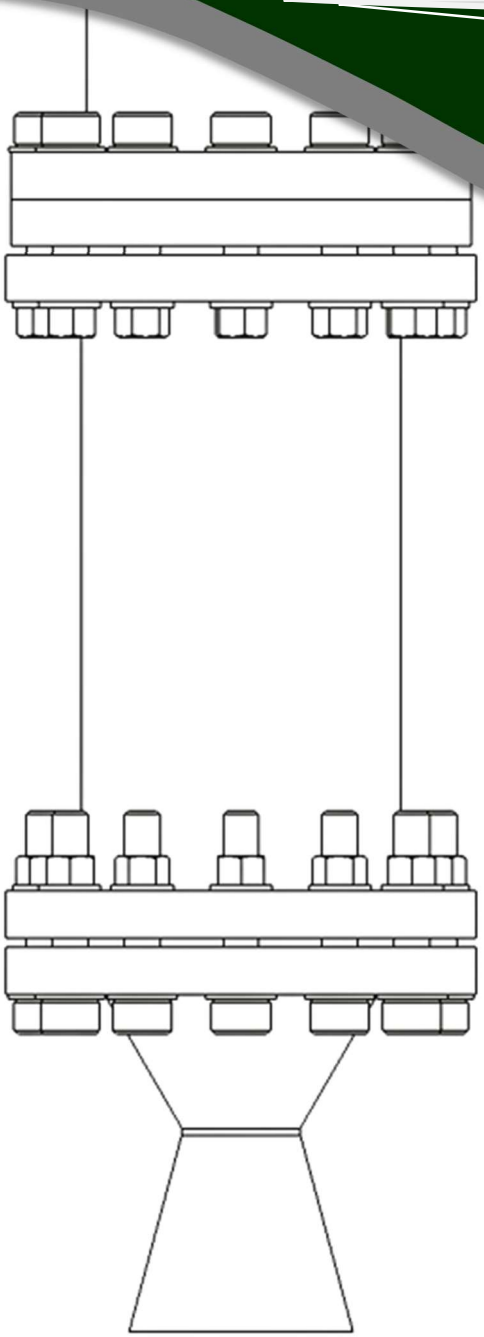
SAN LUIS OBISPO
PROPULSION TECHNOLOGIES



Hot Fire Procedure

REVISION HISTORY			
Revision	Authorizing Engineer	Comment	Date
IR	Alex Kessler	Initial Release for preliminary use. Needs industry review and further documentation	2/14/23
A	Alex Kessler	Added checkboxes and new Lab Floorplan schematic, along with other miscellaneous tweaks.	3/16/23
B	Alex Kessler	Altered schematics to reflect system and safety precautions more accurately. Tweaked procedure slightly.	3/29/23
C	Alex Kessler	Finalized procedure before first Cold Flow.	4/8/23
D	Alex Kessler	Altered procedure based on first Cold Flow. Ready for Hot Fire barring any changes after second Cold Flow.	4/18/23

Table of Contents

1. Scope

This document functions as a checklist for the hot fire procedure of the SPT MK1 Demonstrator rocket engine. It is largely adapted from *Bipropellant Rocket Engine Firing Procedure*, a procedure for firing a similar engine in the Cal Poly AERO Propulsion Lab, and *Hot Fire Procedure for Testing SLRP with Gaseous Oxygen and Ethanol*, a similar procedure used in Paul Staley's SLRP.

2. Warnings

Safety is of the highest priority for SPT. All warnings listed below are credible and must be taken very seriously. This procedure has been specifically designed to mitigate risk and is only safe and effective if followed accordingly.

2.1 Appropriate personal protective equipment (PPE) must be worn by all personnel in the lab throughout the duration of the test. All personnel must have safety glasses, earplugs, long pants, closed-toe shoes, and tied-back hair. The additional PPE that is required for setup and shutdown will be detailed in the procedure in Section 5.

2.2 The pressurant used in the system is argon, which is an inert gas. Inert gases displace air when in high concentrations and can become asphyxiants. For this reason, it can lead to loss of consciousness or suffocation. If a person faints, do not attempt to assist them. Vacate the area immediately and call 9-1-1.

2.3 The fuel used in the system is ethanol. Ethanol is flammable and should be kept away from open flames, high heat sources, sparks, and other sources of ignition.

2.4 The oxidizer in the system is gaseous oxygen (GOX). Oxygen is highly flammable in gaseous form and may create or intensify fire, or even explode if heated. Extreme care must be taken to mitigate the risk of oxygen fires. Keep away from clothing and other combustible materials. Ensure all valves and fittings are free from oil and grease.

3. Conventions

As this document functions as a checklist, it shall be printed out. The individuals conducting the test should have a pen ready to check off steps as they are completed. From here on, directions will be addressed using the below naming conventions:

3.1 This procedure will be conducted by an 'operator' and 'assistants.' Roles should be given before the procedure.

3.2 All other members of SPT present that are not the 'operator' or an 'assistant' shall be deemed a 'spectator.'

3.3 The 'control panel' refers to the black box with red switches and emergency stop button.

3.4 The 'electrical box' refers to the electrical box mounted on the test stand.

3.5 The 'lab' refers to the Cal Poly AERO Propulsion Lab.

3.6 The 'test area' refers to the test area of the Cal Poly AERO Propulsion Lab.

3.7 The 'control room' refers to the control room of the Cal Poly AERO Propulsion Lab.

3.8 The 'system' refers to the MK1 Demonstrator thrust chamber assembly, plumbing, electronics, and test stand.

Below is a list of relevant acronyms that will be used from here on in this document.:

3.9 *APV* - argon purge valve

3.11 *E-STOP* - emergency stop

3.11 *GOX* – gaseous oxygen

3.13 *MFV* - main fuel valve

3.14 *MOV* - main oxygen valve

3.15 *P&ID* - piping and instrumentation diagram

3.16 *PPE* - personal protective equipment

3.16 *TCA* - thrust chamber assembly

The following light code will be used in the procedure.

3.17 *GREEN* - The system is safe. All of operator, assistants, and spectators are allowed in the test cell.

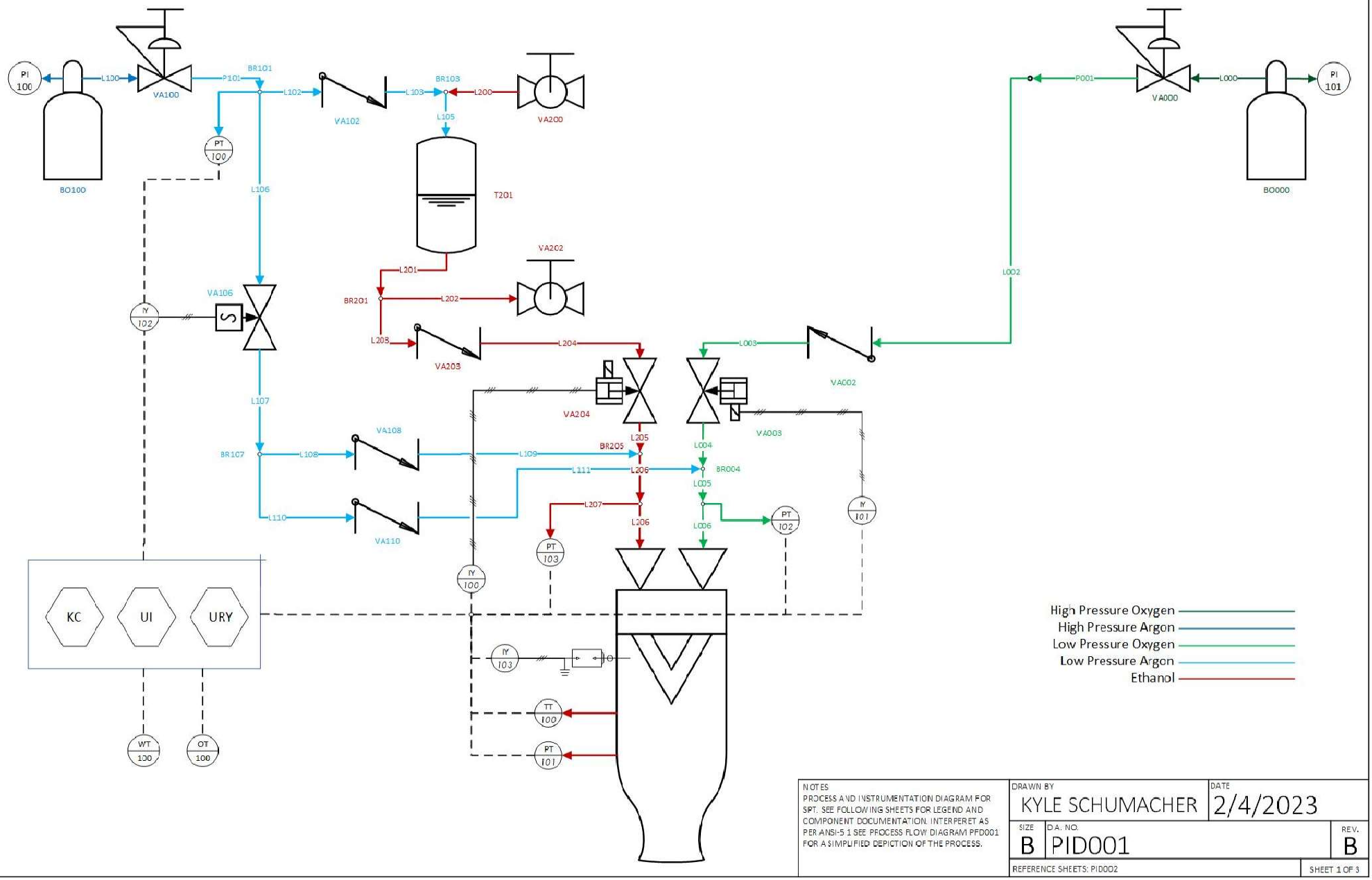
3.18 *YELLOW* - The safety key is turned in or system is pressurized. Only operator and assistants are allowed in the test cell.

3.19 *RED* - The test is currently running. Nobody is allowed in the test cell.

3.20 *FLASHING RED* - The system has entered an automatic shutdown, or E-STOP has been pressed. Refer to section 6 for failure modes and responses. Nobody is allowed in the test cell.

4. Schematics

The schematics shown on the next pages are meant to introduce the operator and the assistants to the system and the lab. These diagrams shall be printed out for immediate availability during the procedure.



NOTES
PROCESS AND INSTRUMENTATION DIAGRAM FOR SPT. SEE FOLLOWING SHEETS FOR LEGEND AND COMPONENT DOCUMENTATION. INTERPERET AS PER ANSI-5 1 SEE PROCESS FLOW DIAGRAM PFD001 FOR A SIMPLIFIED DEPICTION OF THE PROCESS.

DRAWN BY: KYLE SCHUMACHER		DATE: 2/4/2023
SIZE: B	D.A. NO.: PID001	REV.: B
REFERENCE SHEETS: PID002		SHEET 1 OF 3

SYMBOL LEGEND

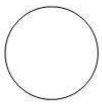
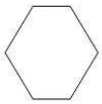
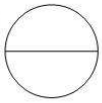
CONNECTION SYMBOLS

———	FLUID LINE
—//—//—//—	12V SUPPLY
– – – – – – – –	5V SIGNAL

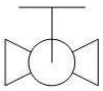
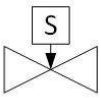
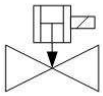
ABBREVIATIONS

PG	PRESSURE GAGUE
IY	ELECTRICAL RELAY
KC	CONTROL COMPUTER
TT	TEMPERATURE TRANSMITTER
PT	PRESSURE TRANSDEUCER
UI	DISPLAY PANEL
URY	DATA RECORDING COMPUTER
WT	LOAD CELL

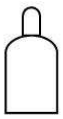
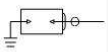
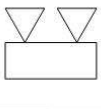
INSTRUMENT SYMBOLS

	DISCRETE INSTRUMENT (GAGUE, CONTROLLER, RELAY, ETC.)
	COMPUTER / SOFTWARE FUNCTION OR CONTROLLER
	OPERATOR ACCESSABLE / ON MAIN CONTROL (CAN BE USED FOR ANY INSTRUMENT TYPE)

VALVE SYMBOLS

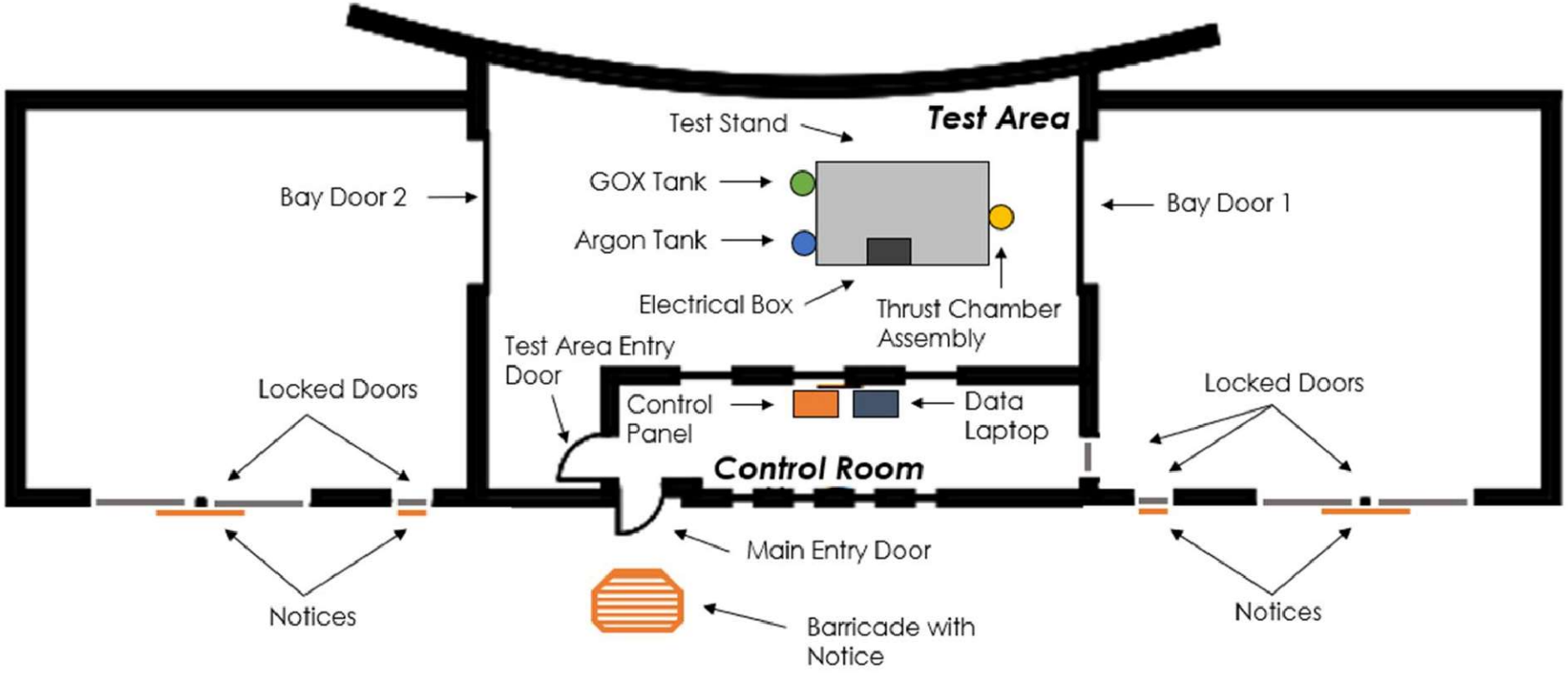
	PRESSURE REDUCING REGULATOR WITH MANUAL SET POINT
	HAND CONTROLLED BALL VALVE
	CHECK VALVE
	SOLENOID CONTROLLED FAIL-CLOSED VALVE
	PNEUMATICALLY ACTUATED SOLENOID CONTROLLED FAIL-CLOSED VALVE

ELEMENT SYMBOLS

	VERTICAL PRESSURE VESSEL, LIQUID FILLED
	PRESSURIZED GAS TANK
	IGNITER
	BI-FLUID INJECTOR
	COMBUSTION CHAMBER

NOTES
SLRP PROCESS AND INSTRUMENTATION DIAGRAM SYMBOL KEY. ADAPTED FROM ANSI-5.1

DRAWN BY	ALEX KESSLER
DATE	3/27/2023
SIZE	B
DIA. NO.	PID002
REV.	A
REFERENCE SHEETS: PID001	
SHEET 2 OF 3	



NOTES PROCESS AND INSTRUMENTATION DIAGRAM FOR SPT. SEE FOLLOWING SHEETS FOR LEGEND AND COMPONENT DOCUMENTATION. INTERPERET AS PER ANSI-5.1 SEE PROCESS FLOW DIAGRAM PFD001 FOR A SIMPLIFIED DEPICTION OF THE PROCESS.	DRAWN BY ALEX KESSLER	DATE 3/29/2023	
	SIZE B	DIA. NO. LFP001	REV. A
	REFERENCE SHEETS : PID001		SHEET 1 OF 3

5. Procedure

Below is the nominal procedure for the hot fire of the system. Safety is the number one priority of SPT during this procedure, and component failures may occur. For this reason, it is important to read through the entire procedure and failure modes and responses in Section 6 in the week before the hot fire. The operator or an assistant shall check off each step on the physical printout of the procedure after completion.

Additional PPE used throughout the procedure includes fireproof PPE (welding jacket, face shield, non-plastic pants and shoes), IR thermometer gun, testing headsets, gas concentration sensors, and adjustable wrenches.

NOTE: READ THROUGH THE FAILURE MODES AND RESPONSES IN SECTION 6 THOROUGHLY BEFORE PROCEEDING.

5.1. General Setup

The steps in this subsection are not meant to be performed in a specific order. Once the operator believes all steps have been completed, he will read through each step-by-step and check them off if they have been completed. Any steps that have not been completed must be completed before proceeding.

5.1.1 Ensure all personnel are wearing safety glasses, long pants, closed toe shoes, and have their hair tied back as necessary. ☐

5.1.2 Ensure all additional PPE listed above is on hand. ☐

5.1.3 Remove any flammable materials and loose objects from the test area and put in the flammables cabinet or outside of the lab. ☐

5.1.4 Point out where fire extinguishers and emergency contact information are. ☐

5.1.5 Ensure all outward-facing doors except for Main Entry Door are locked and all notices are in place (see Lab Floorplan). ☐

5.1.6 Move the test stand (with attached TCA, plumbing, and electronics box), data laptop, control box, cameras, and two ethernet cables into the lab. ☐

5.1.7 Ensure both bay doors are open and lock bay door chains in place. ☐

5.1.8 Position the test stand so that the front end (with TCA) faces Bay Door 1. ☐

5.1.9 Chain the four corners of test stand down to the floor of the test area in the prescribed location in the Lab Floorplan. ☐

5.1.10 Visually inspect that all plumbing connections on the test stand are secure. ☐

5.1.11 Visually inspect that all electrical connections on the test stand are secure. ☐

5.1.12 Remove plastic cap from oxygen concentration sensor, (OT100). ☐

5.1.13 Connect the two ethernet cables from the electrical box to the control panel in the control room, and tape down the ethernet cables in any locations at which it presents a trip hazard (especially important near and around test stand). ☐

5.1.14 Open data viewing software on laptop and open the control panel. ☐

5.1.15 Place all cameras in their prescribed positions. Connect any cables as necessary, and tape down the ethernet cables in any locations at which it presents a trip hazard (especially important near and around test stand). ☐

5.1.16 Attach hose between water sink next to Test Area Entry Door and water deluge solenoid valve, and open water source valve at the sink. ☐

5.1.17 Roll out argon k-bottle and chain it to the pole in its respective position on Lab Floorplan schematic. ☐

5.1.18 Ensure argon regulator is in full out (no pressure) position. ☐

5.1.19 Ensure argon regulator fits to argon k-bottle. Set argon regulator aside. ☐

5.1.20 Roll out GOX k-bottle and chain it to the pole in its respective position on Lab Floorplan schematic. ☐

5.1.21 Ensure GOX regulator is in full out (no pressure) position. ☐

5.1.22 Ensure GOX regulator fits to GOX k-bottle. Set GOX regulator aside. ☐

5.1.23 Attach argon and GOX pigtails to VA002 and VA100 (check valve at MOV and cross-tee to fuel tank). ☐

5.1.24 Ensure ethanol, syringe, and scale is on hand to measure out 2.56 oz. ☐

5.2. Pre-Test Check-Outs

The steps in this subsection are meant to verify that all components of the system are functioning properly. If any check fails, the hot fire test will have to be rescheduled to obtain functioning components.

5.2.1 Using the printout of the P&ID, verify all plumbing/electrical components and necessary whip-checks are present on the test stand. ☐

5.2.2 Ensure all readings are nominal. (0 ± 1 lbf for load cell, 0 ± 5 psi for pressure transducers, Amb. ± 10°F for thermocouple.) ☐

5.2.3 Insert safety key into control panel and turn. Warning lights will be set to YELLOW. Only operator and assistants are allowed in the test area. ☐

5.2.4 The operator shall gear up (safety glasses, headset, face shield, and gloves) and the assistant shall perform a gear check on the operator. ☐

5.2.5 The operator shall approach the test stand. ☐

5.2.6 Actuate the MOV (VA003) open on the control panel. ☐

5.2.7 Check with operator that the visual indicator on the MOV indicates it is open. ☐

5.2.8 Actuate the MOV closed on the control panel. ☐

5.2.9 Check with operator that the visual indicator on the MOV indicates it is closed. ☐

5.2.10 Actuate the MFV (VA204) open on the control panel. ☐

5.2.11 Check with operator that the visual indicator on the MFV indicates it is open. ☐

5.2.12 Actuate the MFV closed on the control panel. ☐

5.2.13 Check with operator that the visual indicator on the MFV indicates it is closed. ☐

5.2.14 Actuate the APV (VA106) open on the control panel. ☐

5.2.15 Check with operator that they heard the APV click open. ☐

5.2.16 Actuate the APV closed on the control panel. ☐

5.2.17 Check with operator that they heard the APV click closed. ☐

5.2.18 The operator shall move within hearing distance of the TCA. ☐

5.2.19 Spark test the igniter on the control panel and check with the operator that sparks were heard. ☐

5.2.20 Ensure igniter is not actively sparking. ☐

5.2.21 The operator shall return to the control room. ☐

5.2.22 Set warning lights to GREEN. All of operator, assistants, and spectators are allowed in the test cell. ☐

5.2.23 Dry run the remaining procedure. Consult with relevant personnel as needed. ☐

5.3. Preparation

5.3.1 Go over failure modes and responses section with all present before proceeding. ☐

NOTE: STEPS 5.3.2 THROUGH 5.3.5 SHALL BE PERFORMED IN A TIME SENSITITVE MANNER TO LIMIT CONTAMINATION. THE OPERATOR AND ASSISTANTS SHALL SPLIT UP THESE TASKS.

5.3.2 Attach argon pigtail to argon regulator. ☐

5.3.3 Attach argon regulator to argon k-bottle. ☐

5.3.4 Attach GOX pigtail to GOX regulator. ☐

5.3.5 Attach GOX regulator to GOX k-bottle. ☐

5.3.6 Everyone shall return to the control room. ☐

5.3.7 Insert safety key into control panel and turn. Warning lights will be set to YELLOW. Only operators and assistants are allowed in the test area. ☐

5.3.8 The operator shall gear up (safety glasses, headset, face shield, and gloves) and the assistant shall perform a gear check on the operator. ☐

5.3.9 The operator shall approach the test stand behind the blast shield. ☐

BEGINNING OF HAZARDOUS STEPS. THE OPERATOR SHALL MAKE AN ANNOUNCEMENT TO ALL PRESENT TO BE ON ALERT UNTIL HAZARDOUS STEPS ARE CONCLUDED.

5.3.10 Actuate MFV open. ☐

5.3.11 Back out argon regulator handle all the way. ☐

5.3.12 Crack open argon k-bottle to its maximum (should be between 2000 and 3500 psi). ☐

5.3.13 Insert argon regulator handle and slowly turn until system gauge starts increasing. ☐

5.3.14 Back off argon regulator until system reads zero. ☐

5.3.15 Actuate MFV closed. ☐

5.3.16 Crack the argon regulator open to less than 5 psi and close after 5 seconds. ☐

5.3.17 Hissing should occur for a brief period before it stops. If this is not the case, the MFV and/or APV are in the open position when it should be closed. This issue must be resolved before conducting click checks again and proceeding. ☐

5.3.18 Actuate MFV open. ☐

5.3.19 Ensure all readings are nominal (0 ± 5 psi for pressure transducers). ☐

5.3.20 Actuate MOV open. ☐

5.3.21 Back out GOX regulator handle all the way. ☐

5.3.22 Crack open GOX k-bottle to its maximum (should be between 2000 and 3500 psi). ☐

5.3.23 Insert GOX regulator handle and slowly turn until system gauge starts increasing. ☐

5.3.24 Back off GOX regulator until system reads zero. ☐

5.3.25 Actuate MOV closed. ☐

5.3.26 Crack the GOX regulator open to less than 5 psi and close after 5 seconds. ☐

5.3.27 Hissing should occur for a brief period before it stops. If this is not the case, the MOV is in the open position when it should be closed. This issue must be resolved before conducting click checks again and proceeding. ☐

5.3.28 Actuate MOV open. ☐

5.3.29 Ensure all readings are nominal (0 ± 5 psi for pressure transducers). ☐

5.3.30 Actuate MOV and MFV closed. ☐

5.3.31 The operator shall return to the control room. ☐

5.3.32 Set warning lights to GREEN. All of operator, assistants, and spectators are allowed in the test cell. ☐

5.3.33 Ensure all cameras are in their prescribed positions. Connect any cables as necessary, and tape down the ethernet cables in any locations at which it presents a trip hazard. ☐

5.3.34 Ensure ethanol drain valve (VA200) is closed. ☐

5.3.35 Open ethanol fill valve (VA202). ☐

5.3.36 Insert syringe and fill slowly to desired ethanol mass of 2.56 oz. Syringe must be pressed in small increments and backed out to ensure no spilling occurs. ☐

5.3.37 Close ethanol fill valve. ☐

5.3.38 Everyone shall return to the control room. ☐

5.3.39 Dry run the remaining procedure. Consult with relevant personnel as needed. ☐

5.3.40 The assistant shall enter the test area with a headset and start all necessary video recordings. ☐

5.3.41 The assistant shall check with the control room that all cameras have been started, and all live video recording is functioning. ☐

5.3.42 The assistant shall return to the control room. ☐

5.3.43 Insert safety key into control panel and turn. Warning lights will be set to YELLOW. Only operators and assistants are allowed in the test area. ☐

5.3.44 The operator shall gear up (safety glasses, headset, face shield, and gloves) and the assistant shall perform a gear check on the operator. ☐

5.3.45 The operator shall approach the test stand behind the blast shield. ☐

5.3.46 The operator shall turn the argon regulator knob to 315 psi. ☐

5.3.47 The operator shall turn the GOX regulator knob to 688 psi. ☐

5.3.48 The operator shall return to the control room. ☐

5.4. Firing

5.4.1 The operator shall tape the replacement safety key under the control panel. ☐

5.4.2 The operator shall place one hand on E-STOP and one hand on the firing button. ☐

5.4.3 Warn all participants that firing is imminent, instruct all participants to don hearing protection. ☐

5.4.4 Count down from 5 and press fire on the control panel. The following steps are a step-by-step account of the automated procedure.

5.4.5 Set warning lights to RED. Nobody is allowed in test area. Additionally, the main entry door and test area entry door shall be closed and locked. Only the relevant personnel are allowed in the control room. ☐

5.4.6 Open APV.

5.4.7 Purge for 5 seconds.

5.4.8 Close APV.

5.4.9 Open MOV and oxygenate chamber for 0.5 seconds.

5.4.10 Open MFV. The rocket will fire.

5.4.11 The operator and assistants will observe the combustion and relevant data for 3 seconds. If an anomaly occurs, the E-STOP button shall be pressed.

NOTE: IF E-STOP OR AUTOMATED STOP OCCURS, THE WARNING LIGHTS WILL START FLASHING RED. REFER TO SECTION 6, ASSESS THE POTENTIAL FAILURE MODE, AND RESPOND ACCORDINGLY.

5.5. Shutdown

5.5.1 Close MOV.

5.5.2 Close MFV.

5.5.3 Open APV.

5.5.4 Purge for 5 seconds.

5.5.5 Close APV.

NOTE: THE PROCEDURE FROM HERE ON IS NO LONGER AUTOMATED BY THE SOFTWARE SYSTEM. ALL STEPS LISTED BELOW MUST BE PHYSICALLY PERFORMED.

5.5.6 Prepare to approach the test stand. All six factors listed below shall be satisfied to consider the system safe.

Quantitative Confirmation		Qualitative Confirmation	
PT101, PT102, and PT103 shall read 15 ± 5 psia	☐	MFV (VA204) and MOV (VA003) visual indicators shall show closed	☐
TT100 shall read < 100 °F	☐	The IR thermometer gun shall be pointed directly at several points around the test stand and shall read Amb. ± 10 °F	☐
OT100 shall read 21 ± 1.5 % oxygen concentration	☐	The safety key shall be out of the control panel and in the possession of the operator	☐

5.5.7 Actuate MFV open and wait until no more fuel is seen exiting TCA. ☐

5.5.8 Actuate MFV closed. ☐

5.5.9 The operator shall gear up (headset, fireproof PPE, and gas concentration sensors) and the assistant shall perform a gear check on the operator. ☐

5.5.10 Set warning lights to YELLOW. Only operator is allowed in test area. ☐

5.5.11 The operator shall approach the test stand behind the blast shield. ☐

5.5.12 The operator shall close the GOX k-bottle. ☐

5.5.13 The operator shall return to control room. ☐

5.5.14 Set warning lights to RED. Nobody is allowed in test area. Additionally, the main entry door and test area entry door shall be closed and locked. Only the relevant personnel are allowed in the control room. ☐

5.5.15 Actuate MOV open for 3 seconds. ☐

5.5.16 Actuate MOV closed. ☐

5.5.17 Actuate APV open and purge for 5 seconds. ☐

5.5.18 Actuate APV closed. ☐

5.5.19 Prepare to approach the test stand. All six factors listed below shall be satisfied to consider the system safe.

Quantitative Confirmation		Qualitative Confirmation	
PT101, PT102, and PT103 shall read 15 ± 5 psia	☐	MFV (VA204) and MOV (VA003) visual indicators shall show closed	☐
TT100 shall read < 100 °F	☐	The IR thermometer gun shall be pointed directly at several points around the test stand and shall read Amb. ± 10 °F	☐
OT100 shall read 21 ± 1.5 % oxygen concentration	☐	The safety key shall be out of the control panel and in the possession of the operator	☐

5.5.20 The operator shall gear up (safety glasses, headset, face shield, gloves, and gas concentration sensors) and the assistant shall perform a gear check on the operator. ☐

5.5.21 Set warning lights to YELLOW. Only operator is allowed in test area. ☐

5.5.22 The operator shall approach the test stand behind the blast shield. ☐

5.5.23 The operator shall close the argon k-bottle. ☐

5.5.24 The operator shall return to control room. ☐

5.5.25 Set warning lights to RED. Nobody is allowed in test area. Additionally, the main entry door and test area entry door shall be closed and locked. Only the relevant personnel are allowed in the control room. ☐

5.5.26 Actuate MFV open for 3 seconds. ☐

5.5.27 Actuate MFV closed. ☐

5.5.28 Actuate APV open and purge for 5 seconds. ☐

5.5.29 Actuate APV closed. ☐

5.5.30 Prepare to approach the test stand. All six factors listed below shall be satisfied to consider the system safe.

Quantitative Confirmation		Qualitative Confirmation	
PT100, PT101, PT102, and PT103 shall read 15 ± 5 psia	☐	MFV (VA204) and MOV (VA003) visual indicators shall show closed	☐
TT100 shall read < 100 °F	☐	The IR thermometer gun shall be pointed directly at several points around the test stand and shall read Amb. ± 10 °F	☐
OT100 shall read 21 ± 1.5 % oxygen concentration	☐	The safety key shall be out of the control panel and in the possession of the operator	☐

5.5.31 The operator and assistants shall gear up (safety glasses, headset, face shield, gloves, and gas concentration sensors) and the assistant shall perform a gear check on the operator. ☐

5.5.32 Set warning lights to YELLOW. Only operator and assistants are allowed in the test area. ☐

5.5.33 The operator and assistants shall approach the test stand. ☐

5.5.34 The operator and assistants shall detach the pigtails. ☐

END OF HAZARDOUS STEPS.

5.5.35 Set warning lights to GREEN. Disassembly of the system can now proceed. ☐

6. Failure Modes and Responses

This section must be well known and reviewed by the operator and assistants.

6.1. Automatic Shutdown Criteria

The criteria listed below will trigger an automatic shutdown. Steps 5.5.1 through 5.5.5 will be performed by the software. Shutdown procedure should proceed as nominal from that point on.

Failure Mode:	Consequence:
PT101 reads > 400 psi	The chamber pressure is higher than expected and not within the margin of safety.
TT100 reads > 1000 °F	The chamber is getting close to its melting point.
System is no longer reading data	We have no way of knowing the state of the system.

6.2. Main Fuel Valve Failure Modes

Failure Mode:	Consequence:	Response:
Unexpected MFV (VA204) OPEN	Pneumatic valve may be open due to an electrical issue.	Cut power to pneumatic valve, it is default closed so it should close. If still open refer to next row.
Unexpected MFV (VA204) STILL OPEN	The remaining fuel and the argon k-bottle will continue to flow through the system.	Press E-STOP. Allow argon to completely deplete k-bottle. Ensure system is safe again. Proceed with shutdown procedure as nominal.
Unexpected MFV (VA204) CLOSED	The valve will remain closed throughout the test, not delivering the propellant.	Press E-STOP. The system will shut down and return to a known state. Proceed with shutdown as nominal. Manually open valve afterwards.

6.3. Main Oxygen Valve Failure Modes

Failure Mode:	Consequence:	Response:
Unexpected MOV (VA003) OPEN	Pneumatic valve may be open due to an electrical issue.	Cut power to pneumatic valve, it is default closed so it should close. If still open refer to next row.
Unexpected MOV (VA003) STILL OPEN	The remaining fuel GOX k-bottle will continue to flow through the system.	Press E-STOP. Allow GOX to completely deplete k-bottle. Ensure system is safe again. Proceed with shutdown procedure as nominal.
Unexpected MFV (VA003) CLOSED	The valve will remain closed throughout the test, not delivering the propellant.	Press E-STOP. The system will shut down and return to a known state. Proceed with shutdown as nominal. Manually open valve afterwards.

6.4. Argon Purge Valve Failure Modes

Failure Mode:	Consequence:	Response:
Unexpected APV (VA106) OPEN	Solenoid valve may be open due to an electrical issue.	Cut power to solenoid valve, it is default closed so it should close. If still open refer to next row.
Unexpected APV (VA106) STILL OPEN	The remaining fuel and the argon k-bottle will continue to flow through the system.	Press E-STOP. Allow argon to completely deplete k-bottle. Ensure system is safe again. Proceed with shutdown procedure as nominal.
Unexpected APV (VA106) CLOSED	The fuel and argon lines can still be purged through the MFV (VA204). The GOX line cannot be purged with Argon.	Press E-STOP. Proceed with shutdown procedure as nominal. GOX must be bled without argon purge. Ensure system is safe after bleeding GOX in 5.5.14 and 5.5.15.

6.5. Igniter Failure Modes

Failure Mode:	Consequence:	Response:
Engine fails to ignite	The propellants exit the thrust chamber as they are.	Proceed with shutdown procedure as nominal. Collect remaining ethanol through the drain valve (VA202) and purge the system once again. Assess ignitor failure.
Engine ignites too late	The TCA experiences a hard start.	Press E-STOP. Proceed with shutdown procedure as nominal. Collect remaining ethanol through the drain valve (VA202) and purge the system once again. Assess ignitor failure.

6.6. Other Failure Modes

Failure Mode:	Consequence:	Response:
Chamber shows excessive heating/degradation	Chamber could be melting or otherwise failing to combustion characteristics.	Press E-STOP. The system will shut down and return to a known state. Allow for TT100 to read Amb. ± 10 °F before assessing failure.
An over-pressurization event happens in fuel line (L200-204)	The fuel line bursts open, leaking the fluid to the environment.	Press E-STOP. Allow argon to completely deplete k-bottle. Ensure system is safe again. Proceed with shutdown procedure as nominal.
An over-pressurization event happens in GOX line (L002-003)	The GOX line bursts open, leaking the fluid to the environment.	Press E-STOP. Allow GOX to completely deplete k-bottle. Ensure system is safe again. Proceed with shutdown procedure as nominal.
An over-pressurization event happens in argon line (L102-106)	The argon line bursts open, leaking the fluid to the environment.	Press E-STOP. Allow argon to completely deplete k-bottle. Ensure system is safe again. Proceed with shutdown procedure as nominal.

Pressure anywhere is greater than anticipated	This is beyond the margin of safety and could cause an over pressurization event.	Press E-STOP. Proceed with shutdown procedure as nominal. System will auto-shutdown if chamber pressure is too high.
Pressure anywhere is less than anticipated	May be cause for a retest after evaluation of the cause.	Proceed with shutdown procedure as nominal.
Burn time is shorter than expected	There is fuel remaining in the ethanol bottle.	Proceed with shutdown procedure as nominal. Collect remaining ethanol through the drain valve (VA202) and purge the system once again. Assess ignitor failure.
A loss of connection is observed on the operator side.	The operator cannot operate the system manually.	Press E-STOP. The system will shut down and return to a known state. Proceed with shutdown as nominal.
Strain gauge is off nominal.	The thrust observed is not what is expected.	Proceed with shutdown procedure as nominal. Shut down the main valves and purge with argon. It is possible the unexpected value is the true value of the system, as this is what we're testing for.

6.7. Extraneous Failure Modes

Failure Mode:	Consequence:	Response:
Unexpected personnel entrance into lab.	The child's safety may be at risk as they do not know the safety procedures associated with the hot fire.	Press E-STOP. The system will shut down and return to a known state. Secure child and remove from lab. Proceed with shutdown as nominal.

Extreme weather event occurs or is incoming.	The safety of the personnel conducting the test is absolutely more important than the components of the system.	Press E-STOP. All personnel shall exit lab immediately. Ensure system is safe and assess damage once the extreme weather passes. Proceed with shutdown procedure as nominal.
Fire occurs.	Ethanol and oxygen fires are both invisible. The operator and assistants shall use the IR thermometer to determine if there is a fire.	Press E-STOP. All personnel shall exit the lab and evacuate to the adjacent parking lot. Call the fire department.
Ethernet cable melts.	The ethernet cable could melt due to a variety of factors. It is important to ensure that the reason was not because of a fire.	Press E-STOP. Ensure there is no fire around the area where the ethernet cable has melted. Proceed with shutdown procedure as nominal.
Safety key is lost.	The system cannot be shut down without taking the key out of the panel.	Take the replacement key taped under the control panel. Press E-STOP. Proceed with shutdown procedure as nominal.
Gas concentration sensors go off.	There may be a high concentration of a certain type of gas present in the room.	Evacuate the test area. Wait for the oxygen concentration in the room to return to normal. Proceed with shutdown procedure as nominal.

7. Sources and References

7.1 Cal Poly AERO Prop Lab, *Bipropellant Rocket Engine Firing Procedure*

7.2 Paul Staley SLRP, *Hot Fire Procedure for Testing SLRP with Gaseous Oxygen and Ethanol*