**Hot Fire Standard Operating Procedures:**

This document details the sequence of steps required to conduct Hot-Fire Testing by the ICLR Propulsion Team as of December 2021. The procedures outlined below must be complied with to ensure that tests are performed safely and with the best chance of success. Failure to comply will be considered a breach in safety and will be dealt with accordingly.

# **Nomenclature:**

Nitrous Oxide in a pressurized tank is being used for these tests. It may be referred to as N2O or nitrous throughout this document.

The DaQ (Data Acquisition) board is an electronic data logging unit. It will be used to collect and store sensor data from the tests.

# **Transit Advance Checks:**

1. Check the weather forecast 24hrs before a test. Postpone the test if rain or other adverse conditions are forecast
2. Check weather again 1hr before leaving for Silwood and postpone if there is a high chance of rain or other adverse conditions
3. Propulsion Safety Officer (PSO),Principle Test Engineers (CTO), Nitrous Oxide Specialist (NOS), and Environment Safety Officers (ESO) should be decided and delegated before each test. Note that the CTO must carry the fluid system arming key with them at all times.
4. Team members involved in handling any parts of the plumbing system should complete the eLearning compressed gases course: <https://www.imperial.ac.uk/staff-development/safety-training/safety-courses-/compressed-gases-e-learning/>
5. All team members must be wearing suitable clothing
   1. Long trousers, close toed shoes (unless borrowing steel toe shoes)

# **Critical Test Operations**

* Lifting Tank onto the Inverter
* Rotating the Tank
* Opening The Valve
* Evacuating the test area
* Initiating the Test

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# **Responsible Test Engineers:**

A team of 7 engineers is expected to be present on the day of testing. For the Hot fire being conducting on the 11th December the team present is as follows

| **Engineer** | **Responsibility** | **Training** |
| --- | --- | --- |
| Philip Tzonev | Chief Test Officer #1   * Take lead on Experimental Procedure * Ensure Experimental checklist is followed exactly | * Previous Hot Fire experience * Three year familiarity with engine * Formal training in pressure regulators and systems from respected Rocketry Company |
| Timothy Van den Wyngaert | Chief Technical Officer   * Provide technical assistance and troubleshoot issues arising on the day | * Three year familiarity with engine * Previous Hot Fire experience |
| Martin England | Propulsion Safety Officer   * Ensure all relevant safety guidelines are adhered to | * Two year familiarity with Safety Procedures * Drafted Risk Assessments and ERP documents |
| Aaditi Vaze | Chief Test Officer #2   * Assist Chief Test Officer #1 in Experimental Procedures * Provide independent confirmation for completion of necessary steps | * Hands on assembly and manufacturing of engine |
| Ray Asahara Thio | Combustion Specialist   * provide detailed troubleshooting of combustion aspects of engine |  |
| Luc Paoli | Nitrous Oxide Specialist   * Provide detailed troubleshooting of run tank and feed system aspects of engine * Assist and Advise Propulsion Safety Officer on all tasks concerning Nitrous Oxide | * Two year in depth research and hands on experience |
| Lasen | Junior Safety Officer   * Assist Safety Officer in duties * Ensure Checklist Checklist is gone through in its entirety   Environment Safety Officer   * Ensure the environment is clear and no civilians are present | * Trained by Safety Officer |
| Piotr Fill | Electronics Specialist   * Provide detailed troubleshooting of electronics aspects of engine | * Two year in depth research and hands on experience |

# **Before Starting Operations:**

1. Before entering the test site:
   1. Members performing tasks must have read the Standard Operating Procedures and should ask about anything unclear
   2. Members operating equipment must be trained in using the equipment to prevent damage or improper setup
2. After entering the test site:
   1. All team members must sign in to the register
   2. Ensure everyone knows the evacuation route from any hazardous areas
   3. Ensure everyone is aware of the exclusion zone location during tests (fenced off area)
   4. Ensure everyone knows the location of the nearest first aid kit or fire extinguisher
   5. Ensure everyone knows the contact number in case of an emergency
   6. All team members put on high-vis jackets (and steel toed shoes if necessary)

# **Onsite Setup Procedures:**

1. Transport N2O tank to the test area from behind Spars building
   1. Unlock tank storage shed
   2. Ensure chain is holding the tank to the trolley and secure further with two ratchet straps
   3. Wheel the tank on the trolley out of the shed, turn right to wheel it out over the concreted area then head towards the gate of the test area
   4. Wheel tank into the test area and remove the tarp covering the outlet connectors
2. Transfer N2O tank from trolley to tank inverter

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## **Checklist BEFORE lifting the tank onto the inverter (2b)**

* Are there enough team members present to lift the tank (minimum of 4)?
* Are all team members lifting the tank wearing steel toe shoes?
* Have all the team members lifting the tank been briefed on the procedure and know their role?
* Are the ratchet straps ready to be secured around the tank immediately after lifting it onto the inverter?
* Are all the components of the tank inverter undamaged from transit, storage and assembly?
* Are all the bolts and T-Nuts on the tank inverter tight? Are all the joints solid and not loose?
* Is the tank inverter base on stable ground and unable to wobble?
* Has the assembled tank inverter been checked by the CTO and PSO to ensure it was put together correctly?
* Has the tank holder been securely locked into the upright position?

**If the answer to any of these points is NO, the procedure should be halted until all measures are satisfied.**

## **Checklist BEFORE rotating the tank inverter 180 degrees (2f)**

* Are there enough team members present to rotate the tank (minimum of 2)?
* Are all team members rotating the tank wearing steel toe shoes?
* Have all the team members rotating the tank been briefed on the procedure and know their role?
* Are at least 2 ratchet straps being used to hold the tank to the tank holder?
* Have the 3 aluminium extrusion crossbeams been bolted to the open side of the tank holder? Are all the bolts tight?
* Are the upper cross beams on the tank holder contacting the tank, preventing it from moving vertically?

**If the answer to any of these points is NO, the procedure should be halted until all measures are satisfied.**

1. Ensure tank inverter is locked in the inverted position before continuing with next procedures
2. Transport test stand and plumbing to test area from the Spars building or transport vehicle
3. Inspect transported equipment for damage prior to use
   1. Check all swagelok connections are tight and no pipes are bent
   2. Check all parallel thread connections have the correct gasket installed
4. Secure test stand to the ground
   1. Push steel stakes through the holding plates on the test stand into the ground
5. Inspection and assembly of the engine
   1. **Wear nitrile gloves (prevent contamination of the injector)**
   2. Use motor retainer to maintain a stable platform
   3. Check that all o-rings are properly seated and undamaged
   4. Inspect nuts and bolts and ensure threads are undamaged
   5. Attach injector to flange using nuts and bolts
   6. Attach nozzle closure to flange using nuts and bolts
   7. Ensure all nuts are tight and there is no play or looseness
   8. Remove injector from flange
6. Fix engine to test stand
   1. **Wear nitrile gloves (prevent contamination of the injector)**
   2. Check that all o-rings are properly seated and undamaged
   3. Place the first injector plate into the injector with the engraved text facing out
   4. Ensure the injector plate reference number for the test is noted down
   5. Place the injector against the mounting plate on the test stand and insert the screws
   6. Do up all screws hand tight, then progressively tighten up with a screwdriver + wrench in a star pattern to apply even pressure
7. Attach data acquisition systems and remote control to test rig
   1. Connect the 3x pressure transducer cables to the DaQ board
   2. Unroll the remote cable from the Spars kitchen to the test area
   3. Connect the wires from the two solenoid valves to one end of the remote control cable
   4. Connect the remote control box to the other end of the cable
   5. Plug in the 24V power supply to a wall outlet in the kitchen and connect to the remote control box
   6. CTO uses the arming key to test that the valves operate as expected
   7. CTO removes the arming key and disconnects the power supply from the remote control box
8. Set up monitoring system
   1. Plant tripod firmly into the ground
   2. Attach webcam to tripod
   3. Connect webcam and Raspberry Pi board using USB connector
   4. Connect Raspberry Pi board and Control room using 50m ethernet cable
   5. Ensure control room receives live feed using web-cam
   6. Using phones or walkie-talkies, position camera to ensure full test set up is in view
9. Attach the long flexible hose from the upstream plumbing section of tank inverter to the downstream plumbing on test rig (refer to wiki article section on reswaging connections)
10. Attach the short flexible hose from the upstream plumbing to the tank outlet
    1. Ensure whip check hose connector is installed incase connectors loosen

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# **Cold Flow Testing Procedure:**

1. Evacuate test area of non-critical team members to the Spars building kitchen
   1. CTO, PSO and NOS remain in the test area (ensure that CTO is carrying arming key at all times)
   2. ESO will perform visual inspection for any members of the public in the vicinity of the test area
   3. If people are spotted, let them know of the hazardous tests that are occurring and ask them to leave the area
   4. Upon completion of inspection, ESO will place warning signs at entrances to exclusion area with instructions to wait for the test to be completed

## **Checklist BEFORE the NOS opens the valve:**

* Are all non-essential team members clear of the test site and in the Spars Kitchen?
* Are all members of the testing team on the attendance sheet accounted for?
* Are both arming keys in the possession of the CTO?
* Are nitrous/CO2 safe gloves being worn by the NOS?
* Is a face shield being worn by the NOS?
* Are all the swagelok nuts and other threaded connections tight?
* Is the whip check hose connector properly in place?
* Has the safety relief valve been properly calibrated during a prior hydrostatic test?

**If the answer to any of these points is NO, the procedure should be halted until all measures are satisfied.**

1. Turn on the test stand electronics box to prepare the DaQ for data logging
2. NOS will open the valve on the N2O tank to allow fluid into the plumbing section upstream of the main solenoid valve **(Skip for repeated tests as valve can remain open)**
   1. NOS must wear appropriate PPE (Face shield, nitrous/CO2 safe gloves)
   2. Valve opened slowly to avoid pressure spikes and allow leaks to be seen earlier on
   3. PSO must be present in case of any failures to oversee appropriate ERPs (Emergency Response Procedures)

## **Checklist BEFORE the test area is evacuated:**

* Are all non-essential team members clear of the test site and in the Spars Kitchen?
* Are all members of the testing team on the attendance sheet accounted for?
* Are both arming keys in the possession of the CTO?
* Has a visual check of nearby areas been done by the PSO to ensure no members of the public are nearby?
* Is the test fire electronics box powered on correctly?
* Has the tank valve been opened properly with no leaks in the system?

**If the answer to any of these points is NO, the procedure should be halted until all measures are satisfied.**

1. Full evacuation of test area
   1. PSO, CTO and NOS exit to the Spars kitchen
   2. PSO takes a register of all ICLR members at the test to make sure they are all inside
   3. PSO checks surrounding area again to ensure there are no members of the public nearby
   4. PSO check windows to ensure blankets are covering windows at risk of shattering
   5. PSO ensures all ICLR members are wearing noise protection devices
   6. ESO gives final go/no before entering Spars kitchen
   7. Spars building door is closed

## **Checklist BEFORE the CTO initiates the test:**

* Are all members of the testing team on the attendance sheet in the Spars kitchen?
* Are both arming keys in the possession of the CTO?
* Has a visual check of nearby areas been done by the PSO to ensure no members of the public are nearby?
* Does the live feed of the test equipment show that nothing unexpected is happening?

**If the answer to any of these points is NO, the procedure should be halted until all measures are satisfied.**

1. Test initiation sequence
   1. PSO gives go ahead for the test if there are no issues
   2. The 24V power supply is connected to the remote control box
   3. CTO inserts the arming key into the remote control box
   4. CTO performs a loud countdown from five and turns the key to open the solenoid valve
   5. Live video feed is watched to verify that test is working as expected
   6. CTO shuts off the test after 3-5 seconds and remove the arming key
   7. Check live video feed to confirm that valves closed successfully
   8. The power supply is disconnected from the remote control box

## **Checklist BEFORE the CTO & NOS enter the paddock:**

* Are all members of the testing team on the attendance sheet in the Spars kitchen?
* Has the solenoid valve been closed?
* Are both arming keys in the possession of the CTO?
* Has a visual check of nearby areas been done by the PSO to ensure no members of the public are nearby?
* Does the live feed of the test equipment show that nothing unexpected is happening?
* Has the power supply been disconnected?

**If the answer to any of these points is NO, the procedure should be halted until all measures are satisfied.**

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# Post-test Analysis:

1. PSO opens the Spars door and walks to within line of sight ~10m from the test setup

## **Checklist BEFORE the CTO & NOS enter the paddock:**

* Are all members of the testing team on the attendance sheet in the Spars kitchen?
* Has the solenoid valve been closed?
* Are both arming keys in the possession of the CTO?
* Has a visual check of nearby areas been done by the PSO to ensure no members of the public are nearby?
* Does the live feed of the test equipment show that nothing unexpected is happening?
* Has the power supply been disconnected?

**If the answer to any of these points is NO, the procedure should be halted until all measures are satisfied.**

1. If everything looks good, CTO and NOS will enter paddock and immediately close N2O tank valve
   1. NOS must wear appropriate PPE (Face shield, nitrous/CO2 safe gloves)
   2. Valve opened slowly to avoid pressure spikes and allow leaks to be seen earlier on
   3. PSO must be present in case of any failures to oversee appropriate ERPs (Emergency Response Procedures)
2. Once main tank valve is closed and everything looks safe, other members may enter
   1. Inspect engine using IR Thermal sensor to see if it is cold
   2. Visually check all plumbing carefully to ensure there are no leaks or disconnected lines
   3. Collect data from the DaQ and back it up on laptops so analysis can be performed later
   4. Stop recording on camera and replace batteries/swap SD cards if necessary

# Followup Testing:

1. Injector is reconfigured for the next test
   1. **Heat insulating gloves must be worn (engine plate will be cold)**
   2. Screws holding engine assembly to the test stand are loosened and removed with a screwdriver + wrench
   3. Engine assembly is removed carefully being wary of inlet hose that is attached
   4. Detach injector head, being wary of injector plate that may fall out
   5. Place a gloved hand over the front of the injector plate and rotate it to face downwards so that injector plate falls out
   6. If injector plate is stuck, push a screwdriver through the ignition ports to lever it out (be careful not to cause damage to o-rings or soft aluminium)
   7. Place the next injector plate to be tested into the injector (ensure the plate reference number is noted down again)
   8. Attach the injector head to the engine and insert screws
   9. Do up all screws hand tight, then progressively tighten up with a screwdriver + wrench in a star pattern to apply even pressure
2. Restart data logging of DaQ as well as recording cameras (ensure live video feed is still running correctly)
3. Repeat the **Cold Flow Testing Procedure**” above
4. Total number of tests may be decided ahead of time or on the test day depending on time constraints

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# **Hot Fire Testing Procedure:**

1. Configure Engine for testing
   1. Engine assembly is removed carefully being wary of inlet hose that is attached
   2. Detach injector head, being wary of injector plate that may fall out
   3. Detach nozzle closure from engine
   4. Place nozzles into nozzle closure and attach closure to engine, inserting screws
   5. Do up all screws hand tight, then progressively tighten up with a screwdriver + wrench in a star pattern to apply even pressure
   6. Slide in insulating alumina ceramic for post combustion chamber
   7. Slide in fuel grain
   8. Make note of fuel grain used
   9. Slide in insulating alumina ceramic for pre-combustion chamber
   10. Assemble ignition System and insert into the pre-combustion chamber
       1. **Wear working gloves when handling steel wool**
       2. Steel wool is wrapped around 3 sparklers
       3. E-match is fed through nozzle and wrapped in with steel wool
       4. Steel Wool - E-match - Sparkler bundle is placed into pre-combustion chamber
   11. Make note of injector plate and attach injector head
   12. Do up all screws hand tight, then progressively tighten up with a screwdriver + wrench in a star pattern to apply even pressure
2. Evacuate test area of non-critical team members to the Spars building kitchen
   1. CTO, PSO and NOS remain in the test area (ensure that CTO is carrying arming key at all times)
   2. ESO will perform visual inspection for any members of the public in the vicinity of the test area
   3. If people are spotted, let them know of the hazardous tests that are occurring and ask them to leave the area
   4. Upon completion of inspection, ESO will place warning signs at entrances to exclusion area with instructions to wait for the test to be completed

## **Checklist BEFORE the NOS opens the valve:**

* Are all non-essential team members clear of the test site and in the Spars Kitchen?
* Are all members of the testing team on the attendance sheet accounted for?
* Are both arming keys in the possession of the CTO?
* Are nitrous/CO2 safe gloves being worn by the NOS?
* Is a face shield being worn by the NOS?
* Are all the swagelok nuts and other threaded connections tight?
* Is the whip check hose connector properly in place?
* Has the safety relief valve been properly calibrated during a prior hydrostatic test?

**If the answer to any of these points is NO, the procedure should be halted until all measures are satisfied.**

1. Turn on the test stand electronics box to prepare the DaQ for data logging
2. Connect e-match ignition lead to DaQ
3. NOS will open the valve on the N2O tank to allow fluid into the plumbing section upstream of the main solenoid valve **(Skip for repeated tests as valve can remain open)**
   1. NOS must wear appropriate PPE (Face shield, nitrous/CO2 safe gloves)
   2. Valve opened slowly to avoid pressure spikes and allow leaks to be seen earlier on
   3. PSO must be present in case of any failures to oversee appropriate ERPs (Emergency Response Procedures)

## **Checklist BEFORE the test area is evacuated:**

* Are all non-essential team members clear of the test site and in the Spars Kitchen?
* Are all members of the testing team on the attendance sheet accounted for?
* Are both arming keys in the possession of the CTO?
* Has a visual check of nearby areas been done by the PSO to ensure no members of the public are nearby?
* Is the test fire electronics box powered on correctly?
* Has the tank valve been opened properly with no leaks in the system?

**If the answer to any of these points is NO, the procedure should be halted until all measures are satisfied.**

1. Full evacuation of test area
   1. PSO, CTO and NOS exit to the Spars kitchen
   2. PSO takes a register of all ICLR members at the test to make sure they are all inside
   3. PSO checks surrounding area again to ensure there are no members of the public nearby
   4. PSO check windows to ensure blankets are covering windows at risk of shattering
   5. PSO ensures all ICLR members are wearing noise protection devices
   6. ESO gives final go/no before entering Spars kitchen
   7. Spars building door is closed

## **Checklist BEFORE the CTO initiates the test:**

* Are all members of the testing team on the attendance sheet in the Spars kitchen?
* Is one arming key in the possession of the CTO?
* Is the other arming key in the possession of the PSO?
* Has a visual check of nearby areas been done by the PSO to ensure no members of the public are nearby?
* Does the live feed of the test equipment show that nothing unexpected is happening?

**If the answer to any of these points is NO, the procedure should be halted until all measures are satisfied.**

1. Test initiation sequence
   1. PSO gives go ahead for the test if there are no issues
   2. The 24V power supply is connected to the remote control box
   3. CTO inserts the arming key into the remote control box
   4. CTO performs a loud countdown from five and turns the key to open the solenoid valve
   5. PSO then presses ignition button, commencing official hot fire
   6. Live video feed is watched to verify that test is working as expected
   7. CTO shuts off the test after 3-5 seconds after combustion can be visually identified and removes the arming key
   8. Check live video feed to confirm that valves closed successfully
   9. The power supply is disconnected from the remote control box

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# Post-test Analysis:

1. PSO opens the Spars door and walks to within line of sight ~10m from the test setup

## **Checklist BEFORE the CTO & NOS enter the paddock:**

* Are all members of the testing team on the attendance sheet in the Spars kitchen?
* Has the solenoid valve been closed?
* Are both arming keys in the possession of the CTO?
* Has a visual check of nearby areas been done by the PSO to ensure no members of the public are nearby?
* Does the live feed of the test equipment show that nothing unexpected is happening?
* Has the power supply been disconnected?

**If the answer to any of these points is NO, the procedure should be halted until all measures are satisfied.**

1. If everything looks good, CTO and NOS will enter paddock and immediately close N2O tank valve
2. NOS must wear appropriate PPE (Face shield, nitrous/CO2 safe gloves)
3. Valve opened slowly to avoid pressure spikes and allow leaks to be seen earlier on
4. PSO must be present in case of any failures to oversee appropriate ERPs (Emergency Response Procedures)
5. Once main tank valve is closed and everything looks safe, other members may enter
   1. Inspect engine using IR Thermal sensor to see if it is hot
   2. Visually check all plumbing carefully to ensure there are no leaks or disconnected lines
   3. Collect data from the DaQ and back it up on laptops so analysis can be performed later
   4. Stop recording on camera and replace batteries/swap SD cards if necessary
6. Inspect engine for any damage or evidence of failure
   1. **Wear thermally insulating gloves (engine may still be warm)**
   2. Screws holding engine assembly to the test stand are loosened and removed with a screwdriver + wrench
   3. Engine assembly is removed carefully, being wary of inlet hose that is attached
   4. Screws holding injector assembly to the engine are loosened and removed with a screwdriver + wrench
   5. Injector head is removed, being wary of the free injector plate that may fall out
   6. Place a gloved hand over the front of the injector plate and rotate it to face downwards so that the injector plate falls out. Note heavy tap might be required to get the injector pate to fall out
   7. Visually inspect o-rings for damage
   8. Carefully transport engine to inside Spars Building where it can be inspected
   9. Carefully remove the ceramic insulation and fuel grains by tipping the engine upside-down, allowing everything to slide out
   10. Inspect fuel grains, taking pictures and recession measurements
   11. Screws holding nozzle to the engine are loosened and removed with a screwdriver + wrench
   12. Carefully remove nozzle, being wary of loose graphite nozzle
   13. Visually inspect internal walls of combustion chamber for damaged sections
   14. Visually inspect threads of all screws for signs of shear or other damage
   15. Scrub inside of combustion chamber, removing charred fuel grain

## **Checklist BEFORE a Followup Test is conducted:**

* Are all of the engine components free of signs of damage?
* Is it more than 30 minutes until sunset?
* Are there any signs of leaking on the feed / fill system?
* Have all post-test analysis steps been completed?
* Is there any cause for concern that something may not be functioning correctly?

**If the answer to any of these points is NO, the procedure should be halted until all measures are satisfied.**

# Followup Testing:

1. Repeat the “**Hot Fire Testing Procedure”** above
2. Total number of tests may be decided ahead of time or on the test day depending on time constraints

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# **Tear-down Procedure:**

1. CTO closes the valve on the N2O tank wearing appropriate PPE (Face shield, nitrous/CO2 safe gloves)
2. Full evacuation of test area (so remaining N2O in plumbing can be vented)
   1. All ICLR members move to the Spars kitchen
   2. PSO takes a register of all ICLR members at the test to make sure they are all inside
   3. PSO checks surrounding area again to ensure there are no members of the public nearby
   4. Spars building door is closed

## **Checklist BEFORE the CTO initiates the vent:**

* Are all members of the testing team on the attendance sheet in the Spars kitchen?
* Are both arming keys in the possession of the CTO?
* Has a visual check of nearby areas been done by the PSO to ensure no members of the public are nearby?
* Does the live feed of the test equipment show that nothing unexpected is happening?

**If the answer to any of these points is NO, the procedure should be halted until all measures are satisfied.**

1. Venting sequence
   1. PSO gives go ahead for the venting if there are no issues
   2. The 24V power supply is connected to the remote control box
   3. CTO inserts the arming key into the remote control box
   4. CTO performs a loud countdown from five and turns the key to open the solenoid valve
   5. Live video feed is watched to verify that system has vented and not more CO2 is leaving the system
   6. CTO shuts off the valve and removes the arming key
   7. Check live video feed to confirm that valves closed successfully
   8. The power supply is disconnected from the remote control box
2. PSO opens the Spars door and walks to within line of sight ~10m from the test setup
3. If everything looks good, team members may enter the test area to continue teardown (including CTO)
   1. **Wear thermally insulating gloves (engine may still be warm)**
   2. Screws holding engine assembly to the test stand are loosened and removed with a screwdriver + wrench
   3. Engine assembly is removed carefully, being wary of inlet hose that is attached
   4. Screws holding injector assembly to the engine are loosened and removed with a screwdriver + wrench
   5. Injector head is removed, being wary of the free injector plate that may fall out
   6. Place a gloved hand over the front of the injector plate and rotate it to face downwards so that the injector plate falls out. Note heavy tap might be required to get the injector pate to fall out
   7. Short flexible hose is disconnected from the N2O tank
   8. Stakes holding the test stand to the ground are removed
   9. Disconnect the pressure transducers from the DaQ
   10. Reel the 30m cable back up and store in Spars building
   11. Disconnect 24V power supply and store in Spars building
4. N2O tank is unloaded from the tank inverter
   1. **Follow “Onsite Setup Procedures” Step 2. in reverse**
5. N2O tank is transported on the trolley back to secure storage shed behind the Spars building
   1. Cover the outlet connections with the tarp
6. Lock the storage shed with the padlock

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# Equipment Checklist:

* Test stand with thrust plate attached
* Tank inverter
* Injector assembly connected to the downstream plumbing (including 2x ball valves)
* Five injector plate test articles (labelled)
* N2O cylinder secured on a trolley
* 12x M5 screws + nuts (to hold injector plate to the test stand)
* Upstream plumbing system with flexible hoses on each end (mounted to aluminium plate)
* 24V power supply
* Remote control box
* ~30m long cable
* Face shield
* Safety glasses/goggles (5-6 pairs)
* Action camera (for analysis of injector flow)
* Spanners (for retightening connectors)
* Screwdrivers
* Pliers
* Data acquisition electronics
* 4x orange ratchet straps
* 5x pairs of steel toe shoes
* 6x high visibility jackets
* Megaphone/air horns