LAZARUS INDUSTRIES

Clatsop Community College
Astoria, Oregon

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Chairman of the Board of Directors; Head of Research and Development

Haley Werst;

Chief Executive Officer; Head of Media

Jennifer Jordan;

Chief of Business Operations; Chief Safety Officer

Sam Daire;

Chief of Manufacturing

Sean Sullivan;

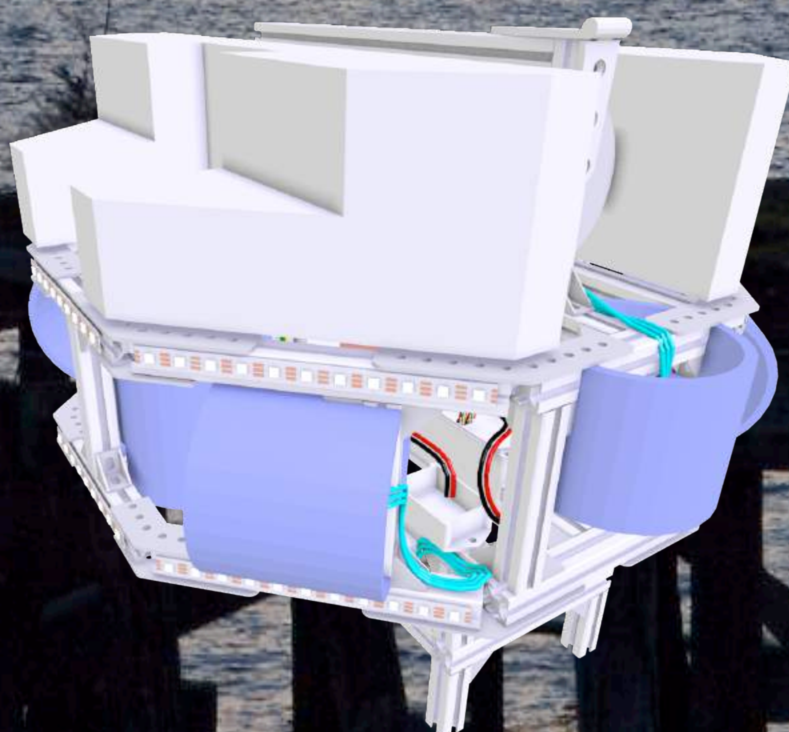
Manufacturing Technician; Head of System Testing

Pat Keefe;

Team Mentor

Iris Daire;

Team Mentor



1.0 Abstract

What follows is Lazarus Industries' response to the MATE Center and Port of Long Beach's 2017 Request for Proposals for an underwater maintenance and diagnostic ROV (remotely operated vehicle) platform. Our proposal to the MATE Center and Port of Long Beach's needs, Lazarus, is a highly capable, and cost-effective machine. Detailed below are Lazarus' exact specifications, capabilities, and limitations, as well as an overview of Lazarus Industries' company structure and industry experience. Should the MATE Center and Port of Long Beach decide to invest in Lazarus Industries' solution, cost-effective production can begin immediately, and more research and development may be conducted to produce more advanced models.

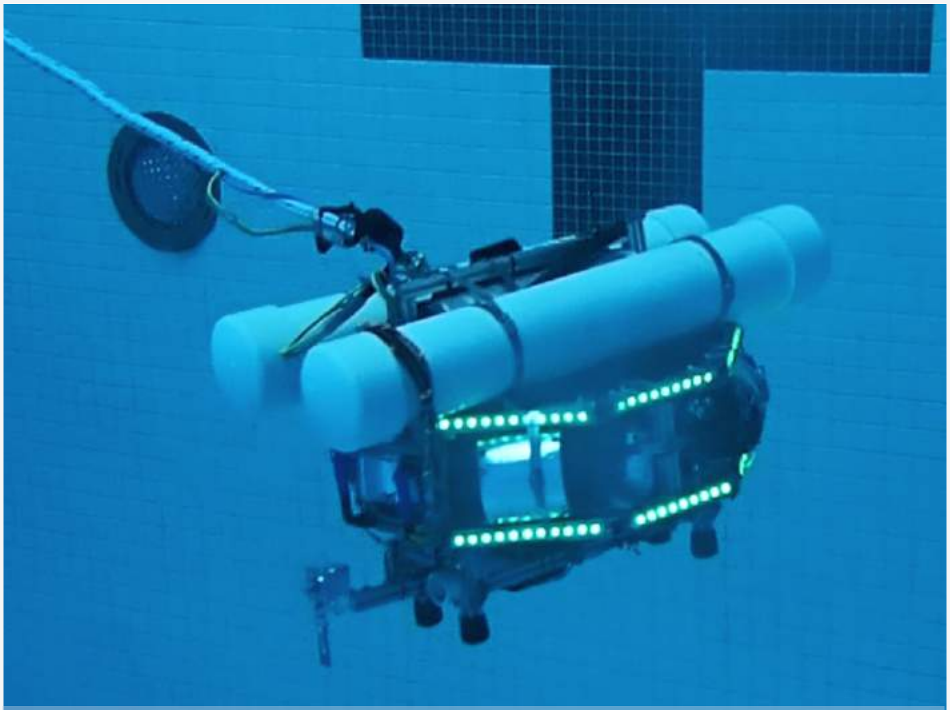


Fig 1.1: Lazarus preforming water tests at the Regional Event in Pacific City, Oregon, April 29th, 2017

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2.0 Company Overview

2.1 Company History

Lazarus Industries is founded on a deep well of underwater robotics manufacturing experience. The preceding members go back many years from the establishment of Lazarus Industries. The pivotal moment in Lazarus Industries' success was in the relative failure of its predecessor, S.Q.U.A.D. (Specialized tasQforce for Underwater Advanced Development). The S.Q.U.A.D. company competed last year in Houston, Texas at the 2016 MATE international ROV event. Immediately following the 2016 company's dissolution, Lazarus Industries was restructured from the ground up aspiring to learn from the shortcomings of the past, both in leadership and design, and advance towards the future. This renewal is the inspiration for Lazarus Industries' name, and the name of its titular ROV (underwater Remotely Operated Vehicle), Lazarus. They are a company reborn from the ashes of the old, cured of their ills.

The history of Lazarus Industries' members dates back to late 2013 with the involvement of Georges Oates Larsen, Lazarus Industries' founder and Chairman of the Board of Directors (CBD). Oates Larsen spent two years gaining experience leading the development of a variety of simple ROVs, including the 2014 MATE international competition qualifier, Sumphero. Oates Larsen's respective teams in 2014 and 2015 chose not to attend the international competition in order to spend time improving upon their designs.

In summer of 2015, Sam Daire, Lazarus Industries' Chief of Manufacturing (CoM) joined the team, along with several other employees later in the year, marking the formation of S.Q.U.A.D. This competition cycle was a technological turning point for the team. During this period of time, S.Q.U.A.D. developed many of the foundational technologies used in Lazarus, including power distribution topologies, subsystem communications protocols, a variety of prototypal manufacturing techniques, early versions of their thruster technology, and early versions of their control architecture.

Thus, we arrive at the formation of Lazarus Industries. Having learned from their failures, they have redesigned both their ROV, and team structure from the ground up, incorporating prior manufacturing methods and past teams' strengths, while systematically eliminating their weaknesses. Joining the ranks of Lazarus Industries this year are the company's Chief of Business Operations (CBO) Jennifer Jordan, Chief Executive Officer (CEO) Haley Werst, and Manufacturing Technician (MT), Sean Sullivan.

Fig. 2.1.1: Lazarus Industries; left to right, Pat Keefe, Haley Werst, Jennifer Jordan, Sean Sullivan, Sam Daire, Georges Oates Larsen

2.2 Company Structure

Lazarus Industries is a small, innovative company. Because of their size, each employee is required to dip their fingers between all of the traditional engineering firm departments. In addition to the employees' designated primary roles, it is not uncommon to see them occupying a variety of official positions, or working in departments outside their primary field of specialization. While this may seem undesirable at first, through the use of innovative team management solutions, they have found this type of structure to be immensely helpful and efficient. Having company members cross-trained to several departments builds team morale and maximizes design synchronization and turnout speed.

Leading the operation is Lazarus Industries' Chairman of the Board of Directors (CBD) and Head of Research and Development (HoR&D), Georges Oates Larsen. Oates Larsen is responsible for high-level team-management, overall system design, electrical design, programming, and overall team vision guidance. Oates Larsen, being deeply familiar with Lazarus's design and programming, also serves as the ROV's pilot.

Serving directly under the CBD is Lazarus Industries' Chief of Business Operations (CBO) and Chief Safety Officer (CSO), Jennifer Jordan. As CBO, Jordan is delegated, by the CBD, responsibility for all aspects of team-management and team vision guidance relating to business operations; this includes fundraising, community outreach, company activity coordination & logistics, budgeting, and technical/company presentation. As CSO, Jordan is in charge of developing, training, and enforcing all safety protocols observed by Lazarus Industries employees. Jordan also serves as a highly-skilled electrical engineer, aiding, and in many cases taking over for the HoR&D on electronics layout and manufacturing tasks. Finally, Jordan serves as mission analyst during ROV operations.

Also serving directly under the CBD is Lazarus Industries' Chief Executive Officer (CEO) and Head of Media (HoM), Haley Werst. As CEO, Werst is responsible for managing company manufacturing, testing, and design operations in the absence of the CBD/HoR&D. This position is incredibly important, as the CBD/HoR&D interacts with the rest of the company in large part via telepresence, and at most times, cannot be directly involved on-site. Werst also manages business operations coordination, when delegated such tasks by the CBO. As HoM, Werst works under the CBO managing certain aspects of online outreach, such as Facebook presence, as well as production of company media, such as photographs, promotional videos, and company event fliers and notifications. During ROV operations, Werst also serves as a co-pilot.

Serving under the CEO and HoR&D is Lazarus Industries' Chief of Manufacturing (CoM), Sam Daire. Daire manages company manufacturing operations, either completing, or, at times, delegating, manufacturing tasks issued by the HoR&D and ensured by the CEO. Daire utilizes his broad range of manufacturing knowledge and experience, serving as a technical advisor to the CEO and HoR&D on matters of material science, system design, and manufacturing approach. During ROV operations, Daire also serves as tether technician and intermittent ROV technician.

Serving directly under the CoM and CBD is Lazarus Industries' Manufacturing Technician (MT) and Head of System Testing (HST), Sean Sullivan. As HST, Sullivan manages the production of Lazarus testing apparatus, such as competition props. Sullivan's responsibilities include managing prop construction, deconstruction, and transport. Sullivan ensures prop design accuracy and testing apparatus part acquisition. As a MT, Sullivan is responsible for a wide range of manufacturing, testing, and development tasks issued by the HoR&D and CoM, serving as a backbone to Lazarus Industries' operations. During ROV operations, Sullivan serves as Lazarus Industries' ROV technician and parts manager.

2.3 Project Management

A robust ROV begins with robust team and project management. To accomplish this, Lazarus' Development was separated into four stages: Stage 0: Pre-Planning, Stage I: Platform Development, Stage II: Platform Specialization, and Stage III: Pilot Training / Documentation Development. Stage 0 was arranged to be completed over the summer. Stage I was planned to be completed over fall term. Stage II and III being completed simultaneously during winter term. This projected timeline left Spring Term as a safeguard to help mitigate any setbacks.

Due to Lazarus Industries limited manpower, getting a head start on development was crucial. As such, system development had to be split into two stages; Stage I (Platform Development) and Stage II (Platform Specialization). This decision was made so that Stage 0 (Pre-Planning) and Stage I could begin at the beginning of summer in 2016, with Stage II taking place after the official release of the 2017 Request for Proposals (RFP).

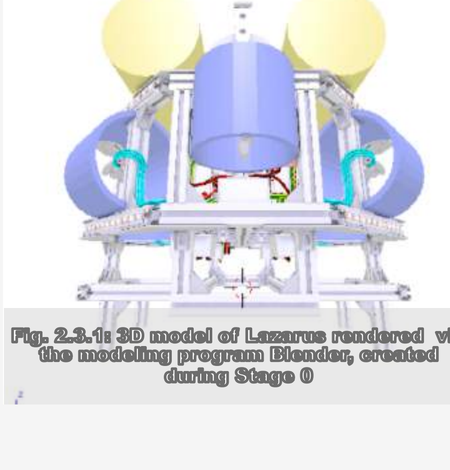


Fig. 2.3.1: 3D model of Lazarus rendered via the modeling program Blender, created during Stage 0

Stage 0 consisted of intensive research conducted by the HoR&D, who read and familiarized himself with the entirety of the technical literature on the 2016 competition ROVs, as well as select literature from the 2015, 2013, and 2010 competitions. Based on this literature, as well as experience gained at the 2016 international competition, the HoR&D developed a specialized type of task-list known as a Notion Implementation Pool (NIP); this document synthesized and itemized all of Lazarus's ideal platform properties. Platform properties specifically refer to the non-specialized aspects of Lazarus's design. Lazarus Industries' HoR&D used the design elements from the NIP to develop computer-assisted models of Lazarus's thruster arrangement, frame, power distribution, and data communication networks. Stage 0 was completed by the end of summer 2016 with a full digital model of Lazarus with no specialized aspects and the complete NIP document.

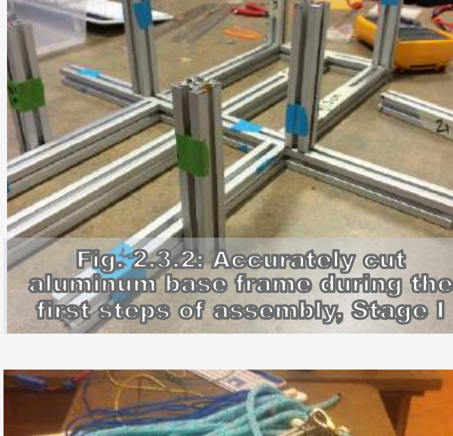


Fig. 2.3.2: Accurately cut aluminum base frame during the first steps of assembly, Stage I

Stage I encompassed the manufacturing of Lazarus and the development of aspects relative to the RFP Port Maintenance theme. The NIP document developed during Stage 0 was accessible to all company members via Evernote, a file-sharing site. Each item on the NIP was split into several sub-lists, detailing the present plan of action, present unsolved issues, planned research activities aimed at resolving unsolved issues, research references, and resources. Company members consistently updated the NIP; the document was easily scanned for concurrent next-steps, and items were removed as they reached their completion. The NIP's comprehensibility allowed for extremely accurate project progress monitoring, efficient task distribution, and preventing minute details from being inadvertently missed.

Fig. 2.3.3: Lazarus fully assembled during Platform Specialization, Stage II

In spite of this optimization, major setbacks and developmental challenges occurred throughout the completion of Stage I, forcing Stage II and III to begin much later than intended. Considering these setbacks, company members began Stage II, developing payload, camera placement, and RFP specific tools, prior to the completion of Stage I. The aforementioned buffer-time built into the original plan was crucial to this being successful.

Upon the completion of Stage I, Platform Specialization (Stage II) and Pilot Training / Documentation Development (Stage III) were conducted concurrently, and in tandem. While this was not the original plan laid out by Lazarus Industries, thanks to the company's planned buffer time and strong management skills, the development cycle was greatly accelerated and ultimately allowed for Pilot Training and Platform Specialization to be especially well-suited for concurrency.

Fig. 2.3.4: Company members mingling with the public at one of their fundraising events during Stage III

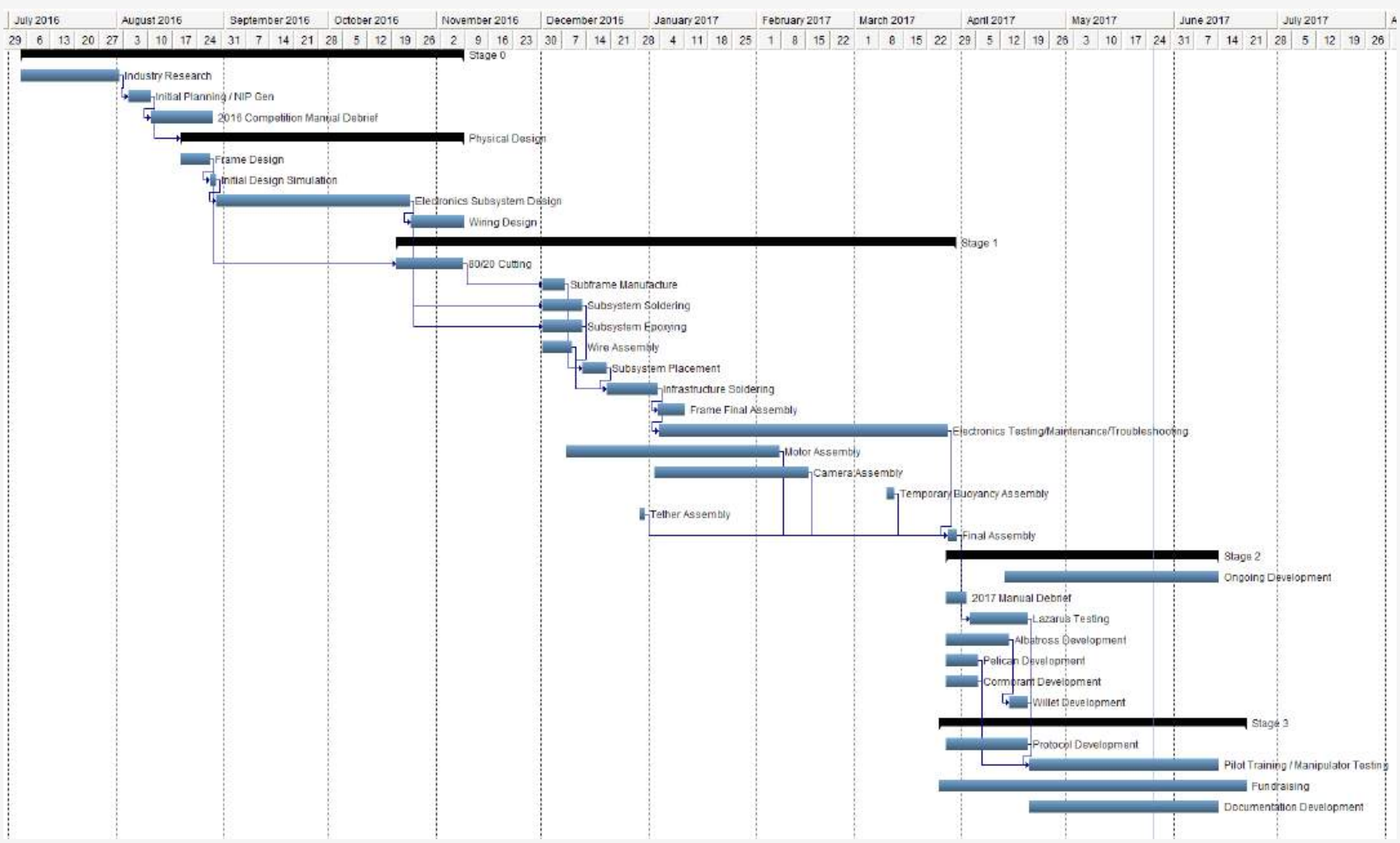
Company management is accomplished using a variety of innovative solutions. This is necessary, with the CBD operating in large part via telecommunications. Tasks are delegated and monitored by the CBD, CBO, CEO, and CoM via the Asana distributed task management platform. All documents are managed and shared through Evernote, such as the NIP, or Google Drive, such as photographs, videos, and protocols. All employees communicate directly using the Discord online chat and voice platform, mostly via text, though sometimes with voice. Use of these online technologies allows very efficient and accurate task management, and enables all employees to communicate with one-another instantly and effectively, regardless of their location or circumstances. Most importantly, these technologies allow the CBD to stay heavily involved in company operations, even at a distance.

Fig. 2.3.5: Company members at their public demonstration / meet and greet event that took place during Stage III

Of course, system development is only half the battle for an engineering firm. Throughout all of these processes, our CBO worked closely with the CBD to concurrently manage community outreach, fundraising, and preparation for technical/company presentations. This component of company management is a key distinguishing factor between Lazarus Industries, and its predecessors. Lazarus Industries was incredibly deliberate in creating and filling the CBO position, ensuring at least one employee was dedicated to managing and planning business operations at all times.

Altogether, Lazarus Industries' employees have dedicated over 6000 hours designing, producing, and working with Lazarus.

2.4 Project Timeline



3.0 Vehicle Design

3.1 Design Rationale

One of the most important lessons Lazarus Industries learned from its predecessors was the importance of ROV ergonomics, manageability, and aesthetic design. The design of Lazarus holds serviceability, ergonomics, manageability, and aesthetics as paramount. The result is an incredibly stable, usable, and safe design. System design started with the aforementioned Notion Implementation Pool (NIP). Specific design aspects, or "Notions," were identified as being particularly influential to Lazarus's structural arrangement: Thruster arrangement/Operational Degrees of Freedom, handle placement, Payload Placement, Supporting Electronics Placement, wire/tether management, and overall size limitations.

Lazarus Industries settled on the following design goals:

1. Thrusters capable of supplying all 6 degrees of freedom.
2. Ergonomically placed handles allowing Lazarus to be carried with both hands by two personnel at all times.
3. Upper and lower deck for supporting subsystems and payload respectively.
4. Robust offsets on undercarriage allowing for safe set-down and preventing payload damage.
5. Removable central control core and serviceable supporting electronics.
6. Aesthetically pleasing, robust and well-managed overall look.

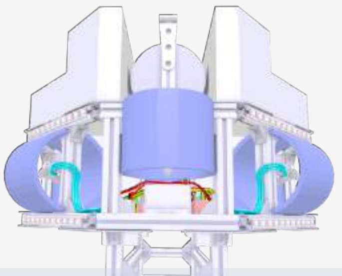


Fig. 3.1.1: 3D render of Lazarus' design

To satisfy these design goals, Lazarus Industries settled on an Octagonal, 8-thruster vectored-thrust arrangement, with four lateral, and four vertical thrusters. Six degrees of freedom might have been accomplished with only 6 thrusters, but this was found to be incompatible with the upper/lower deck design goal and undercarriage offsets. Arranging these thrusters into an octagon maximizes torque, minimizes water flow interference, optimizes frame-design, and creates hollow space in the upper deck for supporting. The octagonal design is also extremely clean, robust-looking, and aesthetically pleasing.

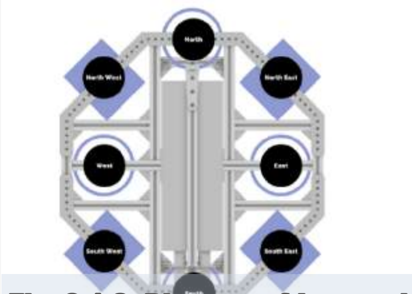


Fig. 3.1.2: Diagram of Lazarus' thruster arrangement

To accommodate the control core and buoyancy, an upper deck above this central octagon was added, with a hinged bar holding the control core in place. A lower deck / undercarriage was also added to the design, providing the desired support offsets, and offering easily reconfigurable payload attach points.

Before continuing the design process, this design concept was quickly tested via simulation based on the 2016 competition tasks and real-world thrust data from prior ROVs. The design concept was found to be quite proficient for completing simulated 2016 tasks, and thus, final frame and electronics design commenced.

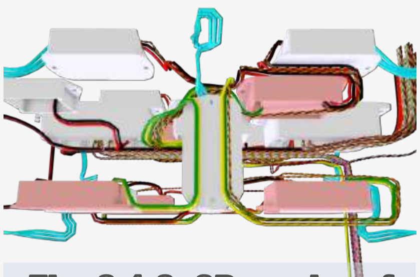


Fig. 3.1.3: 3D render of Lazarus' internal wiring

Over the course of several months, Lazarus' exact electronics subsystems arrangement, wiring, and features were refined and finalized via Computer Aided Design. Meanwhile, Lazarus Industries employees conducted various research experiments, developing new manufacturing techniques for thrusters, obtaining component behavioral data, and determining various specifications required for final parts-order. When parts arrived, and construction finally began, 90% of Lazarus was constructed over the course of only three weeks. The remaining 10% took several months due to various design and manufacturing issues.

Platform Specialization began immediately after Lazarus' construction reached 90% completion. Over the course of several months, various manipulators and camera arrangements were developed and tested independently, ultimately resulting in the payload presented later in this document.

3.2 Thrusters

Fig. 3.2.2: The final motor waterproofing method later replaced by M100 motors

Lazarus Industries presently utilizes Blue Robotics M100 motors and associated propellers, for their superior robustness, waterproofness, and thrust/power characteristics. Lazarus Industries spent a total of 2 months testing a variety of other motor and propeller combinations, even settling on one, and spending 2 more months developing a robust waterproofing method for them. Due to their handmade nature, these motors were subject to slow mechanical failure, requiring gradual replacement.

This, in combination with a low waterproofing success rate, and drastic increases to the price of Lazarus Industries' original motor choice, meant that the Blue Robotics M100 motors were the best option. The M100 motors are not only a cost-comparable choice but have far superior operating characteristics and immense manufacturing-time savings. Hence, all Lazarus' handmade motors were replaced with the Blue Robotics M100s. The motor waterproofing methodology that Lazarus Industries developed before switching to Blue Robotics M100 motors is heavily based on the notes published on the subject by SV Seeker. (See Reference 4)

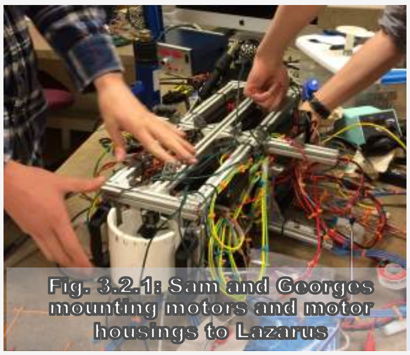


Fig. 3.2.1: Sam and Georges mounting motors and motor housings to Lazarus

A variety of possible motor arrangements were 3D-modelled and considered for robustness and complexity. Ultimately, Lazarus Industries settled on an 8-thruster setup, arranged in two sets of four, the first being a standard vectored thrust arrangement, and the second being entirely vertical. This arrangement offers Lazarus six degrees of freedom, enabling pilots to tilt, rotate, strafe, ascend, and descend as desired. Arranging the thrusters into an octagon optimized mounting point accessibility for each thruster and also minimized the complexity of Lazarus' frame. The thrusters are powered by 12V Tri-Phase Alternating Current (AC) supplied by Lazarus' Electronic Speed Controllers (ESCs).

3.3 Frame

Lazarus' Frame was designed with Lazarus' ideal capabilities in mind. Lazarus Industries' primary design concern was ensuring mounting locations for thrusters, buoyancy, payload, supporting electronics, and the control core. Once Lazarus Industries had settled on a general motor arrangement (four lateral-vectored-thrust, four vertical) several possible arrangements were tried and the required mounting geometries extrapolated. Ultimately, it was found that arranging the frame and motors in an octagonal fashion led to the greatest design simplicity. From there, support points for buoyancy, the control core, supporting electronics, and a mounting point for payload undercarriage were added, all while respecting the MATE center's standard requested size restrictions.

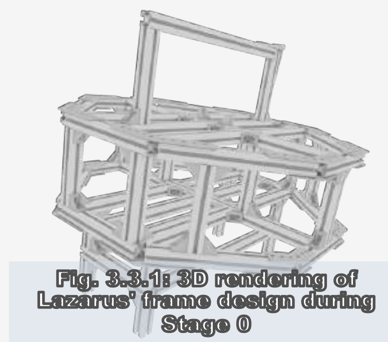


Fig. 3.3.1: 3D rendering of Lazarus' frame design during Stage 0

The frame of Lazarus is constructed from 80/20 extruded T-slot aluminum, this material is lightweight, strong, cost effective, readily machinable, and corrosion resistant. 60% of Lazarus' Frame is constructed from 80/20 salvaged from its predecessor, Maggie. Designs built from 80/20 can easily be reconfigured, and 80/20 used can easily be recycled, thanks to the modular, bracket-and-beam design. The slotted nature of 80/20 allows Lazarus Industries to easily mount necessary components, such as thrusters and supporting electronics, on any location along the structure. Such components are easily replaced or reconfigured when necessary. Ergonomically placed handles allows Lazarus to be carried with both hands by two personnel at all times. Lazarus Industries' choice in frame material is the source of Lazarus' superior adaptability and flexibility.

Fig. 3.3.2: Lazarus' frame being assembled by company members during Stage I

3.4 Control Core

Lazarus' Control Core pressure housing is recycled from Lazarus' predecessor, Maggie. It is a lathed tubular aluminum housing with a grey epoxy endcap. The endcap has two slots-for O-rings, forming a double seal when fully inserted into the aluminum tube. The endcap has a single O-ring pressure release, and four Seacon bulkhead connector pass-throughs. The Marine and Environmental Research and Training Station (MERTS) donated this pressure housing to Lazarus Industries last year. Prior to Lazarus Industries' acquisition it was a housing that had been used years ago for ocean-depth CMOP (Center for Coastal Margin Observation & Prediction) operations.


Fig. 3.4.1: Control core with a double O-ring gasket and Seacon bulkhead connectors

The control core housing contains the brains of Lazarus. Inside is a Raspberry Pi 2, Arduino Mega 2560, and Inertial Measurement Unit, and a variety of supporting electronics, such as a level shifter, I²C (Inter-Integrated Circuit) isolator, and Universal Battery Eliminator Circuit (UBEC) power regulator.

The Raspberry Pi 2 communicates with and manages all Lazarus non-lighting, non-camera subsystems via I²C. The Arduino Mega 2560 manages Lazarus' Wide Area Lighting / Status Indicator, and monitors for status and lighting control signals from the Raspberry Pi 2 via Serial Peripheral Interface (SPI). The Raspberry Pi is connected to Lazarus' central Ethernet switches, allowing it, and in turn all of Lazarus' subsystems, to be connected to and controlled over Ethernet by a piloting laptop at the surface.

3.5 Tether

Lazarus's tether was designed and constructed with simplicity and usability in mind. The tether is consistent of two gauge-10 copper conductors for power (selected specifically for Lazarus' maximum power draw) and a single Ethernet cable. These conductors and cable are fed through a hollow polyethylene rope, which serves both as Buoyancy and strain relief for the entire tether, making the tether almost completely neutrally buoyant. Small amounts of Blue-Robotics Subsea Foam are attached with copious amounts of silicone self-adhesive tape to bias the tether into its desired in-water shape, and to remove the slight amount of negative buoyancy not offset by the polyethylene rope.

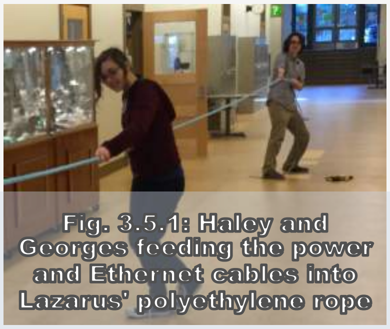


Fig. 3.5.1: Haley and Georges feeding the power and Ethernet cables into Lazarus' polyethylene rope

The tether is attached to Lazarus at its endpoint via a brass quick-release hook, and a U-bolt mounted to Lazarus' frame. Ethernet and power are wired into Lazarus via dry-mate Seacon connectors donated to Lazarus Industries by MERTS. These connections are given minimal but sufficient excess length so that all stress on the tether is transferred to Lazarus via the quick release hook, rather than via Lazarus' electronics, at all tether angles. This design is simple, effective, clean, and meets all specifications laid down by the MATE Center and the Port of Long Beach.

3.6 Electronics

3.6.1 Wiring and Waterproofing Standards

Fig. 3.6.1.1: Jennifer performing wire management and waterproofing soldered joints

One of Lazarus' key distinguishing features over its predecessors is its wiring management and electronics mounting methodologies. Because Lazarus Industries does not possess the funding or manufacturing equipment to produce spacious custom pressure housings, Lazarus Industries opts, instead, to situate all electronics directly in the water. To accomplish this, Lazarus' electronics are separated into distinct, replaceable subsystems, and epoxied inside plastic boxes with bolt-holes allowing the finished products to be mounted directly onto Lazarus' frame. The end-result is an electronics setup that is very simple to manufacture and is incredibly serviceable.

All of Lazarus' wiring was 3D modeled before construction began, allowing Lazarus' wiring to be cut to length, and assembled separately into flat cables, and then later soldered onto Lazarus' subsystems as separate components. All wires on Lazarus are color-coded according to their use and rating. The result is an incredibly clean and serviceable wiring job on an incredibly complex and nuanced machine. Lazarus contains a total of around 180 wires. Lazarus' color codes are as follows:

- Yellow/Green Gauge 14: 48V Power
- Red/Black Gauge 14: 12V Power
- Blue Gauge 14: Thruster Tri-Phase AC
- Red/Grey, Red/Brown, Red/Blue Twisted Pair: 12V or 5V power.
- White/Gray Twisted Pair: SDA/SCL for I²C
- Orange/White, Green/White Twisted Pair: RX/TX for Ethernet
- Purple/Orange Twisted Pair: Neopixel Signal
- Yellow/Grey, Yellow/Brown Twisted Pair: Stepper Motor Power
- Yellow/Blue Twisted Pair: PWM Signal


Fig. 3.6.1.1: Wire orginazation and color-coordination

All Lazarus wiring is constructed into cables according to a strict zip-tie wiring standard. Wires are bound together with evenly spaced zip-tie weaves; forcing Lazarus' wires into flat, parallel arrangements. Wires are cabled together in this way according to their function. The following cable types are employed on Lazarus:

- 3 Conductors, Blue Gauge 14 wires: Thruster Tri-Phase AC.
- 12 Conductors, Yellow/Green Gauge 14: Main Power Bus
- 4 Conductors Red/Black Gauge 14: 12V Power Busses
- 4 Conductors Red/Grey, Grey/White Twisted Pair: I²C Bus
- 24 or 6 Conductors Red/Grey, Orange/White, Green/White Twisted Pair: Ethernet Busses & Channels
- 16 Conductors Yellow/Blue Twisted Pair: Thruster Signal Bus.


Sam Diare, CoM, working on motors

All in-water connections and splices are waterproofed utilizing hot-glue and 3:1 ratio adhesive-lined clear heat shrink. Heat shrink is placed over the connection to be waterproofed, and then injected with hot-glue. The connection is then heat-gunned until the heatshrink is fully contracted, and all air-bubbles inside are removed. The transparency of the heatshrink allows for soldering quality to be inspected, and air-removal to be ensured. This technique is the same as was employed on Lazarus' predecessor and is reliable to great depths. Marine engineers for ocean-depth missions often employ this technique. This technique is recommended for depths exceeding 5000 meters by UNOLS (University-National Oceanographic Laboratory System) (See Reference 1).

3.6.2 Central Power Junction

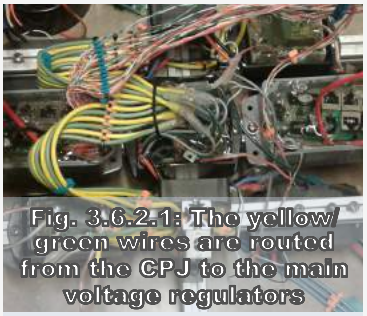


Fig. 3.6.2.1: The yellow/green wires are routed from the CPJ to the main voltage regulators

All 48V power from Lazarus' tether proceeds directly into Lazarus' Central Power Junction (CPJ), where it is passed by a voltage monitor, split up, and passed through several subsystem current monitors, before exiting and being routed to Lazarus' six Main Voltage Regulators. These voltage and current sensors are powered via Lazarus's Auxiliary 12V bus, and interface over I²C via MCP3422 16-bit Analogue to Digital Converters.

3.6.3 Main Voltage Regulators

Once 48V power passes through Lazarus' Central Power Junction, it is routed to Lazarus' six Main Voltage Regulators. Each regulator is a QBVW033A0B Barracuda (See Reference 2) series 48V to 12V isolated DC switching regulator, with a 95.5% efficiency rating, over-current, over-temperature, short-circuit, output over-voltage, and input under-voltage protection, and 30A maximum output.

Four of these regulators are dedicated to Lazarus' thrusters, with two thrusters for each regulator. The remaining two produce 12V power for Auxiliary and Control subsystems respectively. Auxiliary and Motor power is separated from control power for noise reduction on control subsystems. This is possible due to QBVW033A0B's built-in isolation capabilities.

3.6.4 Electronic Speed Controllers


Fig. 3.6.4.1: One of eight ESCs prepped for waterproofing

All of Lazarus' thrusters are powered and controlled by heavily retrofitted hobbyist Electronic Speed Controllers (ESC). Each ESC receives a pulse width modulation (PWM) signal indicating desired output thrust percentage, and utilizes back-EMF sensed on its thruster's coil windings to produce timed three-phase alternating current, and drive its thruster at this desired output thrust percentage.

Each ESC is flashed with Lazarus Industries customized SimonK ESC firmware, allowing for thruster reversibility, increased control signal precision, and improved motor efficiency.


Fig. 3.6.4.2: All eight ESCs potted in epoxy undergoing the curing process

Each ESC is also retrofitted with a 100µF 25V capacitor on its power input, to snub out sudden current draw due to motor directional switch during aggressive piloting. Lazarus' predecessor, Maggie, was subject to system-wide sudden-shut-down due to sudden current draws creating back-EMF and voltage-drop on the tether, and causing its main power regulators, related or otherwise powering motors, to panic and shut down. The addition of these capacitors completely solves this issue.

ESCs are rated for 12V and a maximum current draw of 20 amps, though, through extensive testing, Lazarus Industries has determined a maximum operational draw of only 12A for each thruster.

3.6.5 Sensor Core

Fig. 3.6.5.1 Lazarus Industries MS5837-30BA pressure sensor

Lazarus is equipped with a BNO055 I²C Inertial Measurement Unit with built-in sensor fusion, and a Measurement Specialties MS5837-30BA I²C pressure sensor, allowing for precise automatic state estimation and assisted piloting functions, such as automatic depth and orientation lock. These units receive power from Lazarus' Control 12V bus, and interface directly via Lazarus' I²C bus. The sensor core is equipped with standard level shifters, voltage regulators, and I²C isolators.

3.6.6 Thruster & Servo Drivers

All brushless thrusters and servo motors aboard Lazarus are controlled by one of several Adafruit PCA9685 I²C PWM driver breakout boards. These drivers produce PWM signals of varying specifically timed duty cycles in order to communicate target thrust or target angle information to brushless thrusters or servo motors respectively. All PWM signals are transmitted over twisted pair along with a reference ground to minimize electromagnetic interference. Each PWM generator is equipped with standard voltage regulators and I²C isolators.

3.6.7 Stepper Motor Drivers

All stepper motors aboard Lazarus are controlled by one of several Stepper Motor Drivers, constructed out of slightly modified Adafruit DC Motor + Stepper FeatherWings, which, upon reverse engineering, were found to be minimalistic breakout boards for PCA9685 I²C PWM drivers and TB6612 Dual H-Bridges. The PCA9685 chips are configured over I²C to run at their minimum frequency, and their outputs given the correct duty cycles and phase shifts to drive brushless motors connected to the H-Bridges either clockwise or counterclockwise. Adjusting the PCA9685's global frequency controls speed. Changing the phase shifts on the PCA9685 PWM outputs controls direction. Each Stepper Motor Driver is equipped with standard level shifters, voltage regulators, and I²C isolators.

3.6.8 Central Ethernet Switches

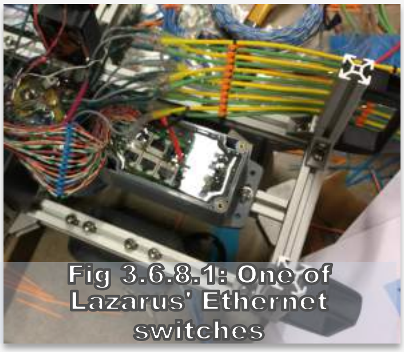


Fig 3.6.8.1: One of Lazarus' Ethernet switches

Lazarus is equipped with two on-board 5-port 100 Mbps Ethernet switches, allowing for all cameras, and the control core to be connected to via a single Ethernet switch. There are a total of 10 Ethernet channels on-board, two of which are used to connect the two switches together, one of which is used to connect the control core, and one of which is used to connect the tether. The remaining six ports are used for cameras. Each switch is also modified to provide 12V power to each of its Ethernet connections. The control core and all digital cameras utilize this 12V supply. The Ethernet channels used by the tether and used to connect the two switches do not have this extra 12V line. Each switch receives power from Lazarus' 12V control bus.

3.6.9 I^2C Bus

All of Lazarus' subsystems, with exception to cameras and lighting, are controlled and interfaced with via Lazarus' I^2C bus. Though Lazarus Industries selected I^2C for its wide array of supported chipsets and ease of use, I^2C has its downsides. Typically I^2C is employed only for relatively short distance, low-noise applications, and Lazarus is neither. To combat these problems, Lazarus Industries utilizes the Texas Instruments ISO1450DR digital capacitive I^2C isolator. The ISO1450 has a number of desirable attributes.

Firstly, it allows all of Lazarus' subsystems to communicate via I^2C even when they are not all on the same power network, and without allowing electromagnetic noise to transfer between said power networks.

More importantly, however, the high-capacitance side of the ISO1450 (See Reference 3) has a maximum rated supply current 100 times that which is standard for I^2C systems. This allows the pull-up resistances employed by Lazarus to be much lower than standard, enabling Lazarus to combat the high capacitance in its I^2C line.

Haley, CEO/HoM working on frame assembly

Finally, utilizing the ISO1450 allows (and, indeed, requires) Lazarus to transmit all ISO1450 signals along with a reference ground and voltage from its control core. Lazarus' strict wiring standards ensure that this power reference follows the same path through space as the I^2C data lines, thereby reducing electromagnetic interference.

3.6.10 Wide Area Lighting & Status Indicator

One of Lazarus' most distinctive visual features is its Wide Area Lighting & Status Indicator (WALSI). The WALSI is constructed from Neopixel LED Strips cut to the desired length, soldered, inserted into a silicone tube, with this tube then injected with clear silicone and allowed to dry. The result are flexible, robustly waterproofed Neopixel strips that can be mounted anywhere on Lazarus' frame. These strips are mounted strategically around the upper and lower lip of Lazarus' main octagon, allowing them to be seen from all angles, and enabling them to serve as wide-area lighting.

Fig 3.6.10.1: Neopixel LED Strip cut to a specified length

Wide Area Lighting is the only purpose these lights serve. In fact, their most important purpose is to indicate Lazarus' operational status. The Raspberry Pi inside Lazarus' control core takes a significant amount of time to boot up, making it difficult for operators to tell if there is something wrong inside the control core, Ethernet communications, or if bootup is still in progress. To combat this, immediately after bootup, the Arduino Mega 2560 begins controlling the WALSI, displaying a progress indicator showing how far the Raspberry Pi should be into its bootup, and then switching to green once the Raspberry Pi begins sending heartbeats. Furthermore, if the Raspberry Pi does not begin sending heartbeat signals within the expected timeframe, or if heartbeats stop at any point during normal operation, the indicator light strips will begin

flashing red, to alert operators that something has gone wrong inside the control core. These indications offer key system information, enabling rapid identification of the exact state of Lazarus during a system fault, expediting the troubleshooting process, and even making normal operations more efficient thanks to the boot-up progress indicator.

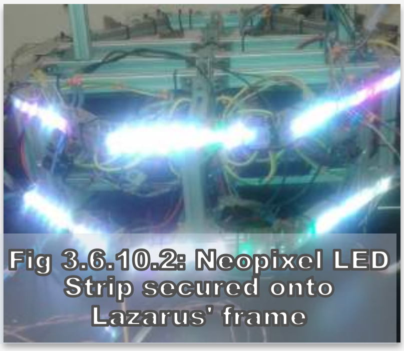


Fig 3.6.10.2: Neopixel LED Strip secured onto Lazarus' frame

During normal operations, Lazarus can send detailed status information to the WALSI, to be displayed to operators. This includes reverse mode, ludicrous mode, depth-target satisfaction, and manipulator operation modes. The WALSI is powered by Lazarus' Auxiliary 12V bus via two onboard 12V to 5V UBEC (Universal Battery Eliminator Circuit) switching regulators with 90% rated efficiency.

3.6.11 Fuse

Without software-imposed limitations, Lazarus is capable of drawing up to 32A under maximum operational load. With a software-imposed maximum thrust limit of 80%, this maximum operational load current is reduced to 22A. Thus, in accordance to the specifications laid out by the MATE Center and Port of Long Beach's Request for Proposals, Lazarus's fuse is set to 30A, or roughly 150% its maximum operational load current.

3.7 Programming

Lazarus' programming is incredibly simple and effective. Upon boot-up, Lazarus automatically starts up a multi-client TCP server capable of receiving and sending state information encoded via JSON. All clients are sent periodic updates of hardware and sensor status. All clients may, at any point, send out a JSON structure indicating desired operation states, such as target thrust on each thruster, or manipulator action status.

This incredibly simple server architecture allows all piloting algorithms to be developed separately to Lazarus' onboard computer. This has many benefits -- Including improved version management, the ability to test algorithms identically on a simulated version of Lazarus, and the ability to change Lazarus' higher-level piloting algorithms without Lazarus actually being powered on.

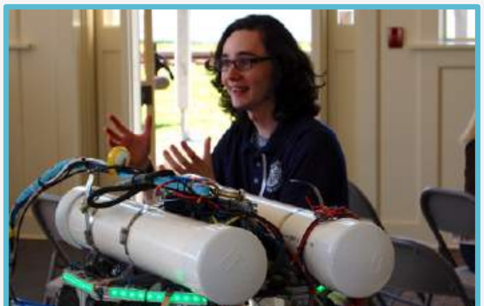

Fig 3.7.1: Lazarus demonstrating the indicating light strip program

Lazarus Industries chose to use JSON, rather than create a proprietary communications protocol for a number of reasons. Lazarus' 100Mbps uplink speed means there is no justification to attempt to optimize control data bandwidth, meaning that the primary downside of JSON, its verbosity, is moot. Meanwhile, JSON is a proven and widely available technology, with implementations already standard in most programming languages. Utilizing JSON meant a faster, more robust software development cycle.

Lazarus' Surface-Side software consists of a control client built using the Unity3D game engine, and a camera display client built using Python. Unity3D, being a 3D game engine, is well suited to the three-dimensional analysis, display, and input functions required by effective piloting software. Thruster computations are incredibly simple, consisting of a basic linear-combination of pre-programmed thrust configurations (for each cardinal direction of force and torque) multiplied by respective target torque/force coefficients input by the pilot, and summed to produce final target thrusts for each thruster.

Target thrusts and torques are input by the main pilot via a dual-joystick Belkin Nostromo N45 USB controller, supported by default by Unity3D. Joysticks are used to input omnidirectional thrust, and vertical toque. Tilting torques are input via function buttons at the back of the controller, and function buttons on the front-face of the controller change Lazarus' operational mode, and control manipulators.

Lazarus can operate in one of three power modes, each having specific purpose. The first two are Normal Mode and Precision Mode, which the main pilot can switch between via the Nostromo N45 controller. The third is Ludicrous Mode.


Georges mingling with the pulbic at a fundraising event

In Normal Mode, all thrusters operate on only 80% of their maximum thrust range, keeping Lazarus power consumption within acceptable limits.

In Precision Mode, vertical thrusters operate at 60% maximum thrust range and lateral thrusters operate at 40% their maximum thrust range, in order to allow for more precise control by the pilot.

In Ludicrous Mode, Vertical thrusters operate at 100% maximum thrust range, with lateral thrusters operating at 80% maximum thrust range. Ludicrous mode is considered dangerous, as if Lazarus is piloted improperly while in this mode, sudden current demand from the vertical motors can cause a system crash, or, at worst, blow the system fuse. Thus, Ludicrous Mode can only be toggled by the co-pilot, and sounds an alarm for the duration during which it is active, to prevent it from being left on by accident. Ludicrous Mode is only used when absolutely necessary, in situations that demand maximum lifting thrust.

3.8 Buoyancy

Lazarus presently utilizes two sealed 4-inch PVC pipes as buoyancy. However, Lazarus Industries has found these pipes to be incredibly heavy. Upgrades are presently underway to Lazarus' buoyancy. Lazarus Industries is investing in higher-cost, but lower-weight and lower-volume foam buoyancy, which will be cut and shaped to fit better within Lazarus' 58cm bounding sphere.

3.9 Payload & Cameras

Lazarus Industries has developed five payload tools. Each payload tool has been specifically designed to ensure the health and safety of our seaports. Lazarus Industries has developed several prototypes and each design has been thoroughly tested to produce the final payload tools. Each payload tool can easily be detached and reattached to the 80/20 frame; this allows for ease in transporting Lazarus and reducing the probability to causing damage to the payload tools. On account of the many mounting locations on the 80/20 frame and the spare power cables that are available, the company is able to modify and/or add on new payload devices as they see fit.

3.9.1 Modular Part-Number Specifications

All Lazarus modular subcomponents are numbered according to the following scheme:

LZS-T-UURR
T: Part-Type. C: Camera; G: General Static Manipulator; S: Specialized Manipulator; V: Claw; U: Clasp; R: Rotator
UU: Two-Digit Unique Identifier
RR: Two-Digit Revision Number


Fig 3.9.1: Willet

LZS-G-0101 Willet; The Willet acts as a multipurpose manipulator and is capable of grappling and moving objects. The Willet has a simple design and is constructed from a long angle bracket; it is reminiscent of the main manipulator employed by Lazarus' Predecessor, Maggie.


Fig 3.9.2: Albatross

LZS-R-0209 Albatross; Lovingly (and unofficially) called "The Valveatross," this manipulator is capable of encapsulating valves up to three inches in diameter and rotating them clockwise and counterclockwise. The Albatross is consists of a single stepper motor and hand-molded clear acrylic catcher with internal catching bumps formed out of hot-glue. The Albatross's use of clear acrylic ensures that operators can see the valve being turned at all times.

Fig 3.9.3: Pelican

LZS-U-0310 Pelican; The Pelican is a stationary clasp designed to manipulate the Power Connector detailed in the **Entertainment: Light and Water Show Maintenance** task specified by the MATE Center and Port of Long Beach. The Pelican has no moving parts, and is designed to snap onto the power plug. It is a lightweight, sturdy tool constructed from hand-molded 5mm acrylic sheet with the opening facing down. Lazarus' operator can pick up the Power Connector simply by pressing down on it, and release the Power Connector by entering into Ludicrous Mode, and lifting up while it is inside the Power Port.

Fig 3.9.4: Cormorant

LZS-U-0411 Cormorant; The Cormorant is a stationary clasp developed to acquire and carry the Fountainhead detailed in the **Entertainment: Light and Water Show Maintenance** task specified by the MATE Center and Port of Long Beach. The Cormorant has no moving parts, and is designed to snap onto the fountainhead. Like the LZS-U-0206 Pelican, It is a lightweight, sturdy tool constructed from hand-molded 5mm acrylic. Lazarus' pilot utilizes the Cormorant by pressing it into the fountainhead to acquire the fountainhead, or by pulling away from the fountainhead when it is in position to release it.

LZS-C-0610 Digital Camera; One of Lazarus' most advanced features is its camera system. Lazarus Industries dedicated much time and many resources to developing a brand-new digital camera system that is vastly superior to the analog cameras employed by Lazarus's predecessor, Maggie. The two key advantages of these new cameras are their weight savings, as compared to the old analog cameras, and their ability to transmit video directly via Lazarus' Ethernet line. Where past tethers were made significantly bulkier by analog coax and power cables, Lazarus' tether is unimpeded by the addition of these digital cameras

Each camera consists of a camera controller, and camera sensor. Each camera controller consists of a Raspberry Pi Zero with Enc28J60, as Ethernet adapter, and Adafruit Trinket as Neopixel driver. All components inside the camera controller communicate via SPI and I²C, and are powered from Control 12V via a UBEC 12V to 5V converter. Each camera controller is epoxied inside its own potting/mounting box.

Each Camera Sensor consists of a 170-degree FOV Raspberry Pi camera and Neopixel ring for lighting, housed inside an ABS endcap and under an acrylic dome sealed with silicone. Each camera sensor is connected to its camera controller via a CSI (Camera Serial Interface) flat flex-cable and Neopixel power/data, both of which are encased inside heat shrink insulation to prevent damage. This heatshrinked cable accesses the camera unit and Neopixel ring inside the dome via an epoxied pass-through.

Fig 3.9.5: Digital Camera Controller and Camera

Fig 3.9.6: Digitial Camera

3.10 System Specifications

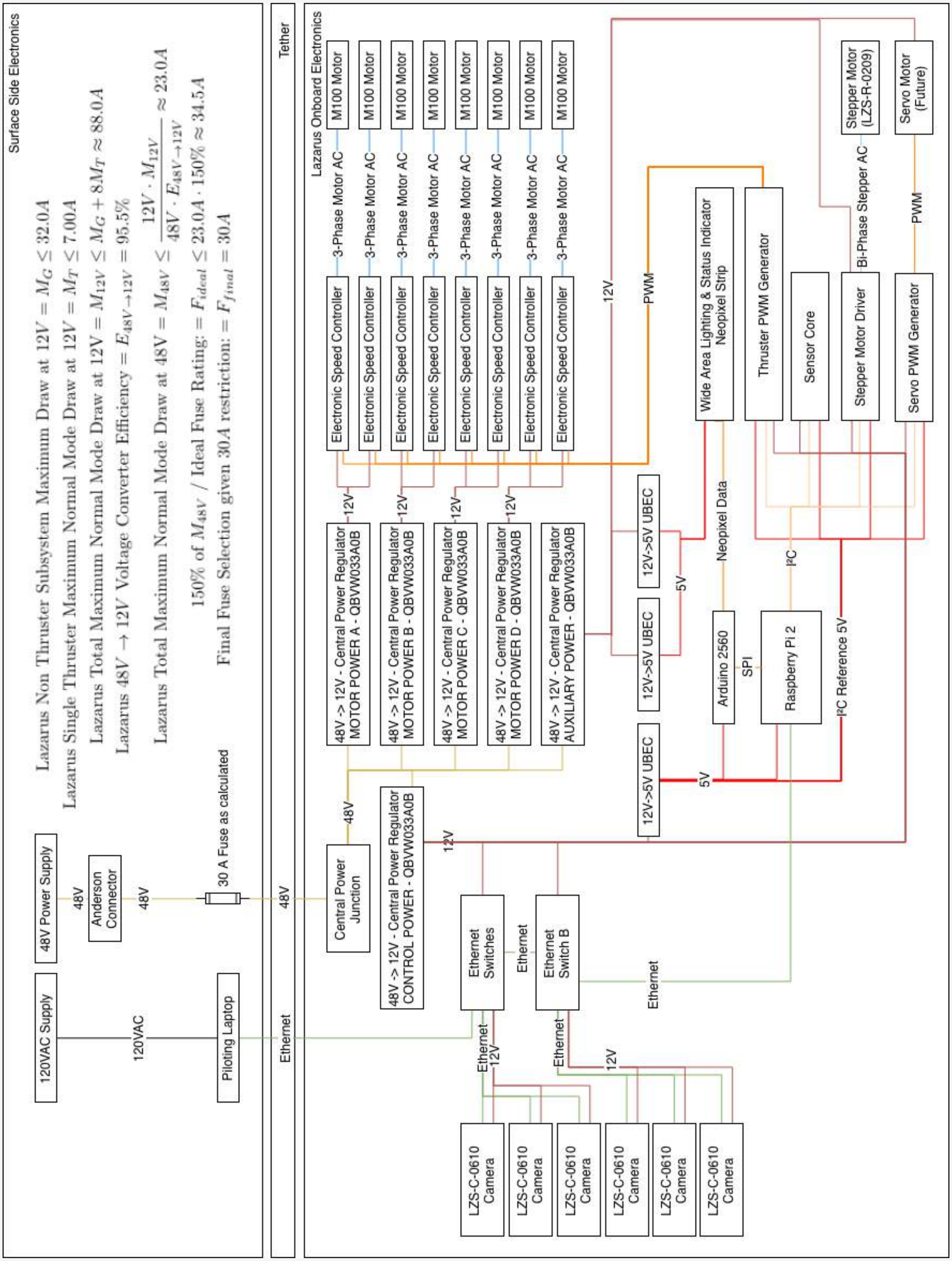
Parameter	Min	Typical	Max	Unit
Total Mass		22		kg
In-Water Weight (Without Buoyancy)		8		kg
Bounding Sphere Diameter			58	cm
Control System Boot Time	15	20	27	s
Total Vertical Thrust		35		N
Total Lateral Thrust		31		N
Operational Load Current (No Throttling)			32	A
Operational Load Current (Ludicrous Mode)			27	A
Operational Load Current (Normal Mode)		12	22	A
Operational Load Current (Precision Mode)		10	12	A
Tether Resistance			156	mΩ
Tether Voltage Drop at 30A, 48V			4.68	V

3.11 Absolute Maximum Ratings

Parameter	Min	Max	Unit
Operating Input Voltage (no load)	36	75	V
Operating Input Voltage @30A	40		V
Maximum Rated Depth		30	m

Left to Right: Georges Oates Larsen (CBD&HoR&D), Sean Sullivan (MT&HST), Haley Werst (CEO), Sam Daire (CoM), Jennifer Jordan (CBO&CSO), Pat Keefe (Advisor)

3.12 System Interconnection Diagram



4.0 Logistics

4.1 Budget & Project Cost

Lazarus Full-System Build Cost				**Research & Development Costs**		**Total Expenses**	
Item	Bought (USD)	Recycled (USD)	Donated (USD)	Item	Cost	Travel	2732.48
Frame 80/20	$80	$53	0	Cameras	$257	Team Polos	253.44
Frame Parts	$200	$133	0	Thrusters	337.92	2017 Actual Build Cost	$2,718
Ethernet Cable	0	16	0	Power Converters	136.2	2017 R&D Total	$2,568
Raspberry Pi Zeros	30	0	0	Miscellaneous Mishaps	341.62	Fundraising Costs	$200
ENC28J60s	17.64	0	0	Sensor Core	100		
CSI Cables	36	0	0	Misc Electronics	200	**Final Balance**	
Wide Angle Cameras	71.7	0	0	Shipping	$300	Total Expenses	$8,472
Thrusters	656	0	0	Equipment & Tools	228.53	Total Funds	8735
Wiring	151.26	0	0	48V Power Supply	366.45	Balance	$263
Cable Ties	41.6	0	0	Testing Props	300		
Main Power Converters	136.2	272.2	0				
UBECs	28.9	0	0	**Funds**			
Neopixel Strips	80.85	0	0	Source	Value (USD)		
Potting Boxes	58.29	0	0	Kathleen Sullivan	20		
Servos	69.8	0	0	James Sullivan	500		
MS5837-30BA	54	0	0	Jennifer & Michael Cameron-Lattek	100		
BNO055	34.95	0	0	Susan Skinner	200		
Ethernet Switches	37.16	0	0	Stephen Emmons	50		
Misc Electronics	89.6	0	0	Lucien & Ute Swordloff	100		
Current Sensors	56.608	0	0	Daryl & Cindy Moore	25		
I²C Isolators	42.8	0	0	Columbia River Maritime Museum	400		
Raspberry Pi 2	0	$40	0	Natalie Sulllivan	200		
Lens Wipes	$9.22	0	0	Susan Skinner	250		
SD Cards	$28	0	0	Liz Bell	25		
Sudden Shutdown Capacitors	23.35	0	0	Anonymous	50		
Epoxy	147	0	0	Patrick Sullivan	100		
Stepper Controller	$40	0	0	Susan Skinner	100		
Stepper Motors	$20	0	0	Katie & Bill Burray Colwill	25		
Fuses	$5	0	0	Mike & Kristin Covert	50		
Alimimum Vent Pipe	$22	0	0	Rick & Terrie Powers	50		
Silicone Tape	$25	0	0	Lisa Sullivan	100		
Pressure Housing	$0	0	$100	Holly Neill	50		
Cable Connectors	$0	0	$160	Reid Ligon	30		
Hose Clamps	$0	25	0	Ed Johnson	25		
Acrylic Sheet	$100	0	0	John Larsen	500		

Buoyancy	$225	0	0		Heather Hansen	50			
Heatshrink	$100	0	0		Carol Newman	100			
					Kesley White	25			
Total Theoretical Build Cost:	$3,417				Mark Redwine	50			
Total Actual 2017 Build Cost:	$2,718				Wende Larsen	50			
2017 Recycled Value:	$539				Evon Jacobsen	20			
2017 Donated Value:	260				Rinda Johnsen	25			
					Nerissa Burr	20			
					Nichole Warwick	20			
					Kyla Overbay	10			
					Iris Daire	50			
					Acacia Pottschmidt	30			
					Anonymous	20			
					Sales of Pictures / Cash Donation	265			
					Marine Technology Society	500			
					Remaining Funding from 2016 ROV Club	1050			
					Estimated Future Donations	3500			
					Total Funds	8735			

4.2 Economic Efficiency

Economic Efficiency has been a key concern of Lazarus Industries throughout the development process. Lazarus Industries has focused its attention and energies on developing innovative, inexpensive alternative manufacturing methodologies wherever possible. This is evidenced the company's in-water electronics architecture, and hand-manufactured 80/20 frame, aluminum thruster housings, and acrylic manipulators.

Where others spend money, Lazarus spends time researching and finding ways to save costs without sacrificing quality. All of Lazarus's components, from its motors to its power converters, were selected through extensive market research, and comparison of prices, capabilities, and specifications. Lazarus Industries has done its best to find the most effective and economically efficient parts available. Sometimes the research process has been expensive, with Research & Development costs exceeding the amount actually placed into Lazarus, but these R&D expenses are worth it, as they have allowed Lazarus Industries to design a truly inexpensive to produce machine.

Left to Right: Sam Daire, Pat Keefe, Jennifer Jordan, Haley Werst, Sean Sullivan, Georges Oates Larsen

Wherever possible, Lazarus Industries has attempted to reduce costs by re-using parts, rather than buying new. 70% of the components that were used on Lazarus' predecessor, Maggie, were salvaged, modified, and reused to build Lazarus, saving hundreds in material costs. This includes the entirety of Maggie's 80/20, structural components, and power converters.

4.3 Fundraising

Lazarus Industries has received incredible support from the Clatsop County and Oregon community. Company members have volunteered teaching ROV classes at the Maritime Museum Grain Festival, helped coordinate the Clatsop Community College Foundation Art Auction, have presented to local high school engineering classrooms, and sold merchandise at two local businesses, the Blue Scorcher Bakery and the Street 14 Cafe. Lazarus Industries has gone above and beyond involving their community in their project. The company has been featured in several newspapers, such as the Daily Astorian, HipFish Monthly, and Clatsop Current News, and interviewed live on radio with KMUN. The publicity that Lazarus Industries has generated in the Clatsop County area through its connections, and creative event-planning and community outreach has allowed the company to exceed its constituents expectations in fundraising. Thanks to these efforts, Lazarus Industries has had the freedom it needs to develop a truly advanced machine for the MATE Center and Port of Long Beach.

Fig 4.4.1: Lazarus Industries full company volunteering at CCC's Foundation Art Auction

5.0 Safety

5.1 Safety Statement

Lazarus Industries is committed to ensuring all their employees are working in a safe environment. This is made possible by strict safety protocols, maintaining a clean and tidy workspace, enacting clear communication between company members, and extensive safety features on Lazarus and all of Lazarus Industries equipment. Lazarus' safety features include 30 amp rated fuses, ergonomic handles for transporting Lazarus, warning stickers on all thruster housings, sealed and waterproofed electronics, and over-current, over-temperature, short-circuit, output over-voltage, and input under-voltage protection in all power regulators.

Each employee is also fully trained and familiar with all safety protocols. Each employee is required to complete all training when applicable, such as saw operations training, hand held machinery safety training, and fire safety. The company workspace is fully stocked with personal protective equipment, such as gloves and goggles. The level of safety reflects on our ability to protect and ensure the health of our employees, Lazarus Industries is committed to providing a consistently innocuous workspace.

5.2 Safety Checklist Protocol

Fig 5.1.1: Company Members reviewing Miter Saw safety protocols prior to use

- Pre-boot up and Start-up Procedure
    - Verify pressure seal is in place
    - Verify bulkhead connectors are clean
    - Verify propellers are shrouded
    - Verify control core is mounted
    - Verify manipulators are present
    - Verify tether is attached to Lazarus and at the ready
    - Verify Lazarus Data cable is plugged in
    - Verify Anderson connectors are attached and secured
    - Verify surge protector is plugged in
    - Verify power supply is plugged into surge protector
    - Check power supply fuses
- Chief of Safety states "Stand by for Power on"; all company

members within 5 feet of any equipment must respond with "standing by" before Power Supply is powered on.)
- Chief of Safety states "Powering On".
  - Boot up Sequence
    - Verify system boot
    - Verify camera boot
  - Stand by for boot sequence to complete
    - Verify Lazarus green status
    - Verify Camera yellow status
- Chief of Safety states, "Stand by for Power down"; all company members within 5 feet of any equipment must respond with "standing by" before the Power Supply is powered down.
- Chief of Safety states "Powering Down".

Fig 5.1.1: Trained company members are required to wear PPE when operating the Miter Saw

5.3 Required Training

Required Training:
- Safety Checklist Procedure training
- Miter saw operations training
- Laser cutter operations training
- Jigsaw operations training
- Heat gun operations training
- Soldering operations training
- Drill press operations training
- Power supply operations training
- Proper posture and lifting form training
- Fire extinguisher locations and operations training

Personal Protective Equipment (PPE):
- Life jacket (when needed)
- Closed toe, non-slip shoes
- Safety goggles
- Nitrile gloves
- Heat resistant gloves
- Non-electrically conductive gloves
- Noise reducing earmuffs
- Fire extinguisher

6.0 Conclusion

6.1 Challenges

One of the biggest issues Lazarus Industries faced in meeting the Request For Proposals (RFP) issued by the MATE Center and Port of Long Beach was reducing Lazarus' weight. While Lazarus Industries was quite deliberate in ensuring its design met the desired size requirements, due to Lazarus Industries' manufacturing techniques, it was not practical to design with overall weight in mind ahead of time. After Stage One construction was completed, Lazarus Industries realized that Lazarus was very slightly overweight. Immediately the company took steps to reduce Lazarus's weight. This included switching from PVC to foam buoyancy, replacing Lazarus' PVC motor housings with lightweight aluminum housings, and performing a system-wide wire-shortening purge. Overall, Lazarus Industries was able to reduce Lazarus' weight by nearly 10 kilograms, placing Lazarus' total weight very slightly within the bounds specified by the MATE Center and Port of Long Beach.

Fig. 6.0.1: Company Members demonstrating Lazarus' abilities to the public

Another very daunting issue that Lazarus Industries overcame was the Sudden-Shutdown bug of Lazarus' predecessor, Maggie. Lazarus industries knew that if changes were not made to the fundamental electrical design of Lazarus as compared to Maggie, this bug (which caused Maggie to experience almost inexplicable system wide sudden shut-down under aggressive piloting), would resurface. With great effort, Lazarus Industries was able to recreate the bug in a laboratory setting using only a single motor and two 48V to 12V Voltage Regulators. Through an incredibly aggressive piloting routine sent to the motor, which was powered by only one of the regulators, Lazarus Industries was able to trigger sudden shutdown in both regulators at once, even when the other regulator was not under load, and digitally record voltage and current data during these shutdowns. It was determined that during motor direction changes, Maggie's ESCs had been producing sudden current spikes that caused a safety panic in the voltage regulators upstream. Lazarus Industries was able to completely eliminate this issue by inserting a snubber capacitor in parallel with the ESC power rails, hence mitigating the degree to which these current spikes could reach Lazarus' voltage converters. Such capacitors are now standard in all Lazarus Industries Electronic Speed Controllers.

6.2 Troubleshooting

Fig 6.2.1: Georges troubleshooting during early Stage I

Excellent troubleshooting skills are critical to the operations of any successful engineering firm. Lazarus Industries is no exception to this rule. Throughout the development of Lazarus, the Lazarus Industries team has had to diagnose and overcome countless arrays of sometimes cascade failures.

Perhaps one of the more interesting instances of this phenomenon occurred very early in Lazarus' development. During early testing, Lazarus' entire I^2C network was prone to crashing, with crashes sometimes occurring dozens of times in a single second. Rather than give up, Lazarus Industries followed a rigorous testing procedure, slowly removing subsystems from the I^2C network until the error was found to disappear. Much to the surprise of the company, the issue stemmed all the way back to the control core. As it happened, the Arduino 2560 was not behaving normally on the I^2C and was causing the whole bus to crash. Switching the communications link between the Raspberry Pi and Arduino 2560 was sufficient to drastically increase the stability of Lazarus' I^2C network stability.

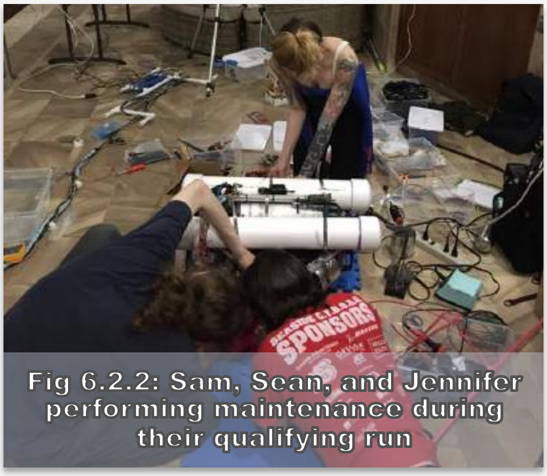


Fig 6.2.2: Sam, Sean, and Jennifer performing maintenance during their qualifying run

Another example occurred during one of Lazarus's qualification runs. Rather suddenly, the pilot began experiencing serious noise on the cameras, and our diver began noticing light sensations of electrocution. Immediately, in accordance with safety protocol, an emergency shutdown was ordered. Once all personnel were safely out of the pool, Lazarus was placed back in the water, powered on, and several test programs were run to determine which motors were causing the camera noise. Indeed, the company was able to narrow down the problem to a single motor that appeared to have failed. Lazarus was then removed from the water, the motor detached, and ground fault tests were performed at various submersion depths with the motor in a small tub of water. Significant voltage leakage to ground was detected with just the motor itself submerged, allowing Lazarus Industries to confirm: The motor's input wires had torn, allowing voltage directly into the water. Lazarus Industries was able to quickly replace the motor with a spare, and continue safe, normal operations that day.

These small examples very effectively demonstrate Lazarus Industries' approach to problem solving:

1. Nail down the exact nature of the problem
2. Eliminate possible causes of the problem until the exact cause is identified
3. Devise, test, and implement a solution to this cause.
4. And, most importantly, never give up.

6.3 Experience and Skills Gained

Georges Oates Larsen: Chairman of the Board of Directors, Head of Research and Development

"Leading this team has been an immense honor. I am proud to have met all of these fine, respectable teammates. They have dedicated themselves far beyond the point I could reasonably ask of them, and for that, I am thankful. Building Lazarus has represented a sort of redemption for me. Lazarus is what its predecessor, Maggie, was meant to be. I am thankful to have had the opportunity to build an ROV properly from the start, and to have had such wonderful teammates to come and support that effort. This has been a truly wonderful learning opportunity for me, as an engineer, as a leader, and as a person."

Haley Werst: Chief Executive Officer, Head of Media

"Prior to joining the Clatsop Community College ROV team, I was an art major. My plans for what to study were vague and my ideas for career paths even more so. Never once thought to try my hand at robotics. While trying to fulfill a lab science credit, I found myself in my college's physics lab and stumbled across a team constructing an underwater robot. I was intrigued to say the least. They showed me how it worked and told me about their goals to compete in an international competition. I started spending more and more of my time with them and became actively involved. It was there I began learning basic electronics, soldering, and other valuable skills to aid the team. When the team returned from the 2016 MATE ROV competition, they decided to start fresh and begin work on a new ROV. It was then that Lazarus Industries was founded. My interest in the team and eagerness to see Lazarus succeed lead to me becoming the team's CEO. It was at that moment my life was irreversibly changed for the better. Fast-forward to now, nearly a year later, and the effects of that change are clear. Not only has my daily life been shaped around the ROV team, my future has been impacted as well. I've decided to pursue a Bachelor of Science in Film, ideally with a minor in Physics. The two halves of my personality, the artistic and the scientific, have been melded seamlessly by the construction of Lazarus. This change and the subsequent confidence boost in my career plans are all thanks to this ROV team and, by extension, the entire MATE ROV competition."

Jennifer Jordan: Chief of Business Operations, Chief Safety Officer

"I've always had a strong drive to study the STEM fields; learning about physics and the structures of the universe, discovering the language of mathematics, and understanding the engineering behind items. From this project, I've learned so much about electronics, structural engineering, programming, and applying innovating thinking. However, my greatest lesson was realizing how important it is to build a strong team and embrace support from the community; No project can be successful without a team of diverse thinkers with a wide range of skills, such as technical, esoteric, or business. In addition, succeeding in this project took our community responding with such positive reception and encouragement to pursue our work in STEM. So, I'd like to thank Pat Keefe, our team advisor, for keeping us all grounded and our team Lazarus Industries, Georges, Haley, Sam, and Sean. Even in times of great uncertainty, we banded together and promoted what we believed in, this project, this ROV, and our future. We will accomplish great things in our lives and this project has already exercised our potential."

Sam Daire: Chief of Manufacturing

"I thank Pat Keefe for making my participation in this possible, and MATE, for organizing the competition itself. Working on Project Lazarus provided an excellent capstone to my years of amateur robotics, and many learning opportunities for me. During all this, I have gained a great many skills I would not readily have learned otherwise; electronics and waterproofing, circuitry, and programming. This is the hardest thing I've ever done, and probably the most exciting, although I hope at least the latter does not remain true."

Sean Sullivan: Manufacturing Technician; Head of System Testing

"In early winter of 2016 I joined Lazarus Industries through an invitation from my cousin, Sam Daire. Being part of the Lazarus ROV team has been one of the most fun and rewarding experiences in my life. In my relatively short time with the team, I have learned a variety of hands on technical skills. These skills range from soldering and waterproofing wires, to cutting and assembling the frame of the ROV. While these are useful skills I will keep with me for the rest of my life, in my eyes, the most valuable thing that I've learned is team skills. My tenure with Lazarus Industries has seen me working with engaging, intelligent people, in close, communication intense environments. This has allowed my communication and team skills to blossom, which will surely aid me in future workplaces and classrooms."

6.4 Future Improvements

One of Lazarus' critical flaws is its weight. Even though Lazarus Industries did all it could to reduce the weight of Lazarus, the ROV is still quite heavy. It is a future goal of Lazarus Industries to investigate alternative manufacturing techniques for the frame and electrical components that might reduce Lazarus' overall weight. IF Lazarus Industries can gain access to the proper manufacturing equipment, a laser-cut fiberglass frame, and custom-built pressure housing with single-board integrated electronics seem like promising next-steps in the evolution of Lazarus Industries' designs.

Furthermore, though Lazarus Industries' snap-on manipulator mechanic generally works quite well, during the fountainhead replacement section of the Entertainment: Water & Lightshow Maintenance task laid out by the MATE Center and Port of Long Beach, it is immensely easy for the LZS-U-0411 Cormorant to accidentally misplace the fountainhead. If this occurs, it is a critical mission failure that cannot be recovered from. Though this can be countered via skilled piloting, it is of immense interest to Lazarus Industries to develop a more failsafe alternative or upgrade to the Cormorant

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