Guemes Island Ferry
Propulsion & Power Study

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Attachments:

(1) M/V GUEMES Driveline Condition Assessment – Diehl Engineering Correspondence, 20th January 2016
(2) M/V GUEMES Ferry Data Project Presentation – Cummins Northwest, 3rd May 2016

References:

(1) M/V GUEMES Engine Data Performance Files – Cummins Northwest, 3rd May 2016

Introduction

Art Anderson Associates (AAA) was contracted by Skagit County to perform a propulsion and power study to evaluate the feasibility of an all-electric battery powered ferry for replacement of the M/V GUEMES, which is nearing the end of its useful economic life. With guidance from Skagit County, the overarching context for this report was to determine the viability of an all-electric propulsion system versus other traditional and non-traditional forms of marine propulsion for a new ferry, with a focus on the following:

- Determining maximum thrust, power and energy requirements for an all-electric ferry on the current ferry route
- Determine the propulsion configuration for a new all-electric ferry and the resulting battery power requirements
- Evaluating preliminary USCG tonnage ratings
- Comparison of different types of propulsion versus all-electric propulsion for the Guemes Island route

The analysis contained in this report includes an evaluation of thrust, power, and energy requirements for an all-electric ferry design. These requirements were obtained via measurements of the power output from the engines onboard the existing M/V GUEMES. Additional data including vessel speed, position, and route was recorded and analyzed to gain an understanding of current conditions along the route which also affect the maximum power demand to support maneuverability and route schedule compliance.

In late 2015, AAA presented an all-electric propulsion system concept to Skagit County. The presentation highlighted two currently available battery technologies with the capability to meet the needs of the Guemes Island route. Vanadium Redox Flow Batteries (VRB) and Lithium Ion batteries are the two leading battery technologies for this application. This propulsion study analyzed the power and energy needs of the route, and examined the performance of each of these battery technologies to power a vessel design of larger size and capacity to that of the existing M/V GUEMES. A new concept vessel design lengthened by 25 feet is assumed for this study and is discussed in further detail below.

Background

The M/V GUEMES is a car and passenger ferry operated by Skagit County that serves residents and visitors who wish to cross Guemes Channel between Anacortes and Guemes Island, WA. The M/V GUEMES, built in 1979, is a 91 gross ton vessel with a USCG Subchapter T Certificate of Inspection. Due to its age and obsolescence of onboard equipment, the cost of maintaining the 36 year old vessel has significantly increased in recent years, as noted by Skagit County Ferry Division leadership. A condition assessment, performed in 2015, estimated that the remaining useful life of the M/V GUEMES is ten to thirteen years. Therefore, Skagit County has begun gathering information pertaining to the replacement of the existing M/V GUEMES ferry. Skagit County is very interested in all-electric technology, and has hired Art Anderson Associates to provide a propulsion and power study for a replacement vessel that is all-electric. For the purpose of this study, it was assumed that the characteristics of the new hull form will be similar to that of the existing hull, but will be lengthened by 25 feet to accommodate additional vehicles and passengers.

General Characteristics	M/V GUEMES Existing Hull	New Hull
Length	124'	150'
Breadth (over guards)	52'	52'
Draft at Design Waterline	6'	6'
Propulsion Type	2 (ea) Azimuthing Drives, Ulstein Model 370-DF	2 (ea) Azimuthing Thrusters, Make/Model TBD
Engines	2 (ea) Cummins KTA19, 600Hp	TBD

Table 1: General Characteristics

Several performance requirements have been established for the new vessel's power system. These requirements are based on the existing hull and focus on maintaining speed and maneuverability in the strong currents through Guemes Channel.

These performance requirements are as follows:

Performance Requirements	M/V GUEMES Existing Hull	New Hull
Capacity (Vehicles/Passengers/Crew)	22/99/3	24-30/Up to 150/TBD
Speed (knots)	10	10
Runs Per Day	23 to 26	23 to 26

Table 2: Performance Requirements

To accomplish this study, the above characteristics and performance requirements were examined. Data gathered from the propulsion plant of the existing vessel was utilized to determine the energy storage and power requirements necessary to meet Skagit County objectives.

The following report outlines the methods, process, and outcomes of the propulsion study and considerations for the installation of an all-electric propulsion system for a new ferry concept. Additionally, this report includes a high level overview of the advantages and disadvantages of an all-electric propulsion systems verses other traditional and non-traditional forms of marine propulsion.

Methodology in Determining Power and Energy Storage Requirements

The highly variable environmental conditions of Guemes Channel (primarily wind and current) make accurate approximation of the power requirements difficult and complex. Engine data from the existing vessel, obtained during typical operations, would lend the most accurate information regarding the load on the propulsion system and the power requirements needed to meet operational objectives. Several methods were utilized to obtain engine performance data throughout the feasibility study.

Power Requirements from Shaft Torque Measurement

Initially, an attempt was made to obtain torque measurements from the shaft of the existing engines through the use of strain gages. Strain gauges measure the deformation of the shaft and from that deformation a correlation is made to the torque being transmitted. Once the shaft torque is calculated, it is used in combination with the engine RPM to determine the engine horsepower output. Shaft torque and RPM are related to horsepower in the following way:

$$Horsepower\ (HP) = Torque\ x\ RPM\ x\ (\frac{1}{5255})$$

*Where Torque is in ft-lbs and (1/5255) is a unit conversion constant.

Due to the splined geometry of the cardan shaft, accurate correlation of strain (or deformation) and shaft torque was not possible within project budgetary constraints.

Power Requirements from Fuel Consumption

The load on the propulsion engines was then approximated by analysis of the fuel consumption. This method was used prior to the data collection by Cummins Northwest and was used in the preliminary stages of the electric propulsion study for initial battery sizing and tonnage calculations. Receipts from fuel purchases throughout the year (2013) were reviewed. By establishing the energy content of the fuel, and the efficiency of the engine in converting the fuel energy to mechanical energy, the power requirements at the output shaft were approximated as an average per round-trip. The current vessel was not equipped with any type of fuel management or monitoring system which might allow real time data logging of the fuel usage for comparison with the Guemes Channel current throughout the day. Since the fuel usage method for propulsion load estimation does not account for idle times, or other “non-route” times fuel is being burned, it was determined that this estimate would produce a higher than necessary propulsion power estimate. For this reason, data collected directly from the engine during normal operations was used as the primary resource for propulsion power predictions. The following information on the energy calculation for diesel fuel calculation is provided. As stated above, the conclusion drawn from this method was used only in the preliminary phases of this study and for comparison with the data obtained directly from the engines by Cummins Northwest.

Diesel fuel (ULSD; ultra-low sulfur diesel) contains 137,500 BTU per US gallon (US Energy Information Administration; http://www.eia.gov/todayinenergy/detail.cfm?id=20092). Fuel usage for the M/V GUEMES in 2013 averaged 7.176 gallons per round trip. This includes fuel for both propulsion and ship service electrical power. Converting this to energy required per trip:

$$Energy_{in}(fuel)\ x\ Efficiency_{Engine} = Energy_{out}$$

7.176 gallons/trip x 137,500 BTU/gal x 0.385 (efficiency) x 1 kWh/3412 BTU = 111.3 kWh/trip

The above efficiency is based on a typical diesel efficiency of 0.40 for full power operations and 0.35 for low power operations. These numbers were confirmed for these specific engines based on the engine testing by Modern Machinery in August 2014.

Power Requirements from Engine Data Logger

In the second attempt for direct data collection, AAA worked with Cummins Northwest to collect data from the pair of KTA19 engines onboard the M/V GUEMES. The goal of the data collection was to establish horsepower required during the crossing. Information collected from the Engine Control Module (ECM) over a stretch of 11 days, including torque and RPM data, allowed AAA to approximate the typical horsepower requirements and therefore establish high load and buffer requirements from that data. In this case, shaft torque was calculated based on engine performance parameters, fuel pressure, and engine speed sensor readings. From these measurements, horsepower was calculated using the equation above.

Energy consumption and power demand was calculated from historical data gathered from the M/V GUEMES during the period from 3/28/16 to 4/8/16 (Attachment 2 and Reference 1). Analysis revealed that the greatest power demand was during the departure from the Guemes pier, as expected and observed during site visits to ride the vessel. The figure below shows the correlation of power required during each portion of one round trip. The Propulsion Power Vs Time chart (See Figure 1) is a representation of the round trip for which the most demanding power requirements were observed.

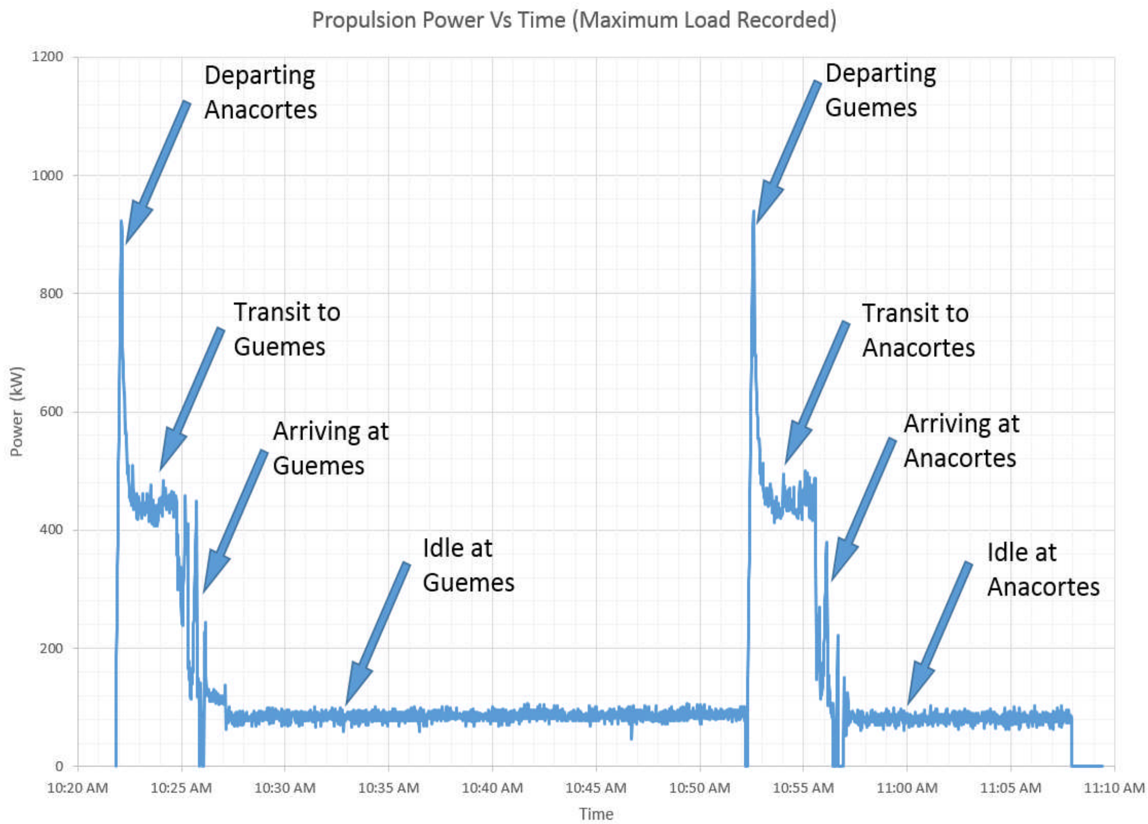


Figure 1: Power Used During Crossing (data was obtained from KTA Engine Control Modules on April 3rd, 2016)

Using torque and RPM data obtained from the data-logger installed on the existing KTA propulsion engines, the calculated average energy use for a round trip was 70.8 kWh. The maximum energy use for a round trip was found to be 110.5 kWh. These are derived from the instantaneous energy use which is in turn calculated from the fuel rail pressure logged during the trial period (Attachment 2). From the data, the total energy use for each round trip during the period was calculated and sorted to give the average and maximum. When comparing this to the energy estimate based on the fuel method, we note that the fuel method results in higher average energy estimates. The higher energy estimates when using the fuel method are likely due to the burning of fuel during times of engine idling or station-keeping (idling times and pierside station-keeping which are not part of the scheduled run). The extra fuel consumption could also include localized ship movements. Idling times, those times when both throttles on a conventional fossil fuel engine would be set to zero, are not considered in the energy use for the electric design. These would be taken into account in the fuel method but are not truly part of the required energy.

The graph below shows the actual energy usage (kWh) in comparison to the current variations for a given period of time. As expected, the peak energy utilization occurred on trips during high current conditions, particularly at 2 knots and above.

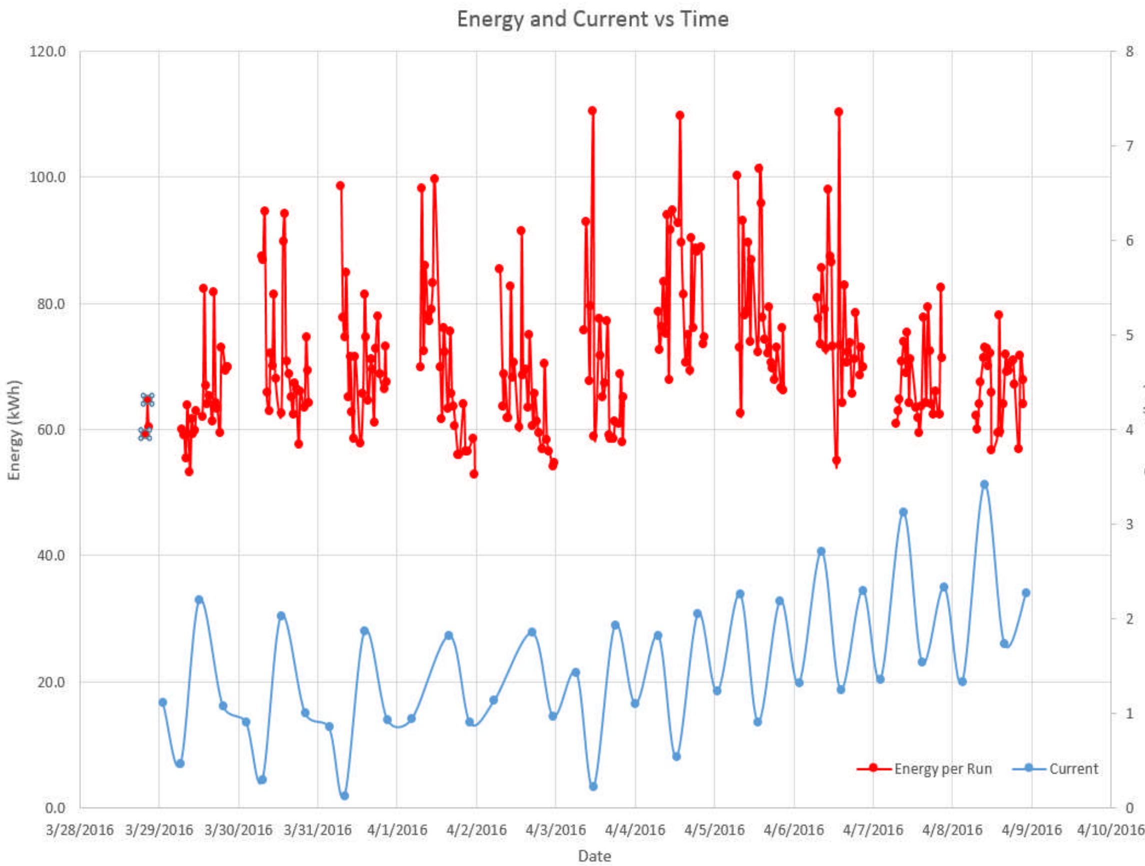


Figure 2: Energy Consumption and Current Over 11 day Trial Period

Power Required for New Vessel

The new concept vessel is assumed to be 25 feet longer than M/V GUEMES, and estimated that in the absence of current, no additional power should be required to propel the vessel at the same speed. The increased skin friction resulting from the added displacement and underwater wetted area arising from increased length are offset by the reduced wave-making and form resistance resulting from a larger length-to-beam ratio, which is a well-documented phenomenon in naval architecture and fluid mechanics. While this is expected to be the case for the new vessel, further hull resistance analysis will be required to validate this estimated performance during future hull form development.

The current in the Guemes Channel ebbs and flows across the ferry route. This cross-current acting on the larger, underwater lateral plane area of the new concept vessel will require additional force to maintain course, especially during maneuvering.

Thruster Requirements for the New Vessel

The existing vessel is equipped with two 600HP engines, each driving an azimuthing thruster. The vessel operators have reported that during high tidal current periods, full power from both thrusters is required to clear the dock. Our calculations indicate that 115 kN force is required to overcome a 3.5 knot current (typical maximum current expected) and 128 kN force for a 3.7 knot current (rare occurrence, but possible during certain parts of the year).

Side Force (Thrust) Calculation

Side force (symbol F) is generally determined using the following equation:

$$F = 0.5 \times \rho \times S \times v^2 \times Cd$$

Where

ρ	=	mass density of the water (=1.9905 lb sec2/ft4 for sea water)
S	=	underwater lateral plane area (ft2)
V	=	current velocity (fps)
Cd	=	drag coefficient, which depends on shape

Assuming current velocity and drag coefficient are unchanged, side force will increase by the ratio of underwater lateral plane areas. Using the General HydroStatics (GHS) program with a geometry file of GUEMES without mid-body extension the underwater lateral plane area at the maximum draft of 6’6-1/2” is 666.76 ft2.

The underwater lateral plane area of the mid-body extension is 163.50 ft2 (= 25.00 × 6.54). The total underwater lateral plane area WITH mid-body extension is then 830.26 ft2 (= 666.76 + 163.50).

Thus the side force should increase by a factor of 1.245 (= 830.26 / 666.76).

A propulsion system utilizing traditional propellers, rudders, and tunnel thrusters was considered, but did not appear to provide adequate lateral thrust to overcome the strong cross-current in the channel when maneuvering. For this reason, azimuthing thrusters are recommended for the replacement vessel.

A newer 500 HP Z-drive thruster should provide 120 kN of thrust.

Increasing the waterline length by 25’ (~25%) will result in a 25% increase in the thrust required to clear the dock (128 kN x 1.25 = 160 kN, see equation above). Twin 500 HP thrusters should be able to provide 240 kN of thrust, which is adequate to push the vessel away from the dock and forward at a 45° angle.

Assuming 30kW is reserved for ship service electrical loads, and 500kW of power available from each battery bus, a 470kW (630HP) thruster could be powered from each bus. The exact size of the thruster can be determined during vessel design, but should be between 500 and 630HP.

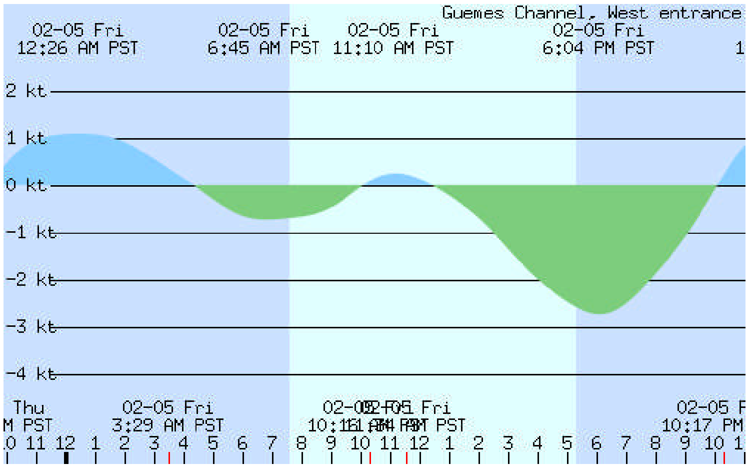


Figure 3: NOAA Current Data for a Typical Day. Data shows current variations ranging from roughly 1 to 2.5 knots, which changes direction from east to west throughout the day with the shifting tide. The channel typically has one strong ebb period during the day.

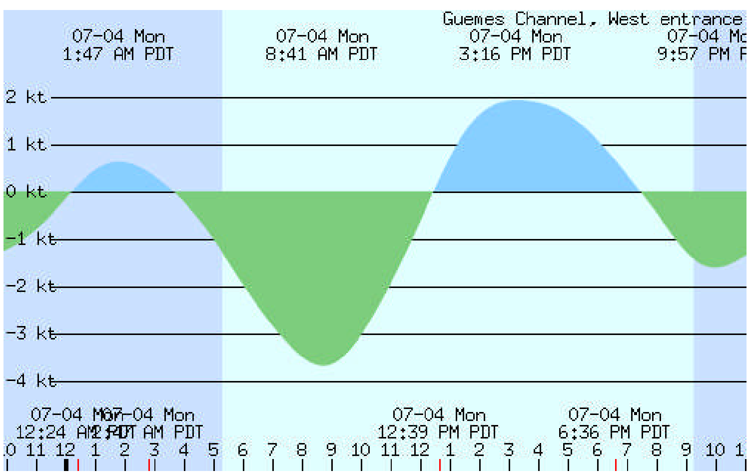
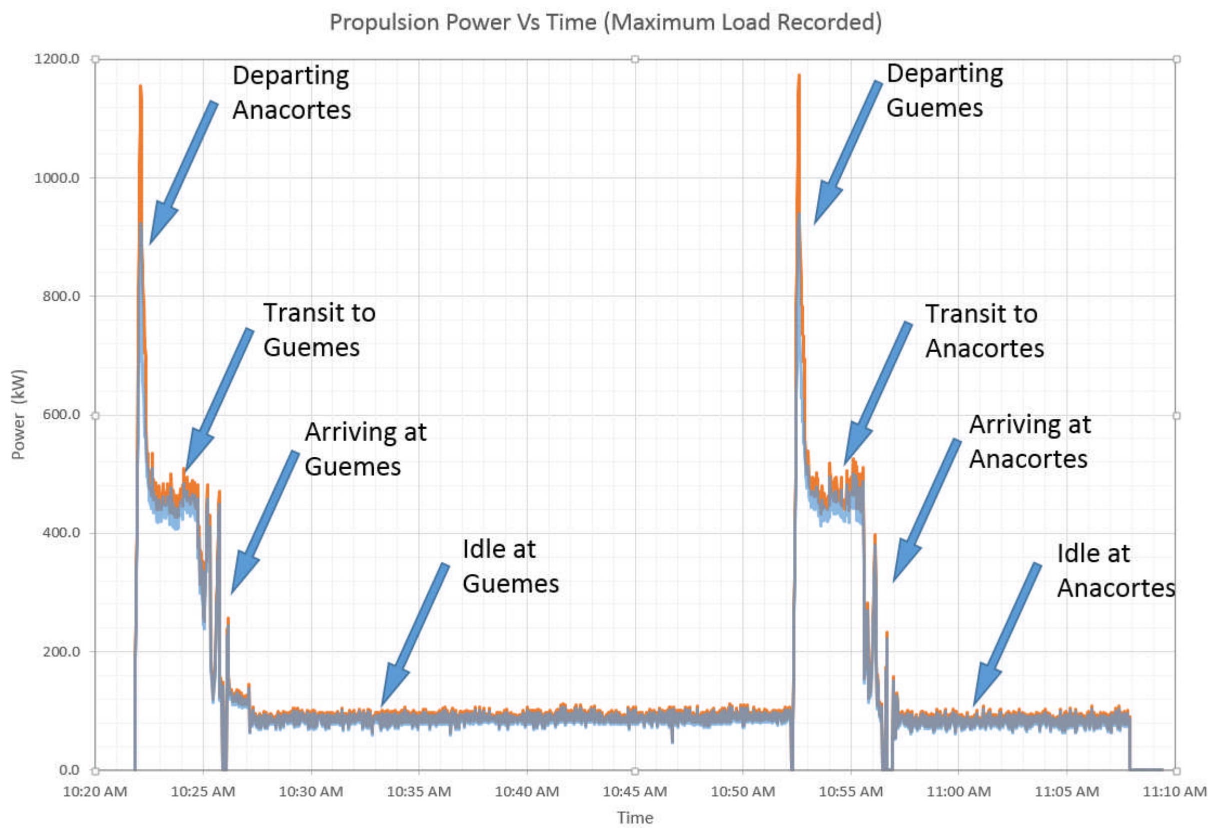


Figure 4: NOAA Current Data for a day with a large tidal swing. Data shows a very strong ebb current which reaches speeds up to 3.5 to 4 knots, resulting in particularly high power demand and energy consumption while arriving and departing at the Guemes Island terminal.

For determining the required capacity of the power source, each day was broken up into three time periods. Each of these periods coincide with a tidal shift throughout the day. NOTE: there are four tidal shifts throughout each day. However, one tide shift was eliminated since one shift will occur during the night when ferry service is not provided. As can be seen in Figure 4 above, on days of extreme tides, one tide will result in higher currents than the averages shown on Figure 3. This time period during the extreme tide is broken into 8 runs and is called Time Period 1 below. Time periods 2 and 3 are considered to be average tides, and are broken into 9 runs each.

After calculation of the total energy needed for one full day (all three periods), an additional buffer was added to account for the power increase needed to maintain course in the Guemes Channel current. The added underwater lateral plane area will result in stronger side forces and additional thruster capacity to leave each terminal and maintain course in transit. This buffer is based on the data received from the engine control module data link, and is 25% while leaving the terminals, and 5% during transit across the channel. This buffer was applied to the total data set for the average power requirements (Periods 2 and 3) as well as the single day with the highest current flow to obtain the requirements for Period 1. The chart below shows the power requirements from Figure 1 (blue line) as compared with the total power with buffer (orange line).



Time Period 1	Time Period 2	Time Period 3
Run Energy Req'd	Run Energy Req'd	Run Energy Req'd
1. 118.2 kWh	1. 77.4 kWh	1. 77.4 kWh
2. 118.2 kWh	2. 77.4 kWh	2. 77.4 kWh
3. 118.2 kWh	3. 77.4 kWh	3. 77.4 kWh
4. 118.2 kWh	4. 77.4 kWh	4. 77.4 kWh
5. 118.2 kWh	5. 77.4 kWh	5. 77.4 kWh
6. 118.2 kWh	6. 77.4 kWh	6. 77.4 kWh
7. 118.2 kWh	7. 77.4 kWh	7. 77.4 kWh
8. 118.2 kWh	8. 77.4 kWh	8. 77.4 kWh
	9. 77.4 kWh	9. 77.4 kWh
Period 1: 118.2 kWh x 8 runs = **945.6 kWh**	Period 2: 77.4 kWh x 9 runs = **696.6 kWh**	Period 3: 77.4 kWh x 9 runs = **696.6 kWh**

Total for one full day (all 3 periods): **2.339 MWh**

Add buffer, 4 round trips to account for extra runs on high traffic days: **77.4 kWh x 4 = 309.6 kWh**

Add Auxiliary Electrical Load: 30 kWh x 18 hr/day = **540 kWh**

Total including lengthening and Aux**: 3.189 MWh**

Operating Scenario and Battery Options

All electric propulsion can provide a multitude of benefits including zero emissions, reduced noise, reduced maintenance and reduced operating cost among many others. Two currently existing battery technologies are considered feasible for marine propulsion. These batteries are Vanadium Redox Flow Batteries (VRB) and Lithium Ion batteries. While neither technology has been used frequently in the marine propulsion market, Lithium ion battery technology has been applied to hybrid technologies in marine propulsion systems, and an all-electric vessel in Norway has been operating since 2015 using Lithium ion batteries. The design and construction of vessels using lithium ion batteries has been reviewed and approved by classification societies and regulatory bodies on several vessels. The same cannot be said of Vanadium Redox Flow batteries. Though unproven in the marine market space, the potential of VRBs is huge considering the lower initial cost and the ability to provide power until completely drained meaning that charging per unit of energy can occur much less often. Below is additional information regarding each of the battery technologies.

Lithium Ion Battery Option

Lithium Ion Batteries are lightweight electrochemical devices that convert chemical energy from positive and negative electrodes into useable electrical energy. There are several different chemistries including Nickel Manganese Cobalt Oxide (NMC) and Lithium Titanate (LTO). Both batteries function by using an electrolyte as a conductive medium for lithium-ions to transfer between electrodes. During battery discharge the positive lithium-ions move from the negative electrode to the positive electrode allowing an external device to perform work. When the battery is charged the reverse process occurs and excess electrical energy is transported back through the electrolyte to the negative electrode for storage. The whole system is monitored by electronic equipment that ensures the safe and efficient transfer of energy.

Vanadium Flow Battery Option

The Vanadium Flow Battery (VRB) is an electrochemical device that stores its energy in liquid electrolytes as opposed to within actual electrodes. The VRB battery contains two electrodes and an electrolyte solution in each cell. The electrolyte solution is made up of both a positively charged electrolyte and a negatively charged electrolyte which are separated by a membrane. Chemical potential energy from these solutions can be converted to electrical energy on demand and excess electrical energy when generated can be converted back into chemical potential energy and stored as new electrolyte ready for the next discharge. In this manner the VRB can be easily charged and discharged according to the needs of the customer. The large electrolyte tanks also act as excellent heat sinks which maintain the overall system at safe operating temperatures and when combined with electronic monitoring equipment allow for years of safe, reliable, cost-effective service.

	NMC (Lithium Ion)	VRB (Vanadium Flow)
Cost/kWh	High	Low
Weight/kWh	Low	High
Volume /kWh	Low	High
Maintenance	Moderate	Low
Safety	Good	Excellent
Complexity	High	Low
Reliability	Good	Excellent
Efficiency	Excellent	Good
Cell Degradation	3-7% / Year	N/A
Changing Cycle	Opportunity Charging Required	Once Daily

Single overnight charge

As shown above, if charging is performed once per day, battery capacity is required to be 3.189 MWh.

A flow battery of this size would be approximately 265 tons and would cost approximately $2.0M to $2.5M. A lithium ion battery of this capacity would be considerably less weight and cost approximately $4.0M to $4.5M. Both cost estimates take into account the costs of the battery management and power electronics systems.

The VRB technology is capable of providing full rated energy, with virtually no degradation over its life as the battery is charged and discharged. This ability lends well to a once-per-day charging strategy. The VRB is better suited for the less frequent but longer charging periods since no degradation is experienced.

Lithium ion batteries are poorly suited for a single overnight charge, since the batteries degrade at an accelerated rate when fully discharged. Utilizing a lithium ion battery and single overnight charging schedule would likely be cost prohibitive due to this degradation of battery energy capacity when fully discharging the battery during daily operations.

Intermediate charging periods

Intermediate charging, or opportunity charging, can substantially reduce many aspects of the Lithium ion battery system including required capacity, weight, and cost. For example, charging during extend wait times in excess of 15 minutes, will reduce the required battery capacity to 862 kWh. *This size is based on the assumption the vessel will have a 10 charge cycles a day and that any ONE of the three intermediate charging periods can be postponed in the event of an emergency or operating problem*.

Substantial weight savings can be realized with lithium ion batteries when utilizing an opportunity or intermittent charging routine. The lithium ion battery is particularly advantageous in the intermittent charging scheme due to its relatively light weight and fast charging times. By reducing the discharge of the battery by recharging more frequently, the degradation of the lithium ion battery is minimized.

The relatively slower charging time of the VRB technology does not lend well to the intermittent charging scheme. The VRB power system recharges at about the same rate that it discharges. Therefore, an intermittent charging schedule would require the same amount of charging time as running time. Considering the current operating schedule, the size of the battery required even with an intermittent charge, would not be significantly reduced.

Annual energy requirements

As explained above, the existing vessel utilizes 70.8 kWh per round-trip for average current, and 110.5 kWh per round-trip for high current. We are estimating an additional 6.6 kWh (77.4 kWh) and 7.7 kWh (118.2 kWh) for average and high current trips, respectively to account for the added length of the new vessel. This value is further increased by the four trip buffer for high traffic or emergency scenarios and a 30 kW electric auxiliaries load. Based on an average of 23 trips per day, and 365 days/year, the estimated annual energy usage and cost is shown below for the two types of batteries under consideration:

	VRB Flow		Lithium Ion
Energy per round trip:	113.3	kWH	113.3
Avg number of round trips:	23	per day	23
	2,606	kWH/day	2,606
System Efficiency:	75%		90%
Utility Power:	3,475	kWH/day	2,895
Power Cost:	0.059509	$/kWH	0.059509
	$207	per day	$173
Total energy cost:	$75,555	per year	$63,145
Utility Demand Cost:	$10.91	per kW(max)	$10.91
Charging Power:	580	kW	536
	$6,328	per month	$5,848
Total demand cost:	$75,936	per year	$70,176
Billing Cost:	$1,326	per year	$1,326
Total Est. Ann. Utility Cost:	$152,817	per year	$134,647

Naval Architecture Considerations

For the purpose of analyzing the feasibility of this new propulsion system, the basic requirements for the new concept design for the Guemes Island ferry are (1) use of all-electric propulsion, (2) comply with 46 CFR Subchapter T “Small Passenger Vessels (Under 100 Gross Tons)” regulations, and (3) similar shape as the existing vessel to accommodate docking at the existing terminals.

A feasible concept design satisfies all three basic requirements. For this study, however, many aspects of the design, such as structural integrity, subdivision, stability, access to spaces, location of propulsion batteries, and passenger accommodations, are assumed feasible without analysis because they do not represent significant departure from standard industry practice.

Since the new all-electric ferry will replace M/V GUEMES on the same route between Anacortes, WA and Guemes Island, WA the size, hull form, proportions, and weights of M/V GUEMES are used as the basis for similar features in the new concept all-electric ferry. Certainly vehicle deck dimensions and shape at the ends must be similar to M/V GUEMES in order to satisfy basic requirement (3). Satisfying basic requirement (1) is discussed further below.

Developing a design with gross tonnage under 100 is the major challenge in satisfying basic requirement (2). Satisfying Subchapter T regulations concerning hull structure, fire protection, means of escape, intact and damage stability, lifesaving equipment, and the like is considered part of the normal design process, therefore feasible. Satisfying tonnage regulations is discussed further below.

Determining battery size, battery chemistry, charging scenario, and economic impact of all-electric propulsion (basic requirement (1)) are covered elsewhere in this report. In order to design a feasible concept, the hull form must have sufficient buoyance, in terms of underwater volume, to carry the vessel's full load weight without sinking deeper than the design load waterline. The full load displacement (weight) of the concept all-electric ferry has been estimated as discussed below.

Increased Service

For a route utilizing a single ferry, service in terms of passenger and vehicle throughput, can be increased fundamentally in two ways. First, without changing the ferry's capacity, the schedule can be changed to add more round trips in the day. Second, the ferry's capacity can be increased while maintaining the same schedule.

For the purposes of this study the owner has elected to maintain the current schedule. Therefore, increased service is accomplished by increasing capacity. GUEMES capacity is currently 99 passengers and 22 cars. The designated increased capacity for the new all-electric ferry concept design is 24-30 cars. Passenger capacity can also be increased up to 150, which is the limit imposed by 46 CFR Subchapter T. Broadly speaking, passenger capacity is governed by stability criteria. Hull form and weight distribution in a new design can be fine-tuned to accommodate the desired passenger capacity.

Tonnage

Tonnage is a measure of a vessel's interior volume calculated under a prescribed measurement system and, as such, relates to the overall vessel's size. Tonnage is used, primarily, in determining the application of safety, security, and environmental regulations; in determining crew licensing requirements; and in the assessment of taxes and fees.

The tonnage regulations do not include provisions for novel, or special purpose vessels such as an all-electric ferry that reduce gross tonnage. The methods and measurement locations used in computing tonnage are, however, explicitly identified by the regulations. This means that in a new design hull form, internal compartmentation, use of fixed water ballast (if needed), and structural arrangements can be developed to achieve - within reason - the desired tonnage. Tonnage under 100 gross registered tons (grt) has been achieved in passenger/vehicle ferries over a wide range of lengths as shown in the following table.

Ship	Length [feet]	Beam [feet]	Depth [feet]	Tonnage [grt]
B. L. DEBERRY	90.7	45.7	11.5	97
WHATCOM CHIEF	99.8	44.1	10.7	69
SANPOIL	109.6	45.7	11.5	97
KEN EICHNER-2	111.5	48.0	12.0	90
GUEMES	124.0	46.0	9.5	91
New Guemes Ferry (Projected)	150.0	50.0	9.5	92
New Whatcom Co Ferry	175.0	50.0	11.8	97 est
CHRISTINE ANDERSON	213.0	66.0	16.5	96
STEILACOOM II	216.0	53.5	16.5	97

Weight Estimate

A vessel's light ship (empty) weight is commonly determined by summing the separately estimated weight of each category in a work breakdown structure. The Ship Work Breakdown Structure (SWBS) with categories listed below was used in this study.

SWBS 100	Hull Structure
SWBS 200	Propulsion Plant
SWBS 300	Electrical Plant
SWBS 400	Command and Surveillance (includes interior and exterior communications and alarms)
SWBS 500	Auxiliary Systems
SWBS 600	Outfitting and Furnishings

Major changes for an all-electric ferry, as compared to a conventional diesel powered ferry, occur in SWBS 200, SWBS 300, and SWBS 500. The SWBS 200 weight is reduced since main propulsion diesel engines and reduction gears are no longer included, but the weight of propellers, thrusters, and connecting shafting remains. The SWBS 300 weight is increased due to the weight of batteries and propulsion motors. The SWBS 500 weight is reduced because auxiliary systems such as fuel fill, transfer, and service systems, lube oil service systems, and combustion air systems are no longer needed. The size, hence weight, of other auxiliary systems such as machinery space ventilation are significantly reduced because demand is reduced.

Additionally, items of variable load for an all-electric ferry are essentially reduced to the weight of crew, passengers, and vehicles since variable loads of fuel and lube oil are no longer needed.

The weight of a new concept Guemes all-electric ferry has been estimated based on similar passenger/vehicle ferries, including M/V GUEMES, and presented in the table below. Since, at this early stage, the design conceptual weights were estimated conservatively high, it is expected that light ship weight will become lower as the design progresses.

Category	Description	Weight [lbs]	[Stons]
SWBS 100	Hull Structure	534,077	267.04
SWBS 200	Propulsion Plant (less batteries)	23,096	11.55
SWBS 300	Electric Plant w/o Batt & Prop. Motors	8,094	4.05
SWBS 300	Batteries and BMS	530,000	265.00
SWBS 300	Propulsion Motors	10,712	5.36
SWBS 400	Command & Surveillance	1,008	0.50
SWBS 500	Auxiliary Systems	9,235	4.62
SWBS 600	Outfitting & Furnishings	6,272	3.14
	22,000 gal FW ballast	183,517	91.76
	Estimated Light Ship Deadweight (Items of variable load)	1,306,011	653.01
	150 Passengers @ 185# ea	27,750	13.88
	3 Crew @ 250# ea	750	0.38
	Vehicles (= 450lb/ft x 532 lane feet)	239,400	119.70
	275 gal fresh water	2,294	1.15
	Spares and stores	2,000	1.00
	Total Deadweight	272,194	136.10
	Full Load Displacement	1,578,205	789.10

Not all vehicles carried will be cars. Pickup trucks, delivery trucks, campers, and other larger vehicles are also carried. For design purposes vehicle weight is estimated assuming a weight per lane-foot that represents a mixture of vehicle types. The total lane-feet is the sum of the lengths of all loading lanes on board. For this study total lane feet is 28 (the desired car capacity) times 19-foot length per car. The 19-foot length per car is used by Washington State Ferries in determining vehicle capacity and includes an allowance for the distance between fenders.

The displacement-to-length ratio (DLR) is used to express how heavy a vessel is relative to its length. As used in this study DLR = DISPL / $(0.01\times LOA)^3$; where DISPL is the full load displacement in short tons and LOA is the overall length. DLR of the conceptual all-electric ferry is compared to M/V GUEMES.

Conceptual all-electric ferry: DLR = 227.3 [= 767.13 / $(0.01\times150)^3$]

M/V GUEMES: DLR = 246.8 [= 470.50 / $(0.01\times124)^3$]

Such close agreement shows that the all-electric ferry concept is feasible.

Shipyard Consultation

Various shipyards were consulted to discuss the feasibility of constructing a vessel utilizing the types of battery modules required of VRB and Lithium ion technology. Builders like Vigor/Kvichak, Nichols Brothers, and Dakota Creek were consulted during this portion of the study. Each builder concurred that a vessel of similar size to the existing M/V GUEMES, utilizing a VRB or Lithium ion battery technology for propulsion power, could be built within reasonable budget and timeline expectations.

Regulatory Body Concerns

Input from the US Coast Guard (USCG) was solicited regarding the regulatory concerns of building a Subchapter T Passenger and Vehicle ferry containing a battery powered propulsion system. Regulatory bodies like the US Coast Guard play a vital role in the safe and successful design and construction of new vessels, particularly when implementing a novel application of technology. Summarized below is the input from the USCG (Marine Safety Center).

The US Coast Guard provided initial requirements regarding the design of a safe and compliant battery powered vessel. These comments include the battery and power management system, ventilation and space requirements, fire detection and suppression system concerns, and automation input. While special consideration needs to be given to the design of the battery support systems, these requirements are not excessively restrictive, and generally apply to all vessels, including those with more traditional power supply systems. The goal of the USCG review is to ensure that the design applies these safety measures to the new technology effectively to ensure safety of the passengers and crew. The USCG has approved several designs involving lithium ion battery technologies. For this reason, this particular battery chemistry is mentioned in the comments below. However, these design considerations apply to both Lithium ion and VRB propulsion power systems.

Battery Modules

- The battery module installation shall be in accordance with the manufacturer's requirements and recommendations.

- The battery monitoring system must be able to sense the temperature for each cell. A single sensor may be located between two cells, but in no case shall a sensor monitor more than two cells.

Battery Management System (BMS)

- The battery charger must be controlled by the BMS, and sized in accordance with the manufacturer recommendation.

- The BMS shall produce an alarm before a battery cell reaches its maximum rated temperature (typically 95%), and shall automatically shut down if a battery cell reaches 100% of its maximum rated temperature.

- The BMS shall produce an alarm and automatically shut down if cell(s) report an abnormal voltage or high deviation between cells in accordance with the manufacturer's design standards.

- Power supply to the BMS must be from a surge-protected source.

Ventilation

- Compartments containing Li-ion batteries shall have sufficient ventilation and environmental conditioners to maintain the ambient temperature in accordance with the manufacturer's recommendations.

- A temperature sensor shall be installed in each compartment containing Li-ion batteries, which alarms at the operating station when the ambient temperature in the compartment exceeds the maximum operating temperature recommended by the battery manufacturer.

- The ventilation for each compartment containing Li-ion batteries shall be such that any gases released as a result of a fire are routed to the open deck, away from passenger spaces and egress routes.

- Ventilation duct work in each compartment containing Li-ion batteries shall be made of aluminum (same as the hull) or a material with a higher melting temperature, and shall not route through passenger spaces.

- The ventilation closure device required under 46 CFR 182.465(h) shall seal the vent duct as close as practicable to the compartment boundary, in order to minimize heat exposure in the event of a fire.

Fire Detection & Suppression

- Fixed fire detection and extinguishing systems shall be installed in each compartment containing Li-ion batteries. The systems shall be installed in accordance with 46 CFR 181 Subpart D. The fire suppression agent shall be suitable for the specific battery chemistry in accordance with the manufacturer's recommendations.

Battery Compartment

- The compartment boundary between each compartment containing Li-ion batteries and passenger spaces shall meet A-0 structural fire protection standards.

- An emergency shutdown switch shall be located outside of each compartment containing Li-ion batteries, and on the bridge, to disconnect the batteries from the DC circuit. If multiple shutdowns are located in close proximity, one or more of the components may be omitted with MSC approval.

Vital System Automation Testing Documents

- In accordance with 46 CFR 182.220(b), the propulsion system must meet the applicable requirements of 46 CFR Subchapters F & J. This will include the requirement for a Qualitative Failure Analysis (QFA), Design Verification Test Procedure (DVTP), and Periodic Safety Test Procedure (PSTP).

- In order for the MSC to evaluate the QFA, DVTP, and PSTP, submittal of the following plans as supporting documentation may be required:

a. A block diagram showing vessel automation system(s) architecture, to include PLCs, communications, and all I/O;
b. Automation equipment layouts with bill of materials;
c. Power management system plans;

d. Propulsion control system plans; and
e. Description of operation for automation system(s).

Alternative Propulsion Analysis

There are several alternatives to an all-electric marine propulsion system, including diesel direct drive, diesel electric, diesel electric hybrid, Liquefied Natural Gas (LNG), and hydrogen fuel cell. As part of this report, several different propulsion technologies were compared. The discussion below highlights the capabilities and shortcomings of several traditional and more recently developed propulsion systems. While each technology has its own benefits and downfalls, no other currently viable technology has the same emissions benefits that an all-electric propulsion system does.

Diesel direct drive and diesel electric propulsion systems rely fully on diesel engines to provide the power to the propeller from either a shaft or an electric motor. These are proven technologies with very clear design criteria and are utilized on the vast majority of motor vessels. The upfront capital cost is the lowest of all options reviewed. However, the total operational cost including fuel and maintenance drive the total lifecycle cost up relatively quickly. In addition, there is the environmental impact of the vessel emissions, which is regulated by the EPA. The required power is near the threshold between EPA tier 3 and EPA tier 4. If the engines are sized such that EPA tier 4 engines are used additional auxiliary systems and fluids will be required to comply with the EPA standards.

Diesel electric hybrid propulsion systems rely on both diesel engines and batteries to supply power to the propeller via an electric motor. Although many land vehicles use diesel electric hybrid systems and a handful of vessel owners and operators have adopted this technology, this is still considered a relatively new technology in the marine industry. Similar to the all-electric propulsion, the ability to use this technology is highly dependent on the route, vessel, battery technology, and operational profile. The power system can be configured in many different ways. Typically, the batteries are sized to handle the peak power required during normal operations and charge during all other times the engines are operating. This configuration provides great flexibility when operating, but still requires the same number and size of diesel engines. The capital investment cost of a diesel electric hybrid system is 2 to 3 times more than a conventional diesel drive system. However, due to the reduced operating time, maintenance and overhaul costs are greatly reduced. Similarly, the operational emissions are reduced by the decreased run time.

Liquefied natural gas (LNG) propulsion systems operate very similarly to diesel engine propulsion systems, the diesel engines are just replaced with LNG and the remaining components are largely the same. This engine technology is relatively new to the marine industry, however there are several operators who have adapted these engines for vessels. The major advantages to these engines are their fuel efficiency and similarity to traditional diesel power plants. However, the fuel storage and transfer systems are quite different and require cryogenic cooling to maintain the gas in a liquid state. This is quite costly and therefore typically only makes it practical for larger vessels. Additionally, the vessel requires special fueling processes that would require either shore side fueling infrastructure improvements or the vessel would have to make special fueling trips. For these reasons LNG engines are cost prohibitive.

Hydrogen fuel cells are a technology that converts the chemical energy of a fuel into electricity via a chemical reaction. There are many different types of fuel cells and the marine industry is exploring their use on vessels. To date, there are a few hydrogen fuel cell powered vessels including a 100-person passenger only ferry operating in Germany. The major advantages of fuel cells are the drastic reduction in emission levels which approach near zero depending on the sources of hydrogen. There are several challenges associated with fuel cells including: storage of hydrogen in either a gas or liquid state, pure hydrogen is corrosive to many metals, and the infrastructure to create hydrogen (either shore side or on the vessel). While a few demonstration vessels are in operation, the technology will take significant time before the commercialization will have a major impact on the marine market. This makes fuel cell powered vessels cost prohibitive at this time.

Conclusion/Recommendations

The power required to propel a new concept all-electric vessel, approximately 25 feet longer than the existing M/V GUEMES ferry is 77.4 kWh on trips of average current, and 118.2 kWh on trips of high current flow through Guemes Channel. The overall capacity of the battery used to provide that power depends largely on the charging schedule utilized by the ferry operator.

VRB has distinct advantages in cost and the ability to provide consistent power down to nearly 0% charge, while the number of lithium ion batteries required to provide this level of energy for all-day operations on one charge is feasible, but extremely costly. If charging throughout the day at intermittent opportunities is considered, the amount of energy storage, or battery volume, can decrease considerably. When taking this strategy into account, the lithium ion battery becomes much more affordable. In this scenario, the lightweight and smaller size of the lithium ion battery package is very attractive.

In order to provide enough energy storage to power the new vessel throughout the day, the battery must be able to store 3.189 MWh of usable energy. Energy storage of this magnitude would allow 26 runs per day, as currently scheduled for the busiest day of the week (Friday), plus a buffer for the proposed increased size of the new vessel and an additional 4 round trip runs to account for the possibility of added trips throughout the day when schedule permits. Both the VRB and lithium ion batteries are capable of providing this level of energy storage. One clear difference between the VRB and lithium ion battery technologies is the ability of the VRB to provide the rated power down to nearly 0% charge with no degradation of battery capacity, while the lithium ion battery has diminished battery capacity with each discharge. In lithium ion batteries, the rate of diminishing capacity depends on how deeply the battery is discharged. For this reason, it is likely to be cost prohibitive to operate a once-per-day charging strategy with the lithium ion battery. Due to the power degradation, the lithium ion battery must have additional cells to bolster overall energy capacity. What the lithium ion loses in energy degradation, it makes up for in weight. The lithium ion battery package needed to power the new concept vessel is significantly lighter than the VRB, even with the added cells previously discussed. With the capacity needed to power the vessel all day with one charge, the VRB would weigh approximately 530,000 lbs and would cost between $2.0M to $2.5M. The lithium ion battery would weigh considerably less, approximately 8,000 to 10,000 lbs, and cost approximately $4.0M to $4.5M.

Both cost and weight estimates are taking into consideration both the battery management system and power electronics.

Significant reduction in capacity, weight, and initial cost are realized if it is decided that the batteries can be charged at intermittent opportunities throughout the day. Particularly suitable for the intermittent charging is the lithium ion battery due to its light weight and rapid charging. Other analysis, such as facilities upgrades to support intermittent charging would be required to finalize a feasibility study for potential operations scenarios and resultant schedules.

Housing an all-electric propulsion system in a hull meeting Skagit County's requirements was also investigated. Service provided by the ferry can be improved by increasing the passenger and vehicle capacity of the vessel. To maintain compliance with 46 CFR subchapter T, the vessel capacity can be increased to a maximum of 150 passengers. Lengthening the vessel by twenty-five feet will certainly provide the space for an additional 51 passengers, plus additional vehicles. The addition of these passengers and vehicles does not cause concern from a vessel weight or stability standpoint. Also required to maintain Subchapter T classification, the vessels tonnage must remain under 100 gross tons. Since the new concept vessel serving the Guemes Island route is a new design hull form, internal compartmentation, use of fixed water ballast (if needed), and structural arrangements can be developed to achieve - within reason - the desired tonnage. For this reason, maintaining the gross tonnage under 100 tons for the new vessel is feasible. One measure used to determine an acceptable weight of a vessel is the displacement-to-length ratio. The weight of the all-electric vessel was estimated to determine the full load displacement. The displacement-to-length ratio of the new concept vessel closely agrees with the displacement to length ratio of the existing M/V GUEMES.

The USCG's regulatory requirements will need to be met during the design of a vessel with an all-electric propulsion system. Though all-electric propulsion is still relatively uncommon, there are many vessels in service utilizing lithium ion for all, or some, of their propulsion power. VRB technology and the design required to integrate its use, has not been implemented in a marine vessel. In either case, close coordination with regulatory and class societies will be required to ensure that the design meets all regulatory and class requirements.

In summary, an all-electric propulsion system for a new concept vessel to replace the M/V GUEMES is highly feasible for this particular route and its unique environmental conditions. Alternative battery chemistries and configurations will allow Skagit County a number of options to optimize the battery size to meet their particular operational requirements. It is recommended that all-electric propulsion be considered for the design of a replacement vessel that will provide safe and reliable service.

Attachment 1

M/V GUEMES Driveline Condition Assessment – Diehl Engineering Correspondence, 20 January 2016

From: Rob Diehl [mailto:rdiehl@diehlengineering.com]
Sent: Wednesday, January 20, 2016 22:59
To: Eric Engelbrecht <eengelbrecht@artanderson.com>; 'Joe Payne' <joe.payne@eesimarine.com>
Cc: 'Eric Diehl' <ediehl@diehlengineering.com>; 'Scott Crawford' <scrawford@diehlengineering.com>; jcogswell@diehlengineering.com
Subject: RE: Guemes Driveline

All-
I preformed the requested ship check this evening after the vessel tied up for the night. It too all of about 10 minutes. I am sorry to say that there is no suitable place to measure engine shaft torque using strain gages.
I am of the opinion that the only feasible way to calculate engine power output is thermodynamically by measuring fuel burn rates. One approach would be to install accurate flow meters into the fuel supply and return lines, again sending the flow signals to a data logger. This would provide a real time measurement of fuel burn rates on each engine, which could then be used to calculate instantaneous engine load and power. This approach probably could produce accuracies in the mid to high 90 percent range. There may already be a commercially available system on the market for doing this. I suggest you talk to Cummins and see what they have to offer. Perhaps Cummins has a way to pull and record real time fuel rack data from the fuel controller, while the vessel is working.
At this point, I don't see how we can be of further assistance on this project.
Regards,
Rob Diehl, P.E.
Diehl Engineering Company

From: Eric Engelbrecht [mailto:eengelbrecht@artanderson.com]
Sent: Wednesday, January 20, 2016 3:26 PM
To: Rob Diehl; 'Joe Payne'
Cc: Eric Diehl; Scott Crawford; jcogswell@diehlengineering.com
Subject: RE: Guemes Driveline

Hi Rob,

Do you still recommend conducting the shipcheck?

Need to know soon…Rachel is getting resources in place to support.

Best,
Eric

Eric Engelbrecht | Vice President - Marine Division
Office 360.479.5600 x2268 | Mobile 206.605.5489

1

From: Rob Diehl [mailto:rdiehl@diehlengineering.com]
Sent: Wednesday, January 20, 2016 2:32 PM
To: 'Joe Payne'
Cc: Eric Engelbrecht; Eric Diehl; Scott Crawford; jcogswell@diehlengineering.com
Subject: RE: Guemes Driveline

Joe-
The problem with the shaft, as depicted on the drawing, is that the splined section extends the entire length of the shaft section between u-joint yokes. The straight section along the O.D. is covered with a grease shield. But even if it were not, I do not think that you could get a reliable torsion reading there as the spline teeth will not tend to transfer the shaft torque evenly as that thinner section is not as stiff torsionally as the thicker section towards the left yoke. And locating the gages on the thicker section closer to the left yoke would not work well as the yoke ears would tend to introduce bending stresses into that area. We really need a straight section of shafting with a constant cross section in order to accurately scale measured torsional strain into shaft torque and horsepower.
I really do not think we can use the cardon shaft for this purpose, and hope to get any kind of accuracy in our calculations.
-Rob Diehl

From: Joe Payne [mailto:joe.payne@eesimarine.com]
Sent: Wednesday, January 20, 2016 2:14 PM
To: 'Rob Diehl'
Subject: FW: Guemes Driveline

See below and attached. Maybe we'll get lucky tonight.

Joseph Payne, PE, LEED AP
www.EESImarine.com
tel/text: 360-710-1424

From: David Lee [mailto:dlee@drivelinesnw.com]
Sent: Wednesday, January 20, 2016 2:11 PM
To: joe.payne@eesimarine.com
Subject: FW: driveline

Here is some torsional data on the driveshaft. **There is no tubing in that driveline**. I have attached a drawing.

Moment of Inertia = 0.07320 kgm^2
Stiffness = 3.17 deg @ 15200Nm
Weight = 80 Lbs

If you have any further questions please don't hesitate to ask. ***[David Lee]*** sorry about the confusion.
[David Lee]

Dave

ATTACHMENT 2

M/V GUEMES Ferry Data Project Presentation – Cummins Northwest,

3rd May 2016

Skagit County Guemes Island Ferry

Art Anderson Associates' Propulsion Feasibility Study

(Datalogging Support)

Brian Pinkstaff, P.E.

Rev.02 – 6/20/2016

Background

- Art Anderson and Associates
  - Pacific Northwest Naval Architecture and Marine Engineering Firm.
  - Requested the support for a extended duration datalog (7-14 days) of the existing Guemes Island Ferry propulsion engines.
- Cummins Inc.
  - Beginning in late Jan. 2016, Cummins Northwest's Engineering team developed a C185 datalogger to collect data on both engines simultaneously starting in Mar. 2016.
  - Data collected includes engine parameters, as well as GPS for position, distance, and speed of the vessel.
  - NOTE: This data summary presentation is provided for a overview reference only, the full data set(s) are included in the export to Art Anderson and Associates to draw appropriate conclusions in their own post processing analysis in support of their propulsion study on the Guemes Island Ferry.

C185 Datalogger System Components

3. Wiring Harness
   - -24V PWR
   - -GPS
   - -CAN Engine 1
   - -CAN Engine 2

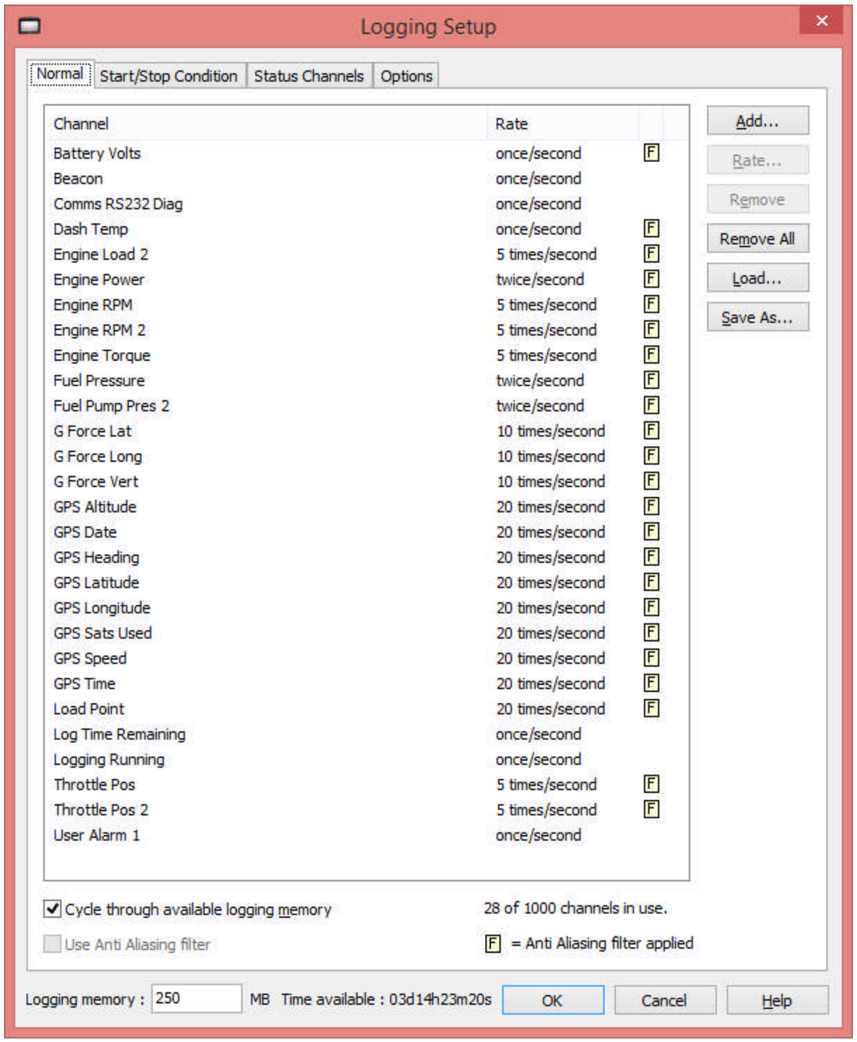
1. Vansco Datalink Gateway
   -Convert the J1587 to J1939 protocol from each engine control module (ECM).

2. C185 Motec Data Logger
   - -User programmable
   - -Display
   - -Memory (250mB)

C185 Datalogger Configuration

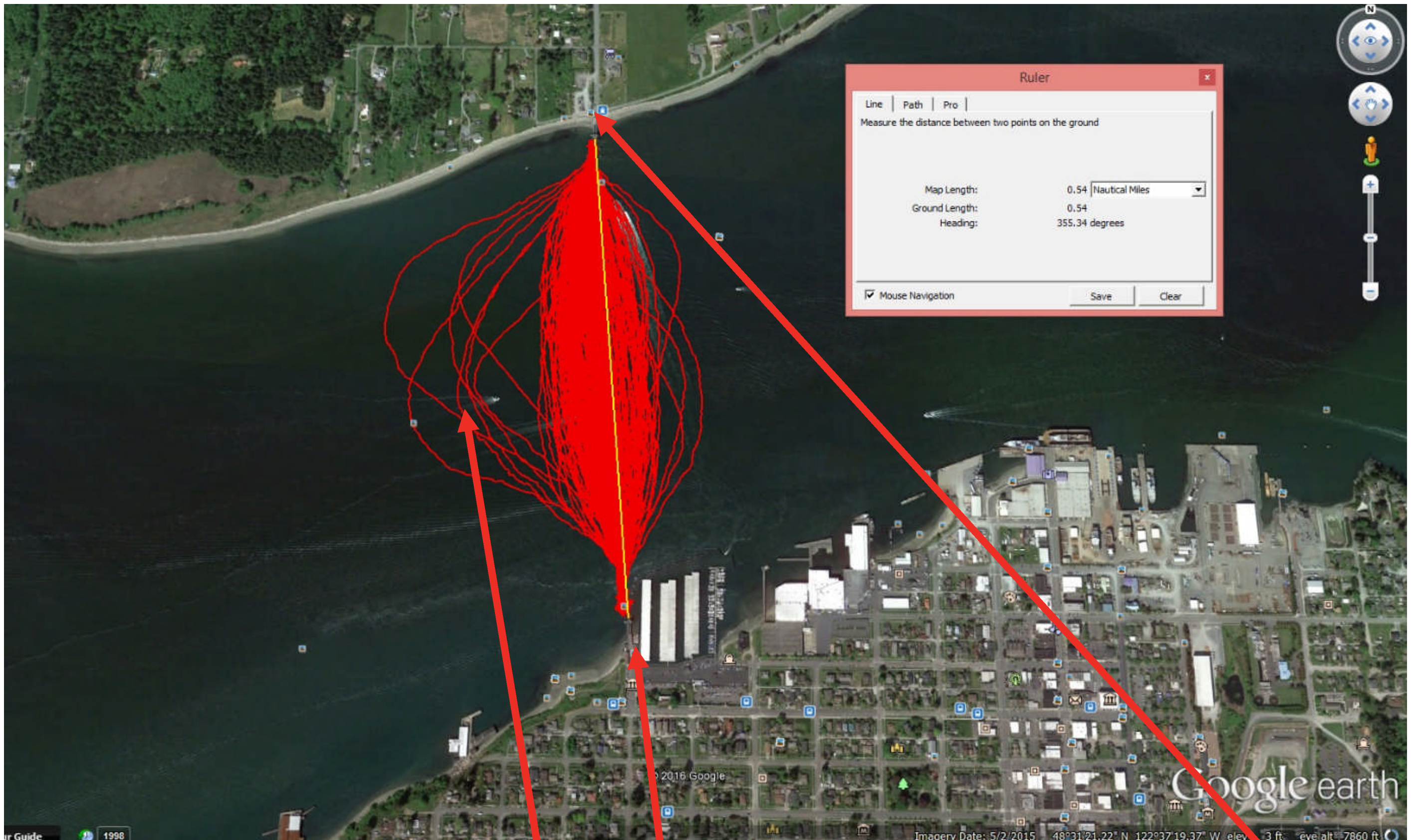
- Parameters
  - Vessel
    - GPS Data – Position
    - GPS Data – Date/Time
    - GPS Data – Speed
    - Total Vessel Power Output (both engines)
  - Engine 1 and 2
    - Engine Speed (RPM)
    - % Throttle
    - % Load/Torque
    - Fuel Rail Pressure
    - Engine Power Output (calculated)

C185 Datalogger Configuration



- Sample Rates
  - GPS 20 Hz
  - G-Force 10 Hz
  - Engine Parameters 5 Hz
  - Status Channels 1 Hz
- Post Processing
  - Full rates using i2 Analysis
  - 1 Hz output to Excel
- Duration
  - Begin 3/29/16 at 6:30PM
  - End 4/9/2016 at 4:30 PM
  - 11 Days of Operation

Ferry Route (~0.52 NM 1-way)

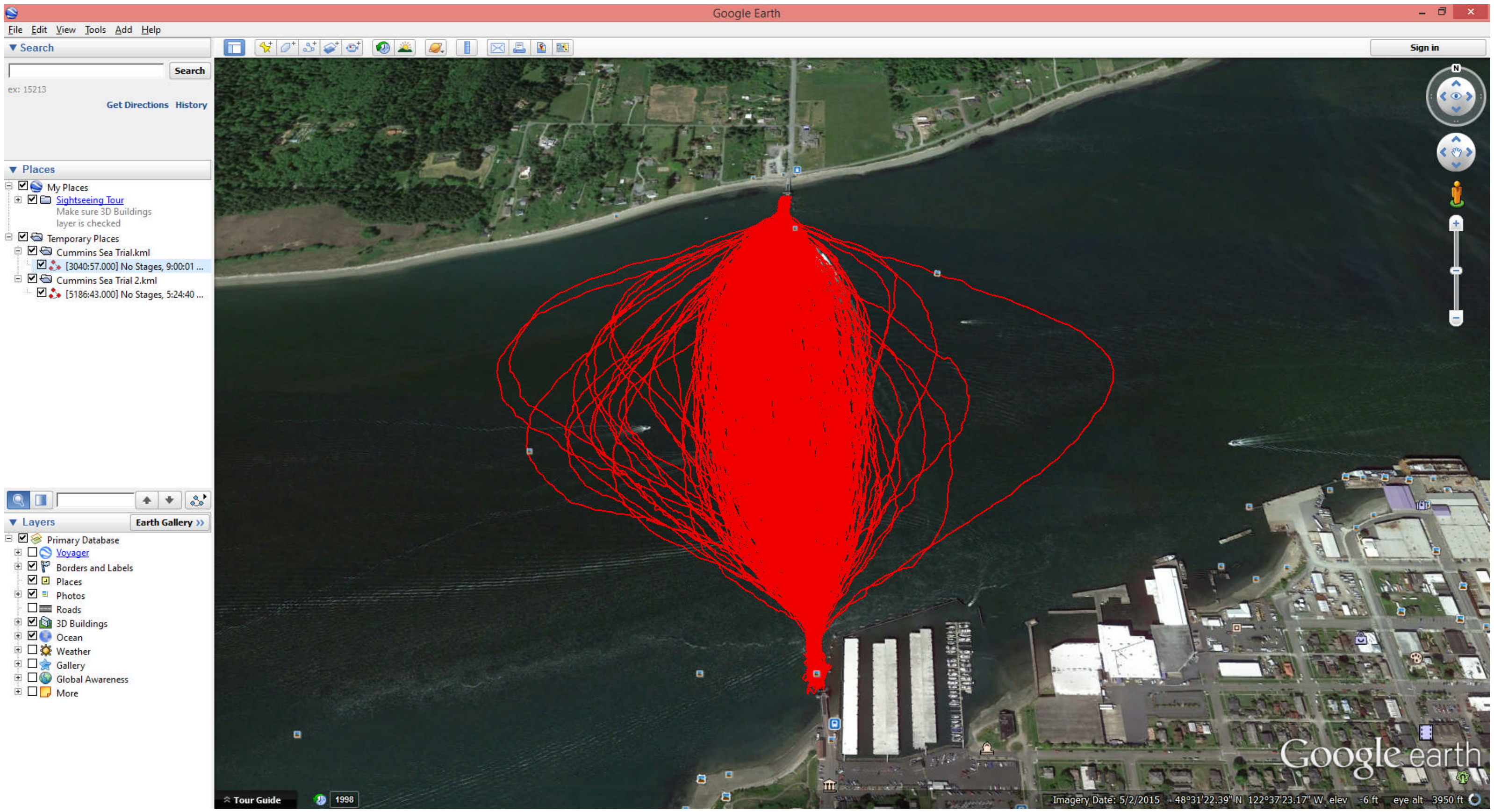


Anacortes, WA Terminal

Guemes Island Ferry Route

Guemes Island, WA Terminal

Ferry Route (All sailings for 11 days)



C185 Vessel Data Summary

- Parameters
  - Vessel
    - Speed
      - Maximum speed = 12.1 knots
      - Average speed underway (terminal to terminal) = 8 knots
      - Average WOT steady state cruise speed = 9.5 knots
    - Power
      - Maximum Total Vessel Power Output = 1304 hp
      - Average Total Vessel Power Output (underway) = 566 hp
    - Distance
      - 1.02 NM per round trip (straight-line)
      - 1.03 NM per round trip traveled path average (1930 m)

C185 Engine 1 Data Summary (To Island)

- Parameters
  - Engine 1
    - Maximum Engine Speed (RPM) = 1956
    - WOT Rated Engine Speed (RPM) = 1805
    - Average Engine Power at rated speed = 317 hp
    - Average Engine Load at rated speed = 53%
    - Maximum Throttle = 100%
    - Maximum Load/Torque = 107%
    - Maximum Fuel Rail Pressure = 1004 kPA
    - Maximum Engine Power Output (calculated) = 662 hp
      - Data summary from i2 Standard on 4/4/2016, 20:42.04.

C185 Engine 1 Data Summary (To Anac.)

- Parameters
  - Engine 1
    - Maximum Engine Speed (RPM) = 1896
    - WOT Rated Engine Speed (RPM) = 1806
    - Average Engine Power at rated speed = 287 hp
    - Average Engine Load at rated speed = 48%
    - Maximum Throttle = 100%
    - Maximum Load/Torque = 107%
    - Maximum Fuel Rail Pressure = 992 kPA
    - Maximum Engine Power Output (calculated) = 664 hp
      - Data summary from i2 Standard on 4/3/2016, 23:42.52.

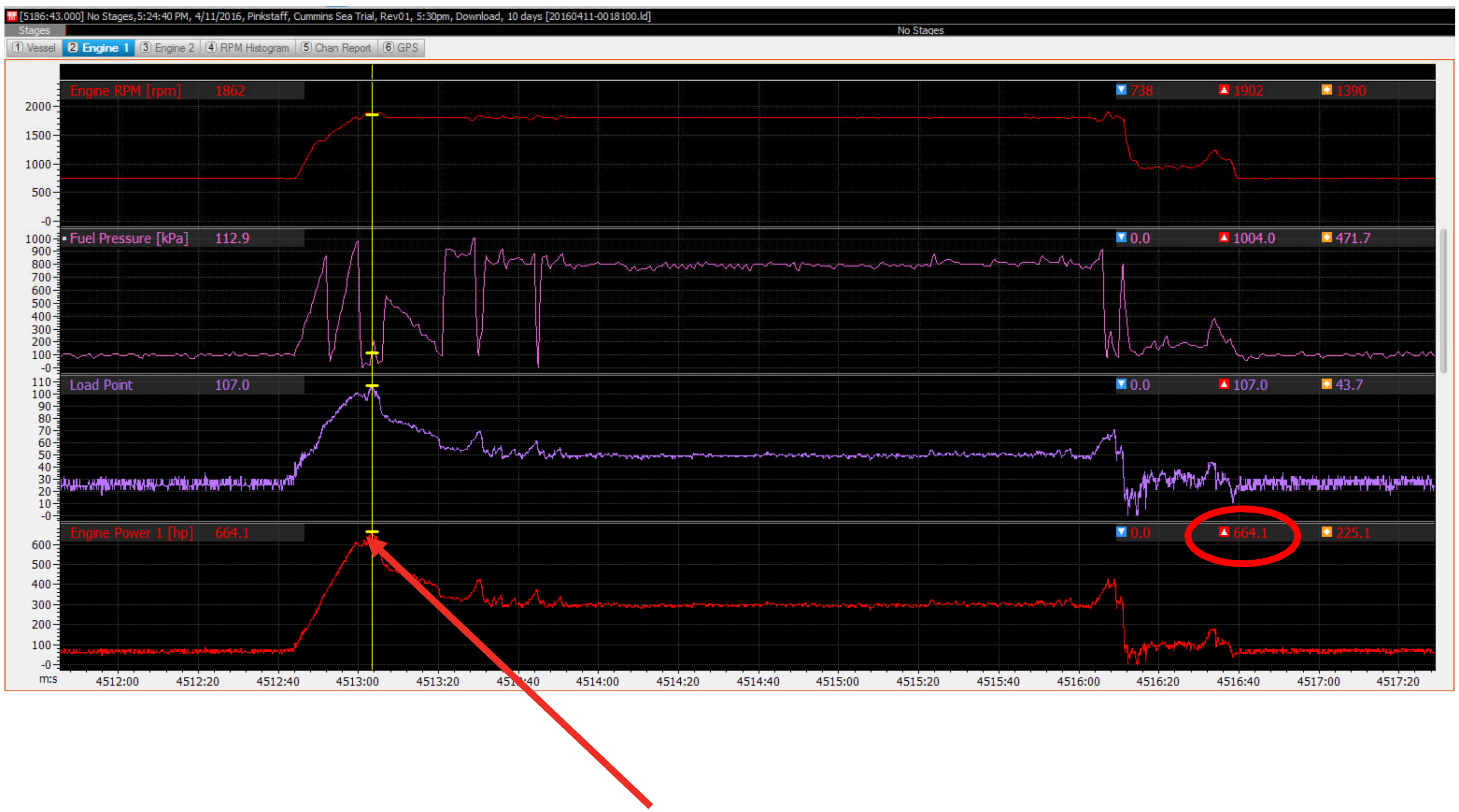
C185 Engine 2 Data Summary (To Anac.)

- Parameters
  - Engine 2
    - Maximum Engine Speed (RPM) = 1932
    - WOT Rated Engine Speed (RPM) = 1805
    - Average Engine Power at rated speed = 273 hp
    - Average Engine Load at rated speed = 46%
    - Maximum Throttle = 100%
    - Maximum Load/Torque = 107%
    - Maximum Fuel Rail Pressure = 988 kPA
    - Maximum Engine Power Output (calculated) = 661 hp
      - Data summary from i2 Standard on 4/8/2016, 17:04.55.

C185 Engine 2 Data Summary (To Island)

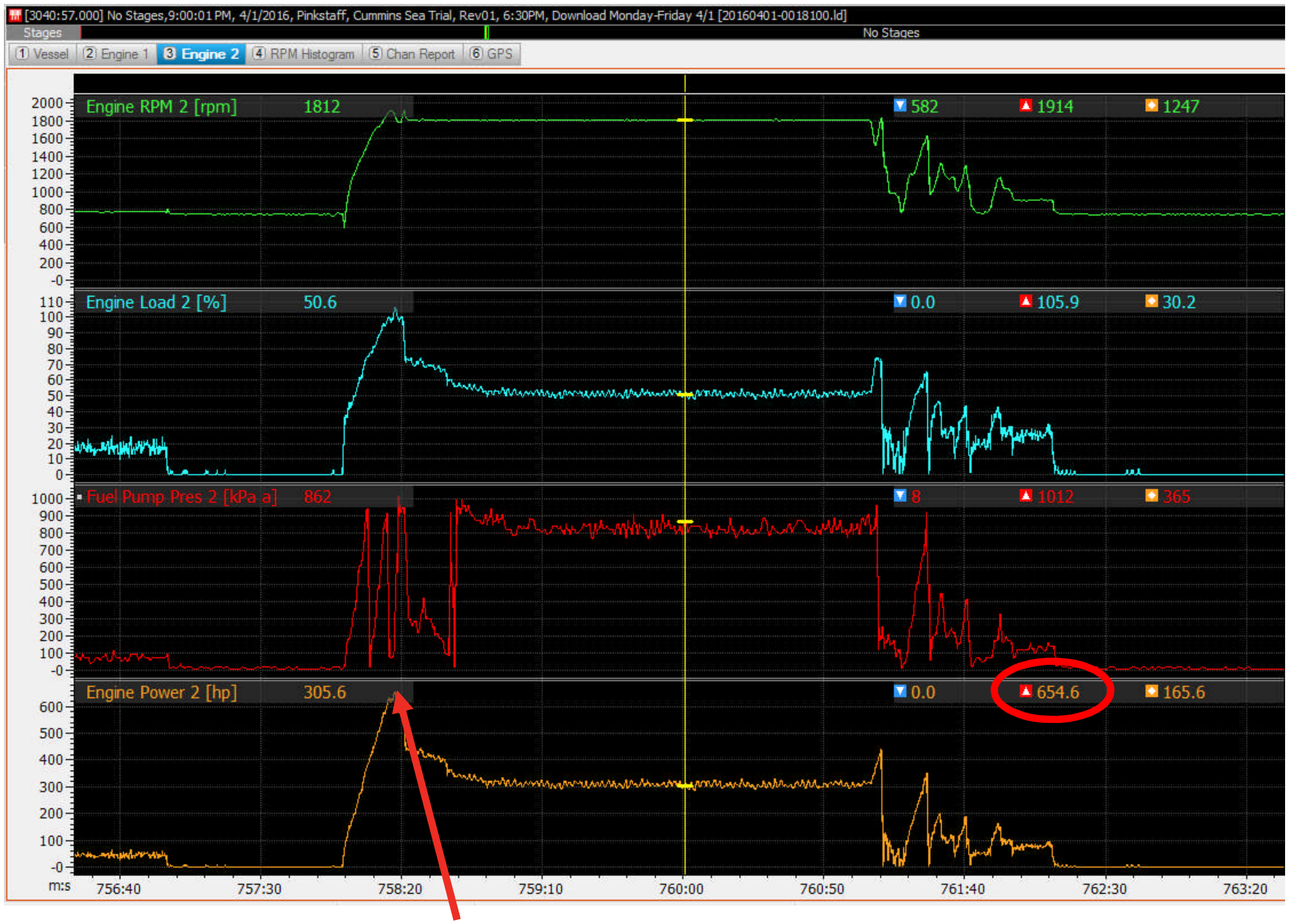
- Parameters
  - Engine 2
    - Maximum Engine Speed (RPM) = 1914
    - WOT Rated Engine Speed (RPM) = 1806
    - Average Engine Power at rated speed = 286 hp
    - Average Engine Load at rated speed = 52%
    - Maximum Throttle = 100%
    - Maximum Load/Torque = 106%
    - Maximum Fuel Rail Pressure = 1012 kPA
    - Maximum Engine Power Output (calculated) = 654 hp
      - Data summary from i2 Standard on 3/30/2016, 1:46.40.

Engine 1 Data Summary Graph



Maximum engine hp output upon departure of terminal on Guemes Island’s side, 664 hp, 107% load.

Engine 2 Data Summary Graph



Maximum engine hp output upon approach to terminal, 656 hp, 106% load.

Vessel Data Summary Graph

Maximum engine 1 and engine 2 combined hp output upon departure 1275 hp (Anacortes), 1304 hp (Guemes Island).

Vessel Data Graph (Modes of Operation)

1. Vessel with engines at idle at Anacortes, WA terminal. Per schedule.

2. Vessel maximum power zone 1 during push-off from terminal. 99-109% Power. 0.5 min average to WOT.

3. Vessel up to speed at WOT during transit across channel. 50-65% Power. 3 min average.

3. Vessel transient deceleration approaching the terminal on Guemes Island's Island. 90-110% Power. 2.75 min average.

4. Vessel with engines at at high idle on Guemes Island's Island terminal to keep position against current. 5 min average. 16 min total round trip.

Appendix A: Revision History

- 5/1/2016 Confirmed correct rated torque value to be used in Engine Power output calculations.
  - Service department records from 2006 to 2016 show history of service support. The current settings (fuel pump code, and ECM calibration) are setup at 600HP @ 1800 RPM since May of 2014. (E479 Fuel Code, and A04030 ECM calibration)
  - Slide 8-15 – Total Power and Average Power values
  - Slide 20 – Calculated Power, Performance Curve 4244.