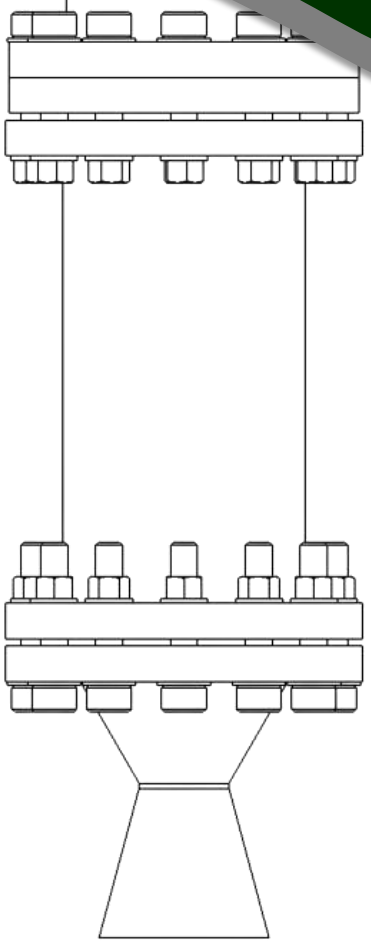
SAN LUIS OBISPO
PROPULSION TECHNOLOGIES



Cold Flow Procedure

REVISION HISTORY			
Revision	Authorizing Engineer	Comment	Date
IR	Mohab Wahdan	Initial Release for preliminary use. Needs industry review and further documentation	3/10/23
A	Mohab Wahdan	Updated document with revised schematics/Lab Floorplan, added checkboxes, and other miscellaneous tweaks.	3/16/23
B	Alex Kessler	Finalized schematics and tweaked pre-test check-outs.	4/2/23
C	Mohab Wahdan	Finalized procedure for first Cold Flow.	4/8/23
D	Alex Kessler	Altered procedure based on first Cold Flow. Ready for second Cold Flow.	4/17/23

Table of Contents

1. Scope

This document functions as a checklist for the *Cold Flow Procedure* of the SPT MK1 Demonstrator rocket engine. The procedure will entail replacing ethanol with deionized water and replacing gaseous oxygen with argon. It is largely adapted from the current *Hot Fire Procedure* for the same system, which is based on *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 their hair tied back. The additional PPE that is required for setup and shutdown will be detailed 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, vacate the area immediately and call 9-1-1.

2.3 This system operates under high pressure and can cause serious injury or even death if not handled with extreme caution. Do not attempt to tamper with or modify any part of the system without proper training and authorization. Always wear appropriate personal protective equipment (PPE), including eye protection and gloves, when working with the system. Keep all body parts and loose clothing away from the system's high-pressure components. Before performing any maintenance or repair work, release all pressure from the system. Failure to follow these guidelines can result in catastrophic failure of the system, causing harm to yourself or others in the vicinity.

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

3.10 *DI* - deionized

3.11 *E-STOP* - emergency stop

3.13 *MWV* - main DI water valve

3.14 *MAV* - main argon valve

3.15 *P&ID* - piping and instrumentation diagram

3.16 *PPE* - personal protective equipment

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.

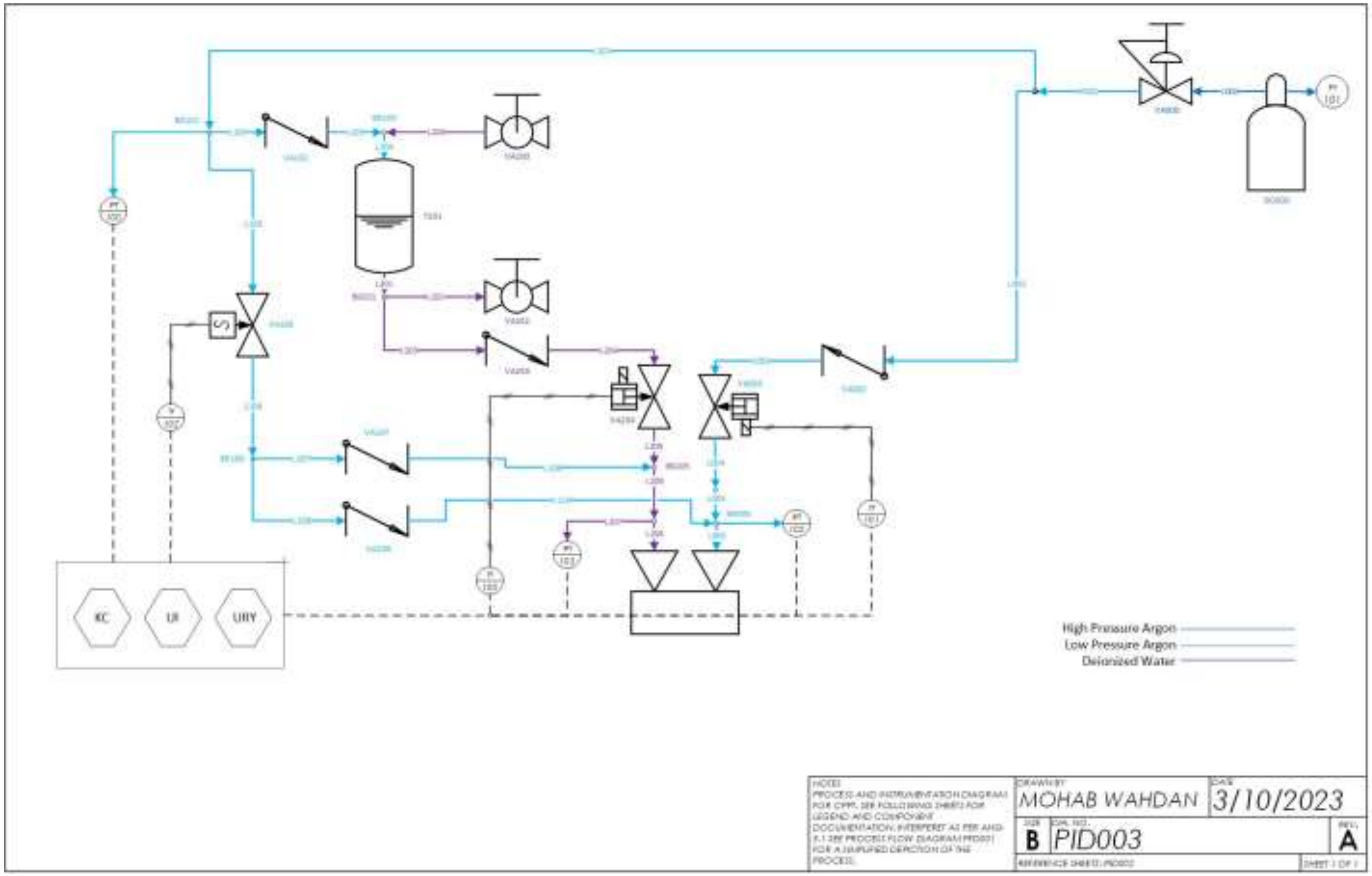
3.18 *YELLOW* - The safety key is turned in or system is pressurized. Only operator and assistants are allowed in the test cell.

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.


KC
UI
URY
High Pressure Argon
Low Pressure Argon
Deionized Water
DRAWN BY
MOHAB WAHDAN
DATE
3/10/2023
B
PID003
A

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

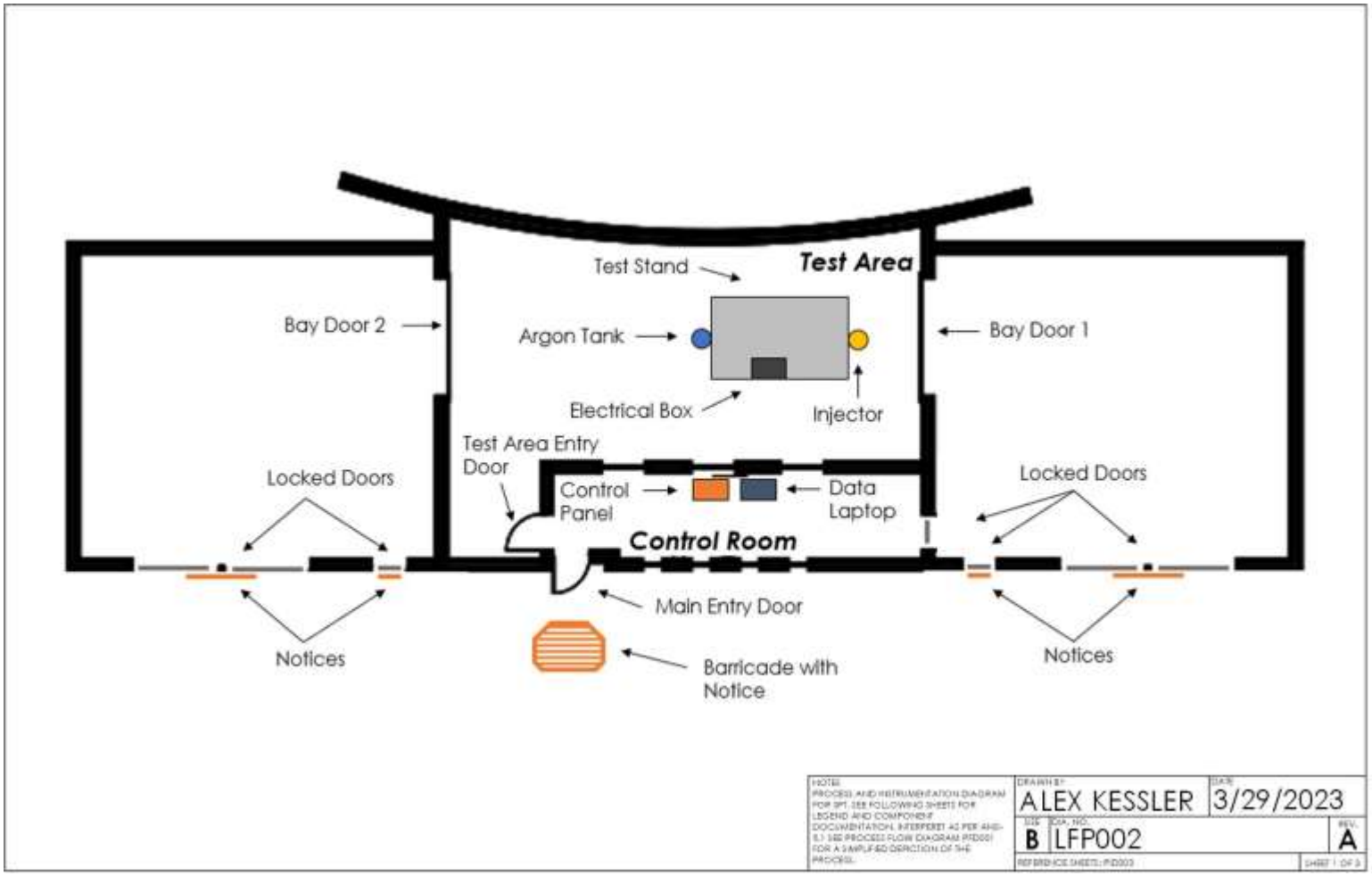
	PRESSURE REDUCING REGULATOR WITH MANUAL SET POINT
	HAND CONTROLLED BALL VALVE
	CHECK VALVE
	SOLENOID CONTROLLED FAIL-CLOSED VALVE
	PNEUMATICALLY ACTUATED SOLENOID CONTROLLED FAIL-CLOSED VALVE

ELEMENT SYMBOLS

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

NOTES:
SOME PROCESS AND INSTRUMENTATION DIAGRAM SYMBOLS KEY ADAPTED FROM ANSI-Y.1

DRAWN BY: ALEX KESSLER		DATE: 3/27/2023
SIZE: B	DWG NO.: PID002	REV.: A
REFERENCE SHEETS: P0001		SHEET 2 OF 3


Test Stand
Test Area
Bay Door 2
Argon Tank
Bay Door 1
Electrical Box
Injector
Test Area Entry Door
Locked Doors
Control Panel
Data Laptop
Locked Doors
Control Room
Main Entry Door
Notices
Barricade with Notice
Notices
NOTES:
PROCESS AND INSTRUMENTATION DIAGRAM FOR SPT. SEE FOLLOWING SHEETS FOR LEGEND AND COMPONENT DOCUMENTATION. INTERPRET AS PER ANSI-S.1. SEE PROCESS FLOW DIAGRAM PFD001 FOR A SIMPLIFIED DEPICTION OF THE PROCESS.
DRAWN BY
ALEX KESSLER
DATE
3/29/2023
SIZE
B
SCA. NO.
LFP002
REV.
A
REFERENCE SHEETS: PFD003
SHEET 1 OF 3

5. Procedure

Below is the nominal procedure for the cold flow 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 cold flow. The operator or an assistant shall check off each step on the physical printout of the procedure after completion.

Testing headsets, gas concentration sensors, and adjustable wrenches will be used throughout the procedure to simulate the environment of a hot fire.

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 Point out where fire extinguishers and emergency contact information are. Ensure all present understand protocol for contacting emergency services (Notify police that they are at Cal Poly, building 41B, room 144) ☐

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

5.1.5 Move the test stand (with attached ball valves, plumbing, and electronics box), data laptop, control box, injector assembly, cameras, and two ethernet cables into the lab. ☐

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

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

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

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

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

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

Commented [WD1]: might be redundant but can we make this a bigger step? checking the integrity of the plumbing and the electronics can each have their own section

Commented [WD2R1]: @Alexander C. Kessler we dont need to include it here, it could just be a section later that they flip to that has the procedure

Commented [ACK3R1]: I like it here, because we can catch it early on

Commented [WD4R1]: I want us to be checking it here too, but im saying lets elaborate on the checking process in another part for us to reference when we come to this step

Commented [ACK5R1]: Oh okay gotcha

5.1.12 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). ☐

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

5.1.14 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). ☐

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

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

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

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

Commented [ACK6]: Need to ask wendy

Commented [WD7R6]: wym fits

5.1.19 Attach pigtails to VA002 and VA100 (check valve at MAV and cross-tee to DI water tank). ☐

5.1.20 Attach other ends of pigtails to tee. ☐

5.1.21 Attach tee to modified FFM tee (with female ends capped). ☐

5.1.22 Ensure DI water, 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 operators 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 MAV (VA003) open on the control panel. ☐

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

5.2.8 Actuate the MAV closed on the control panel. ☐

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

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

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

5.2.12 Actuate the MWV closed on the control panel. ☐

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

5.2.14 Actuate the APV (VA105) 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 return to the control room. ☐

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

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

5.3. Leak Checking

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

5.3.2 Attach argon regulator to modified FFM tee. ☐

5.3.3 Ensure both ball valves connected at the inputs to the injector are in the open position. ☐

5.3.4 Everyone shall return to the control room. ☐

5.3.5 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. ☐

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

5.3.7 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.

5.3.8 Actuate MAV, MWV, and APV open. ☐

5.3.9 Back out regulator handle all the way. ☐

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

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

5.3.12 Back off regulator until system reads zero. ☐

5.3.13 Actuate MAV, MWV, and APV closed. ☐

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

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

5.3.16 Actuate MAV, MWV, and APV open. ☐

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

5.3.18 The operator shall close both ball valves connected at the inputs to the injector. ☐

5.3.19 Actuate MAV, MWV, and APV closed. ☐

5.3.20 The operator shall move behind the blast shield. ☐

5.3.21 Pressurize system with regulator knob to 700 psi (or maximum). ☐

5.3.22 The operator shall return to the control room. ☐

5.3.23 Actuate MWV, MAV, and APV open. ☐

5.3.24 Monitor and ensure that all pressure transducer readings are 700 ± 40 psi. ☐

5.3.25 Wait ten minutes. If pressure transducers start to read off nominal, press E-STOP and proceed with nominal shutdown in section 5.5. ☐

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

5.3.27 Ensure MS-SNOOP is on hand and ready for the operator to use after the system is pressurized. ☐

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

5.3.29 Apply MS-SNOOP to all connections using a spray bottle. ☐

5.3.30 Inspect each connection for bubble formation, take note of any connection with bubble formation and communicate to assistant. ☐

5.3.31 The operator shall return to the control room. ☐

5.3.32 Actuate MAV, MWV, and APV closed. ☐

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

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

5.3.35 The operator shall close the k-bottle. ☐

5.3.36 The operator shall open both ball valves connected at the inputs to the injector. ☐

5.3.37 The operator shall return to the control room. ☐

5.3.38 Actuate MAV, MWV, and APV open. ☐

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

5.3.40 If leaks were found, assess severity and repair any connections as needed. If further leak checking is needed, return to step 5.3.6 and proceed to step 5.3.40, omitting steps 5.3.13 through 5.3.17 and step 5.3.19. ☐

5.3.41 Wipe all connections down to ensure the exteriors are free from residual MS-SNOOP. ☐

5.3.42 Ensure floor is dry, wipe down if needed. ☐

5.4. Cold Flowing

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

5.4.2 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. ☐

NOTE: STEPS 5.4.2 THROUGH 5.4.10 SHALL BE PERFORMED IN A TIME SENSITITVE MANNER TO LIMIT CONTAMINATION. THE OPERATOR AND ASSISTANTS SHALL SPLIT UP THESE TASKS.

5.4.3 Remove both ball valves connected at the inputs to the injector. ☐

5.4.3 The assistant shall slide the injector assembly on to the rails and hold it in place under inputs. ☐

5.4.4 The operator shall attach all four stand offs to the test stand. ☐

5.4.5 The operator shall attach the inputs to the injector. ☐

5.4.6 Ensure DI water drain valve (VA200) is closed. ☐

5.4.7 Open DI water fill valve (VA202). ☐

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

5.4.9 Close DI water fill valve. ☐

5.4.10 Everyone shall return to the control room. ☐

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

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

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

5.4.14 The assistant shall return to the control room. ☐

5.4.15 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. ☐

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

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

5.4.18 Actuate MAV, MWV, and APV open. ☐

5.4.19 Back out the regulator handle all the way. ☐

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

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

5.4.22 Back off regulator until system reads zero. ☐

5.4.23 Actuate MAV, MWV, and APV closed. ☐

5.4.24 Pressurize system with regulator knob to 688 psi. ☐

5.4.25 The operator shall return to the control room. ☐

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

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

5.4.28 Warn all participants that system operation is imminent, instruct all participants to don hearing protection. ☐

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

5.4.30 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.

5.4.31 Open APV.

5.4.32 Purge for 5 seconds.

5.4.33 Close APV.

5.4.34 Open MAV for 5 seconds.

5.4.35 Open MWV. The injector will cold flow.

5.4.36 The operator and assistants will observe the system and the relevant data for 3 seconds. If an anomaly is detected, the operator will press the E-STOP button.

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

5.5. Shutdown

5.5.1 Close MAV.

5.5.2 Close MWV.

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 three factors listed below shall be satisfied to consider the system safe.

Safety Factors	
PT102 and PT103 shall read 0 ± 5 psi ☐	MWV (VA204) and MAV (VA003) visual indicators shall show closed ☐
The safety key shall be out of the control panel and in the possession of the operator ☐	

5.5.7 Actuate MWV open and wait until no more water is seen exiting injector. ☐

5.5.8 Actuate MWV closed. ☐

5.5.9 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. ☐

5.5.10 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 argon 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 MAV open for 3 seconds. ☐

5.5.16 Actuate MAV closed. ☐

5.5.17 Actuate MWV open for 3 seconds. ☐

5.5.18 Actuate MWV closed. ☐

5.5.19 Actuate APV open and purge for 5 seconds. ☐

5.5.20 Actuate APV closed. ☐

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

Safety Factors	
PT100, PT102, and PT103 shall read 0 ± 5 psi ☐	MWV (VA204) and MAV (VA003) visual indicators shall show closed ☐
The safety key shall be out of the control panel and in the possession of the operator ☐	

5.5.22 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. ☐

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

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

5.5.25 The operator and assistants shall detach the pigtails. ☐

END OF HAZARDOUS STEPS.

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

5.6. Water Deluge System Check

5.6.1 Actuate water deluge solenoid open for 3 seconds. ☐

5.6.2 Actuate water deluge solenoid closed. ☐

5.6.3 Ensure functionality of water deluge system. ☐

5.6.4 Disassembly of the system can now proceed. ☐

Commented [ACK8]: Okay I think I'm done can you go through and tell me where I've fucked up @Adam Joseph Boegel

Commented [ACK9R8]: Also gonna look through failure modes

Commented [AB10R8]: Yep yep, I'm also updating HFP if you wanna check over

Commented [ACK11R8]: Ok, will probably look over it tomorrow morning

Commented [ACK12R8]: @Adam Joseph Boegel lol 149 steps!

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 5.5.6 will be performed by the software. Shutdown procedure should proceed as nominal from that point.

Failure Mode:	Consequence:
System is no longer reading data.	We have no way of knowing the state of the system.

6.2. Main DI Water Valve Failure Modes

Failure Mode:	Consequence:	Response:
Unexpected MWV (VA204) OPEN	Pneumatic valve may be open due to an electrical issue.	Cut power to the pneumatic valve, it is default closed so it should close. If still open refer to next row.
Unexpected MWV (VA204) STILL OPEN	The remaining DI water and the argon in the k-bottle will continue to flow through the system.	Press E-STOP. Allow argon to completely deplete the k-bottle. Ensure the system is safe again. Proceed with shutdown procedure as nominal.
Unexpected MWV (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 Argon Valve Failure Modes

Failure Mode:	Consequence:	Response:
Unexpected MAV (VA003) OPEN	Pneumatic valve may be open due to an electrical issue.	Cut power to the pneumatic valve, it is default closed so it should close. If still open refer to next row.
Unexpected MAV (VA003) STILL OPEN	The remaining argon in the k-bottle will continue to flow through the system.	Press E-STOP. Allow argon to completely deplete the k-bottle. Ensure the system is safe again. Proceed with shutdown procedure as nominal.
Unexpected MAV (VA003) CLOSED	The valve will remain closed throughout the test.	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 (VA105) 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 (VA105) STILL OPEN	The remaining DI water 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 (VA105) CLOSED	The DI water and purge lines can still be purged through the MWV (VA204). The GO 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. Other Failure Modes

Failure Mode:	Consequence:	Response:
An over-pressurization event happens in DI water line (L200-204)	The water line bursts open, leaking the fluid to the environment.	Press E-STOP. Allow argon to completely deplete the k-bottle. Ensure the system is safe again. Proceed with shutdown procedure as nominal.
An over-pressurization event happens in argon line (L002-003)	The argon line bursts open, leaking the fluid to the environment.	Press E-STOP. Allow argon to completely deplete the k-bottle. Ensure the 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.
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.

6.6. 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 more important than the components of the system.	Press E-STOP. All personnel shall exit the lab immediately. Ensure the system is safe and assess damage once the extreme weather passes. 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 or oxygen concentration sensor (OT100) is reading off nominal value.	There may be a high concentration of a certain type of gas present in the room.	Press E-STOP. 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*

7.3 SPT, *Hot Fire Procedure*