Space Enterprise at Berkeley

Eureka-1 Safety Report

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1 Safety

This safety report provides a detailed account of the guidelines and procedures Space Enterprise at Berkeley follows when working with the Eureka-1 rocket. Furthermore, this document outlines all required safety documentation as required by the Friends of Amateur Rocketry for participation in the Dollar Per Foot Challenge.

1.1 Personnel Safety

The most critical operation in rocketry is personnel safety. Due to the inherent dangers present when working with highly volatile materials and potentially hazardous situations, operational standards must be considered at all times. To minimize the risk to personnel, each of these dangers must be made clear to each member of the team, whether they operate on the system and its sub-components or not. Personnel that physically work with the system must be attentive to potential risks or points of failure of the system at all times and work to prevent dangerous situations. All members, not just those in close proximity with the system, must be made aware of system risks, inform and remind others of proper safety procedures, and be knowledgeable on how to respond if a dangerous situation does occur. To ensure safety procedures are followed by all personnel, new members are required to complete safety training before beginning their work. This training, led by the Chief Safety Officer, emphasizes and informs members of the potential dangers of rocketry, of required Personal Protective Equipment (PPE), and of our operational standards.

1.2 System Safety

Personnel safety is dependent on the physical state of the systems that members are expected to operate on. The team must be knowledgeable of the situations that could develop at any moment due to dynamic factors such as high pressures, cryogenics, and flammable substances. While human error may be the cause of some safety risks, it is crucial that all systems be physically resistant to such errors to account for occasional and unavoidable mistakes.

1.2.1 Pressure

The first of three primary dangers that rocketry presents are high pressures. All propulsion systems on E-1 operate at high pressure, with a Maximum Expected Operating Pressure (MEOP) of 4,500 psi. Even at lower pressures, failure to adhere to proper operating procedures can result in serious injury or death.

Pressure is dangerous due to the stored energy contained within the pressurized system; when a pressure vessel is breached, the compressed gas will expand, sometimes explosively. Furthermore, pressure-induced stresses can cause pressure vessels to become structurally compromised over time. Repeated pressurization and depressurization at higher than nominal pressures imply cyclic loads, which can lead to eventual deformation or even catastrophic failure. When operating procedures are followed, these stresses can be managed indefinitely.

The most effective means of preventing catastrophic pressure-related risks are by using components well within their respective factors of safety. High pressure nitrogen gas is stored at up to 4,500 psi in a DOT (Department of Transportation) rated pressure vessel with a factor of safety of 4.9. Even with an exceptionally high safety factor, the ability for the tank to always vent through software-controlled remote valves and manual vents has been implemented. The propellant tanks are expected to operate at significantly lower pressures, but have a different set of safety parameters since they are operated at cryogenic temperatures.

One source of high pressure is through procedural pressurant fill, which is controlled via remotely operated valves. When pressurant procedures begin, personnel are required to wear PPE, maintain a safe distance from the system, and strictly follow written procedures.

Another source of high pressure is autogenous pressurization in the propellant tanks due to the use of cryogenic liquids that boil off as gas at ambient temperatures. This is monitored during and following propellant fill and managed through controlled venting of excess gas in the tanks. Because of this, each tank has four depressurization techniques. The first is a manual vent on the rocket, which can be used during fill procedures. The second is the Rocket Emergency Depressurization System (REDS), which operates independently of other electronics, and is controlled both manually and electronically. The third is an independent mechanical valve which opens automatically at a pre-set pressure. Finally, the main valves act as a final relief system. In the unlikely case where all three valves fail to relieve pressure from the tanks, the main valves can be manually opened and act as a high flow rate vent system. These multiple sources for venting serve as redundant checks for over-pressurization, and combined, significantly lower the possibility for critical failure.

Pressure must also be considered when operating the main valves, which are actuated by pneumatic cylinders. As this system is isolated from other pressure systems on E-1, there are multiple electronic and manual vents that can be remotely and directly opened to relieve potentially dangerous pressures. Furthermore, the dome-loaded regulators used for controlling downstream system pressures have a pilot volume that is filled to a set pressure and may be vented via a manual vent. Due to the extremely low volume of this pilot port, the danger posed by this important but isolated pressure system is low. Regardless, precautions are always taken when working with pressurized systems of all magnitudes.

1.2.2 Cryogenics

The second of the primary dangers is the use of cryogenic liquids. A cryogen is defined as a substance at or below -150°C (-238°F). Like with high pressure, the team must take extraordinary measures to ensure personnel safety when handling substances of this nature.

Cryogens are most dangerous due to their cold temperatures. At -150°C, many other liquids freeze, including water. This can freeze valves, vent ports, and other system-critical components. To prevent this, any system or container that is expected to be in contact with cryogens is thoroughly cleaned and dried before use.

Cryogenic contact with human skin can cause frostbite and freeze burn, with consequences similar to that of a heat burn. Cryogens can also bring down the external temperatures of uninsulated containers and other materials. Cooled materials will cause flesh to stick and potentially tear if there is a forced removal attempt. To prevent this from happening, all personnel operating around cryogens should wear proper PPE, including a face shield, cryogen rated gloves, and a cryogen rated apron.

Cryogens are also dangerous because of their volatility, most often caused by large volume expansion ratios from liquid to gas that many cryogens exhibit as they warm and evaporate. Liquid cryogens start to boil at around -190°C, releasing large amounts of gas into the area. The cryogens used during E-1 devleopment have high expansion ratios of 1:861 for LOx and 1:694 for LN2. This means that for every unit volume of liquid oxygen, it will boil off to occupy 861 times its original volume in its gaseous form. In a closed container, the gas will quickly build pressure, which can lead to an overpressurization event. In this scenario, there exist all of the risks associated with high pressures, but the cryogenic temperatures will also make many materials–such as metal–brittle. This means that this type of cryogenic overpressurization event will not simply tear open a pressure vessel, but shatter it, releasing shards of the material to fire in all directions.

Furthermore, the large volume of gas released from a cryogen will easily and rapidly displace the air in the surrounding area. When handling liquid nitrogen, this can lead to displacement of all oxygen in the area, which can lead to asphyxiation of surrounding personnel and operators. While the boiloff of liquid nitrogen is often easy to spot, it is colorless and odorless in its gaseous state, making it impossible for an operator to notice its presence. This can lead to loss of consciousness through asphyxiation, potentially without any noticeable symptoms, and subsequently death if caution is not taken when operating with liquid nitrogen. Liquid oxygen can cause slightly different–but equally as catastrophic–situations when boiling off. Oxygen is a colorless, odorless oxidizer, meaning it is highly flammable. Combustion of incompatible materials, like oil, grease, hair, asphalt, kerosene, cloth, and tar, can occur with any small spark to result in a fire or explosion. To reduce the chance of gaseous buildup during fill procedures, fill should always be performed in open spaces, with venting performed a safe distance from personnel and the system. Furthermore, lighter gasses should be vented higher up in the air, while heavier gasses should be vented lower to prevent mixing.

1.2.3 Flammables

The third of the primary dangers the team must consider is the use of flammable substances. Very generally, a flammable substance is anything that can combust. Due to the potential for serious harm or death if not handled properly, there are extensive procedures in place when members interact with any flammables.

There are three requirements for any substance to combust: fuel, oxygen, and heat. Remove one and combustion will not occur. To guarantee personnel safety, all substances that may combust are used in isolation without one of these core requirements, except for controlled testing in specialized facilities. For example, the team utilizes propane without LOx or an ignition source, and black powder without an ignition source and in low quantities. The team elects to use LOx only at the Friends of Amateur Rocketry site, in the presence of certified pyrotechnic operators.

Given that it is in the nature of rockets to use combustion reactions to their advantage, there are several flammable materials that the team must interact with, including liquid propane, liquid oxygen, high power solid rocket motors, and black powder. Each can cause potentially hazardous situations to develop if used incorrectly or irresponsibly. The most effective means of preventing such scenarios is informing all personnel of the risks associated with working with flammable substances and maintaining an atmosphere of responsibility. Furthermore, any and all devices that produce large amounts of heat or sparks and lead to premature ignition, putting personnel at risk, are kept out of use while flammables are in use.

Liquid propane is an oil product that exists at -40°C (-40°F) at atmospheric pressure and is highly flammable in the presence of an oxidizer. Due to its highly efficient combustion with oxygen, it is E-1's choice of fuel. Liquid propane is heavier than air, and tends to pool close to the ground. Due to this behavior, the team must cordon off large areas around the system when using propane due to the risk of ignition from mundane tasks such as starting electronics or motor vehicles. Furthermore, propane is sold with an additive creating a foul smell to alert users of its presence. To ensure propane is not trapped or enclosed, the team only operates with propane in open spaces, and provides ample time for the propane to disperse before subsequent operations.

High power rocket motors and black powder have similar safety requirements, as both require some form of heat energy or electric-match to light. Rocket motors and black powder both contain the necessary fuel to burn, while black powder usually requires an external source of oxygen, which can be satisfied by atmospheric conditions. To ensure team safety, ignition sources should never be used during the production or initial assembly phase, with an understanding that the fuel will be added later on. During final assembly, care should be taken that ignition sources, such as an e-match, are disconnected and have no possibility of going live. Only during final launch operations should e-matches or other ignition sources be active and connected to firing mechanisms.

1.3 FAR DPF Requirements

In addition to E1 safety details and features created and maintained by the club, the Friends of Amateur Rocketry Dollar Per Foot Challenge (DPF) outlines its own set of safety requirements to ensure the safety of the FAR facility and personnel during static fires and launch. Each of the required safety documents is detailed below.

1.3.1 Safety Checklist

A checklist of required safety equipment and procedure is provided by FAR to ensure safe rocket operations. Each of these items have been included in the design and assembly of E-1, with the exception of a pressurant tank relief valve, which is exempted by two procedures. The pressurant tank is a SCBA tank, which is both a COTS component and DOT rated. Furthermore, in the event a depressurization is necessary, on board controls software automatically vents the tank through the propellant tanks.

- ☐ Pressurant Tank Relief Valve
- ☑ Pressurant Tank Proof Test
- ☑ Pressurant Remote Vent Valve
- ☑ Pressurant Pressure Transducer
- ☑ Pressurant Fill Port
- ☑ Pressurant Umbilical Pneumatic/Mechanical Release
- ☑ Fuel Tank Relief Valve
- ☑ Fuel Tank Proof Test
- ☑ Fuel Remote Vent Valve
- ☑ Fuel Remote Emergency Depressurization System (REDS) Connection
- ☑ Fuel Pressure Transducer
- ☑ Fuel Fill Port at Bottom of Rocket
- ☑ Valve Seals Compatible with Fuel
- ☑ Oxidizer Tank Relief Valve
- ☑ Oxidizer Remote Emergency Depressurization System (REDS) Connection
- ☑ Oxidizer Tank Proof Test
- ☑ Oxidizer Pressure Transducer
- ☑ Oxidizer Fill Port at Bottom of Rocket
- ☑ Valve Seals Compatible with Oxidizer

- ☑ Metal Components and Hoses Compatible with Oxidizer
- ☑ Components Cleaned for Oxidizer
- ☑ Pressurant Tank Safety Worksheet
- ☑ Recovery Arming Plug at Bottom of Rocket
- ☑ Pull-Off Electrical Umbilical
- ☑ Ignition Key Lockout Switch at Rocket
- ☑ Ignition Key Lockout Switch at Controller

1.3.2 Rocket Emergency Depressurization System

The Rocket Emergency Depressurization System (REDS) is an independent backup system that allows for an emergency depressurization of propellant tanks prior to launch in case of a total loss of other control systems. On E-1, both propellant tanks are connected to individually operated A2011-2M-T-TO-C204 GEMS solenoid vent valves, operated at 24 volts. Furthermore, a separate plug is mounted internally between the two propellant tanks, and each valve is connected to a pigtail from the ground. The pigtail is a separate wire from other avionics systems, and is run to the control room to ensure easy access in the case of a catastrophic failure requiring immediate depressurization of the propellant tanks.

1.3.3 Pressure Tank Safety

The following table outlines how each pressurized tank on the system was proven to be safe. On Eureka-1, the pressurant tank is a DOT rated SCBA (Self-contained Breathing Apparatus) tank. The propellant tanks are identical COTS (Commercial Off-the-shelf) tanks, and a separate but identical sample tank was water pressure tested to proof the tanks for use.

Fuel Tank	
Operating Pressure (OP) (psi)	600
Test Method	Water Pressure Test
Calculated Proof Pressure (CPP) (psi)	900
Calculated Relief Pressure (CRP) (psi)	750
Rated or Tested Proof Pressure (TPP) (psi)	900
Relief Valve Pressure (RVP) (psi)	725
Oxidizer Tank	
Operating Pressure (OP) (psi)	600
Test Method	Water Pressure Test
Calculated Proof Pressure (CPP) (psi)	900
Calculated Relief Pressure (CRP) (psi)	750
Rated or Tested Proof Pressure (TPP) (psi)	900
Relief Valve Pressure (RVP) (psi)	725
Pressurant Tank	
Operating Pressure (OP) (psi)	4500
Test Method	DOT Rated
Calculated Proof Pressure (CPP) (psi)	6750
Calculated Relief Pressure (CRP) (psi)	5625
Rated or Tested Proof Pressure (TPP) (psi)	22000
Relief Valve Pressure (RVP) (psi)	N/A

1.3.4 Rocket Safety Diagram

This diagram outlines the primary subcomponents of the rocket, and highlights all of the safety components on the system.