**Operators: Include Team members (Triyan Pal Arora, Noah Buttrey, Dr Eduardo Anselmi Palma, and assigned test facility technicians)*

Risk Assessment Form

CU-SHE-FORM-3.01

V4.0

Risk Assessment Number:	1 of 1	**Title:**	HYDRA Hybrid Rocket Engine, CranSEDS 2022-2023 v2.0
Task/Activity assessed:	Hot Fire Rocket Engine Test		
Name/job role of people consulted during assessment:	Project Supervisor, Project Mentors, Test Site Manager, Health and Safety Officers, Department Head.	**Date of Assessment**	10th March 2024

Acknowledgements, Sign off and Authorisation				
	Acknowledgement	**Name**	**Signature**	**Date**
Risk Assessor:	By signing this risk assessment, I acknowledge my responsibility as the Risk Assessor for conducting this risk assessment in accordance with CU-HAS-PROC-3.01, Risk Assessment Procedure.	Triyan Pal Arora, E. Project Manager		10th March 2024
Checked by:	By signing this risk assessment, I acknowledge my responsibility as the checker for this risk assessment in accordance with CU-HAS-PROC-3.01, Risk Assessment Procedure.	Dr. Eduardo Pan Anselmi, Test site safety Inspector		
Checked by:	By signing this risk assessment, I acknowledge my responsibility as the checker for this risk assessment in accordance with CU-HAS-PROC-3.01, Risk Assessment Procedure.	Dr. Rosemary Burns, Cranfield Health and Safety Officer		
Checked by:	By signing this risk assessment, I acknowledge my responsibility as the checker for this risk assessment in accordance with CU-HAS-PROC-3.01, Risk Assessment Procedure.	Scott Booden, Test Site Supervisor		
Authorising Person:	By signing the risk assessment, I acknowledge my responsibility as the Line manager/Supervisor for reviewing and approving this risk assessment and communicating controls and any additional controls to staff/students (as appropriate).	Dr. Vassillios Pachidis		

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Tasks/Operational steps/Sub tasks/Events:		**Significant hazards** • What could happen and why?	**Who is affected and how** • Who might be hurt? • How bad could it reasonably be?		**What are your existing controls?** (Reference all Safe Systems of Work (SSOW), Standard Operating Procedures (SOP) and Emergency Procedures)	**Existing Risk Rating** (**C**onsequence x **L**ikelihood = Total)			**Are additional controls needed? Y/N** (If Yes, RAMP required)
						C	**L**	**TOTAL**	
1	*Stored gas pressure vessel failure (e.g., where filling run-tanks with high pressurise fluids (Nitrous Oxide, Oxygen, and Nitrogen)).*	The tank connector, feed line or the tanks themselves could either become disconnected or rupture due to over pressurisation.	Operators	Minor injury due to fill pipe disconnecting and flailing during filling. Possibility of tanks rupturing due to over pressurisation. Blast effects, possible - shrapnel.	• The maximum expected operating pressure (MEOP) of the system is significantly less than the maximum allowable tank pressures (60 Bar maximum working pressure to be held within the 207 bar rated run tanks – safety factor of 3.45x MEOP). • To prevent the tanks from over pressurisation, each feed line shall have a pressure relief valve rated to 130 Bar. • The pressure relief valve directs the excess outside the experiment area to exhaust it in open atmosphere. • All tanks used during firing shall undergo a hydrostatic pressure test prior to use, alongside being new and certified for use. • All feed line system components are rated sufficiently in excess (227 bars of N_2 gas) at 130 bar pressure relief valve setting. • A nitrogen pressurisation leak test shall be conducted using soapy water to ensure all feed system connections are reliable and secure. • Filling shall be done in a well-ventilated area. • All stored gas cylinders to be secured when not being transferred to avoid unintentional shock loads. • PPE kit advised in COSHH documents and SDS must be worn during filling operations. • The run tank employed shall have a maximum allowable pressure of 200 bars. • The run tank shall incorporate dip tube and proper external connection to secure the gas in the tanks properly.	5	2	10	N
2	*Electrical Fire in test house when*	Control system short circuiting, cable melting or being exposed to	Operators	Could cause the generation of	• Ensure the test house is well ventilated.	3	2	6	N

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	preparing to test fire or during/after firing.	extreme engine temperatures, causing an electrical fire. Engine failure exposing tanks to excessive heat.		asphyxiate gas (e.g., CO/CO_2). The fire could reach the propellant tanks which could heat them to a sufficient temperature to cause over pressurisation and compromise their structural integrity.	• All operators shall wear fire protection lab coats and have water and CO_2 fire extinguishers readily available next to the blast door. • A metal blast shield shall be mounted onto the tank stand to deflect any excess heat from the engine. • The tank stand tower, containing the electrical equipment shall be located besides the engine as opposed to behind the engine, to reduce the risk of failure if the engine's injector were to fail. • All wires have been selected to withstand the maximum likely current expected, reducing the risk of wires melting due to short-circuit or overloading. • Pressure relief valves over tanks aid in protecting the tank in case of excessive heat and over pressurisation, that would rupture first and release its contents, as opposed to rupturing the tanks. • All test operations shall be conducted 10 m away from the engine, behind a blast-proof shield, in an outdoor area. • If the fire becomes uncontrollable, all operators shall evacuate the test site and gather in the test site car park. Follow the emergency guidelines provided. • 2 Fire blankets, 2 buckets of water, 2 buckets of sand kept at 5-6 m distance from the engine near the blast door, in order to be accessed by personnel in the emergency procedure for trained health and safety supervisor.				
3	*Engine dismounting from test stand during firing.*	Engine plume may be directed towards the tank stand and/or the control room (containing the operators). Breakage of interfaces, creating an explosion.	Operators	Potential to cause damage to test site equipment and burn to personnel. Hearing and eyesight damage is also possible.	• All test operations shall be conducted 10m away from the engine, behind a blast-proof shield, in a well-ventilated room, thereby reducing the risk to operators. • The control system has an integrated emergency stop button which in emergency will shut off the power supply and bring the system back to safe mode. • The engine is safely secured to the test stand using O-ring clamps, preventing significant lateral and transverse movements while providing room for longitudinal play for the load cell.	3	2	6	N
4	*Flashback from the engine to the*	Could cause an internal feed system fire which may result in tank	Operators	Fire injury to personnel and	• A flashback arrestor of rated 25 bars will be used on all 3 feed lines different for oxygen, nitrogen and nitrous oxide.	4	2	8	N

	feed system tanks.	rupture and/or an uncontrollable fire.		damage to equipment. Feed line or valve failure / possible ignition / shrapnel.	• A positive pressure difference of at least 10 Bar across the injector (i.e., between the feed system and the engine's combustion chamber) shall be maintained throughout the burn, with the injector acting as a check valve reducing the risk to operators by preventing any pressure oscillations causing reverse flow into feed lines. • The feed-line will incorporate non-return valves to prevent any backwash due to pressure differential between the gas tanks, as they end up on across junction to the combustion chamber.				
5	*Power cut/ instability during firing.*	Engine becomes uncontrollable from the remote-control unit.	Operators	The engine may burn for longer until it depletes the fuel and oxidiser, increasing the risk of engine failure and overheating the system.	• Solenoid valves selected for nitrous oxide and oxygen feed line are designed to fail-shut. Thus, preventing the flow of oxidiser to the engine and stopping the combustion process. • The Nitrogen purge line has normally open valves, to allow the whole system to be purged and extinguished with the high pressure nitrogen. Nitrogen tank will sit on the highest pressure in order to push out all gases and combustion particles during purge. • The safety officer will assess and declare the area as safe to enter, following which test personnel will go ahead to close the manual valves on the feed-lines.	2	2	4	N
6	*Electric shock.*	Electrocution of an operator from the 230 VAC power supplies.	Operators	A double insulated wiring connection may become exposed and contact personnel resulting in burns and/or a cardiac arrest.	• The control system is designed to be 12VDC (within the control room) and 24VDC (by the engine) power systems, using step-down transformers to ensure a safe operating voltage. • The wiring within the control room is insulated by the control box and the box is grounded to the floor of the control room. • The more exposed 230V AC cable on the tank stand is covered to reduce the risk of contact when live. • The DAQ system is powered by a 12 V DC LiPo battery isolated and enclosed within a plastic box mounted on the tank tower.	4	1	4	N
7	*Gas tank's toppling.*	Physical impact and/or dangerously expelling combustion fluids.	Operators	Nearby persons may endure a high energy impact resulting in significant physical harm if a	• The tanks shall be secured to their places using multiple sandbags and straps on the tower, while keeping them away from the thrust trail of the engine. • During assembly, integration and testing (AIT), the personnel are required to wear safety boots with	3	1	3	N

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				tank connector were to break-off a tank.	steep cap to protect from tanks falling on the foot of the personnel. • The tanks bought will be adequately certified and have flat bottom to provide better stand capability. • The feed line will incorporate a plastic tube before the feed line goes to the injector. This plastic tube will carry the excessive thrust loads and displacements in order to protect the feed line system and tanks from transference of big loads and impacts causing damage to the interfaces. • All operators will remain at least 10m away from the engine during firing and behind a blast proof shield. Operators must wear safety boots during preparation and testing.				
8	*Personnel contact with hot parts post firing.*	Heat damage to skin	Operators	Minor injury from burns	• Warning signs and barriers to be put in place immediately pre-firing • Operators only to approach engine after ambient temperature achieved – determined visually and using thermal hand sensors. • Operators to use heat-resistant protective gloves when handling hardware post-burn	3	1	3	N
9	*Combustion after firing terminates eg. from fuel residuals.*	External heating of rocket engine chamber.	Operators	Cosmetic damage to motor, burns to operators inspecting after firing.	• Ensure equipment is clean, no loose, potentially flammable items within range of motor plume. • Purge each feed line and the engine with nitrogen gas after every burn. • CO_2 and dry powder fire extinguisher(s) to be available during test fire – can be used to extinguish any post-test burning.	2	2	4	N
10	*Upstream leakage of gas: N_2O / O_2 / N_2 - during loading / ignition / hot fire / purge.*	High pressure gas leak: fire and / or asphyxiant.	Operators	Minor injury from ejected gas Damage to instrumentation and feed system	• Low pressure gas test of plumbing (10 Bar) – *balance* between pressure required for MEOP + safety factor hydraulic test, and risk from high pressure gas in event of a mechanical failure. • PPE (full face masks and fire-retardant suits) to be worn during loading. • All operator staff to be remote (min 10m and behind a blast proof shield) during firing. • All plumbing connections double checked for leaks with soapy water. • 2 O_2 detectors, 2 CO detectors, 2 N_2O detectors to be placed on either side of the feed-line and engine system in -order to evaluate the atmospheric	3	2	6	Hydraulic cold flow test of fully assembled plumbing, from tanks to injector.

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					composition and check for hazardous contaminants in concentrated form. These detectors will have visual and hearing signal capability. • Pressure testing and cold flow testing of engine, feed line system shall be done prior to complete integration at the set pressure to assess all points of failure.				
11	*Burn through of engine chamber*	Burn the internal side of the casing, melt it, and deform the surface. Causes corrosion of the metal during cool down after the burn out.	Operators	Cosmetic damage to motor, minor burns to operators inspecting after firing, damage to the casing making it prone to failure, damaging thermocouples and pressure transducer, and damaging the gasket lining.	• The chamber casing will be painted to protect from corrosion, and completely covered with a thick layer (5 mm) of cork liner to protect from the combustion of the engine. • The thickness of the casing is 6 mm to protect from any burn through. Thicker metal makes it difficult for conductive heat transfer. • Compressible engine grade gasket will be used with a compression of 40-50% thickness in order to ensure tight and secure interface connection. The gasket will be replaced with a new set after every firing. • The gasket will cover complete flange face going around flange bolts to keep the system interface uniform and secure.	2	2	4	N
12	*Nozzle failure*	Nozzle breaks, the exhaust flow is deviated, due to cracked nozzle, creating unresolved loads on structure. blocks the combustion chamber outflow, makes it a high pressurized and high temperature gas cylinder, with explosive potential.	Operators	Potential to cause damage to test site equipment, may damage the engine setup, may lead to an explosion.	• The nozzle is tested through simulations for higher than worst case loading. • The graphite nozzle sits on nozzle casing with 2 compressive radial O-rings, creating sealed outer zone. • The fitting of nozzle and nozzle casing is tolerance fit of < 0.1 mm, making it difficult to break and create a space pocket in the combustion chamber. • The graphite nozzle can break due to overpressurisation or shock wave. The system was checked and ensured no resonant mode exist for the firing. The selected graphite material Duragraph is capable to take >1500 N thrust on the same nozzle area ratio.	4	2	8	N
13	*Nozzle blockage and overpressure of chamber*	Blocks the combustion chamber, makes it a high pressurized and high temperature gas	Operators	Potential to cause damage to test site equipment, may damage the	• If the nozzle is blocked and/or the chamber is overpressured, the rear end of the nozzle casing with 2 mm of steel layer fails and pops out the graphite	4	2	8	N

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		cylinder, with explosive potential.		engine setup, may lead to an explosion	nozzle. This releases the internal overpressure and saves crucial components from damaging.				
14	*Overpressure of combustion chamber*	High pressure of 33.5 bars, but low velocity causes pressure build up, which may crack/ rupture the chamber.	Operators	Potential harm to equipment, any personnel standing close, or in unsafe manner	• The thickness of combustion chamber is considered with a big margin to be 6 mm. • The chamber has been pressure tested up to 50 bars as pre-requisites with cold flow testing and hot fore testing heritage.	4	1	4	N
15	*Structural failure due to vibrations, heat and thrust loads*	The test stand, structure or any interface can fail due to vibrational loads, heat loads, and thrust loads	Operators	Potential harm to equipment, any personnel standing close, or in unsafe manner	• The design of components has been thoroughly tested against possible worst thrust loads, heat loads, and vibrational loads. A minimum factor of safety of 2 was targeted and achieved, to keep the components safe and optimally designed. • All bolt connections will be tightened using at least 3.1 N-m torque wrench.	3	2	6	N
16	*Malfunctioning or failure of feed line component (valves, regulators)*	Valves and regulators malfunction due to unexpected pressure load, internal mechanical failure, or electrical failure	Operators	The leakage of any gas may concentrate the surrounding atmosphere and make it toxic. Oxidiser leak may lead to fire or explosion.	• The feed line components are checked for valid certifications before putting in all together. • The valves and regulators will be tested multiple times during the cold flow test to ensure no leaks or failure occurrence. • The components will be sealed with Teflon tape and copper thread locker to eliminate any sliver of opening and ensure tight connections at all the interfaces. Tightening the adapters with a 2 N-m torque wrench.	4	2	8	N
17	*Leakage from feed line pipes*	Feed line pipe connections not tight enough, the pipes used are of low quality, causing cracks due to high pressured flow.	Operators	The leakage of N_2O may concentrate the surrounding atmosphere and make it hazardous. O_2 leak may lead to fire explosion.	• The feed line pipes are 3/8 in steel Swagelok pressure fluid tubes. They are rated for pressures higher than ones calculated for the experiment. Valid certifications for the tubes are linked. • The tubes will be tested during the cold flow test to ensure no leaks or failure occurrence. The tubes will be pressure tested upto 50 bars as well to ensure the assembly easily takes the required loads without any recorded failure. • The pipes will be sealed with Teflon tape and copper thread locker to eliminate any sliver of opening and ensure tight connections at all the interfaces.	4	1	4	N

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18	*Improper assembly, misalignment*	May lead to gaps in interfaces, weakening the structure, single point failures, the exhaust plume will not be in the anticipated direction	Operators	Potential harm to structure, if not enclosed, the exhaust plume can pollute the surroundings	• The assembly is checked for correct alignment using handset inclinometer at each step of the assembly and integration. The fixtures prepared aid in correctly aligning the line assembly onto the test stand for correct alignment for the plume. • The setup will be tested during cold flow test to ensure proper alignment has been achieved. • The structure is capable enough to take unanticipated loads with a safety factor of at least 2.	3	2	6	N
19	*Ignition failure or delayed ignition*	Uncontrolled propellant buildup or incomplete combustion. Affects the recorded engine performance. The required voltage for ignition is a potential danger.	Operators	Incomplete combustion means intermittent species (CO, NO, NOx) existing in the exhaust which will be harmful to personnel	• The ignition will be tested before the actual test firing. The burning of the Nichrome wire (28 AWG) will be measured, with the required distance to keep the controls behind the blast cover. • The required voltage may be potentially dangerous and will be shielded using electrical breaks (fuses) • The data acquisition system shall have plenty of storage to allow for recording all the data readings, which will be removed in post processing of the obtained results. This will be correlated with the firing through the camera feed.	3	2	6	N
20	*Noise, shockwave, or acoustic hazard during firing*	The noise and acoustic hazard are inevitable in test firing. Acoustic vibrations may shake components in surrounding, like tanks, cameras, sensor placement	Operators	Large noise may be harmful to human ears. May cause nearby equipment to shake due to acoustic vibrations	• The test stand is mounted on a concrete test block itself bolted down to ground using 8 M24 bolts with >15 mm threaded connection. • The tanks and cameras will be fixed in place of sandbags. • The tower containing the electronics will be shielded by a wooden board to protect from shock waves and any kind of explosion. • The operators shall always wear 120db rated ear defenders atleast. • The sensor readings may have jitters, which can be removed in post processing of the obtained results. • The test facility area will be alerted before the testing. The area will be blocked from any outsider to enter.	2	3	6	N
21	*After-firing Exhaust*	The exhaust after test firing may contain unburnt combustion products (like CO, NO, NOx) which are dangerous to humans,	Operators	Potential to cause damage to test site equipment. Hazardous to humans and	• To clear up the surroundings from large exhaust concentration, electric fans will be used kept at sufficient distance to avoid any hazardous reaction of the unburnt particles in the exhaust or causing an electrical short. • The purging phase through nitrogen gas will be extended by 5 seconds to ensure safety.	3	3	9	N

		and may react with equipment.		nearby personnel.	• The setup will be placed outside the test house in open atmosphere reducing chances of building up concentrated contamination. • The area will be kept closed for a certain pre-determined time to ensure the exhaust is completely dissipated and there's no chance of harm from the exhaust to the personnel or equipment anymore. This will be assessed and declared by the health and safety officer. The enclosed area shall be enough that beyond which ea defenders are not required.				
22	*Failure of data acquisition system operation*	The system hardware is loose and circuit is broken, leading to incapability to capture any significant data from either one or all sensors.	-	No recording of data or loss of data will lead to waste of test firing towards substantial research work. May cause fire due to overheating.	• The circuit components of the DAQ system shall be tightly secured and placed in well structured container and longer wires to avoid snapping. • The DAQ system/ box shall be isolated from the main engine setup, and shall be mounted separately affixed to the gas tank tower. • Ensuring proper recoding of data before initiating the test, and including a small check before the test firing in the pre-firing checklist item. • A real-time UI maybe computationally expensive, however, will ensure the transmission and collection of data from the test firing.	1	3	3	N

		PERSONAL PROTECTIVE EQUIPMENT (PPE):										
		 ☒	 ☐	 ☒	 ☒	 ☐	 ☒	 ☐	 ☐	 ☒	 ☐	 ☐
		For every item of PPE required, specify the type and other relevant information below: • **1 x LABORATORY COAT (PER OPERATOR)** • **1 x SAFETY GLASSES (PER OPERATOR)** • **1 x SAFETY GLOVES (PER OPERATOR)**										

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		• **1 X SAFETY EAR DEFENDERS (PER OPERATOR)** • **1 X SAFETY BOOTS (PER OPERATOR)**	
		Type	**Other relevant information** ***e.g material, level of protection, etc.***

Emergency Planning Arrangements relating to operations/event

		• Follow Emergency procedures including CU-SHE-PROC-3.06a Hazardous and Difficult Waste disposal procedure CRANFIELD, and Spill Prevention and Response Procedure. • In case of doubt, immediately vacate the contaminated area and attempt to quickly find a personnel trained and equipped with emergency health and safety procedures. • Contact Emergency Services at 999 • Contact MOD Guard service on 2222 or 01234 752999. • In case of leak or explosion, cut off the main power supply and shut off the main valves of the propellants from the control room. • Do not approach to the contaminated area without assessing the hazardous environment and a prior authorisation from the Health and Safety supervisor. • Inform the test site supervisor and Health and Safety officer of the accident and the following emergency. • Stay calm, and follow the emergency procedures in place.

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Risk Rating Matrix

RISK MATRIX					
Consequence **Likelihood**	Negligible (1)	Minor (2)	Medium (3)	Major (4)	Severe (5)
Almost Certain (5)	5	10	15	20	25
Likely (4)	4	8	12	16	20
Possible (3)	3	6	9	12	15
Unlikely (2)	2	4	6	8	10
Very Unlikely (1)	1	2	3	4	5

Rating	Interpretation	Authorisation
≤ 6 = Low Risk	Acceptable but ensure that controls are maintained	Line Manager or equivalent
8 -12 = Medium Risk	Adequate but look to improve if reasonably practicable	Line Manager or equivalent
15 – 25 = Unacceptable Risk	STOP activity and make immediate improvements	PVC School/Director of PSU

CONSEQUENCE (considered WITH controls in place)		
5	Severe	• Fatality (ies) • Severe or chronic illnesses or permanent life changing impact
4	Major	• Injury such as fracture of bones, dislocation, or acute ill health e.g. occupational asthma, occupational dermatitis
3	Medium	• An injury that requires first aid treatment and subsequent treatment by health care professional • No lost time illnesses and no chronic/acute health effects
2	Minor	• An injury that requires basic first aid treatment such as administering a plaster, individual able to continue at work e.g. minor cuts, bruising, abrasions, strains or sprains
1	Negligible	• Superficial or no physical injury or health effects

LIKELIHOOD (considered WITH controls in place)		
5	Almost Certain	• Will occur/greater than a likelihood of 1 in 1(yr)
4	Likely	• Known to occur/probably occurs most circumstances/No greater than a likelihood of 1 in every 10
3	Possible	• Might occur /no greater than a likelihood of 1 in 1000
2	Unlikely	• Not likely/could occur at some time/no greater than a likelihood of 1 in 10,000
1	Very Unlikely	• May only occur in exceptional circumstances/no greater than a likelihood of 1 in 100,000