must be installed directly straight into the fitting to catch the threads without binding.
- Never force binding threads. This can strip the fitting.

2.11. Discussion of H2O2 engine operation

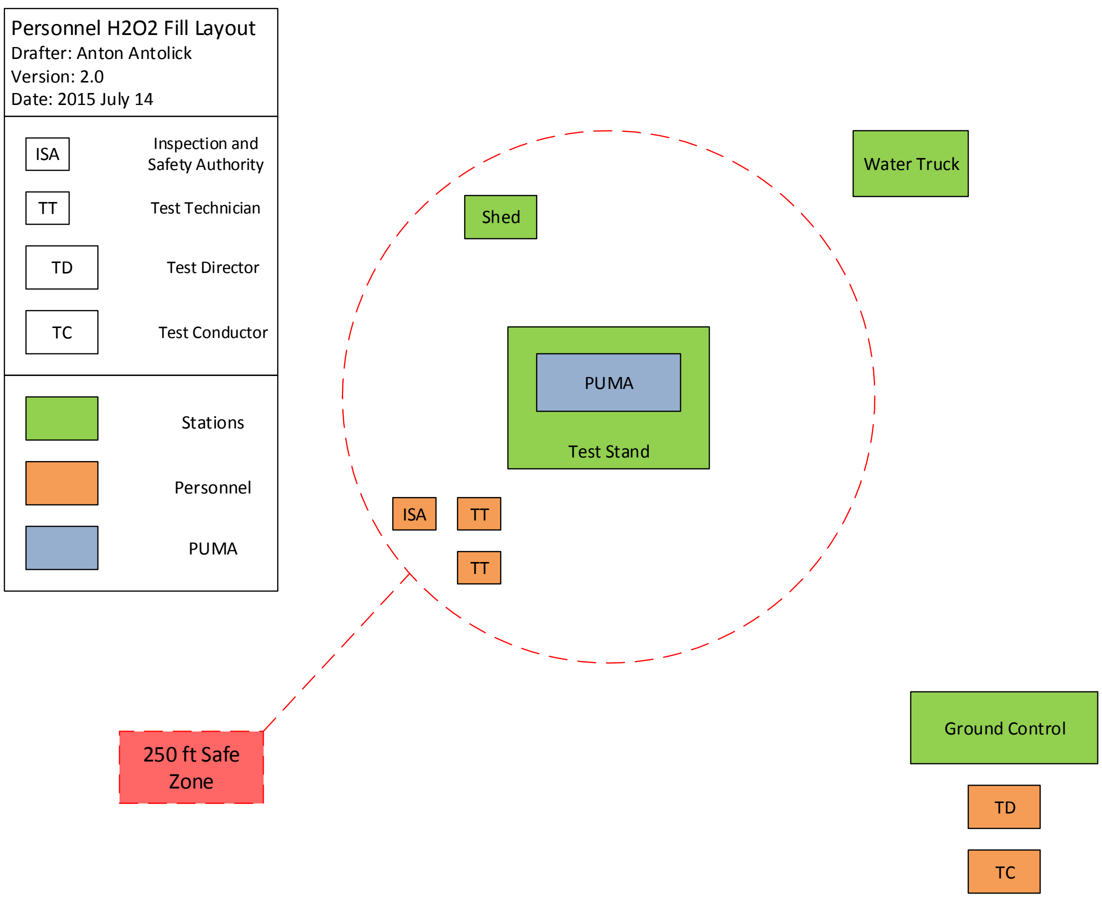
Key elements to discuss:

- The primary mechanism is hydrogen peroxide decomposition
- Concentrated 90% H2O2 enter the rocket engine, then passes through a catalyst bed made from 5 different pure metals: silver, gold, platinum, palladium, rhodium
- The catalyst decomposes the peroxide into oxygen and superheated steam (the reaction generates a lot of heat, which makes water change phase from liquid to gas)
- Products enter the rocket nozzle, which accelerates the gases and results in more thrust generated.

2.12. Discussion of Personnel Layout During H2O2 Fill

Key elements to discuss:

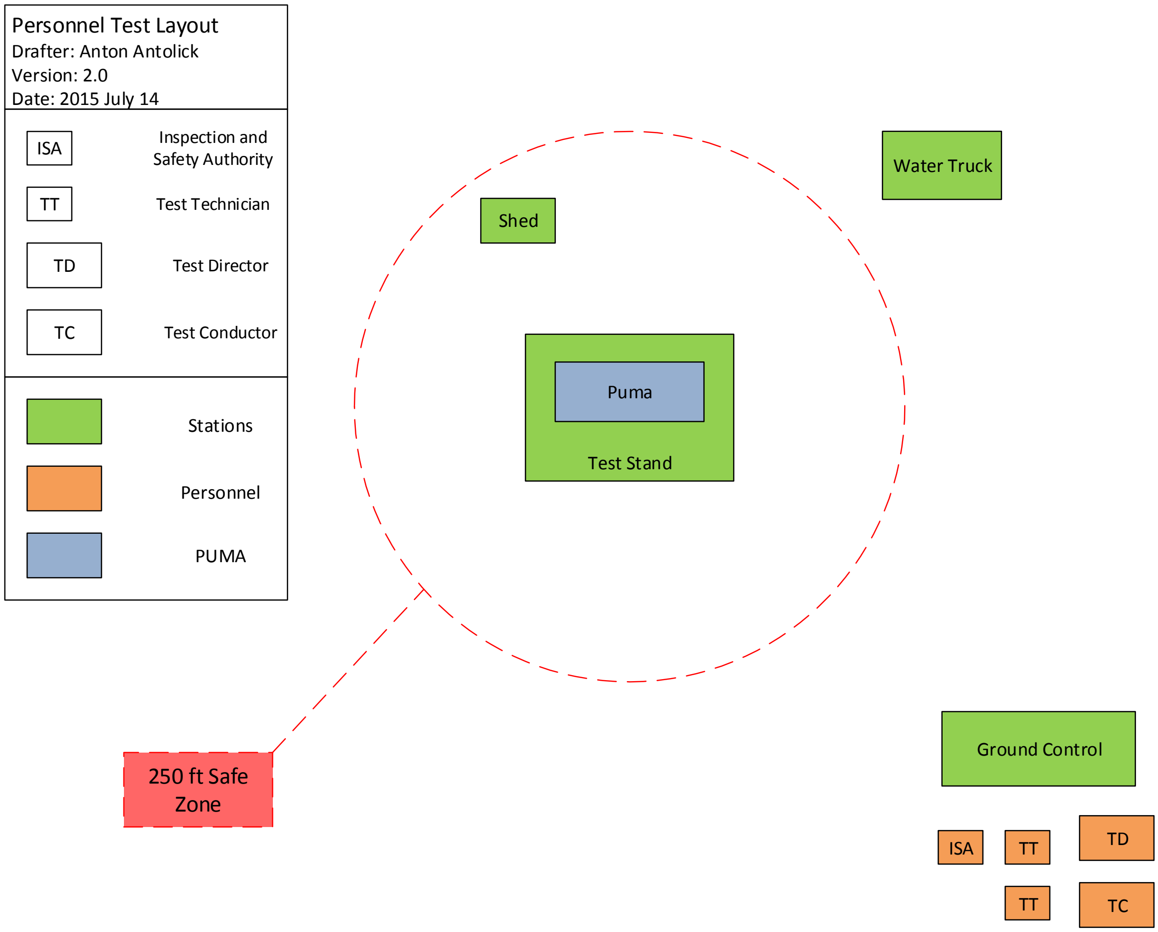
- The primary location stations, personnel, and Puma during this phase of testing.
- The responsibilities of all personnel during this phase of testing.



2.13. Discussion of Personnel Layout During Test

Key elements to discuss:

- The primary location stations, personnel, and Puma during this phase of testing.
- What criteria must be met in order for personnel to be allowed to enter safe zone.
- The responsibilities of all personnel during this phase of testing.


Personnel Test Layout
Drafter: Anton Antolick
Version: 2.0
Date: 2015 July 14
ISA
Inspection and Safety Authority
TT
Test Technician
TD
Test Director
TC
Test Conductor
Stations
Personnel
PUMA
Water Truck
Shed
Puma
Test Stand
250 ft Safe Zone
Ground Control
ISA
TT
TD
TT
TC

Puma Flight Testing – Material Readiness

The Pennsylvania State University
Lunar Lion Team

Material Readiness Signature Page

<u>Instructions</u>

The following signatures indicate the approval of the undersigned of this document(s) and/or procedure(s) to be used for testing as described within. Once signed, the document is locked in its current form. If any updates or revisions are made, a formal revision must be produced and reapproved.

Submitted by:

______________________________ **Date:** ____________

John Targonski
Integration and Test Lead

Program Approval:

______________________________ **Date:** ____________

Michael Paul
Mission Director

______________________________ **Date:** ____________

TBD
Research and Development Engineer

______________________________ **Date:** ____________

TBD
Occupational Safety and Environmental Health Specialist

REVISION DESCRIPTION and HISTORY			
Rev	**Issue Date**	**Description and History**	**Initiator**
2.0	07/20/2015	New Material Readiness Plan for Puma Flight Testing Campaign at Larson Test Track	John Targonski

1. Introduction

The Lunar Lion team will be conducting static and flight tests of the Puma craft at the Larson Test Track. The Plumbing and Instrumentation Diagram (P&ID) below describes the craft setup, data collection points, propellant storage and feed paths, and control points for the system used to execute these tests.

Prior to testing, the test team will examine the test facility and hardware, and confirm that the system is set up in concurrence with the P&ID. The Test Director will sign and date a copy of the P&ID to indicate their concurrence, and attach it to the AS-RUN procedure for that test. The Test Director will also confirm that the LABView control screen version of the P&ID matches this document.

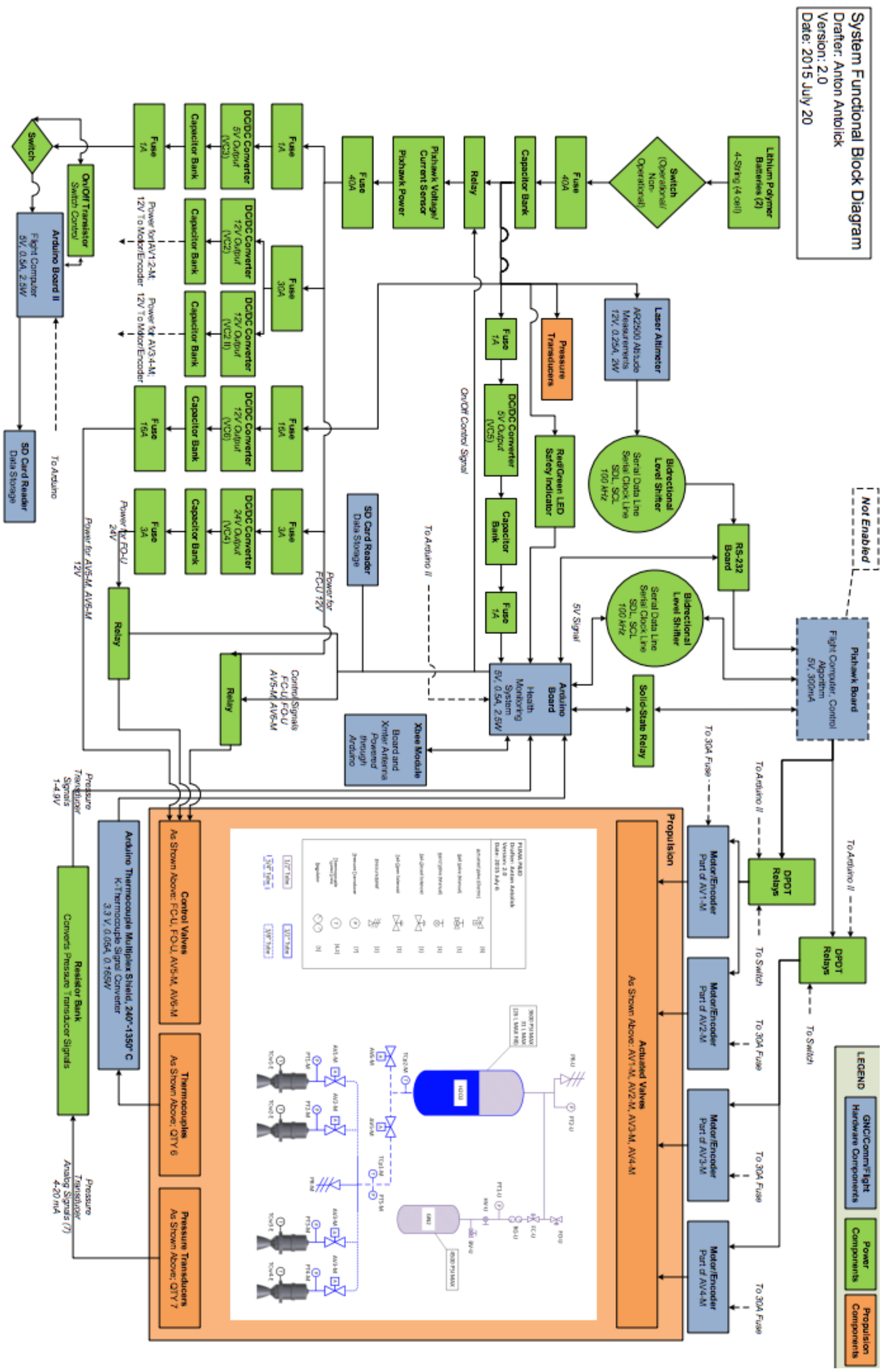
This signed Material Readiness document is the master document. Changes to the test setup must be approved by the signatories. These changes must be captured by either marking the P&ID in red pen hear in or by the Test Director or a signing and releasing a new version of the Material Readiness document. In addition, the changes must be described in the Material Change Log below.

Version Tracking

Description	Version
Puma P&ID	2.0
Puma LabVIEW Ground Control Station	2.0
Puma System Functional Block Diagram	2.0
Puma Testing Operational Procedures	2.0.3
Puma MEL	2.0

Master Equipment List

This is an AS-IS component list that reflects the current hardware configuration of the engine test stand, in accordance with the H2O2 Engine Test Stand P&ID. Changes to the physical system must be captured by marking the P&ID in red pen hear in and filling out the Material Change Log below.



Component Name	Original Serial No.	New Serial No.	Reason for hardware change	Installed By Name	Initials	Date

Chemical Selected:
Hydrogen Peroxide 100%

Shop this chemical

Material	Compatibility
ABS plastic	A-Excellent
Acetal (Delrin®)	D-Severe Effect
Aluminum	A-Excellent
Brass	D-Severe Effect
Bronze	B[1]-Good
Buna N (Nitrile)	D-Severe Effect
Carbon graphite	C-Fair
Carbon Steel	D-Severe Effect
Carpenter 20	D-Severe Effect
Cast iron	B-Good
Ceramic Al203	A-Excellent
Ceramic magnet	A-Excellent
ChemRaz (FFKM)	B-Good
Copper	D-Severe Effect
CPVC	A-Excellent
EPDM	D-Severe Effect
Epoxy	A-Excellent
Fluorocarbon (FKM)	A-Excellent
Hastelloy-C®	A-Excellent
Hypalon®	D-Severe Effect
Hytrel®	N/A
Kalrez	A-Excellent
Kel-F®	B-Good
LDPE	C[2]-Fair
Natural rubber	C-Fair
Neoprene	D-Severe Effect
NORYL®	A-Excellent

Explanation of Footnotes
1. Satisfactory to 72°F (22°C)
2. Satisfactory to 120°F (48°C)

Ratings -- Chemical Effect

A = Excellent.
B = Good -- Minor Effect, slight corrosion or discoloration.
C = Fair -- Moderate Effect, not recommended for continuous use. Softening, loss of strength, swelling may occur.
D = Severe Effect, not recommended for ANY use.
N/A = Information not available.

Nylon	D-Severe Effect
Polycarbonate	A-Excellent
Polyetherether Ketone (PEEK)	A-Excellent
Polypropylene	B[1]-Good
Polyurethane	D-Severe Effect
PPS (Ryton®)	C-Fair
PTFE	A-Excellent
PVC	A-Excellent
PVDF (Kynar®)	A[1]-Excellent
Silicone	B-Good
stainless steel - 304	B[2]-Good
stainless steel - 316	A[2]-Excellent
Titanium	B-Good
Tygon®	B-Good
Viton®	A-Excellent

WARNING

The information in this chart has been supplied to Cole-Parmer by other reputable sources and is to be used ONLY as a guide in selecting equipment for appropriate chemical compatibility. Before permanent installation, test the equipment with the chemicals and under the specific conditions of your application.

Ratings of chemical behavior listed in this chart apply at a 48-hr exposure period. Cole-Parmer has no knowledge of possible effects beyond this period. Cole-Parmer does not warrant (neither express nor implied) that the information in this chart is accurate or complete or that any material is suitable for any purpose.

DANGER

Variations in chemical behavior during handling due to factors such as temperature, pressure, and concentrations can cause equipment to fail, even though it passed an initial test.

SERIOUS INJURY MAY RESULT

Use suitable guards and/or personal protections when handling chemicals.

Puma Avionics System Design Document

The Pennsylvania State University
Lunar Lion Team

Author: Yeyuan Xin

Version 2.0

Date: 7/13/2015

List of Revisions

1. Scope

The Puma Avionics System Design Document details the current components in the avionics casing of the craft and the flight software that governs craft behavior. The onboard processors are two Arduinos – a Flight Controller Arduino to control the throttling valves, and a Health Monitoring Arduino to process sensor data and execute and relay user commands, as well as communicate with the Ground Control Station. Various sensors collect data on the state of the craft, and the software is programmed to respond appropriately to both sensor readings and human commands.

2. Requirements

The Avionics System must meet the following requirements:

Manipulate the positions of the following valves:

- Throttling actuated valves (x4)
- Fuel tank isolating actuated valve
- Fuel dump actuated valve
- Pressurant isolating fail-closed valve
- Pressurant vent fail-open valve

Read the following sensors:

- Thermocouples
- Pressure transducers
- Battery voltage sensor

Communicate the following data to the ground station:

- Thermocouple values
- Pressure transducer values
- Battery voltage
- Actuated valve positions
- State of craft

Receive and carry out the following commands from the ground station:

- Change the state of non-throttling valves
- Simulate the flight profile
- Activate the throttle valves to run the flight profile

Slowly lower craft when:

- Temperature readings exceed predefined limits
- Pressure readings exceed predefined limits
- Battery voltage drops below nominal value
- Issued a Softkill command by Ground Control

Respond to commands to bring craft to a safe state when:

- The red button switch at Ground Control is pressed
- Issued a Hardkill command by Ground Control

Provide the following file access features:

- Log all flight data in a text file
- Accept flight profile coded in a text file

Autonomously bring craft to a safe state when communication is lost for more than 5 minutes

3. Trade Space / Design Decisions

3.1. Manipulate the positions of valves

The Flight Control Arduino, which operates at 10Hz, controls the position of the four valves that throttle the four engines. Each engine has a valve above it, which controls the flow rate of the propellant. Each valve has a servo motor attached to it which controls the position of the valve. It is activated by the Health Monitoring Arduino, which also initiates its simulate or flight sequence. When it is ordered to simulate the profile, it will read in the PWM values from the SD card and relay the information back to the Health Monitoring Arduino without actually outputting those values to the servos. When it is initiated and ordered to begin the flight sequence, it will actually send the PWM signals to the servos, as well as relay the information back. The PWM signals determine the positions of the servo motors attached to the valves, which are calibrated to be fully closed at 1000ms pulses and fully open at 2000ms pulses, with a linear relationship in between. Note that the throttling actuators and controlled only by uploading desired profile to SD card before test. Refer to Example Flight Profile in Appendix.

The Health Monitoring Arduino, which operates at 5Hz, activates sequences on the Flight Control Arduino, and controls the tank isolating valve and the tank dump valve with PWM signals, and the pressurant isolating fail-close valve and pressurant vent fail-open valve with binary voltage signals.

See Operational Code in Appendix for more information.

3.2. Read sensor values

The Health Monitoring Arduino is attached to a thermocouple multiplexer shield that reads in and processes thermocouple data from six thermocouples. It is also directly attached to seven pressure transducers and a voltage sensor that provide analog voltage signals. Raw signal values are processed on board for efficiency.

3.3. Communicate data to Ground Control

Communication throughout the entire system is through Serial ports at 9600 baud. Data (as specified in Section 2) to Ground Control is transmitted via the Xbee wireless module.

3.4. Communicate commands from Ground Control

Communication throughout the entire system is through Serial ports at 9600 baud. Commands (as specified in Section 2) from Ground Control are received via the Xbee wireless module.

3.5. Ability to slowly lower craft autonomously or on command

When any of the criteria for this abort sequence is met (as specified in Section 2), the craft will enter a Softkill state. Additionally, sensors must consistently read outside the predefined abort limits for at least 5 cycle durations unless otherwise noted. This accounts for potential spikes or noise that could occur in the signal lines. Refer to Section 7 for full description of Softkill state.

3.6. Ability to instantaneously bring craft to safe state on command

When the command is sent from Ground Control (via Labview or the button switch) the craft will enter a Hardkill state. Refer to Section 7 for full description of Hardkill state.

3.7. Provide file access features

An SD card reader is attached to each Arduino. The SD card on the Flight Controller holds the flight profile, and the SD card on the Health Monitoring Arduino holds the data log file.

3.8. Autonomously and bring craft to safe state on communication loss

If the craft does not receive any communication for 5 minutes, it will automatically enter the Hardkill state. Refer to Section 7 for full description of Hardkill state.

4. Design Validation Process

During the design and implementation of the flight system, software was tested rigorously, and only known, stable versions of code were used for continued development. Unstable or intermediary pieces of code are available either as stand-alone files or as commented out sections for future analysis of design decisions.

Hardware functionality is tested extensively through the integration process, and any future component failures can be identified during system checkouts before testing. All testing sequences and operations can be run without propellant in the lines in order to test and ensure complete functionality.

5. Construction Process and Procedures

The development of software was conducted in small teams of developers that worked on specific tasks, and the overall integration of the entire flight system occurred continuously during development.

The physical construction process was completed in close coordination with the Power Subsystem. Most of the connections to both Arduinos are comprised of header pins soldered over pieces of perforated board, except for the SD card shields, which are soldered to removable connectors.

6. Design

6.1. Electronic Components

Part ID	Description	Purpose

Arduino Mega 2560	Flight Control Arduino	Controls the position of the throttling actuated valves based on a text file on the attached SD card
Arduino Mega 2560	Health Monitoring Arduino	Reads data from the thermocouple shield, pressure transducers, and voltage sensor, communicates the data to and from the Xbee as well as the Flight Control Arduino to control the initiation of different sequences. Logs all testing data.
MicroSD Shield (x2)	Breakout boards attached to each Arduino	One contains the flight profile, and the other contains the data log from the Health Monitoring System
Xbee Pro S1	Wireless Communication Module	Wirelessly transmits information to and from the Health Monitoring Arduino and the Ground Control Station
Ocean Shield Thermocouple Shield v1.4	Thermocouple Multiplexer Shield	Multiplexes the signals from the thermocouples and relays them to the Health Monitoring Arduino

6.2. Sensors

Part ID	Description	Purpose
Pressure Transducer (x7)	Pressure Transducer	Measures pressure
Thermocouple (x6)	Thermocouple	Measures temperature
Pixhawk Voltage Sensor	Voltage Sensor	Measure battery voltage

6.3. Pin Assignments

Flight Control Arduino
AV(1-4)-T – 3-6
SD Card Shield – 53 (CS), 50 (MISO), 51 (MOSI), 52 (CLK)
Communication with Health Monitoring Arduino – Serial 2 (TX2 and RX2)

Health Monitoring Arduino
AV5-M – 12
AV6-M – 11
FO-U – 44
FC-U – 45
Power Relay – 8 and 10
Thermocouple Shield – 24 (CS); 26, 27, 28 (AD0-2); 29 (MX_EN); 50 (MISO); 52 (CLK)
SD Card Shield – 53 (CS), 50 (MISO), 51(MOSI), 52 (CLK)
Pressure Transducers 1-7 – A0-A6

Communication with Xbee module – Serial 1 (TX1 and RX1)
Communication with Flight Controller – Serial 2 (TX2 and RX2)

7. Craft States

7.1. Standby Power

The craft defaults to standby power when first powered. On standby power, the Health Monitoring Arduino is powered and will collect, store, and transmit all sensor data. The pressurant isolating fail-closed valve, pressurant vent fail-open valve, the tank isolating actuated valve, and the tank dump actuated valve can all be controlled in this state. The Flight Controller Arduino is not powered in this state, and thus the flight profile can neither be simulated nor run.

7.2. Full Power

Ground Control sends commands to toggle full power on or off. On full power, all of the electrical components are powered, and the Flight Controller Arduino can be commanded to simulate or run the flight profile, or to follow a Softkill or Hardkill sequence by the Health Monitoring System. The actuated throttle valves in this state are fully closed.

7.3. Simulate

When Ground Control sends the command to simulate the flight profile, the flight profile uploaded to the SD card on the Flight Controller Arduino will be read and transmitted back to Ground Control to view, but the signals will not actually be sent to the actuated throttle valves. After simulating a profile, Ground Control should send a signal to reset the counter for reading in the flight profile.

7.4. Run

When Ground Control sends the command to run the flight profile, the flight profile uploaded to the SD card on the Flight Controller Arduino will be read and transmitted back to Ground Control to view, and the signals will also be sent to the actuated throttle valves. When the profile is run completely, the actuated valves will default to a full closed state, but Ground Control should also send a signal to revert to a full power state.

7.5. Softkill

When a Softkill is triggered (see Section 2 for Softkill criteria), the actuated throttle valves will close at a rate of 5 degrees per second until fully closed. When they are fully closed, if Softkill is still triggered, it will remain in Softkill. Otherwise, it will automatically revert to a full power state. All of the other valves will remain unchanged, but can be changed as needed by Ground Control. See Example Softkill Script in Appendix for more information.

7.6. Hardkill

When a Hardkill is triggered (see Section 2 for Hardkill criteria), the actuated throttle valves will completely open, the tank isolating and pressurant isolating valves will close, and the pressurant vent valve will open. When Hardkill is no longer triggered, all valves will remain in these positions until Ground Control commands otherwise. See Example Hardkill Script in Appendix for more information.

7.7. Not Powered

When the craft is not powered or if the power fails, there will be no communication between the craft and Ground Control. All actuated valves will remain in their current positions, the pressurant isolating valve will fail closed, and the pressurant vent valve will fail open.

8. Appendix

8.1. List of Additional Documents and Version Numbers

Example Flight Profile	(Version 2.0)
Example Softkill Script	(Version 2.0)
Example Hardkill Script	(Version 2.0

Puma Ground Control System Design Document

The Pennsylvania State University
Lunar Lion Team

Author: Yeyuan Xin

Version 2.0

Date: 7/13/2015

List of Revisions

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1. Scope

The Puma Avionics System Design Document details the current components in the avionics casing of the craft and the flight software that governs craft behavior. The onboard processors are two Arduinos – a Flight Controller Arduino to control the throttling valves, and a Health Monitoring Arduino to process sensor data and execute and relay user commands, as well as communicate with the Ground Control Station. Various sensors collect data on the state of the craft, and the software is programmed to respond appropriately to both sensor readings and human commands.

2. Requirements

The Ground Control System must meet the following requirements.

- Send commands to manipulate the positions of the following valves:
- Fuel tank isolating actuated valve
- Fuel dump actuated valve
- Pressurant isolating fail-closed valve
- Pressurant vent fail-open valve

Receive, calibrate, and display data from the craft:

- Thermocouples (x6)
- Pressure transducers (x7)
- Battery voltage sensor
- All current valve states (x8)

Send commands to begin the following sequences:

- Turn on full power
- Simulate a flight profile
- Run a flight profile
- Softkill
- HardkillTrade Space / Design Decisions

3. Trade Space / Design Decisions

3.1. Send commands to manipulate valve positions

The user can click on the valve they wish to toggle on the P&ID of the craft on the right screen of the user interface to send the command. The tank dump actuated valve control will show a confirmation message before activating.

3.2. Receive, calibrate, and display data from the craft

When the LabVIEW program is run, the incoming data should be calibrated by pressing the Calibrate button and verifying or changing the calibration values. These calibration values apply to the pressure transducers and the voltage sensor, as the temperature readings should be processed on the onboard thermocouple shield. The software was designed to visually display all of the data both at a glance on the craft diagram, as well as on separate graphs for each sensor, making data readily accessible in multiple contexts. The maximum value for each sensor will also be displayed. See Puma Ground Control Documentation in Appendices for more details.

All valve states will accurately reflect any sequence activated by the user in the LabVIEW program. If a Hardkill is activated manually by the button switch or on the craft, valve indicators may not show their correct states. This is not a concern, because Hardkill will only be activated outside the LabVIEW program either by the button switch if the program crashes, or by a timeout if there is no communication for over 5 minutes. In both cases, the LabVIEW program will not be functional, so valve indicator states are irrelevant. A screenshot of this LabVIEW GUI could be found in the [1] Operational Readiness.

3.3. Send commands to begin sequences:

All specified commands can be triggered by buttons located on the left screen. These commands activate the hard coded sequences in the flight system. See Puma Ground Control GUI Documentation for more details.
In the event that the LabVIEW program crashes, a Hardkill command can also be sent by activating the red button switch attached to the Data Processing Arduino.

4. Design Validation Process

The Labview software was tested rigorously during development, and only known stable versions of code were used for continued development. Any future component failures on the Ground Control Station can be identified during system checkouts before testing. All testing sequences and operations can be run without propellant in the lines in order to test and ensure complete functionality.

5. Construction Process and Procedures

The development of software was conducted in small teams of developers that worked on specific tasks, and the overall integration of the Ground Control Station occurred continuously during development. Connections on the Ground Control Arduinos are soldered over perforated board pieces.

6. Design

Part ID	Description	Purpose
Arduino Mega 2560	Data Processing Arduino	Processes data from Labview, craft, and button switch, and relays the appropriate messages between the Labview program and the Wireless Communications Arduino.
Arduino Mega 2560	Wireless Communications Arduino	Receives messages from craft and sends it to the Data Processing Arduino, and receives messages from the Data Processing Arduino and transmits it to the craft.
PC Computer	Ground Control Computer	To run the Labview program which provides a visual and graphical user interface to monitor and control the craft.

Button Switch	Manual Hardkill Button	Used to trigger a manual Hardkill in the event that the Labview program crashes or otherwise malfunctions.

7. Appendix

7.1. List of Additional Documents and Version Numbers

Command Characters (Version 2.0)

8. Reference Material

8.1. List of Documents Version Numbers

[1] Operational Readiness (Version 2.0)

[1a] LabVIEW Display (Operational Readiness v 2.0)

Puma Power Systems Design Document

The Pennsylvania State University
Lunar Lion Team

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PENN STATE LUNAR LION TEAM

List of Revisions

v 2.1: 7/20/2015 Clarified system descriptions in § 3.1, 3.2, 3.4 REB

1. Scope

The Puma Power System Design Document includes all of the electronic components and connections which exist on the Puma craft, and also the external apparatus for charging and discharging batteries. This includes the contents of the electronics enclosure which are not assigned to the GNC subsystem – that is, batteries, power distribution components, interconnects, power conversion, electronic switching, protection & isolation, and signal conditioning. Microcontroller boards and associated expansion boards (thermocouple multiplexer, laser altimeter input, memory, wireless communication) are assigned to the GNC subsystem – however, Power is typically responsible for the interconnects and any necessary signal conditioning. All electrically powered components on the Puma, including valves, sensors, microcontrollers, and other discrete electronics are tied into the Power System. Refer to Top Level Schematic and Block Diagram in Appendices for a high level overview of the system. For a full list of all electrical components on Puma, refer to Bill of Materials in Appendices.

2. Requirements

The Puma power system must:

- Supply the valves, sensors, and other electronics with sufficient power for their operation.
- Minimize interference from internal or external sources.
- Be capable of remote operation and shutdown
- Be capable of local shutdown and rapid battery changeover
- Maintain parity, when possible, with projected requirements for future stages of the project

3. Trade Space / Design Decisions

3.1. Supply the valves, sensors, and other electronics with sufficient power for their operation:

The voltage and current levels needed by the test stand are largely driven by the component requirements. DC voltage levels of 24, 12, and 5 volts are supplied through six different DC/DC converters, as well as some more robust components which are powered directly from the batteries.

Normal operation may be broken down into three modes – standby, flight, and shutdown. From the perspective of the power systems, the standby and shutdown modes are functionally identical, and may be characterized by the operation of one 5 V, one 12 V, and one 24V DC/DC converter. Respectively, these provide power to the health-monitoring Arduino, the isolation valves for the propellant and pressurant tanks, and the pressurant vent valve. In addition, standby operation provides power to the pressure transducers, peripheral shields for the health-monitoring Arduino, and a visual indicator of the system state. The Arduino peripherals include a SD-card-based memory shield, the thermocouple demultiplexer shield, and an XBee wireless module to facilitate communication with the ground station. In addition, during standby power, the pressurant isolation valves draw power directly from the battery.

Entering flight operation mode requires the health-monitoring Arduino to activate the main power relay (K1), enabling the three remaining voltage converters (5 V, 12 V, 12 V). These provide power to the flight control computer and its peripheral devices, as well as the remaining throttle valves.

Estimated battery lifetime can accommodate approximately 50 minutes of standby time plus two minutes of flight. These estimates incorporate a set of pessimistic assumptions, including low converter efficiency, constant valve operation at maximum power, battery operation at minimum expected voltage, and factor in an additional safety margin of 25%. To facilitate extended operation, the initial battery capacity was doubled to include two 4-cell, 4 Amp*hour lithium-polymer batteries in parallel. An estimated charge profile can be found in the Appendices (refer to Power Calculations).

3.2. Maximize system robustness and EMC:

Wherever possible, systems have been diode-isolated and shielded to reduce the possibility of interference. All inductive loads are additionally protected by a flyback diode. In cases which have not adversely affected noise levels, external cables are shielded to the chassis. Power converters have protective fuses at their inputs and outputs. Each valve output line is independently fused to prevent system damage as a result of peripheral malfunction.

3.3. Be capable of remote operation and shutdown:

Solenoid and servo valves were chosen that allow operation of the system either autonomously through the flight-control and health-monitoring microcontrollers, or remotely via a wireless link to a ground station equipped with LabVIEW. Each valve may be individually operated from the ground station.

In the event of an emergency system shutdown, the ground station sends a signal to the health-monitoring Arduino, and valves must move to a safe state. Although the solenoid valves will default to a safe unpowered state, the servo valves require power to operate. Towards this end, the dump valve and propellant tank isolation valve receive power through a separate DC/DC converter. Upon receipt of a shutdown signal, the health-monitoring Arduino should command each of these servo valves to move to a known safe position.

3.4. Be capable of local shutdown and rapid battery changeover:

As long as the system is in a safe state, complete shutdown is enabled by a local toggle switch which will completely isolate the system from the batteries. Once this has been accomplished, the batteries can be easily removed and exchanged from the battery compartment.

Visual indication of the system status is present through red and green LEDs, which show the status of the main power relay. Illumination of the red LED indicates that the main power relay is in a closed position, and that valves are not necessarily in a safe state. Illumination of the green LED indicates that the main power relay is in an open position, and that valves should have reverted to their safe default states. Simultaneous illumination of both LEDs is not normally possible. Since this is indicative of system error, it should be treated with caution.

3.5. Maintain parity, when possible, with projected requirements for future stages of the project:

To a large extent, this requirement was secondary to the evolving needs of the propulsion and GNC subsystems. Although future stages of the project will use similar design principles and structure, re-use of the current system is not anticipated at this time.

4. Design Validation Process

The design of the power system evolved from the previously designed power and switching system supporting the bipropellant thruster. While following these principles, the system has grown organically in response to shifting design requirements.

5. Construction Process and Procedures

The Power Systems group will lead the construction of the power system, coordinating efforts with the other subsystems as necessary.

Initial testing and construction of the electrical systems will take place in the Lunar Lion facility in Research West. This will encompass complete testing and assembly of the electronics enclosure, ground station, and remote shutdown system, along with their component electronics. After component-level verification has been completed, the electrical systems will undergo internal subsystem level testing prior to full integration with the propulsion system. Once integration has been completed and continuity has been verified, system level tests will be conducted by through the GNC ground station.

5.1. Individual Component Acceptance Criteria and Procedures

5.1.1. Power Supplies (DC/DC)

Each power supply should provide a known voltage level and range of acceptable output currents. Output levels should not significantly deviate under transient load conditions.

5.1.2. Master Control Switch

The master control switch should cut all system power when toggled.

5.1.3. Electromechanical and Solid-State Relays

Each actuated valve will be individually tested by the GNC and Power Subsystems. To pass, the valves must completely close and open within the specified response time and at the voltage/amperage specified by the supplier. They must default to their correct fail open/closed state when power is cut off. Function of the valves is incumbent upon correct function of the relays.

Independent, component-level testing of each electromechanical relay will demonstrate that the correct connection has been made or broken as required. Solid-state relays must instead show output levels correlating to their expected state. In addition, relay coils and control inputs will be examined to verify their isolation from the relay outputs.

5.1.4. LED Indicators

The red and green LED indicators should be effectively, though not explicitly, present in an XOR configuration. Both indicators will be tested for illumination under the appropriate setting of the main power relay. The indicators will also be checked as the system-level verification tests proceed.

5.1.5. Sensor Calibration

Each sensor must be tested to ensure that it is receiving power at expected levels. Sensor output values should have been previously calibrated against expected values, and these may be verified independently.

5.1.6. Valve Operation
Each electrically actuated valve will be individually tested by the GNC and Power subsystems. To pass, the valves must completely close and open within the response time and voltage/amperage specified by the supplier. They must default to their correct fail open/closed state when power is cut off. Servo valves must demonstrate the capability of moving to the correct position, subject to an acceptable degree of error determined by the Propulsion group.

6. Construction Verification Procedure Pass/Fail Criteria

6.1. Control Integration
Initial integration with the on-board microcontrollers is essential to the proper operation of the power system. Successful integration may be confirmed by the proper system response to commands from the microcontrollers – that is, valve performance and sensor output are as expected. Secondary integration includes control from the ground station – including manual overrides – as will be used during system operation. As before, independent verification of each valve and sensor is required.

6.2. Emergency Shutdown
The emergency shutdown system must be evaluated before the system is deployed. Unlike previous systems, the GNC manual hard-kill button switch necessarily has no hard link to the power supply of Puma. Instead, the button switch triggers a software-based override from the ground station, designed to immediately initiate automatic shutdown procedures. The hard-kill procedure, as well as a soft-kill procedure, may be separately triggered if the system detects unexpected values, including pressure and temperature values as well as voltage and current data recorded from the batteries, or if communication is lost for an extended period of time. The system-level emergency stop tests should verify that power levels past the main power relay are negligible. In the event of a manual shutdown, some diagnostic procedures must be performed prior to restoring the power. Other than the fault-oriented diagnostics, these procedures focus on tests to ensure that transient conditions caused by the shutdown did not damage the system.

6.3. Sensor Signal Conditioning
Each sensor and control line has electrical and electronic components. Prior to use, each line must be inspected and evaluated for continuity and for conformation with previously calibrated values

7. Design

7.1. Power Supply & Conversion
The power system is designed to provide stable power at certain DC voltage levels as needed. The output of each power supply is stabilized against voltage droop by a local capacitor bank. Other than previously described, additional circuitry was only necessary to accommodate the vagaries of the Pixhawk flight controller. Although the Pixhawk uses a 5 V source, it operates internally at 3.3 V, and requires inputs to function at the 3.3 V voltage level. In order to meet these requirements, a series of bidirectional level shifters were constructed, including a monolithic shunt-based 3.3 V voltage regulator.

7.2. Isolation & Protection Circuitry
Every peripheral component which contains an inductive load – the valves – is protected by an isolation diode combined with a flyback diode. If the inductive loads of the solenoids or spark coil build up unexpectedly high voltage levels, the flyback diode will clamp the excess energy, allowing it to dissipate safely across the load. Additionally, each switched peripheral receives its power through an isolation diode. In conjunction with the

flyback diodes, these should prevent power problems from affecting other peripherals. Each of the solenoid valves is powered through an optically isolated solid-state relay.

The primary power line and each secondary power converter are individually protected by fuses. In the event of component failure and an electrical short, the fuse should blow, preventing damage to the power supplies.

To avoid previously experienced difficulties with peripheral shorts causing local damage to the control circuits, each valve output features an independent output fuse.

8. Maintenance Required and Schedule

8.1. Emergency Shutdown

In the event of an emergency shutdown caused by a fault in the electrical system, the fault should be identified and repaired before a full power-up is performed. The electrical system may be isolated and powered up in sections to aid in diagnostic procedures. All fuses and cables should be checked for continuity.

9. Appendices

9.1. List of Additional Documents and Version Numbers

Puma Composite	(Version 2.1)
Bill of Materials	(Version 2.0)
Power Calculations	(Version 2.0)
4 Cell 14.8V LiPo 25c Battery Discharge Reference	(Reference)

10. Reference Material

10.1. List of documents and where they can be found:

[1] Material Readiness	
[1a] System Functional Block Diagram	(Version 2.0)

Puma Propulsion System Design Document

The Pennsylvania State University
Lunar Lion Team

List of Revisions

1. Scope

The Puma Propulsion System Design Document includes all of the components that come in contact with hydrogen peroxide (H2O2) and pressurant gas during testing, including the ball valves, pressure regulators, pressure reliefs, pressure transducers, pump, solenoid valves, tanks, thermocouples, tubing, and associated fittings. It does not include the design of the thruster, power supply or data acquisition for these components, or their specific operation and control during testing. For more information on component specifications and materials, see Master Equipment List [2a]. For more information on procedures, see Operational Procedures [1].

2. Requirements

The Puma propulsion system must:

- Safely store and handle H2O2 during fills, testing, and not testing
- Supply the engine with H2O2 at sufficient pressure and flow rates
- Prevent and/or manage any uncontrolled H2O2 decomposition
- Produce sufficient thrust for desired flight profile
- Fly, constrained vertically, to sufficient altitude
- Be remotely operated and shutdown
- Allow Puma to safely lower in event of abort during flight
- Default to a safe mode in the event of power failure or shutdown

3. Trade Space / Design Decisions

3.1. Safely store and handle H2O2 during fills, testing, and not testing

H2O2, particularly in rocket-grade concentration, is a highly corrosive and reactive material. The propulsion system must always maintain the propellant with safety as first priority.

3.1.1. Propellant tank

The propellant tank was selected to accommodate high pressure testing requirements and store enough H2O2 for short terms to supply the engines with sufficient propellant to complete the test profile. It is carbon fiber wrapped and lined with aluminum 6061, with a maximum volume of 8 gallons and a maximum allowable working pressure of 3600 psi.

3.1.2. Propellant tank filling

The propellant tank will be filled through propellant dump valve AV6-M with the use of a pump. After filling, AV6-M will be closed and the pump setup disconnected.

3.1.3. Propellant lines

The manifold is plumbed with seamless stainless steel tubing to transfer H2O2 to the engines. The propellant line at the downstream tank adapter is of ¾-inch diameter and splits to two ½-inch lines. These lines each split again and reduce to 3/8-inch diameters, with all four branches each supplying one engine with H2O2.

3.2. Supply the engine with H2O2 at sufficient pressure and flow rates

This system is constant pressure-fed to supply H2O2 to the engine at pressures sufficient to facilitate the propellant flow rate necessary to achieve the desired thrust. The minimum volume of pressurant in the propellant tank must be at least 20% of the tank's total volume. For pressurant component sequence, see Puma P&ID [1a].

3.2.1. Pressurant tank

Puma will carry an onboard pressurant tank of compressed gaseous nitrogen (GN2). Its maximum allowable working pressure is 4500 psi, and will be filled to approximately 2700 psi prior to testing.

3.2.2. Pressurant tank filling

Pressurant fill valve BV-U, a stainless steel manual ball valve located at the pressurant tank, will allow refilling of GN2.

3.2.3. Pressurant lines

Pressurant will be supplied to the propellant tank through ½-inch seamless stainless steel tubing.

3.2.4. Regulating pressure

Analog pressure regulator RG-U, located at the pressurant tank, will supply pressurant to the lines. It will both indicate pressurant tank pressure and regulate constant delivery pressure. In addition to filling the pressurant tank, BV-U will also be used to vent GN2 from the regulator to decrease delivery pressure. RG-U was selected to accommodate intended delivery pressures of 500-900 psi.

3.3. Prevent and/or manage any uncontrolled H2O2 decomposition

No materials that could react with H2O2 will be allowed at any wetted surfaces. Stainless steel pressure relief valves PR-M and PR-U are strategically located to be able to safely vent pressure from any point in the manifold in the event of uncontrolled H2O2 decomposition. Pressurant vent valve FO-U, a stainless steel fail-safe-open solenoid, will vent residual pressure in lines and propellant tank. For more information on H2O2-compatible materials and components chosen, see Material Readiness [2]. For more information on valve configuration, see Puma P&ID [1a].

3.3.1. Weep holes

H2O2 trapped in the cavity of a closed ball valve may decompose, causing a pressure buildup that must be vented. Any ball valve that comes into contact with H2O2 must therefore be modified by drilling a "weep hole" into the chamber to relieve such pressure. Weep holes must be thoroughly inspected before use to ensure that there are no remaining burrs that could potentially contaminate the H2O2 or damage the integrity of the valve seals.

3.4. Produce sufficient thrust for desired flight profile

Puma is propelled by four H2O2 monopropellant engines that operate nominally at about 100 lbf. The operating conditions of the engines (e.g. flow rate, chamber pressure, chamber temperature, etc.) must produce sufficient thrust to accommodate the desired flight profile.

3.4.1. Chamber heating

Operating conditions must facilitate complete H2O2 decomposition, such that the exhaust contains only superheated steam and oxygen. Thus the chamber must be sufficiently heated prior to liftoff by including a “burp sequence” at the beginning of the flight profile. The heat released from several brief H2O2 reactions will facilitate proper thermal conditions for complete decomposition during the flight.

3.4.2. Throttle valves

Not only must the engines be capable of producing sufficient thrust for Puma to lift off the ground, but also they must be throttleable to match the varied thrust requirements of the flight. Each engine will be throttled by a stainless steel ball valve, AV1:4-M, actuated by a Torxis motor.

3.5. Fly, constrained vertically, to sufficient altitude

Puma must be capable of vertical flight and hovering. It will be constrained to the vertical axis, and will therefore not be required to maneuver with roll, pitch or yaw. The four engines will therefore point thrust directly downward.

3.6. Be remotely operated and shutdown

Valves were chosen that allow remote operation of the thruster through LabVIEW. No personnel will be permitted to approach the craft between H2O2 fill and when Puma is in a safe state.

3.7. Allow Puma to safely lower in event of abort during flight

Puma must be capable of automatically initiating a soft kill sequence to safely lower the craft to the ground in the event of an abort condition being triggered during flight. This sequence would cause the throttle valves to transition from any given position to fully closed at a slow and constant rate. This rate will be dictated not by openness of the valve, but rather by minimum H2O2 flow rate.

3.8. Default to a safe mode in the event of a power failure or shutdown

Fail-safe solenoids were chosen for appropriate points along the line such that, in the result of a power failure, the default state of the valves will bring the system to a safe state. Pressurant iso valve FC-U, a stainless steel fail-safe-closed solenoid, will isolate pressurant supply to the manifold. Pressurant vent valve FO-U will allow any pressure to vent. Emergency shutdown will also initiate an automatic shutdown sequence that will close propellant iso valve AV5-M, a Torxis motor-actuated stainless steel ball valve, to prevent further H2O2 supply to the engines. For more information on valve configuration, see Puma P&ID [1a].

4. Design Validation Process

The plumbing system has been iteratively designed in coordination with ARL technicians and safety authorities. Before use, it must be approved by the signature page signees.

5. Construction Process and Procedures

The Propulsion subsystem will lead in the construction of the plumbing system in coordination with ARL technicians. All parts coming into contact with H_2O_2 will be thoroughly "LOX cleaned" with Simple Green and deionized water, passivated in a weak nitric acid bath to provide a protective oxide layer on all wetted surfaces, and soaked in weak concentration H_2O_2 to preemptively react with any possible residual contaminants.

6. Construction Verification Procedure Pass/Fail Criteria

6.1. Plumbing system leak checks

The pressure in the supply lines must hold upstream of the throttle valves. The readings at the pressure transducers must not drop more than 2 psi within 5 minutes when pressurized to operating pressure with the pressurant hand valve closed. The system must also demonstrate no visible leaks when checked with Snoop™.

6.2. Verification of construction

ARL test site technicians will verify that the system has been built to the specifications in the Piping and Instrumentation Diagram and that all direction sensitive components are installed in the correct orientation.

7. Design

7.1. Individual component description and purpose

Part ID	Description	Purpose
AV1:4-M	Throttle actuated valves	Controls flow rate of H2O2 supplied to engines
AV5-M	Propellant tank actuated remote isolation ball valve	Isolates H2O2 supply to manifold
AV6-M	Propellant tank actuated fill/dump ball valve	Drains propellant tank of residual H2O2 at testing conclusion. Also used to fill propellant tank with DI water or H2O2
BV1-U	Pressurant fill/vent manual ball valve	Allows pressurant tank to be filled with GN2. Also vents pressure from regulator
FC-U	Pressurant fail-closed isolation solenoid valve	Isolates pressurant supply to propellant tank. Fail-safe-closed to prevent pressurization of tank in event of power loss
FO-U	Pressurant fail-open vent valve	Vents GN2 from pressurant lines and propellant tank. Fail-safe-open to allow depressurization in event of power loss
HV-U	Pressurant hand valve	Opens or closes pressurant supply to regulator
PR-M	Manifold pressure relief	Fail-safe to vent manifold if pressure reaches critical levels
PR-U	Pressurant pressure relief	Fail-safe to vent tank and pressurant lines if pressure reaches critical levels
PT1:4-M	Manifold pressure transducers upstream of engines	Measure and send pressure data from upstream of engines to control system. Used to approximate chamber pressures
PT5-M	Manifold pressure transducer midstream of plumbing lines	Measures and sends pressure data from manifold
PT1-U	Pressurant tank pressure transducer	Measures and sends pressure data from pressurant tank to control system
PT2-U	Propellant tank pressure transducer	Measures and sends pressure data from pressurant lines to control system. Used to approximate propellant tank pressure
RG-U	Pressurant regulator	Regulates the delivery pressure of GN2 to propellant to propellant tank and indicates pressurant tank pressure
TCw1:4-E	Engine weld-on thermocouples	Measure and send temperature data from engine chambers to control system
TCp1-M	Manifold probe thermocouple downstream of propellant iso valve	Measures and sends temperature data from downstream of propellant iso valve to control system
TCp2-M	Manifold probe thermocouple downstream of propellant tank	Measures and sends temperature data from downstream of propellant tank to control system

8. Maintenance Required and Schedule

8.1. Plumbing leak checks

The system is checked for leaks as part of the normal system on procedures. The procedure outlined previously in 6.1 will be followed when checking for leaks.

8.2. Visual inspection

After each set of tests, when the vehicle is deemed safe to approach, a visual inspection of the system will be performed. All parts of the plumbing, including components, tubing, and fittings, will be visually checked for signs of damage and/or corrosion.

9. Reference Materials

9.1. List documents and locations where they can be found

[1] Operational Procedures	(Operational Procedures v2.0)
[1a] Plumbing and Instrumentation Diagram	(Puma P&ID v2.0)
[2] Material Readiness	(Material Readiness v2.0)
[2a] Master Equipment List	(MEL v2.0)

Puma Structures Design Document

The Pennsylvania State University
Lunar Lion Team

Author: John Targonski Version 2.0 Date: 7/15/2015

List of Revisions

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1. Scope

The Puma Structures Design Document includes the entire structure that holds all of the components of Puma including the pressurant tank, propellant tank, engines, flight hardware, etc. The vehicle structure will be designed to maintain integrity during all phases of testing. The structure will feature force provided by thrusters. The structure system will not account for wind and assume thrust forces imparted in vehicle bolted-down test configuration.

2. Requirements

The Puma Structure must:

- Have a dry mass of 90 kg
- Include attach points for the vertical flight test stand
- Include a mounting mechanism for the propellant tank, pressurant tank, batteries, GNC equipment, and flight hardware (may be implemented with GNC equipment).
- Designed such that the batteries can be easily recharged.
- Design such that the tank can be easily refilled.
- Resonance of the engine will not match that of the material for the spacecraft or vertical flight test stand.

3. Trade Space / Design Decisions

3.1. Have a dry mass of 90 kg

90 kg dry mass will ensure there will be a high enough thrust to weight ratio to achieve the desired flight profile. A detailed description of all the components and their corresponding mass can be found in the mass budget analysis located in the appendix.

3.2. Include attachment points for the vertical flight test stand

Cable guides in vertical alignment with each other are attached to the bottom and middle of the craft in three different vertical locations. Utilizing three cable guides will restrain Puma to one degree of freedom in the vertical z axis. The tips of the cable guides are removable to allow for attachment to the cables.

3.3. Include a mounting mechanism for the propellant tank, pressurant tank, batteries, GNC equipment, and flight hardware

The main mounting container that will house all of the power supplies as well as most of the GNC equipment will be the power box. This will be attached to the outside of the structure, opposite the pressurant tank to offset the weight. The primary tank will be housed in the center of the craft, at the center of mass and in the most protected spot.

3.4. Batteries can be easily recharged and tanks can be easily refilled

The power box, housing for all power equipment, will be easily accessible by an exterior, sealed door and a modular interior. The tank will be filled using a gravity pump, and the inlet to the tank can be easily accessed at the top of the craft.

3.5. Prevent continued vibrational/resonance movement

Vibration and resonance have been seen as a result from the engines. This could cause movement throughout the structure. If it is deemed necessary, the use of damping spacers will be added to absorb the excess mechanical energy. This should prevent continued movement of the thruster arm through the entire flight and test duration.

3.6. Movement only in the z-axis

The flight test at the Larson test track restrains the motion of the craft to the z-axis, and the engines are placed so that the thrust vector of each engine is parallel to the z-axis. This ensures with little error that the movement will only occur in the vertical direction.

4. Design Validation Process

4.1. Static Finite Element Analysis

Testing was done during the construction of Puma 1.0 to imitate a static tie down test and confirm a structurally reliable craft with a FOS of 1.5 to 2.0. The test had confirmed a fixed geometry and withstands a load of 200 lbf thrust in each engine. Puma 2.0 utilizes the same material of Aluminum 6061-T6 as well as bolted connections allowing for the FEA to be transferred to the new craft.

4.2. Weight Loading

The purpose of the weight loading test is to validate the static finite element analysis completed during design. This test is conducted by hanging a 100 lbf weight on each of the engine mounts in order to confirm the integrity of the craft. This qualitative test showed minimal deflection in the craft. Further quantitative tests can be completed to measure deflection of the arms and then be cross-referenced with the FEA.

5. Construction Process and Procedures

The construction site for the structure was located in the Penn State Learning Factory, and the construction process began after a final design was agreed upon and analyzed thoroughly. Construction was fairly straight forward; with the design schematics followed closely using the correct materials, the primary structure was built during this time.

On the day of testing, our bolts will be tightened to the recommended torque. For the ¼-20 bolts, the recommended torque is 14 Ft. Lb and for the 10-32 bolts the recommended torque is 13.58 Ft. Lb. The bolts will then be partially sealed at the outside to visibly show if bolt loosening had occurred. Once all bolts are tightened and sealed, the structure will be completely ready for testing.

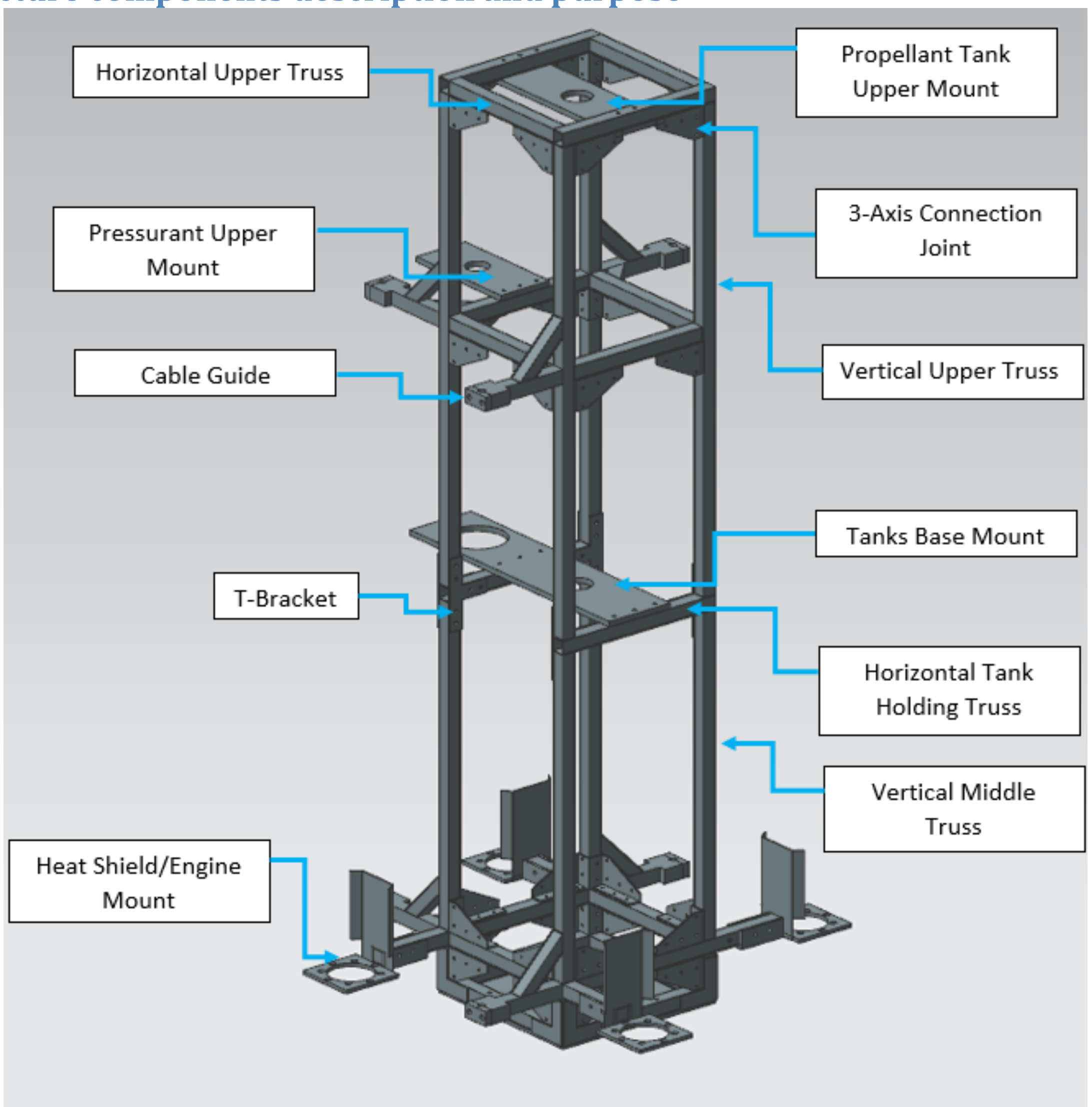
6. Construction Verification Procedure Pass/Fail Criteria

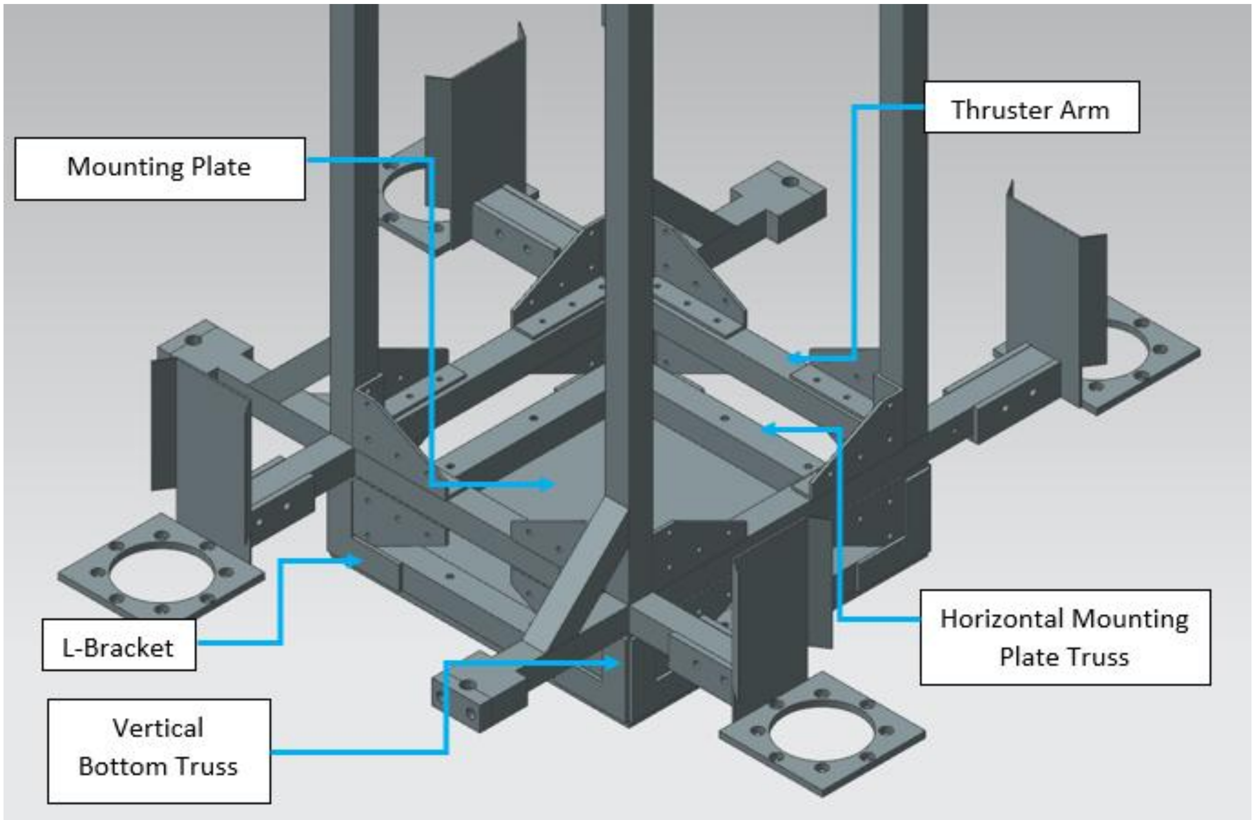
The verification for construction pass or fail is through physical testing. First, the structure is characterized with static load testing greater than the dynamic loads Puma will be experiencing (i.e. hanging weights from inverted thruster arms and measuring deflection). The next step is fixed dynamic testing in the forms of tie down testing and thrust vector characterization. If previously stated testing trials are completed without failure of the structure, the craft has passed the criteria and may continue on with testing.

A complete rigorous analysis of the bolts was not performed due to research showing the bolts being rated far above the loads they will be experiencing (>10x). The torque specifications for our specific bolts are mentioned in Section 5. of the Puma Structures Design Document.

7. Design

7.1. Structure components description and purpose





Name	Material	Purpose
3-axis Connection Joint	*Nickle Plated Steel*	To combine a multi-axis joint. The factory made part allows for compatibility as replacements are on an as needed basis. The 90 degree pieces allow for ease of construction in creating a perfectly square structure.
Cable Guide	*Aluminum 6061-T6*	To connect Puma to cables for vertical flight testing. Off-set from Puma to allow for ease of mounting before testing. Cable Guides span the height of the craft to prevent yawing and rolling.
Heat Shield/ Engine Mount	*Stainless Steel 304*	To mount the Hydrogen Peroxide (H2O2) engines to the craft as well as to protect Puma from the heat created by the engines.
Horizontal Mounting Plate Truss	*Aluminum 6061-T6*	To allow for mounting of the Mounting Plate used for static and vertical testing.
Horizontal Upper Truss	*Aluminum 6061-T6*	To provide structure at the top of the craft as well as hold the propellant tank in its proper place.
Horizontal Tank Holding	*Aluminum 6061-T6*	To provide support for the Tanks Base Mount and a mounting location for the Power Box. The truss spans the

Truss		entire structure to allow the weight of the tanks to have a load path through the vertical members as opposed to being placed on the shear strength of bolts.
L-Bracket	*Aluminum 6061-T6*	To create a connection between the horizontal Tank Holding Trusses and the two Vertical Trusses. Factory made to allow compatible parts.
Mounting Plate	*Aluminum 6061-T6*	To provide a location for mounting to the table for static testing and a location to land on the honeycomb during vertical testing.
Pressurant Upper Mount	*Aluminum 6061-T6*	To provide a location for the pressurant tank to be held in place from an upper location.
Propellant Tank Upper Mount	*Aluminum 6061-T6*	To provide a location for the propellant tank to be held in place from an upper location.
T-Bracket	*Aluminum 6061-T6*	To create a connection between the Horizontal Mounting Plate Truss and the Vertical Bottom Truss. Factory made to allow compatible parts.
Tanks Base Mount	*Aluminum 6061-T6*	To support the bottom of both the pressurant and propellant tanks. Weight from the two tanks will travel through the Horizontal Tank Holding Truss and down the Vertical Middle Truss.
Thruster Arm	*Aluminum 6061-T6*	To provide a location for the engines to be mounted. The close proximity to the craft allows for shortened plumbing.
Vertical Bottom Truss	*Aluminum 6061-T6*	To provide the support for the structure. Allow for the mounting of the Mounting Plate to be below the bottom of the engines so as not to damage them when structure is not in flight.
Vertical Middle Truss	*Aluminum 6061-T6*	To provide the support for the structure. Carries the load of the tanks as opposed to putting the load into the shear of bolts.
Vertical Upper Truss	*Aluminum 6061-T6*	To provide the support for the structure. Allows for the mounting of the pressurant tank as well as the Power Box.

8. Maintenance Required and Schedule

8.1. Fatigue inspection

Before testing, holes will be inspected for crack formation and thruster arms will be inspected for plastic deformation. Fatigue of parts will be insignificant with the length of each test as well as the number of tests. At the end of this testing phase, the structure will be replaced with a new set of materials.

9. Appendices

9.1. List of Documents and Version Numbers

Puma Mass Budget (Version 2.0)

Puma Thermal System Design Document

The Pennsylvania State University
Lunar Lion Team

Author: Zachary Skank Version 2.0 Date: 7/12/2015

List of Revisions

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1. Scope

1.1. Introduction

In order for a successful test of Puma, a number of thermal issues had to be dealt with. The two most critical to Puma's success are the thermal shield and wire sleeve. The heat shield is designed as a barrier between the engines the aluminum frame sitting inches away. Conductive heat transfer to the arm from the engine is also a potential issue. Appendix 9.2 shows that, even without insulation between the mount and arm, the main structure will not be harmed by the engines. The wire sleeve encloses all of the external wiring surrounding Puma. A large amount of wiring comes within a foot of one of the engine plumes. A number of sample tests and supplier specifications assured us the sleeve could withstand the estimated 326°C (618° F) plume without damaging the wiring.

1.2. Thermal Shield

Need for thermal shields on Puma was based on temperature effects from the H2O2 engines. Manufacturer quotes and testing showed an engine wall temperature upwards of 500°C (932°F). Due to location of the engines to structure, the thermal subsystem designed a heat shield to be placed between the engine and Puma. Insulating the entire thruster showed to be problematic for the plumbing components upstream of the engine. The shield is designed to eliminate thermal radiation.

1.3. Wire Sleeve

Damage to wiring from H2O2 engines plume is avoided by running all electronic lines through a heat resistant fiber glass sleeve. Off the shelf Techflex sleeve met requirements and was readily available. The sleeve will be able to withstand near direct contact with the plume and keep the heat from damaging wiring.

2. Requirements

2.1. Thermal Shield

The Puma thermal shield must

- Be able to withstand extreme temperatures of 500°C (932°F) and greater generated by engine throughout multiple tests
- Mitigate thermal effects due to radiation on structure, plumbing, and components placed near engine
- Reduce the reheating of the engine through thermal reflectivity
- Be insulated on the structure side to reduce thermal transfer
- Conduction through shield engine mount must be minimized
- Surround surface area of engine facing craft to reduce thermal effects
- Surround the H2O2 engine combustion chamber facing the structure, where temperatures will be highest
- Not be extended past throat to eliminate plume impingement
- Remain fixed during operation
- Not interfere with plumbing or motor
- Not add considerable weight to vehicle

2.2. Wire Sleeve

- Sleeve must be able to withstand thermal effects of plume at close proximity
- Sleeve internal temperature must stay below melting point of wire insulation
- Sleeve diameter must allow at least two lengths of wire to minimize material
- Sleeve should be lightweight
- Sleeve should be flexible enough to turn around tight corners and change direction
- Sleeve effectiveness should be reduced under vibration or strain

3. Trade Space / Design Decisions

3.1. Thermal Shield

3.1.1. Withstand extreme temperatures generated by engine throughout multiple tests

Shield was fabricated from 16 gauge non-galvanized sheet steel with a melting point of 1370°C (2498°F). Steel was chosen for maximum durability and survivability through multiple tests

3.1.2. Mitigate thermal effects due to radiation on structure, pluming components placed near engine

Shield facing the engine will be covered with heat barrier with surface reflectivity of at least .70. Shield was placed on engine amount to come between thruster and aluminum arm. Shield has two slits on bottom that slide onto the engine mount to ensure no gaps.

3.1.3. Reduce the heating of the engine

Wings of shield designed to redirect heat in multiple directions to reduce the reheating of the thruster during operation.

3.1.4. Insulated on the structure side

Rear side of shield will be insulated to eliminate heat transfer through the backside of the shield.

3.1.5. Conduction through shield engine mount must be minimized

Three layers of ceramic insulation with a heat transfer coefficient of .60 @ 600 F is placed between engine mount and aluminum arm to minimize heat transfer.

3.1.6. Mitigation effects must ensure F.O.S. of 1.5

Original PUMA design called for a factor of safety of 1.5 with acrylonitrile butadiene styrene (ABS) components being limiting material of structure. ABS is no longer a constraint.

3.1.7. Dimensions must surround surface area of engine facing craft to reduce thermal effects

In to mitigate as much thermal radiation as possible the shield is designed to come between entire face of thruster and craft.

3.1.8. Must run entire combustion chamber where temperature will be highest
Peak temperatures were predicted to be in the upper portion of the thruster in the combustion chamber. Shield was designed to be placed along upper half of the thruster.

3.1.9. Shield should not extend past throat due to plume impingement
Keeping any extrusions above the throat avoids impingement from the plume. Plume impingement would additional thermal energy and create unwanted torques on the structure.

3.1.10. Remain in place during testing
Shield is welded to the engine mount to ensure the attachment would not detach from structure during operation.

3.1.11. Dimensions of shield should not interfere with plumbing or motor
Design was extended to top of thruster and placed at the end of the arm to avoid interference with plumbing and propulsion components.

3.1.12. Weight
Steel shield including engine mount add 2.2 kilograms to each arm

3.2. Wire Sleeve

3.2.1. Sleeve must be able to withstand thermal effects of plume at close proximity
Techflex sleeve is heat resistant up to 650°C (1202°F), higher than predicted plume temperature of 210°C (410°F).

3.2.2. Sleeve internal temperature must stay below melting point of wire insulation
Sleeve internal temperature requirement determined to be 50°C (122°F).

3.2.3. Sleeve diameter must allow at least two lengths of wire to minimize material
¼ inch sleeve allowed two lengths of Puma wiring to be drawn through without sleeve modification.

3.2.4. Sleeve should be lightweight
Techflex sleeve adds 0.028 kg per meter with a current length of sleeve on the craft of 33.668 meters.

3.2.5. Sleeve should be flexible enough to turn around tight corners and change direction
Techflex braided design allows to it manipulated without external tools or previous planning.

3.2.6. Sleeve effectiveness should be reduced under vibration or strain
Braided fiberglass design allows it withstand intense vibration, strain, and temperature changes without reduction in effectiveness

4. Design Validation Process

4.1. Thermal Shield
Design was analyzed and validated with thermal FEA using ANSYS Thermal Steady State and Thermal Transient modules and Siemens NX. For analysis results, see appendix.

4.2. Wire Sleeve

Techflex sleeve was chosen after confirming material properties and application with company. Sleeve surface was heated to 205°C (401°F) for 120 seconds and experienced an increase of internal temperature of 2°C (4.5°F), meeting temperature requirements.

5. Construction Process and Procedures

5.1. Thermal Shield

Four shields were fabricated at the Learning Factory at The Pennsylvania State University. Each Shield was water jetted from 16 gauge steel sheets. A metal brake was used to bend the shields to specification. Shields were attached to engine mounts via Gas Tungsten Arc Welding. The results of the welds can be viewed in Figure 5.1. Shields were then cleaned and are covered with aluminum based insulation

5.1.1. Design As Built

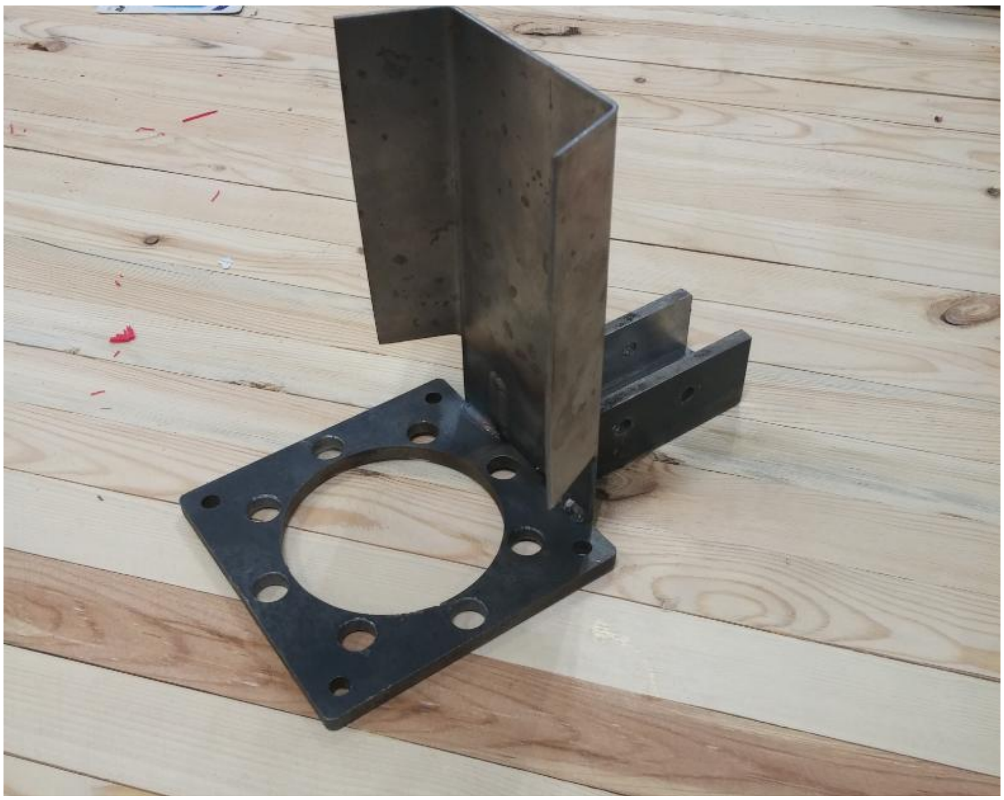


Figure 5.1. Bare steel heat shield welded to engine mount

5.2. Wire Sleeve

Power and Thermal subsystems oversaw installation of Puma's sleeves. Pieces were cut to meet initial wire length estimates. Pressure transducer and thermocouple lines were run through the same sleeve when applicable. Sleeve was then attached to the frame using high temperature zip ties and stainless steel clips.

6. Construction Verification Procedure Pass/Fail Criteria

6.1. Thermal Shield

6.1.1. Temperature and Structural Checks

The shield and weld must be able to maintain temperatures for 600°C (1112°F) for 60 seconds during flight. Insulation will be applied to reduce heat transfer. Engine mount and shield should not experience any significant movement during operation.

6.1.2. Verification of Construction

The Thermal Subsystem inspected the final shields for damage and structural defects. The welds were also inspected to verify workmanship

6.2. Wire Sleeve

The sleeve was inspected on arrival for defects and compared to supplier specifications

7. Design

7.1. Thermal Shield

7.1.1. Individual Component Description and Purpose

Part ID	Description	Purpose
HS1:4	16 gauge non-galvanized steel sheet, formed around engine and attached to engine mount	Reduce direct heat transfer to aluminum in close proximity to engines
CI	Aluminum Oxide based ceramic insulation	Insulation is placed between the engine mount and arm to minimize heat transfer

7.1.2. Model

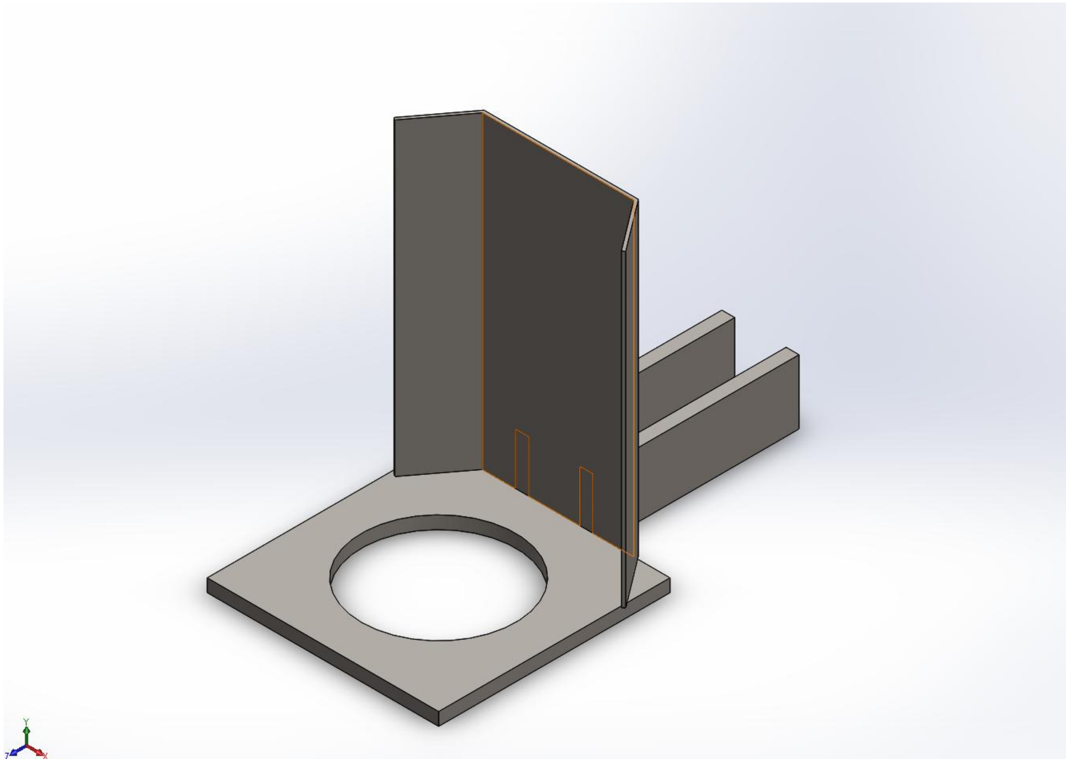


Figure 7.1. Solid Works model of engine mount and shield

7.2. Wire Sleeve

7.2.1. Individual Component Description and Purpose

Part ID	Description	Purpose
SLV	Braided fiberglass sleeve	Puma wiring is run through sleeve for protection from heat and direct contact with plume

8. Maintenance Required and Schedule

8.1. Thermal Shield

After each test a visual inspection of the shields and insulation will be performed. Any visual degradation of components will require replacements to maintain performance.

8.2. Wire Sleeve

After each test a visual inspection of the shields and insulation will be performed. Any visual degradation of components will require replacements to maintain performance

9. Appendix

9.1. List of Documents and Versions

Puma v 1.0 Shield Steady State Analysis Report	(Version 1.0)
Puma v 2.0 Shield Steady State Analysis Report	(Version 2.0)

EXAMPLE FLIGHT PROFILE SCRIPT

Action Start (sec)	Componet(s)	PWM	Description	Phase
SECTION 1: RUN TEST				
0	AV1-M, AV2-M, AV3-M, AV4-M	1333	Open throttle valve to 30°	Burp
2	AV1-M, AV2-M, AV3-M, AV4-M	1000	Close all throttle valves	Burp
5	AV1-M, AV2-M, AV3-M, AV4-M	1333	Open throttle valve to 30°	Burp
7	AV1-M, AV2-M, AV3-M, AV4-M	1000	Close all throttle valves	Burp
10	AV1-M, AV2-M, AV3-M, AV4-M	2000	Open throttle valve to a max of 90°	Ascend
13	AV1-M, AV2-M, AV3-M, AV4-M	1750	Set throttle valve to 67.5°	Hover
15.5	AV1-M, AV2-M, AV3-M, AV4-M	1700	Set throttle valve to 63°	Hover
18	AV1-M, AV2-M, AV3-M, AV4-M	1600	Set throttle valve to 54°	Hover
21	AV1-M, AV2-M, AV3-M, AV4-M	1333	Set throttle valve to 30°	Soft Touchdown
23	AV1-M, AV2-M, AV3-M, AV4-M	1000	Close all throttle valves	Landing

SD Card Format

Channel	Common Name	
AV1-M, AV2-M, AV3-M, AV4-M	Propellant throttle valve	1333, 1333, 1333, 1333, 1000, 1000, 1000, 1000, 1333, 1333, 1333, 1333

1000 is closed	** SD Card Script has a predetermined time step interval. At each time step the SD card reads PWM signals in a packet of 4**
2000 is fully open	
PWM is linear with 1000 being fully closed and 2000 being fully open	

Example Soft Kill Script

A soft kill will be automatically executed if 3 readings are read above the temperature and pressure limits*
The soft kill script will take the current valve position state and decrease the PWM signal by 10 per cycle until to PWM signal reads 1000
The decrease in PWM approximates to 9 degrees per second

Kill Start (sec)	Componet(s)	PWM	Description	Valve Position
SECTION 1: Abort Automatically or Manually Executed				
0	AV1-M, AV2-M, AV3-M, AV4-M	1XXX	PUMA recieves signal to perform soft kill	XX°
1	AV1-M, AV2-M, AV3-M, AV4-M	1XXX-90	Valves begin to close at a rate of 9°/second	XX°-9°
2	AV1-M, AV2-M, AV3-M, AV4-M	(1XXX-90)-90	Valve continues to close at a rate of 9°/second	(XX°-9°)-9°
...Process continues until craft lands...				
Touchdown	AV1-M, AV2-M, AV3-M, AV4-M	1000	Valves are fully closed	0°

SD Card Format

Channel	Common Name	
AV1-M, AV2-M, AV3-M, AV4-M	Propellant throttle valve	1400, 1400, 1400, 1400, 1310, 1310, 1310, 1310, 1220, 1220, 1220, 1220, 1130, 1130, 1130, 1130, 1040, 1040, 1040, 1040, 1000, 1000, 1000, 1000

1000 is closed	** SD Card Script has a predetermined time step interval. At each time step the SD card reads PWM signals in a packet of 4**
2000 is fully open	
PWM is linear with 1000 being fully closed and 2000 being fully open	

Example Hard Kill Script

A hard kill will be automatically executed if it is manually pressed using Labview or Hard Kill Button
When executed, the next loop will send 1000 PWM signal to all valves mentioned instantaniously
This will put PUMA in a safe state

Kill Start (sec)	Componet(s)	PWM	Description	Valve Position
SECTION 1: Abort Automatically or Manually Executed				
0	AV1-M, AV2-M, AV3-M, AV4-M, AV5-M	1XXX	PUMA recieves signal to perform hard kill and immediately close throttle and iso valves	XX°
0	FC-U	1000	Puma recieves signal and isolates pressurant to the sysyem	0°
	FO-U	1000	Puma recieves signal and vents pressure from system	0°
	AV5-M	1000	Puma recieves signal and isolates propellant from system	0°
0	AV1-M, AV2-M, AV3-M, AV4-M, AV5-M	2000	PUMA recieves signal completely close thorttle and iso valves	90°

In reality, the valve will take 1.5 seconds from 90° to 0°

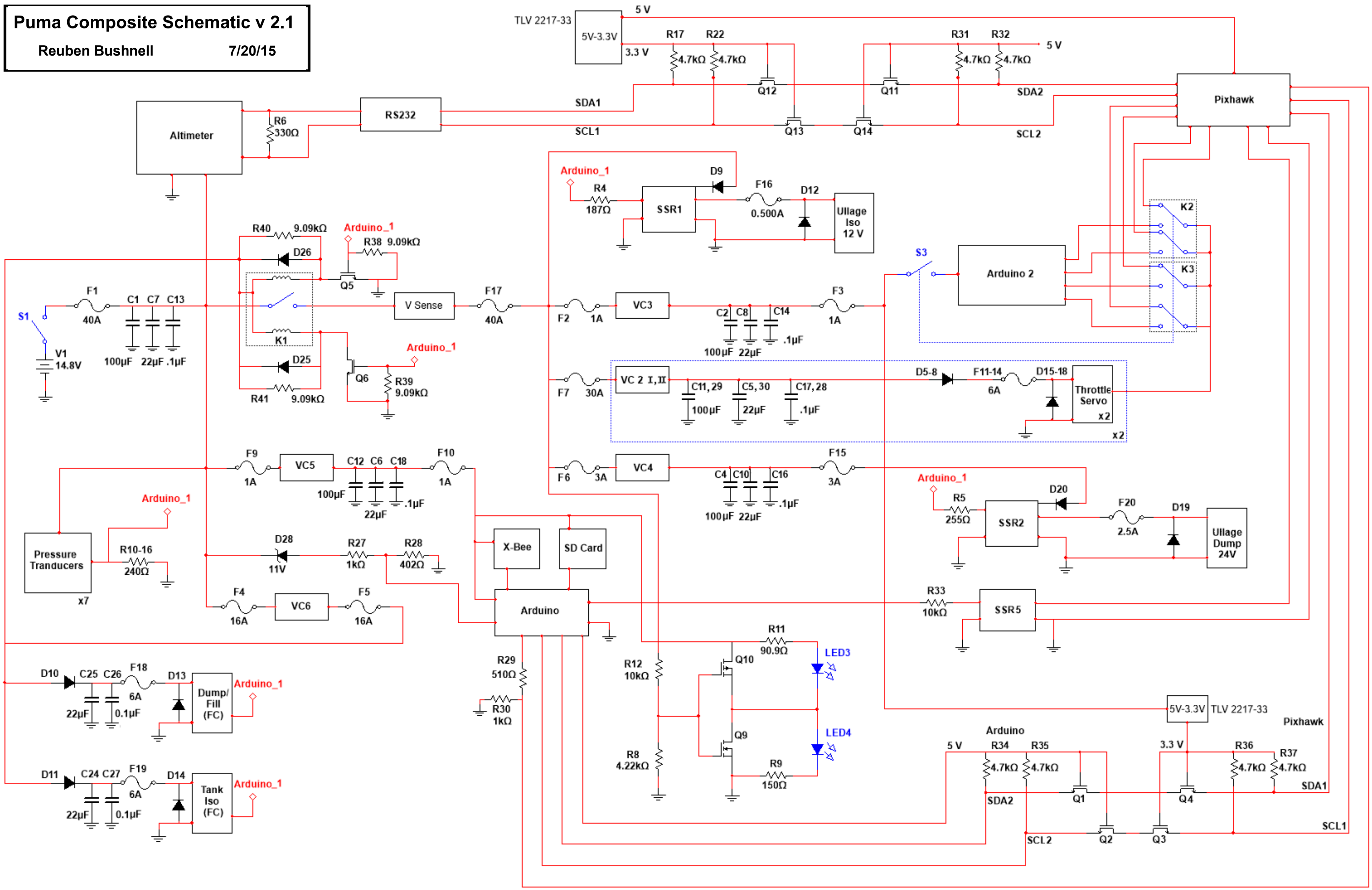
SD Card Format

Channel	Common Name	
AV1-M, AV2-M, AV3-M, AV4-M, AV5-M	Propellant throttle valve	1400, 1400, 1400, 1400, 1000, 1000, 1000, 2000, 2000, 2000, 2000

1000 is closed	** SD Card Script has a predetermined time step interval. At each time step the SD card reads PWM signals in a packet of 4**
2000 is fully open	
PWM is linear with 1000 being fully closed and 2000 being fully open	

Puma Command Characters
Version 2.0

Command Character	Action
s	Safety
t	Tank isolating valve open
v	Tank dump valve open
a	Hardkill
z	Full power on
r	Reset
d	Pressurant vent valve open
o	Run Flight Profile
k	Softkill
i	Pressurant isolating valve open
p	Simulate Flight Profile
e	Soft Kill Abort Triggered by Craft



Puma Composite Schematic v 2.1
Reuben Bushnell
7/20/15
TLV 2217-33
5V-3.3V
5 V
3.3 V
R17
R22
4.7kΩ
4.7kΩ
Q12
Q11
R31
R32
4.7kΩ
4.7kΩ
5 V
SDA1
SDA2
SCL1
SCL2
Q13
Q14
Pixhawk
Altimeter
R6
330Ω
RS232
Arduino_1
R4
187Ω
SSR1
D9
F16
0.500A
D12
Ullage Iso 12 V
K2
K3
S3
Arduino 2
R40
9.09kΩ
D26
R38
9.09kΩ
Q5
K1
V Sense
F17
40A
F1
40A
C1
C7
C13
100µF
22µF
.1µF
S1
V1
14.8V
D25
R41
9.09kΩ
Q6
R39
9.09kΩ
F2
1A
VC3
C2
C8
C14
100µF
22µF
.1µF
F3
1A
F7
30A
VC 2 I,II
C11, 29
100µF
C5, 30
22µF
C17, 28
.1µF
D5-8
F11-14
6A
D15-18
Throttle Servo x2
x2
F9
1A
VC5
C12
C6
C18
100µF
22µF
.1µF
F10
1A
F6
3A
VC4
C4
C10
C16
100µF
22µF
.1µF
F15
3A
R5
255Ω
SSR2
D20
F20
2.5A
D19
Ullage Dump 24V
Pressure Trandsucers
x7
R10-16
240Ω
D28
11V
R27
1kΩ
R28
402Ω
X-Bee
SD Card
Arduino
R33
10kΩ
SSR5
F4
16A
VC6
F5
16A
R29
510Ω
R30
1kΩ
R11
90.9Ω
LED3
Q10
R12
10kΩ
Q9
LED4
R8
4.22kΩ
R9
150Ω
D10
C25
C26
F18
6A
D13
22µF
0.1µF
Dump/ Fill (FC)
D11
C24
C27
F19
6A
D14
22µF
0.1µF
Tank Iso (FC)
TLV 2217-33
Pixhawk
Arduino
5 V
R34
R35
4.7kΩ
4.7kΩ
SDA2
Q1
SCL2
Q2
Q3
3.3 V
R36
R37
4.7kΩ
4.7kΩ
Q4
SDA1
SCL1

Power - Bill of Materials

Part	Manufacturer	Supplier	Supplier p/n	Description	Needed	Unit Cost	Total	
B1-2	Zippy	HobbyKing	ZC.4000.4S.25	Li-poly 4S battery, 14.8 V, 4 Ah, 25C, 370 g	2	$33.97	$67.94	
C13-14, 16-18, 26-28	Murata	Digikey	490-5401-ND	capacitor 0.1 uF, 50 V, 10%, ceramic	7	$0.17	$1.21	1.211
C1, 2, 4, 11-12, 29	Kemet	Digikey	399-6104-ND	capacitor 100 uF, 35 V, 20%, electrolytic	5	$0.14	$0.70	0.7
C5-8, 10, 24-25, 30	Kemet	Digikey	399-6108-ND	capacitor 22 uF, 50 V, 20%, electrolytic	7	$0.12	$0.85	$0.85
D5-11, 20	Vishay	Digikey	STPS20L15DPBF-ND	diode, isolation, 20 A, 0.41 V	8	$1.55	$12.40	12.4
D12-19, 25-26	Diodes, Inc.	Digikey	SBR1045SD1-TDICT-ND	diode, flyback, 10 A, 0.55V	8	$0.68	$5.42	5.424
D28	NXP Semiconductors	Digikey	568-7925-1-ND	diode, zener, 11V, 400 mW	1	$0.22	$0.22	0.22
F1, 17	Littelfuse	Digikey	F1037-ND	40A slow-blow fuse - battery out, power relay out	2	$1.97	$3.94	
F6, 15	Bel Fuse	Digikey	507-1297-ND	3A slow-blow fuse - 24 V converter in/out	2	$0.27	$0.54	
F16	Bel Fuse	Digikey	507-1243-ND	500 mA slow-blow fuse, 5x20 mm, ASCO valve	1	$0.22	$0.22	
F7	Eaton Bussmann	Digikey	283-2199-ND	Fuse 30 A, slow blow, 12V converter	1	$1.99	$1.99	
F2-3, 9-10	Bel Fuse	Digikey	507-1225-ND	1 A fuse, fast-acting, 5x20 mm, 5V converter in/out	4	$0.21	$0.83	
F11-14, 18-19	Bel Fuse	Digikey	507-1533-ND	6A fuse, slow blow, servo output	6	$0.33	$1.98	
F4-5	Littelfuse	Digikey	F4644-ND	16A, fuse, slow blow, 12V converter for FC servos	2	$1.48	$2.96	
F20	Bel Fuse	Digikey	507-1279-ND	2.5 A fuse - relay output for AA valves	3	$0.24	$0.72	
FC1-2	Littelfuse	Digikey	F1085-ND	Fuse holder, F1, 17	2	$20.57	$41.14	
FC3-18	Eaton Bussmann	Digikey	283-2826-ND	Fuse clip, 1/4" diameter, F7-8, 11-14, 18-19	16	$0.72	$11.52	11.52
FC19-28	Bel Fuse	Digikey	507-1415-ND	Fuse clip, 5 mm diameter, F2-6, 9-10, 15-16, 20	20	$0.08	$1.64	1.64
J1, J3		HobbyKing	AM1009x10	HXT 4mm connector, 10 pc	2	$4.44	$8.88	8.88
J17-18	Molex	Digikey	WM1325-ND	3 Line Plug Housing, FC servo	2	$0.27	$0.54	0.54
J2		HobbyKing	JSTMF-4S-20	JST-XH battery charging connector extensions, 10 pc.	1	$4.47	$4.47	
J2	Molex	Digikey	WM1242-ND	Crimp Housing Plug. Battery charger external	1	$0.27	$0.27	0.27
J4-7	Molex	DIgikey	WM1223-ND	4 Square Pin and Socket Plug Housing. FC servo	4	$0.40	$1.60	1.6
J8	Molex	Digikey	WM1847-ND	4 Line Plug Housing. AA FO	1	$0.45	$0.45	0.45
J9	Molex	Digikey	WM1222-ND	4 Line Plug housing. Asco FC	1	$0.40	$0.40	0.4
J9-16	Molex	Digikey	WM1221-ND	3 Line Plug housing. PT	8	$0.26	$2.08	2.08
JP17-18	Molex	Digikey	WM1338-ND	3 Line Receptacle Housing, panel mount. FC servo	2	$0.41	$0.82	0.82
JP2	Molex	Digikey	WM1243-ND	Pin and Socket Receptacle, panel mount. Battery charger	1	$0.54	$0.54	0.54
JP4-7	Molex	Mouser	538-03-06-1043	4 Square Receptacle Housing, panel mount. FC servo	4	$0.71	$2.84	2.84
JP8	Molex	Digikey	WM1852-ND	4 Line Receptacle Housing, panel mount. AA FO	1	$0.45	$0.45	0.45
JP9	Molex	Digikey	WM4463-ND	4 Line Receptacle Housing, panel mount. Asco FC	1	$0.29	$0.29	0.29
JP9-16	Molex	Digikey	WM1204-ND	3 Line Receptacle Housing, panel mount. PT	7	$0.29	$2.03	2.03
K1	Panasonic	Digikey	255-2599-ND	Power relay - 60A SPST, latching, 12V	1	$54.81	$54.81	54.81
K2-3	TE Connectivity	Digikey	PB1169-ND	Relay DPDT, throttle control switching	2	$4.70	$9.40	9.4
LED3	Avago	Digikey	516-2805-1-ND	Red LED, 7400 mcd	1	$0.85	$0.85	0.85
LED4	Avago	Digikey	516-2802-1-ND	Green LED, 16500 mcd	1	$1.35	$1.35	1.35
Q1-4, 11-14	Diodes, Inc.	Digikey	ZVNL110ASCT-ND	nFET for bidirectional level shifter	4	$0.80	$3.20	3.2
Q5, 6, 9	Fairchild	Digikey	RFP12N10L-ND	transistor, nFET	3	$0.89	$2.67	2.67
Q10	Diodes, Inc.	Digikey	ZVP2106A-ND	transistor, pFET	1	$0.89	$0.89	0.89
R27, 30	Stackpole Electronics	Digikey	RNF12FTD1K00CT-ND	resistor, 1 kOhm, 1/2W, 1%	2	$0.15	$0.30	0.3
R12, 33	Vishay Dale	Digikey	CMF10.0KHGCT-ND	resistor, 10 kOhm, 1/2 W, 1%	2	$0.45	$0.89	0.894
R11, 38-41	Vishay Dale	Digikey	PPC9.09KXCT-ND	resistor, 9.09 kOhm, 1/2 W, 1%	5	$0.31	$1.55	1.55
R6	Yageo	Digikey	330ADCT-ND	resistor, 330 Ohm, 1/4 W, 0.1%, altimeter sense	1	$0.46	$0.46	0.46

Part	Manufacturer	Supplier	Supplier p/n	Description	Needed	Unit Cost	Total	
R10-16	Stackpole Electronics	Digikey	S240CACT-ND	resistor, 240 Ohm, 1/4 W, 1%, pressure sense	7	$0.10	$0.67	0.665
R17, 22, 31-32, 34-37	Vishay Dale	Digikey	CMF4.70KHA-ND	resistor, 4.7 kOhm, 1/2 W, 1% - I2C pull-up	8	$0.43	$3.42	3.424
R4	Yageo	Digikey	187XBK-ND	resistor, 187 Ohm, 1/4W, 1%, SSR1 current limiting	1	$0.10	$0.10	0.1
R8	Vishay Dale	Digikey	CMF4.22KHFCT-ND	resistor, LED circuit voltage divider bottom, 4.22 kOhm, 1/2 W	1	$0.61	$0.61	0.61
R9	Vishay Dale	Digikey	PPC150XCT-ND	resistor, red LED current adjust, 150 Ohms, 1/2W, 1%	1	$0.29	$0.29	0.29
R11	Vishay Dale	Digikey	PPC90.9XCT-ND	resistor, green LED current adjust, 90.9 Ohms, 1/2 W, 1%	1	$0.29	$0.29	0.29
R28	Vishay Dale	Digikey	CMF402HFCT-ND	resistor, 402 Ohm, 1%	1	$0.74	$0.74	0.74
R5	Vishay Dale	Digikey	CMF255HFCT-ND	resistor, 255 Ohm, 1/2 W, 1%, SSR2-4 current limiting	1	$0.74	$0.74	0.74
R29	Yageo	Digikey	510H-ND	resistor, 510 Ohm, 1/2 W, 5%	1	$0.10	$0.10	0.1
SSR1	Omron	Digikey	TLP3542F-ND	Asco FC valve relay, 2.5 amp rating, 1.33 V turn-on, 20 mA	1	$5.40	$5.40	5.4
SSR2	IXYS	Digikey	CLA280-ND	AA valve relay, 9A/ss (40A peak) 1.2 V turn-on, 10 mA - design	3	$6.55	$19.65	19.65
SSR5	Teledyne	Jameco	2144737	1A solid-state relay for failsafe valves	1	$5.49	$5.49	5.49
SW1	NKK	Digikey	360-2095-ND	Charging / Operating switch, 30 V, 50 A	1	$49.44	$49.44	
SW1A	NKK	Digikey	360-1606-ND	SW1 boot	1	$2.89	$2.89	2.89
VC2 (I-II)	Cui	Digikey	102-2258-ND	12 V DC/DC converter 9-36V input, 12.5 A output	2	$160.53	$321.06	
VC3, 5	TDK-Lambda	Digikey	445-2435-ND	5V DC/DC converter, 9-18 V input, 2 A output	2	$26.26	$52.52	
VC4	Murata	Digikey	811-2228-5-ND	24 V DC/DC converter, 9-36V input, 3A output, 89%	1	$66.00	$66.00	
VC6	Cui	Digikey	102-1982-ND	12 V DC/DC converter 10-36V input, 16.7A output	1	$173.57	$173.57	
VC7-8	TI	Digikey	296-21611-5-ND	5 to 3.3 V regulator	2	$0.98	$1.96	1.96
			Unlabelled connectors and assorted hardware					
	Molex	Digikey	WM3680CT-ND	Male connector pin, 18-24 AWG, PT, Asco FC, Midwest	47	$0.06	$2.62	2.6226
	Molex	Digikey	WM1001-ND	Female connector pin, 18-24 AWG, PT, Asco FC, Midwest	47	$0.10	$4.64	4.6436
	Molex	Digikey	WM1127CT-ND	Male connector pin, 20-24 AWG, FO	4	$0.17	$0.68	0.68
	Molex	Digikey	WM1125CT-ND	Female connector pin, 20-24 AWG, FO	4	$0.21	$0.84	0.84
	Molex	Digikey	A100579CT-ND	Socket, 10-12 AWG. Battery charger	2	$0.22	$0.43	0.432
	Molex	Digikey	A100578CT-ND	Pin, 10-12 AWG. Battery charger	2	$0.20	$0.40	0.396
	Molex	Digikey	WM1102CT-ND	Male connector pin, 18-22 AWG. AA FC	6	$0.12	$0.72	0.72
	Molex	Digikey	WM1103CT-ND	Female connector pin, 18-22 AWG. AA FC	6	$0.12	$0.72	0.72
	Molex	Digikey	WM2573CT-ND	Connector pin, 22-24 AWG. PT, Asco FC	28	$0.19	$5.41	5.4096
	Molex	Digikey	WM9727CT-ND	Connector pin, 22-30 AWG. AA FO/FC Servo (Need 12 total)	12	$0.10	$1.20	1.2
	Molex	Digikey	WM9728CT-ND	Connector pin, 22-30 AWG. Throttle (Need 12 total)	12	$0.64	$7.68	7.68
	Molex	Digikey	WM4201-ND	3 Pin Header. White. PT	8	$0.28	$2.24	2.24
	Molex	Digikey	WM2877-ND	3 Pin Connector for Header. Black. PT	8	$0.35	$2.76	2.76
	Molex	Digikey	WM2745-ND	3 Pin Header. Natural. AA FC. Now used for Throttle Servo	2	$0.37	$0.74	0.74
	Molex	Digikey	WM2001-ND	3 Pin Connector for Header. White. AA FC. Now used for Th	2	$0.19	$0.38	0.38
	Molex	Digikey	WM4202-ND	4 Pin Header. White. Asco FC	1	$0.37	$0.37	0.37
	Molex	Digikey	WM2878-ND	4 Pin Connector for Header. Black. Asco FC	1	$0.38	$0.38	0.38
	Molex	Digikey	WM2746-ND	4 Pin Header. Natural. AA FO/ Servo FC	1	$0.76	$0.76	0.76
	Molex	Digikey	WM2614-ND	4 Pin Connector for Header. White. AA FO/ Servo FC	1	$0.40	$0.40	0.4
	Molex	Digikey	WM4431-ND	Battery plug, male, board-mount	1	$5.07	$5.07	5.07
	Molex	Digikey	WM1927-ND	Battery socket, female, inline	1	$1.37	$1.37	1.37
	Molex	Digikey	WM1951CT-ND	Female connector pin, battery socket	2	$1.66	$3.32	3.32
	Molex	Digikey	WM2578-ND	motor encoder connector panel-mount socket - 6 pin 22-24 AW	4	$1.25	$5.00	5
	Molex	Digikey	WM2567CT-ND	motor encoder connector socket pins	24	$0.25	$6.00	6

Part	Manufacturer	Supplier	Supplier p/n	Description	Needed	Unit Cost	Total	
	Molex	Digikey	WM2904-ND	motor encoder plug	4	$0.38	$1.52	1.52
	Molex	Digikey	WM9139CT-ND	motor encoder plug pins	24	$0.17	$4.20	4.1952
	TE Connectivity	Mouser	571-322316	connectors for SW1 - 10-12 AWG, 14 stud	6	$2.52	$15.12	15.12
		PJRC	CABLE_USB_PANEL	USB connector to panel-mount - mini-B to B receptacle	1	$5.50	$5.50	***5.5***
	Startech	Newegg	N82E16812200477	USB connector to panel mount - B to B receptacle	1	$7.99	$7.99	**7.99**
	Linx Technologies	Digikey	CSA-RPSM-216-RSFB-ND	RP-SMA cable - female to panel-mount male - for antennas	2	$11.45	$22.90	
	Molex	Digikey	WM9728CT-ND	Connector pin, 22-30 AWG. Throttle valves (Need 12 total)	4	$0.64	$2.56	2.56
	Molex	Digikey	WM9727CT-ND	Connector pin, 22-30 AWG. AA FO/FC Servo (Need 12 total)	6	$0.10	$0.60	0.6
	Molex	Digikey	WM1721-ND	Picoblade connector female 3-pin - switch	1	$0.30	$0.30	0.3
	Molex	Digikey	WM1142CT-ND	Picoblade female pin, 26-28 AWG	8	$0.06	$0.47	0.4736
	Molex	Digikey	WM1723-ND	Picoblade connector female 5-pin - serial, power	2	$0.41	$0.82	0.82
	Harwin	Digikey	952-2228-ND	Pixhawk end connectors 3-pin 0.1" pitch	10	$0.15	$1.46	1.46
	Harwin	Digikey	952-2158-ND	Pixhawk end connector female pin	30	$0.08	$2.52	2.52
	Assmann	Digikey	AE08B-5-ND	ribbon cable, 5', 28 AWG	2	$3.46	$6.92	6.92
	Linx Technologies	Digikey	CONREVSMA003.031-ND	SMT RP-SMA male jack, 0.031" spacing, antenna board	1	$3.52	$3.52	3.52
		HobbyKing	ACC6	Battery charger - Accucel 6	2	$24.10	$48.20	
		HobbyKing	258000053	HXT 8mm connector, 2 sets	4	2.32	$9.28	*9.28*
	TP-Link	Amazon	B004PFWFDG	2.4 GHz antenna	1	$6.61	$6.61	*6.61*
		Amazon	B003Z6ZR5O	Battery charger power supply, 12 V, 5A, 2.5mm x 5.5mm	2	$6.63	$13.26	*13.26*
	Samtec, Inc.	Digikey	SAM1067-50-ND	header rectangular male pins long - Arduino to board 50 pos	1	$2.68	$2.68	2.68
	TE Connectivity	Digikey	A28787-ND	header rectangular male pins right angle 2 row - Arduino base -	4	$4.55	$18.20	18.2
	Sullins Connector	Digikey	S1211EC-20-ND	header rectangular male pins normal 20 pos	3	$0.53	$1.59	**1.59**
	Sullins Connector	Digikey	S9495-ND	header rectangular male pins right angle - data logger 8 pos	2	$0.64	$1.28	**1.28**
	Sullins Connector	Digikey	S9429-ND	socket rectangular - data logger 8 pos	2	$0.26	$0.52	**0.52**
	Sullins Connector	Digikey	S9473CT-ND	socket female pins - data logger	16	$0.09	$1.43	**1.4272**
	Sullins Connector	Digikey	S7043-ND	socket rectangular to board - Arduino 10 pos	2	$0.84	$1.68	**1.68**
	Assmann	Digikey	AE10784-ND	standoffs, bottom, 18 mm	14	$0.44	$9.40	9.4
	Assmann	Digikey	AE10787-ND	standoffs, top	24	$0.38	$9.12	9.12
	B&F Fastener	Digikey	H762-ND	nuts for standoffs, M3	100	$0.04	$3.84	**3.84**
		McMaster-Carr	90133A005	rubber washers for standoffs, box of 100, 0.12" ID	1	$6.81	$6.81	**6.81**
	B&F Fastener	Digikey	H772-ND	lock washers for standoffs	20	$0.04	$0.85	**0.852**
				M3 6mm screws for standoffs (already in stock)	*20*		$0.00	**0**
	3M	Digikey	3M11996-ND	cable mounts, adhesive	25	$0.96	$23.93	**23.93**
	HellermannTyton	Digikey	1436-1593-ND	cable ties	100	$0.04	$3.93	**3.93**
							$1,256.34	$395.92

Power - Calculations

Summary

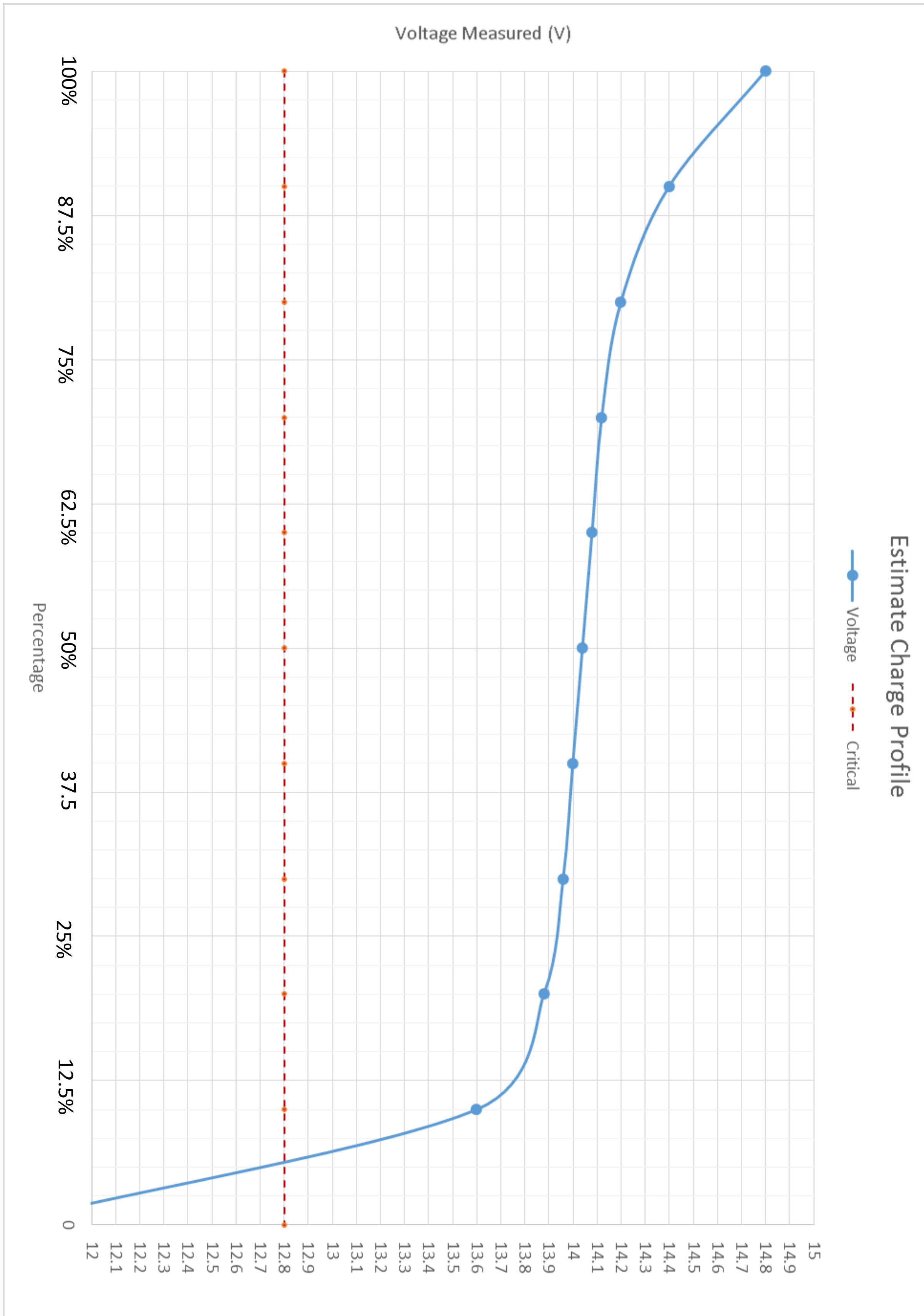
Full Power	Full System
Power Required	488.46 W
Battery Energy*	403200 J
Battery Capacity after 2 minutes	85%

Standby Power	Full System	Half System
Power Required	114.36 W	99.51 W
Standby†	58.7 min.	67.5 min.
Standby after 2 min flight	50.2 min.	57.7 min.

** Rated capacity at minimum normal cell voltage (3.5 V), two batteries*
† Discharge to minimum safe cell voltage (~ 3.2 V)

4 Cell 14.8V LiPo 4000 mAH Battery Reference Sheet

Use reference for estimation purposes ONLY



Description	QTY	Unit Mass	On Craft?	Estimated Mass	Growth	Growth	Total Descent Stage Mass	Total Landed Mass	Total Mass
Lunar Lion		(kg)	(Yes = 1)	(kg)	(%)	(kg)	(kg)	(kg)	(kg)
Puma Craft				#VALUE!	#VALUE!	#VALUE!			#VALUE!
Propulsion				#VALUE!	#VALUE!	#VALUE!			#VALUE!
Engines	4.0	2.00	1.0	8.00	0.00	0.00			8.00
3/4" H2O2 Valve	2.0	1.82	1.0	3.64	0.00	0.00			3.64
3/8" H2O2 Valve	4.0	0.55	1.0	2.18	0.00	0.00			2.18
Ball Hand Valve	1.0	0.24	1.0	0.24	0.00	0.00			0.24
Fail closed solenoid	1.0	1.54	1.0	1.54	0.00	0.00			1.54
Fail open solenoid	1.0	1.34	1.0	1.34	0.00	0.00			1.34
Throttle Actuator w/mounting hardware	6.0	1.22	1.0	7.32	0.00	0.00			7.32
Fuel Tank	NA	6.00	1.0	#VALUE!	#VALUE!	#VALUE!			#VALUE!
6.6 L Ullage Tank	NA	1.00	1.0	#VALUE!	#VALUE!	#VALUE!			#VALUE!
Pressure Relief	2.0	0.34	1.0	0.68	0.00	0.00			0.68
Pressure Transducer, 1K	6.0	0.15	1.0	0.92	0.00	0.00			0.92
Pressure Transducer, 5K	1.0	0.15	1.0	0.15	0.00	0.00			0.15
Thermocouple (Weld on)	4.0	0.03	1.0	0.10	0.00	0.00			0.10
Thermocouple Probe	2.0	0.03	1.0	0.05	0.00	0.00			0.05
1' of 3/8" Tubing	1.0	0.06	1.0	0.06	0.00	0.00			0.06
1' of 1/2" Tubing	NA	0.10	1.0	#VALUE!	#VALUE!	#VALUE!			#VALUE!
1' of 3/4" Tubing	NA	0.22	1.0	#VALUE!	#VALUE!	#VALUE!			#VALUE!
Ti bracket	NA	0.16	1.0	#VALUE!	#VALUE!	#VALUE!			#VALUE!
Steel engine mount/heat shield	4.0	0.82	1.0	3.27	0.00	0.00			3.27
bolts, nuts, washers for engine mount	NA	0.50	1.0	#VALUE!	#VALUE!	#VALUE!			#VALUE!
Fittings (estimated)	NA	2.00	1.0	#VALUE!	#VALUE!	#VALUE!			#VALUE!
Power				#VALUE!	#VALUE!	#VALUE!			#VALUE!
All Wiring outside Power Box	1.0	2.00	1.0	2.00	0.00	0.00			2.00
Abrasion Shielding			1.0	0.00	#DIV/0!	0.00			0.00
Batter Compartment Zip Ties	-1.0	0.01	1.0	-0.01	0.00	0.00			-0.01
Plastic Zip Ties	20.0	0.00	1.0	0.02	0.00	0.00			0.02
Beige Zip Tie Holder (Mounting Point)	19.0	0.00	1.0	0.03	0.00	0.00			0.03
Battery	2.0	0.73	1.0	1.46	0.00	0.00			1.46
Board Weight	NA	2.09	1.0	#VALUE!	#VALUE!	#VALUE!			#VALUE!
Battery Compartment Door	NA								
MISCELLANEOUS	1.0	-0.02	1.0	-0.02	0.00	0.00			-0.02
GNC				0.29	0.00	0.00			0.29
Xbee (5V)	1.0	0.009	1.0	0.01	0.00	0.00			0.01
Autopilot	1.0	0.038	1.0	0.04	0.00	0.00			0.04
Controller	2.0	0.0349	1.0	0.07	0.00	0.00			0.07
Laser Range Finder	1.0	0.125	1.0	0.13	0.00	0.00			0.13
Thermocouple	1.00	0.02	1.0	0.02	0.00	0.00			0.02
RS232 Adapter	1.00	0.02	1.0	0.02	0.00	0.00			0.02
SD Card System	2.00	0.00343	1.0	0.01	0.00	0.00			0.01
Structures				#VALUE!	#VALUE!	#VALUE!			#VALUE!
1"x1"x1/16" Al6061-T6	NA	0.12	1.0	#VALUE!	#VALUE!	#VALUE!			#VALUE!
Engine Servo-Valve Bracing Structure	NA	0.22	1.0	#VALUE!	#VALUE!	#VALUE!			#VALUE!
Shaft Coupling	NA	0.07	1.0	#VALUE!	#VALUE!	#VALUE!			#VALUE!
2" ø0.25" Bolt	NA	0.01	1.0	#VALUE!	#VALUE!	#VALUE!			#VALUE!
Lock Washer	NA	0.00	1.0	#VALUE!	#VALUE!	#VALUE!			#VALUE!
ø0.625" Washer	NA	0.00	1.0	#VALUE!	#VALUE!	#VALUE!			#VALUE!
1"x1"x1/16" Al6063	NA	0.12	1.0	#VALUE!	#VALUE!	#VALUE!			#VALUE!
Standoff, Blue	NA	0.01	1.0	#VALUE!	#VALUE!	#VALUE!			#VALUE!
Standoff, White	NA	0.01	1.0	#VALUE!	#VALUE!	#VALUE!			#VALUE!
Thermal				0.53	0.00	0.00			0.53
Cable Sleeving	9.2	0.01	1.0	0.08	0.00	0.00			0.08
MLI Blanket	7.3	0.06	1.0	0.45	0.00	0.00			0.45
Science Payload									

22 April 2015 Update - Current craft weight is 38.65 kg, with total expected mass at 60.57 kg this can be updated by toggling "On Craft" Option

Puma v 1.0 Shield Steady State Thermal Analysis Report

The Pennsylvania State University
Lunar Lion Team

List of Revisions

1. Thermal Analysis of Engine Mount

1.1. Introduction

One of the main areas of concern in Puma's design is heat transfer from the engines to the aluminum frame. The steel mounting bracket makes direct contact with the aluminum. In order to measure the heating and cooling in this area a solid works model was created of the engine, mount, shield, and six inches of the arm. This model was imported into ANSYS Steady State Thermal to analyze heat transfer from the engine to the arm during a worst case scenario. It was determined that the heat generated by the engine does not pose a threat to Puma's aluminum structure. Convective heat transfer provides a significant amount of cooling in certain locations of the model.

1.2. Model

The model was created in solid works to scale with a simplified engine geometry so the analysis could be conducted outside of the lab. The aluminum arm was shortened to six inches to reduce the amount of geometry for the analysis. No bolts or drilled holes was included in the model. It is assumed the bolts will provide negligible heat transfer and will not drastically alter heat flow. A newer high fidelity model will be built in the future. To import the SolidWorks model into ANSYS Workbench the assembly was saved as a polarsolid file (.x_b). No insulation or thermal buffers were used in the model.

1.3. Setup

During the analysis set up materials are a signed and meshes generated on each component. A refined mesh was place on the engine mount and arm. Engine temperatures were tabulated using propulsion test data. Engine temperature increases in a time frame similar to that of current tests being run. A convective environment was placed on all surfaces. An ambient temperature of 22 Celsius and convective heat transfer coefficient of 25 w/Cm^2 were assumed. Surface to surface radiation condition was placed on the engine surface and front of the shield with a constant emissivity of .8. Analysis was done in 20 steps with a maximum engine temperature at step six. Computational power limited the number of steps that couldn't be taken.

1.4. Solution and Conclusions

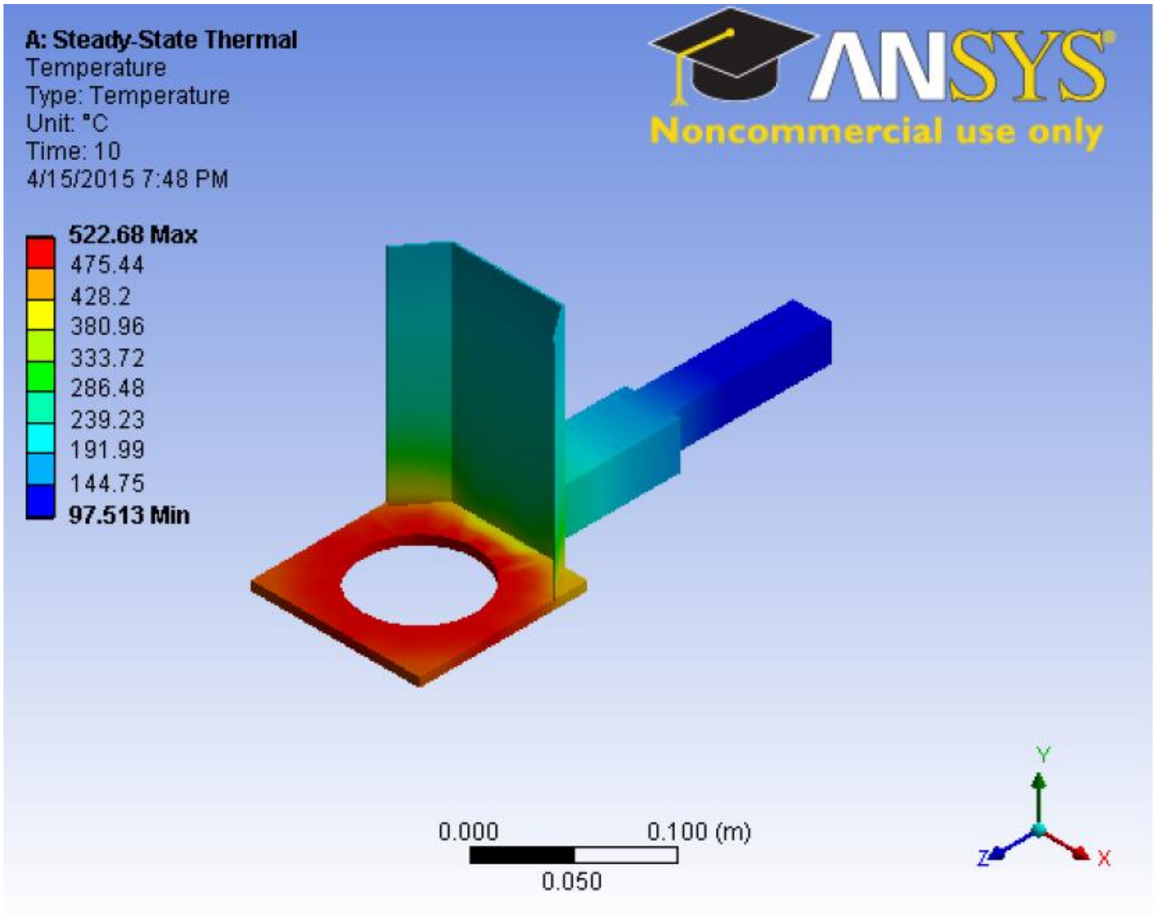


Figure 9.1. Steady state solution of engine mount model (Isotropic view)

ANSYS solver indicates that during a worst case scenario, the aluminum arm will be kept within operational temperatures. High temperatures do not conduct far down the aluminum arm with the maximum temperature at the tip. The maximum temperature on the arm is 210.1 Celsius. The majority of convective heat transfer occurs on the shield. This likely due to the larger surface area compared to other components. Due to the shield being made out of sheet steel it is more conductive then other components. The top half of the shield significantly cooler compared to the bottom portion. Both halves are the same distance from the engine. From initial observations we can conclude that heat from the engine is not going to damage the aluminum frame. A majority of the heat transfer is due to convective cool of the shield. The shield itself, although there to be a heat barrier, could also be used as a cooling fin. Future work in this area will include a thermal transient analysis to determine the time to reach these temperatures.

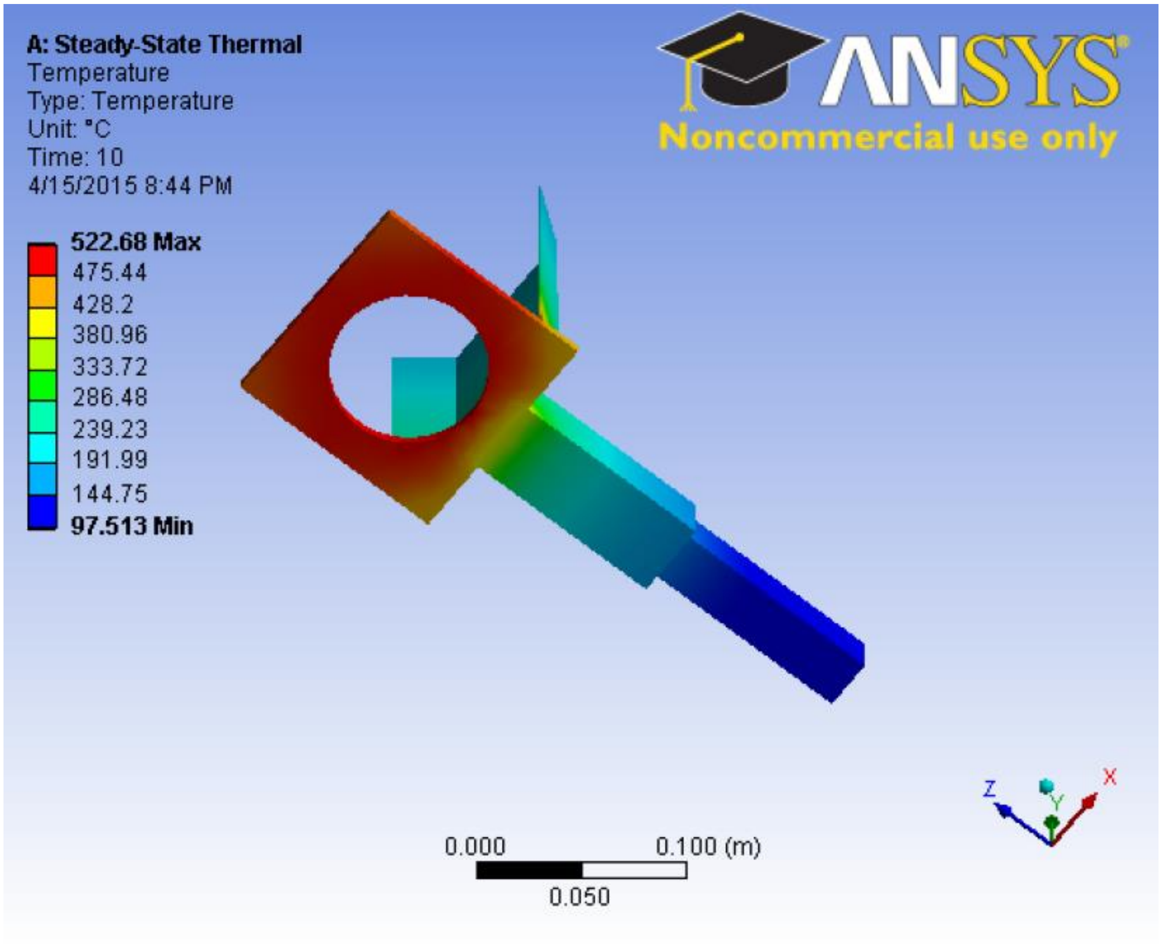


Figure 9.2. Bottom view of steady state analysis.

Puma v 2.0 Steady State Thermal Analysis Report

The Pennsylvania State University
Lunar Lion Team

List of Revisions

1. Thermal Analysis of Engine Mount

1.1. Introduction

One of the main areas of concern in Puma's design is heat transfer from the engines to the aluminum frame. The steel mounting bracket makes direct contact with the aluminum. In order to measure the heating of the engines and frame the NX model of Puma V2.0 was put through a Thermal FEA using NX Thermal/Flow. A steady state model was created in order to determine the worst case hot scenario and pin point any problem areas. It was determined that the heat generated by the engine does not pose a threat to Puma's aluminum structure or nearby components. The increased distance from the engines significantly reduces heat transfer above the mid deck of Puma V2.0. Convective heat transfer provides a significant amount of cooling in certain locations of the model.

1.2. Model

The model was created in Siemens NX part modeler and is representative of the final Puma V2.0 as constructed. Plumbing and fittings were removed due to heat transfer being a coupled thermal and flow problem that is beyond the scope of this analysis. There are no bolts in the model and it assumed their effect on heat transfer will be negligible. In order to produce the worst case hot scenario. No insulation or thermal buffers were used in the analysis, including the shield. Full Puma V2.0 model is shown in figure 1.

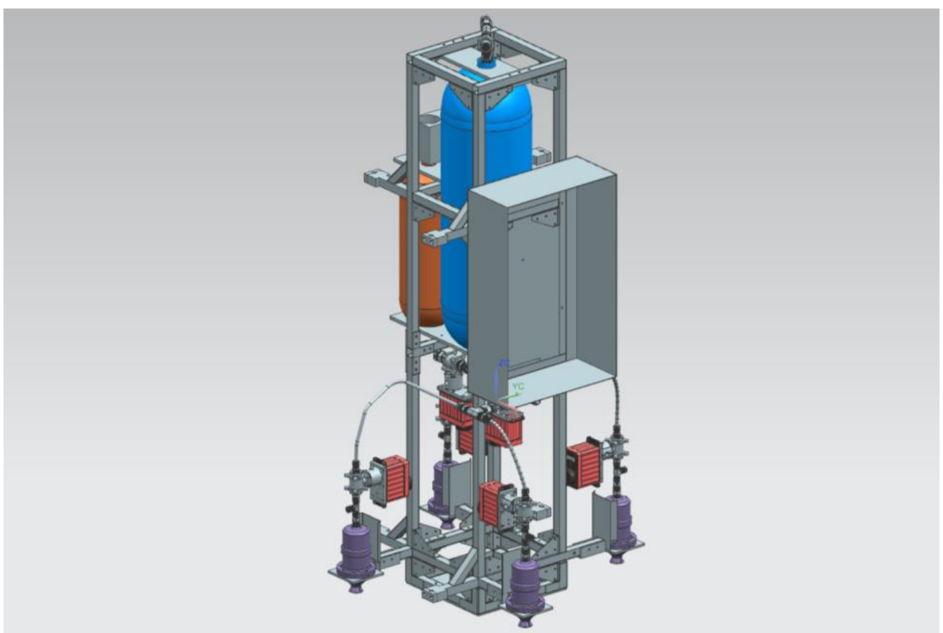


Figure 1. CAD model of Puma V2.0

1.3. Setup

All polygon bodies were meshed using element sizes of 0.2 to 0.4 inches with the engine mount and aluminum body receiving a high fidelity mesh. 1,506,212 elements were used in the analysis. Materials were assigned to all components. Ambient temperature of 32°C (90° F) The higher temperature is to account for super-heated steam added to an environment that is originally 22°C (68° F). Convection to environment boundary condition was placed on all surface and the average convective heat transfer coefficient was determined to be 25 W/m^2C. Surface to surface radiation coupling was placed on components within view of the engine and heat shield.

Effective emissivity varied between .60 and .85 Conductive coupling was down on all polygon bodies with a Total heat transfer coefficient between 3 W/C and 5 W/C. The combustion chamber outer wall temp is constrained at 500°C (936°F) and the internal wall temp is constrained at 800°C (1472°F). Combustion chamber temperatures are based on experimental data from engine testing. Unmeshed polygons are the results of free edges or unnecessary polygons in the analysis.

1.4. Solution and Conclusions

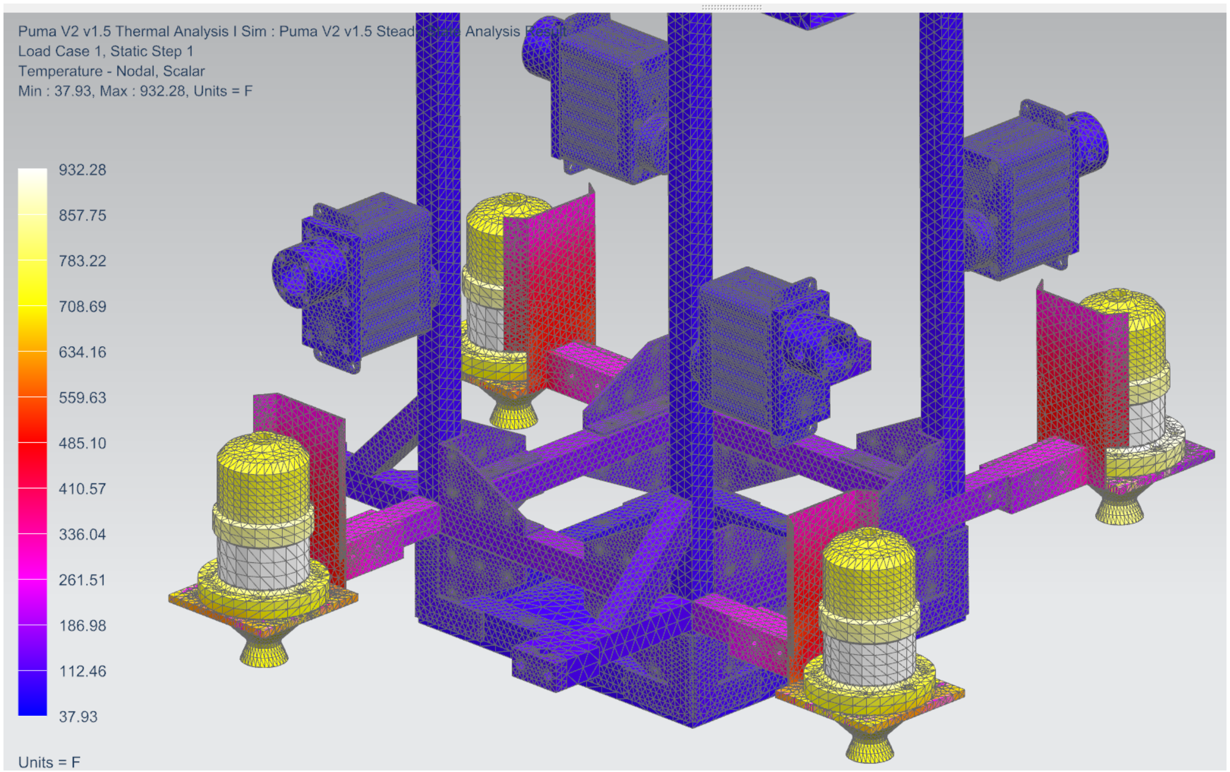


Figure 3. Steady state solution of Puma V2.0 (Lower, Isometric)

The NX Thermal/Flow simulation illustrates that during the worst case hot scenario Puma's components will be kept in operational their operational temperature range. The areas of concern are around the engines up to the H2O2 and ullage tanks. Conduction through the aluminum arms becomes negligible as distance increases. A maximum arm temperature is 121°C (257°F) near the tip of the arm. The shield itself acts as a heat sink and because of its large surface area experiences a high amount of convective cooling. This shields highest surface temperature is at the base of the mount and is approximately 250°C (482°F). For Puma operation the shield will have a surface insulation covering the back plate. The cable tether mounts experience little radiative heat transfer from the shield and combustion chamber with temperatures only reaching 43°C (111°F). The valve and motors reach temperatures couple degrees above ambient and will not be a concern during flight. Due to their distance the power box and tanks experience low heat fluxes from conduction and radiation. With the increased ambient temperature the steady state analysis verifies our design and shows no problem areas during operation. Even under steady state conditions all components fall within their operational limits.

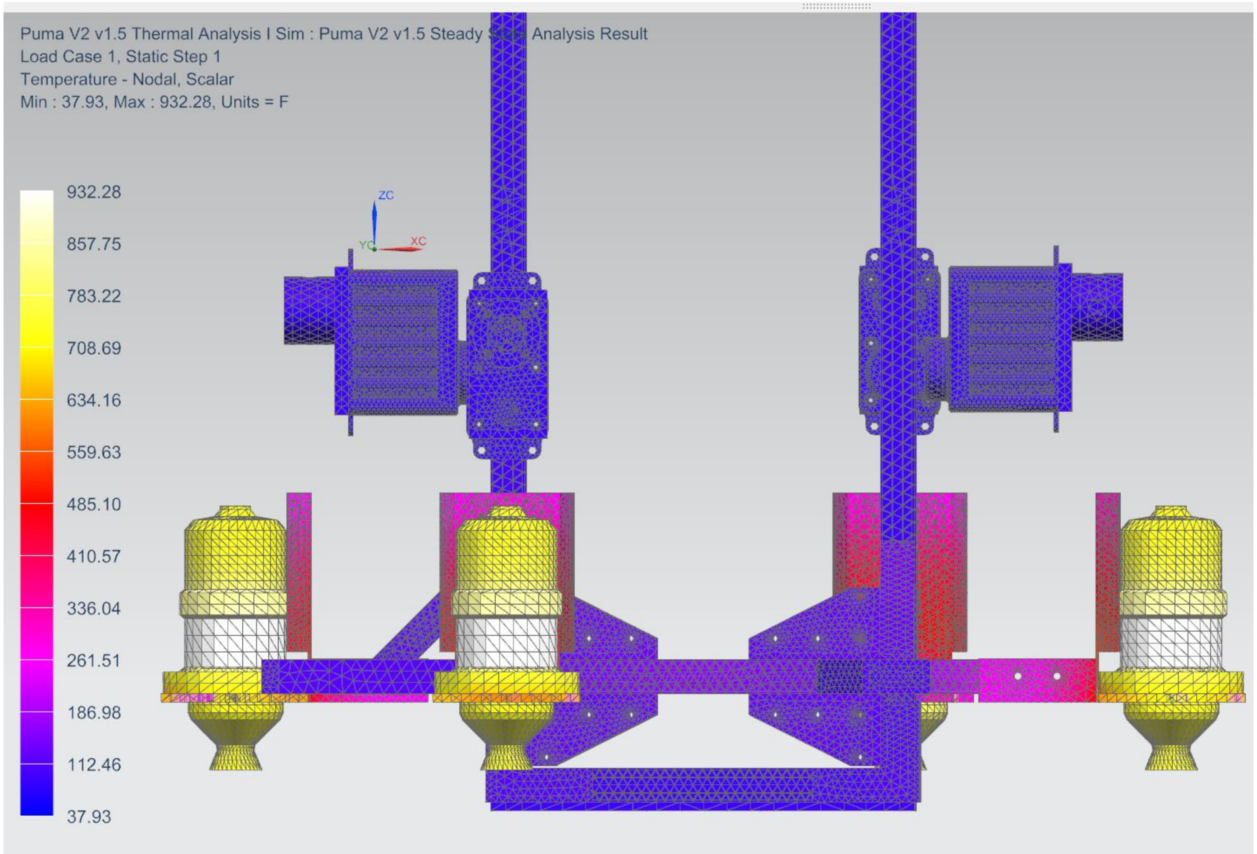


Figure 4. Bottom view of steady state analysis 2.0 (side)

Puma v 2.0 Transient Analysis Report

The Pennsylvania State University
Lunar Lion Team

List of Revisions

1. Thermal Analysis of Engine Mount

1.1. Introduction

One of the main areas of concern in Puma's design is heat transfer from the engines to the aluminum frame. The steel mounting bracket makes direct contact with the aluminum. In order to measure the heating and cooling of the engines and frame the NX model of Puma V2.0 was put through a Thermal FEA using NX Thermal/Flow. A transient model was created in order to heating after a 60 second burn of the 4 engines. It was determined that the heat transfer over 1 minute by the engines does not pose a threat to Puma's aluminum structure or other components. Temperatures after 1 minute of heating are significantly lower than steady state temperatures. Convective heat transfer provides a significant amount of cooling in certain locations of the model. Focus of this analysis is the H2O2 tank and blow. The distance between the heat source and top of the vehicle negates conductive and radiative heat transfer. This analysis only simulates heat transfer during the 60 second flight.

1.2. Model

The model was created in Siemens NX part modeler and is representative of the final Puma V2.0 as constructed. Plumbing and fittings were removed due to heat transfer being a coupled thermal and flow problem that is beyond the scope of this analysis. There are no bolts in the model and it assumed their effect on heat transfer will be negligible and if anything reduce heat transfer. In order to produce the worst case hot scenario. No insulation or thermal buffers were used in the analysis, including the shield. Full Puma V2.0 model is shown in figure 1.

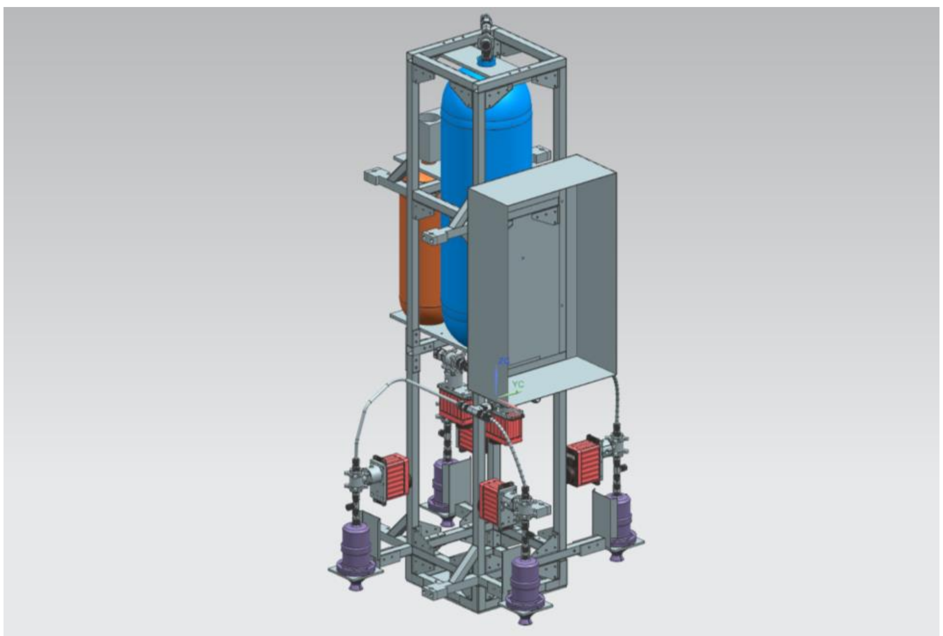


Figure 1. CAD model of Puma V2.0

1.3. Setup

All polygon bodies were meshed using element sizes of 0.2 to 0.4 inches with the engine mount and aluminum body receiving a high fidelity mesh. 1,506,212 elements were used in the analysis. Materials were assigned to all components. Ambient temperature of 32°C (90° F) The higher temperature is to account for super-heated steam added to an environment that is originally 22°C (68° F). Convection to environment boundary condition was placed on all surface and the average convective heat transfer coefficient was determined to be 25 W/m^2C. Surface to surface radiation coupling was placed on components within view of the engine and heat shield. Effective emissivity varied between .60 and .85 Conductive coupling was down on all polygon bodies with a Total heat transfer coefficient between 3 W/C and 5 W/C. The combustion chamber outer wall temp is constrained at 500°C (936°F) and the internal wall temp is constrained at 800°C (1472°F). Combustion chamber temperatures are based on experimental data from engine testing. Unmeshed polygons are the results of free edges or unnecessary polygons in the analysis. The solution was set to start at zero seconds in run through 60 seconds with 10 time steps in between. After the results of the steady state solution were known, some of the geometry and meshes at the top of the model were removed to reduce the computation time of the solution. The engine temperature does not start at ambient conditions and ramp to 500°C (946°F) but is instead at its constrained temp from start of analysis. This raises the initial heat transfer and slightly raises the final surface temperatures. Combustion chamber temperatures are expected to reach 500°C (946°) in less than 10 seconds when running. Heat transfer couplings were turned off for one engine to reduce computation time.

1.4. Solution and Conclusions

The NX Transient Thermal/Flow simulations illustrates that heat generation inside the combustion chamber over 1 minute do not great increase component temperatures. Experienced heat transfer is only a fraction of steady state temperatures. The Heat shield experiences the most significant heat flux as designed and reaches temperatures of 232°C (400°F) after one minute. Maximum arm temperature is 48°C (110°F) at the tip of the arm. The extended cable tether mounts experience an increase above ambient temperature by a few degrees Celsius. After 60 seconds there is no heat transfer of raise in temperatures on components near the tanks, power box, and up. Like earlier models the heat shield behaves somewhat like a cooling fin. The solution illustrates that during the entire flight, the structure and components will be within their operational temperature ranges. The will be some additional heating after the flight as the engines cool and heat generation ceases, this will be examined in future work.

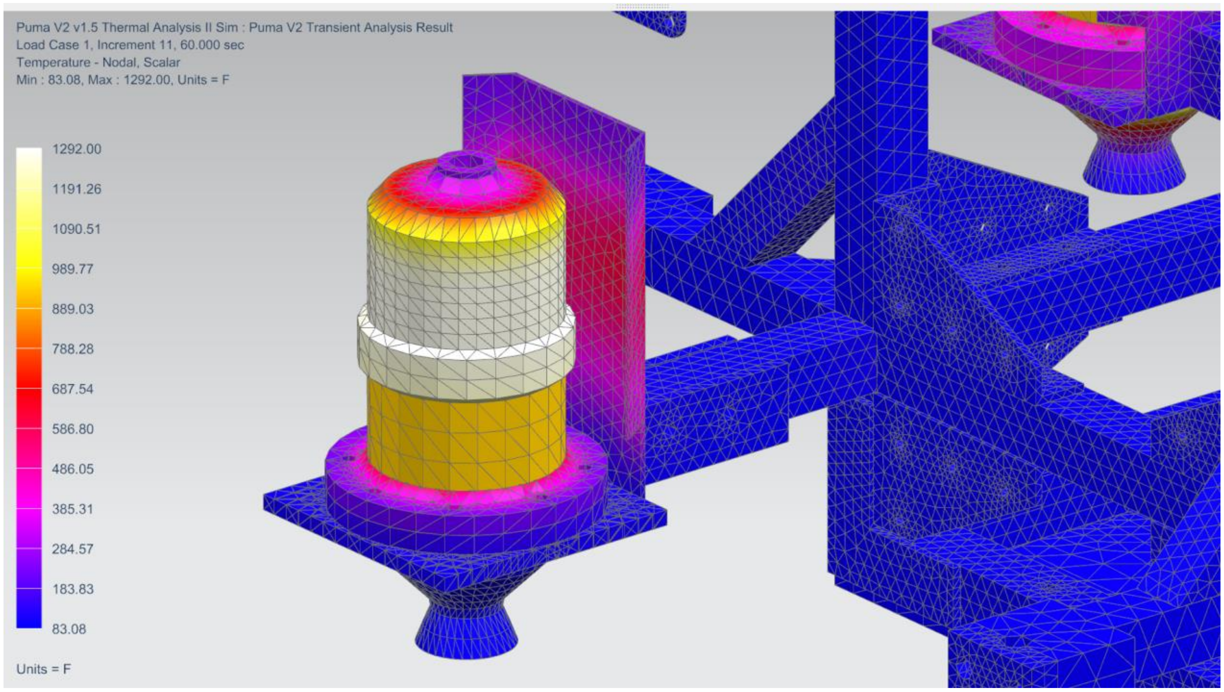


Figure 2. Transient Solution of engine, mount, and shield after 60 seconds