BACHELOR THESIS & COLLOQUIUM – ME1841038

FORENSIC ANALYSIS AND DATA DIAGNOSTIC OF ABNORMALITIES FROM DATA OPERATIONS OF SELECTED CONTAINER SHIPS

ACHDANIEL FARIKHI
NRP. 04211641000003

SUPERVISORS :
Prof. Dr.-Ing. Karsten Wehner
Dr.-Ing Wolfgang Busse

DOUBLE DEGREE PROGRAM
DEPARTMENT OF MARINE ENGINEERING
FACULTY OF MARINE TECHNOLOGY
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
SURABAYA
2020

BACHELOR THESIS & COLLOQUIUM – ME1841038

FORENSIC ANALYSIS AND DATA DIAGNOSTIC OF ABNORMALITIES FROM DATA OPERATIONS OF SELECTED CONTAINER SHIPS

ACHDANIEL FARIKHI
NRP. 04211641000003

SUPERVISORS:
Prof. Dr.-Ing. Karsten Wehner
Dr.-Ing. Wolfgang Busse

DOUBLE DEGREE PROGRAM
DEPARTMENT OF MARINE ENGINEERING
FACULTY OF MARINE TECHNOLOGY
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
SURABAYA
2020

"This page is intentionally left blank"

SKRIPSI – ME1841038

ANALISIS FORENSIK DAN DIAGNOSTIK DATA ABNORMAL DARI DATA OPERASI KAPAL KONTAINER YANG TERPILIH

ACHDANIEL FARIKHI
NRP. 04211641000003

Pembimbing :
Prof. Dr.-Ing. Karsten Wehner
Dr.-Ing. Wolfgang Busse

DOUBLE DEGREE PROGRAM
DEPARTMENT OF MARINE ENGINEERING
FACULTY OF MARINE TECHNOLOGY
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
SURABAYA
2020

"This page is intentionally left blank"

APPROVAL SHEET

FORENSIC ANALYSIS AND DATA DIAGNOSTIC OF ABNORMALITIES FROM DATA OPERATIONS OF SELECTED CONTAINER SHIPS

BACHELOR-THESIS

Submitted to Comply One of the Requirement to Obtain a Bachelor Engineering Degree

On

Hochschule Wismar, Faculty of Engineering, Department of Maritime Studies

and

Institut Teknologi Sepuluh Nopember, Faculty of Marine Technology, Department of Marine Engineering

Prepared By:

ACHDANIEL FARIKHI

NRP. 04211641000003

Approved by Academic Supervisor:

Prof. Dr.-Ing. Karsten Wehner ( )

Dr.-Ing. Wolfgang Busse ( )

"This page is intentionally left blank"

APPROVAL SHEET

FORENSIC ANALYSIS AND DATA DIAGNOSTIC OF ABNORMALITIES FROM DATA OPERATIONS OF SELECTED CONTAINER SHIPS

BACHELOR THESIS

Asked To Meet One Of The Conditions

Obtained a Bachelor's Degree In Engineering

on

Major *Marine Operational and System* (MOM)

Department of Marine Engineering S-1 Double Degree Program

Faculty Marine Technology

Institute Technology Sepuluh Nopember

By:

Achdaniel Farikhi

NRP. 04211641000003

Approved by,

Head of Department of Marine Engineering

Beny Cahyono, S.T., M.T., Ph.D

NIP. 197903192008011008

SURABAYA

AGUSTUS, 2020

"This page is intentionally left blank"

AUTHOR DECLARATION

I hereby declare that I completed this work independently and that I have used no aids other than those referenced.

All parts of the thesis have been obtained from other sources by wording or meaning, have been marked accordingly. This also applies to drawing applies to drawings, sketches, figurative images and sources from the internet.

The thesis's title is:

"Forensic Analysis and Data Diagnostics of Abnormalities from Data Operations of Selected Container Ships".

I declare furthermore that I have not and will not submit this thesis to any other examination board. If there is plagiarism act in the future, I will fully responsible and receive the penalty given by ITS according to the regulation applied.

The submitted written version matches the version stored on the digital medium.

Warnemünde, 31st July 2020

Achdaniel Farikhi

"This page is intentionally left blank"

FORENSIC ANALYSIS AND DATA DIAGNOSTIC OF ABNORMALITIES FROM DATA OPERATIONS OF SELECTED CONTAINER SHIPS

1. NAME

1.1 Name : Achdaniel Farikhi

1.2 NRP : 04211641000003

2. SUPERVISOR

2.1 Supervisor : Prof. Dr.-Ing Karsten Wehner

2.2 Co-Supervisor : Dr.-Ing Wolfgang Busse

3. ABSTRACT

In this research, the proposer has an incomplete data sets of performance of 2 ships which is sister-ship. However, performance of both ships is difference which is quite hard to explain. In this research, the incomplete data will be used to obtain useful information such as variation, abnormalities, and fluctuations. The data obtained is only brake power, ship speed, and engine/propeller speed. In order to approach the abnormalities and variance, theoretical study will support the hypothesis by using empirical formula and several previous research. The causes might be from external factor such as weather condition which influence the increasing resistance. On some specific dates, the ship had fluctuations in propeller load and stays there until the end of recorded date which is currently unknown for the causes. The result of this research neither can accepted nor rejected since the data is not complete for knowing the exact causes. It is necessary to analyze the abnormalities with incomplete data sets by estimating and making hypothesis of operating conditions to help in future or upcoming problem occurrence with the same circumstances.

Keywords: (Abnormalities, Container, Forensic, Performance, Fuel Consumption)

"This page is intentionally left blank"

ANALISIS FORENSIK DAN DIAGNOSTIK DATA ABNORMAL DARI DATA OPERASI KAPAL KONTAINER YANG TERPILIH

1. NAMA

1.1 Nama : Achdaniel Farikhi

1.2 NRP : 04211641000003

2. PEMBIMBING

2.1 Pembimbing 1 : Prof. Dr.-Ing Karsten Wehner

2.2 Pembimbing 2 : Dr.-Ing Wolfgang Busse

3. ABSTRAK

Dalam penelitian ini pengusul memiliki data set kinerja 2 kapal yang tidak lengkap yang merupakan sister-ship. Namun, performa kedua kapal ini memiliki perbedaan yang cukup sulit dijelaskan. Dalam penelitian ini, data yang tidak lengkap akan digunakan untuk memperoleh informasi yang berguna seperti variasi, kelainan, dan fluktuasi. Data yang diperoleh hanya tenaga rem, kecepatan kapal, dan kecepatan engine / propeller. Untuk mendekati abnormalitas dan varians, studi teoritis akan mendukung hipotesis tersebut dengan menggunakan rumus empiris dan beberapa penelitian sebelumnya. Penyebabnya mungkin dari faktor eksternal seperti kondisi cuaca yang mempengaruhi peningkatan resistensi. Pada beberapa tanggal tertentu, kapal mengalami fluktuasi beban baling-baling dan tetap di sana sampai akhir tanggal yang tercatat yang saat ini tidak diketahui penyebabnya. Hasil penelitian ini tidak dapat diterima maupun ditolak karena datanya tidak lengkap untuk mengetahui penyebab pastinya. Hal ini diperlukan untuk menganalisis ketidaknormalan dengan kumpulan data yang tidak lengkap dengan mengestimasi dan membuat hipotesis kondisi operasi untuk membantu terjadinya masalah yang akan datang dengan keadaan yang sama.

Keywords: (Abnormalities, Container, Forensic, Performance, Fuel Consumption)

"This page is intentionally left blank"

PREFACE

In the Name of Allah, the Most Gracious, the Most Merciful. All the praises and thanks be to Almighty Allah for giving the author opportunity, determination and strength to finish this bachelor thesis with the tittle "FORENSIC ANALYSIS AND DATA DIAGNOSTIC OF ABNORMALITIES FROM DATA OPERATIONS OF SELECTED CONTAINER SHIPS" in order to fulfill the requirements to get a Bachelor of Engineering degree in the Department of Marine Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember Surabaya.

The author would like to express his gratitude to all those who helped, supported, and offered encouragement on this bachelor thesis writing:

1. Beloved parents and also beloved sister who always give unconditional love, prayer, support and encouragement to the author.
2. Mr. Benny Cahyono, S.T., M.T., Ph.D, as a Head of Marine Engineering Department, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember.
3. Ir. Dwi Priyanta, M.SE. as the student supervisor. Thank you for guiding on the academical process for this through semester.
4. Prof. Dr.-Ing K. Wehner as a bachelor thesis supervisor 1. Thank you for taking the time out of your busy schedule to guide and support the author. Thank you so much for sharing your knowledge.
5. Dr.-Ing. Wolfgang Busse as a bachelor thesis supervisor 2 who taking the time to guide and teach the author. Thank you for always ready to help if the author had difficulties during the process of writing this bachelor thesis.
6. All civitas academic of Marine Engineering Department, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember.
7. All of my friends "VOYAGE 16", thank you for your warm support and help ever since the day we first met.

The author realizes that in writing this report there are many shortcomings, so the constructive criticisms and suggestions that the author hopes for. Hopefully this bachelor thesis can be beneficial for us. Finally, may Allah bestow His mercy and blessings for us.

Warnemünde, 31st July 2020

Author

"This page is intentionally left blank"

TABLE OF CONTENTS

LIST OF FIGURES

"This page is intentionally left blank"

LIST OF TABLES

"This page is intentionally left blank"

LIST OF ABBREVIATIONS

Lpp	Length of Perpendicular (meters)
Loa	Length Overall (meters)
Lwl	Length of waterline (meters)
B	Breadth (meters)
T	Draught (meters)
DWT	Deadweight Tonnage (tons)
Pb	Brake Power (kilowatt)
n	Engine/propeller rotation per minute or second (rpm/rps)
Vs	Service Speed (knots)
ΔV	Speed difference
ΔP	Brake power difference
SFOC	Specific Fuel Oil Consumption (g/kWh)
Bh	Fuel Consumption (kg/h)
Va	Advance Velocity (knots)

“This page is intentionally left blank”

CHAPTER I
INTRODUCTION

1.1 Background

Data analysis is important for processing raw data into understandable information for further decision making. Furthermore, in shipping industries the data analysis is used to improve and increase their qualities including products, services, and financial benefits. Technical analysis in ship is necessary in order to reduce gas emissions and fuel consumption for upcoming event. Both design and propulsion planning are highly demanded for improvement to resist such issues. The data analysis is worth to do in order to validate whether the actual performance can achieve the designed performance both in calm weather condition and rough weather. Technical condition covers the performance of the ship which may affected by several factors such as engine performance, weather, and hull condition as well. Those several factors play a big role in performance.

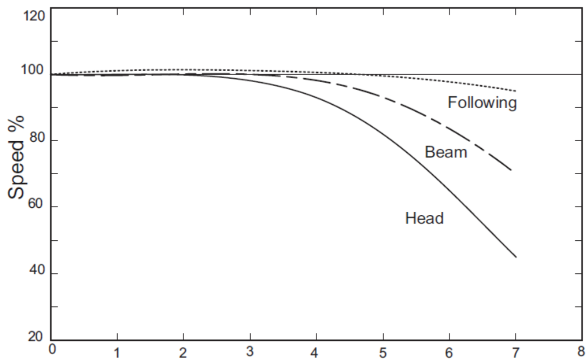

Figure 1 *The effects of Beaufort Number on decreasing ship's speed.*
Source: *(F. Molland, Wind & Wave Resistance)*

According to F. Molland [1], a ship that face weather condition in Beaufort Number 5 and facing head sea will decrease the ship's speed up to 20% which can make the increasing fuel consumption due to achieve constant speed, yet with the consequence engine power will increase. Another main factors which directly influence the ship performance is ship's resistance.

Ship's resistance basically represents the effectiveness of ship's hull form, the higher resistance, the higher power required to move the ship. The ship's resistance is proportional to the square ship's speed ($Rt \approx Vs^2$) which means the more speed to achieve the higher resistance will be and it will require more power.

In Figure 2, shows that both ships have difference performance. However, those ships are sister-ship which should have similar performances. At nearly same average of engine speed, Impala requires higher power and fuel consumption compared to Liberta. The data sets also contain several abnormal relations between 3 parameters, where at calm resistance, the engine speed indicated at heavy load, and vise-versa, which is hard to explain. This research is added in order to approach any explanation of abnormalities and variations of measured data operations.

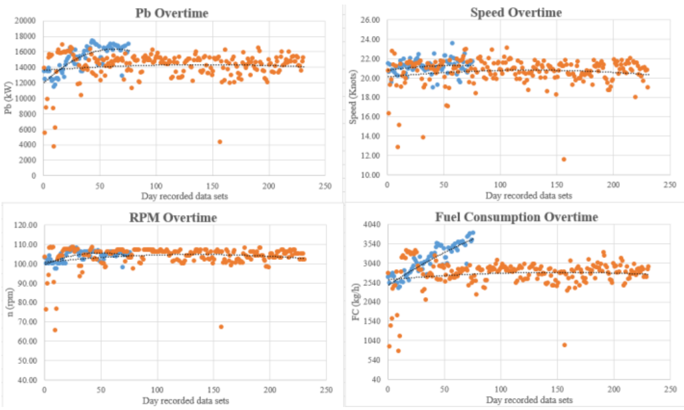

Figure 2. *Performances comparison of both ships.*

1.2 Problem Analysis

Based on the background that has explained above, the problem that would be discussed are:

1. Are the data on-board plausible?
2. How to evaluate the on-board measurement data under conditions of incomplete information?
3. What is the cause of fluctuations, variation and abnormalities of onboard measurements?

1.3 Scopes and Limitations

The scopes and limitations for this bachelor thesis are:

1. The main focus of this bachelor thesis is data diagnostics.
2. The data operations that available are the engine speed, engine power, and speed of the selected ships.
3. Engine is in good technical condition.

1.4 Objectives

The purposes and the objectives for this research are:

1. To show a method that can be used to obtain useful on-board data analysis under incomplete information condition.

1.5 Benefits

The main benefits for this research are:

1. Better understanding in data diagnostic and analysis.
2. Experiencing data analyst.
3. For future input modelling.
4. As a reference for same issues with simple data operations.

1.6 Deliverable

The output and results for this proposed bachelor thesis is the method to use incomplete data sets to obtain useful data analysis.

"This page is intentionally left blank"

CHAPTER II
LITERATURE REVIEW

2.1 Previous Research

Previous research regarding this topic indicates that external factor may conduct various performances of the ships. When a ship encounter rough sea condition, the resistance will be higher which may cause decreasing efficiency, especially propeller efficiency. Ship designer often to make a constant wake value fraction, however the wake faction value does not only depend on hull form but it is also depending on wave condition, such as wave length and height. A research from Taskar (2017) [2] higher waves amplitude may cause variation and fluctuation of brake power and conduct higher engine load. Fouled hull will also increase the wake fraction value [3].

Fouled hull could become another factors in increasing brake power and fuel consumption at constant speed. Munk [4] in his research stated that after a ship done a dry docking maintenance, the increasing resistance due to fouling growth at first stage will be around 0.5%-2%. More issues will occur when the propeller of the ship is fouled, where the propeller may lose its efficiency and cavitation.

2.2 Ship's Engine

Ship's engine is the main source of the power as the prime mover to move the ship. Operators have to keep monitoring the engine performance through the monitor and record it for ship management system and evaluation. The engine its self has to be maintained routinely to keep its performance. Overall, merchant ships are using diesel engine due to its benefits compared to another type of engines, even though there are some passenger ships that using turbine engine due to its ability of lack noise which increase comfortability for the passengers. One of the benefits of diesel engine is its thermal efficiency which is higher over other engines. For low-speed diesel engines that have been applied in maritime world, the thermal efficiency is about 50%.

Basically, diesel engine is divided into two types, two-stroke and four-stroke. It converts chemical energy into mechanical energy through combustion chamber. Diesel engine is using high pressure ratio for combustion which is different with the petrol engine in which use sparks to ignite the fuel for combustion.

2.3 Ship's Resistance

When the ship is moving or sailing on the ocean, there will be forces that working against its propulsion and it is called ship's resistance [5]. The ship's resistance depends on ship particular, hull condition and form, ship's speed, and displacement. The ship's resistance does not only come from below waterline but above waterline/air resistance as well. The formula for total towing resistance is:

$$R_T = R_A + R_F + R_R$$

R_A stands for air resistance which represent the weather condition. Based on MAN basic propulsion paper, the air resistance in calm weather is proportional with the square of ship's speed. In total, the air resistance normally only contributes 2% of total towing resistance.

R_F represents the frictional resistance which means the friction between the hull's wetted part and the water its self. The frictional resistance would be higher if the hull is not clean or there are fouling that exist on the hull. The marine biofouling could increase the hull form which makes the wetted surface area increase. Another factors that could increase the frictional resistance is the draft condition. Higher waterline means higher wetted surface and it would increase the total resistance.

R_R is divided into 2 parts which are eddy resistance and wave resistance. Wave resistance represents of wave-making due to ship's movement and maneuvering, while the eddy resistance is caused by the flow separation and creates eddies wave usually at the aft side of the ship [5]. MAN assumes the contribution of the residual resistance for low-speed ships which is about 8-25% of total towing resistance.

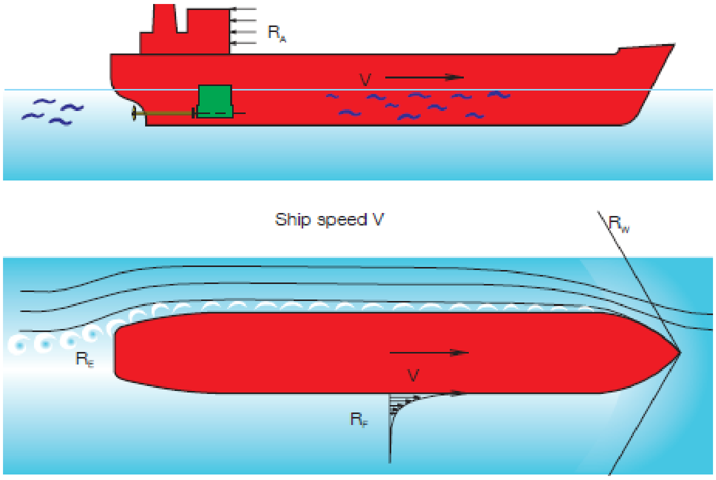

Figure 3 *Illustration resistance against ship's movement.*

Well-designed ship would decrease the ship's resistance which may requires fewer power for its performance. Ship maintenance also plays big part to its performance to decrease the ship resistance especially frictional resistance due to biofouling in which could decrease ship's speed at the same power.

2.4 Marine Biofouling

Marine biofouling is a serious issue and enemy for every ships and ocean structure that exist in maritime world. Algae, barnacles, tubeworms, protozoa, and fungi are the examples of macro biofouling. Biofouling is an accumulation growth of microorganisms, plants, and animal in micro and macro as well. Its negative effects could disserve such economical side such as the increasing of fuel consumption due to higher power required to against the ship's resistance.

Figure 4 *The various of macrofoulers.*
Source: *(Claire Hellio and Diego Yebra, Marine Antifouling Coatings and Technologies)*

There are several factors that influence the biofouling growth, such as temperature which is depends on region, salinity, flow rates, nutrients capacity, and solar radiation. The biofouling growth is hampered in winter season because lack of temperature, light, and solar radiations. Based on geographical perspective, the tropical region consistently gives the biofouling nutrients and solar radiations which could stimulate the biofouling growth but with less variation. However, the biofouling growth is complex to predict.

Munk's research (2006) states that the ship's resistance will increase about 0.5-2% per month after dry-docking for cleaning and some ship the biofouling growth percentage is up to 5-6% per month. Munk also provides information that cleaning on dry-docking could decrease 30% of added resistance due to biofouling growth. This biofouling growth could also have environmental damage which increase the air pollution (CO_2, NO_X, and SO_2) due to more fuel to burn to move the ship with the same speed.

2.5 Wind & Wave and Its Effects

Same as marine biofouling, this natural phenomenon could give negative impact for the ship especially in economical side. When time is the main factor in shipping, ship is pushed to operate at constant speed and need a sufficient power to maintain speed in various weather. Aerrtssen has estimated the influence of wind and wave on ship's speed and power through experimental and theoretical method. Based on F. Molland the wind and wave condition is scaled into beaufort scale (Table 1).

Beaufort number *BN*	Description	Limits of speed knots	Limits of speed m/s	Approximate wave height (m)
0	Calm	1	0.3	–
1	Light air	1–3	0.3–1.5	–
2	Light breeze	4–6	1.6–3.3	0.7
3	Gentle breeze	7–10	3.4–5.4	1.2
4	Moderate breeze	11–16	5.5–7.9	2.0
5	Fresh breeze	17–21	8.0–10.7	3.1
6	Strong breeze	22–27	10.8–13.8	4.0
7	Near gale	28–33	13.9–17.1	5.5
8	Gale	34–40	17.2–20.7	7.1
9	Strong gale	41–47	20.8–24.4	9.1
10	Storm	48–55	24.5–28.4	11.3
11	Violent storm	56–63	28.5–32.6	13.2
12	Hurricane	64 and over	32.7 and over	–

Table 1 *Beaufort Scale.*
Source: *(F. Molland, Ship Resistance and Propulsion)*

Aerrtssen experiments on cargo vessel at various beaufort scale and found that increasing BN will decreasing the ship's speed due to increasing ship's resistance. Also it would require higher power to catch up the margin at the same speed. This condition makes the production of air pollution increased. From Aerrtssen formula and experiments, cargo vessel that sailing at BN 4 resulting power increase about 10-20% at the same speed.

Aerrtssen Formula:

$$\frac{\Delta V}{V} \times 100\% = \frac{m}{LPP} + n$$

The value of m and n is various over the beaufort number and direction of the wind and waves. It is divided into 3 directions which are head, bow, beam, and following sea. The conclusion is the increasing power due to wind and waves is vary widely and depend on the area of operation.

CHAPTER III
METHODOLOGY

3.1 Methodology

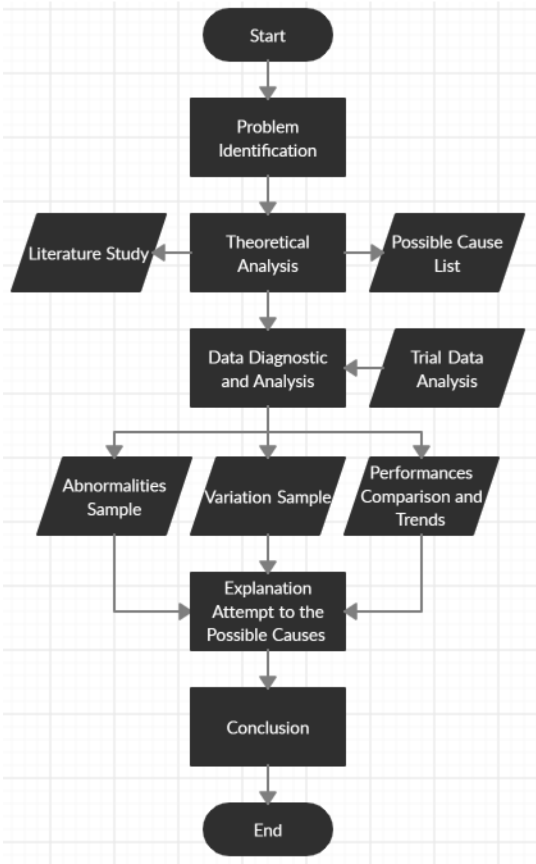

Figure 5 *Methodology flow chart*

3.2 Methodology Description

3.2.1 Problem Identification

The first stage to write this bachelor thesis and research is to identify the problem. The problem can be identified by comparing the data with another. Problem statement can also determine the specified objective to complete this research.

3.2.2 Theoretical Analysis

In this stage, the research will be supported by any literature such as paper, journal, regulation, etc. to obtain information and empirical formula from the latest and existing research. Moreover, the causes of the variations and abnormalities in this research will be identified both with high and low possibilities based on the literature that has been read and studied. The theoretical analysis will be explained and studied in general and detail for further and better understanding.

3.2.3 Data Diagnostics and Analysis

Processing data is the stage where the data is processed. In this first step of analysis, the data will be processed in Microsoft Excel tools by using scatter plotting. Then, the abnormalities will be identified by detecting any untypical relation of the parameters. The identification will be done by grouping the value of Cpv and Cpn. Trial data will be used as comparison and reference for the data diagnostics. Trends in performance will be analyzed as well.

3.2.4 Abnormalities and Variations Explanation

The variations and the abnormalities that have identified will be explained for the possible causes based from the references in the theoretical analysis. The theoretical calculations will be compared with the actual data within acceptable margin. However, there is possibility if the abnormal data sets could not be explained using the references/literatures and equation. Hence, the sensor failure may conduct the inaccurate measurements.

3.2.5 Conclusion

In this section, the suggestions and conclusions of writing are explained as well as the results and purpose of this research.

3.3 Tools

The main tools that will be used for this research is Microsoft Excel.

"This page is intentionally left blank"

CHAPTER IV

DATA ANALYSIS

4.1 Ships Data

The ships data that has been obtained and both is sister-ship. The overall data is described in table below:

Container Vessel Type WARNOW CV 2500		
LOA	m	208.11
LPP	m	197.19
LWL	m	199.2
Tmax	m	11.4
H	m	16.4
B	m	29.8
CB	-	0.65
DWT at Tmax	t	34000
Weight / Light Displacement	t	11078
Loaded Displacement	t	45078
Main Engine (MCR)	kW	19810
Volume Displacement	m^3	43978.5
Main Engine Rpm	-	108

4.2 Onboard Data

There are 2 on-board data sets that will be used for analysis, MV. Impala and MV. Liberta. On-board recorded data that has been given are attached in the appendix I.

4.3 Sea Trial Data

No	Load	Power (kW)		RPM	Speed (Kn)	SFOC (g/kWh)	Wind		Wave	
	%	Pi	Pb				Speed (m/s)	Direction (◦)	Height (m)	Direction (◦)
1	64	13634	12676	101.1	20.9	197.5	7	75	1	75
2	69.6	14781	13796	104	22	181.22	2	350	0.5	340
3	74.3	14902	14720	104.1	20	178.9	6	280	1	280
4	75.8	15414	14710	104.1	21.5	180	6	310	0.5	10
6	77	16072	14840	103.4	20.5	178	3	80	0	0
5	80	16483	15850	108	22	177	5	300	0.5	300
7	82.1	17282	16259	108	22.2	179.59	8	135	0.5	180
8	83	16963	16440	107.9	21	185.6	8	10	1.5	35

No	Draft (m)		
	Fore	Aft	Avg
1	8.7	59.5	9.1
2	9.8	10.4	10.1
3	11.5	11.6	11.55
4	10.4	11.1	10.75
6	10.3	11.5	10.9
5	9.7	10.7	10.2
7	9.9	10.3	10.1
8	11	11	11

Table 2. *Trial Data.*

The trial data above is used as base analysis and also for comparison to the onboard data analysis.

4.3.1 Estimation of Propeller Load Diagram (Trial Based Condition)

The estimation of propeller load diagram can be done by processing the trial data of brake power (Pb) and rpm of the engine. The lowest Cpn and Cpv on Trial recorded data will be defined as still-water load diagram, since the trial based recorded data having higher resistance.

$$Cpv\_min = \frac{Pb}{Vs^{Epv}}$$

$$Cpn\_min = \frac{Pb}{n^{Epn}}$$

Pb = Brake power (kW)

Vs = Recorded ship's speed (Knots)

Epv = Experience coefficient value (chosen value: 4)

n = Recorded engine speed (Rpm)

Epn = Experience coefficient value (chosen value: 3)

No	Cpv	Cpn	Output Pb (%)	Output rpm (%)
1	0.0664	0.0123	63.09	93.61

2	0.0589	0.0123	68.67	96.30
3	0.0920	0.0130	73.27	96.39
4	0.0688	0.0130	73.22	96.39
5	0.0840	0.0134	73.87	95.74
6	0.0677	0.0126	78.89	100.00
7	0.0669	0.0129	80.93	100.00
8	0.0845	0.0131	81.83	99.91

Table 3. *Value of Output BHP and RPM*

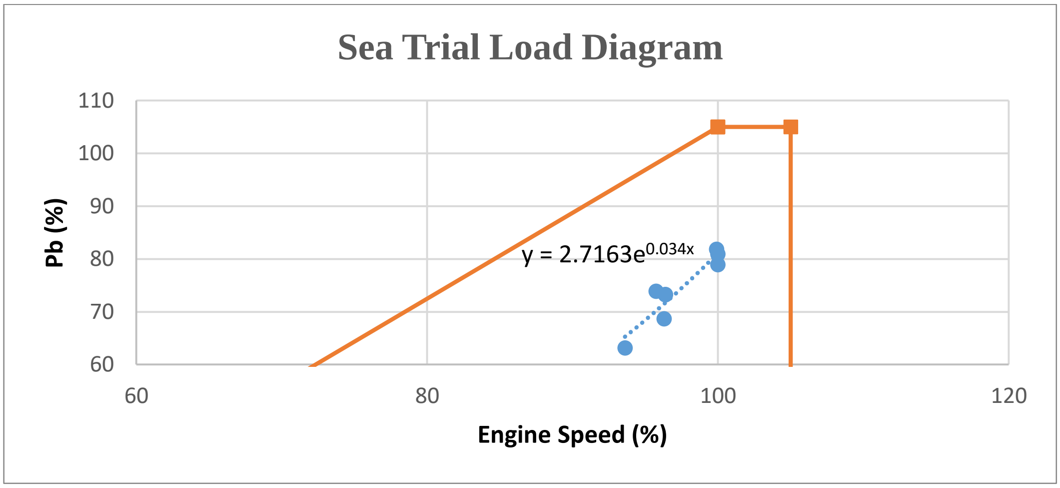

Figure 6. *Sea Trial Load Diagram.*

The load diagram in Figure 6. shows that the performance is still inside the overload limit of the engine which is described in solid orange line. The overload limit based on MAN project guide is 105%. The lowest Cpn and Cpv is at data sets number 2 (Table 2-3) which has 0.0589cpv, 0.123cpn, 13796 kW brake power, 104 rpm, and 22 knot. The still-water propeller load diagram is in Figure 7.

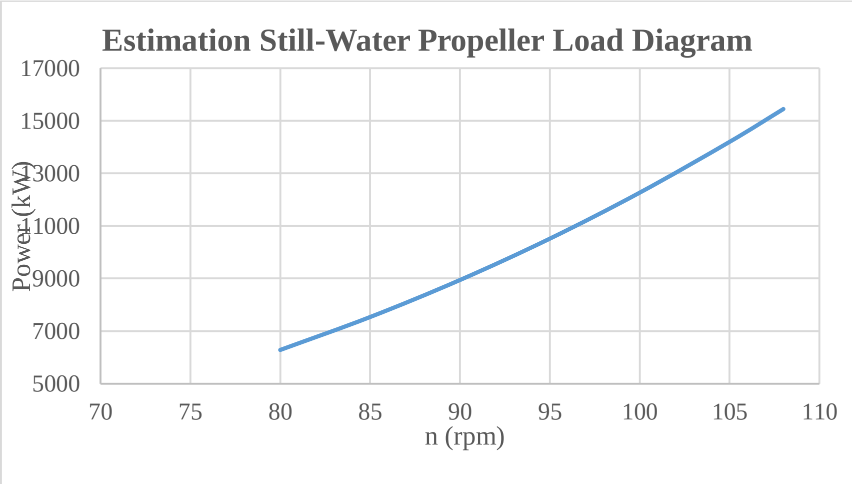

Figure 7. *Estimation of propeller load diagram.*

4.3.2 Estimation of base SFOC at Estimated Propeller Load Diagram

SFOC is used to determine the fuel consumption rate at gram per kilowatt hour (g/kWh). The SFOC of trial report is already described in Table 2., thus the ISO standard of SFOC has to be estimated as a base ISO standard SFOC. The estimation is based on MAN project guide. The optimization point (O) used in here is the estimated still-water propeller load diagram in Figure 7. It is used to determine how much SFOC reduced through the line.

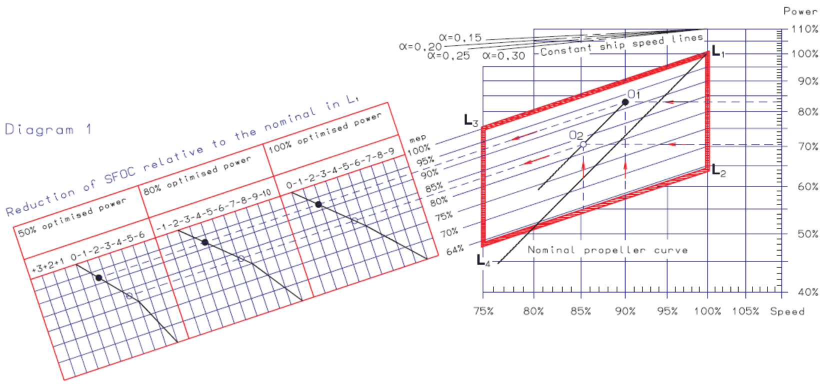

Figure 8. *MAN Method for SFOC Estimation at Optimization Point.*

By using this method, the base SFOC at ISO:3046 standards can be done. At 100% optimizing point the expected SFOC at ISO standard is reduced for -7.0 g/BHPh.

Optimizing Point 1	Brake Power		Rpm	% of L1		SFOC	SFOC	
	kW	HP		Engine Speed (%)	Power (%)		g/bhph	g/kWh
100%	15449.0	20083.7	108	100	78.23	-5	123	167.23
80%	12359.2	16066.96	100	93.5	62.4	-7	121	164.51
50%	7724.5	10041.85	80	80	38.99	-4	124	168.59

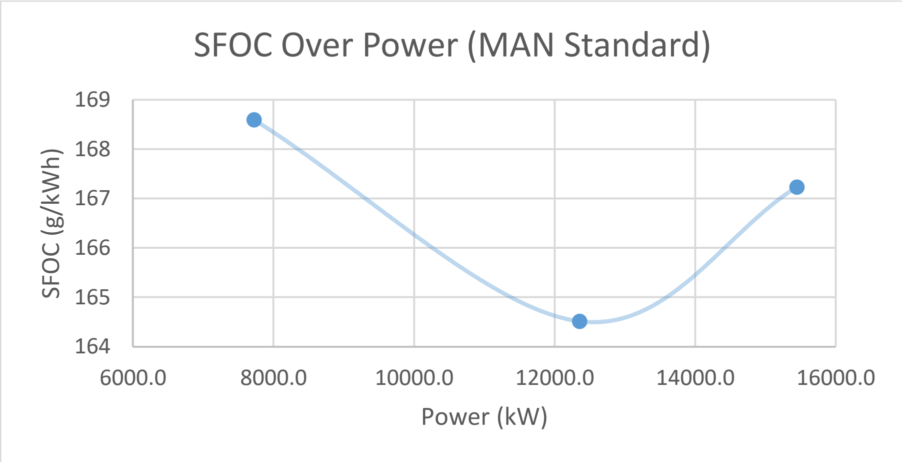

Figure 9. *SFOC graph at ISO Standard.*

Figure 9. shows that the lowest minimum of SFOC guarantee in optimization point ISO condition is 164.51 g/kWh. In the Table 2. the recorded SFOC of trial data will be corrected into ambient correction. This method is in accordance with ISO standard 3046. In order to complete the correction, a several calculations will be added.

$$SFOCx = \beta \times SFOCr \tag{1}$$

$$\beta = k/\alpha \tag{2}$$

$$\alpha = k - 0.71(1-k)\left[\frac{1}{\mu m} - 1\right] \tag{3}$$

$$\mu m = \frac{Pi}{Pb} \tag{4}$$

$$k = \left(\frac{Px}{Pr}\right)^m \left(\frac{Tr}{Tx}\right)^n \left(\frac{Tcr}{Tcx}\right)^s \quad (5)$$

SFOCx = Specific fuel oil consumption at site condition (g/kWh)

SFOCr = Specific fuel oil consumption at reference condition (g/kWh)

β = Correction factor

α = Power adjustment factor

k = Ratio of indicated power

μm = Mechanical efficiency

Tr = Ambient air temperature at reference condition

Tx = Ambient air temperature at site condition

Tcr = Charge air coolant temperature at reference condition

Tcx = Charge air coolant temperature at site condition

m, n, and s = Numerical value refer to ISO:3406. (m = 0.7 n = 1.2 s = 1)

Table 4. *Result of SFOC ambient correction.*

No	Power (kW)	NCV	Bh	Engine Efficiency	Px (kW)	α	k	μm	β	SFOCx g/kWh
	Pb	kJ/KG	Kg/h							
1	12676	40130	2503.5	0.451	11448.13	0.66	0.68	0.930	1.025952	178.5156
2	13796	40130	2500.1	0.491	11731.49	0.68	0.69	0.933	1.022827	177.9719
3	14720	40180	2633.4	0.497	13193.53	0.76	0.77	0.988	1.002697	174.4692
4	14710	40170	2647.8	0.494	12240.60	0.71	0.72	0.954	1.013535	176.3551
6	14840	40250	2641.5	0.498	11838.31	0.69	0.70	0.923	1.025596	178.4536
5	15850	40090	2805.5	0.503	13433.72	0.78	0.78	0.962	1.007899	175.3744
7	16259	40040	2920.0	0.497	13729.84	0.79	0.80	0.941	1.011063	175.925
8	16440	40180	3051.3	0.479	14331.18	0.83	0.83	0.969	1.004548	174.7914

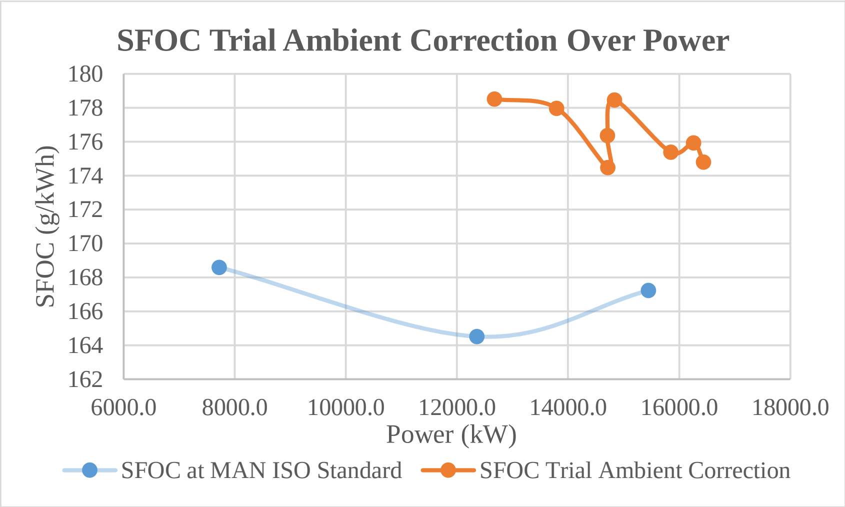

Figure 10. *Graph of SFOC trial condition vs MAN ISO Standard*

Therefore, the trial data provides NCV data as specified in Table.4. Thus, if the engine is working under ISO:3046 condition and using fuel with specification 42700 kJ/kg at 50% engine efficiency, the SFOC minimal would be 167 g/kWh. The correction for lower calorific value will be added by using formula:

$$SFOCy = SFOCx \times \frac{NCVx}{NCVISO}$$

SFOCy = Specific fuel consumption correction for lower calorific value

SFOCx = Specific fuel consumption ambient correction

NCVx = Net calorific value at site conditions

NCV ISO = Net calorific value at reference condition (ISO:3046) = 42700 kJ/kg

No	NCV kJ/kg	SFOCx g/kWh	SFOCy g/kWh
1	40130	178.52	167.77
2	40130	177.97	167.26
3	40180	174.47	164.17
4	40170	176.36	165.91

6	40250	178.45	168.21
5	40090	175.37	164.65
7	40040	175.93	164.97
8	40180	174.79	164.48

Table 5. *SFOC Trial after LCV Correction*

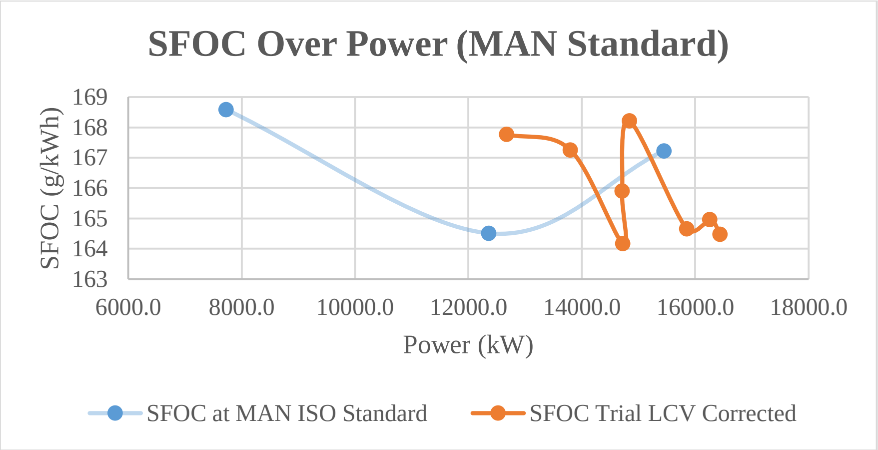

Figure 11. *SFOC Trial at LCV Correction.*

The results of the equation show that there is a gap between trial and MAN expected SFOC with ISO ambient and LCV correction standards. The error of the calculation is approximately +-5%. The minimal SFOC that Trial condition got is 164.17 g/kWh at 49.7% engine efficiency. The inconsistent of the SFOC at trial condition is caused by the difference fuel that was used. The quality fuel its self could affect the efficiency. At given engine efficiency, if the NCV is lower than ISO standard, the SFOC will be higher. Vise-versa, when the NCV of fuel is higher than ISO Standard, the SFOC approximately will be decreased 1%. The other factors that influence the SFOC is ambient temperature. Higher ambient temperature means more humidity and causing higher SFOC at same power. The gap between SFOC trial and MAN ISO standard will be defined as normal deviation.

4.3.3 Setting Upper (Heavy Running) and Lower (Light Running) Limit

In the Table 3. the lowest Cpv in recorded trial is 0.589. This value is the most economical value compared to the other where at 14781 kW power, the highest speed is obtained which is 22 Knot. And the upper limit which also defined as heavy running will be estimated at highest Cpv (recorded in trial), which is 0.092. The condition of light running and heavy running is described in Table 6. Observing both condition, even the estimated light running condition still has some influence from weather which is 2 m/s of wind and 0.5 m of wave height both are at bow sea.

Condition	Power (kW)		Cpv/Cpn	Speed (Kn)	Wind		Wave		Draft (m)		
	Pi	Pb			Speed (m/s)	Direction (◦)	Height	Direction (◦)	Fore	Aft	Avg
LR	14781	13796	0.0589/0.0123	22	2	350	0.5	340	9.8	10.4	10.1
HR	14902	14720	0.092/0.0130	20	6	280	1	280	11.5	11.6	11.55

Table 6. *Condition of Light Running and Heavy Running.*

Figure 12. *Estimation of Pb over Vs upper and lower limit*

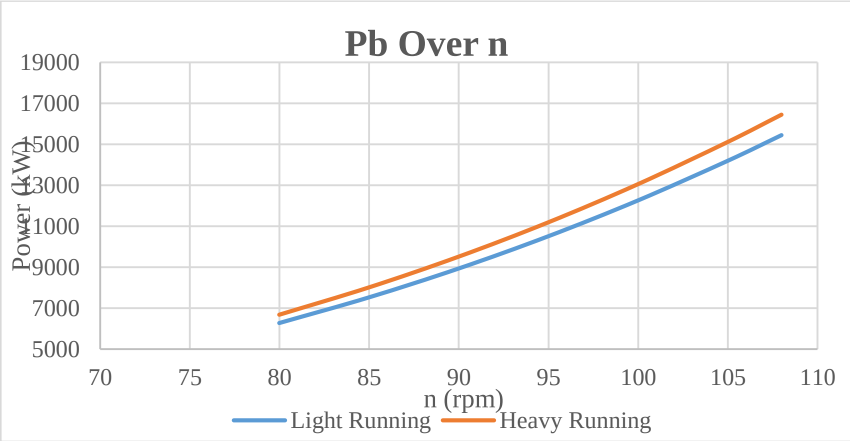

Figure 13. *Estimation of light running and heavy running of Pb over n.*

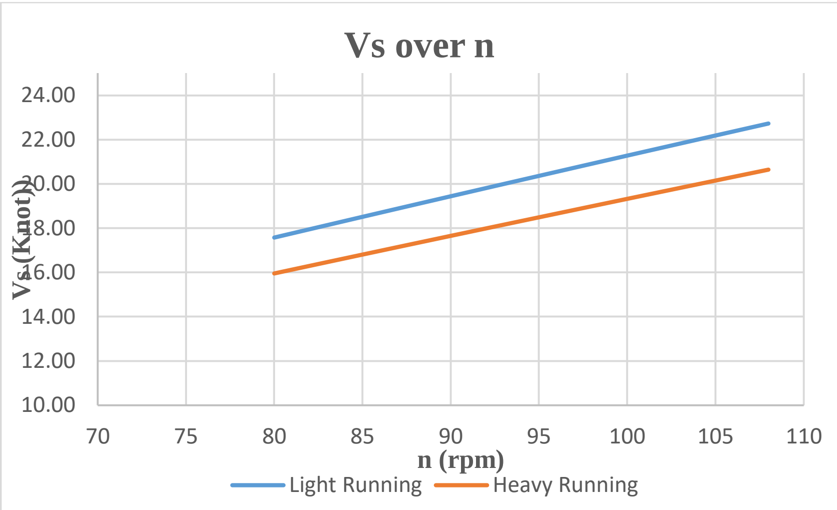

Figure 14. *Estimation of Light Running and heavy running of Vs over n.*

4.4 Onboard Data Identification

In order to approach identification data outliers, the statistical method is used. By grouping range of Cpn and Cpv and selecting which data sets will be in the same group, the outliers will be identified where power, engine speed and ship speed are the 3 parameters that focused and highlighted. The outlier data check is used to find unusual recorded data for deeper analysis and hypothesize regarding the causes of abnormalities. The characteristic of outlier in this research is when data set where the Cpn and or Cpv is not at the same group. In the meaning of that, at lower Cpv (at low resistance) the Cpn is expected to be lower in response of lower running condition. Variation is also to be summarized.

4.4.1 MV. Impala Data Check

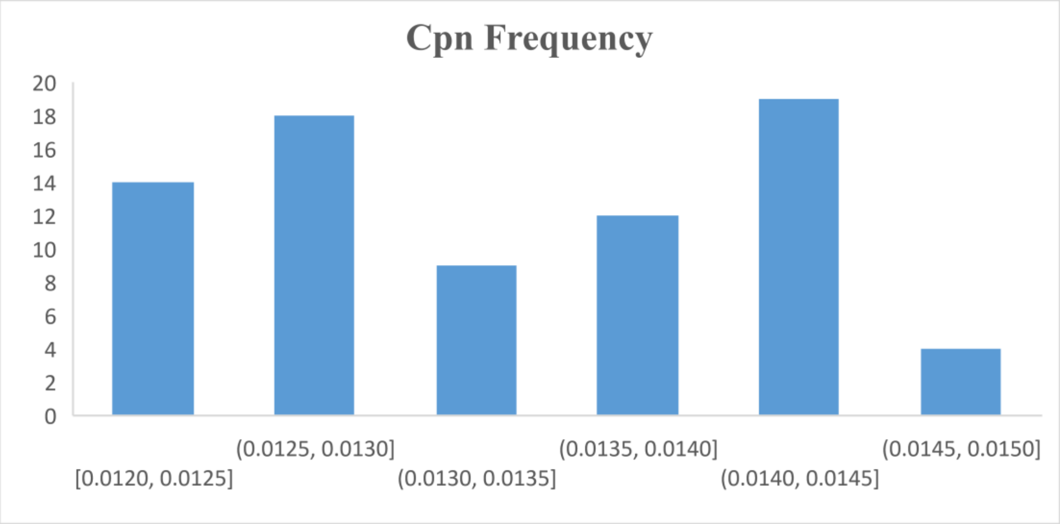

Figure 15. *Cpn frequency from MV. Impala.*

In Figure 15. show the variance of the Cpn in on-board data MV. Impala. Cpn range at 0.0120-0.0130 dominates the performance of engine rpm. The group is made by range of Cpn. Each of group range is described below:

a. Group 1: 0.0120 – 0.0130
b. Group 2: 0.0130 – 0.0140
c. Group 3: 0.0140 – 0.0150

Then, the Cpv group will be added and grouping which range of Cpn at the same group. By using this method, extreme condition and outliers can be identified.

Selection 1 Cpv 0.050-0.060			
Cpn Group	**Min**	**Max**	**Frequency**
Group 1	0.012	0.013	4
Group 2	0.013	0.014	0
Group 3	0.014	0.015	1
Data Entry	5		

Selection 2 Cpv 0.060-0.070			
Cpn Group	**Min**	**Max**	**Frequency**
Group 1	0.012	0.013	14
Group 2	0.013	0.014	7
Group 3	0.014	0.015	0
Data Entry	21		

Selection 3 Cpv 0.070-0.080			
Cpn Group	**Min**	**Max**	**Frequency**
Group 1	0.012	0.013	12
Group 2	0.013	0.014	8
Group 3	0.014	0.015	6
Data Entry	26		

Selection 4 Cpv 0.080-0.090			
Cpn Group	**Min**	**Max**	**Frequency**
Group 1	0.012	0.013	2
Group 2	0.013	0.014	5
Group 3	0.014	0.015	7
Data Entry	14		

Selection 5 Cpv 0.090-0.130			
Cpn Group	**Min**	**Max**	**Frequency**
Group 1	0.012	0.013	0
Group 2	0.013	0.014	1
Group 3	0.014	0.015	8
Data Entry	10		

The selection describes that higher Cpv is followed with higher Cpn. When Cpv rising, at the constant ship speed, the required power is higher in order to bear the increasing engine speed at higher resistance. This linear relation may be caused by several factors, such as weather, draught condition and hull roughness. Nonetheless, due to various operation condition, the variation of performance is widely different. The sample is taken for the variation which is 2 parameters nearly the same and the other parameter is significantly different. The sample is described in Table 7 for speed variation and Table 8 for brake power variation.

Variation Comparison (Speed Var.)		
Pb (kW)	16115	16054
n (rpm)	106.085	106.11
Vs (Knot)	22.492	20.853
Cpv	0.06297	0.0849
Cpn	0.0135	0.0134
Difference	7%	

Table 7. *Impala variation sample data sets.*

Variation Comparison (Brake Power Var.)		
Pb (kW)	13846	16539
n (rpm)	104.117	104.481
Vs (Knot)	20.788	20.556
Cpv	0.074144	0.092631
Cpn	0.0123	0.0145
Difference	19%	

Table 8. *Brake power variation sample of MV. Impala*

Outlier Sample Data Sets	
Pb (kW)	16640
n (rpm)	104.805
Vs (Knot)	23.536
Cpv	0.0542279
Cpn	0.0145

Table 9. *Outlier is detected where the Cpv and Cpn is not correlated each other.*

The comparison of variation in Table 7. explains that at nearly same 2 parameters (brake power and engine speed), resulting significantly different ship speed which the causes are currently unknown. The same condition occurs in Table 8. Which has brake power variation with almost same 2 other parameters. Moreover, in Table 9. the data set is defined as outlier, since at lower resistance, the engine speed is lower at constant brake power. If this operation condition is compared to referenced condition in Figure 13. at heavy running to generate 108 rpm, the required brake power is about 16437 kW.

4.4.2 MV. Liberta Data Check

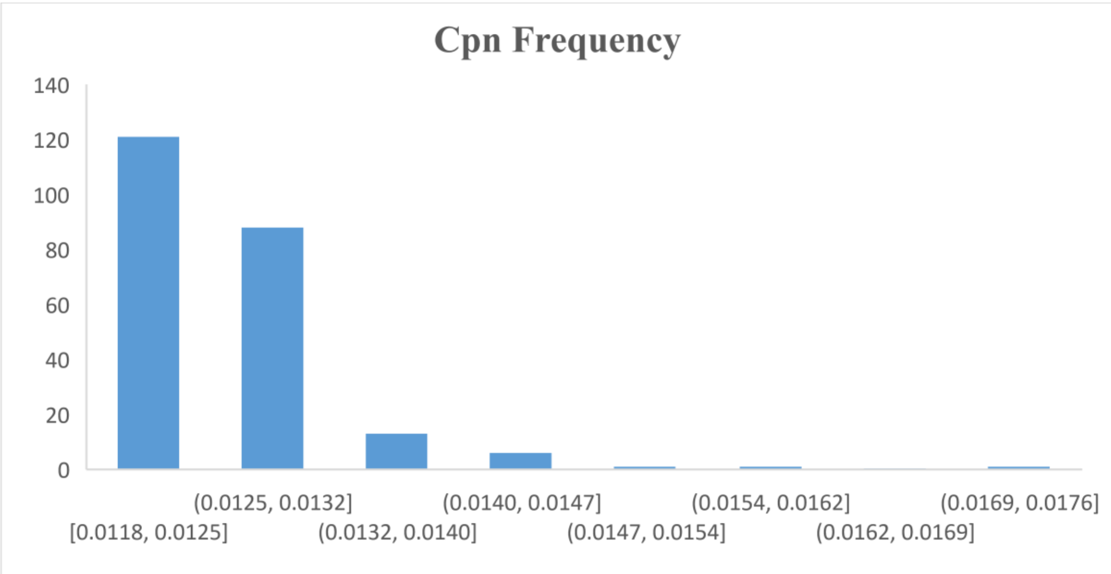

Figure 16. *Cpn frequency of MV. Liberta.*

Data check for MV. Liberta's Cpn shows that the Cpn in range 0.0118-0.0125 is dominating the performance that have been recorded. However, the highest fluctuation of Cpn recorded is 0.0176. In order to find the outlier, the same method in Impala (4.4.1) is added by grouping Cpn and Cpv. Data set is defined as an outlier if the Cpn and Cpv condition is not correlating each other (case like Impala outlier: 4.4.1). The group of Cpn is divided into 6 groups and described below:

a. Group 1: 0.0118 – 0.0125

b. Group 2: 0.0125 – 0.0130

c. Group 3: 0.0130 – 0.0135

d. Group 4: 0.0135 – 0.0140

e. Group 5: 0.0140 – 0.0150

f. Group 6: 0.0150 – 0.0180

Then, the Cpv group will be added and grouping which range of Cpn at the same group. By using this method, extreme condition and outliers can be identified.

Selection 1 Cpv 0.050-0.060			
Cpn Group	**Min**	**Max**	**Frequency**
Group 1	0.0118	0.0125	8
Group 2	0.0125	0.0130	0
Group 3	0.0130	0.0135	0
Group 4	0.0135	0.0140	0
Group 5	0.0140	0.0150	0
Group 6	0.0150	0.0180	0
Data Entry	8		

Selection 2 Cpv 0.060-0.070			
Cpn Group	**Min**	**Max**	**Frequency**
Group 1	0.0118	0.0125	55
Group 2	0.0125	0.0130	5
Group 3	0.0130	0.0135	0
Group 4	0.0135	0.0140	0
Group 5	0.0140	0.0150	0
Group 6	0.0150	0.0180	0
Data Entry	60		

Selection 3 Cpv 0.070-0.080			
Cpn Group	Min	Max	Frequency
Group 1	0.0118	0.0125	44
Group 2	0.0126	0.0130	29
Group 3	0.0131	0.0135	2
Group 4	0.0136	0.0140	0
Group 5	0.0141	0.0150	0

Group 6	0.0151	0.0180	0
Data Entry	75		

Selection 4 Cpv 0.080-0.090			
Cpn Group	**Min**	**Max**	**Frequency**
Group 1	0.0118	0.0125	9
Group 2	0.0125	0.0130	24
Group 3	0.0130	0.0135	3
Group 4	0.0135	0.0140	1
Group 5	0.0140	0.0150	0
Group 6	0.0150	0.0180	0
Data Entry	37		

Selection 5 Cpv 0.090-0.20			
Cpn Group	**Min**	**Max**	**Frequency**
Group 1	0.0118	0.0125	3
Group 2	0.0125	0.0130	9
Group 3	0.0130	0.0135	12
Group 4	0.0135	0.0140	6
Group 5	0.0140	0.0150	4
Group 6	0.0150	0.0180	1
Data Entry	39		

Selection 6 Cpv 0.20-0.40			
Cpn Group	**Min**	**Max**	**Frequency**
Group 1	0.0118	0.0125	0
Group 2	0.0125	0.0130	0
Group 3	0.0130	0.0135	0
Group 4	0.0135	0.0140	0
Group 5	0.0140	0.0150	1
Group 6	0.0150	0.0180	1
Data Entry	2		

The result of data check is almost the same with MV. Impala. Due to more data entry, the variations are also higher than MV. Impala. The sample is taken for the variation which is 2 parameters nearly the same and the other parameter is significantly different. The sample is described in Table 9.

Variation Comparison (Speed Var.)		
Pb (kW)	15207	15128
n (rpm)	107.107	106.063
Vs (Knot)	22.148	20.423
Cpv	0.06320	0.0870
Cpn	0.0124	0.0127
Difference	8%	

Table 10. *Variation sample with 2 nearly same parameters and 1 different parameter.*

Outlier Sample Data Sets		
Pb (kW)	11848	11246
n (rpm)	98.758	97.285
Vs (Knot)	18.981	18.392
Cpv	0.09128	0.0983
Cpn	0.0123	0.0122

Table 11. *Outliers sample taken from data operation.*

From Table 9. at the similar 2 parameters (brake power and rpm), the other parameter (ship speed) is different, which is about 8% ship speed loss and the causes of the variation is also unknown (incomplete data).

4.4.3 Specific Fuel Oil Consumption Data Check

The specific fuel oil consumption data check is needed in order to check whether the SFOC is according to the Trial condition or not for both ships. However, the recorded data for both ships is under incomplete condition. There are no data of NCV of the fuel, ambient temperature condition, charge air temperature, etc. As point 4.3.2 explains that the minimal SFOC under ISO correction is 164.17 g/kWh at 49.7% engine efficiency.

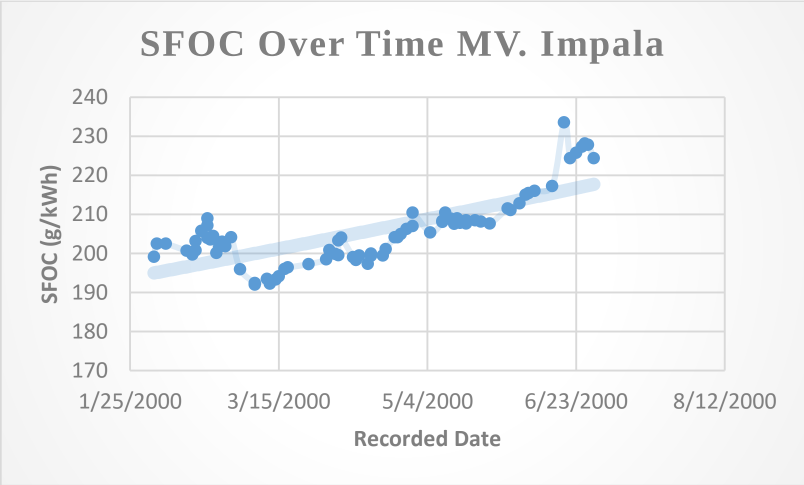

Figure 17. *SFOC over time recorded of MV. Impala.*

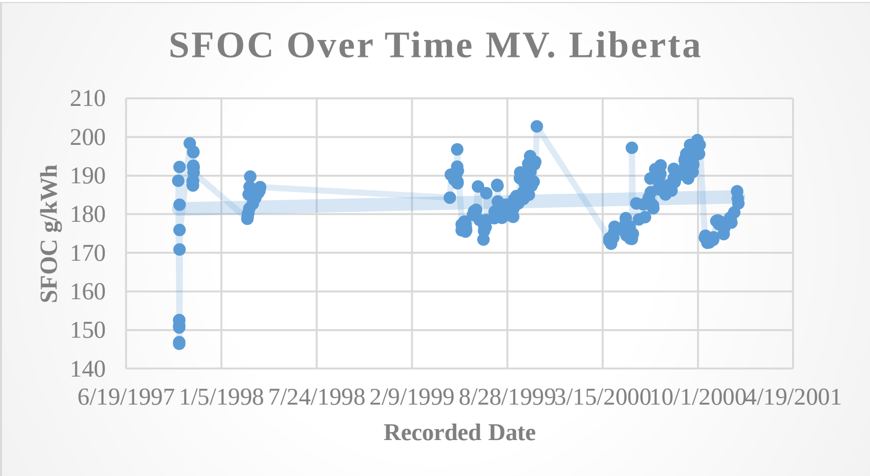

Figure 18. *SFOC over time recorded of MV. Liberta*

Figure 17 and 18 shows the specific fuel oil consumption per kilo watt hour for both ships. Impala has 5 months recorded date, while MV. Liberta has 3 years recorded onboard data. By looking the trend of the data, Impala has increasing SFOC overtime, while Liberta is also increasing and ramping at some dates, yet after several ramping performances of SFOC in MV. Liberta, the SFOC is decreasing to normal state and back increasing again. This mean that MV. Liberta was doing maintenance when the upper peak SFOC is reached. The other issue is the lowest SFOC recorded on MV. Liberta is 146.40 g/kWh, which is lower than the trial condition with ISO-3046 corrected which is approximately 164.17 g/kWh (4.3.2). The pre-assumption why the SFOC can be lower than the ISO standard correction is because the ship used better quality of fuel (more NCV) which might be the cause of decreasing SFOC. However, both ships used HFO as fuel oil which is averagely has 40.8 MJ/kg NCV. Although the ships using other type of fuel, the maximum estimation is the ship using diesel oil where the NCV is about 45 MJ/kg. Thus, in order to achieve 146.4 g/kWh, the NCV of fuel has to be 49.2 MJ/kg at 50% engine efficiency where there is no type of marine diesel oil that has that value of NCV. The SFOC that below the lower limit (164.17 g/kWh) will be defined as misreading of fuel consumption.

4.4.4 Summary of Data Check of Both Ships

In point 4.4.1 – 4.4.2 the data check in order to observe the variation and abnormalities. The abnormalities (outlier) from both ships occur when the value of Cpv and Cpn have untypical relation. From Table 9 and 11. the abnormalities have been detected. However, the case of abnormalities from both ships is vise-versa. In MV. Impala at lower Cpv, which means at lower resistance, the engine speed has untypical relation with the brake power and ship speed, where the engine speed seen to be heavy load. In the other side, MV. Liberta, at higher Cpv value, (means higher resistance), the engine speed characteristic is at lower load which can be seen from Cpn value (lower). Both cases have untypical relation where at increasing Cpv value (higher resistance) the brake power is expected to be rising as well. At the same time, in order to obtain the constant ship speed, at higher load characteristic for the engine speed, the brake power is expected to be rising. In short, those 3 parameters should have linear relation.

Regardless the abnormalities, the variation also occurs from the data sets. From both ships 2 samples are taken for deeper analysis. From both samples (Table 7 and 9) at similar 2 parameters (brake power and engine speed) the ships speed is different where the loss is 7% from Impala and 8% from Liberta. This operation condition might happen because of higher resistance.

4.5 Possible Causes Abnormalities and Variations

Following the data check in point 4.4, there are several factors that might be causing the abnormalities and variation on performance from both ships, since the ships are sister-ship. Sister-ships means they share same design and engine, yet in the recorded data both ships have different or lot of variation at a same variable, regardless the recorded data in Impala is only 3 months while the Liberta is 3 years recorded data. As the data is under incomplete information, the rest of the data required is an estimation. To approach the causes of the variations and abnormalities, the tasks are divided into group of cases and followed by pre-assumptions which also supported by literature. The comparison between 2 ships is also added in the group of cases. The group of cases are:

a. Impala and Liberta Variations of Speed (Table 7 & 10).
b. Impala Variations of Brake Power (Table 8).
c. Impala Outlier (Table 9).
d. Liberta Outliers (Table 11).
e. Liberta and Impala Comparison in Overall Performance

4.5.1 Case 1: Impala and Liberta Variations of Speed

The primary issue in this case is the ship speed variation, where at similar 2 parameters, the ship speed is different (Table 7). In order to support the data forensic analysis, literature will be the key to solve the case because the data is under incomplete condition.

Pre-assumptions: The causes of the ship speed variation (ship speed reduction) is weather factor, since it could reduce the ship speed due to increasing resistance and could influence the ship motion. And at the same time, the increasing resistance against ship's direction will decrease the ship speed at constant power.

Data evidence: The Cpv in the data set is higher compared to the other (Table 7 & 10).

Supported Data and Literature: The Cpv formula is the derivation of power formula which is power proportional to resistance times ship speed. The ship speed reduction due to weather is various depend on the sea condition (Table 1). The formula from Aertssen is used to approach this case (F. Molland). The Aertssen formula is defined as:

$$\frac{\Delta V}{V} \times 100\% = \frac{m}{Lpp} + n$$

Lpp = Length between perpendicular

ΔV = Ships speed loss

m and n = Aertssen numerical value (Table 12)

BN	Head Sea		Bow Sea		Beam Sea		Following Sea	
	m	n	m	n	m	n	m	n
5	900	2	700	2	350	1	100	0
6	1300	6	1000	5	500	3	200	1
7	2100	11	1400	8	700	5	400	2
8	3600	18	2300	12	1000	7	700	3

Table 12. *Aertssen numerical value for m and n.*

BN	Ship's Speed Reduction Rate (%)			
	Head Sea	Bow Sea	Beam Sea	Following Sea

5	6.56	5.55	2.77	0.51
6	12.59	10.07	5.54	2.01
7	21.65	15.1	8.55	4.03
8	36.26	23.66	12.07	6.55

Table 13. *Reduction rate at various BN.*

Impala Variation Explanation (Head sea BN 5)				
Parameter		**Theoretically Speed Red. (%)**	**Speed Result Theoretically (Kn)**	**Actual Data**
Pb (kW)	16115	6.56	21.02	16054
rpm	106.085			106.11
Vs (Kn)	22.49			20.85
Differences of Theory Red. and Actual			0.78%	
Liberta Variation Explanation (Head sea BN 5)				
Parameter		**Theoretically Speed Red. (%)**	**Speed Result Theoretically (Kn)**	**Actual Data**
Pb (kW)	15207	6.56	20.70	15128
rpm	107			106
Vs (Kn)	22.15			20.42
Differences of Theory Red. and Actual			1.31%	

Table 14. *Result of theoretical speed reduction and compared to the actual data.*

Result: By using the formula from Aertssen, the highest speed reduction rate is when the ship facing head sea condition where the waves and wind direction is opposite of the ship’s direction. Looking back to the Table 7 and 10, the ship speed reduction for the sample in Impala is 7% and 8% respectively. The reason for the BN 5 taken as the weather factor speed reduction is because the speed reduction rate is the closest to the actual speed variations. And the result of the pre-assumptions is acceptable with 0.78% and 1.31% differences of ship speed respectively.

However, even the calculations show acceptable margins, both practically and theoretically those 3 parameters show untypical relation. At the nearly same engine speed and brake power, the ship speed also should be in the same range. Although the ship encountered higher resistance (due to worst weather condition) at the same brake power, the ship speed and engine speed should be decreasing. Thus, if the crews decided to had constant speed, the required brake power to rotate the engine/propeller will be in higher load in which increasing fuel consumption as well. In shorts, 2 parameters have to be changed in order to achieve a constant parameter.

Furthermore, in Table 14, both ships have similar ship speed and engine speed, however the brake power is significantly difference. Although both ships are sister-ship, the performance is completely difference, where Impala required more brake power compared to Liberta. This condition could not be explained since there is no data regarding condition of engine. Nevertheless, the causes of differences might come from inside the engine such as: contaminated fuel, loss of engine compression and injection timing error. Those factors may lead worse performance [6].

4.5.2 Case 2: Impala Brake Power Variations

This case occurs because of the significantly difference of brake power at similar ship speed and engine speed. In order to approach and solve the case, several formulas from literature is added to support the pre-assumptions. The pre-assumptions in this case is divided into 3 scenarios, since the causes of increasing power at constant speed are various.

Pre-assumptions 1: The causes of the brake power variation are various, moreover the data is incomplete. However, by looking the data operations (Table 8), the value of Cpv is higher and followed with the increasing value of Cpn, which means the ship was at higher resistance and the engine had to increase the brake power at constant speed in order to overtake the margin. One of the causes might come from weather factor since the propeller and engine rotation is affected due to weather condition. And with rough assumption the ship decided to have constant speed and have higher brake power while encountered rough sea condition.

Data Evidence: The Cpv and Cpn is higher compared to the other data set in Table 8.

Supported Data and Literature: Kwon (2008) derivate the formula of increasing power at constant speed at various sea condition. At the same time, due to weather factor, wake fraction might be changing overtime, since the wake fraction is actually affected by wave motions and length [7]. Also, an investigation from Taskar (2015) shows that unstable propeller inflow might cause the increasing brake power. At higher wake fraction, the propeller efficiency is decreasing. To approach the brake power increase, derivation formula from Kwon (2008) is used:

$$\frac{\Delta P}{P} = (nx + 1)\frac{\Delta V}{V}$$

$\frac{\Delta P}{P}$ = Power increase rate

nx = Typical values. Container = 2.16

$\frac{\Delta V}{V}$ = Speed reduction rate (Table 13)

BN	Ship's Brake Power Increase Rate (%)			
	Head Sea	Bow Sea	Beam Sea	Following Sea
5	20.74	17.54	8.75	1.61
6	39.79	31.82	17.51	6.35
7	68.41	47.72	27.02	12.73
8	114.57	74.77	38.14	20.7

Table 15. *Brake power increase rate using Kwon formula.*

Impala Variation Explanation (Head sea BN 5)

<table>
<tr><th colspan="2">Parameter</th><th>Theoretical Brake Power Inc. (%)</th><th>Brake Power Theoretically (kW)</th><th>Actual Data</th></tr>
<tr><td>Pb (kW)</td><td>13846</td><td rowspan="3">20.74</td><td rowspan="3">16717.66</td><td>16539</td></tr>
<tr><td>rpm</td><td>104.117</td><td>104.481</td></tr>
<tr><td>Vs (Kn)</td><td>20.788</td><td>20.556</td></tr>
<tr><td colspan="3">Differences of Theoretical and Actual</td><td colspan="2">1.07%</td></tr>
</table>

Table 16. *Result of theoretical brake power increase due to weather factor and compared with actual data.*

Pre-assumptions 2: The causes of increasing brake power at constant speed might from increasing draught level. The causes of changing draught level are also various, for example increasing cargo load and water characteristic (temperature and density). Since the higher Cpv data set was recorded in June 2000, which is Summer, the density and temperature will be higher, thus the increasing draught might come easily. In this case, the water characteristic is assumed to be constant and the variable to be changed is the increasing cargo load which can increase the draught. Taking reference from the trial data (Table 2), the highest Cpv is 0.092 (closest to the sample) with average draught 11.5 meters. Assumed that the lower Cpv value in this sample has 10 meters draught. Hence, at the constant speed and engine speed, the power must be increasing due to increasing wetted surface area which is directly affect the resistance.

Data evidence: Table 8.

Supported Data and Literature: Taking reference in Table 2, at Cpv value 0.092, which is closest to the (higher) Cpv value in this sample, the draught is 11.5 meters. To approach the increasing power due to draught level, the admiralty formula can be used:

$$\frac{Pb2}{Pb1} = \left(\frac{T2}{T1}\right)^{5/6}$$

Pb 2 = Required power after draught change (kW).

Pb 1 = Power before draught change (kW).

T 2 = Draught level change.

T 1 = Draught level before change.

<table>
<tr><th colspan="5">Impala Variation Explanation (Draught Level Inc.)</th></tr>
<tr><th colspan="2">Parameter</th><th>Brake Power Result Theoretically (kW)</th><th>Theoretical Brake Power Inc. (%)</th><th>Actual Data</th></tr>
<tr><td>Pb (kW)</td><td>13846</td><td rowspan="4">15556.28</td><td rowspan="4">12%</td><td>16539</td></tr>
<tr><td>rpm</td><td>104.117</td><td>104.481</td></tr>
<tr><td>Vs (Kn)</td><td>20.788</td><td>20.556</td></tr>
<tr><td>Assumed T (m)</td><td>10</td><td>11.5</td></tr>
<tr><td colspan="3">Differences of Theoretical and Actual</td><td colspan="2">6%</td></tr>
</table>

Table 17. *Impala brake power increase theoretical versus actual data.*

Pre-assumptions 3: Both scenarios above are explaining only with 1 factors in the variation. Thus, in this scenario (pre-assumption), both scenario is combined whether this method can explain the variations with reasonable margin. The increasing power might come from increasing draught level and the ship encountered rough sea condition. The data evidence of the higher Cpv in this sample explains that the resistance is at higher form (extreme condition).

Data Evidence: Table 2 as reference and Table 8 as evidence.

Supported Data and Literature: Combination of scenario 1 and 2 both literature, equation, and data.

Impala Brake Power Variation Explanation (Combined Factor)							
Parameter	**Actual Data**		**Inc. Power due T (kW)**	**Brake Power Result due to T + Weather (BN 5) in kW**			
	Data A	**Data B**		**Head Sea**	**Bow Sea**	**Beam Sea**	**Following Sea**
Pb (kW)	13846	16539	15556.28	18782.66	18284.86	16917.4588	15806.74009
rpm	104.117	104.481					
Vs (Kn)	20.788	20.556					
Assumed T (m)	10	11.5					
Differences of Theoretical and Actual			6%	14%	11%	2%	4%

Table 18. *Combined factors of power variations.*

Result: The variation in brake power at constant speed and engine speed may various. Moreover, the data is incomplete, hence the assumptions and estimation come from literatures and references from trial data. The result is weather factor plays big role in variation of brake power since it causes increasing resistance significantly while the draught factor might be in rank 2 in role of variation of brake power. There is a chance that the causes of power variation are combination factors as the Table 18 shown. Nevertheless, in this sample, by using formula from Kwon (2008) in scenario 1, the theoretical increasing brake power has closest difference to the actual data which is 1.07%. The formula and result also describe when a ship encounter rough sea condition and decided to have constant speed, the propeller inflow will unstable due to increasing wake fraction and at the same time the propeller efficiency will be decreasing as well which is in accordance with the theory in supported literature. However, same as previous point (4.5.1) the similar 2 parameters should be resulting same range 1 other parameter. And the actual data sets in this sample has no typical relation. In the data sets in this sample at higher Cpv, at the same brake power, the engine speed should be at 108 rpm and ship speed 22.2 knots (refer to trial conditions Table 2).

However, the higher resistance could be caused by weather, which may reduce both ship speed and engine speed.

4.5.3 Case 3: Impala Outlier Data Set

This case is the hardest case to solve due to untypical relation of three parameters (Table 9). In one side, the relation between power and speed has a typical relation at lower resistance, while the power and engine speed has typical relation in higher resistance which is contradiction each other. Even though if the wake fraction value is increasing, there must be a factor that might change the wake fraction, since wake fraction is affected by wave length and motion (Nakamura and Naito, 1975).

Pre-assumptions: The causes of this abnormalities might come from following sea at BN 2 which has approximately 0.7 meters wave heights (Table 1) which may cause increasing wake fraction and disrupting the propeller rotation. Considering biofouling factor that also influence the wake fraction (MAN, 2012), since the outlier data is recorded in the middle May, 2000 (2nd month of recorded data).

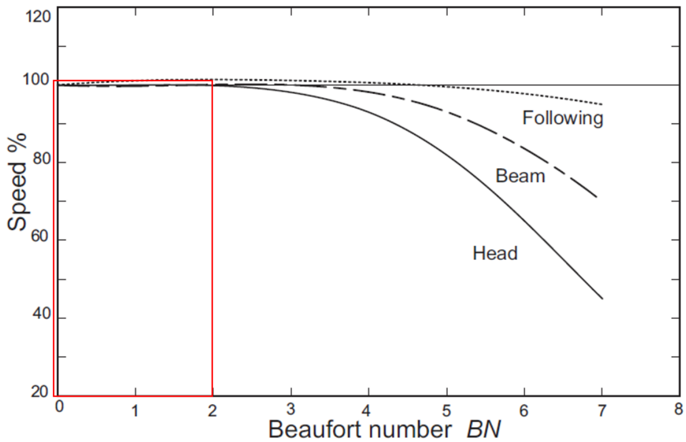

Figure 19. *Weather factor of speed reduction. Source: A.F Molland*

Data Evidence: Table 9 shows the untypical relation.

Supported Data and Literature: Looking at Figure 19, at BN 2 following sea condition, the ship speed might be increase a little bit. Due to wave heights and motion at 0.7 meters, there is a chance for increasing wake fraction which may cause lower rpm. If using classical method, the advance velocity/propeller inflow formula is:

$$\frac{Va}{V} = (1 - w)$$

Assumed that w value is increasing from 0.26 to 0.30, hence at 23.5 knots the value of advance velocity is 16.45 knots. If the classical formula is used as reference which is:

$$J = \frac{Va}{n \times D}$$

Va : Advance velocity (Kn).

n : propeller rotation per second (rps).

D : Diameter propeller.

Result: There is a possibility to explain the untypical relation of the abnormalities. Somehow at calm resistance, the wake fraction is increasing (whether from biofouling factor with calm weather or at BN 2 following sea). By looking the classical formula, if the value of w increase, the value of Va will be decreased. At given J value and diameter propeller, the total propeller rotation in rps will be decreased as well. The decreasing Va value will decrease the propeller efficiency. However, this case is hard to explain with incomplete data. Another causes of this abnormalities might come from sensor failure since the characteristic of Impala recorded data does not match with data set that abnormal (Figure 20). By looking at the Figure 20, the ship speed should be below 19 knots. If the causes of abnormality come from sensor failure, then the data set might be false, whether from engine speed, brake power, or ship speed.

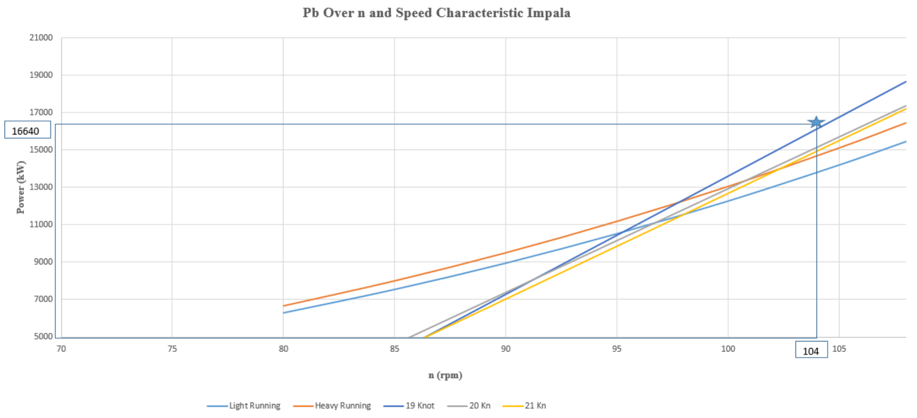

Figure 20. *Pb over n and ship speed characteristic of Impala.*

If the causes of this abnormal data set come from the sensor failure, hence the error range from each parameter will be defined:

a. Brake power (kW) : 2%

b. Engine speed (rpm) : 2%-3%

c. Ship speed (Knots) : +- 1 Knot

By setting this error range, the sensor failure might come from the engine speed sensor which may conduct inaccurate measurement. Assumed that the engine speed sensor had a precise measurement which is at given brake power (figure 20), the engine speed diagram position will move to the right and might be at correct actual speed. Hence, the abnormalities can be explained which is caused by the sensor failure of measurement at engine speed.

4.5.4 Case 5: Liberta Abnormalities/Outliers

This case is the vise-versa of Impala outliers case in 4.5.1. At higher resistance (which can be seen in Cpv value Table 11), the propeller rotation is at light load condition which is shows untypical relation. Definitely it is hard to explain with such incomplete data.

Pre-assumptions: If the load of propeller seems at light load condition, then there is a possibility that the ship encountered calm weather, hence the wake fraction might be at lower form. The only reason of the Cpv value at higher point is because draught condition. Thus, at the constant speed, the power required will be higher due to increasing draught level. Taking reference from trial data in Table 2 number 2, the draught level at 10.1 m has Cpv value at 0.058, hence the brake power estimation at abnormal data set ship speed parameter can be estimated. Thus, the draught before changing is assumed at 10.1 meters.

Data Evidence: Table 11.

Supported Data and Literature: By using admiralty formula, the brake power change can be estimated at constant speed and engine speed also at referenced weather (Table 2 number 2).

Liberta Outliers Explanation (Draught Increase Factor)				
Assumption		**Theoretical Brake Power Inc. (%)**	**Brake Power Result Theoretically (kW)**	**Actual Data**
Pb (kW)	8306.23	9255.16874	0.11	11848
rpm	98.76			98.76
Vs (Kn)	18.981			18.981
Assumed T (m)	10.1			11.5
Differences of Theoretical and Actual			28.0%	

Liberta Outliers Explanation (Draught Increase Factor)				
Assumption		**Brake Power Result Theoretically (kW)**	**Theoretical Brake Power Inc. (%)**	**Actual Data**
Pb (kW)	7322.23	8158.75	0.11	11246
rpm	97.29			97.29
Vs (Kn)	18.981			18.39

Assumed T (m)	10.1			11.5
Differences of Theoretical and Actual			37.8%	

Table 19. *Liberta theoretical versus actual data for outliers.*

Result: The pre-assumptions could not explain the abnormalities from the Liberta, where the margin between theoretical and actual data sets is not acceptable which is at 28% and 37.8% respectively. Similar as the Impala outlier/abnormal data set where the correlation between 3 parameters have untypical relation and hard to explain for the causes. One parameter is indicating at higher resistance and the other parameters indicating at lower resistance which is abnormal. However, there is a possibility that the abnormalities are caused by sensor failure or misreading. If the causes of this abnormal data set come from the sensor failure, hence the error range from each parameter will be defined:

a. Brake power (kW) : 2%
b. Engine speed (rpm) : 2%-3%
c. Ship speed (Knots) : +- 1 Knot

By setting this error range, the sensor failure might come from the engine speed or ship speed sensor which may conduct inaccurate measurement. Hence, the abnormalities can be explained which is caused by the sensor failure of measurement in engine speed or ship speed. Through, if the value of engine speed is decreased with error margin, the value of Cpn is in the right position/condition which is at heavier condition (since the value of Cpv is in heavy running).

4.5.5 Case 6: Liberta and Impala Comparison in Overall Performances

In this case, the overall performances of both ships will be compared each other. The result that to be expected in this case is the performances of both ship has similar curves since both ships are sister-ship. All onboard measurements in recorded data will be compared overtime.

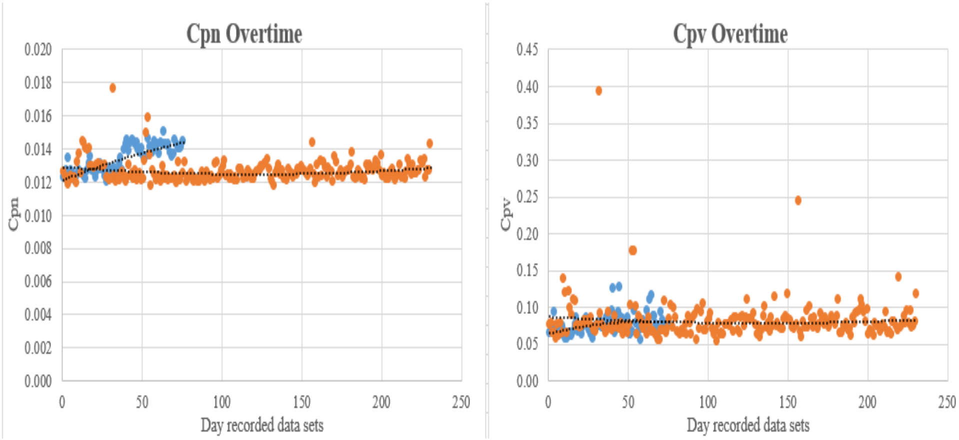

Figure 21. *Cpn and Cpv overtime of both ships.*

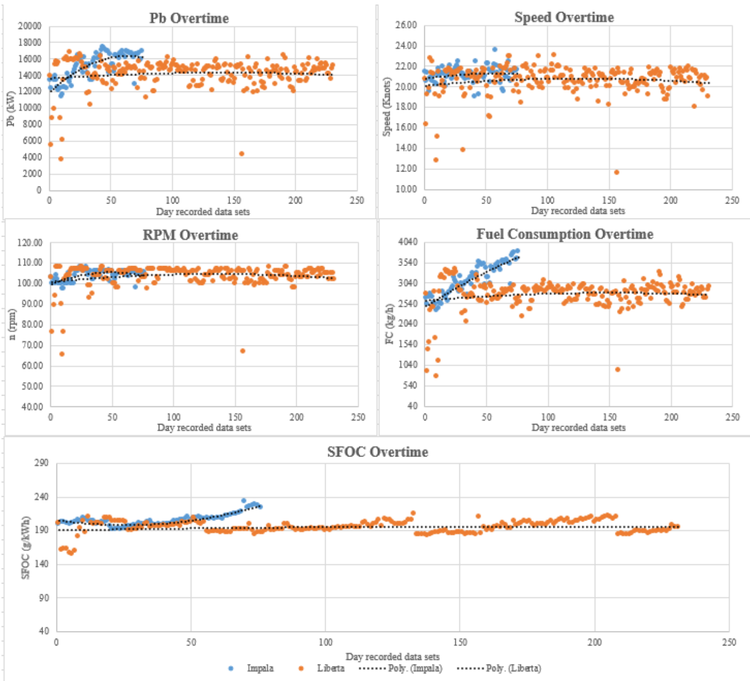

Figure 22. *Impala versus Liberta in overall performances shows Pb and Bh is different significantly.*

Figure 21 explain that Impala had increasing value of Cpn overtime which means the required brake power is increasing to obtain specific engine/propeller rpm. In Figure 22, the comparison shows significance differences in brake power and fuel consumption which is correlating in SFOC directly. The first assumption is Impala has higher resistance due to fouling growth overtime. However, the graph and diagram of ship speed shows the vise-versa, theoretically. At nearly same engine speed (both ships) the Impala has higher speed in overall. Thus, the causes of differences in both ships might not dominated by fouling growth. Even though weather is the causes, there is no possibility that weather will occur overtime, where Impala start to fluctuate on 11.04.2000 and the propeller diagram stay increasing overtime. The factor that may influence the brake power and fuel consumption might come from internal factor which is engine efficiency. The engine efficiency at some point may start degrading. The engine efficiency is dependent in fuel quality and fuel consumption. Lower quality of fuel may degrade and wear off the engine. In continuous operation and without any gently care of fuel, fuel may cause deposits, clogging and corrosion. Moreover, without any proper maintenance, the condition may be worst overtime. Leakage of fuel will decrease the pressure in fuel system which may lead to increasing fuel consumption and increasing brake power. Cleaning and maintenance the engine, such as filter and tank cleaning, leakage check, and engine check (cylinder and injection) is important in order to keep the performances at desire conditions. At this point, MV. Impala needs to be maintained at least in engine perspective since the power and fuel consumption is rising overtime up to its peak condition. If the maintenance does not possible to done, the increasing cost of investments will be more expensive than it should be.

CHAPTER V
CONCLUSION

5.1 Conclusion

By grouping the value of Cpv and Cpn, the outliers/abnormal, fluctuations, and variations can be detected. While the causes of fluctuations, abnormalities, and variations of performances from both ships is vary and widely. Higher Cpv and Cpn value means the ship faced higher resistance which may lead to heavy load condition. Weather factor is the highest factor that might influence the variations both performance of ships. Weather factors occurs when the ship has sudden increase in resistance due to worse weather which may indicated by higher value of Cpv. However, the factors that have mentioned neither can be accepted nor rejected since the available data is limited/incomplete. The certain causes cannot be assured with incomplete onboard measurements. In the other hand, a single factor whether increase or decrease might affect the other factor respectively. For example, a fouling hull or propeller will have higher wake fraction and thrust deduction factor, thus might affect the propulsion power. More problems if the combined factors occur at the same time, which may conduct increasing operation cost. However, the abnormalities could not be explained under incomplete measurement data sets. By only reckoning or depending on literatures is not sufficient to find out the causes of abnormalities. In this research the abnormalities might come from the sensor failure, since the abnormal data sets shows untypical relation of the parameters.

By comparing the sister-ships, the performance of both ship actually do not have similar performances in overall, where the brake power and fuel consumption in Impala performance is higher than Liberta. The causes of the differences in the performance might come from the degrading main engine due to continuous operation. Thus, the ship (Impala) needs to be maintained in order to maintain the ship at best condition and investment cost as well.

In shorts, data diagnostics and analysis under incomplete data situations can only estimate the load of the ship when the data is recorded and also hypothesized that the ship encountered various resistance which is indicated by the value of Cpv and Cpn without knowing the exact operation conditions.

5.2 Suggestion

In order to increase accuracy of estimation the complete data is required to perform better diagnostics. The minimum required data for better data analysis is weather condition during the recorded operation. Thus, the causes of fluctuations or abnormalities might can be explained by external factor at least. Data regarding the ambient conditions and engine conditions might be useful for further data diagnostics in order to analyze engine condition.

REFERENCES

[1] A. F. Molland, S. R. Turnock and D. A. Hudson, Ship Resistance and Propulsion, New York: Cambridge University Press, 2011.

[2] B. Taskar, P. B. Regener and P. Andersen, "The Impact of Propulsion Factors on Vessel Performances in Waves," Research Gate, Technical University of Denmark, 2019.

[3] MAN, "Basic Principles of Ship Propulsion," 2010.

[4] C. H. a. D. Yebra, Advances in Marine Antifouling Coatings and Technologies, 2009.

[5] L. Birk, Fundamentals of Ship Hydrodynamics: Fluid Mechanics, Ship Resistance and Propulsion, New Orleans: Wiley Online Library, 2019.

[6] P. Dempsey, Troubleshooting and Repairing Diesel Engines 4th Edition, McGraw Hill Education, 2007.

[7] N. S. and N. S., "Propulsive Performance of a Container Ship in Waves," *Society of Naval Architects of Japan,* vol. 15, 1977.

[8] Holtrop, "An approximate power prediction method," in *Shipbuilding prog.,* 1982, pp. 166-171.

[9] B. Taskar, K. K. Yum, S. Steen and E. Pedersen, "The effect of waves on engine propeller dynamics and propulsion performances of ships," //www.researchgate.net/publication/305309069, Trondheim, 2016.

[10] R. Lu, O. Turan, E. Boulogouris, A. Incekik and C. Banks, "A semi empirical ship operational performance prediction model for voyage optimization towards energy efficient shipping," Glasgow, 2015.

"This page is intentionally left blank"

AUTHOR BIOGRAPHY

Achdaniel Farikhi was born in Jombang, East Java on 24th September, 1997. He starts his formal education at SDN Kepanjen II, Jombang (2004-2010), SMPN 2 Jombang (2010-2013), SMAN 2 Jombang (2013-2016). After graduation from high school, the author was accepted at the Department of Marine Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember Surabaya through the SNMPTN in 2016. During the study period, the author was active in various activities and organizations such as member of Marine Operation and Maintenance Laboratory of Marine Engineering Department ITS. The author decided to take the field of data diagnostic for the bachelor thesis.

He can be contacted via his email: danielfarikhi01@gmail.com

"This page is intentionally left blank"

APPENDIX

DATA OPERATIONS

MV LIBERTA						
No	***Date***	***Time***	***N***	***Pb***	***Bh***	***Vs***
			[rpm]	***[kW]***	***[kg/h]***	***[kn]***
1	10/6/1997	14:56:01	103.149	13848	2776	20.742
2	10/8/1997	15:02:44	76.159	5455	876	16.284
3	10/8/1997	16:45:43	89.533	8723	1414	19.230
4	10/8/1997	17:16:15	94.035	9838	1595	19.790
5	10/8/1997	18:29:59	108.138	15230	2377	22.719
6	10/8/1997	20:16:00	108.189	15650	2435	21.357
7	10/8/1997	22:48:23	108.110	15333	2454	22.490
8	10/9/1997	16:44:03	108.186	15496	2813	21.188
9	10/9/1997	17:50:42	90.104	8688	1684	19.208
10	10/9/1997	18:34:22	65.461	3691	754	12.790
11	10/9/1997	20:22:11	76.426	6115	1143	15.073
12	10/31/1997	3:11:20	102.148	13344	2813	21.399
13	11/6/1997	0:42:57	103.303	15877	3181	19.025
14	11/6/1997	8:08:29	104.140	16186	3226	20.171
15	11/6/1997	12:42:21	104.113	15813	3168	20.513
16	11/6/1997	15:10:00	104.142	15768	3162	19.468
17	11/6/1997	17:17:47	106.267	16856	3357	19.900
18	11/7/1997	1:43:50	107.192	15858	3303	21.507
19	11/7/1997	2:45:19	107.223	15915	3318	21.433
20	11/7/1997	3:38:26	107.193	15842	3302	21.690
21	11/7/1997	5:51:16	107.191	15951	3257	21.593
22	11/7/1997	7:31:59	107.208	16066	3286	21.507
23	11/7/1997	9:59:24	107.153	16047	3283	21.136
24	11/7/1997	13:58:10	107.168	15949	3260	21.308
25	11/7/1997	17:49:57	108.209	16495	3366	21.205
26	11/7/1997	21:25:21	108.197	16335	3312	21.442
27	2/28/1998	17:35:53	106.118	15565	2958	20.718
28	3/1/1998	8:46:22	107.106	15043	2868	21.460
29	3/2/1998	0:52:11	106.986	14947	2860	21.598
30	3/2/1998	23:09:31	107.232	14915	2857	21.741
31	3/3/1998	7:27:53	98.772	11716	2304	19.852
32	3/4/1998	16:23:12	93.082	14213	2741	13.795
33	3/5/1998	20:01:56	98.758	11848	2355	18.981

34	3/6/1998	23:29:11	95.190	10358	2088	19.242
35	3/12/1998	11:58:58	104.247	13789	2677	20.993
36	3/16/1998	2:42:31	104.230	13685	2688	21.476
37	3/16/1998	22:04:13	104.159	13998	2745	21.426
38	3/17/1998	16:16:11	104.160	14194	2778	19.804
39	3/20/1998	1:18:00	104.253	13906	2738	20.931
40	3/21/1998	14:43:29	104.146	13583	2689	21.109
41	3/22/1998	18:23:30	106.697	14890	2935	21.166
42	3/23/1998	11:30:34	107.823	16319	3217	20.763
43	3/24/1998	5:12:07	108.175	15643	3089	21.579
44	3/26/1998	9:27:32	102.120	13283	2627	20.456
45	3/27/1998	14:30:00	102.544	13084	2600	20.804
46	4/30/1999	5:07:46	105.963	15115	2960	21.042
47	5/1/1999	14:32:15	102.110	12881	2604	21.256
48	5/9/1999	8:52:25	106.003	14621	2935	21.711
49	5/12/1999	10:37:54	106.003	14855	2978	21.300
50	5/13/1999	0:33:04	105.993	14357	2904	21.679
51	5/15/1999	8:42:06	100.138	12236	2559	20.030
52	5/15/1999	14:48:29	100.112	13315	2721	19.042
53	5/15/1999	20:43:57	100.018	14922	2988	17.086
54	5/16/1999	0:48:57	97.854	14820	2960	17.045
55	5/16/1999	17:37:16	98.199	12860	2613	18.899
56	5/24/1999	21:15:10	106.106	14067	2650	21.774
57	5/25/1999	2:04:29	106.063	15128	2826	20.423
58	5/28/1999	4:57:50	105.056	14407	2710	20.360
59	5/30/1999	2:12:53	105.112	13993	2647	20.901
60	5/31/1999	9:05:18	105.053	14057	2660	21.157
61	6/1/1999	8:27:12	105.928	14661	2748	21.021
62	6/1/1999	15:10:25	106.017	14300	2695	21.900
63	6/2/1999	2:29:06	106.007	15411	2874	20.604
64	6/2/1999	13:40:15	106.054	14799	2775	21.194
65	6/3/1999	2:28:41	107.013	14927	2789	21.753
66	6/17/1999	6:39:09	107.060	15085	2882	21.787
67	6/19/1999	6:43:04	107.102	14803	2836	21.913
68	6/20/1999	1:12:25	106.986	14914	2865	22.208
69	6/20/1999	21:30:38	107.050	14913	2864	22.895
70	6/21/1999	4:16:31	107.122	15092	2890	22.917
71	6/23/1999	19:24:20	106.061	14755	2840	21.566
72	6/27/1999	18:31:44	101.122	12343	2455	20.634

73	7/1/1999	2:04:45	106.050	15660	2970	19.505
74	7/9/1999	8:33:37	106.046	14415	2657	21.744
75	7/10/1999	15:06:30	103.072	13514	2523	20.930
76	7/11/1999	3:12:23	103.083	13648	2563	20.130
77	7/14/1999	7:05:59	103.068	14403	2703	19.415
78	7/15/1999	7:27:50	104.188	13544	2568	20.892
79	7/15/1999	11:40:26	97.285	11246	2216	18.392
80	7/31/1999	23:55:43	107.127	15183	2887	20.553
81	8/1/1999	7:54:03	107.078	15362	2922	21.988
82	8/2/1999	3:51:59	107.023	14852	2851	21.945
83	8/5/1999	13:25:06	107.068	14745	2835	22.121
84	8/6/1999	5:56:30	107.090	14888	2862	21.697
85	8/7/1999	12:13:59	100.133	12069	2406	20.854
86	8/8/1999	4:24:02	100.099	12010	2391	20.005
87	8/8/1999	12:48:05	103.049	13300	2590	21.448
88	8/11/1999	20:02:52	102.121	13374	2592	19.845
89	8/16/1999	9:15:54	107.029	15229	2899	21.046
90	8/16/1999	21:25:50	107.012	14673	2812	22.024
91	8/17/1999	10:43:27	107.023	15449	2939	20.650
92	8/18/1999	2:23:05	107.066	15125	2882	20.324
93	8/20/1999	11:58:32	107.056	14840	2849	22.900
94	8/21/1999	6:04:54	107.013	15134	2903	19.951
95	8/21/1999	19:32:19	107.070	14897	2876	21.460
96	8/23/1999	2:08:57	106.092	15589	2998	20.289
97	8/24/1999	6:12:56	107.118	16207	3107	19.861
98	8/26/1999	9:02:55	106.048	14509	2813	21.465
99	8/29/1999	12:53:42	106.048	14721	2842	21.603
100	9/5/1999	21:28:18	106.038	15149	2890	20.879
101	9/8/1999	11:48:38	105.993	15363	2935	20.790
102	9/9/1999	12:35:57	106.075	15819	3014	20.407
103	9/10/1999	12:44:50	107.094	15157	2924	21.523
104	9/11/1999	9:02:48	107.107	15207	2945	22.148
105	9/11/1999	20:54:31	106.065	14531	2839	21.556
106	9/12/1999	1:17:27	106.155	14881	2885	23.080
107	9/12/1999	12:26:37	106.077	14512	2831	20.821
108	9/12/1999	22:04:12	106.078	14446	2819	21.894
109	9/15/1999	19:48:04	107.084	15084	2938	22.004
110	9/16/1999	15:01:04	106.007	14382	2823	21.956
111	9/19/1999	23:13:36	104.083	14374	2798	20.843

112	9/20/1999	11:28:16	105.057	14748	2865	21.016
113	9/20/1999	18:29:23	105.078	14609	2844	21.009
114	9/24/1999	4:35:57	101.060	12546	2524	20.303
115	9/24/1999	18:14:57	101.147	12699	2575	19.871
116	9/30/1999	19:10:21	106.046	14615	2883	21.731
117	10/1/1999	3:32:39	106.127	15137	2959	20.518
118	10/4/1999	5:33:41	102.040	13309	2657	19.840
119	10/8/1999	10:06:35	106.031	14485	2902	21.502
120	10/11/1999	15:22:42	101.131	12614	2588	20.975
121	10/12/1999	22:28:12	107.102	15274	3003	20.531
122	10/15/1999	8:45:13	100.085	12626	2617	19.474
123	10/15/1999	17:45:34	100.188	12709	2613	20.360
124	10/15/1999	23:58:18	100.119	12747	2624	19.723
125	10/16/1999	7:30:57	101.182	13406	2720	18.716
126	10/17/1999	20:13:32	104.060	14559	2898	20.438
127	10/18/1999	8:25:59	104.044	14772	2942	20.490
128	10/19/1999	6:53:04	103.977	14755	2947	20.558
129	10/19/1999	13:21:26	104.082	15051	3004	20.219
130	10/22/1999	20:02:13	105.609	15003	3004	21.053
131	10/24/1999	1:30:17	104.939	14039	2878	21.778
132	10/26/1999	5:20:46	104.992	13928	2864	20.888
133	10/29/1999	9:35:37	101.148	12177	2623	21.342
134	3/29/2000	16:49:48	105.959	14873	2746	21.554
135	3/30/2000	0:23:48	107.048	15619	2873	20.567
136	3/30/2000	4:33:37	107.044	15958	2933	19.959
137	4/1/2000	9:25:29	106.079	14846	2744	21.263
138	4/2/2000	6:10:02	106.050	15140	2773	21.028
139	4/6/2000	20:31:24	106.964	14881	2750	21.732
140	4/9/2000	1:14:39	103.052	13434	2504	19.982
141	4/9/2000	9:10:24	103.101	13263	2491	20.574
142	4/22/2000	23:13:24	101.997	13487	2523	18.554
143	5/2/2000	13:44:47	107.015	15211	2869	21.248
144	5/2/2000	17:40:41	107.062	15336	2891	21.045
145	5/3/2000	1:49:04	105.064	14221	2704	21.126
146	5/4/2000	2:21:29	102.135	13211	2460	20.866
147	5/4/2000	6:25:19	102.066	13214	2450	20.861
148	5/10/2000	8:39:15	106.051	15200	2815	20.629
149	5/10/2000	21:35:19	103.037	13892	2592	19.998
150	5/10/2000	23:29:20	100.115	12965	2436	18.259

151	5/11/2000	6:11:11	102.120	13470	2518	20.021
152	5/12/2000	9:14:09	106.069	15086	2784	20.708
153	5/14/2000	7:45:04	106.085	14913	2769	21.314
154	5/14/2000	18:49:28	107.036	15125	2806	21.493
155	5/15/2000	1:35:41	106.013	14993	2787	21.183
156	5/15/2000	20:57:08	106.042	15246	2812	21.200
157	5/15/2000	22:59:36	67.003	4309	903	11.542
158	5/18/2000	7:19:26	105.884	14703	2733	21.770
159	5/25/2000	5:13:56	100.181	11973	2325	21.296
160	5/30/2000	23:50:02	102.101	13874	2633	20.425
161	6/8/2000	21:14:46	100.220	12296	2385	20.347
162	6/12/2000	13:18:38	106.976	16210	3087	20.340
163	6/17/2000	7:36:13	106.057	14729	2861	21.322
164	6/20/2000	18:12:04	101.137	13652	2673	19.230
165	6/21/2000	15:08:53	104.084	14433	2814	20.410
166	6/23/2000	22:06:25	99.115	11886	2390	20.128
167	6/24/2000	9:06:32	100.183	12898	2545	19.721
168	6/29/2000	4:07:57	105.754	14953	2896	21.197
169	6/30/2000	5:46:15	106.707	15244	2940	21.670
170	7/4/2000	3:07:39	100.194	12041	2452	19.916
171	7/11/2000	21:43:34	102.109	14388	2850	19.932
172	7/12/2000	4:09:23	102.203	14039	2790	20.237
173	7/12/2000	10:44:02	102.125	13150	2650	20.448
174	7/14/2000	17:35:27	100.147	12480	2552	19.571
175	7/14/2000	20:26:49	101.115	13050	2641	20.222
176	7/15/2000	5:00:00	100.164	12342	2526	20.410
177	7/24/2000	5:24:04	105.021	14504	2885	20.728
178	7/25/2000	16:55:33	107.968	15866	3120	20.685
179	8/2/2000	22:01:57	104.077	14307	2853	20.320
180	8/6/2000	8:52:47	103.113	13841	2760	20.655
181	8/7/2000	0:02:20	103.167	14253	2838	20.117
182	8/7/2000	6:15:47	103.091	15067	2980	19.242
183	8/11/2000	19:07:06	105.982	14578	2933	21.823
184	8/12/2000	1:01:06	102.044	12954	2639	21.221
185	8/14/2000	0:54:32	106.015	14581	2918	21.115
186	8/23/2000	9:23:24	106.004	15078	3047	21.463
187	9/4/2000	0:46:34	104.084	14109	2907	20.645
188	9/4/2000	10:21:12	104.059	13740	2837	21.209
189	9/5/2000	3:38:17	106.069	14643	2999	21.414

190	9/6/2000	19:42:41	104.046	13564	2819	21.679
191	9/9/2000	13:16:42	108.099	16438	3313	20.987
192	9/11/2000	2:54:01	108.074	16006	3218	21.309
193	9/12/2000	15:59:08	104.035	14609	2973	19.997
194	9/14/2000	13:24:59	104.100	14381	2924	19.846
195	9/14/2000	14:28:13	102.074	13496	2786	19.463
196	9/14/2000	16:35:24	101.269	13402	2763	18.692
197	9/14/2000	19:30:56	98.185	12519	2602	18.695
198	9/15/2000	7:40:16	98.152	12342	2579	19.074
199	9/15/2000	10:28:21	98.102	11994	2523	19.684
200	9/20/2000	8:30:48	103.122	14911	3024	19.804
201	9/21/2000	1:39:46	104.988	14267	2931	21.874
202	9/22/2000	4:23:59	104.911	14437	2958	21.464
203	9/24/2000	4:51:41	103.063	13335	2788	21.247
204	9/24/2000	15:56:14	103.222	13332	2795	21.664
205	9/30/2000	8:19:54	103.020	13267	2808	20.362
206	10/2/2000	13:28:30	104.084	14145	2972	20.868
207	10/4/2000	1:22:06	106.086	15224	3165	21.348
208	10/5/2000	13:18:09	106.034	14707	3093	21.768
209	10/15/2000	22:58:40	103.124	13276	2453	20.893
210	10/17/2000	4:59:59	103.110	13481	2498	20.603
211	10/21/2000	9:18:06	107.075	15277	2802	21.413
212	10/25/2000	17:48:05	107.083	15986	2933	20.433
213	11/2/2000	4:41:20	105.089	14205	2617	21.742
214	11/3/2000	11:29:59	105.050	14242	2633	21.495
215	11/9/2000	11:19:36	106.052	14491	2744	21.969
216	11/11/2000	18:19:33	106.033	14953	2835	20.883
217	11/14/2000	12:14:21	103.024	14540	2754	20.744
218	11/14/2000	19:26:00	107.062	15970	3011	21.631
219	11/17/2000	4:22:21	106.040	14777	2796	21.529
220	11/24/2000	16:46:15	104.095	14654	2722	17.998
221	11/25/2000	20:37:02	107.050	15312	2870	21.509
222	11/27/2000	0:30:15	107.134	15359	2894	21.186
223	12/7/2000	12:37:31	105.057	14729	2785	20.321
224	12/8/2000	7:21:37	105.072	14730	2803	20.869
225	12/9/2000	2:03:16	105.058	15388	2914	20.113
226	12/9/2000	12:51:24	105.014	15162	2879	20.985
227	12/10/2000	22:44:41	102.109	14160	2675	19.667
228	12/16/2000	22:26:40	104.884	14113	2706	21.084

229	12/22/2000	14:06:01	102.093	13507	2669	20.728
230	12/24/2000	10:00:42	105.136	14729	2880	20.810
231	12/25/2000	13:29:06	102.021	15167	2946	19.005

MV IMPALA						
No	***Date***	***Time***	***N***	***Pb***	***Bh***	***Vs***
			[rpm]	***[kW]***	***[kg/h]***	***[kn]***
1	2/2/2000	5:31:15	103.138	13413	2671	21.438
2	2/3/2000	10:23:26	100.117	12455	2522	20.573
3	2/6/2000	17:33:01	102.111	13494	2732	21.324
4	2/13/2000	22:37:23	100.106	13453	2699	19.526
5	2/15/2000	6:47:58	104.117	13846	2765	20.788
6	2/16/2000	10:33:59	102.059	13429	2696	20.652
7	2/16/2000	23:17:43	100.119	12525	2544	20.556
8	2/18/2000	12:26:19	100.100	12138	2497	21.066
9	2/20/2000	4:03:13	100.146	12371	2523	20.285
10	2/20/2000	13:29:47	97.318	11403	2382	20.182
11	2/20/2000	21:33:46	97.358	11663	2416	21.214
12	2/21/2000	2:05:05	100.078	12534	2551	21.716
13	2/21/2000	18:33:46	100.110	12525	2551	21.016
14	2/22/2000	7:59:40	100.026	12373	2529	21.342
15	2/23/2000	1:47:27	105.148	14175	2836	21.944
16	2/24/2000	17:30:14	102.113	13510	2724	21.255
17	2/25/2000	16:44:35	100.100	13151	2669	20.443
18	2/26/2000	9:13:09	100.136	13594	2743	19.995
19	2/28/2000	1:51:13	100.061	12709	2594	20.953
20	3/2/2000	14:43:20	104.166	14251	2792	21.247
21	3/7/2000	9:41:37	106.128	14677	2824	22.006
22	3/7/2000	23:25:11	106.061	15054	2890	21.375
23	3/11/2000	7:19:19	106.094	15247	2949	20.764
24	3/12/2000	6:03:38	107.890	16461	3164	20.999
25	3/14/2000	7:42:33	108.002	16042	3101	21.615
26	3/15/2000	6:39:56	107.014	15663	3040	21.836
27	3/17/2000	12:29:44	106.151	14723	2886	22.000
28	3/18/2000	20:18:49	106.069	14331	2814	22.419
29	3/25/2000	22:48:42	107.991	16172	3190	21.742
30	3/31/2000	0:25:05	106.063	15254	3027	21.304
31	4/1/2000	8:12:59	104.139	14297	2871	21.034
32	4/3/2000	6:30:09	106.066	15050	3007	21.214

33	4/4/2000	9:09:22	106.082	15325	3058	20.855
34	4/4/2000	16:38:38	102.121	13421	2728	20.738
35	4/5/2000	21:44:44	102.041	13456	2745	20.873
36	4/9/2000	0:08:39	106.134	15629	3111	21.391
37	4/10/2000	5:28:34	106.110	16054	3183	20.853
38	4/11/2000	3:29:19	106.097	15086	3008	21.462
39	4/14/2000	5:45:01	106.132	16632	3281	21.312
40	4/15/2000	9:16:42	104.119	16074	3204	20.295
41	4/15/2000	21:38:38	103.664	16204	3240	18.977
42	4/19/2000	7:22:04	106.049	16480	3287	22.445
43	4/20/2000	23:08:29	105.993	17087	3436	21.038
44	4/23/2000	13:57:37	106.107	17381	3547	20.827
45	4/24/2000	9:51:44	106.205	17314	3534	19.225
46	4/25/2000	2:33:05	106.125	17064	3496	21.160
47	4/27/2000	2:10:41	105.633	16896	3484	21.262
48	4/29/2000	6:23:28	106.617	16894	3497	21.703
49	4/29/2000	23:46:13	101.221	14243	2997	20.790
50	5/5/2000	4:35:08	105.898	16599	3408	21.031
51	5/9/2000	7:22:30	104.096	15230	3168	22.271
52	5/9/2000	15:04:32	104.130	15233	3172	22.235
53	5/10/2000	0:26:44	102.123	14364	3022	21.635
54	5/12/2000	11:32:10	104.120	16428	3431	20.436
55	5/13/2000	11:39:32	105.145	16386	3400	21.461
56	5/14/2000	2:11:00	105.047	16305	3406	21.463
57	5/15/2000	8:08:46	105.199	16014	3327	22.121
58	5/17/2000	1:40:07	104.805	16640	3469	23.536
59	5/17/2000	19:49:00	105.974	16729	3473	22.027
60	5/20/2000	22:15:36	105.923	16952	3533	21.367
61	5/22/2000	2:32:05	106.078	16358	3404	21.932
62	5/25/2000	15:05:03	104.095	16167	3356	20.347
63	5/31/2000	2:04:53	105.976	16929	3580	21.658
64	6/1/2000	7:58:22	103.713	16750	3535	19.749
65	6/4/2000	20:13:09	105.588	16808	3577	19.510
66	6/6/2000	18:49:15	105.572	16655	3581	20.936
67	6/7/2000	13:19:34	105.454	16711	3600	20.941
68	6/9/2000	22:50:29	105.878	16328	3527	21.582
69	6/15/2000	5:18:38	106.085	16115	3500	22.492
70	6/19/2000	19:41:41	98.108	12884	3008	20.712
71	6/21/2000	20:35:54	104.481	16539	3710	20.556

72	6/23/2000	10:48:09	105.191	16608	3749	21.292
73	6/25/2000	0:38:04	106.064	16675	3790	21.622
74	6/26/2000	0:24:11	104.083	15748	3592	21.732
75	6/27/2000	13:32:33	104.032	15895	3620	21.538
76	6/29/2000	18:43:52	105.678	16984	3810	21.638