COLUMBIA
SPACE INITIATIVE

STANDARD OPERATING TESTING PROCEDURES

Version 1.1

2022-2023 Operating Team

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Contents

1 Description

All testing procedures will follow all aspects of the National Association of Rocketry High Power Rocket Safety Code.[1] The requirements of this Safety Plan will be reviewed with all team members and enforced throughout the event.

2 Hazard Assessment

Hazards associated with this project are a result of the static fire. However, appropriate measures will be taken to ensure that all personnel are kept safe. During static fire, all observers will be kept at a minimum of 100 feet from the launch site, as per the NAR's safety standards. All applicable NAR safety regulations will be enforced.

3 Static Fire Hazard Checklist

Priority (1-4, with 1 highest)	Item	Rationale
1	Gas regulator for Nitrous Oxide tank	• Helps better control flow of gas from full sized cylinder. • Allows for better regulation & measurement of pressure released for process. • Regulator should operate at 75% of maximum rated pressure, so sizing needs account for this
1	Gas cylinder stand	• RARAF may need their cart on the same day so buying your own would be great • If you fabricate your own , make sure it is study
1	Compressed Gas Rascal course	• TC5450 • Any member who works with compressed gases should take this course
2	More Safety glasses	• Minimum ANSI Z87.1 approved • Everyone working on the rig should have a pair ☺
2	Caution tape	• To wrap around test area so no wandering humans get to close in test scenario
2	Standard Operating Procedure draft	• Continue working on SOP • Aim to have a finalized "trial" version by competition date
2	"Spill kit"	• Materials to clean up a small spill of any fuel pellets/working materials in the field or transport
3	Step ladder	• More study than a chair
3	More fire barrier tiles	• More surface area covered under and around rig
4	Flag/Physical Sign Communication System	• "What if phones don't work and walkie talkies aren't charged" • Flag could double to figure out wind direction (so nobody is standing downstream)
4+	Fire pit	• Especially if more vertical firing in the future • Would have to work with Nevis facilities

[1] http://www.nar.org/safety-information/high-power-rocket-safety-code/

Hazard	*Mitigation/Safety Measure(s)*
Fuel	Motors used in this rocket will all be commercially available motors. Motors will not be tampered with and in most cases be purchased on sight. Transportation of motors will require the use of a metal storage box.
Fire	No launches will occur in extremely dry conditions. A charged fire extinguisher and first aid kit will be onsite and readily accessible. All personnel will be advised of procedures in case of a a spread of fire before any testing is done. ALL incidents and injuries (regardless of severity) will be reported to EHS.
Ignition of the rocket	We will be utilizing a launch control box, which will allow us to remotely ignite the motors from a safe operating distance. This launch method has been tested and proven several times prior launch events.
Rocket goes in wrong direction	The rocket will be launched from a pad provided by xxxx. This launch pad will make use of a rail and bead system to ensure that the rocket will travel in the correct direction, and cannot launch towards a crowd of observers.
During descent of the rocket	During launch and recovery, everyone must maintain a safe distance from the rocket. At apogee, one drogue parachute will deploy. At 500 feet, we deploy a main parachute to ensure a low descent rate when the rocket lands.
Weather Conditions	Weather must be suitable for launch. No launches will occur when clouds or other obscuring phenomena of more than five tenths coverage prevails, where horizontal visibility would be less than five miles during launch. No operation of rockets will occur in clouds. Launch will be cancelled if there are strong winds outside of safe NAR guidelines.
Contact FAA	The nearest FAA ATC facility will be contacted 24 hours prior to launch and they will be provided with the following information: The name and address of the operator; except when there are multiple participants at a single event, the name and address of the person so designated as the event launch coordinator, whose duties include coordination of the required launch data estimates and coordinating the launch event; Date and time the activity will being; Radius of the affected area on the ground in nautical miles; Location of the center of the affected area in latitude and longitude coordinates; Highest affective altitude; and Duration of the activity.

Hazard	*Mitigation/Safety Measure(s)*
Nitrous oxide	The oxidizer tank should be unpressurized prior to any maintenance.
Propulsive fastener disconnect	All propulsive fasteners should be properly swaged to standard and inspected prior to filling procedures.
Pressurized vessels	There should be no pressurized vessels within 25 ft of the test stand assembly. All valves on the rocket should be checked prior to full setup and ensure that they are reading zero pressure.
Fire	No static fires will occur under extremely dry conditions. A charged fire extinguisher and first aid kit will be onsite and readily accessible. Around the test stand, the ground will be watered with a hose and flame diverters should be placed underneath the engine to minimize burning the ground. ALL incidents and injuries (regardless of severity) will be reported to EHS.
Ignition of the rocket	We will be utilizing a launch control box, which will allow us to remotely ignite the motor from a safe operating distance. This launch method has been tested and proven in several prior static fire events.
Inadvertent rocket motor or pyrotechnic initiation	User education of standard operation procedures is absolutely necessary. A two-person verification system is in place to confirm any and all operation commands for the static fire event. All equipment prior to this event shall be disarmed and battery for ground electronics should remain completely disconnected.
Structural test stand issues	All structural fasteners on the test stand should be fastened to 35 lbf. The helicoidal mounts should also be fully screwed into the ground for their entire length to ensure that the test stand does not move during fire.
Weather Conditions	Weather must be suitable for static fires. No static fires will occur if there is any ongoing precipitation past 1pm.

4 Testing Protocol

Preparation and Testing Protocol: Upon obtaining appropriate approvals to perform testing and using a designated test site, the following procedure will be followed to ensure the safety measures referenced in the Risk Assessment are in place.

- Verify all required approvals are obtained.
  - Risk Management
  - Security
  - EHS
- Communicate to the EHS scheduled test dates and times to allow the option for oversight.
- When required, ensure appropriate supervision is available and onsite during testing procedures.
- When applicable, ensure nearby building occupants are informed of the event.
- Ensure all team members are aware of their roles and responsibilities (including emergency response procedures).
- Ensure the test area is cordoned off, free of personnel, and is clear of obstructions.
- Inspect all testing equipment and safety devices for defects and functionality.
- Ensure all mitigation/safety measures referenced in the Risk Assessment are in place and functioning.
- Ensure all participants know and understand this assessment and its requirements.
- When applicable, conduct a final check to ensure all personnel are clear of the defined test area.

5 STANDARD OPERATING TESTING PROCEDURES

The following document defines the Standard Operating Testing Procedures for the Columbia Rocketry Team.

6 COLD FLOW

6.1 Phase 1: Test Stand Mount

Following Standard Mounting Procedure of Static Test Stand, the Team will make sure that the safety requirements are met:

1. All GSE fasteners must be fastened to rated torque
2. Helicoidal Mounts grounded for the entirety of the length
3. No Fire Hazards nor Pressurized vessels are involved in the phase

6.2 Phase 2: Propulsion Mount on Test Stand

Following Standard Mounting Procedure of Propulsion, the Team will make sure that the safety requirements are met:

1. Oxidizer Tank Unpressurized
2. Fuel unloaded in Combustion Chamber
3. All Propulsive fasteners swaged to standard
4. All Structural Fasteners fastened to 35 lbf
5. No fire sources nor pressurized vessels within 25 ft of the assembly
6. All valves checked in no-pressure load in this phase

6.3 Phase 3: Propulsion and Electronics Mate

Following Standard Mounting Procedure of Electronics, the Team will make sure that the safety requirements are met:

1. All electrical apparatus tested on site before Phase 2 initiates
2. Electronics disconnected from power supply
3. Double redundancy in mechanical connections is met
4. All electrical connectors fastened positively

6.4 Phase 4: Filling Tank Connect

Following Standard Operating Procedure for Filling Tank, the Team will make sure that the safety requirements are met:

1. Only one trained member will perform the action of bolting the filling tank to the filling pipe. The member handling the filling tank should wear cryogenic gloves and a face shield.
2. If the tank does not have a dipstick/educt tube the tank will be laid on its side/flipped to ensure liquid availability.
3. All other Members at least 25ft away
4. Leaks will be checked using soap solution.

6.5 Phase 5: Filling Sequence Device Arming

Following Standard Filling Procedure the Team will make sure that the safety requirements are met:

1. Control Station at least 100ft from the Propulsion Apparatus
2. All members will stand at least 100ft from the Propulsion Apparatus
3. The Filling will require both team leads approval.
4. If any member opposes the filling, the operation will be aborted until the problem gets resolved
5. At approval, the mechanical power switch will be turned to ON and the interface filling button will be pressed. A yellow light will light up next to the firing station. Filling Procedure:

(a) Calibrate all pressure transducers

(b) Both vent and fill solenoids open (fill command on firing station)

(c) Using monocular, team member watches tank for frost line progression

(d) When frost line reaches desired fill point or liquid nitrous starts emerging from vent, the team will close the fill solenoid, wait 1.5s, then close the vent solenoid (stopfill command). If a thermocouple is available, the temperature reading at the top of the oxidizer tank will serve as a reference for stopping the fill sequence (the temperature will drop suddenly when the fill line reaches the top of the tank)

(e) The team will then use the pressure measured at the vent to determine the temperature of the tank via the vapor pressure of the nitrous oxide – when the pressure reaches 750 psi, the fire sequence can commence

(f) If at any point the pressure in the oxidizer tank exceeds 900 psi, the vent valve will automatically open to depressurize until the pressure is below 750 psi. This is the keep command, and our default state while waiting for firing.

6.6 Phase 6: Fire Device Arming

Arming procedure defined according to the Spaceport America Cup Design, Test, and Evaluation Guidelines: opening communication between control interface and propulsion apparatus. Following Standard Arming Procedure the Team will make sure that the safety requirements are met:

1. Control Station at least 100ft from the Propulsion Apparatus
2. All members will stand at least 100ft from the Propulsion Apparatus
3. The Arming will require both team leads' approval.
4. If any member opposes the arming, the arming operation will be aborted until the problem gets resolved.
5. At approval, the mechanical power switch will be turned to ON and the interface arming button will be pressed. A red light will light up next to the firing station.

6.7 Phase 7: Cold Flow

As the Propulsion Apparatus is Armed, the engine can be fired. The set of rules to be enforced:

1. Fire Extinguishers at Control Station
2. All members will stand at least 100ft from the Propulsion Apparatus
3. Arming will require both team leads approval.
4. If any member opposes the firing, the arming operation will be aborted until the problem gets resolved.
5. At approval, the mechanical power switch will be turned to ON and the interface arming button will be pressed.
6. Abort Button is armed and will depressurize the oxidizer tank if any fault is detected.
7. In case of detected overpressurization, abort will be automatically triggered.

6.8 Phase 8: Disarmament

After the engine is fired and the flame extinguishes, the engine will be disarmed. The following safety procedures will be met:

1. Oxidizer tank will be vented open redundantly (abort command)
2. A minimum of 5 minutes will pass before the team will approach the engine
3. The team will carry the Fire Extinguisher while approaching the rocket.
4. One member of the team will shut the main cylinder valve in the filling tank
5. Oxidizer tank will be vented open redundantly will fill valve open to clear the tubing (fill command)
6. If any member of the team feels uncomfortable, they are entitled to halting the approach until the problem is resolved.
7. Electronics will be disarmed and Power shut off.

7 STATIC FIRE

7.1 Phase 1: Test Stand Mount

Following Standard Mounting Procedure of Static Test Stand, the Team will make sure that the safety requirements are met:

1. All GSE fasteners must be fastened to rated torque.
2. Helicoidal Mounts grounded for the entirety of the length.
3. No Fire Hazards nor Pressurized vessels are involved in the phase

7.2 Phase 2: Propulsion Mount on Test Stand

Following Standard Mounting Procedure of Propulsion, the Team will make sure that the safety requirements are met:

1. Oxidizer Tank Unpressurized
2. Fuel loaded in Combustion Chamber
3. All Propulsive fasteners swaged to standard
4. All Structural Fasteners fastened to 35 lbf
5. No fire sources nor pressurized vessels within 25 ft of the assembly
6. All valves checked in no-pressure load in this phase
7. The only fire hazard associated with this method is the paraffin wax in the combustion chamber which does not ignite at atmospheric pressure and therefore is totally safe to handle.

7.3 Phase 3: Propulsion and Electronics Mate

Following Standard Mounting Procedure of Electronics, the Team will make sure that the safety requirements are met. All electrical apparatus tested on site before Phase 2 initiates:

1. Relays will be checked for the full fill sequence

2. Electronics disconnected from power supply
3. Double redundancy in mechanical connections is met
4. All electrical connectors fastened positively

7.4 Phase 4: Filling Tank Connect

Following Standard Operating Procedure for Filling Tank, the Team will make sure that the safety requirements are met:

1. Only one trained member will perform the action of bolting the filling tank to the filling pipe. The member handling the filling tank should wear cryogenic gloves and a face shield.
2. If the tank does not have a dipstick/educt tube the tank will be laid on its side/flipped to ensure liquid availability All other Members at least 25ft away
3. Leaks will be checked using soap solution

7.5 Intermediary Phase: Fire Deflection

The following measures are in effect to contain any fire within the test stand confinement.

1. Place flame deflectors in the flame trench area of the test stand
2. Deflector plates are to be placed lengthwise at 45 degrees with respect to the ground.
3. L-Brackets are used to hold down the deflector plates to prevent any displacement during static fire
4. Fire brick is placed under the seams of the deflector plate and is used to offset the plates off the ground plane.

7.6 Phase 5: Filling Sequence Device Arming

Following Standard Filling Procedure the Team will make sure that the safety requirements are met:

1. Control Station at least 100ft from the Propulsion Apparatus
2. All members will stand at least 100ft from the Propulsion Apparatus
3. The Filling will require both team leads approval.
4. If any member opposes the filling, the operation will be aborted until the problem gets resolved.
5. At approval, the mechanical power switch will be turned to ON and the interface filling button will be pressed. A yellow light will light up next to the firing station.
6. Filling Procedure:
    (a) Calibrate all pressure transducers
    (b) Both vent and fill solenoids open (fill command on firing station)
    (c) Using monocular, team member watches tank for frost line progression
    (d) When frost line reaches desired fill point or liquid nitrous starts emerging from vent, the team will close the fill solenoid, wait 1.5s, then close the vent solenoid (stopfill command). If a thermocouple is available, the temperature reading at the top of the oxidizer tank will serve as a reference for stopping the fill sequence (the temperature will drop suddenly when the fill line reaches the top of the tank)
    (e) The team will then use the pressure measured at the vent to determine the temperature of the tank via the vapor pressure of the nitrous oxide – when the pressure reaches 750 psi, the fire sequence can commence
    (f) If at any point the pressure in the oxidizer tank exceeds 900 psi, the vent valve will automatically open to depressurize until the pressure is below 750 psi. This is the keep command, and our default state while waiting for firing.

7.7 Phase 6: Fire Device Arming

Arming procedure defined according to the Spaceport America Cup Design, Test, and Evaluation Guidelines: opening communication between control interface and propulsion apparatus. Following Standard Arming Procedure the Team will make sure that the safety requirements are met:

1. Control Station at least 100ft from the Propulsion Apparatus
2. All members will stand at least 100ft from the Propulsion Apparatus
3. The Arming will require both team leads approval.
4. If any member opposes the arming, the arming operation will be aborted until the problem gets resolved.
5. At approval, the mechanical power switch will be turned to ON and the interface arming button will be pressed. A red light will light up next to the firing station.

7.8 Phase 7: Static Fire

As the Propulsion Apparatus is Armed, the engine can be fired. The set of rules to be enforced:

1. Fire Extinguishers at Control Station
2. All members will stand at least 100ft from the Propulsion Apparatus Arming will require both team leads approval.
3. If any member opposes the firing, the arming operation will be aborted until the problem gets resolved.
4. At approval, the mechanical power switch will be turned to ON and the interface arming button will be pressed.
5. Abort Button is armed and will depressurize the oxidizer tank if any fault is detected.
6. In case of detected overpressurization, abort will be automatically triggered.

7. Firing Procedure (fire command):
    (a) The pyrocutter fires, severing the nitrous fill line (0.5s delay)
    (b) The igniter fires, lighting the solid rocket motor and fuel grain (2.5s delay)
    (c) The pyrovalve fires, beginning oxidizer flow into the combustion chamber

7.9 Phase 8: Disarmament

After the engine is fired and the flame extinguishes, the engine will be disarmed. The following safety procedures will be met:

1. Oxidizer tank will be vented open redundantly
2. A minimum of 5 minutes will pass before the team will approach the engine
3. The team will carry the Fire Extinguisher while approaching the rocket.
4. One member of the team will shut the main cylinder valve in the filling tank
5. Oxidizer tank will be vented open redundantly will fill valve open to clear the tubing
6. If any member of the team feels uncomfortable, they are entitled to halting the approach until the problem is resolved.
7. Electronics will be disarmed and Power shut off.

8 DISCLAIMER ABOUT WEATHER

Conditions during the static fire and cold flow testing should be sunny or cloudy. In case of any snow, rain, or thunderstorm conditions at any point during the test fire, the test fire will be immediately paused until weather conditions clear up, or rescheduled to a later date.

9 Safety Protocols

9.1 In Case of Sustained Fire

Fires are an immediate danger if certain measures are not taken immediately after a static fire event. The hazards presented by grass fires caused by the ignition of combustibles after static fire can be mitigated by having adequate fire suppression equipment on the range, training range personnel in its use, and having an emergency plan for suppression of fire by the Section which includes a contact plan for professional assistance should that be required. The following is the Columbia Space Initiative protocol in case of sustained fire or a spread of fire.

9.1.1 Fire Extinguishing

There will be a minimum of two fire extinguishers at all times, ready to be used during static fires. These are to be stored in shaded areas when not in use. One fire extinguisher will remain with the Nitrous Oxide filling tank, and the other fire extinguisher will remain by the truck nearest to the ground station crew. During static fire events, the operating team must carry a full fire extinguisher placed nearest to the Nitrous Oxide filling tank to facilitate the operations of two key steps:

1. Trained Individual will close shut the filling tank
2. Trained Individual will use the fire extinguisher to suppress fire

A trained individual will have access to the Nitrous Filling tank area immediately after the test area has been deemed accessible to approach a small fire contained within the bounds of the test stand. The trained individual must shut the Nitrous Oxide filling tank valve closed, and an ***abort*** command will be issued to vent any remaining Nitrous Oxide in the tank and the filling line. The trained individual will then gain access to the affected area and must pull the pin from the fire extinguisher, aim downwards towards the affected area, and squeeze the handle to suppress the fire, moving in side-to-side motions.

9.1.2 Water Hose

A water hose will be used as a back-up to the fire extinguisher suppression plan. A spigot is on-site and will be in working-order before the start of a static fire.

This hose will remain near the Nitrous Oxide filling tank to provide ease of access to the nitrous oxide filling valve. The same procedure as above applies.

9.1.3 Shutdown Procedures Following Fire Suppression

After a fire has been completely extinguished by the trained individual and venting procedures have been successfully carried out, the operating team must disconnect the battery to prevent any further danger of ignition of combustibles. Once completed, the operating team may approach the test stand with precaution. Safety glasses must be worn at all times during the shutdown procedure following a fire suppression event. The team must handle equipment and the test stand with precaution, as surfaces may still be hot from combustion.

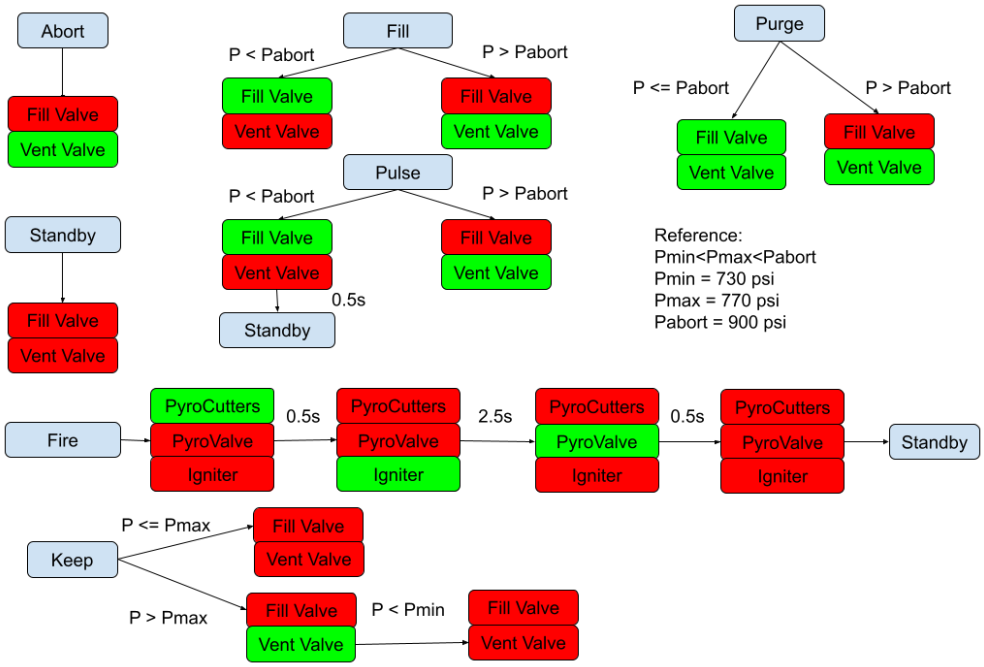
9.1.4 Emergency Services

Inadequate fire suppression or failure to comply with the above in any manner can result in a larger spread of fire and injury. The operating team will contact emergency services to take control of the situation.

10 APPENDIX

10.1 Ground Operation State

ATTENTION to highlighted and bolded portions of this text. GREEN indicates the immediate and surrounding area is safe to approach. YELLOW indicates live electronics/states and the immediate area and surrounding areas should not be approached by inexperienced personnel. **AREA IS PRESSURIZED/HAZARDOUS** indicates the immediate area should be evacuated with haste. **Commands** are indicated by bolded and italicized text.



10.2 Static Fire Command Procedure

10.2.1 Section W

Battery DISCONNECTED, Fill tank CLOSED, Igniters DISCONNECTED

1. All physical components installed, electronics linked to computer
2. If the tank does not have dipstick/educt tube, lay it down flat/invert it if possible
3. Test Relays:
   (a) Run ***fill***, listen for relay click
   (b) Run ***abort***, listen for relay click
4. Test Fire sequence:
   (a) Run ***fire***, listen for all relay clicks
5. Connect battery

10.2.2 Section X

Battery CONNECTED, Fill tank CLOSED, Igniters DISCONNECTED

1. Test Servos:
   (a) Run ***fill***, listen for solenoid click
   (b) Run ***abort***, listen for solenoid click
2. Disconnect battery
3. Wet the ground
4. Measure battery voltage, confirm > 11.5V
5. Connect igniters
6. Connect battery
7. **AREA IS PRESSURIZED: CLEAR IMMEDIATE AREA**
8. [WITH CRYO GLOVES AND FACE SHIELD] Open fill tank with quarter turn

10.2.3 Section Y

Battery CONNECTED, Fill tank OPEN, Igniters CONNECTED

1. Run ***calibrate*** for pressure sensors
2. (Optional) Test Servo Releases:
   (a) Run ***fill***, listen and observe pressure rise
   (b) Run ***standby***, observe ox tank pressure for leaks
   (c) Run ***abort***, listen for venting
3. Fill Ox tank
   (a) Run ***pulse***, observe mass change from load cells sensors, repeat until desired mass is reached
   (b) Run ***keep***, observe all solenoids close

4. Holding on Pad
    (a) ***Keep*** sequence should be looping, observe ox tank pressure staying inside desired range
5. **AREA IS HAZARDOUS: CLEAR SURROUNDING AREA**
6. Run ***fire***
7. Disarming:
    (a) Run ***abort***, ensure ox tank pressure is zero
    (b) [WITH CRYO GLOVES AND FACE SHIELD] Close fill tank

10.2.4 Section Z

Battery CONNECTED, Fill tank CLOSED, Igniters CONNECTED

1. Run ***purge***, listen for nitrous bleed to stop
2. Run ***standby***
3. Disconnect battery
4. **AREA IS SAFE**
5. Extinguish fire
6. Download data
7. Disconnect electronics