Fishing Vessel Energy Analysis Tool

Executive Summary of the Data Model

Alaska Fisheries Development Foundation, Inc.

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By: Chandler Kemp
Nunatak Energetics

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1 The Fishing Vessel Energy Analysis Tool

The Fishing Vessel Energy Analysis Tool (FVEAT) provides a virtual energy audit of fishing operations and presents relevant energy conservation measures (ECMs). FVEAT is based on data collected from 49 Alaskan fishing vessels. Data loggers were installed on 30 of those vessels to measure the propeller shaft power required for a range of transit speeds, the brake specific fuel consumption of the engines, energy use of hydraulic loads, electrical power consumption and numerous other loads. The remaining vessels provided information about their operating procedures and equipment without having data loggers installed on their vessels. A mathematical model of energy consumption was developed that allows vessel fuel consumption to be estimated based on information provided by users of the tool. In the absence of input values, default values were defined based on the average performances observed in the fleet. The following sections further detail the logic and default values used by FVEAT.

2 Engine performance

The engine fuel consumption model calculates a fuel consumption rate (gal/hr) based on the engine load (kW). The model is defined by Equation 1, where P is the engine load, and and α and β are coefficients that must be estimated based on engine parameters. Equation 1 shows that the fuel consumption rate increases linearly with engine load.

$$Q = \alpha + \beta P \tag{1}$$

The linear model shown in Equation 1 is supported by sea trial data from 29 vessels as well as manufacturers' engine specifications. The default values for α and β are set to the average values measured for this project. Unique default values were calculated and applied to FVEAT for auxiliary and propulsion engines, because the efficiency of the two classes of engine were observed to be significantly different. When available, engine capacity ratings are used to fine tune the values of α and β, because larger engines tend to have larger α values and smaller β values.

3 Propulsion

Sea trials on 29 vessels were used to establish a relationship between vessel length, beam, speed and the required propulsion power. The relationship estimates propulsion power with an accuarcy of at least 72% in 70% of vessels in our data set. The accuracy of the model is limited because there are numerous additional factors that have significant effects on vessel drag, including the degree of hull fouling, hull shape, vessel displacement, and propeller efficiency. These factors were omitted from the model because the energy audits did not provide sufficient information to quantify each factor and fishermen may not be able to specify those factors for their vessel. Furthermore, the tool is designed to produce meaningful results while minimizing the number users must answer.

Correction factors are applied if the vessel often operates with a full hold or with stabilizers deployed. The correction factor in FVEAT was set to the average fractional increase in power under those conditions in comparison to baseline measurements taken in sea trials.

4 Refrigeration

The method used to calculate the refrigeration load is shown in Equations 2 and 3. P

denotes a power and the subscripts *tot*, *circ*, *pump*, and *cond* denote total, circulation pump, compressor and condenser pump, respectively. f_{circ} is the ratio of time that the circulation pump runs to time the compressor runs, and f_{comp} is the fraction of total hours that the compressor runs. h is the total hours in a particular mode. η_{ref} is an estimate of the refrigeration power source efficiency factor, defined as the ratio of the engine load of the power system selected by the user to the power that would be consumed with a direct drive system.

$$P_{tot} = \left(\mathrm{P_{circ}} f_{circ} + \mathrm{P_{comp}} + \mathrm{P_{cond}}\right)/\eta_{ref} \quad (2)$$

$$E = \mathrm{P_{tot}} h f_{comp} \quad (3)$$

All refrigeration systems are modeled using Equations 2 and 3. $\mathrm{P_{circ}}$ may be the power required by a fan in a blast freeze system or a pump in a refrigerated sea water system. In a plate freeze system, $\mathrm{P_{circ}}$ is simply set equal to zero.

The default values for the variables in Equation 2 depend on three factors: the operating mode type, refrigeration system type (refrigerated sea water (RSW), blast freeze, or plate freeze), and power source (electric, hydraulic or direct drive). The default values are based on long term measurements made on ten vessels (5 troll, 3 seine and 2 tender). In addition, short term measurements of circulation pump and fan loads were made on 8 vessels.

5 Hydraulics

Hydraulic energy demand is calculated according to Equation 4, where *P* is the power consumed by the hydraulics, *D* is the duty cycle (the fraction of time the hydraulics are used while in the fishing propulsion mode), and *H* is the total hours in the fishing propulsion mode. Default values for P and D are estimated based on recordings from two seine vessels, two gill net vessels, two troll vessels and four long line vessels. Existing data from 16 long line vessels included in Alaska's electronic monitoring program were also included in the duty cycle estimate. Manufacturer specifications and fishermen responses to surveys were used to estimate the power and duty cycle of hydraulic loads in other fisheries.

$$E = P \times D \times H \quad (4)$$

6 AC loads

FVEAT considers two classes of AC loads (excluding refrigeration loads): lighting and electric heaters powered directly by AC generators. AC refrigeration loads are included in the refrigeration section, and AC loads supplied from an inverter powered by batteries are considered DC loads. Lighting and electric heat were found to be the most significant remaining AC loads in measurements completed on 11 vessels and owner surveys regarding 11 additional vessels. Lighting loads default to 100 watts, but the range in lighting power is very broad throughout the fleet (even within different fisheries), so the user input greatly reduces uncertainty in AC power demand. Electric heat defaults to zero watts. Lighting energy is calculated according to Equation 4.

7 DC loads

DC loads were found to be small and consistent across most vessels audited for the FVEAT. To simplify the user experience, DC loads are lumped into one “base load” variable that can be modified in FVEAT. By default, FVEAT estimates the base load to be 0.3 kW.

8 Results

The energy consumption calculated by each of the subsections above is attributed to the various engines on the vessel and multiplied by the β values defined in Section 2. The products are the fuel consumption due to each load class. Engine overhead fuel consumption is calculated by multiplying the α values from Section 2 by the operating hours of each engine.

Appendix A: Default values and data visualization

The data model specifies how the user inputs and default values are used to estimate fuel consumption. The model is described by the formula organization chart shown in Section A.6. In the chart, user inputs are listed as bulleted items in the round cornered boxes. Intermediate calculated variables are shown as variables in round cornered boxes, and equations are shown in square cornered boxes. The following subsections define each variable in the model and default values (when applicable).

The core of the model is Equation A1.

$$F_{ijkm} = \begin{cases} \beta_i f_{ijkl} E_{jkl} \text{ for } k \neq \text{ engine overhead} \\ h_{jl} \alpha_i \text{ for } k = \text{ engine overhead} \end{cases} \tag{A1}$$

In Equation A1, the subscripts i, j, k and l specify the engine, operating mode, load class and propulsion mode respectively. h_{jl} is the time a vessel spends in operating mode *j* and propulsion mode *l*. α and β are the coefficients used to calculate the brake specific fuel consumption rate for each engine. f is the fraction of each load category applied to each engine. E is an array storing the energy demanded by each load category in each operating mode and propulsion mode. Summing F along any three of its axes yields the fuel consumption attributed to each category in the fourth axis.

E is calculated within the model based on more detailed user inputs and specific load modeling. The method for calculating a particular E_{jkm} within E depends on the specific indexes being considered. The Formula Organization Chart shows the equations used to calculate E for all indexes and provides a visualization of the relationships between the equations.

A.1 Sets referenced in the Formula Organization Chart

- *Engines* The set of engines that exist for a vessel (Primary propulsion, secondary propulsion, and primary auxiliary, secondary auxiliary)
- *Op modes* The set of operating modes that exist for a vessel (eg. troll, tender)
- *Loads* The set of load categories (propulsion, refrigeration, hydraulic, AC, DC, engine overhead)
- *Prop modes* The set of propulsion modes (transit, anchor, fishing)
- AC The set of all AC loads

A.2 Subscripts

- *i* Index defining an engine
- *j* Index defining an operating mode

- *k* Index defining a load class
- *l* Index defining a propulsion mode
- *m* Index defining a particular load within a load class

A.3 User input variables

- B Vessel beam (ft)
- $\mathrm{f}_{\mathrm{stab,jl}}$ Fraction of time that stabilizers are used
- $\mathrm{f}_{\mathrm{tank,jl}}$ Fraction of time that a vessel is tanked
- $f_{hours,jl}$ Fraction of hours in operating mode *j* spent in propulsion mode *l*
- $f_{eng,ijl}$ Fraction of hours in operating mode *j* and propulsion mode *l* that engine *i* runs (only a user input for auxiliary engines)
- f_{hyd} Fraction of time that hydraulic loads apply
- L Length of vessel (ft)
- N_{day} Number of days in a particular operating mode
- P_{DC} Total DC base load
- P_m Power demanded by a particular AC load (kW)
- P_{comp} Compressor power while the compressor is running (if the user does not specify this variable, then a distinct default value is used for each operating mode type)
- P_{circ} Circulation system power while the system is running (if the user does not specify this variable, then a distinct default value is used for each operating mode type)
- R Engine rating ($Propulsion\ default$: $300\ hp$)
- s Speed (kn)
- η_{hyd} Hydraulic system efficiency compared to fleet average
- Deck equipment type
- Estimated annual fuel consumption
- Operating mode types
- Refrigeration system type
- Refrigeration power source

A.4 Constants defined in the model

- c_0 Coefficient for calculating α that depends on the engine application

$$c_0 = \begin{cases} 0.26 \text{ if engine is used for propulsion (gal/hr)} \\ 0.45 \text{ if engine is auxiliary (gal/hr)} \end{cases}$$

- c_1 Coefficient for calculating α that depends on the engine application

$$c_1 = \begin{cases} 8.1 \times 10^{-4} \text{ if engine is used for propulsion (gal/hp} - \text{hr)} \\ 0.0 \text{ if engine is auxiliary (gal/hp} - \text{hr)} \end{cases}$$

- c_2 Coefficient for calculating β that depends on the engine application

$$c_2 = \begin{cases} 0.080 \text{ if engine is used for propulsion (gal/kWh)} \\ 0.061 \text{ if engine is auxiliary (gal/hr)} \end{cases}$$

- c_3 Coefficient for calculating β that depends on the engine application

$$c_1 = \begin{cases} -2.1 \times 10^{-5} \text{ if engine is used for propulsion (gal/kWh} - \text{hp)} \\ 0.0 \text{ if engine is auxiliary} \end{cases}$$

- c_4 Coefficient used to calculate propulsion power

$$c_4 = 3.6 \times 10^{-3} \text{ kW}/ft^{1.5}$$

- c_5 Ratio of propulsion power needed by a vessel when tanked to power needed when empty

$$c_5 = 1.27 \text{ tanked power: empty power}$$

- c_6 Ratio of propulsion power needed by a vessel with stabilizers deployed to a vessel with no stabilizers

$$c_6 = 1.64 \text{ stabilized power: standard power}$$

- c_{14} Coefficient used to calculate propulsion power

$$c_{14} = 0.57\ kn^{-1}$$

- η_{alt} Alternator efficiency

$$\eta_{alt} = 0.6 \text{ electrical power out: mechanical power in}$$

- η_{batt} average round trip charge/discharge efficiency of the batteries

$$\eta_{batt} = 0.8 \text{ electrical energy out: electrical energy in}$$

A.5 Variables determined by the operating mode type

Numerous variables are defined by the model based on qualitative user inputs that define the operating system type, refrigeration power source, or similar items. The following tables list all of the default values that the model may use depending on user responses to qualitative questions.

Default time fractions and fishing speeds by operating mode

Operating mode	Fishing Fraction	Transit Fraction	Anchor Fraction	Fishing Speed (kts)
Seine	0.47	0.33	0.20	5.2
Troll	0.67	0.13	0.20	2.8
Longline	0.49	0.31	0.20	2.0
Gill net	0.64	0.16	0.20	2.9
Tender	0.18	0.62	0.20	0.0
Pot	0.49	0.31	0.20	2.0
Other	0.64	0.16	0.20	3

Default refrigeration time fractions by operating mode

Operating mode	f_{circ}	f_{comp} Transit	f_{comp} Fishing	f_{comp} Anchor
Seine	1.4	0.35	0.7	0.27
Troll	1	0.9	0.9	0.9
Gill net	0.64	0.16	0.20	2.9
Tender	0.18	0.62	0.20	0.0
Pot	0.49	0.31	0.20	2.0
Other	0.64	0.16	0.20	3

Default refrigeration power components by system type and operating mode

Operating mode	P_{circ}	P_{cond} Transit	P_{comp} Fishing
System Type: RSW			
Seine	3.4	1.1	9.5
Tender	6.1	0.4	16.9
Other	4	1	10
System Type: Blast Freeze			
Troll	0.66	0.66	5.99
Other	0.66	0.66	5.99
System Type: Plate Freeze			
Troll	0.66	0.66	5.99
Other	0.66	0.66	5.99

Default refrigeration efficiency factor by power source

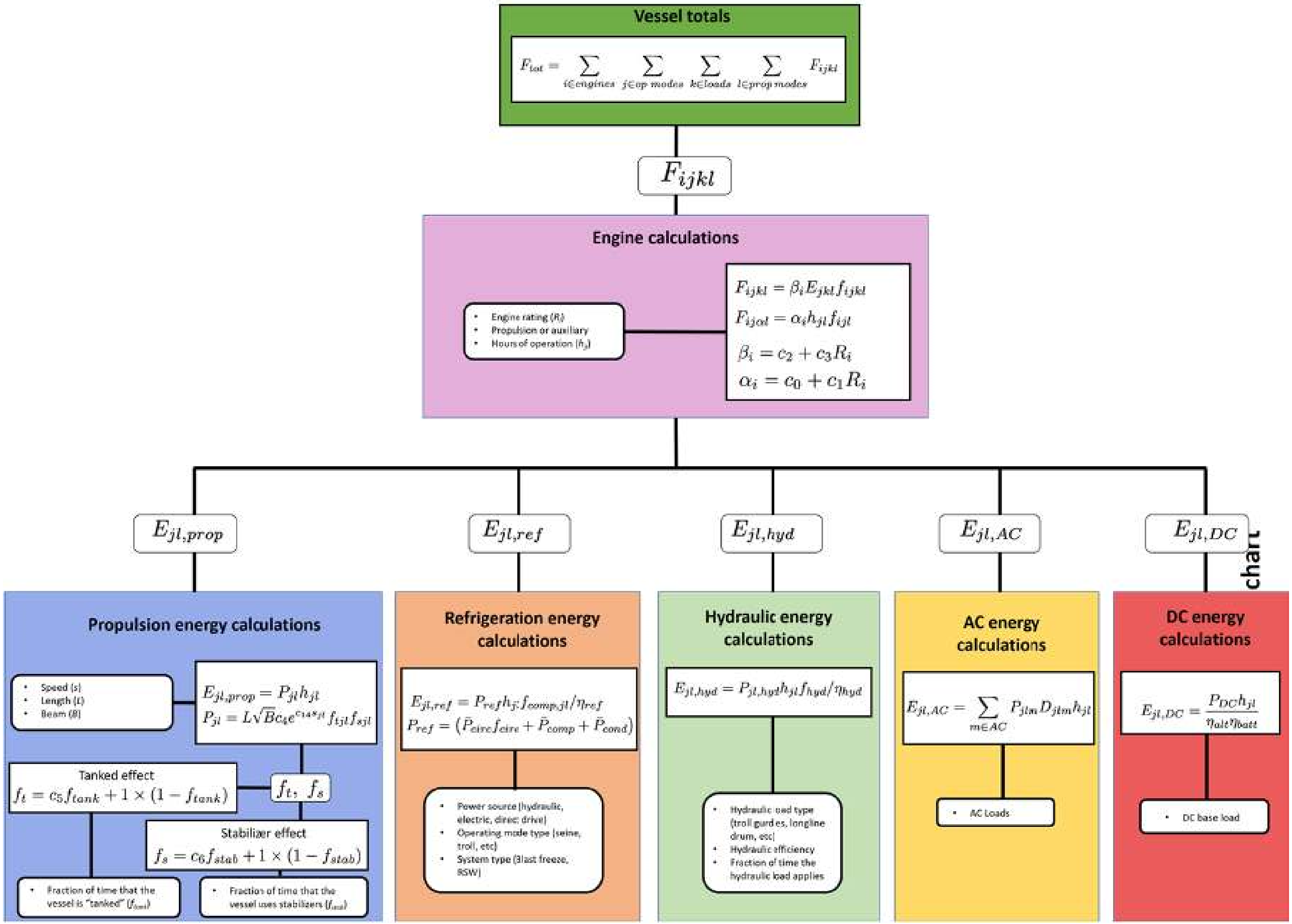
Power source	Efficiency factor
Direct drive	1
Electric drive	0.82
Hydraulic drive	0.63

Hydraulic load library and default use fractions

Hydraulic deck load	Default power (kW)	Duty Cycle
Seine winch AND power block	35	0.2
Gurdies	3.7	1
Gill net drum	3.5	0.21
Gill net drum AND power roller	5.2	0.21
Autoline haul system	7.4	0.48
Longline Sheave OR drum	2.3	0.48
Longline sheave AND drum	2.8	0.48
Large pot hauler	8	0.48
Small pot hauler	4	0.48
Other (cranes, etc)	1	1

Default hydraulic efficiency factors

Efficiency selection	Efficiency factor
High	1.33
Medium	1
Low	0.5


Vessel totals
$F_{tot} = \sum_{i \in engines} \sum_{j \in op\ modes} \sum_{k \in loads} \sum_{l \in prop\ modes} F_{ijkl}$
F_{ijkl}
Engine calculations
Engine rating (R_i)
Propulsion or auxiliary
Hours of operation (h_{jl})
$F_{ijkl} = \beta_i E_{jkl} f_{ijkl}$
$F_{ijol} = \alpha_i h_{jl} f_{ijl}$
$\beta_i = c_2 + c_3 R_i$
$\alpha_i = c_0 + c_1 R_i$
$E_{jl,prop}$
$E_{jl,ref}$
$E_{jl,hyd}$
$E_{jl,AC}$
$E_{jl,DC}$
Propulsion energy calculations
Speed (s)
Length (L)
Beam (B)
$E_{jl,prop} = P_{jl} h_{jl}$
$P_{jl} = L\sqrt{B} c_4 e^{c_{14} s_{jl}} f_{tjl} f_{sjl}$
Tanked effect
$f_t = c_5 f_{tank} + 1 \times (1 - f_{tank})$
$f_t,\ f_s$
Stabilizer effect
$f_s = c_6 f_{stab} + 1 \times (1 - f_{stab})$
Fraction of time that the vessel is "tanked" (f_{tank})
Fraction of time that the vessel uses stabilizers (f_{stab})
Refrigeration energy calculations
$E_{jl,ref} = P_{ref} h_{jl} f_{comp,jl} / \eta_{ref}$
$P_{ref} = (\bar{P}_{circ} f_{circ} + \bar{P}_{comp} + \bar{P}_{cond})$
Power source (hydraulic, electric, direct drive)
Operating mode type (seine, troll, etc)
System type (Blast freeze, RSW)
Hydraulic energy calculations
$E_{jl,hyd} = P_{jl,hyd} h_{jl} f_{hyd} / \eta_{hyd}$
Hydraulic load type (troll gurdies, longline drum, etc)
Hydraulic efficiency
Fraction of time the hydraulic load applies
AC energy calculations
$E_{jl,AC} = \sum_{m \in AC} P_{jlm} D_{jlm} h_{jl}$
AC Loads
DC energy calculations
$E_{jl,DC} = \frac{P_{DC} h_{jl}}{\eta_{alt} \eta_{batt}}$
DC base load

chart