# eastern Edge robotics

## Employee Information

| Name | Role/Discipline |
|---|---|
| Calvin Gregory | Chief Executive Officer |
| Stephen Chislett | Chief Financial Officer |
| Racheal Seymour | Chief Operating Officer |
| Christian Samson | Chief Safety Officer |
| Nick Graham | Chief Technical Officer - Electrical |
| Tybalt Lea | Chief Technical Officer - Mechanical |
| Michaela Barnes | Chief Technical Officer - Payload |
| Cal Pratt | Chief Technical Officer - Software |
| Keely Lullwitz | Pilot |
| Michael Howse | Electrical |
| Adam Pelley | Finance |
| Josh Kearney | Mechanical |
| Aaron Kennedy | Mechanical |
| Adam Tremblett | Mechanical |
| Mark Belbin | Payload |
| Nathan Hollett | Payload |
| Biko Brideau | Software |
| Keith Sutherland | Software |
| Connor Whalen | Software |


**Company Mentors**

Paul Brett, B.Sc (Hons), B.Ed Post Secondary, M.Sc

Jai Ragunathan, B.Sc, B.Ed, M.Sc

Joe Singleton, P.Eng

Anthony Randell, B.Eng

**Memorial University, St. John's, Newfoundland and Labrador, Canada**

**MATE International ROV Competition 2017**

**Explorer Class**

MEMORIAL UNIVERSITY

MARINE INSTITUTE

## Abstract

The enclosed technical report outlines the design and construction of a world-class Remotely Operated Vehicle (ROV): Vimy. Vimy is an Explorer class vehicle custom designed and built by Eastern Edge Robotics to meet the challenges outlined in the request for proposals established by the Port of Long Beach. The vehicle and its payload have been tailored to the client's needs. Vimy is fully capable of performing Hyperloop infrastructure installation, entertainment unit maintenance, health inspection, and accident site safety surveys. The pinnacle of the Company's small ROV fleet, Vimy is ready to deliver unmatched performance. It weighs 16.25 kg in air, has maximum dimensions of 525 x 390 x 325 mm, and costs less than 6,200.00 USD to produce.

Eastern Edge Robotics has been developing ROVs for the past 15 years. The Company's team of 19 employees is a group of multidisciplinary specialists devoted to the development of next-generation underwater vehicle solutions. Their expertise span the fields of software development, system design, product fabrication, and ROV piloting among many others. The Company's in-house manufacturing capabilities allow for precise and cost-effective solutions to be quickly delivered to clients and each vehicle to be customized for its mission. These custom solutions can then be deployed by the veteran pilots and crew of Eastern Edge Robotics to meet any work scope requirements.

***Figure 1:*** *Company Employees. Photo Taken at the Marine Institute's Flume Tank*

***Back (L-R):*** *Calvin Gregory, Adam Tremblett, Shephen Chislett, Christian Samson, Keith Sutherland, Nick Graham, Connor Whalen, Michael Howse, Tybalt Lea*

***Front (L-R):*** *Michaela Barnes, Mark Belbin, Cal Pratt, Biko Brideau, Aaron Kennedy, Nathan Hollett, Josh Kearney, Keely Lullwitz*

***Missing:*** *Racheal Seymour, Adam Pelley*

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# 1. Company Overview

## 1.1. Company Introduction

Eastern Edge Robotics (EER or the Company) is comprised of post-secondary students attending Memorial University of Newfoundland from a multitude of disciplines and backgrounds with a common goal: to develop effective and reliable solutions for the challenges faced in harsh subsea environments. The Company has been an industry leader in Remotely Operated Vehicle (ROV) Technology for the past fifteen years where it has excelled in the Marine Advanced Technology Education (MATE) Competition with four first place finishes and three second place finishes to date.

This year's ROV, Vimy, was designed in accordance with the request for proposals (contract) set forth by the Port of Long Beach. Vimy is named in celebration of Canada's 150th anniversary of Confederation and to commemorate the 100th anniversary of the Battle of Vimy Ridge. In particular, the Battle of Vimy Ridge symbolizes the emergence of Canada as a nation on the global scene. It represents the ingenuity and resolve of the Canadians who succeeded in capturing Vimy Ridge where other armies had failed; a decisive moment in the World War I battle of Arras.

## 1.2. Organizational Structure

The Company has an extensive workforce with diverse technical and non-technical backgrounds. In order to organize and apply its personnel resources effectively, the Company employs a tiered organizational structure as depicted in Figure 2. Employees are divided into discipline teams based on their education, experience, and interests. Discipline Chief Technical Officers (CTO) direct the efforts of their sub-teams in accordance with the project vision of senior executives. This allows the company to utilize its employees to their greatest potential and coordinate deliverables across multiple task groups within the Company.

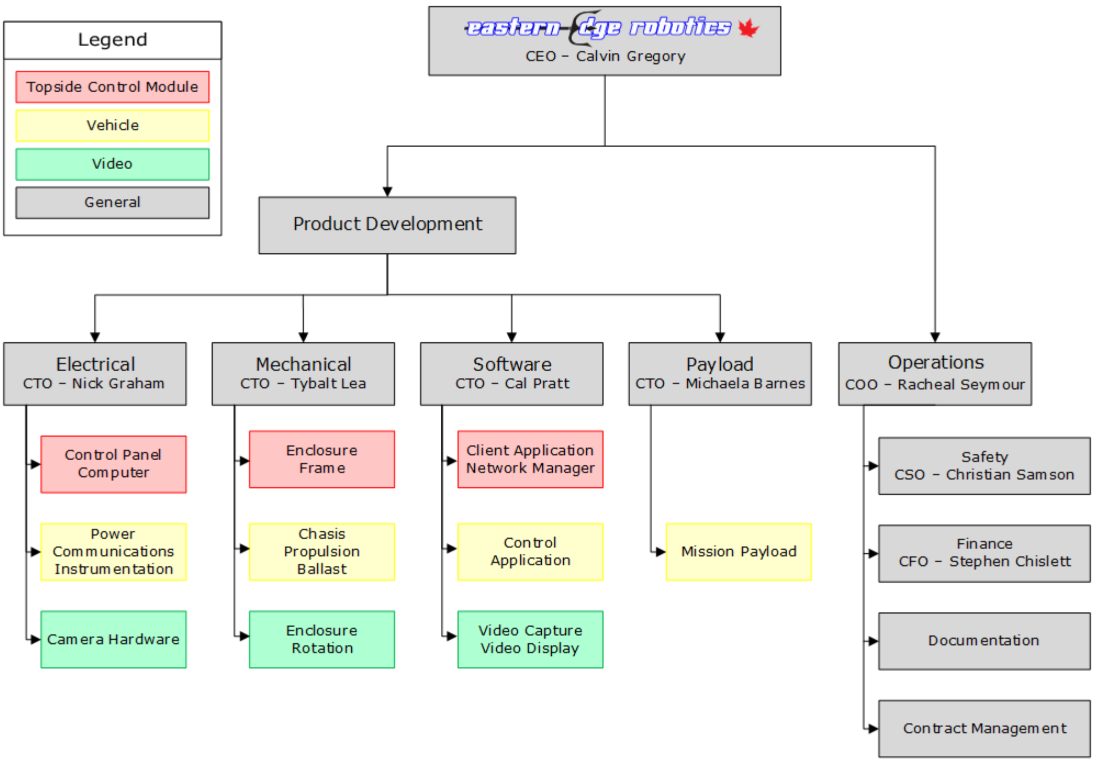



***Figure 2:*** *Company Organizational Structure*

Team leads are nominated based on their technical knowledge and experience, leadership potential, and overall enthusiasm for the role. At the beginning of each contract year, returning employees are called to a general meeting where employee roles are discussed in depth and the nominees are submitted for Company approval. This meeting concludes with the assignment of leadership roles for the upcoming year.

## 2. Logistics

### 2.1. Project Management

Each of the major vehicle systems are comprised of multidisciplinary components requiring coordinated use of both resources and materials. To maximize productivity, EER utilizes an authoritative project management structure. This type of project management is characterized by a strong core of senior managers who have a vision for the project which they share with their teams. The Chief Executive Officer (CEO) is responsible for establishing company procedures and best practices based on consultations with senior members. Based on these procedures and the project schedule, goals are assigned to each of the discipline CTOs who then generate tasks for each of the employees under their management. Discipline leads and executives work closely together to ensure that resource control is optimized by fostering teamwork, delegating projects and sub-projects, and encouraging employees to play to their strengths.

The Company places great value in developing the skills of its employees. The period immediately after the introduction of new members to the Company was devoted to new member training. Senior members ran technical workshops in each of the discipline areas, which taught critical skills that the Company saw as beneficial to their new employees including shop safety, Solidworks, soldering, and different programming languages. These workshops served to familiarize new employees with Company best practices and imparted some of the knowledge gained by senior members over the years. This is an essential step in ensuring the longevity of the Company by preparing the employees for both the 2017 MATE contract and future challenges.

Discipline leads set short term goals and milestones to keep employees motivated. Experience has shown that achieving a series of smaller goals helps to maintain employee morale over the long term and keep their focus on overarching project objectives. It also serves to help discipline leads track progress and keep the project moving forward. The Company holds debrief meetings after the completion of each major milestone in which contributors can reflect on what went well and what did not. Records of these reflections help to continually improve the Company’s product quality and time management practices. Reflections from the 2016 contract served as useful references when developing the Company’s 2017 schedule.

### 2.2. Scheduling

Work on the 2017 MATE contract began in September 2016. Meetings were held among senior members to discuss project scheduling and new member training strategies. At this time the Company also created a Gantt chart, seen in Appendix A – Gantt Chart, with intended start and completion dates for project milestones.

In October 2016 the Company held an open house and new member orientation, which lead to an increase in personnel resources. Weekly meetings held throughout October and November consisted of workshops lead by senior employees to pass on skills and best practices to the new junior employees. The workshop content was chosen by each discipline’s CTO to teach skills required to becoming productive members of the team. In addition to these workshop meetings, senior members conducted additional design meetings to lay the groundwork for a new vehicle design.

The design phase began in earnest during November 2016 and concluded in February 2017 with design refinements being integrated continuously thereafter. During this period Company activities were predominantly focused on the detailed design of vehicle subsystems and part procurement. The newly designed vehicle was then manufactured and assembled during March and April. Once Vimy was fully constructed and operating, the Company entered the testing and refinement phase from April onward.

## 3. Finances

### 3.1. Preliminary Budget

Based on the financial performance of EER from 2016 and the scope of work outlined in the contract, the management team chose to pursue a vehicle budget similar to the previous year. A budget of $7,750 USD was set. This budget aligned with the previous year's budget while still providing a level of flexibility should unforeseen expenditures be required. With the Canadian dollar hovering around $0.75 per US dollar during the 2016-2017 competition year, purchasing parts from the United States became an expensive endeavour. To mitigate this issue, the Company decided to purchase the majority of components from Canadian distributors in order to avoid incurring unnecessary expenses. The Company is also traveling a considerable distance to compete for the 2017 contract, and therefore a budget of $34,220 USD was estimated to cover this expense. A tabular view of the Company's overall budget for the 2017 contract can be found in Table 1.

*Table 1: Preliminary Budget Summary*

| **EER Preliminary Budget 2017** | | |
|---|---|---|
| Vehicle Expenses | Electrical & Software | $5,950.00 |
| | Mechanical & Payload | $950.00 |
| | General and Administration | $850.00 |
| **Vehicle Budget Total** | | $7,750.00 |
| Travel Expenses | Flights (19 people, $800 each) | $15,200.00 |
| | Hotel Room (11 rooms, 8 nights, $135.00/night) | $11,800.00 |
| | Rental Vehicles & Gas (2 vehicles, $650/vehicle) | $1,300.00 |
| | Misc. Travel Costs (16 people, $370/person) | $5,920.00 |
| **Travel Budget Total** | | $34,220 |
| **Total** | | **$41,970** |

### 3.2. Project Costing

As a result of careful planning and repurposing of materials from the Company's inventory, the Company came in under-budget this year by over $500 USD. A summary of vehicle expenditure can be found in the left half of Table 2. It should be noted that while purchases for Electrical & Software were under the planned budget estimates, Mechanical & Payload purchases exceeded the planned budget. The initial estimates in these categories were off due to the unplanned large purchase of stock construction material. This purchase was approved by the management team because the material was substantially less expensive in bulk. The volume of material purchased during the current year is a sufficient supply to accommodate the Company's needs for several more years, leading to reduced future expenses for Mechanical & Payload.

The decision was made early on that the 2017 ROV would be built entirely new, which would leave the 2016 vehicle assembled and functional to serve as a tool testing platform. All the necessary hardware needed to be procured again instead of reusing components common to both vehicles. This meant that new thrusters and other expensive components needed to be purchased which accounted for another large portion of the 2017 expenses. The Topside Control Module (TCM) was deemed fully functional and so was reused largely unaltered. A donated tether from Leoni-Elocab also helped save upwards of $2000 USD.

Vimy's Fair Market Value of $6,139.03 USD was calculated by considering all the materials required to construct the ROV and the TCM. This included items purchased, donated, and discounted. The fair market values are summarized in the right half of Table 2. A more detailed breakdown of these estimates is provided in Appendix C – Fair Market Value.

*Table 2: Vehicle Expenditure as of May 26, 2017 and Fair Market Value*

| **EER Vehicle Expenditures 2017** | |
|---|---|
| Electrical & Software | $3,351.68 |
| Mechanical & Payload | $3,459.65 |
| General Administration | $434.25 |
| **Total** | **$7,245.58** |

| **Vimy Fair Market Value** | |
|---|---|
| ROV Total | $4,530.41 |
| Topside Total | $1,608.62 |
| **Fair Market Value** | **$6,139.03** |

EER's travel expenditures at $26,544.26 USD were below the initial budgeted amount by approximately $7600 USD due to the Company's careful planning. A detailed breakdown of these expenditures is shown in Table 3. An overall depiction of total expenditures of the Company as well as donations and funds provided to EER can be found in Appendix B – Overall Expenditure.

*Table 3: Company Travel Expenditure Summary*

| **EER Travel Expenditures 2017** | |
|---|---|
| Item | Cost (USD) |
| Flights (18) | $9,148.62 |
| Hotel Room (10 rooms, 8 nights) | $10,175.64 |
| Rental Vehicle (2) & Gas (estimated) | $1,300.00 |
| Misc. Travel Costs (estimated) | $5,920.00 |
| **Total** | **$26,544.26** |

# 4. Safety Culture and Practices

## 4.1. Safety Philosophy

At EER, the primary concern is the safety of Company employees, the environment, and the public. The Company strives to achieve an open safety culture whereby employees are encouraged to speak up about any safety concerns related to EER's practices or products. Actively engaging employees in safe work practices and safety promotion keeps these concerns at the forefront of their minds at all times. This open safety culture goes hand in hand with the Company's safety philosophy: Nobody gets hurt.

## 4.2. Operational Safety Practices

The company utilizes toolbox talks which include the use of Job Safety and Environment Analysis (JSEA), and an Operational Safety Checklist (OSC). Toolbox talks are performed at the beginning of each work day which encourages personnel to follow safe working practices and discuss safety concerns before starting work. JSEAs and OSCs are also required before every vehicle deployment operation. This fosters a safety conscious work environment, reducing incidents of injury and increasing efficiency and effective work practices. All JSEAs and OSCs are reviewed regularly by the Company's Chief Safety Officer (CSO) so work practices can be updated or faulty machinery can be replaced before an incident occurs.

In 2015, the company began a Safe Work Observation Program (SWOP). The SWOP gives employees the opportunity to bring attention to hazards or incidents that occur in the workplace as well as commendations of fellow employees who exhibit exceptional safety conscious behaviour. These forms are reviewed regularly by the CSO, who discusses the forms at weekly Company meetings. These meetings also include safety moments brought forth by individual employees which highlight hazards most relevant to the upcoming week. This practice reinforces the Company's open safety culture where all safety concerns are welcomed and treated with respect.

Newly introduced in 2016-2017 are Safety Passports. Safety Passports serve as a record of each employee's health and safety training and are kept in the workplace at all times. If an employee wishes to use a piece of equipment in the workplace, a senior member will train the employee on the safe work practices of that machine and the Personal Protection Equipment (PPE) that must be donned to operate that piece of equipment. Once training is complete, the senior member signs off on the Safety Passport indicating that the employee is properly trained on that machine. An employee is not permitted to operate any piece of equipment without proper authorization on the Safety Passport.

## 4.3. Vehicle Safety

Vimy exceeds all safety requirements outlined in the 2017 contract. Vimy's safety features include but are not limited to a 30 Amp circuit breaker located within 30 cm from the ROV power supply, thruster guards, smooth or rounded edges on all components on the vehicle, warning labels on rotating parts and power connections, and strain relief on the vehicle's tether. The Company is constantly looking to improve the safety of their vehicles. A new measure introduced in 2017 was to replace all nuts on the chassis and electronics enclosure with threaded inserts and to use counterbores under most of the screw heads. This reduced the amount of protruding metal on the chassis and thus eliminated many potential cut hazards.

# 5. Design Rationale and Vehicle Systems

## 5.1. Design Philosophy

A user-centered approach to design is featured prominently in all Company products. This design philosophy emphasizes user experience in all aspects of the vehicle development. To that end, pilots should experience intuitive and consistent behaviour from the vehicle without needing to understand, or even see, the complex subsystems driving it. To successfully achieve this, the vehicle's design must be inherently stable and move naturally, the payload must be easy to use, and the controls must be intuitive and logical for the pilot.

## 5.2. Design Constraints

The 2017 contract issued by the Port of Long Beach and the MATE Center imposes several restrictions which influenced the Company's vehicle design. These constraints were as follows:

- Each of the vehicle's faces must fit through a 580 mm diameter circle illustrated in Figure 3.
- The vehicle and tether combined must weigh less than 17.0 kg.
- The vehicle must be powered from a 48 V, 30 A supply.

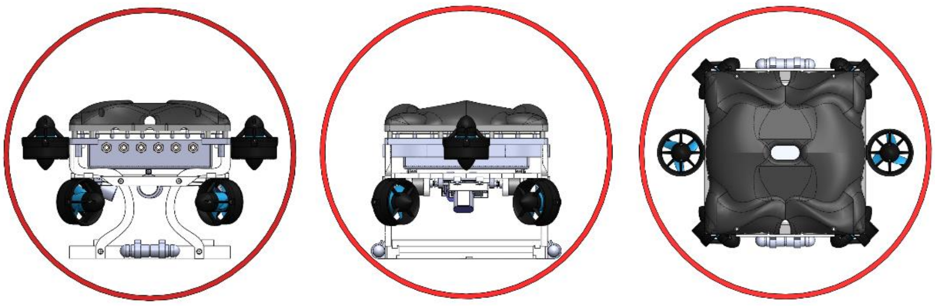


*Figure 3: CAD Rendering of Vimy with a 580 mm Diameter Circle in Each Axis*

The impact of these constraints was factored into the design and selection process for all vehicle components. Each component was optimized for size, weight, power and cost while maintaining optimal functionality.

## 5.3. Topside Control Module

In 2016 the Company introduced its new Topside Control Module which added simplicity, reliability and transportability for the topsides electronics and pilot system. The TCM houses all control hardware including a desktop computer, an integrated monitor, power connection points for the tether and power supply, and outboard diagnostic sensors.

*Figure 4: Topside Control Module*

The TCM shown in Figure 4 also contains a pilot interface panel, equipped with integrated control features such as buttons and sliders that control ROV movement and payload. TCM control functionality has been further expanded to support the requirements outlined in the 2017 contract. The addition of tactile buttons and sliders allow the pilot and co-pilot to adjust vehicle performance quickly, maximizing mission efficiency.

TCM upgrades were also required to meet the 2017 safety specifications outlined in the contract. Safety requirements for the 2017 contract include control stations being manufactured in a neat manner and all DC and AC wiring being physically separated from each other. To meet these specifications EER reworked and rewired the entirety of its pilot control panel and electrical equipment layout. All wires inside the TCM have been properly secured, organized and protected with cable ducting. All cables entering and leaving the TCM have appropriate strain relief. The pilot control interface was constructed using a clear Lexan panel so the internal hardware can be observed externally showing proper connections and functionality which simplifies safety checks from both Company employees and clients.

## 5.4. Chassis

Vimy's chassis was designed through multiple iterations to meet the size and weight constraints imposed in the 2017 MATE contract. The chassis, shown in Figure 5, was custom designed for the 2017 contract to be both small and lightweight and was manufactured entirely in-house by EER. To support the 17.0 kg vehicle weight in air specified in the MATE contract and endure impacts of up to 1 m/s underwater, the chassis was constructed out of High Density Polyethylene (HDPE) and Ultra-High Molecular Weight Polyethylene (UHMW).

The chassis design was first evaluated using finite element analysis (FEA) and HDPE was found to be the most suitable primary construction material. HDPE has a density of 0.96 g/ $cm^3$ and a tensile strength of 31.7 MPa. Its low cost coupled with a lower density when compared to other materials considered such as polycarbonate (1.22 g/$cm^3$) and aluminum (2.70 g/ $cm^3$) made it the optimal choice. While UHMW has similar properties to HDPE, it is more costly. Therefore, it was used for select structural members on the chassis identified as critical to vehicle functionality. UHMW features a superior tensile strength and density of 40.0 MPa and 0.93 g/ $cm^3$ respectively. Given these characteristics, one vehicle component on which UHMW was used was the lateral thruster support brace which cannot accept significant warpage without altering the thrust vectors, and by extension, the flight characteristics of the vehicle. Both the HDPE and UHMW were easily machinable using the Company's Computer Numerical Control (CNC) router, allowing the company to perform the required fabrication work in-house.

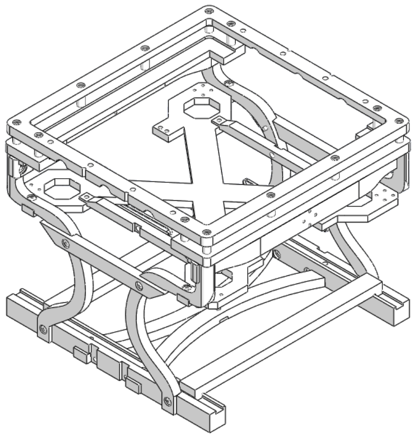


*Figure 5: CAD Rendering of Vehicle Chassis*

In line with the Company's user-centered design philosophy and the constraints placed on vehicle, the chassis design maximizes open tooling space. Vimy is capable of bi-directional operation which doubles the available tooling space and allows it to complete mission tasks more effectively. Minimal structural members on the vehicle's fore and aft sections increase the available tooling space and assure the pilot's view of their payload is unobstructed.

## 5.5. Stability

Vimy is trimmed using a fixed floatation and ballast system. Static stability is achieved by maximizing the distance between the floatation at the top and ballast at the bottom. This keeps the Center of Buoyancy above the Center of Gravity, which generates a righting moment when the vehicle tips and causes it to return to an upright position.

Vimy uses closed-cell Divinycell foam for floatation. This was chosen for its low density, durability, and ease of machining on the Company's CNC router. The main buoyancy block is machined in a predominantly convex shape which acts as a fairing to streamline the vehicle's ascent motion. This allows the vehicle to ascend more quickly without experiencing unstable drag which could cause the vehicle to pitch or roll. The main buoyancy block was designed for easy removal to improve disassembly and troubleshooting time. The ballast system consists of modular weights mounted on the tooling skids. These can be shifted as necessary to accommodate an unbalanced payload.

### 5.6. Propulsion

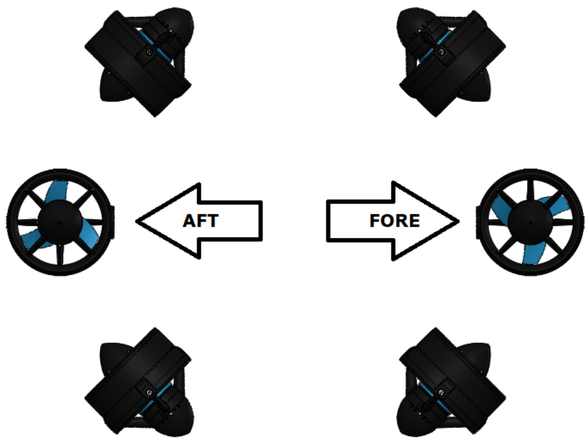



*Figure 6: CAD Rendering of Thruster Layout*

Vimy uses six Blue Robotics T200 brushless thrusters for vehicle propulsion. Commercial thrusters were chosen as they offer greater efficiency and reliability at a higher thrust output than the Company could manufacture. As well, while the cost per unit for the commercial thrusters was greater than estimates for those manufactured in-house, the purchase saved the company considerable resource time which was allotted to other mission critical systems. The Blue Robotics T200 thrusters were chosen for their low cost, ease of integration and low mass when compared to their commercial counterparts. Four lateral thrusters are mounted on a common plane at the corners of the vehicle and are vectored at 45° angles. Two vertical thrusters are mounted on the vehicle's fore and aft sides. The placement of the thrusters provides Vimy with five degrees of freedom: Surge, Sway, Heave, Yaw, and Pitch. The Company chose to use a six thruster configuration as seen in Figure 6 which has allowed for effective vehicle mobility in the past and allows for an advantageous balance between power and weight. The addition of further thrusters would only serve to increase both the size and weight of the vehicle. Given the constraints as outlined in the contract, it was felt that additional investment in size and weight resources would be better used to expand Vimy's payload system. Further to this, removing thrusters would reduce the efficiency of the thrust vectoring, reducing the vehicles mobility.

The design for this year's vehicle featured the vertical thrusters being mounted on the fore and aft in comparison to previous models where they were mounted on the vehicle's port and starboard sides. Vimy has control over its pitch motion as opposed to roll. The change was made based on expressed concern in relation to alignment sensitive tasks whilst using previous design models.

### 5.7. Cameras

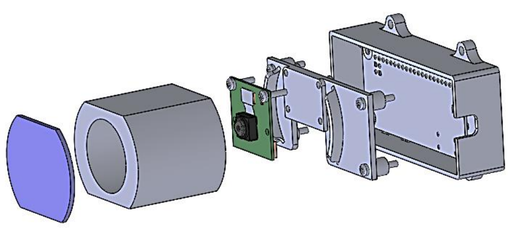


*Figure 7: Exploded View of Vimy's Camera Module*

The Company has been successful using small, disposable camera units built on a Raspberry Pi single board computer (SBC) and camera module. The company chose to follow the same design rationale for the 2017 vision system. The Raspberry Pi and camera module were chosen because of their low cost, availability, and the accessibility of technical support. The electronic components of the camera module are mounted in a 3D printed shell shown in Figure 7 which is then filled with potting compound to protect the components from water. These have replaced the Company's more traditional O-ring sealed camera systems which were found to fail frequently due to their complexity. Although near impossible to fix once broken, the disposable camera modules offer a substantially lower rate of failure and lower cost of replacement. This allows for substantial cost savings in relation to the operating and maintenance costs for this type of camera in relation to that of an O-ring sealed camera module. The reduced rate of failure also improved efficiency in work execution.

This disposable camera system also offers many advantages from a software integration perspective. As an example, the video is encoded and transmitted over Ethernet for the TCM to decode and display. This avoids the issue of memory overloads caused by streaming uncompressed video observed during testing. Encoding the video means that it does not require as much network bandwidth, keeping latency and communication errors to a minimum. The video is streamed at 30 frames per second at a resolution of 720p, which was found to be a good compromise between clear picture quality and low latency.

*Figure 8: 2016 Camera Module (Left) and 2017 Camera Module (Right)*

The disposable camera concept has been further refined in 2017 with the introduction of the Raspberry Pi Zero version 1.3. This model is less than half the size of the Raspberry Pi Model A used in the 2016 camera module and one fifth of the cost while boasting similar hardware specifications. This has allowed the Company to reduce the size of the Vimy camera modules by 47%. This reduction in size as seen in Figure 8, specifically in width, means that the cameras can now be mounted higher on the chassis which offers a better view of the payload for pilots.

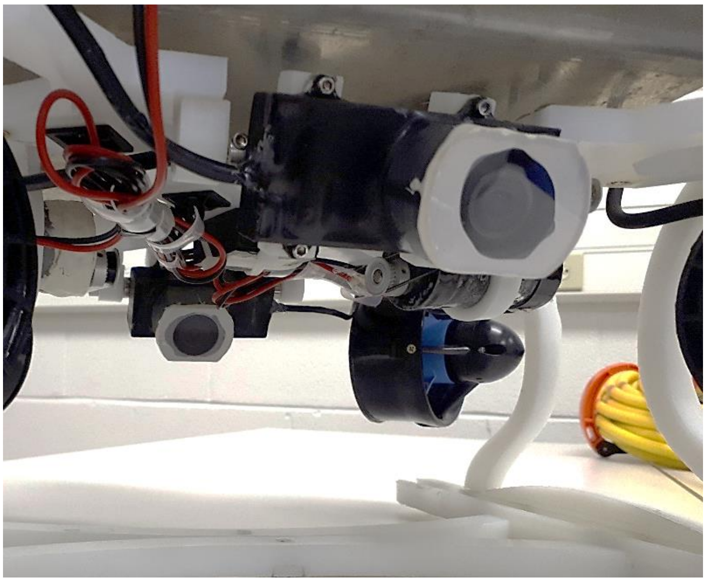


*Figure 9: Vimy's Camera System Attached to Chassis*

The Vimy camera system also includes tilt control, shown in Figure 9, to maximize the pilot's effective field of view. The cameras can be rotated in excess of 180° about a fixed axle using a DC motor and timing belt mounted underneath the electronics enclosure. This mechanism means that the pilot can achieve a clear view of the vehicle's payload and surroundings using only two cameras. By rotating both cameras to look at the same side of the vehicle, the pilot can more easily perceive depth which simplifies tasks requiring sensitive alignment.

### 5.8. Electronics Enclosure

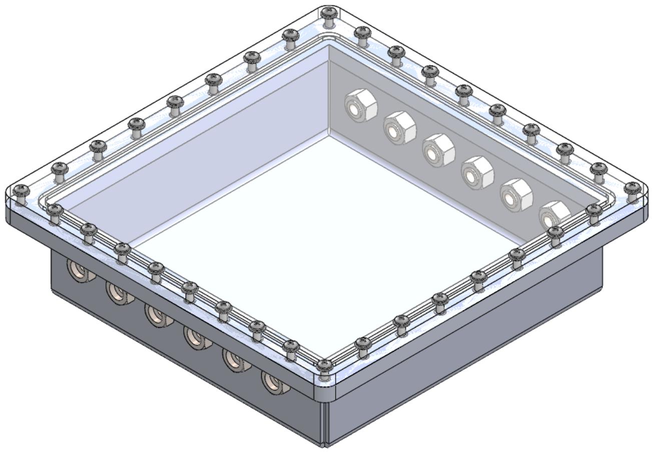


Figure 10: CAD Rendering of Vimy's Electronics Enclosure

The Company chose to build a new pressure vessel to contain the vehicle's onboard electronics, integrating lessons learned during previous work scopes. The new electronics enclosure, shown in Figure 10, was designed as a rectangular prism with external dimensions of 302 x 298 x 81.2 mm and a mass of 2.81 kg. The rectangular shape means that the electronics can be densely packed within the enclosure to minimize size. During previous contracts, one of the most significant difficulties encountered was assembly and maintenance of the onboard electronics. Minimization of the size of the internal enclosure volume in previous vehicles resulted in it becoming nearly impossible to work on the electronics without removing them from the enclosure which was a difficult and tedious process. In 2017 additional space was added to the enclosure's interior, improving access to key devices to reduce troubleshooting time.

With the internal electronic devices being so densely packed there is very little space for air to circulate within the enclosure. With prolonged use, the internal devices may overheat and cause a vehicle shutdown. To mitigate this problem the Company chose to build the enclosure out of aluminum due to its excellent strength and heat dissipation properties. The internal components which generate the most heat were mounted to a large heat sinking plate at the base of the enclosure which can dissipate heat through the enclosure walls and into the surrounding water. This design required high precision machining and welding work. As EER lacks the welding facilities required to fabricate the enclosure, it was contracted to Memorial University Technical Services at a discounted rate.

The enclosure design was evaluated using FEA in Solidworks. It was found to be capable of surviving the pressure at a depth of 5 m with a safety factor of 2.25. The seal between the enclosure's lid and base consists of a ⅛" Buna-N O-ring designed according to the Parker O-ring handbook guidelines and is capable of surviving depths of over 1 km. This O-ring is compressed by a set of screws joining the lid to the enclosure's top flange. On the previous vehicle model, these screws were joined to the enclosure via tapped holes in the flange which corroded over time. This joining method was replaced by stainless steel inserts in the flange for the 2017 enclosure, improving the safety and lifetime of the pressure vessel.

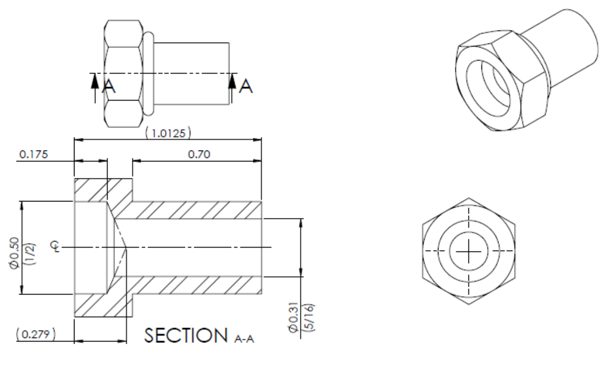



Figure 11: Custom Machined Penetrator

Wires are passed into and out of the electronics enclosure through the Company's custom machined penetrators shown in Figure 11. These penetrators are machined out of stock ½" stainless steel seal bolts with built in O-ring face seals which are modified by Company employees on a lathe. Wires are then fed through these modified bolts and the internal cavity is encased in potting compound. The penetrators are arranged in two lines: one on the port side of the enclosure and one on the starboard. They are positioned in this manner to avoid interference with the internal electronics and to allow easy access to each individual penetrator for extraction and replacement should an external device fail.

### 5.9. Electronics

Vimy is equipped with an entirely reconstructed and expanded electronics system for the 2017 contract. Lessons learned from the previous vehicle electronics systems were utilized in the new design in order to improve reliability and stability of the overall system. This expanded system uses a more logical layout with better overall organization, allowing employees to better manage the main control hardware for the ROV.

The electronics system uses three onboard voltages: 48 V is sent from the surface down the tether and converted to 12 V and 5 V onboard the vehicle. This allows the Company to select a variety of hardware to integrate into the system. The overall power distribution and communications layout can be found in Appendix D – System Integration Diagram. The 12 V bus uses three parallel DC/DC converters for redundancy which allows for up to two converter failures and minimizes operation interruptions.

The communication network backbone is provided by a fibre to Ethernet switch onboard the vehicle which was chosen for its small size and multiple Ethernet ports. The system currently utilizes three of the five Ethernet ports, one for the primary control Raspberry Pi, or RasPrime, and two for the onboard cameras. The remaining two ports can be used to expand the camera or control system as the user desires.

The electronics system layout from the 2016 vehicle was built in three layers where organization was sacrificed in the name of space conservation. This design was difficult to repair or troubleshoot due its lack of organization or working space. These problems have influenced the design of the 2017 system. Vimy's electronics system is arranged in two layers inside the enclosure, categorized by voltage level, 12 V on the bottom layer shown in Figure 12, and 5 V on the top layer shown in Figure 13. It was designed to be easier to repair and replace components. The company chose this approach as the most common repairs and additions to the system require access to the 5 V system where examples include faults with the sensors, the Bluetooth modules, and the camera system. Improving ease of access to these components reduces troubleshooting and repair time. This layout also minimizes the amount of wires that transferred between the two layers. The 12 V layer includes the thruster Electronic Speed Controllers (ESCs), and motor controllers, both of which do not require extensive maintenance once implemented. There are four motor controllers on Vimy, compared to the previous year's three. This was done for the ability to expand past the passive tooling system implemented in 2016 and add additional motor expansion for mission payload.

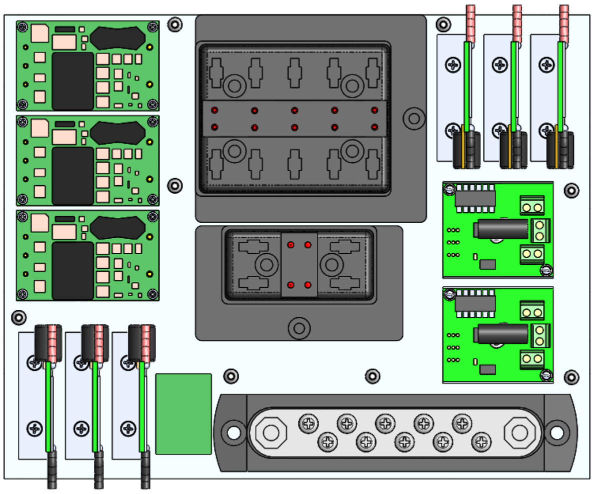


*Figure 12: Onboard Electronics 12 V Bottom Layer*

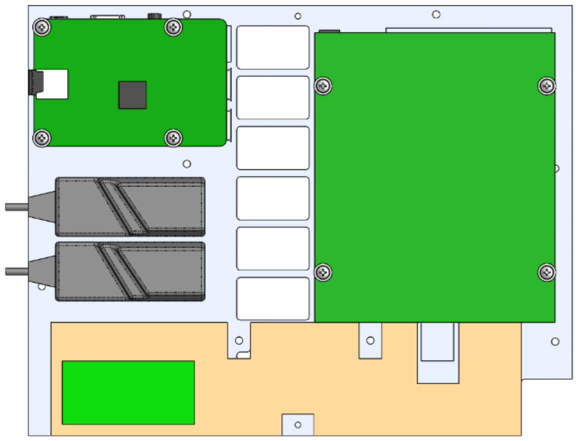


*Figure 13: Onboard Electronics 5 V Top Layer*

A new addition to the 2017 electronics system was the integration of terminal blocks for payload motor conductors. Terminal blocks are commonly used in the industry to replace hard wired connections between two conductors allowing for easy maintenance and cable organization. These terminal blocks act as a connection point for conductors inside the electronics enclosure to cables inside the enclosure penetrators. The electronics system uses spring loaded terminal blocks for the motor connection points which allows for penetrator removal without needing to remove wires from any of the internal devices. This has made system maintenance and debugging much simpler.

Some other added features in Vimy's electronics system are an Inertial Measurement Unit (IMU), depth sensor, and real time monitoring of DC/DC converters. The IMU and depth sensor allows for expanded capabilities for integrated software tools in order to complete client missions as well as improve vehicle control. Power monitoring allows the operator to determine how much power is being lost through the tether as well as the stability and overall health of the power system which is key to diagnosing failures early.

### 5.10. Tether

Power and communication are transferred from Vimy's TCM to the vehicle's onboard electronics through an 18m tether designed by EER and generously manufactured and donated by Leoni-Elocab. The length of the tether was calculated to reach all mission props, while also allowing for 3m distance between the water entry point and the TCM. The tether weighs 158 g/m in air and has a total weight of 2.84 kg, and is neutrally buoyant in fresh water. The buoyant outer jacket aids in tether management in and out of the water. Inside the tether are two copper conductors for power and two pairs of optical fibres for communication, one of which is redundant, shown in Figure 14. EER uses multimode optical fibres for their high bandwidth, superior reliability, electrical noise immunity, and lower mass when compared with copper alternatives. The 2017 tether differs from the 2016 tether in its larger wire gauge and four optical fibres compared to two from the previous year. This allows the company to expand power capacity from the onboard electronics system as well as provided additional two spare fibre lines for reliability and expansion.

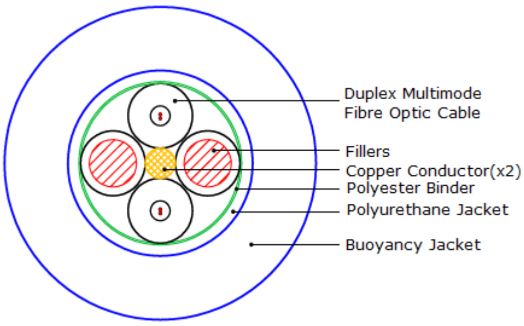



*Figure 14: Tether Cross Section View*

### 5.11. Software

The Company's control software application is the second generation of its kind, expanding upon the framework created for the 2016 MATE contract. This application is developed in the Java programming language, which was chosen because it is a widely used and well supported language within the software development industry.

#### 5.11.1. Distributed Communication

Two network switches, each containing a fiber optics channel, are placed in the onboard electronics enclosure and in the TCM. The fiber optics channel on both switches are connected by the tether, creating an ROV subnet. Software for Vimy exists as a distributed application, with software components running independently on each of four computers: the TCM, the RasPrime, and the two onboard cameras. This network topology can be seen in Figure

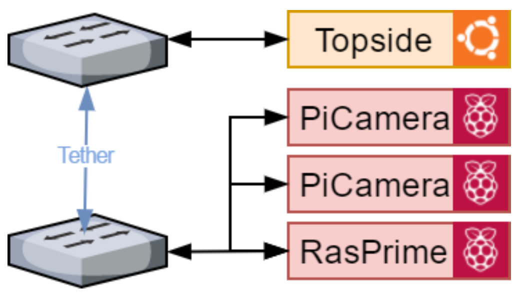



*Figure 15: Network Diagram*

15. Each computer on the subnet receives broadcast messages from all other computers in the form of serialized Java objects. The receiver de-serializes all incoming objects and searches for objects with types relevant to its functionality, ignoring object types which do not match. This creates a scalable, loosely coupled environment where any number of computers can be added to the subnet without having to re-configure existing devices.

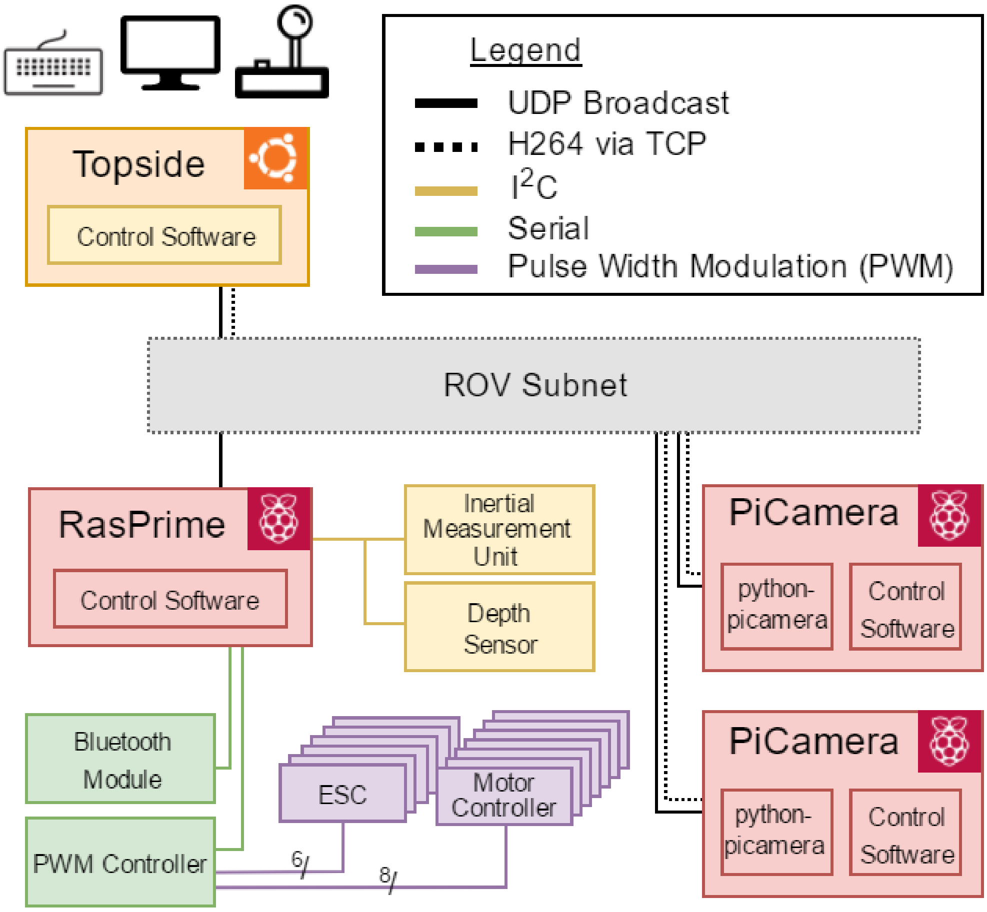



*Figure 16: Software Communications Block Diagram*

### 5.11.2. Control System Overview

The inter-device communication structure is shown in Figure 16. The RasPrime, a Raspberry Pi 3, is located inside the electronics enclosure and is responsible for controlling all moving parts, such as motors and thrusters. This device monitors the health of the onboard electronics system by reading heat, voltage, and current outputs from devices within the onboard electronics enclosure. In the event of a system failure the RasPrime will autonomously shut down the ROV, which mitigates potential damage and ensures the ROV is safe to handle.

Two Raspberry Pi Zero SBCs, called PiCameras, initialize video streams between a camera module and the Topside computer. Vimy's video software was rewritten to remove the use of third-party applications. The application listens to User Datagram Protocol (UDP) broadcast messages pertaining to video, and performs tasks by invoking methods in a Python script wrapped in a Java class to serialize and de-serialize data.

The Topside computer is located within the TCM and is responsible for translating user inputs into ROV operations, displaying sensor information, and displaying video streams. The Topside video software was also reworked by introducing the JavaCV computer vision library. The control software is now able to process and display video frames without the use of third-party video viewers. This has enabled Company employees to create algorithms such as those required by the Distance Calculator.

### 5.11.3. Distance Calculator

The Distance Calculator is a tool which combines data from the IMU, depth sensor, and camera images to determine distances between points on the ground plane. The distance from the ROV to the ground is proportional to the difference in external pressure when the ROV is resting on the ground versus its current position. Using the IMU to calculate the vehicle's pitch and by placing the camera at a known angle, the angle between the camera normal vector and the distance vector can be determined as shown in Figure 17. The angle between a camera's normal vector and an image pixel, can be determined as a function of the intrinsic properties of the camera which were calculated using functions in the JavaCV library. This creates enough known variables to solve the seven variable system required to reconstruct the projective transformation matrix which can be used to estimate the distance from the ROV to any ground plane point in the camera's view. This tool is used to perform the safety risk mitigation mission task by calculating the distance between cargo containers on the sea floor.

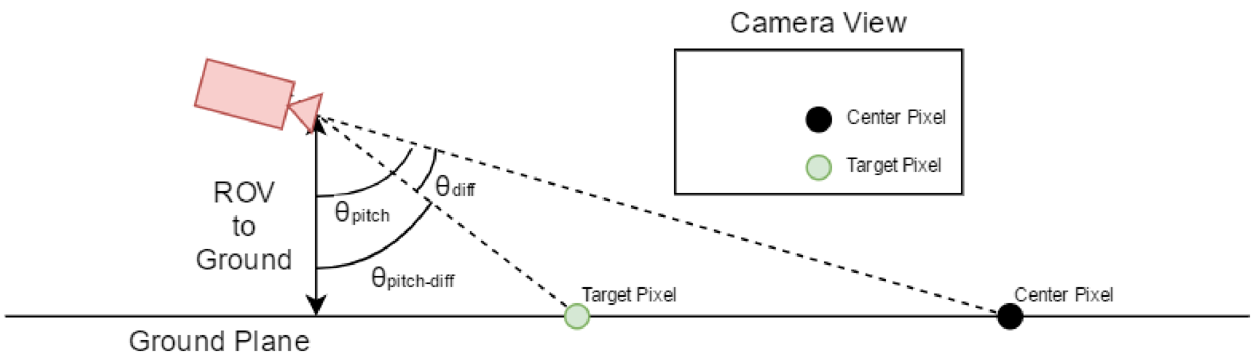


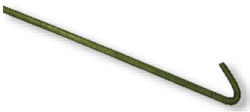

*Figure 17: Distance Calculation Diagram*

## 5.12. Payload

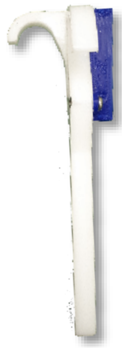
The 2016 contract year saw a change from the previously used pneumatic tooling system to an entirely passive system. This year the company switched to an integrated passive and motor operated tooling system. This was chosen due to the robustness of passive tools and the expanded electrical system which allows for DC motors to be added to the payload system. Vimy's payload is integrated into the chassis design and sits on a tooling skid shown in Figure 18 which can slide along the bottom of the ROV from fore to aft. This tooling skid allows Vimy's tooling setup to be quickly adapted during practice and allows for shorter set up and tear down time.

*Figure 18: Tooling Skid*

EER has developed an arsenal of mission specific payload tools to complete all tasks outlined in the 2017 contract. Vimy's payload is more than capable of handling Hyperloop platform construction, performing maintenance on entertainment infrastructure, providing environmental remediation, and assessing the risk of shipping debris at the bottom of the ocean.



The Hook: Chosen for its low weight and extendable reach, this multipurpose hook is used for multiple mission tasks such as removing the pin from the frame, repositioning the concrete hose or power connector, and retrieving clams from the seafloor.



Super Quick Universal Interface Device (SQUID): Similar to its cephalopod namesake, the SQUID also thrives in deep ocean environments. This versatile tool has three hooks in the X and Y planes making it adaptable to perform multiple tasks which include moving the locking mechanism on the entertainment centre and bumping the frame into the baseplate. On the base of this tool sits two LEDs; one LED functions as a Raman spectrometer to identify contaminants and the other is used to activate Radio Frequency Identification Devices (RFIDs). This tool also conveniently houses the onboard Bluetooth module for reading the RFIDs of shipping containers.

Sticky Stick-it: This simple yet incredibly useful tool is attached to the bottom of Vimy's chassis, and consists of wide strips of Velcro pointed towards the bottom of the sea floor. Its positioning along with its simplistic design allows Sticky Stick-it to attach to three beacons at once, and is strong enough to carry those beacons to the surface with ease.

$M^3$ (Magnetic Motor Mover): The $M^3$ is one of two actuated tools on Vimy. $M^3$ is a bidirectional motor with a series of magnets placed on the rotation mechanism. This multipurpose tool is used to spin values, move rebar and perform other miscellaneous tasks.

Bident: Resembling the Company's trident logo, the Bident is used to pick up and install the fountain heads. This tool is custom manufactured to fit the size of the object being handled. In the case of the 2017 contract, it is used to manipulate the fountain head.

Proboscis: The Proboscis is Vimy's second actuated tool. It uses a powerful suction mechanism used to gather agar from the sea floor. The tubular section of Proboscis slides easily into the sediment at the bottom of the sea floor while suction is applied to the sediment by a bilge pump. This suction allows Vimy to collect and return samples to the surface of the water.

Buoy-O-Buoy: This simple design utilizes a carabiner and metal plate to safely attach a buoy to high risk shipping containers. The metal plate is attached to the magnet of $M^3$, and once the carabiner is attached to the shipping container, Vimy can easily fly away while leaving the buoy attached to the container.

# 6. Lessons Learned

## 6.1. Interpersonal Skills Gained – Employee Training

During the 2017 contract year, the Company recognized the requirement for knowledge transfer due to the large division of technical experience throughout its workforce as well as anticipated succession issues amongst technical and non-technical experts. Therefore, the Company recognized the requirement to begin training junior employees in the technical and non-technical areas necessary to ensure competitiveness in the bidding process for future contracts.

The transfer of knowledge between experienced employees and the junior workforce required Company personnel to expand on their communication skills, specifically in the area of teaching and training. The Company provided workshops and training sessions in which junior members could learn essential skills and design theory. These seminars along with general employee interactions enhanced the communication skills of both senior and junior workers.

## 6.2. Technical Skills Acquired - Two-Sided Machining

The Company does most of its in-house machining work on a three-axis CNC router. The router head's three degrees of freedom only allows it to perform top-down machining operations: it cannot cut parts with overhangs or internal pockets. Any such additional features must be added through hand machining after the initial CNC cutting. This process is both more time consuming and less accurate than CNC machining. Until recently, the Company has restricted the shapes of tight-tolerance components to those which can be cut using top-down operations only. This year, the mechanical department refined a method of consistently aligning parts to the same origin after the stock material is flipped over. By keeping the coordinate system consistent before and after a flip, Company machinists can align features cut during separate operations: one for the top face and one for the bottom. Detailed machining operations can now be performed on both sides of a workpiece, increasing the complexity of geometry that Company members can design and fabricate in-house. This was used on numerous components for Vimy including chassis braces and the primary buoyancy block.

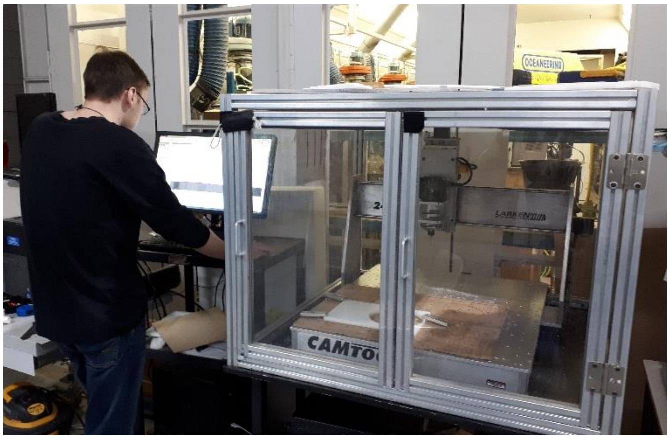


*Figure 19: Christian Samson Operating Company CNC Router*

## 6.3. System Testing & Troubleshooting

EER has always drawn on a strong testing and troubleshooting philosophy to be industry leaders in ROV design and manufacturing. This philosophy is centered around testing one system at a time or making only one change at a time when troubleshooting.

The main premise of this philosophy is that individual components are tested individually before being integrated into the overall system. This allows for easy integration and troubleshooting, minimizing issues before complete assembly. Once all individual components and control systems are tested, they are integrated into the overall system which is then tested as a complete unit. This philosophy ensures easier troubleshooting, minimizes overall system complications and reduces down time.

Whenever possible, new concepts undergo a minimum of one full prototyping and testing cycle before being integrated into the vehicle. This applies to all systems and disciplines including tools, chassis components, electronic devices, and software. The process of building a theoretical concept and bringing it into reality often highlights unforeseen problems that must be corrected to avoid damaging the vehicle or posing a safety hazard to employees. It can also bring to light flaws with the vehicle design early in the design process so that employees do not invest too much time in modules and components which may never work on the final vehicle.

### 6.4. Technical Challenge - Electronics Enclosure Fabrication Error

This year, the Company designed the electronics enclosure from the ground up then purchased the required material and contracted the fabrication work to a third party due to EER's lack of appropriate welding facilities. Due to a manufacturing error, the final enclosure was 8mm shorter in internal depth than was specified in the design. This error resulted in the onboard electronics no longer being able to fit inside the enclosure.

The solution began with a joint venture by the Company's mechanical and electrical departments. Since the electronics were distributed between two tiers inside the enclosure, the Company first sought ways to decrease the space in between the two layers, decreasing the height of the support columns by 5 mm, and further compressing an already tight layout on the bottom layer of electronics. The company then decreased the risers on the electronics equipment on the top layer by 3 mm. Decreasing the allotted height for the top layer proved most problematic, as there was no longer space for electronics header pins or connector wires without significant strain on conductors and hardware. The Company resolved this by extending some hardware into the bottom layer and using custom 3D printed brackets to hold the electronics in place. However, there remained restrictions to the height of select electronic devices inside the enclosure. This error also means that the Company will be unable to use this custom-built enclosure past the 2017 contract.

### 6.5. Non-Technical Challenge - Employee Retention

EER struggles with employee retention every year. At the beginning of each contract year, the company acquires many interested employees into their workforce. However, as the contract begins to require extensive person hours, those numbers dwindle, leaving a smaller crew than the Company had planned. The Company attributes this to the struggle of balancing work, academics, and personal as well as the Company's ability to engage junior members in its activities.

For the 2017 contract, EER focused on keeping as many junior members as possible. The Company did this by assigning tasks and responsibilities to every individual member based on experience and skill set. This allowed junior employees to see fulfillment in their work, and understand that every employee is valuable to the company. The result of these efforts is an increased retention of junior members, providing EER with personnel resource stability.

### 6.6. Future Improvements – Employee Resource Management

For the past several years, EER has employed a very generic resource management structure, whereby senior members manage and assign tasks to junior members based on skill and expertise. However, due to the large variance in Company employee experience across the board, a new resource management structure more closely related to that of small start-up companies may be a better method of resource management.

The Company will be trying to improve its current resource management structure in 2018 by switching to a Kanban strategy. Kanban is a simple resource management strategy that involves visually displaying project tasks according to status on a Kanban board. This board displays tasks in different sections of the board which indicate what status they currently hold (i.e. To Do, In Progress, In Refinement, Completed, etc.). This strategy is very successful in smaller team environments and projects because it is easy for all employees to see the progress being made on all projects. Individual employees can choose to the take initiative to tackle tasks on their own when they are aware of an existing problem. It also shows progress and gives company employees more opportunities to develop skills of their choosing.

## 7. Acknowledgements

EER would like to thank the following organizations for their support in the development of Vimy, Company travel to Long Beach, and of the MATE ROV Competition both regionally in Newfoundland & Labrador and internationally.

- Atlantic Canada Opportunities Agency: Monetary Donation
- Crosbie Group Limited: Monetary Donation
- Department of Tourism, Culture, Industry and Innovation: Monetary Donation
- ExxonMobil Canada Hibernia Company Ltd: Monetary Donation
- Fugro GeoSurveys Inc: Monetary Donation
- GitHub: Free Code Hosting
- Husky Energy: Monetary Donation
- Leoni-Elocab: Donation of Fibre Optic Tether
- Marine Institute of Memorial University: Monetary Donation and Use of Facilities
- Memorial University Faculties of Business, Engineering and Science: Monetary Donation
- Memorial University Technical Services: Discount on Enclosure Machining
- OpenJDK: Open Source Java Runtime
- Raspbian: Open Source Operating System used on Raspberry Pis
- Solidworks: Donation of Software Licences
- Statoil Canada Ltd: Monetary Donation
- Subsea 7: Monetary Donation
- Ubuntu: Open Source Operating System used on TCM
- Women in Science and Engineering Newfoundland: Monetary Donation

Finally, the Company extends a heartfelt thank you to our mentors Paul Brett, Joe Singleton, Jai Ragunathan, and Anthony Randell for their time, administrative support, and unwavering encouragement.

## 8. References

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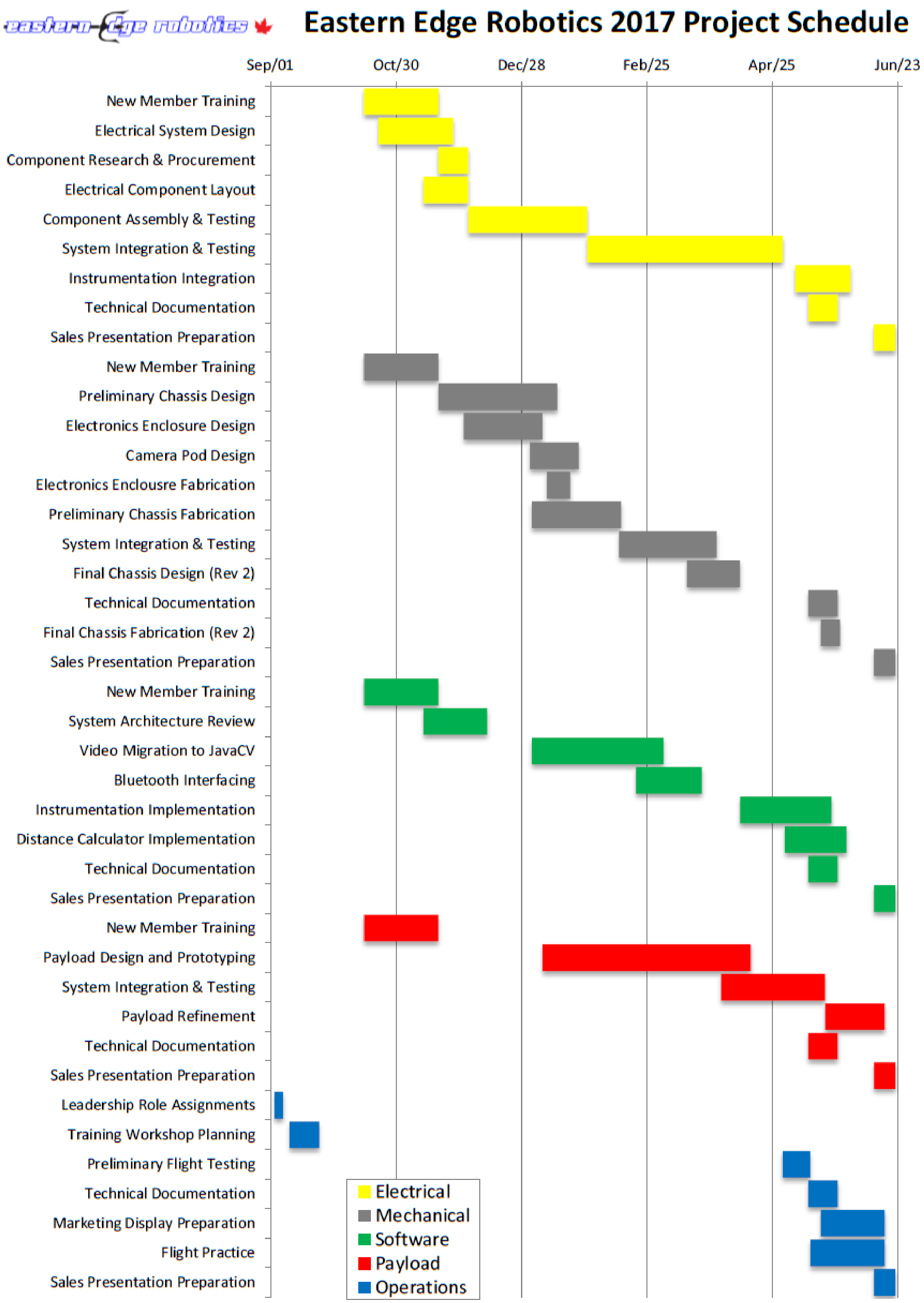
# Appendix A – Gantt Chart



# Appendix B – Overall Expenditure

| Eastern Edge Overall Expenditures | | |
|---|---|---|
| **Funding** | The Fisheries and Marine Institute of Memorial University | $5,000.00 |
| | Memorial University Faculty of Engineering, Science and Business | $10,000.00 |
| | Corporate and Government Funding | $20,250.00 |
| | Student Contribution | $6000.00 |
| **Overall Funding Provided** | | **$41,250.00** |
| **Donations** | Leoni-Elocab Fibre Optic Tether | $4,172.44 |
| **Overall Donations Provided** | | **$4,172.44** |
| **Onboard Electronics** | Miscellaneous Cables, Wires, Connectors, etc. | $333.675 |
| | Thrusters and ESCs | $1,303.78 |
| | Bluetooth Modules | $31.79 |
| | Power Converters | $332.80 |
| | Power Distribution (Fuse Blocks, Ground Bus, etc.) | $90.03 |
| | Network Devices (Fibre Optic Switch, Ethernet-USB Converters, etc.) | $223.23 |
| | Fibre Optic Connectors and Hot Melts | $323.26 |
| | Raspberry Pis | $160.42 |
| | Pololu Maestro | $47.12 |
| | Camera Hardware | $147.14 |
| | Pressure Sensor | $37.49 |
| | Terminal Blocks | $14.40 |
| **Topsides** | Cable Organizers | $71.93 |
| | Potentiometer Sliders | $9.32 |
| | Hardware | $50.82 |
| | Junction Box | $17.93 |
| **Mechanical** | Chassis Material | $1565.44 |
| | Payload and Camera Motors | $143.67 |
| | Miscellaneous Hardware | $1,544.28 |
| | Sealants | $152.00 |
| **Payload** | Power Screws | $10.20 |
| | Hardware | $15.98 |
| | Props | $39.50 |
| **Tools** | General Equipment (Heat Gun, Clamps, etc.) | $276.69 |
| **Overall Vehicle Expenditure** | | **$6,942.90** |
| **Admin** | Registration Fees | $267.46 |
| **Travel Costs** | Flights (18) | $9,148.62 |
| | Hotel Room (10 rooms, 8 nights) | $10,175.64 |
| | Rental Vehicle (2) & Gas (estimated) | $1,300.00 |
| | Team Funding Recovery (estimated) | $5,920.00 |
| | Misc. Travel Costs (estimated) | $5,920.00 |
| **Admin and Travel Expenditure** | | **$32,731.72** |

**Note**: All dollar amounts expressed in USD.

# Appendix C – Fair Market Value

| Vimy 'ROV' Fair Market Value | | | | |
|---|---|---|---|---|
| **Item** | **QTY** | **Price Each** | **Ext. Price** | **New/Used** |
| Thrusters + ESCs | 6 | $185.80 | $1,114.80 | Purchased |
| Electronics Enclosure | 1 | $1,168.22 | $1,168.22 | Purchased |
| Tether(18 m) | 1 | $426.76 | $426.76 | Purchased |
| High Density Polyethylene(48'',96'',1/2'' sheet) | 1 | $203.55 | $203.55 | Purchased |
| DC/DC Converters (12 V, 5V) and PCBs | 4 | $82.11 | $328.43 | Purchased |
| Camera(Board,Lens,Enclosure,Rotation Mech.) | 2 | $36.31 | $72.61 | Purchased |
| DC Motor Controls | 4 | $66.26 | $265.04 | Re-Used |
| Misc. Wires | 1 | $139.54 | $139.54 | Purchased |
| Misc. Connectors | 1 | $139.54 | $139.54 | Purchased |
| Networking Equipment(Switch,Fiber Converter,etc.) | 1 | $245.97 | $245.97 | Purchased |
| Vehicle Stability (Foam Topper) | 1 | $77.52 | $77.52 | Donated |
| Power Distribution & Circuit Protection | 1 | $71.28 | $71.28 | Purchased |
| Potting Compound (MG 832B) | 1 | $30.20 | $30.20 | Purchased |
| Electronics Can Penetrators | 12 | $5.28 | $63.36 | Purchased |
| Pololu Maestro 24 | 1 | $45.94 | $45.94 | Purchased |
| Lighting(LED) | 2 | $2.26 | $4.52 | Purchased |
| Raspberry Pi 3 | 1 | $50.28 | $50.28 | Purchased |
| Instrumentation(Magnet,Bluetooth,Bilge Pump,etc.) | 1 | $43.82 | $43.82 | Reused |
| Payload Motor | 3 | $13.01 | $39.03 | Purchased |
| **Total** | | | **$4,530.41** | |

| Vimy Topside Control Module Fair Market Value | | | | |
|---|---|---|---|---|
| **Item** | **QTY** | **Price Each** | **Ext. Price** | **New/Used** |
| Topside Computer Components | 1 | $295.69 | $295.69 | Re-used |
| Case + Foam | 1 | $244.33 | $244.33 | Re-used |
| Pilot Monitor | 1 | $155.04 | $155.04 | Re-used |
| Co-Pilot Monitor | 1 | $139.53 | $139.53 | Re-used |
| Buttons | 18 | $6.20 | $111.60 | Re-used |
| Networking Equipment(Switch,Fiber Connector,etc.) | 1 | $245.97 | $245.97 | Purchased |
| Power Meters | 2 | $44.03 | $88.06 | Re-used |
| Polycarbonate(0.125''x48''x24'') | 1 | $49.97 | $49.97 | Re-used |
| HDPE(0.5''x48''x24'') | 1 | $42.85 | $42.85 | Purchased |
| Arduino Mega | 1 | $39.90 | $39.90 | Re-used |
| USB Panel Mount Plug | 4 | $8.88 | $35.52 | Re-used |
| Topside Circuit Breaker | 1 | $33.74 | $33.74 | Re-used |
| In-line Circuit Breaker | 1 | $33.74 | $33.74 | Purchased |
| Joystick | 1 | $19.37 | $19.37 | Re-used |
| 48 V Power Connectors | 3 | $5.67 | $17.01 | Re-used |
| USB 2.0 Hub | 1 | $22.37 | $22.37 | Purchased |
| Tether Junction Box | 1 | $17.71 | $17.71 | Purchased |
| Ethernet Panel Mount Plug | 1 | $6.74 | $6.74 | Re-used |
| Slider Potentiometers | 12 | $0.72 | $8.64 | Re-used |
| 120 V NEMA Power Input Plug(Panel Mount) | 1 | $0.84 | $0.84 | Re-used |
| **Total** | | | **$1,608.62** | |

**Note**: All dollar amounts expressed in USD.

# Appendix D – System Integration Diagram