CAL POLY SPACE SYSTEMS
[CPSS]

HYBRID MOTOR TEST FIRING PROCEDURES

Table of Contents

1 PROCEDURE REVIEW SHEET

Topic:

Meeting Facilitator:

Summary:

Attendees:

Name	Signature	Name	Signature

Signed:_____Date_____

(Name of SSO or deputy)

Signed:_____Date_____

(Advisor)

2 TEST AUTHORIZATION SHEET

Name of Test			
Date		Procedure Class:	I II III
Location			
Description of Test			
Summary of Test Results			
Student Safety Officer Present		Test Conductor	
Test Participants	Name	Signature	

Advisor Signature:_____Date:_____

Student Safety Officer or Deputy:_____Date:_____

EHS Signature:_____Date:_____

Test Conductor Signature:_____ Date:_____

Procedure for Hybrid Motor Test Firing

Purpose: This procedure enables the safe static test firing of hybrid rocket motors.

Description: The process for inspecting components, setting up test systems, pre-fire checks, test firing and post-firing inspection are all included in this document. This procedure contains a safe progression of steps for completing the aforementioned tasks and as such should be followed astutely to ensure nominal testing results. **Only the advisor can approve any "redline" changes to the test procedure.**

3 ROLES AND RESPONSIBILITIES

Role	Responsibilities	Name(s)
Test Conductor/Test Lead (TC)	Conducts the specified test.	
	Assures that all steps of the procedure are followed correctly and completely.	
	Reviews the test procedure with all the participants.	
	Maintains position of command and control during the procedure.	
Safety Officer(SO)	Assures that safety procedures are properly and fully implemented.	
	Assures all nonessential personnel are clear of test area.	
Fire and Sensor Control (FSC)	Operates the ignition circuit, actuated disconnects, and firing valves.	
	Shuts off the ignition circuit and firing valves in the event of an abort.	
	Manages sensors and data acquisition program(s).	
	Controls filling and venting operations.	
Range Safety (multiple)	In radio communication with Test Conductor.	
	Prevents bystanders from approaching the test area.	

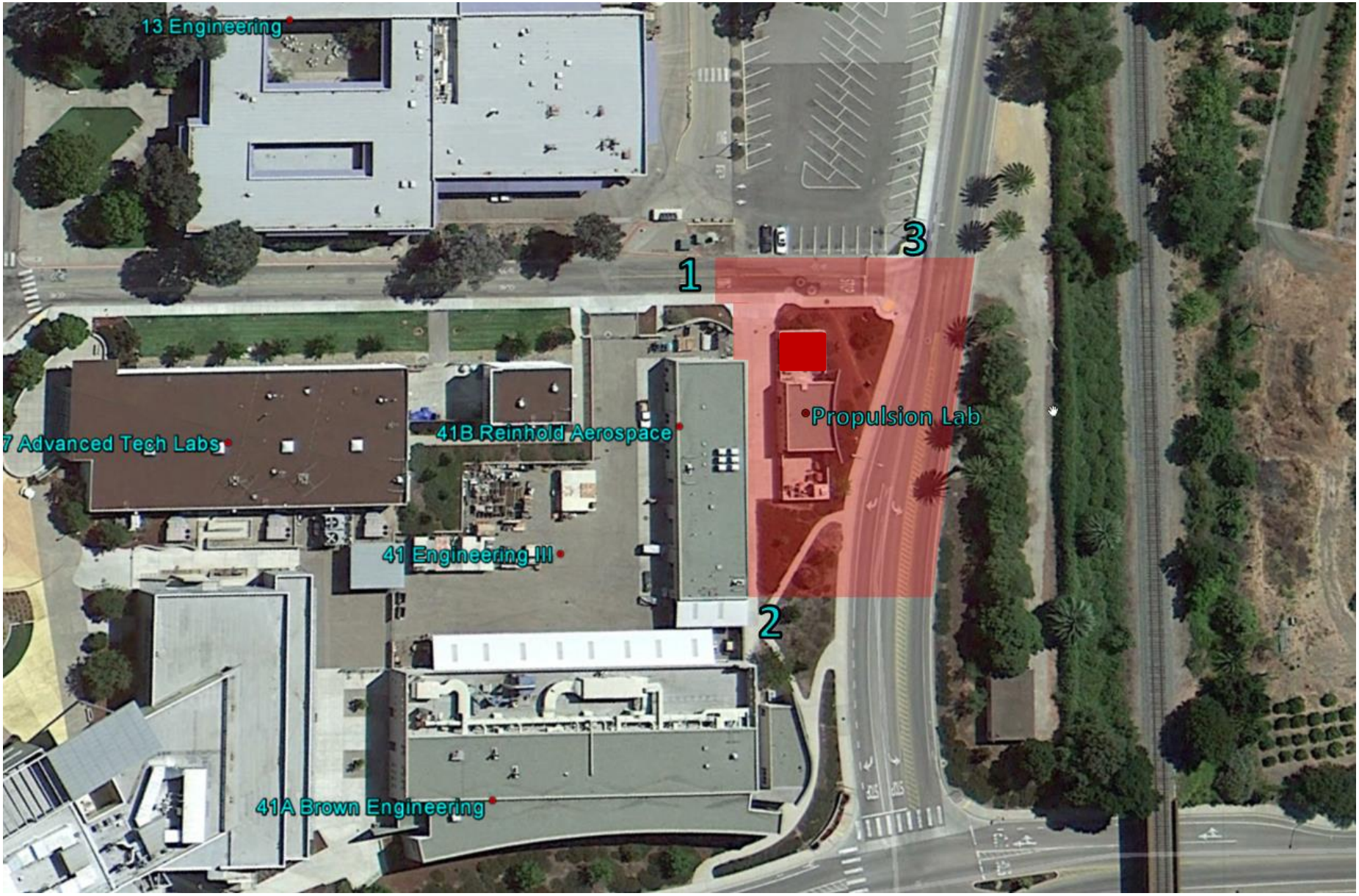

Figure 1: Map of Area Around Propulsion Lab
The red area indicates the region where bystanders are not allowed during fill and fire procedures. The numbers signify where range safety is posted. The dark red area is the downrange, restricted area of the propulsion lab, which is the south yard.

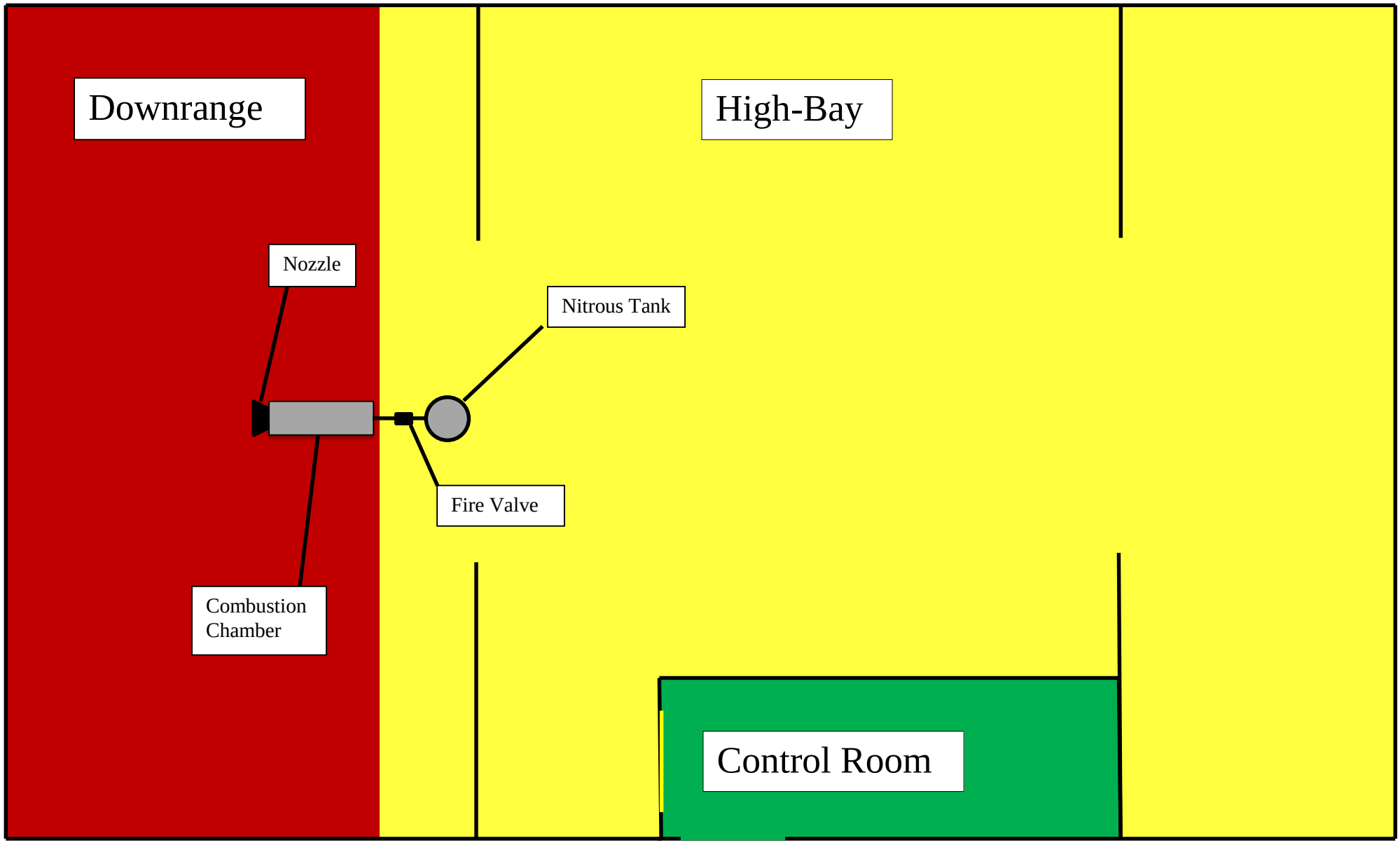

Figure 2: Diagram of Restricted, Controlled, and Safe Areas of the Propulsion Lab. The restricted area is in the south yard

4 SAFETY CALLOUTS AND PPE

4.1 Initial Safety Callouts (To be read out loud before beginning the procedure)

1. Unless otherwise specified in Off-Nominal Procedures, no-one may enter the Controlled or Restricted areas of the test cell during the Fill and Fire procedures (6.3 and 6.4, respectively). No one may enter the Restricted Area of the test cell during the Procedure Activities (6) and the Post Fire-Procedure Activities (7).
2. Everyone present is encouraged to have a questioning attitude, and should be on the lookout for potential hazards. Everyone present has the responsibility to call an all-stop in the event that he or she perceives something as unsafe.
3. The controlled area in the prop lab can only be entered when the system does not have nitrous oxide under pressure and when no liquids or gasses are flowing in the system. The controlled area at the trailer can only be approached when no liquids or gasses are flowing in the system. At no point during Fill Procedure (6.3) and Fire Procedure (6.4) will anyone enter the Restricted area of the test cell. Authorized personnel can only enter the Controlled area when specifically allowed in the Off-Nominal Procedures (8), or with the permission of the Advisor in special circumstances.
4. The Nitrogen bottle on the trailer will be referred to as the N_2 Bottle. The nitrous oxide bottle on the trailer will be referred to as the N_2O bottle. The nitrous oxide tank at the test stand will be referred to as the nitrous tank.
5. Range Safety will call "hold, hold, hold" if anyone enters the test range during sections 6.3 (Fill Procedure) and 6.4 (Fire Procedure).
6. Any participant may call "hold, hold, hold" if an anomaly is noticed or the situation becomes unsafe.

4.2 PERSONAL PROTECTIVE EQUIPMENT

1. All participants are required to wear ear plugs or ear muffs during section 6.4 (Fire Procedure).
2. All participants must wear long pants and close toed shoes.
3. All participants must wear safety glasses during this procedure when working on or around equipment.
4. The test lead must wear a face shield when in close proximity to the launch trailer or test stand. The launch trailer can be approached by only the test lead as specified in sections 6 and 7.
5. Designated participants must wear nitrile gloves and a face shield when handling the pre-heater.

5 PRE-PROCEDURE ACTIVITIES

Test Stand is located inside the prop lab walls and is connected to the trailer via long hoses and wires. The trailer is located outside the prop lab. The test stand contains the motor, fire valve and nitrous tank. The trailer contains the test computer, N_2O bottle and N_2 bottle. The task list associated with this test must be completed prior to beginning this section.

5.1 TRAILER PREPARATION

5.1.1 Power Connections

_____1. Verify 12-Volt Trailer Battery is charged and connected
_____1. Connect Trailer Computer to power
_____2. Connect the Launch Box and Trailer Computer

5.1.2 Sensor Connection

_____1. Verify Sensors are connected to the Black Box on the trailer

5.1.3 LabVIEW Initialization

_____2. Verify the Trailer Computer is on and LabVIEW is running
_____3. Verify the Trailer Computer is connected to the Data Acquisition System
_____4. Verify all relevant instruments connected and data is shown is LabVIEW

5.1.4 Compressed Air Connection

_____1. Attach Trailer to compressed air supply of 80 psi or higher

5.2 MOTOR PREPARATION

This step must be completed in a well ventilated area (in the high bay) on a surface that is fire resistant. Motor assembly must be performed with nitrile gloves, safety glasses, and a face shield. ***If the preheater ignites during the following steps, vacate the area and allow 5 minutes for the smoke to dissipate.***

5.2.1 Pre-heater Preparation

_____1. Motor assembler must ground the propellant container and themselves.
_____2. Remove a propellant grain from the propellant container and record its linear density (mass/length).
_____3. Cut the propellant grain so it has a mass of 12g ± 1g. **Actual mass**: _____
_____4. Peel away the liner of the cut section
_____5. Remove the e-match from the propellant container and extend the leads if necessary. Leads must be about 22 inches long.
_____6. Using electrical tape, attach the e-match to the inner surface of the propellant grain.

5.2.2 Motor Assembly

_____1. Place the pre-heater grain at the forward end of the fuel grain, and use a small amount of 5-minute epoxy to affix the pre-heater to the fuel grain
_____2. Once cured, slide the grain into the combustion chamber casing.
_____3. Verify nozzle O-ring is in place and insert the nozzle so the pressure port lines up with the port in the combustion chamber casing wall.
_____4. Thread aft chamber cap onto the motor and tighten so the port in the cap lines up with the port in the chamber wall.
_____5. Thread forward chamber cap onto the motor and tighten.
_____6. Thread the pressure transducer line into the nozzle and tighten. Teflon/PTFE tape should be used on threads.
_____7. Attach motor the fire valve assembly and tighten threads.
_____8. Affix motor to the test stand bearing plates using four U-bolts.
_____9. Attach pressure transducer to the nozzle.
_____10. Verify igniter leads are not connected to the Lunch Box. Touch leads together and connect to the motor.

Motor is now assembled. Once clear of the motor, assembler can remove face shield.

6 PROCEDURE ACTIVIES

This is the beginning of the test fire procedure activities. Essential personnel are those with assigned positions in the procedure and may enter the test cell when instructed during the procedures. All non-essential personnel must remain in the control room or designated safe area. Once the Test Conductor closes the control room door, permission from the test conductor is needed to use the doors.

6.1 PRE-IGNITION CHECKLIST

_____1. Turn cameras(s) to Wi-Fi mode and connect to wireless device. Web-cam cameras should be verified operating at this time. Begin livestream now if applicable.

The following verifications will be made visually by the test lead

_____2. Verify N_2O Fill valve actuation
_____3. Verify N_2 to N_2O valve actuation
_____4. Verify N_2 Fill valve actuation
_____5. Verify Dump valve actuation
_____6. Verify Vent solenoid activation
_____7. Verify N_2O quick disconnect operation
_____8. Verify disconnects do not physically interfere with pressure transducers when disconnecting
_____9. Verify Fire valve actuation

6.2 PRE-NITROGEN PURGE

The following verifications will be made visually by the test lead

_____1. Verify N_2 Fill is CLOSED
_____2. Verify N_2 regulator is set to MINIMUM
_____3. Verify N_2 to N_2O valve is CLOSED
_____4. Verify N_2O fill is CLOSED
_____5. Verify Dump valve is CLOSED
_____6. Verify N_2O Bypass is OPEN
_____7. Connect regulator to N_2 bottle
_____8. Open N_2 tank valve and adjust N_2 tank regulator to 100psi
_____9. Open N_2 to N_2O valve
_____10. Open N_2O Fill valve until pressure stabilizes
_____11. Open Vent Solenoid for 10 seconds and close
_____12. Close N_2O Fill valve
_____13. Open N_2 Fill Valve until pressure stabilizes
_____14. Open Vent Solenoid for 10 seconds and close
_____15. Close N_2 Fill Valve
_____16. Close N_2 to N_2O valve
_____17. Set N_2 regulator to 800 psi
_____18. Open N_2O Fill Valve
_____19. Open Dump valve until N_2O line and Oxidizer Tank are depressurized
_____20. Close N_2O Fill Valve
_____21. Close Dump Valve

6.3 FILL PROCEDURE

_____1. Visually Verify N_2O Fill valve is closed
_____2. Connect N_2O fill line to N_2O tank
_____3. Assign Range Safety personnel to positions specified
_____4. Test is now live. Only Authorized personnel are allowed within Controlled areas as specified by the procedure.
_____5. Open N_2O Tank valve
_____6. Hold tank weight in LabVIEW
_____7. Begin recording with GO-PRO(s) or range cameras
_____8. Open N_2O Fill valve
_____9. Open Vent valve periodically to maintain pressure by venting system when pressure is above equilibrium pressure for the current temperature. (Refer to nitrous data sheet in Appendix A)
_____10. Close Fill valve when the tank weight readout shows the desired weight. Note: 0.2lb of N_2O is in the Fill line which will be disconnected.
_____11. Disconnect Fill assembly
_____12. Open N_2 Fill valve

6.4 Fire Procedure:

This section will be read aloud before proceeding to ensure everyone present understands what will occur.

_____1. Attach igniter leads
   i. Touch both igniter leads to ground before connecting
_____2. Verify range safety is in position
_____3. Begin LabVIEW data recording
_____4. Put on Ear Protection
_____5. Test Conductor begins ten second countdown over the radio.
   i. Keep radio clear at T- 5 seconds so that range safety can notify the Test Conductor in the event of an anomaly.
_____6. Ignite preheater grain
_____7. Confirm through GO-PRO image or test webcam that preheater grain has lit and wait 8 seconds. If pre-heater grain does not light, enter Off-Nominal Procedure 8.1
_____8. Open Fire valve (This starts the flow of nitrous into the combustion chamber and will be very loud). If Fire valve does not open, enter Off-Nominal Procedure 8.2
_____9. Wait for confirmation that the nitrous is depleted. (The thrust load cell should read near zero and the noise level should drop significantly from the peak. The sound of nitrogen gas flowing may still be audible)
_____10. Close N_2 Fill valve
_____11. Wait 10 seconds
_____12. Close Fire valve

6.5 System Safing

Lines are depressurized when the flow of gas from the dump valve is no longer audible. Ear protection may be removed at this time.

_____1. Open N_2O Dump Valve until N_2O line is depressurized
_____2. Close N_2O Dump Valve
_____3. Close N_2O Tank Valve
_____4. Close N_2 Tank Valve
_____5. Open N_2O Dump Valve
_____6. Open N_2O Fill Valve
_____7. Open N_2O to N_2 Valve and wait until lines are depressurized
_____8. Close N_2O to N_2 Valve
_____9. Close N_2O Fill Valve
_____10. Close N_2O Dump Valve

The Test Conductor may enter the Controlled area as specified in the procedure. ***Absolutely no one else may enter the Restricted or Controlled areas of the test cell.***

7 POST FIRE-PROCEDURE ACTIVITIES

7.1 Post-Fire N2 Purge

_____1. Verify N_2 Fill is CLOSED
_____2. Set N_2 Regulator to MINIMUM
_____3. Verify N_2 to N_2O valve is CLOSED
_____4. Verify N_2O fill is CLOSED
_____5. Verify Dump valve is CLOSED
_____6. Verify N_2O Bypass is OPEN
_____7. Open tank valve and adjust regulator to 100psi
_____8. Open N_2O to N_2 valve
_____9. Close N_2O to N_2 valve
_____10. Open Dump valve until system depressurizes
_____11. Close Dump valve
_____12. Open N_2 Fill Valve until pressure stabilizes
_____13. Open Vent Solenoid for 10 seconds and close
_____14. Manually close N_2 tank valve
_____15. Open Vent Solenoid until Oxidizer Tank is depressurized
_____16. Close N_2 Fill valve
_____17. Range Safety may be recalled to the Control Room
_____18. Announce "ALL CLEAR"

All areas of the Propulsions Lab are now safe to enter. Required PPE must be worn until procedures have concluded and all systems have been disassembled and stored.

8 OFF-NOMINAL CONDITIONS PROCEDURES

The Controlled area can only be entered when the system does not have nitrous oxide under pressure and when no liquids or gasses are flowing in the system. At no point between 6.3 Fill Procedure and 6.4 Fire Procedure may anyone enter the Restricted area of the test cell.

8.1 Failure to Ignite

Failure to ignite means that the pre-heater grain did not ignite.

_____1. Ensure firing circuit is armed and proceed back to 6.4.1. If the second attempt fails, continue below.
_____2. Disable fire valve circuit
_____3. Check continuity on igniter from relay and work through system to igniter
_____4. If continuity check finds no faults, disconnect ignition leads and ensure correct functioning of fire circuitry. If there is a fault, attempt to repair the fault if personnel only need to enter allowable areas to fix the fault. If the fault cannot be fixed, proceed with the following until the range is considered safe.
_____5. If no problems are detected, the igniter is assumed defective, and a new igniter must be placed in motor
_____6. Notify Range Safety that the nitrous tank will be vented
_____7. Ensure Fill Valve circuit is not armed.
_____8. Open Dump Valve until N_2O line is depressurized
_____9. With everyone but Range Safety in the Control Room, activate the vent valve until tank pressure is zero and wait five minutes (so the nitrous can dissipate)

The Test Conductor may now enter the Controlled Area, but may not enter the Restricted area

_____10. The Test Conductor will grab the e-match wire with a grabber, and pull it out through the nozzle
_____11. The Test Conductor and the Advisor will then inspect the e-match to see if it fired
_____12. If the e-match did not fire, the range is considered safe, and the combustion chamber may be disassembled
_____13. If the e-match did fire, the pre-heater grain is considered dangerous, (it was given enough energy to potentially fire, but did not, so it must be made safe to handle)
_____14. The Test Conductor, while standing in the Controlled Area, will point a hose, which will be held by a pole, into the nozzle mouth
_____15. Turn on the hose, and rinse for two minutes, to ensure that the pre-heater grain is at a low enough temperature to be considered safe to handle
_____16. Turn off the hose
_____17. The range is now considered safe, and the combustion chamber may be disassembled

8.2 N_2O Fire Valve Failure After Ignition Grain Activation

_____1. Disable fire valve circuit
_____2. Check wiring in the test cell control room.
_____3. Ensure sufficient air pressure to fire valve actuator
_____4. Reattempt opening of fire valve. If valve does not open, the test is aborted and the following items will safe the system.
_____5. Notify Range Safety that the nitrous tank will be vented
_____6. Open Vent solenoid to depressurize oxidizer tank and wait 5 minutes (so the nitrous can dissipate)
_____7. Proceed to 7.1 (Post Fire N2 Purge)
_____8. Troubleshoot fire valve as necessary

8.3 Significant N_2O Leak

_____1. Depressurize leaking line/vessel using appropriate vent.
_____2. Proceed to 6.5 (System Safing) to safe system. Continue with section 7.1. Once completed return to the following.
_____3. Disassemble leaking connection and inspect for cause of leak
_____4. Reassemble connection, ensure to torque to appropriate specification

8.4 Catastrophic Failure

_____1. Immediately shut any open valves in the N_2O systems starting with the remotely actuated valves.
_____2. Check for visible fire. (The GO PRO and test webcam should still be running) If there is a fire or anyone is injured call 911. Evacuate the control room if safe and necessary to do so.
_____3. Seek guidance from Advisor and/or other R.P.

9 TROUBLESHOOTING

In the event that an off-nominal condition occurs that prevents continuation of the procedures but is not covered in Section 8, the following troubleshooting procedures shall be followed.

_____1. De-energize any electrical control circuits via safety switches
_____2. Identify sources of off-nominal condition
_____3. Disconnect connectors to ignition charge if connected
_____4. Depressurize Oxidizer tank if personnel need to enter the controlled area
_____5. If the problem is electrical, check electrical connects with a multimeter
_____6. When problem is resolved the procedures may be restarted with an O.K. from the advisor.

10 APPROVAL

Date: **Advisor:** Dr. Ian Johnson

Date: 2/18/16 **Additional Signoff:** Tom Featherstone

11 APPENDIX A: NITROUS PROPERTIES

Thermophysical properties of nitrous oxide on the saturation line for temperature in degree Celsius

t °C	p kPa	ρ(l) kg/m^3	ρ(g) kg/m^3	h(l) kJ/kg	h(g) kJ/kg	$\Delta_{vap}h$ kJ/kg
-90.82	(87.73)	1222.8	(2.613)	(-474.)	(-96.8)	(377.)
-90	(92.29)	1220.6	(2.738)	(-473.)	(-96.3)	(377.)
-88.46	101.325	1216.3	(2.987)	(-470.)	(-95.4)	375.
-85	124.2	(1206.7)	(3.609)	(-464.)	(-93.3)	371.
-80	164.2	(1192.7)	(4.680)	(-455.)	(-90.4)	365.
-75	213.6	(1178.3)	(5.982)	(-446.)	(-87.6)	359.
-70	273.6	(1163.7)	(7.546)	(-438.)	(-85.0)	353.
-65	345.7	(1148.8)	(9.406)	(-429.)	(-82.5)	346.
-60	431.5	(1133.6)	(11.60)	(-420.)	(-80.2)	340.
-55	532.3	(1118.0)	(14.16)	(-411.)	(-78.1)	333.
-50	649.9	(1102.0)	(17.14)	(-402.)	(-76.1)	326.
-45	785.8	(1085.6)	(20.58)	(-392.)	(-74.4)	318.
-40	941.7	(1068.8)	(24.53)	(-383.)	(-72.9)	310.
-35	1119.	(1051.4)	(29.05)	(-374.)	(-71.6)	302.
-30	1321.	1033.4	34.22	(-364.)	(-70.5)	294.
-25	1547.	1014.8	40.11	(-355.)	(-69.8)	285.
-20	1801.	995.4	46.82	(-345.)	(-69.3)	276.
-15	2083.	975.2	54.47	(-335.)	(-69.2)	266.
-10	2397.	953.9	63.21	(-325.)	(-69.5)	255.
-5	2744.	931.4	73.26	(-315.)	(-70.3)	244.
0	3127.	907.4	84.86	(-304.)	(-71.7)	232.
5	3547.	881.6	98.41	(-293.)	(-73.7)	219.
10	4007.	853.5	114.5	(-281.)	(-76.6)	204.
15	4510.	822.2	133.9	(-269.)	(-80.6)	188.
20	5060.	786.6	158.1	(-255.)	(-86.2)	169.
25	5660.	743.9	190.0	(-241.)	(-94.4)	147.
30	6315.	688.0	236.7	(-224.)	(-108.)	117.
35	7033.	589.4	330.4	(-203.)	(-138.)	64.9
36.42	7251.	452.	452.	(-200.)	(-200.)	0

12 APPENDIX B: TRAILER VALVE SCHEMATIC