BACHELOR THESIS AND COLLOQUIUM – ME184841

ANALYSIS OF PROPELLER PERFORMANCE TYPE C4-40 WITH VARIOUS DISTRIUTION PITCH FOR CONTROLLABLE PITCH PROPELLER USING CFD

Edli Kemal Mahadika
NRP. 04211541000019

Lecture Supervisors :
Irfan Syarief Arief, S.T., M.T.
Sunarsih, S.T., M. Eng., Ph. D.

DEPARTMENT OF MARINE ENGINEERING
FACULTY OF MARINE TECHNOLOGY
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
SURABAYA
2019

BACHELOR THESIS AND COLLOQUIUM – ME184841

ANALYSIS OF PROPELLER PERFORMANCE TYPE C4-40 WITH VARIOUS DISTRIBUTION PITCH FOR CONTROLLABLE PITCH PROPELLER USING CFD

Edli Kemal Mahadika

NRP. 04211541000019

Lecture Supervisors

Irfan Syarief Arief, S.T., M.T.

Sunarsih, S.T., M.Eng., Ph.D.

DEPARTMENT OF MARINE ENGINEERING

Faculty of Marine Technology

Institut Teknologi Sepuluh Nopember

Surabaya

2019

“this page is intentionally left blank”

BACHELOR THESIS AND COLLOQUIUM – ME184841

ANALISA PEFORMA PROPELLER TIPE C4-40 DENGAN VARIASI DISTRIBUSI PITCH UNTUK CONTROLLABLE PITCH PROPELLER MENGGUNAKAN CFD

Edli Kemal Mahadika

NRP. 04211541000019

Dosen Pembimbing

Irfan Syarief Arief, S.T., M.T.

Sunarsih, S.T., M.Eng., Ph.D.

DEPARTEMEN TEKNIK SISTEM PERKAPALAN

Fakultas Teknologi Kelautan

Institut Teknologi Sepuluh Nopember

Surabaya

2019

“this page is intentionally left blank”

ENDORSEMENT PAGE

ANALYSIS OF PROPELLER PERFORMANCE TYPE C4-40 WITH VARIOUS DISTRIBUTION PITCH FOR CONTROLLABLE PITCH PROPELLER USING CFD

BACHELOR THESIS

Submitted to Comply One of the Requirements to Obtain Bachelor

Engineering Degree

on

Marine Manufacture and Design (MMD)

Bachelor Program Department of Marine Engineering

Faculty of Marine Technology

Institut Teknologi Sepuluh Nopember

Prepared by:

EDLI KEMAL MAHADIKA

NRP. 04211541000019

Approved by Supervisors:

Irfan Syarief Arief, S.T., M.T. ( )

NIP. 196912251997021001

Sunarsih, S.T., M. Eng., Ph. D. ( )

NIP. -

“this page is intentionally left blank”

ENDORSEMENT PAGE

ANALYSIS OF PROPELLER PERFORMANCE TYPE C4-40 WITH VARIOUS DISTRIBUTION PITCH FOR CONTROLLABLE PITCH PROPELLER USING CFD

BACHELOR THESIS

Submitted to Comply One of the Requirements to Obtain Bachelor Engineering Degree

on

Marine Manufacture and Design (MMD)

Bachelor Program Department of Marine Engineering

Faculty of Marine Technology

Institut Teknologi Sepuluh Nopember

Prepared by:

EDLI KEMAL MAHADIKA

NRP. 04211541000019

Approved by

Head of Marine Engineering Department

Dr. Eng. Muhammad Badruz Zaman, S.T., M.T.

NIP. 197708022008011007

“this page is intentionally left blank”

ENDORSEMENT PAGE

ANALYSIS OF PROPELLER PERFORMANCE TYPE C4-40 WITH VARIOUS DISTRIBUTION PITCH FOR CONTROLLABLE PITCH PROPELLER USING CFD

BACHELOR THESIS

Submitted to Comply One of the Requirements to Obtain Bachelor

Engineering Degree

on

Marine Manufacture and Design (MMD)

Bachelor Program Department of Marine Engineering

Faculty of Marine Technology

Institut Teknologi Sepuluh Nopember

Prepared by:

EDLI KEMAL MAHADIKA

NRP. 04211541000019

Approved by
Representative of Hochschule Wismar in Indonesia

Dr.-ing. Wolfgang Busse

“this page is intentionally left blank”

Analysis of Propeller Performance Type C4-40 with Various Distribution Pitch for Controllable Pitch Propeller Using CFD

Name : Edli Kemal Mahadika

NRP : 04211541000019

Supervisor : 1. Irfan Syarief Arief, S.T., M.T.

2. Sunarsih, S.T., M. Eng, Ph.D.

ABSTRACT

Nowadays, many ships are made using Controllable Pitch Propellers (CPP). Both for ships and offshore structures, usually are made of ducted CPPs. The characteristics of CPP has many differences of substantial items from fixed pitch propellers. There is no systematic information given on the propeller blade spindle torque for CPP, it is including for all possible blade pitch settings which is from full positive pitch to full negative pitch and over the complete four quadrants. The objective in this thesis is finding the propeller performance of CPP type C4-40 P/D 1.4 with various distribution pitch using CFD. The geometry of the propeller is produced by MARIN application that just giving input parameter which is the diameter of the propeller. The model has been manufactured; in case it will be done experimental process on the next opportunity. First of all, the author made the 3D model of the propeller and make it solid file using the rhinoceros and solidworks. After that, the model should be meshed on Hexpress before it is going to be simulated in Fine Marine. The meshing quality of the propeller is around 1-2 million cells. In Result, all of events are happening in this simulation. At first, the performance of distribution pitch +1.6 is getting higher than the original pitch. The thrust produced by the propeller are higher and so does the moment. But in distribution pitch +1.2, there are event of propeller gave the thrust negative which mean force backwards. It is happening while J1.2 and J1.4, the thrust is negative but the moment still positive. It can be seen like the propeller try to stop the movement forward of the ship. There are ahead, crashahead, backing, and crashback happening in this analysis, which can be shown in four quadrant graphs.

Keywords: Propeller, CPP, Distribution Pitch, Performance, Four Quadrant

“this page is intentionally left blank”

Analisa Peforma Propeller Tipe C4-40 dengan Variasi Distribusi Pitch untuk Controllable Pitch Propeller Menggunakan CFD

Nama : Edli Kemal Mahadika

NRP : 04211541000019

Dosen Pembimbing : 1. Irfan Syarief Arief, S.T., M.T.
2. Sunarsih, S.T., M. Eng, Ph.D.

ABSTRAK

Saat ini, banyak kapal dibuat menggunakan *Controllable Pitch Propeller* (CPP). Baik untuk kapal maupun struktur lepas pantai, biasanya terbuat dari *ducted CPP*. Karakteristik CPP memiliki banyak perbedaan item substansial dari baling-baling pitch tetap. Tidak ada informasi sistematis yang diberikan pada torsi spindle blade baling-baling untuk CPP, termasuk untuk semua pengaturan blade blade yang memungkinkan, mulai dari pitch positif penuh hingga pitch negatif penuh dan lebih dari empat kuadran lengkap. Tujuan dalam tesis ini adalah menemukan kinerja propeller CPP tipe C4-40 P / D 1.4 dengan berbagai pitch distribusi menggunakan CFD. Geometri baling-baling dihasilkan oleh aplikasi *MARIN* yang hanya memberikan parameter input yang merupakan diameter baling-baling. Model telah dibuat; dalam hal ini akan dilakukan proses eksperimental pada kesempatan berikutnya. Pertama-tama, penulis membuat model *propeller* 3D dan membuatnya menjadi file solid menggunakan *Rhinoceros* dan *solidworks*. Setelah itu, model harus disambungkan pada Hexpress sebelum akan disimulasikan dalam Fine Marine. Kualitas sambungan baling-baling adalah sekitar 1-2 juta sel. Hasilnya, semua peristiwa terjadi dalam simulasi ini. Pada awalnya, kinerja pitch distribusi +1.6 semakin tinggi dari pitch asli. Dorongan yang dihasilkan oleh baling-baling lebih tinggi dan begitu juga saat ini. Namun dalam pitch distribusi +1.2, ada baling-baling yang memberikan gaya dorong negatif yang berarti gaya mundur. Ini terjadi saat J1.2 dan J1.4, dorongan negatif tetapi saat ini masih positif. Ini bisa dilihat seperti baling-baling yang mencoba menghentikan gerakan ke depan kapal. Ada peristiwa *ahead*, *crashahead*, *backing*, dan *crashback* terjadi dalam analisis ini, yang dapat ditampilkan dalam empat grafik kuadran

Keywords: Propeller, CPP, Distribution Pitch, Performance, Four Quadrant

“this page is intentionally left blank”

PREFACE

Thanks to almighty Allah SWT which has given his blessing to the author, therefore this bachelor thesis could be finished which is titled "Analysis of Propeller Performance Type C4-40 with Various Distribution Pitch for Controllable Pitch Propeller Using CFD "

Bachelor Thesis and Colloquium proposed to fulfill one of requirements for finishing undergraduate degree in Department of Marine Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember.

The author would like to appreciate for all people who had supported and assistance him among all the processes to finish this bachelor thesis.

1. dr. H. Elfiedi Sofyan and Hj. Mastalinda, S.E, the author's beloved parents, which always support him in all the way.
2. Edli Arrafi, S.E., B. Econ and Edli Muhammad Athif, the author's beloved brothers, which always support him in all the way.
3. Dr. Eng., M. Badruz Zaman, S.T., M.T., as the head of Marine Engineering Department, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember.
4. Irfan Syarief Arief, S.T., M.T., as first lecture advisor who has given many assistances and guidance to the author.
5. Sunarsih, S.T., M.Eng., Ph.D, as second lecture advisor who has given many assistances and guidance to the author.
6. Dr. I. Made Ariana, S.T., M.T., as the supervisor of the author who has given knowledge and support to the author.
7. Friends of arms ITS-120 in Department of Marine Engineering as general, and Marine Manufacturing and Design Laboratory as special who always provide support and enthusiasm to the author to complete this thesis.
8. All of friends that has big roles to support and motivate the author to finish this bachelor thesis which could not be mentioned one by one.

In the end, the author realized that this thesis has many weaknesses, therefore the author always be humble and opened to all advices and suggestion for the further knowledge and experience that he will face in the future.

Surabaya, Juni 2019

The Author

“this page is intentionally left blank”

TABLE OF CONTENTS

“this page is intentionally left blank”

LIST OF FIGURES

“this page is intentionally left blank”

LIST OF TABLES

“this page is intentionally left blank”

CHAPTER I
INTRODUCTION

1.1. Introduction

This chapter gives basic reasons that the author decides to analyse the propeller performance of Wageningen C-Series which exactly type C4-40. Since the background, then goes to problem that exist. Research objective is determined and make some limitations. The benefits of this bachelor thesis also be mentioned.

1.2. Research Background

Propeller is a part of the ship propulsion system; it transmits power by converting rotational motion into trust. When the ship moves through water at a certain speed, ship experiences resisting forces due to water and air. Trust will overcome the resistance forces. Besides it is used for the thrust if ship or aircraft, the propeller is also used for the power plant such as wind turbine.

Designers and engineers worldwide usually used The Wageningen Propeller B-Series. It contains the open water characteristics of conventional fixed pitch propellers with various blade area ratios and number of blades for different pitch. Several propellers have characteristics in 4-quadrants (positive and negative rpm and positive and negative speed) which were published by MARIN in the sixties and seventies.

Today many ships are made using Controllable Pitch Propellers (CPP). Both for ships and offshore structures, usually are made of ducted CPPs. The thrust-torque performance of these units is not only of importance for ship designers but also for accurate analysis of speed trial results, DP (dynamic position) systems and DP-simulation models, and also the manoeuvring simulators. The characteristics of CPP has many differences of substantial items from fixed pitch propellers.

Moreover, a CPP blade has completely different blade form than an FPP. It is happening because of more practical issues need to be considered for a CPP. For example, the blades must be able to pass each other from positive pitch to negative pitch, it must to be positioned really properly between the bolt holes on the blade foot, it overhang at the blade foot should preferably be avoided to prevent stress concentration; the blade tips must not touch the inner side of a duct at any deflected pitch angles for the ducted CPPs. the cavitation and propeller performance must be acceptable for a wide range of operational pitch settings.

Besides all of these problems, one of the important and unique issues is the blade spindle torque of CPP. There is no systematic information given on the propeller blade spindle torque for CPP. It is including for all possible blade pitch settings which is from full positive pitch to full negative pitch and over the complete two quadrants. There is also no systematic information is available on blade feathering performance.

1.3. Problem Statement

In this thesis, the propeller is C-Series type C4-40 P/D 1.4. The author will analyse the performance of the propeller from different various distribution pitch and the effect which is occurred. So, the statement problem is How the propeller performance of C4-40 series with different distribution pitch.

1.4. Research Objective

The objectives to be obtained in this thesis is to determine the performance of the propeller C4-40 due to various distribution pitch.

1.5. Scope of Problem

The research has scope of problems which are based on propeller C4-40 with the specification below:

Diameter	= 316.6 mm
Model Pitch	= 1.4
Expanded Area Ratio	= 0.4
Number of blades	= 4

1.6. Research Benefits

The benefits to be obtained from this thesis are:

1. For ship-owner which is using this propeller C4-40, it can be one of your reference to choose the optimal propeller for your vessels.
2. For author and reader, it can be your reference for the further research development related to this thesis.

CHAPTER II
LITERATURE REVIEW

2.1. Introduction

This chapter presents the framework of theories relevant to the research and a thorough review of the literature and past researches whose topics are significant to identify the research gap, understand the detail of the research and provide a basis for designing the research methodology. The chapter contains literature on four quadrant propeller characteristics, four quadrant wake and thrust deduction fractions, and ship manoeuvring modelling and computer simulation programming.

2.2. Propeller C-series

The Wageningen B-series is one of the most popular to be used, which is designed in such a way that the number of blades, the blade area ratio and the pitch-diameter ratio were systematically varied, while the blade contour, the skew distribution, the pitch distribution, the rake angle, the hub-propeller diameter ratio and the section profiles are all kept the same for the whole series.

While designing the Wageningen C- and D-series propellers, an extensive propeller database search has been carried out first. A large number of practical propeller designs, made with up-to-date hydrodynamic knowledge was gathered. The relation of the propeller main dimensions to the typical applications has been found out from studies which make each design of the blades reflects a certain scenario of a typical application. For example, a 4-bladed CPP with high pitch ratios and large blade area is often used for the fast ship or vessel such as fast ferries and cruise ships where the focus is the comfortable rather than the efficiency. 4-bladed CPP with low pitch ratio and small blade area is typically used by transport ships with a large amount of harbour activities, such a shuttle tanker, where the propulsive efficiency is more important rather than the comfort. In the other side, 5 bladed CPP is designed to overcome the applications for the navies.

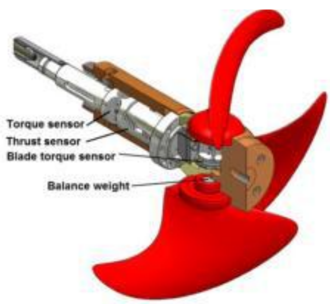


Figure 2. 1 C4-40 Propeller shaft thrust, torque sensors and the blade spindle torque sensor (source: Quasi-Steady Two-Quadrant Open Water Tests for the Wageningen Propeller C- and D-Series)

The statistics from the database also showed that the CPP hub size changes noticeably with the blade area ratio and the blade design pitch ratio for open propellers. This is because these main parameters of a propeller are closely related to the power density on the blade, which determines how strong a hub should be and how large the pitch actuating system should be. However, this tendency is not found for the ducted CPPs. These findings are applied to the present series designs where the C-series has different hub-propeller diameter ratios for each propeller design; while the D-series propellers have the same hub propeller diameter ratio for all designs.

Each propeller in the series was designed individually with the best present design practice with the compromise between efficiency, comfort and mechanical requirements, which comprise the blade strength requirements, minimum blade passing distance when going from positive to negative pitch, fitting the blade root between the bolt holes, blade root over-hang, tip clearance in a duct while the pitch is actuated through the whole stroke, etc.

The design methodology and philosophy discussed above for these C- and D-series propellers can be summarized that these series represent contemporary and practical CPP design.

2.3. Propeller Geometry

Propeller geometry are parts of the propeller itself. Parts of the propeller has its own definition. If it get any damaged, it will decrease the performance of the propeller. We can show from the figure below:

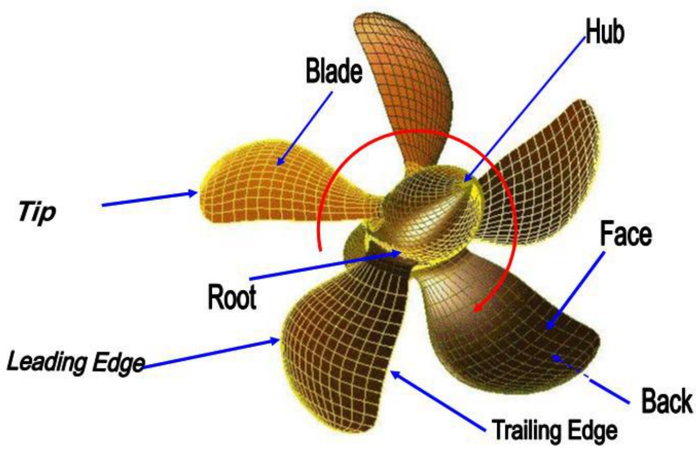


Figure 2. 2 Propeller Geometry
(source: Alexandria university)

The propeller part has defition as below:

1. **Trailing edge** is the edge of the propeller adjacent to the aft end of the hub. When viewing the propeller from astern, this edge is closest. The trailing edge retreats from the flow when providing forward thrust.
2. **Leading edge** is the edge of the propeller blade adjacent to the forward end of the hub. When viewing the propeller from astern, this edge is furthest away. The leading edge leads into the flow when providing forward thrust.
3. **Root** is fillet area. The region of transition from the blade surfaces and edges to the hub periphery. The area where the blade attaches to the hub.
4. **Hub** is solid cylinder located at the center of the propeller. Bored to accommodate the engine shaft. Hub shapes include cylindrical, conical, radius, & barreled.
5. **Tip** is maximum reach of the blade from the center of the hub. Separates the leading and trailing edges.
6. **Face** is pressure Side, Pitch Side. Aft side of the blade (surface facing the stern).
7. **Back** is **s**uction Side. Forward side of the blade (surface facing the bow).

This is really essential to have understanding of basic propeller geometry to appreciate fully propeller hydrodynamic action from either the empirical or theoretical stand point. Propeller need the existence of hyrodynamics issue in other words hydrofoil where in the presence of an elevator and drag, an lift force must be greater than a drag force which basically occurs in a fluid with a certain speed to experience hydrodynamics. Hydrodynamics itself is a difference in speed at the bottom and top. The fluid at the top will experience faster than the speed below the aerofoil. This phenomenon will cause a difference in pressure which will eventually lead to a lift or lift force.

2.3.1. Airfoil

The aerofoil sections which together comprise the blade of a propeller are defined on the surface of cylinders whose axes are concentric with the shaft axis; hence the term cylindrical sections which is frequently encountered in propeller technology [4].

Propeller series C4-40 is using the NACA 66 (MOD) thickness distribution and the NACA a=0.8 meanline for all of the propeller blades for the present propeller series. The thickness distribution is, however, applied perpendicular to the nose-tail line of the section profile. In order to prevent very thin blade trailing edges in model scale, the trailing edges of the propeller model blades are thickened to minimal 0.4 mm, starting gradually from the maximum thickness of the profile to the trailing edges by a parabolic distribution [1].

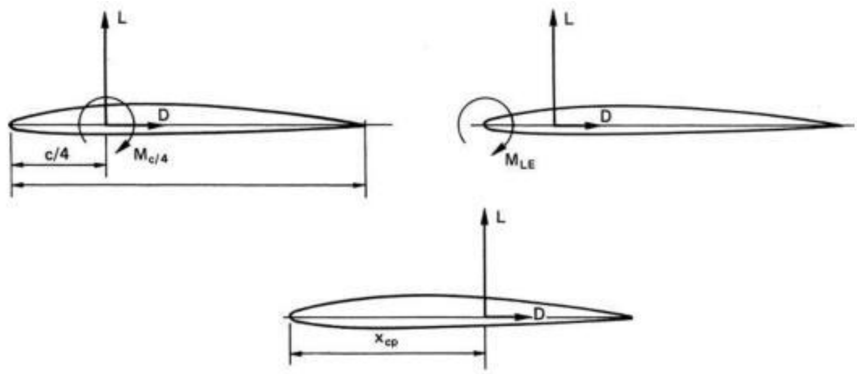


Figure 2. 3 Moment and force definitions for aerofoils
(source: marine propellers and propulsion by John Carlton)

2.3.2. Pitch

Pitch is an axial distance traveled by a propeller at one rotation (360 degrees). In principle, the notion of pitch can be analogized to the same as the gear on a car. A pitch view can be seen in Figure 3. By definition number 1 is pitch length.

The design pitch is defined based on the nose-tail line of the blade section profile. At off-design condition, the pitch setting refers to the pitch of the blade at 0.7R which is based on the nose-tail line of the section profile at that pitch setting (R is the propeller radius at design pitch).

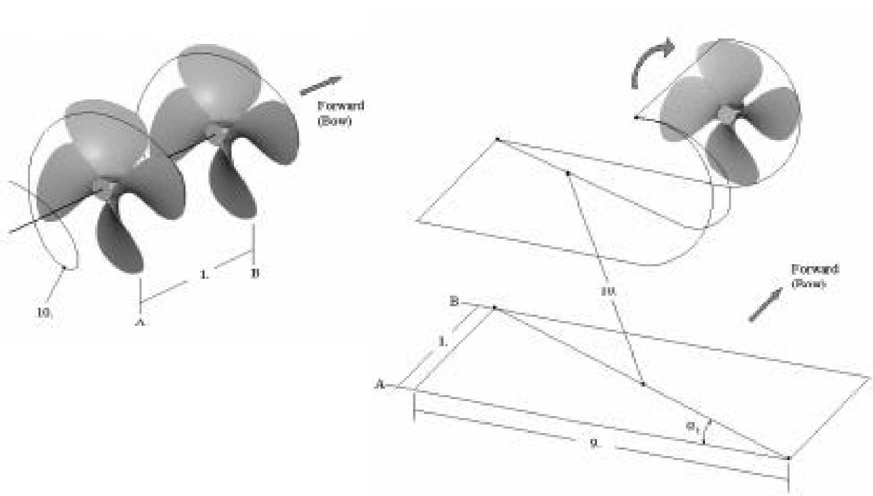


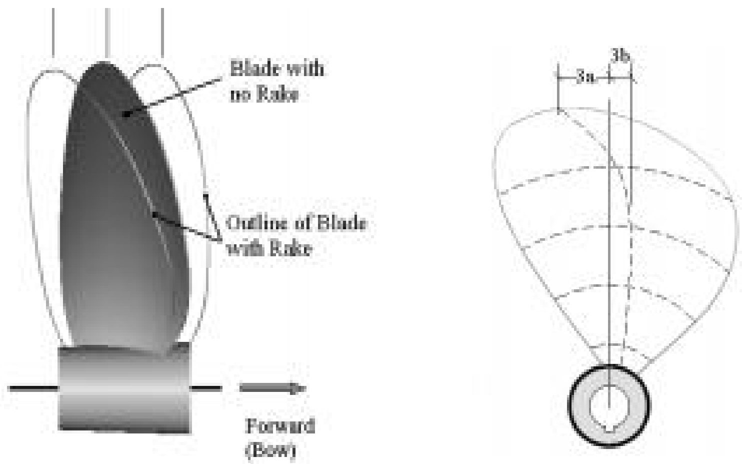
Figure 2. 4 Definition of pitch propeller
(source: propeller geometry terms and definitions)

2.3.3. Rake and Skew

The terms rake and skew, although defining the propeller geometry in different planes, have a cross coupling component due to the helical nature of blade sections. As with the Cartesian reference frame, many practitioners have adopted different definitions of skew.

Rake is the slope of the propeller leaf to the front or back of the Blade. Rake is positive which means the slope of the propeller leaves towards the rear end of the hub. While the negative rake means the slope of the propeller leaf towards the front end of the hub. It can be specified in inches at the propeller leaf tip or in degrees. It is the longitudinal distance of the tip from the vertical plane which has purpose to increase clearance of the tip from the hull, the rake always being aft.

Skew is the shifted distance of the tip in opposite direction to propeller rotation. The propeller skew angle is defined as the greatest angle, measured at the shaft centre line, in the projected plane, which can be drawn between lines passing from the shaft centre line through the mid-chord position of any two sections. Propeller skew also tends to be classified into two types: balanced and biased skew designs.



(a) (b)

Figure 2. 5 Rake propeller (a) and Skew propeller (b)
(source: Propeller Geometry Terms and Definitions)

For C4-40 series propeller geometry data that is using MC440 software which can be downloaded at the Maritime Research Institute Netherlands. which will produce a C4-40 series image

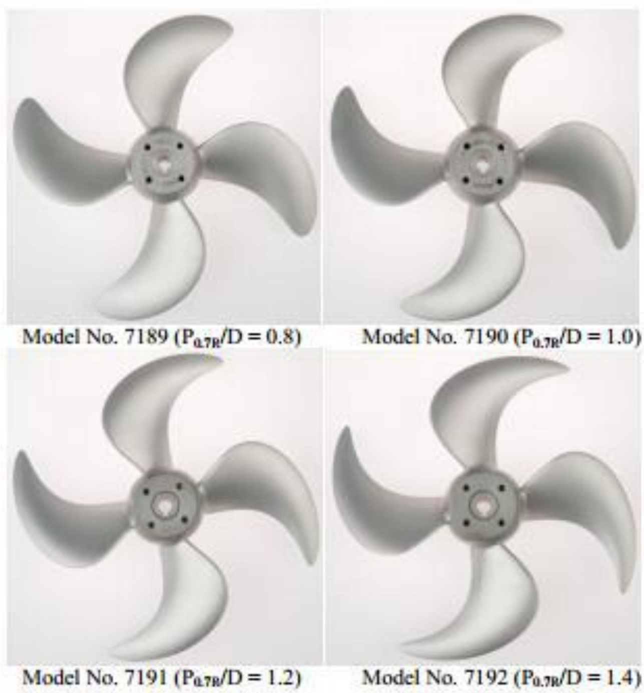
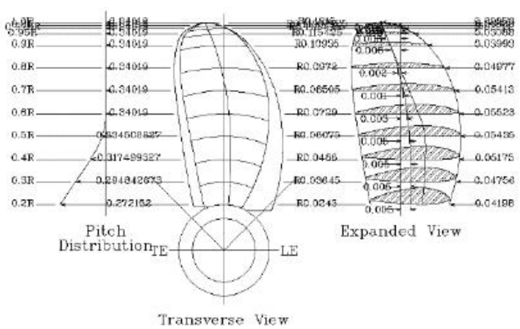


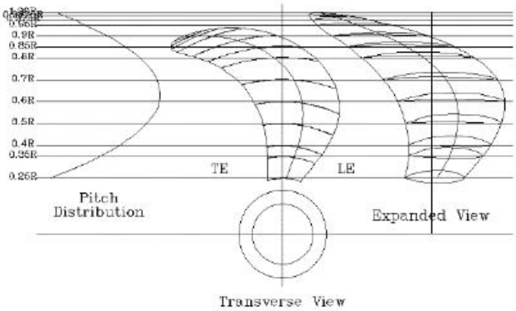
Figure 2. 6 C4-40 Series Propeller Model
(source: the Wageningen C-series and D-series propellers)

From the above understanding, in general, the changes from the B4-40 series propeller to become a C4-40 series propeller can be seen as below.



r/R	C	tmax	P	S	X
[-]	[m]	[m]	[m]	[m]	[-]
0.2	41.98	8.89	272.1	-5	
0.3	47.56	7.87	294.8	-5	
0.4	51.75	6.85	317.4	-5	
0.5	54.35	5.83	334.5	-5	
0.6	55.23	4.81	340.19	-3	
0.7	54.13	3.79	340.19	-1	
0.8	49.77	2.77	340.19	2	
0.9	39.93	1.75	340.19	6	
0.95	30.88	1.24	340.19	8	
0.975	22.32	0.99	340.19	10	
0.9875	16.03	0.86	340.19	10	
1	0.73	0.37	340.19	11	

Figure 2. 7 B4-40 Series Propeller
(source: PropCAD)



r/R	C	tmax	P	S	X
[-]	[mm]	[mm]	[mm]	[mm]	[mm]
0.25172	32.71025	7.28156304	281.8035	-3.17401	1.37849
0.35	40.59644	6.135437624	308.8726	-9.73784	1.266294
0.4	44.68141	5.555222113	319.5688	-12.0849	0.701586
0.5	52.44484	4.455525513	334.7394	-14.5835	-1.01378
0.6	58.81488	3.484324416	341.6144	-13.4864	-2.92648
0.7	62.5272	2.667020816	340.1938	-7.48965	-4.34577
0.8	61.70405	1.992882377	330.4776	5.283677	-4.59232
0.85	58.57026	1.696265758	322.5086	14.95494	-4.06663
0.9	52.47597	1.415042436	312.4657	27.28405	-2.99815
0.95	41.0451	1.137708089	300.3489	42.6669	-1.30517
0.975	30.84942	0.996286651	293.5128	51.637	-0.19916
0.9875	22.68827	0.924065245	289.9003	56.46642	0.423142
1	0	0.8505	286.1582	61.53522	1.093306

Figure 2. 8 C4-40 Series Propeller
(source: AutoCAD)

From the figure 6 and 7 above, we can conclude that:

1. Can be seen from Chord Length on C4-40 with radius r/R = 0.6 until r/R=1.0 will be greater than B4-40.
2. Can be seen from the average thcikness of foil on C4-40 is more less rather than B4-40, but specially on r/R= 0.9875 it is greater.
3. Can be seen from the Pitch length on C4-40 with r/R=0 until r/R=0.6 will be greater than B4-40, but it opposite at the other r/R.
4. Can be seen from the form of the skew on r/R = 0.25 will be less dan r/R = 0.5 will be greater than negative value, beside on r/R = 1.0 will be greater than positive value.
5. Can be seen from the form of the rake on C4-40 will be various with every r/R and on B4-40 only used 15°.

2.4. Factors Affecting Propeller Selection

In terms of choosing the propeller, there are several factors which has big role to support the designer to decide. Factors that affecting propeller selection are:

2.4.1. Propeller Diameter

Diameter of the propeller has a big impact for the propeller performance. It gives influence to the rotation and the torque needed. The big value of propeller diameter will give less rotation of the propeller; therefore, it will need torque bigger. It can be shown on formula below:

$$n\ Design = \frac{Va}{JD} \qquad (1)$$

n = Design rotation of propeller after EPM

Va = Fluid Velocity

J = Advanced coefficient

D = Diameter of propeller

2.4.2. Propeller RPM

The velocity of the propeller will give influence to the diameter of the propeller. The bigger velocity of the propeller will give effect to the diameter which is smaller. But we have to consider about the faster velocity if the propeller can be sometime decreasing the efficiency based on the chart.

2.4.3. Blades Number

The number of blades has influence to the propeller efficiency. Propeller with the big number of blades will decrease the efficiency. But, the propeller with less blades will give more efficiency. In that case, we have also need to consider the risk of force and pressure which blades received will be greater that the propeller which has more blades.

2.4.4. Pitch of Propeller

Propeller Pitch is translation distance issued by the propeller in one round. Propeller with fixed steps (fixed propeller pitch, FPP) has excess torque resulting in high, fuel consumption more economical, minimal noise or vibration, and minimal cavitation, usually designed individual so that it has special characteristics for certain ships it will have efficiency value optimum. Characteristics of propeller load can display with graphs by several coefficients in size. The diagram gives Torque and Thrust as a function of speed. Characteristics propeller consists of Thrust coefficient (K_T), coefficient torque (K_Q), and advanced coefficient (J).

2.5. Propeller Open-Water Test

It is practical to cover the full speed range of interest and to carry out the load variation test at only one speed. In the next sections we shall focus on the relation between the various tests, including the propeller open-water test and resistance test.

2.5.1. Speed Variation Test

It is customary to carry out the speed variation test at a standard loading, e.g. according to Froude’s skin friction coefficients. Adhering to this standard, also if the customer requires another method of extrapolation, is good practice. This standard Froude loading implies that for smaller ships the propeller loading corresponds roughly to the loading of the full-scale propeller. For large ships the model propeller is somewhat overloaded, but this is considered favourable for the propeller-hull interaction, the Reynold's number of the model propeller and the dynamometer loading. We should not forget that in model tests for large ships the model propeller is comparatively small and that this class of propellers is rotating slowly.

The results of the speed variation test are made non-dimensional in several ways. First, the propeller thrust and torque are expressed as K_T and K_Q. The speed and rotation rates are combined to give the apparent advance coefficient. When plotted on a basis of the apparent advance coefficient it appears that for merchant ships the K_T and K_Q values are found in a cluster.

The variation is usually quite small the variation in the apparent advance coefficient depends on the range of Froude numbers covered. It appears that the speed wise variation of the apparent advance coefficient corresponds to the variation in C_{TM}. The smallest value of J is attained when the ship model passes the main hump at a Froude number of 0.5. From this plotting anomalous data points can be traced.

2.5.2. Load Variation Tests

The load variation test is carried out for a speed which corresponds roughly to the service speed of the ship. By definition the model speeds in the load variation test are equal. Minor deviations of this speed occur but for the analysis they are not very important. If these departures are large is worthwhile to correct the measured towing force by the resistance difference as determined from the resistance test and to analyse the test points as if they were taken at exactly the average speed of all the points in the load variation test. Thrusts and torques need not to be corrected for minor speed differences.

The results of the load variation test are made non-dimensional in the same manner as the results of the speed variation test. In addition, the towing force F is plotted and analysed in relation to the total propeller thrust. It is quite practical to plot T on an F basis and to inspect whether or not the results of the load variation test fall on a straight line.

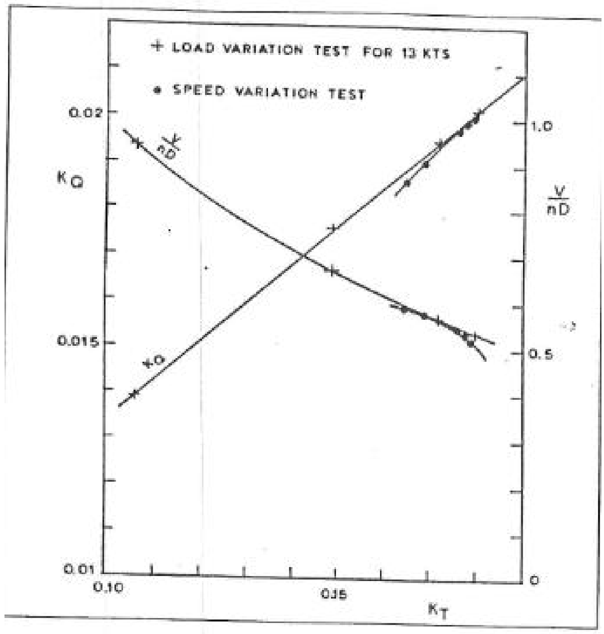


Figure 2. 9 Non-dimensional Propulsion Test

In these diagrams the results of the speed variation tests are indicated as well. About the linear relationship between *F* and *T* is noted that for loading with a towing force in forward direction the linearity is nearly always preserved. This applies to all kinds of hull forms and propulsors. Only for the fullest forms with relatively small propellers there could be a tendency of a departure in the range of zero towing force. A typical constellation of measuring points, including data at extremely overloaded.

2.5.3. Propeller Performance

Propeller coefficients *J*, K_T and K_Q Propeller theory is based on models but, to facilitate the general use of this theory, certain dimensionless propeller coefficients have been introduced in relation to the diameter d, the rate of revolution n, and the water's mass density r. The three most important of these coefficients are mentioned below.

The advance number of the propeller *J* is, as earlier mentioned, a dimensionless expression of the propeller's speed of advance *Va*.

$$J = \frac{VA}{n\, x\, d} \qquad (2)$$

The thrust force *T*, is expressed dimensionless, with the help of the thrust coefficient K_T, as

$$KT = \frac{T}{\rho \; x \; n^2 \; x \; d^4} \qquad (3)$$

And propeller torque,

$$Q = \frac{Pd}{2\pi \; x \; n} \qquad (4)$$

is expressed dimensionless with the help of the torque coefficient K_Q, as

$$KQ = \frac{Q}{\rho \; x \; n^2 \; x \; d^5} \qquad (5)$$

The propeller efficiency n_o can be calculated with the help of the above-mentioned coefficients, because, as previously mentioned, the propeller efficiency η_o is defined as:

$$\eta o = \frac{\mathrm{PT}}{PD} = \frac{T \; x \; VA}{Q \; x \; 2\pi \; x \; n} = \frac{KT}{KQ} \; x \; \frac{J}{2\pi} \qquad (6)$$

With the help of special and very complicated propeller diagrams, which contain, i.e. *J*, K_T and K_Q curves, it is possible to find/calculate the propeller's dimensions, efficiency, thrust, power, etc.

2.6. Propeller Characteristic at Extreme Loads

Four quadrant operation involves propeller function in extreme loadings. During a crash stopping manoeuvre (stopping from headway movement), the propeller is operated in reverse rotation called as crashback to stop the ship from moving headway as quickly as possible. Ueda et al. (1981) found that in such dynamic conditions, propeller properties fluctuate considerably larger than in normal ahead operation most probably due to unstableness of flow field in the vicinity of the propeller. Figure 2.10. depicts various flow fields around the ducted and open propellers in Ueda's et al. (1981) observations. Four operating conditions representing ahead, early crashback and crashback operation at extreme loadings are set to effectively depict the crash stopping manoeuvres as follows. J = 0.41 and J = -1.1 respectively represent ahead and early phase of crashback operations. J = -0.3 and J = -0.1 both represent propeller operation at extreme loadings near the bollard pull condition at J = 0.

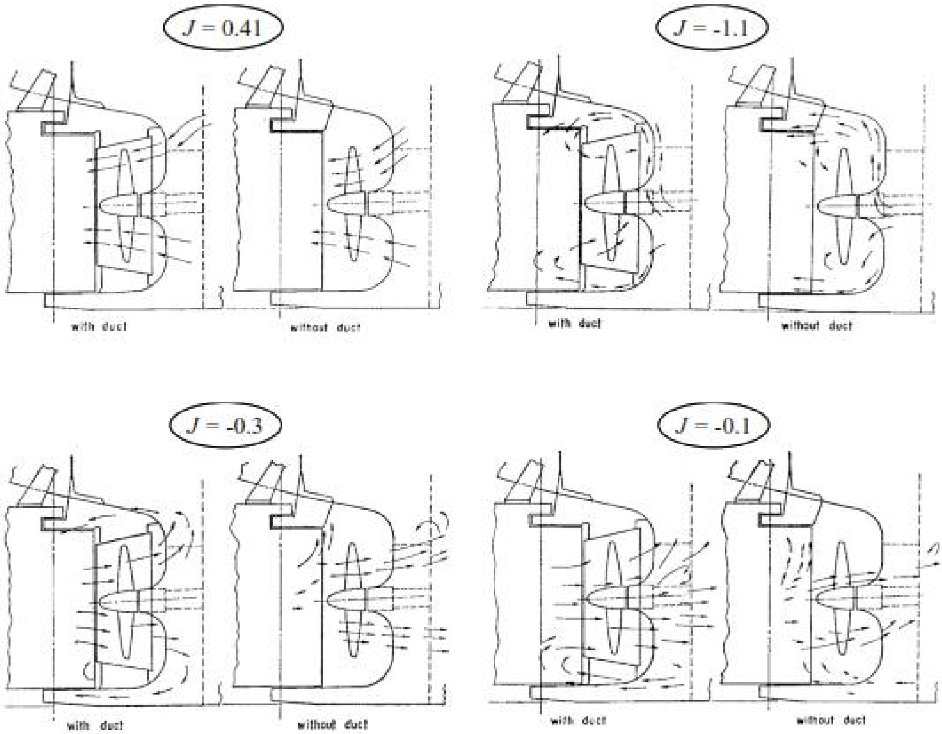


Figure 2. 10 Flow Field at Various Manoeuvrings Conditions

As observed from the figure, ahead operation at J = 0.41 creates a streamline flow field. Early phase of crashback operation at J = -1.1 forms an irregular flow field. At two low J values of -0.3 and -0.1 representing extremely high propeller loadings, the propeller induced velocity changed the flow field to be dominated by reverse propeller inflow. The change of behaviour in the propeller inflow is more pronounced for ducted propeller as compared to open propeller due to separation of the flow field (Ueda et al., 1981).

Black and Swithenbank (2009) analyse propeller forces during crashback operation. At interval J ∈ [-0.5,0) in crashback operation, propeller behaves similarly to a steady backing operation (henceforth is referred to as 'similar to backing' operation). In such range of operation representing extreme propeller loadings, the induced propeller inflow velocities are considerably strong to fully reverse the flow field in the vicinity of the propeller. The phenomenon conforms the propeller flow field observation by Ueda et al. (1981).

Figure 2.11 depicts the open water properties at ‘similar to backing’ operation obtained from towing tank and water tunnel measurements by Black and Swithenbank (2009). It also shows the prediction results using PIV (particle image velocimetry) with some limitations and reasonable agreement to the towing tank and water tunnel measurement results from the work.

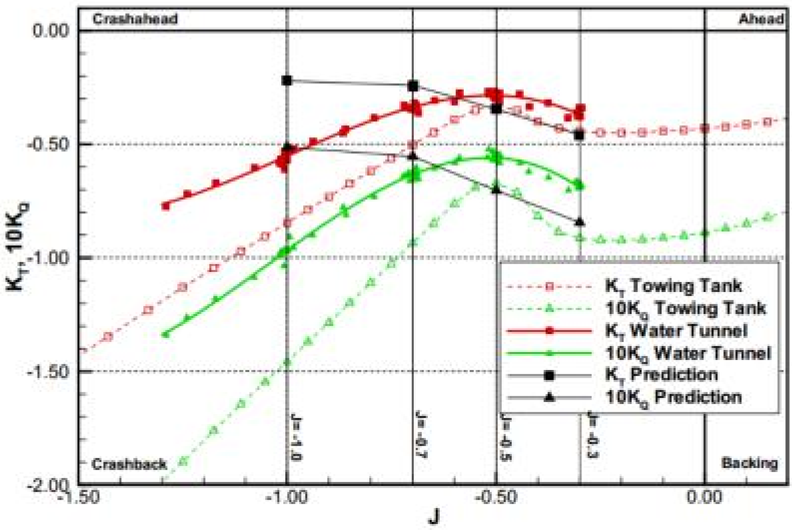


Figure 2. 11 K_T and K_Q at “similar to backing” region

Harvald (1977) who establishes propeller properties at normal to extreme loadings in open water and behind conditions for both deep and shallow water also states the peculiarities. In normal loadings represented by higher J values, small differences appear for both K_T and K_Q values and different water depths. For propeller efficiency η_0 defined by $\eta_0 = J/2\pi \times K_T/K_Q$, normal propeller loadings result in higher propeller efficiency for shallow water operation as shown in Figure 2.12. An obvious difference occurs for both K_T and K_Q values at extreme propeller loadings for the observed water depths at lower J values. At extreme loadings, a change of water depth from deep to shallow water by a ratio of $h/D = 2.5$ for similar K_T or K_Q values results in an average change of J by around 7%. Propeller efficiency for both deep and shallow water depths in such conditions are similar.

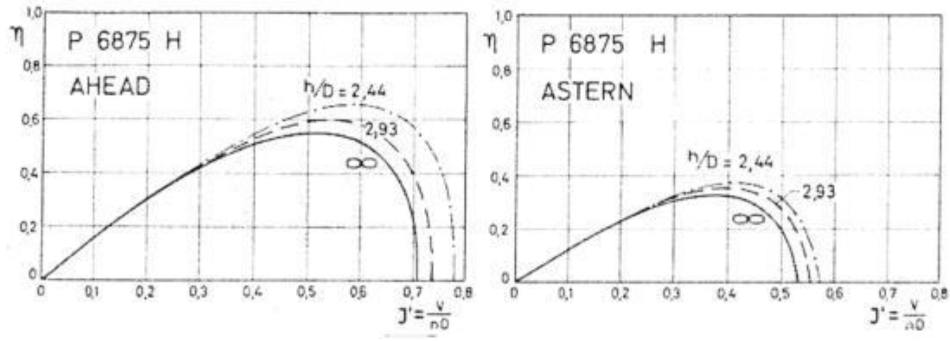


Figure 2. 12 Propeller Efficiency in Various Operating Conditions

In relation to experimental overload tests, MARIN (1996) provides typical patterns of measurement results as illustrated in Figure 2.20. The linearity of the T-F lines indicating the propeller thrust T and towing force F relationship in forward direction is almost found in load variation tests. A change of T-F slope appears at negative towing forces indicating extremely high propeller loadings referred to as overload conditions. At such operating condition, the slopes of the T-F lines conform to the bollard pull result obtained at zero ship speed. The knowledge is critical for accurate identification of wake and thrust deduction fractions in various manoeuvring conditions which is executable only by extensive overload tank tests (Voorde, 1974).

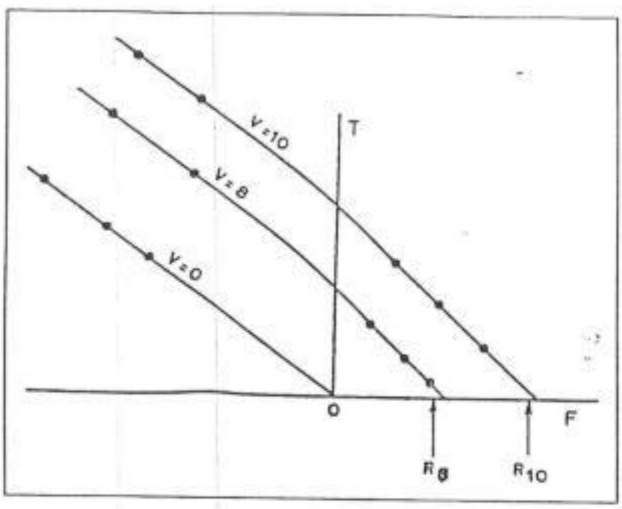


Figure 2. 13 T-F diagram to extremely high propeller loadings

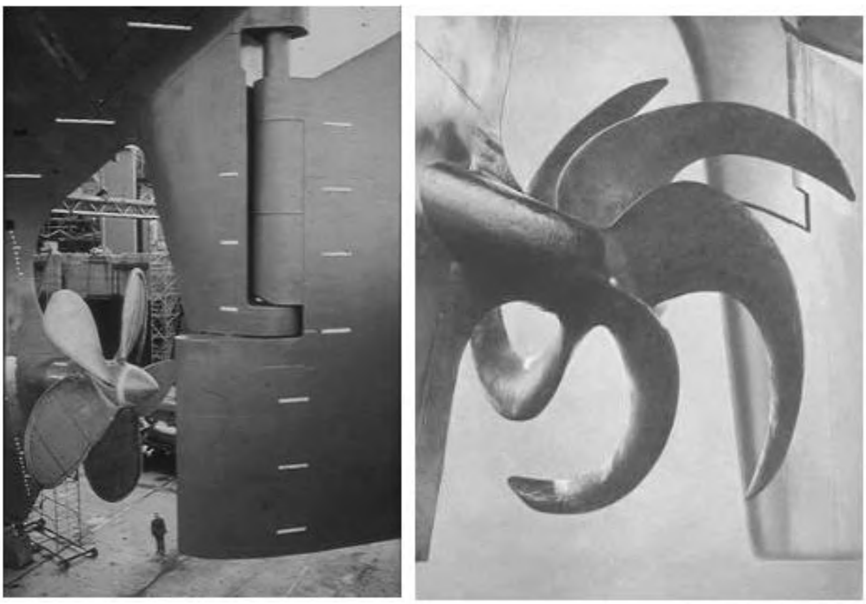
2.7. Propeller Types

Propeller has variation types that classified based on such as its physical form and the system which working on. These are the propeller classification based on types as below.

2.7.1 Fixed Pitched Propeller (FPP)

Mono-block or built-up propeller is the basis form of fixed pitch propeller. It has blades which are cast separately from the boss and the bolted. Because of that, it is being the disadvantage due to the inability to get great quality large castings and partly to the difficulties in defining the correct blade pitch. The advantages, it has generally larger boss radius than its fixed pitch counterpart.

The FPP normally cast in one block and made of a copper alloy. The propeller pitch and the position of blade is fixed which are given the pitch that cannot be changed. It usually used for the ship which does not need the high manoeuvrability.



(a) (b)

Figure 2. 14 (a) large four-bladed propeller for a bulk carrier, and (b) biased high-screw, low-blade-area ratio propeller (source: marine propellers and propulsion by John Carlton)

2.7.2 Controllable Pitched Propeller (CPP)

It provides an extra degree certainly with its ability to change the blade pitch. The controllable pitch propeller has found application in the most of the propeller types with the possible exception of the contra-rotating and tandem propellers.

Last forty years ago, CPP has grown with popularity which is representing a small proportion of the propeller produced to the current position in getting a very substantial market share.

The CPP relatively has larger hub compared with FPP due to give a space for hydraulically activated mechanism for control the pitch. It also more expensive up to 3-4 times rather than FPP. Because of the larger hub, the efficiency considers to be lower. The CPP usually used in Ro-Ro ship, shuttle tankers, and similar ships which are needed high degree of manoeuvrability.

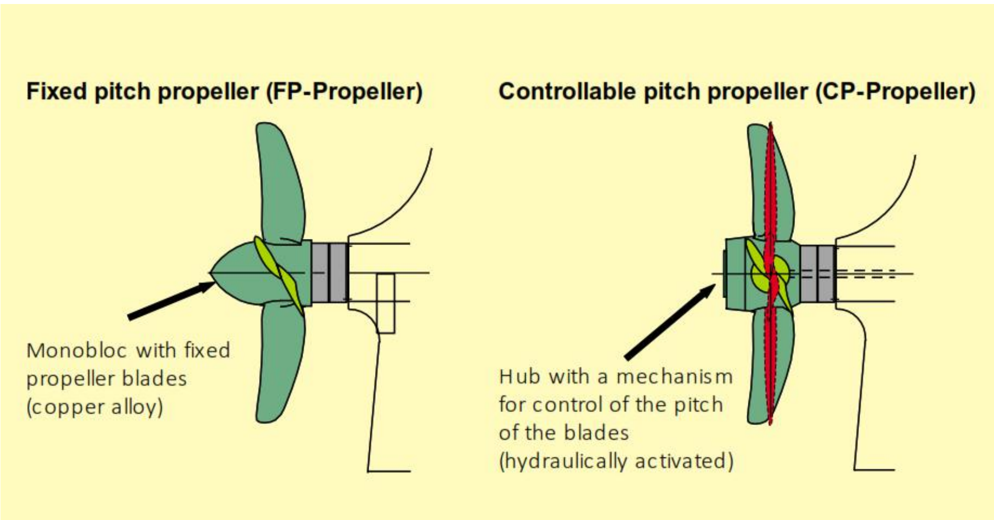


Figure 2. 15 (a) Fixed Pitch Propeller, and (b) Controllable Pitch Propeller (source: basic of ship propeller paper)

2.7.3 Ducted Propeller

Ducted propeller has two principles component, first is annual duct using aerofoil type cross-section which maybe either of uniform shape around duct. And the second component is the propeller which has design of the blades to be modified to take account of the flow interaction caused by the presence of the duct in its flow field.

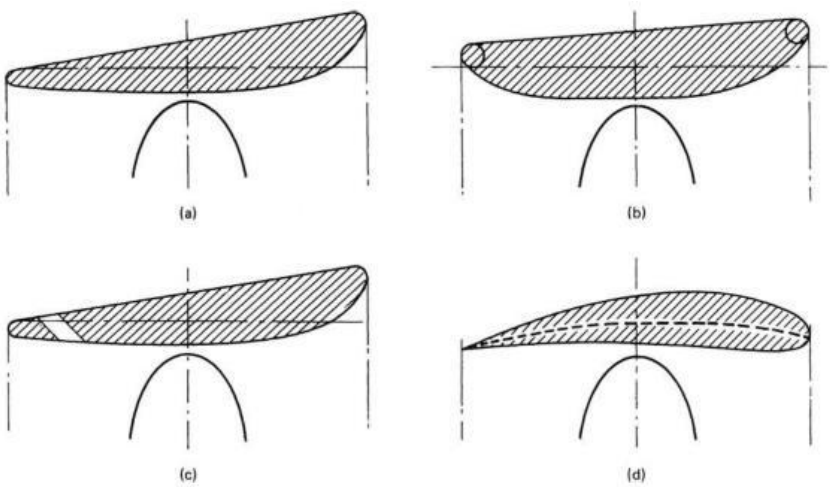


Figure 2. 16 (a) accelerating duct; (b) pull-push duct; (c) hannan slotted duct, and (d) decelerating duct (source: marine propeller and propulsion by John Carlton)

2.8. Computational Fluid Dynamic (CFD)

Computational Fluid Dynamic (CFD) is a numerical analysis method used to solve fluid dynamics problems. Since major advances in computer performance, the Computational Fluid Dynamic (CFD) method has been used to solve the Reynolds Averaged Navier-Stokes (RANS) equation that has been applied to various types of Subhas (2012) propellers.

The history of CFD dates back to the 60s and became famous in the 70s, initially the use of the CFD concept was only used for fluid flow and chemical reactions, but along with the development of the industry in the 90s CFD was increasingly needed in various other applications. For example, now there are many CAD software packages that include the concept of CFD that is used to analyse the stress that occurs in the design made. CFD usage is generally used to predict:

1. Flow and heat.
2. Mass transfer.
3. Phase changes as in the process of melting, condensation and boiling.
4. Chemical reactions such as combustion.
5. Mechanical movements such as the piston and fan.
6. Voltage and support on solid objects.
7. Electromagnet waves

2.8.1 Pre-Processor

Pre-Processor is the initial stage in Computational Fluid Dynamic (CFD) which is the stage of data input which includes determining the domain and boundary condition.

At this stage meshing is also carried out, where the objects analyzed are divided into a number of specific grids.

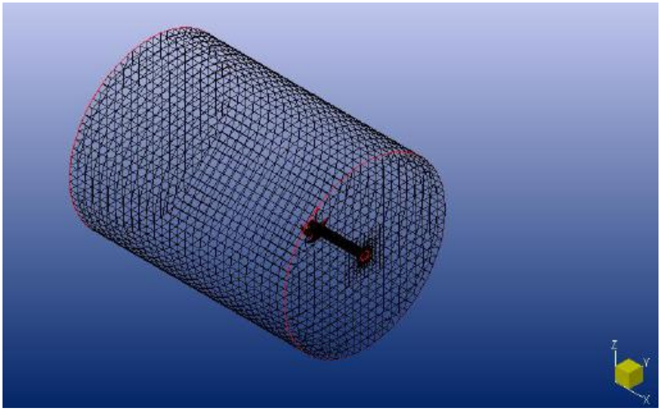


Figure 2. 17 Determination of Boundary Condition and Meshing
(source: Numeca FINEMarine)

2.8.2 Processor

The next stage is the processor stage, where at this stage the process of calculating the data that has been entered using an associated equation iteratively is carried out until the results obtained can reach the smallest error value.

2.8.3 Post Processor

The last stage is the post processor stage, the results of the calculation at the processor stage will be displayed in images, graphics and animation.

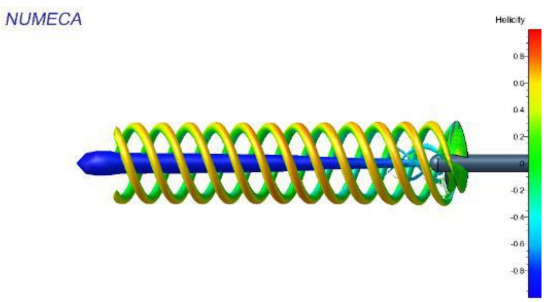


Figure 2. 18 Result of helicity in CFD
(source: Numeca FINEMarine)

The benefits of the Computational Fluid Dynamic (CFD) method compared to other methods to solve Fluid Dynamic modeling problems are as follows:

1. **Deep Knowledge**

With CFD analysis we will easily know and see the data needed to make products that are efficient, influential parameters and physical phenomena that occur can even be said to be far more profound than the prototype.

2. **Full Prediction**

With CFD simulation we can change the existing parameters to see the results, change them again until the desired condition is obtained before the physical prototype is made. So, at the same time we can do a test of the CFD model that we made, see the results, and change the existing variables to get optimal results and in a short time.

3. **Efficiency**

CFD is a tool to shorten the design and development cycle of a product. So that we get a short design cycle, low cost and short time that will be associated with efficiency that will also increase.

“this page is intentionally left blank”

CHAPTER III
METHODOLOGY

3.1. Introduction

The required elements of the research methodology have been summarised in the theoretical framework. Past researches in the related field have been reviewed and the findings have been taken into consideration. The proposed approach and analytical process presented in this chapter have been devoted to detail out the method employed and activities performed to achieve the research objectives.

3.2. Research Methodology Flowchart

Research Methodology Flowchart helps to guide the author finishing the research to achieve the objectives as explained in the first chapter. The flowchart can be seen as below.

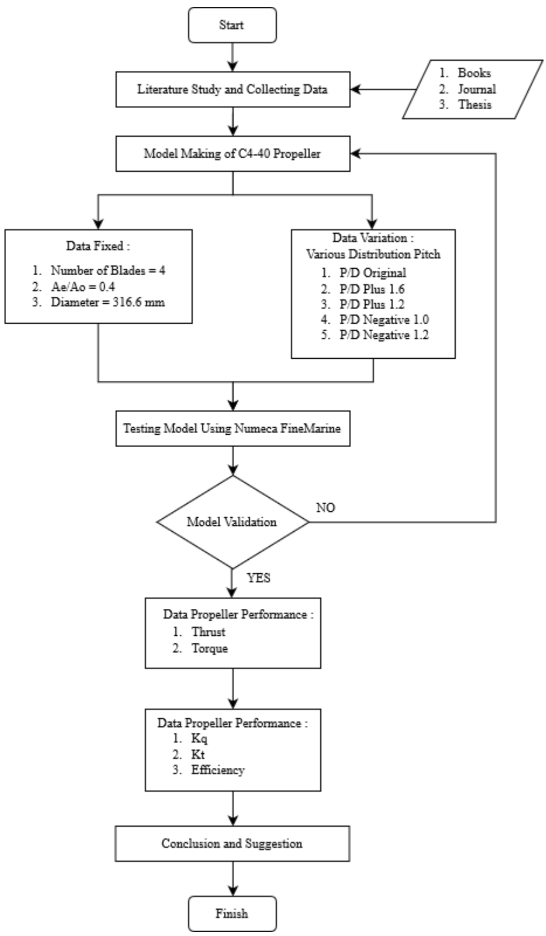


Figure 3. 1 Flow Chart Methodology

3.3. Statement of Problems

The stage of where the start to look and identify the problems which are considered to be ideas of the thesis and never been taken by another person. After getting the ideas of thesis, it will be formulated which needs to be discussed whatever is related to the title of the thesis.

3.4. Study of Literature

This is the stage of finding references to be used as reference in the work of the thesis, the reference must be related to the theme and work of the thesis worked on. The literature used includes:

1. Books
2. Journals
3. Thesis

3.5. Model Making of C4-40 Propeller

At this stage the first geometry that is already in the reference is used as a reference for drawing. at first the propeller geometry is in the form of dots then connected between points so that it is shaped foil by pressing the create / modify curve tool then pressing from points after giving the surface by pressing tool create surface then simple surface then making a propeller wall that serves to limit the flow of regarding propeller, then giving the body by pressing create body at specified point, then next meshing by pressing and filling the global mesh setup, part mesh setup, surface mesh setup, and compute mesh in sequence, then after the meshing is complete the next step is running. in the running analysis type in the form of body, back, face, hub, inlet, outlet, and wall are things that must be fulfilled by filling in some parts, for example angular velocity. Then determine the control solver by filling in the max iterations then clicking apply then clicking ok.

To make the propeller become solid / surface 3D your model can use rhinoceros 3d software and which converter surface to solid software is here for me using SolidWorks. There are 3 steps in making 3D model, namely making framework, making surface and convert to solid. For making frames you can go to software rhinoceros then select the curve tab, select free form then select interpolate points. Copy and paste all coordinates on part of the face so that it forms

3.5.1. General Geometry

Propeller type C4-40 P/D has been made based on reference by MARIN it self. The geometry has been served in their application, we only input several data to it, and the output come up with complete geometry.

Table 3. 1 C4-40 P/D 1.4 Propeller Geometry

MARIN

C4-Series Propeller Geometry
(Main parameters)
Version 1.1 / 13-06-2012

Project: C- and D-series JIP
Client: Participants
Date: 15 May 2019

A_E/A_0	$P_{0.7R}/D_{prop}$	D_{prop}	D_{hub}/D_{prop}	D_{hub}	Z
[-]	[-]	[mm]	[-]	[mm]	[-]
0.4000	0.8000	316.60	0.2527	80.00	4

	r/R	r	c	P	s	x	f_{max}	t_{max}
	[-]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
Blade root	0.2527	40.00	40.87	214.00	-2.22	1.97	1.86	9.76
	0.3500	55.41	51.08	231.23	-5.46	1.87	2.51	8.24
	0.4000	63.32	56.46	238.20	-6.74	1.16	2.74	7.46
	0.5000	79.15	66.75	248.35	-7.27	-1.07	2.99	5.96
	0.6000	94.98	75.30	253.42	-3.74	-3.62	2.95	4.66
	0.7000	110.81	80.45	253.42	5.02	-5.56	2.64	3.57
	0.8000	126.64	79.72	248.33	19.70	-5.98	2.04	2.69
	0.8500	134.56	75.82	243.88	29.32	-5.33	1.64	2.30
	0.9000	142.47	68.06	238.17	40.45	-3.96	1.16	1.92
	0.9500	150.39	53.34	231.18	53.02	-1.74	0.62	1.53
	0.9750	154.34	40.14	227.21	59.82	-0.28	0.32	1.32
	0.9875	156.32	29.54	225.11	63.35	0.54	0.16	1.22
Blade tip	1.0000	158.30	0.00	222.93	66.95	1.43	0.00	1.11
Additional r/R	0.3	47.49	45.75	222.98	-3.82	2.17	2.21	9.03

limitations: $0.40 \leq A_E/A_0 \leq 0.70$
$0.80 \leq P_{0.7R}/D \leq 1.40$

Note: without tip form, anti-singing edge, blade root fillets

3.5.2. Blade of Propeller

From the geometry, we can convert it to the 3D making software called Rhinoceros. In that application the author made the blade precisely to the geometry. After making the blade, the author also put the additional part below the blade for connecting it to the hub. It is similar to the model that has been manufactured because it being made based on this model.

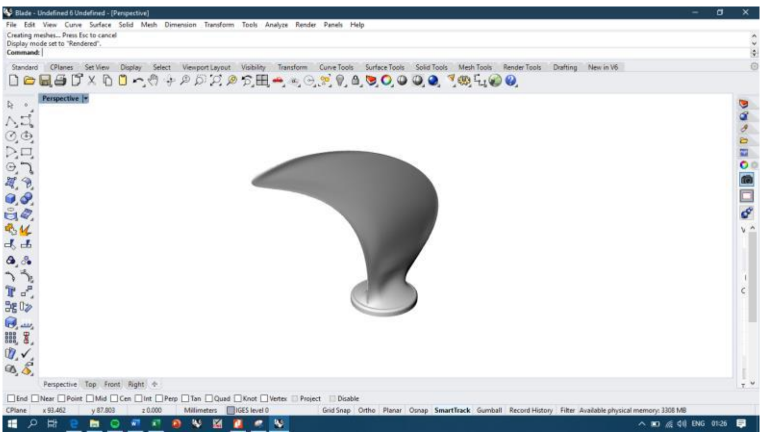


Figure 3. 2 Model of Blade C4-40 P/D 1.4

3.5.3. Hub and Shaft of the propeller

The hub of the propeller is being made as similar as the manufactured model. It is has the space of circle due to suppor the CPP operating system. The shaft of the propeller is made to be two meter for the simulation purpose. It is made as long as possible so when the simulation is going to do the meshin, the shaft will be cut as long as needed. After that, the result of the simulation could be precisely correct.

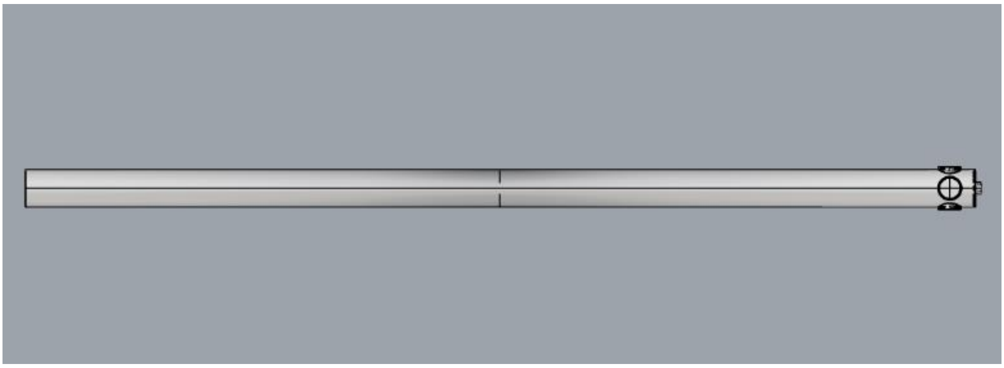


Figure 3. 3 Shaft of the propeller

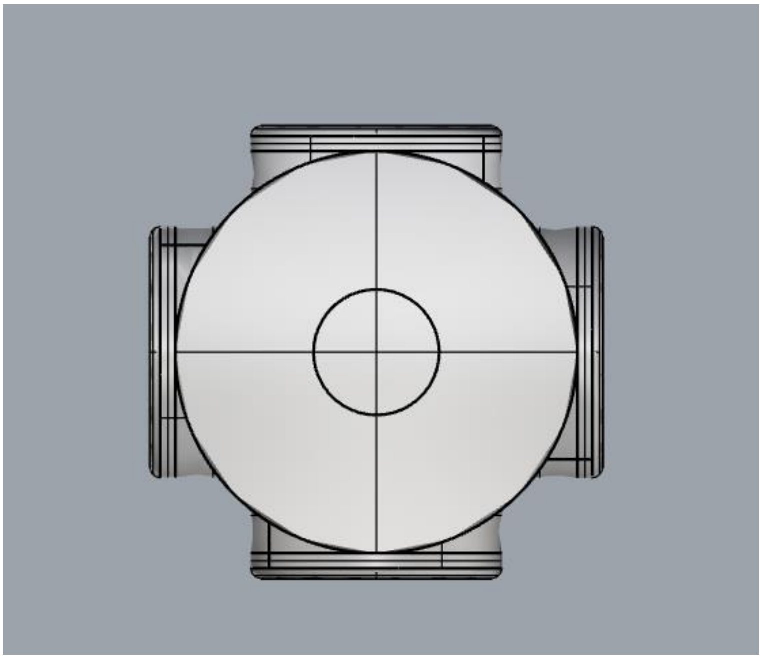


Figure 3. 4 Hub of the propeller

3.6. CFD Simulation

After drawing the model, the model in simulation uses the same software as well. Analysis begins by defining each part. After that the settings regarding input such as flow speed, rotation and pressure are given. After that the model is ready to run.

The simulation will be done by giving the velocity of the propeller by 900 RPM. The rotation speed of the propeller will be same for every part of the simulation. The model will be done by parameter of various distribution pitch and various velocity advance (*Va*).

3.6.1. Starting C-Wizard

C-Wizard give the automatic adjustment for the domain dimension by giving the input parameter such as propeller speed, velocity advanced, and direction preferences.

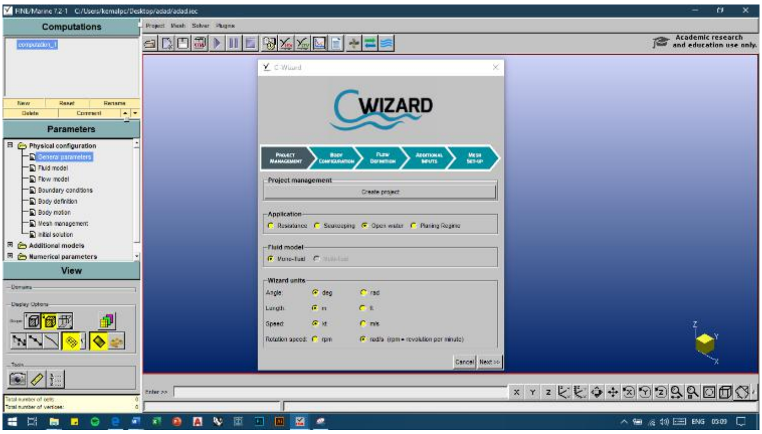


Figure 3. 5 interface of C-Wizard

These are several steps of C-Wizard:

1. Project Management

In this step, we have to decide the application that we would like to do. There are many options such as resistance, seakeeping, and planning regime. Because the simulation to be done is about open water test, we choose this option. Then we have to choose the fluid model and the units.

2. Body Configuration

This step will input the Parasolid model, then choose orientation we want such as the fluid (inlet to the propeller) and the sense of rotation of the propeller. We also have to determine the centre of propeller; it depends how we make the propeller at first.

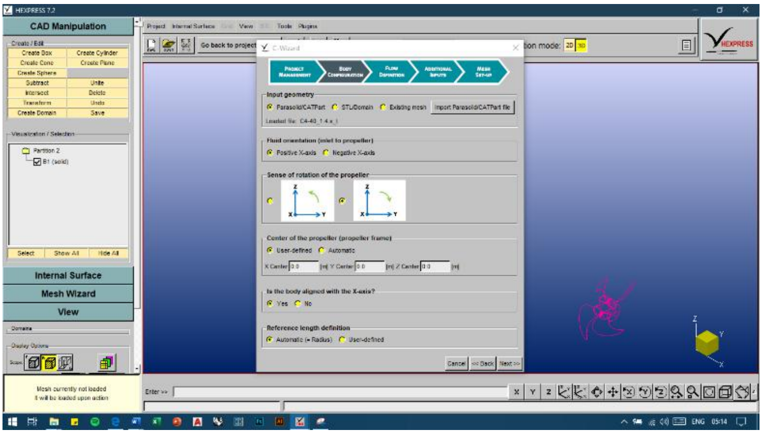


Figure 3. 6 C-Wizard Body Configuration

3. Flow Definition

It is about to determine the rotation speed, and the flow velocity of the fluid. The density of the water will be chosen to in this step as the parameter for the domain that will be meshing in the next process.

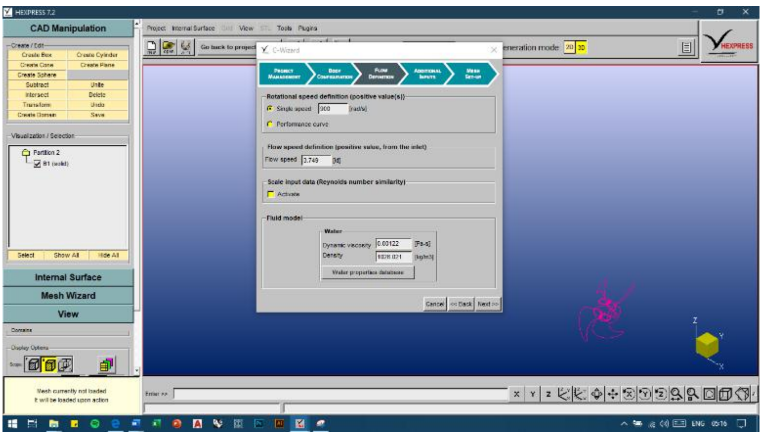


Figure 3. 7 C-Wizard Flow Definition

4. Additional Input

There is no need to prescribe additional inputs for open water simulation. Nothing to be done in this step.

5. Mesh Set-up

This step will be much more important for the automatic meshing in the next process. We can determine the density of the mesh. We can add extra refinement for the wake field and some other functions.

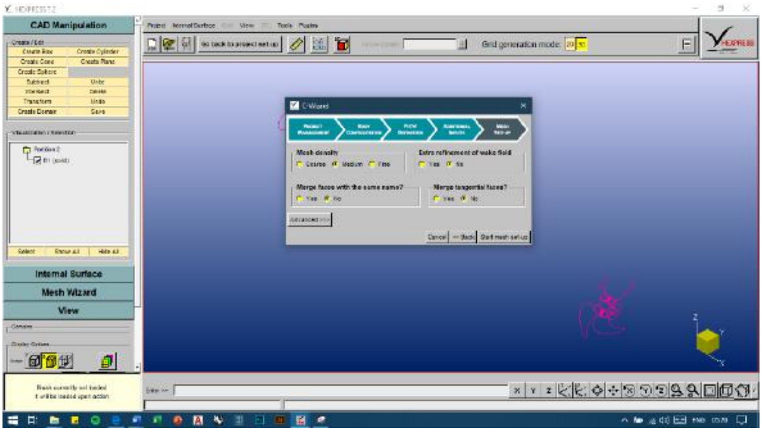


Figure 3. 8 C-Wizard Mesh Set-up

3.6.2. Meshing Process

Meshing is a process of dividing the geometry of the model into smaller elements and nodes. In the process of testing the model with CFD software, each of these elements will be given a calculation by CFD software. The size of the meshing on the propeller is smaller / more detailed than the other domains, so that better results are obtained. In NUMECA Hexpress, there is a domain that has a boundary standard so that the analysis results can be in accordance with the actual environmental conditions.

1. Initial Mesh

In Initial Mesh, geometry is divided into all domains. The domain is divided into box-shaped cells according to the defined domain.

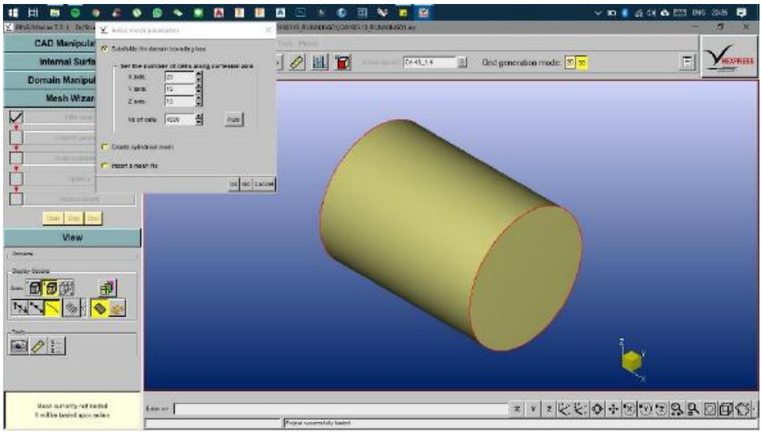


Figure 3. 9 Initial Mesh

2. Adapt to Geometry

In Adapt to Geometry, a Refinement of cells that have been divided is carried out according to geometry. In addition to smoothing, trimming is also done which is to remove cells that cross each other or that are located outside of geometry.

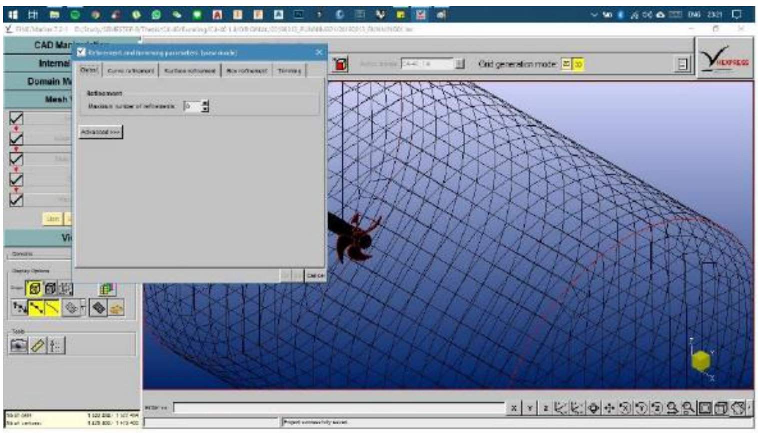


Figure 3. 10 Adapt to Geometry 1

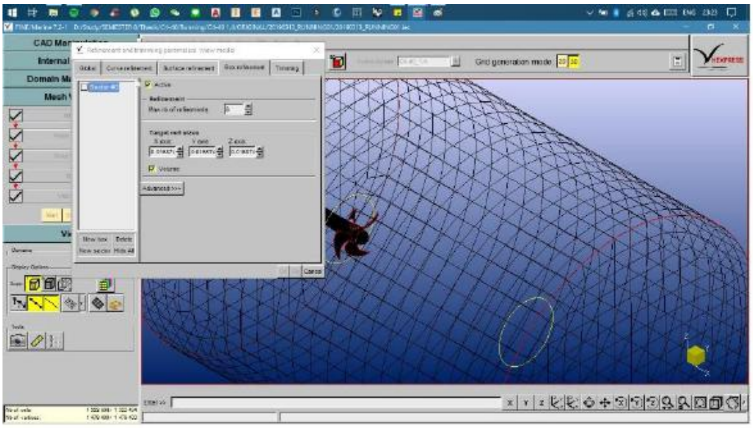


Figure 3. 11 Adapt to geometry 2

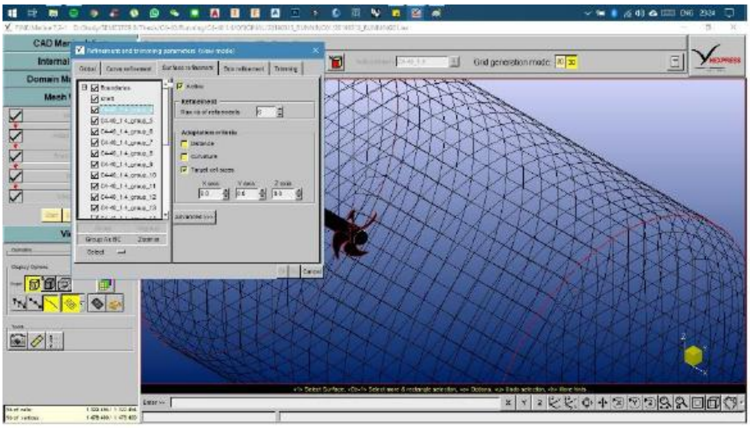


Figure 3. 12 Adapt to geometry 3

3. Snap to Geometry

The purpose of this automatic step is to project a mesh obtained from previous results on geometric shapes so as to produce a smooth geometric shape.

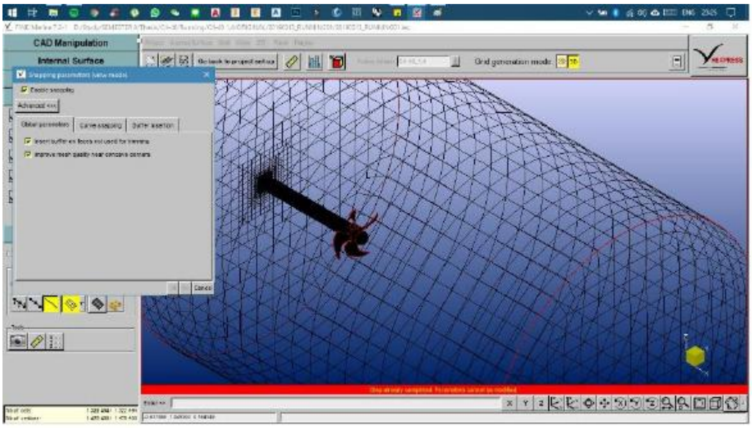


Figure 3. 13 Snap to Geometry

4. Optimize

In Optimize, optimization of mesh results that have poor quality such as concave cells, negative cells, twisted cells is optimized. To find out the quality of cells, it can be seen with a mesh quality menu.

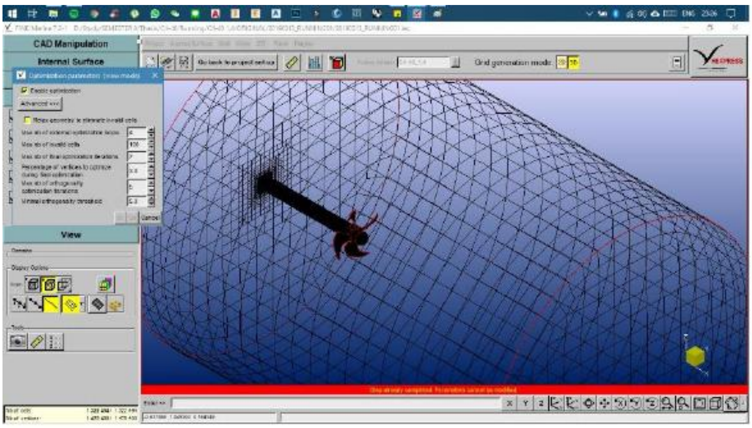


Figure 3. 14 Optimize

5. Viscous Layers

In Viscous Layers, a specific approach is applied in the insertion of the viscous layer based on velocity so that Reynolds numbers and Froude numbers are generated which are influenced by the speed and size of the propeller.

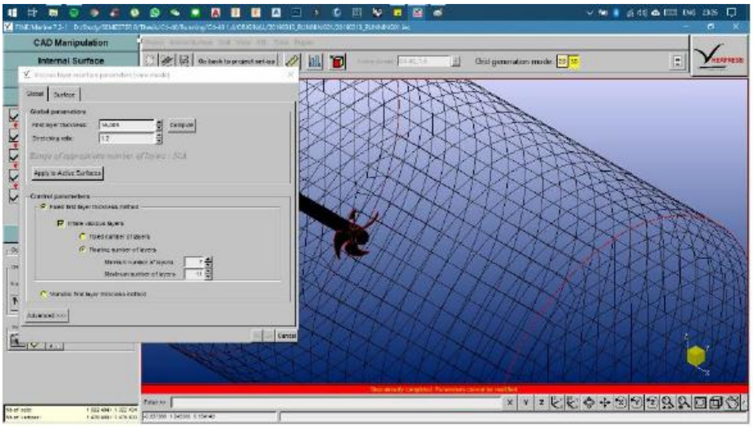


Figure 3. 15 Viscous Layers

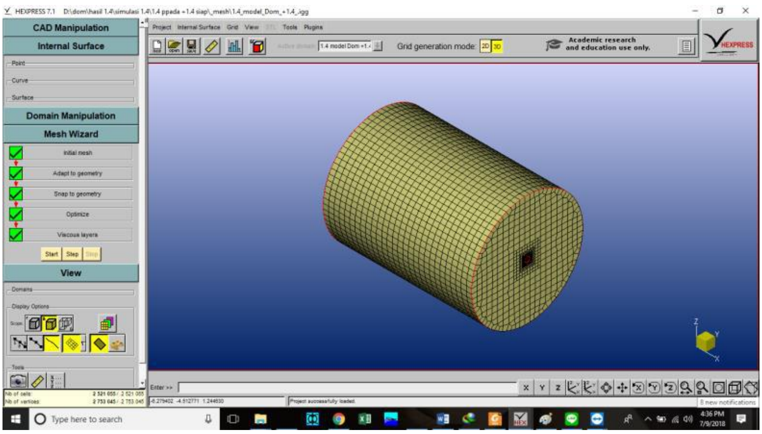


Figure 3. 16 Meshing Result

3.6.3. Validation of Meshing

Validation is the process of establishing documentary evidence demonstrating that a procedure, process, or activity carried out in testing and then production maintains the desired level of compliance at all stages. Meshing will be validated between 0.5 – 2 Million Cells and compare with the thrust result after the simulation. The number of cells in meshing really affect the time needed for the running process in the software. In this case, we choose the number of cells in the middle, 1 million cells.

Table 3. 2 Meshing Validation C4-40 P/D 1.4

Validation of Meshing on Thrust Model C4-40 P/D 1.4		
Million Cells	J	T (N)
0.557	0.8	857.243
1.247	0.8	885.837
2.36	0.8	883.298

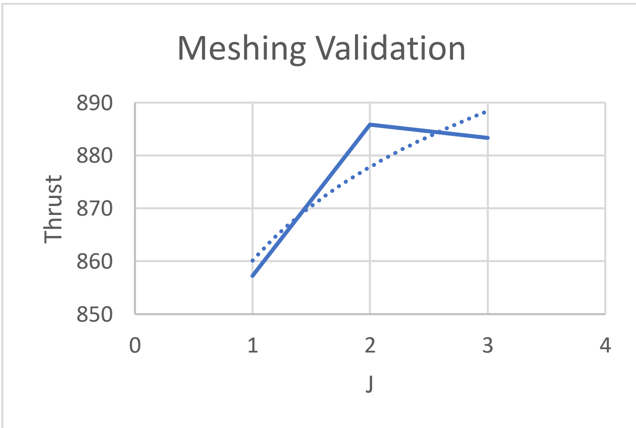


Figure 3. 17 Meshing Validation Graph

In this case, from figure 3.15 has shown the difference between the thrust which were produced between 1.247 and 2.36 million cells only has 2 newton difference. Therefore, the author chooses the meshing around 1 million cells due to the time was taken quicker and eager the process.

3.6.4. Running Simulation

The geometry of the model that has been completed is given a simulation process or running using the Computational Fluid Dynamic (CFD) method. This simulation process uses CFX-solver software, to see the results. With the parameters specified as follows:

1. General Parameter

In this general parameter regarding configuration time on the simulation results when the time step is specified. there are 2 choices namely Steady and Unsteady. Steady is used if you want to get running results at the last time step and Unsteady is used if you want to get the simulation results at a certain time step. In this study using unsteady.

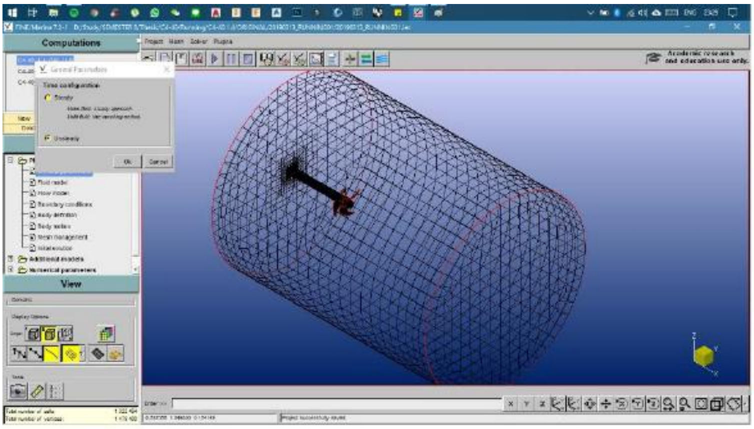


Figure 3. 18 General Parameter

2. Fluid Model

In Fluid configuration this model is the definition of fluid used. In this study using fluid water.

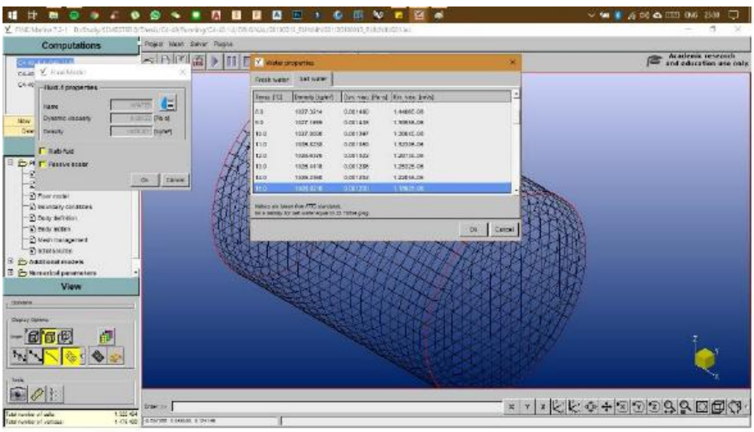


Figure 3. 19 Fluid Model

3. Flow Model

In Flow Model configuration this is a definition to determine the characteristics of the flow to be used. there are two choices, namely laminar and turbulent flow and the intensity of gravity. In the Reference parameters section to define the calculation of the Froude number and Reynolds number that are set on the Fluid Model setting.

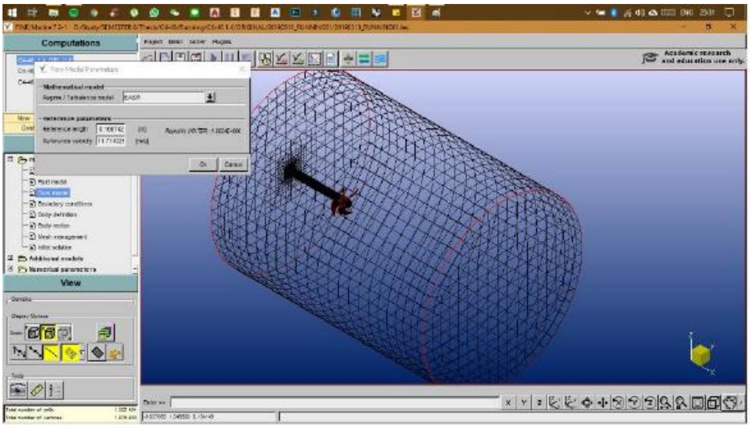


Figure 3. 20 Flow Model

4. Boundary Condition

Boundary Condition is a definition of the condition of the boundaries that will be simulated. In the solid condition configuration used in this study is to define propeller as a wall-function, while the shaft as a slip. Whereas the external inlet and cylinder conditions are included in the velocity advance on the x axis, while the prescribed pressure is at the output.

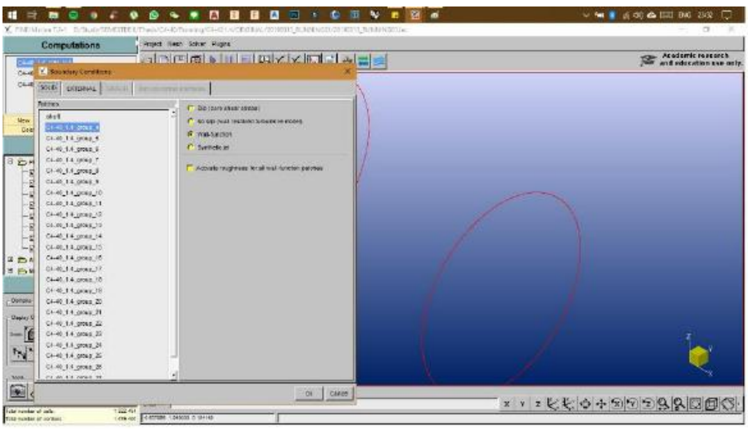


Figure 3. 21 Boundary Condition 1

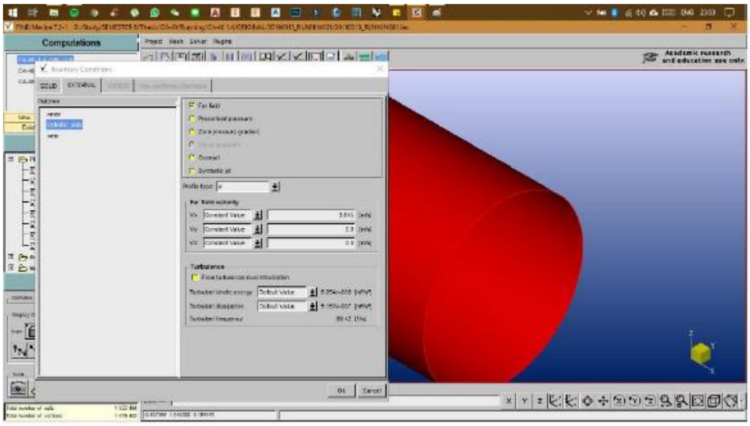


Figure 3. 22 Boundary Condition 2

5. Body definition

Body Definition is done to determine the parts that will be used as a body to be tested. In this configuration in one group and for 2 sub-blades and shafts.

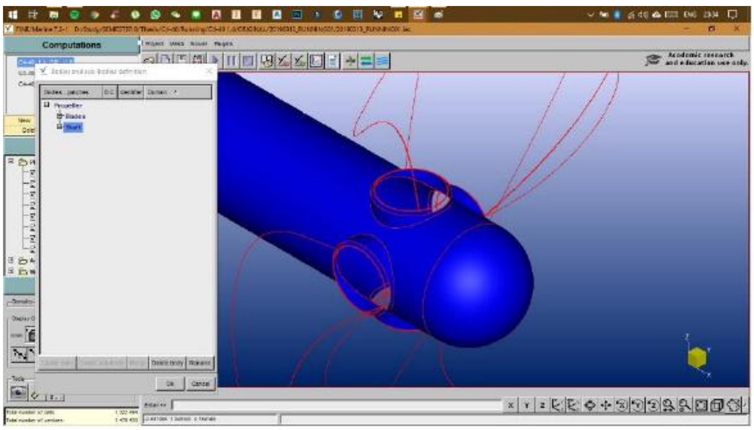


Figure 3. 23 Body definition

6. Body Motion

Body Motion is the part that determines the motion of the object to be tested. The propeller is rotated at a speed of 900 rpm and in this study uses 1/2 sinusoidal ramp on the x axis.

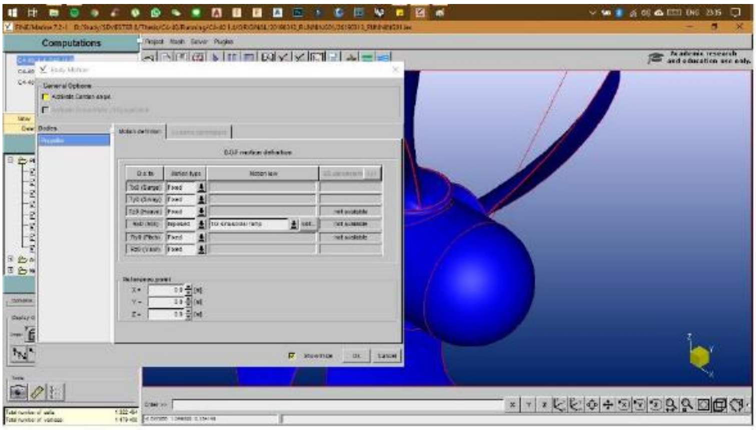


Figure 3. 24 Body Motion

7. Mesh Management

Mesh Management is the decisive part to be rotated or on rotation. In this study using the x axis.

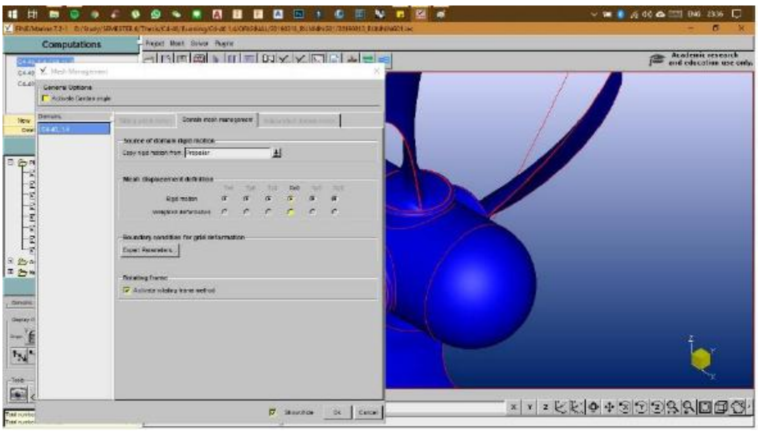


Figure 3. 25 Mesh Management

8. Initial Solution

Initial Solution is the amount of flow velocity on the rotary axis. In this study the flow used is the x axis.

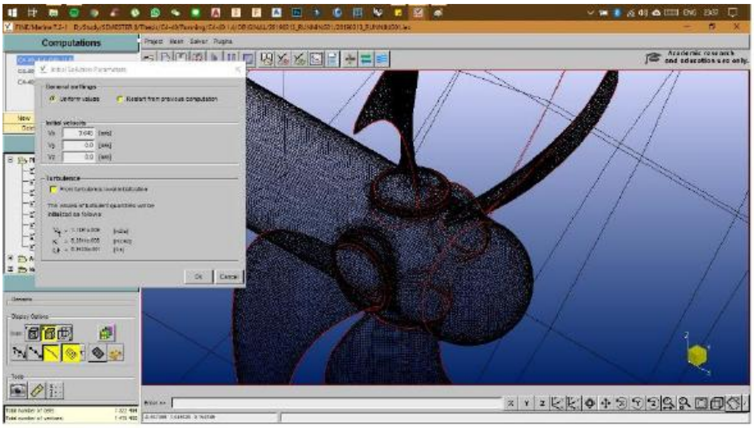


Figure 3. 26 *Initial Solution*

9. Computational Control Variables dan Output

Variable control is a configuration to determine the iteration calculation and the number of time steps, namely the period of movement of the ship used. Output to determine the outcome variable obtained from the simulation. After the parameters have been determined, the simulation can be executed by activating the button running solver.

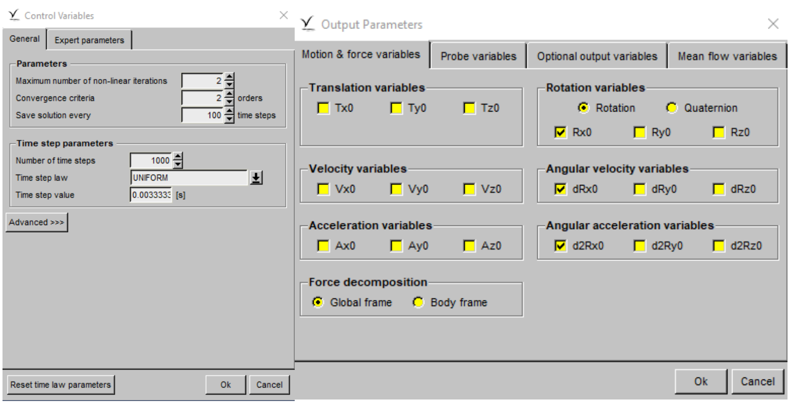


Figure 3. 27 Computational Control Variables dan Output

3.6.5. Result of Running Simulation

The next process after running the simulation, the simulation data can be obtained by reading the graph on the Monitor. In this study, the data taken in the form of Motion, Thrust, Moment and Cavitation in CFview is a part that occurs on the x axis so that the graph is read as (*Fx*).

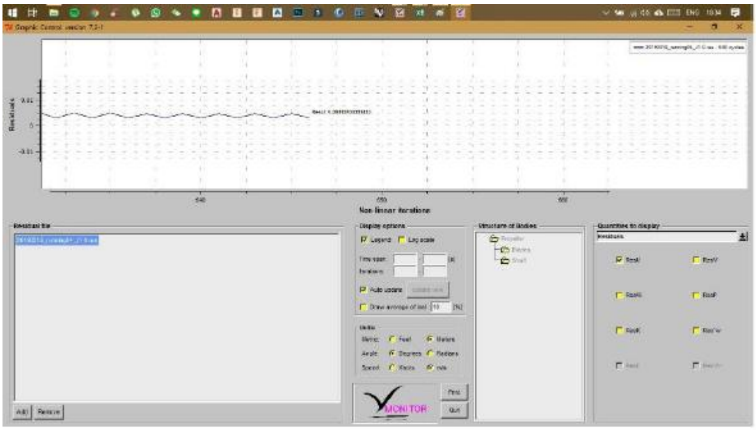


Figure 3. 28 Residuals Monitor

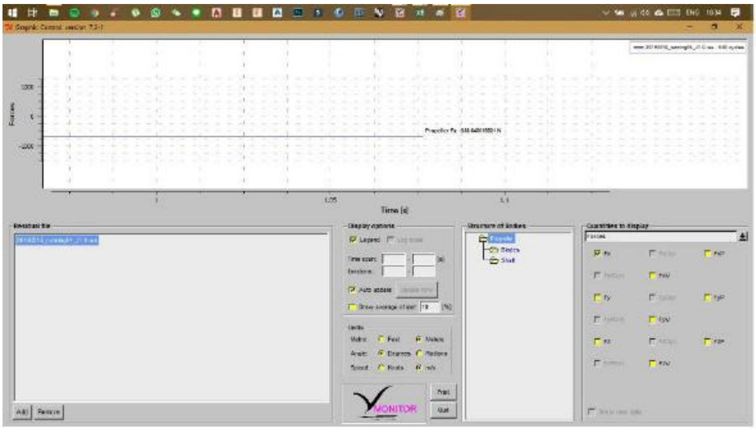


Figure 3. 29 Force Monitor

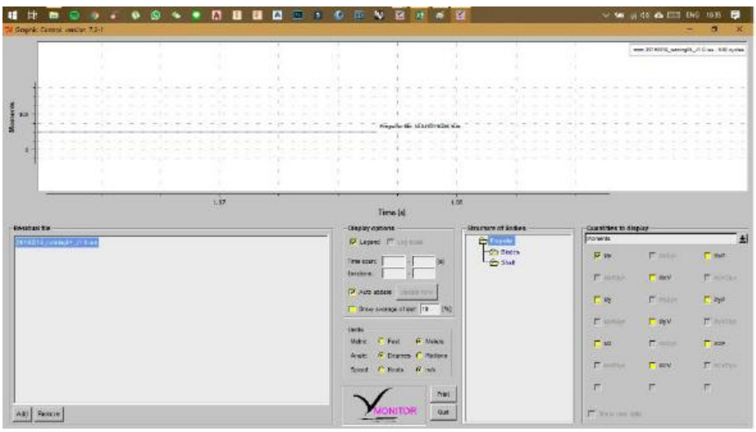


Figure 3. 30 Moments Monitor

3.7. Data Analysis and Discussion

At this stage analysis of data from the simulation results with the help of the CFD, then performed calculations regarding the simulation results. at this stage it will appear for the value of the torque, pressure and also the wall shear on the face and back of the propeller. Then from the simulation results it will be processed to produce torque and also thrust. so that the final results of this workmanship are obtained by K_Q, K_T, and J curves. After the calculations and discussion are carried out, an evaluation is needed to determine whether the results are feasible or acceptable. If it cannot yet be received, it will be repeated the execution of the thesis from the drawing of the model using CFD software.

3.8. Conclusion

If calculations and analysis can be accepted, then conclusions can be drawn immediately about the effect of changes in pitch distribution on propeller type C4-40 performance for Controllable pitch propellers.

“this page is intentionally left blank”

CHAPTER IV
RESULT AND DISCUSSION

4.1. Introduction

This propeller has been designed and manufactured. The design is modified to be various distribution pitch in Rhinoceros. After that, it is produced to be solid by fixing the crashed part in SolidWorks. Then, being simulated in Fine Marine, the result is the further data for calculation to achieve this thesis's objectives.

4.2. 3D Model Result

3D model of propeller is made in Rhinoceros. To make sure it is solid for simulation, it must be converted to IGES file so it can be detecting the failure of some parts in SolidWorks. After that, the file is exported to Parasolid file before it starts to be simulated.

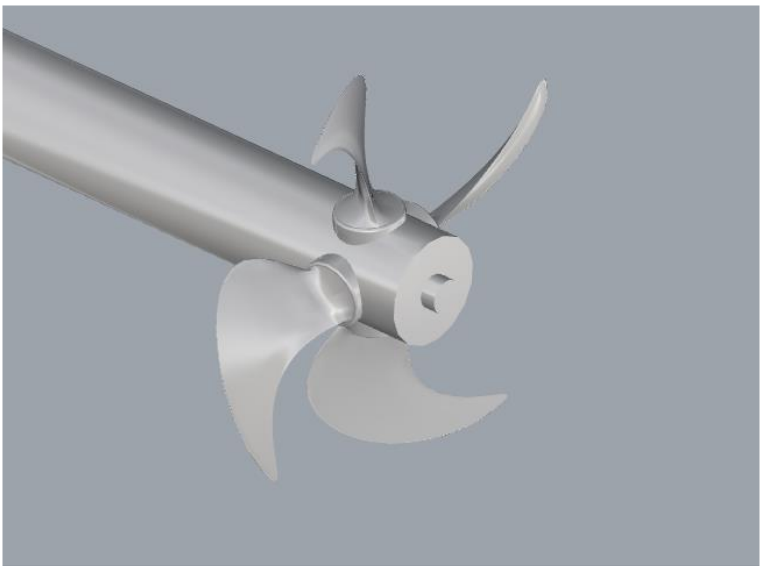


Figure 4. 1 3D Model of C4-40 P/D 1.4

4.3. Various Distribution Pitch

The different of various distribution pitch is done by the simple calculation. First finding the pitch, then tan (a), after that finding out the angle pitch of the propeller. From that value, we can know the angle used for every distribution pitch. Which is know the value of R0.7 is 110.810 mm and D is 316.6 mm.

Table 4. 1 Various Distribution Pitch Setting

Distribution pitch	**P**	**tan(a)**	**Angle Pitch**	**Angle Used**	**Keterangan**
P/D +					
1.6	506.560	0.727	36.027	3.556	None
1.4	443.240	0.636	32.471	0.000	Parameter
1.2	379.920	0.545	28.610	-3.861	None
P/D -					
1.2	379.920	0.545	28.610	-61.082	None
1.0	316.600	0.455	24.444	-56.915	None

The angle used is a reference for modelling when rotating the blade. It is determining how much the angle to achieve the pitch the author desired. The author makes the distribution pitch which are +1.6, +1.2, -1.0, and -1.2.

4.3.1. C4-40 1.4 P/D +1.6

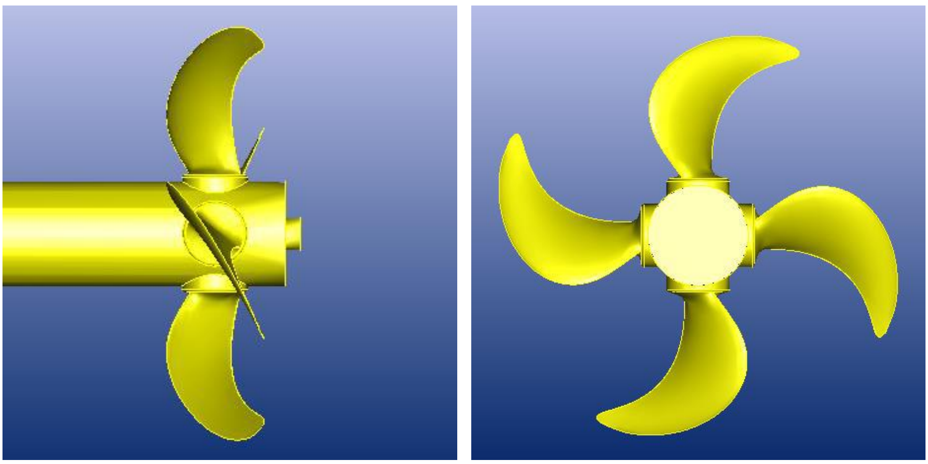


Figure 4. 2 C4-40 1.4 P/D +1.6 side view (left) and front view (right)

Based on figure 4.2. it is show the propeller C4-40 with distribution pitch +1.6. The blade was rotated based on the table 4.1 which shown before. The angle used is 3.556 from the original position of the blade from x axis.

4.3.2. C4-40 1.4 P/D +1.2

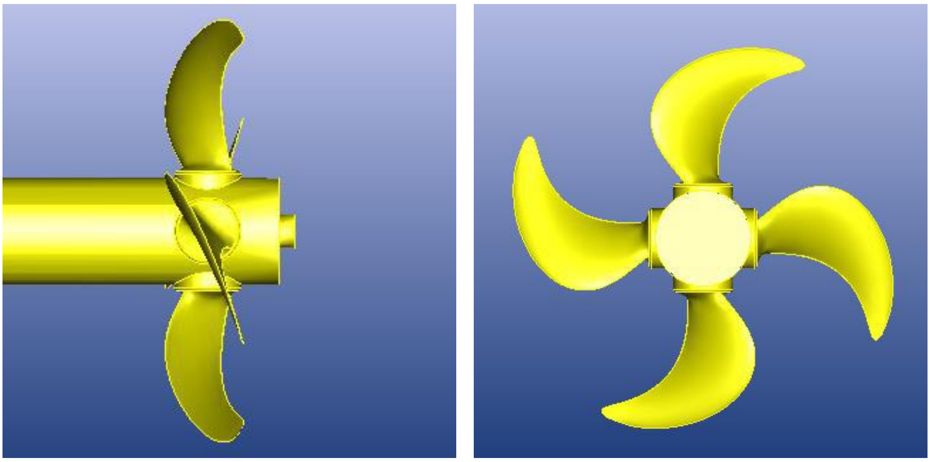


Figure 4. 3 C4-40 1.4 P/D +1.2 side view (left) and front view (right)

Based on figure 4.3. it is show the propeller C4-40 with distribution pitch +1.2. The blade was rotated based on the table 4.1 which shown before. The angle used is -3.861 from the original position of the blade from x axis. We can see a lack of difference between this propeller and the original one, but the difference change of angle approximately similar with propeller +1.6 does.

4.3.3. C4-40 1.4 P/D -1.0

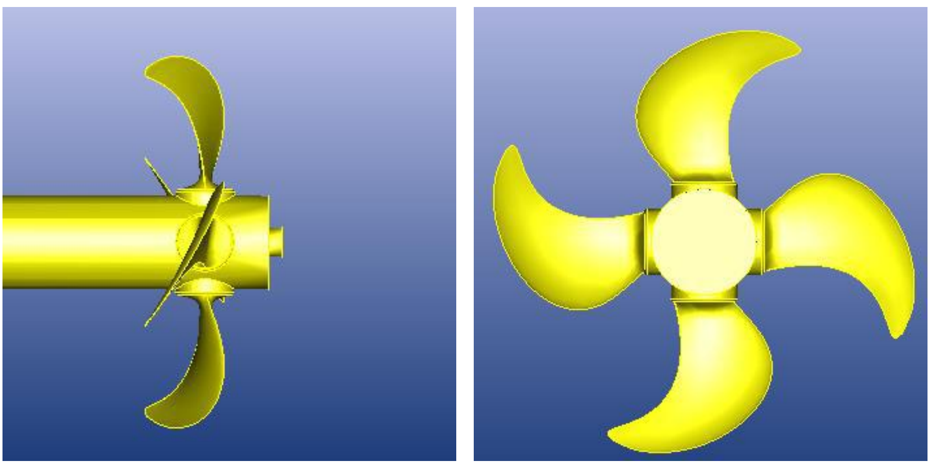


Figure 4. 4 C4-40 1.4 P/D -1.0 side view (left) and front view (right)

Based on figure 4.4. it is show the propeller C4-40 with distribution pitch -1.0. The blade was rotated based on the table 4.1 which shown before. The angle used is -56.915 from the original position of the blade from x axis.

4.3.4. C4-40 1.4 P/D -1.2

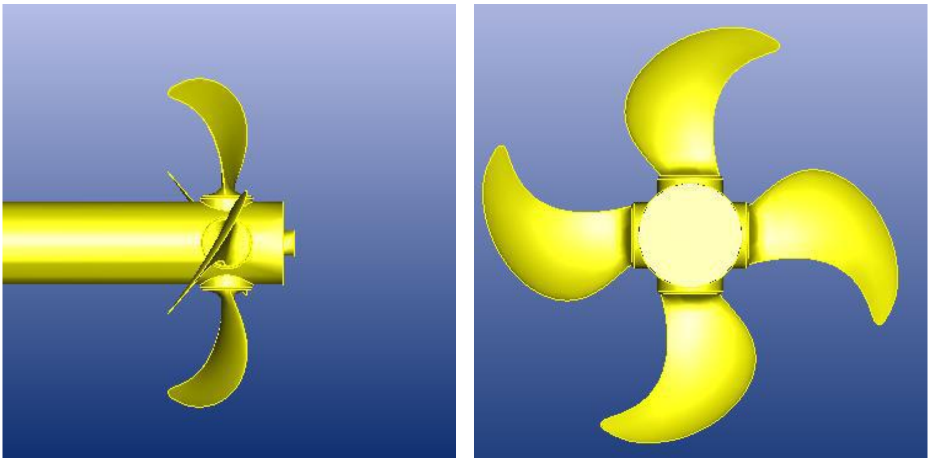


Figure 4. 5 C4-40 1.4 P/D -1.2 side view (left) and front view (right)

Based on figure 4.5. it is show the propeller C4-40 with distribution pitch -1.0. The blade was rotated based on the table 4.1 which shown before. The angle used is -61.082 from the original position of the blade from x axis. The negative distribution pitch gives more difference form and of course different purpose. It shows that the leading edge of the propeller are turning to another side. Means the pressure which produce thrust will push the ship backwards. Meanwhile, the positive pitch has normal leading edges direction which is same like original C4-40 pitch does.

4.4. Propeller Performance

Propeller performance result is the main key of this thesis. The author looking completely how the propeller type C4-40 P/D 1.4 and its various distribution pitch perform well in two quadrats.

4.4.1. Original Pitch

Table 4. 2 Propeller Performance P/D 1.4

Variation		Propeller Performance					
J	Va	T(N)	Q(N)	KT	KQ	10KQ	ɳo
-1.400	-6.649	3400.163	221.050	1.466	0.301	3.010	-1.085
-1.200	-5.699	2727.974	180.279	1.176	0.246	2.455	-0.915
-1.000	-4.749	2186.395	144.619	0.943	0.197	1.969	-0.761
-0.800	-3.799	1821.732	113.205	0.785	0.154	1.542	-0.648
-0.600	-2.849	1207.796	75.323	0.521	0.103	1.026	-0.485
0.000	0.000	1394.234	93.295	0.601	0.127	1.270	0.000
0.600	2.849	1096.071	74.407	0.473	0.101	1.013	0.445
0.800	3.799	885.837	62.926	0.382	0.086	0.857	0.567
1.000	4.749	658.645	50.849	0.284	0.069	0.692	0.652
1.200	5.699	425.488	37.984	0.183	0.052	0.517	0.677
1.400	6.649	177.678	23.221	0.077	0.032	0.316	0.540

Based on table 4.2, the higher thrust shown from J-1.4 which is 3400.163 Newton. The thrust gradually decreasing due to the J value getting higher. In this case, there are two conditions that happen which are ahead and crashahead. Ahead situation means while the current coming from ahead and the ship trying to move forward, the propeller will give the best thrust to keep the ship moving. Meanwhile, the crashahead means the current comes from stern. The current will give additional thrust to the ship that is why the thrust value is higher, see figure 4.6.

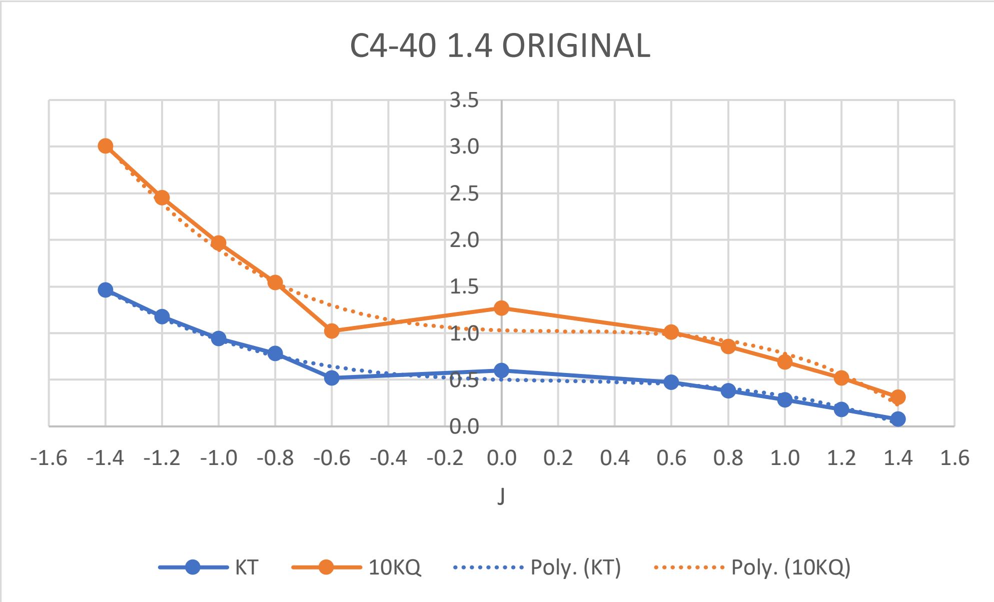


Figure 4. 6 C4-40 P/D 1.4 Propeller Performance

4.4.2. Pitch +1.6

Table 4. 3 Propeller Performance P/D +1.6

Variation		Propeller Performance					
J	**Va**	**T(N)**	**Q(N)**	**KT**	**KQ**	**10KQ**	**ɳo**
-1.400	-6.649	3391.325	254.920	1.462	0.347	3.471	-0.938
-1.200	-5.699	2836.208	213.730	1.223	0.291	2.911	-0.802
-1.000	-4.749	2376.366	181.393	1.025	0.247	2.470	-0.660
-0.800	-3.799	1749.208	132.782	0.754	0.181	1.808	-0.531
-0.600	-2.849	1331.659	96.710	0.574	0.132	1.317	-0.416
0.000	0.000	1490.149	118.506	0.642	0.161	1.614	0.000
0.600	2.849	1247.567	95.903	0.538	0.131	1.306	0.393
0.800	3.799	1080.514	85.119	0.466	0.116	1.159	0.512
1.000	4.749	867.268	72.070	0.374	0.098	0.981	0.606
1.200	5.699	640.463	57.914	0.276	0.079	0.789	0.668
1.400	6.649	406.412	42.771	0.175	0.058	0.582	0.670

Based on table 4.3, the higher thrust shown from J-1.4 which is 3391.325 Newton. The thrust gradually decreasing due to the J value getting higher which has same situation like the original propeller before. But there is something different. The J0.0 has thrust 1490.149 Newton, then it decreases on J-0.6 to be 1331.659 Newton. It should not be like that; this case might happen because an error exists.

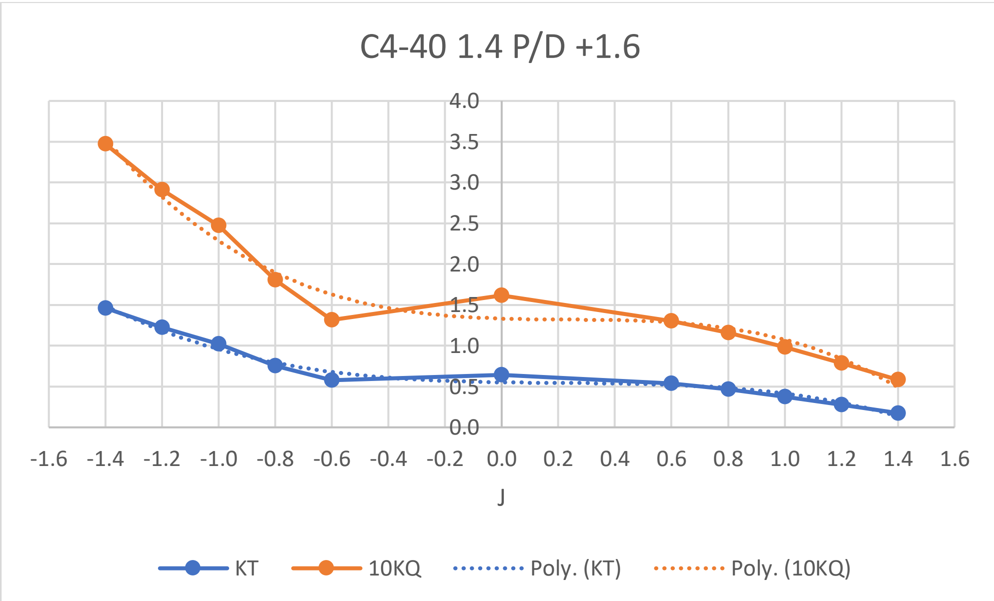


Figure 4. 7 C4-40 P/D +1.6 Propeller Performance

4.4.3. Pitch +1.2

Table 4. 4 Propeller Performance P/D +1.2

Variation		**Propeller Performance**					
J	**Va**	**T(N)**	**Q(N)**	**KT**	**KQ**	**10KQ**	**ηo**
-1.400	-6.649	3271.823	182.991	1.411	0.249	2.492	-1.261
-1.200	-5.699	2629.369	148.829	1.134	0.203	2.027	-1.068
-1.000	-4.749	2029.873	114.090	0.875	0.155	1.554	-0.896
-0.800	-3.799	1481.543	82.909	0.639	0.113	1.129	-0.720
-0.600	-2.849	1011.116	54.525	0.436	0.074	0.743	-0.560
0.000	0.000	1395.503	78.444	0.602	0.107	1.068	0.000

0.600	2.849	868.710	52.657	0.375	0.072	0.717	0.499
0.800	3.799	651.954	42.853	0.281	0.058	0.584	0.613
1.000	4.749	415.584	31.856	0.179	0.043	0.434	0.657
1.200	5.699	167.132	19.121	0.072	0.026	0.260	0.528
1.300	6.174	-16.085	11.049	-0.007	0.015	0.150	-0.095
1.400	6.649	-147.699	2.694	-0.064	0.004	0.037	-3.866

Based on table 4.4, the higher thrust shown from J-1.4 which is 3271.823 Newton. The thrust gradually decreasing due to the J value getting higher which has same situation like the last two propellers before (Original and Plus 1.6). But there is something different. The J0.0 has thrust 1395.503 Newton, then it decreases on J-0.6 to be 1011.116 Newton. It should not be like that; this case might happen because an error exists.

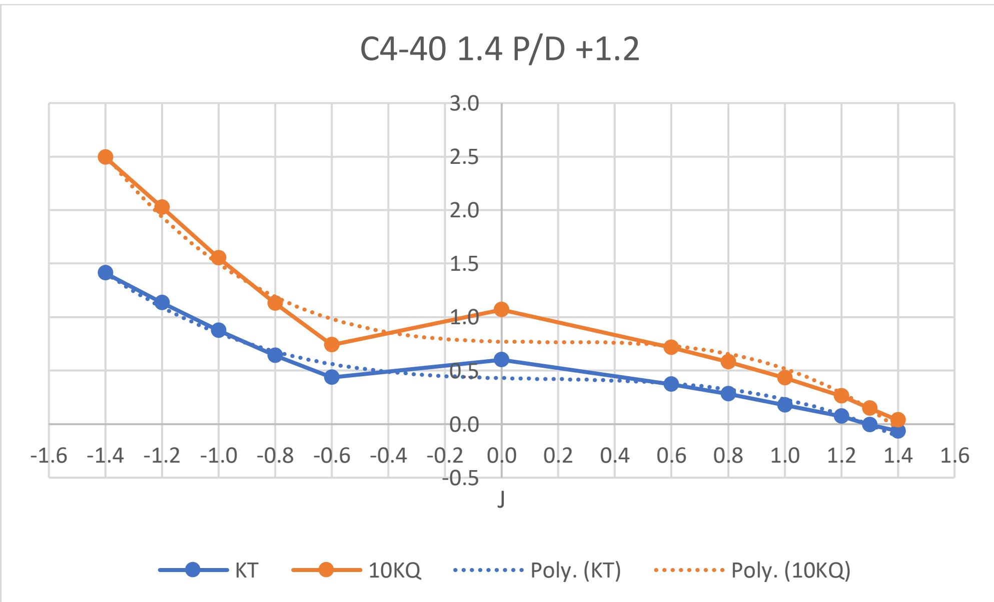


Figure 4. 8 C4-40 P/D +1.2 Propeller Performance

4.4.4. Pitch -1.0

Table 4. 5 Propeller Performance P/D -1.0

Variation		Propeller Performance					
J	Va	T(N)	Q(N)	KT	KQ	10KQ	ηo
-1.400	-6.649	-3548.175	-166.236	-1.530	-0.226	-2.264	-1.505
-1.200	-5.699	-2786.354	-139.554	-1.201	-0.190	-1.900	-1.207
-1.000	-4.749	-2256.478	-118.412	-0.973	-0.161	-1.613	-0.960
-0.800	-3.799	-1812.989	-98.079	-0.782	-0.134	-1.336	-0.745
-0.600	-2.849	-1328.949	-77.925	-0.573	-0.106	-1.061	-0.515
-0.500	-2.375	-1142.880	-70.012	-0.493	-0.095	-0.953	-0.411
-0.400	-1.900	-994.449	-64.100	-0.429	-0.087	-0.873	-0.313
-0.300	-1.425	-906.274	-62.073	-0.391	-0.085	-0.845	-0.221
-0.200	-0.950	-879.376	-64.031	-0.379	-0.087	-0.872	-0.138
-0.100	-0.475	-908.034	-69.158	-0.391	-0.094	-0.942	-0.066
0.000	0.000	-914.010	-2.054	-0.394	-0.003	-0.028	0.000
0.600	2.849	-526.034	-48.613	-0.227	-0.066	-0.662	0.327
0.800	3.799	-339.471	-37.266	-0.146	-0.051	-0.507	0.367
1.000	4.749	-107.711	-25.458	-0.046	-0.035	-0.347	0.213
1.200	5.699	330.826	-6.221	0.143	-0.008	-0.085	-3.214
1.400	6.649	590.137	-6.970	0.254	-0.009	-0.095	-5.970

Based on table 4.5, The higher thrust is at J1.4 which has thrust 590.137 Newton. The values of thrust are gradually increase from J-1.4 to J1.4. In this case, there are two conditions will happen. First is backing, we can see it on positive J. Second is crashback, we can see it on negative J.

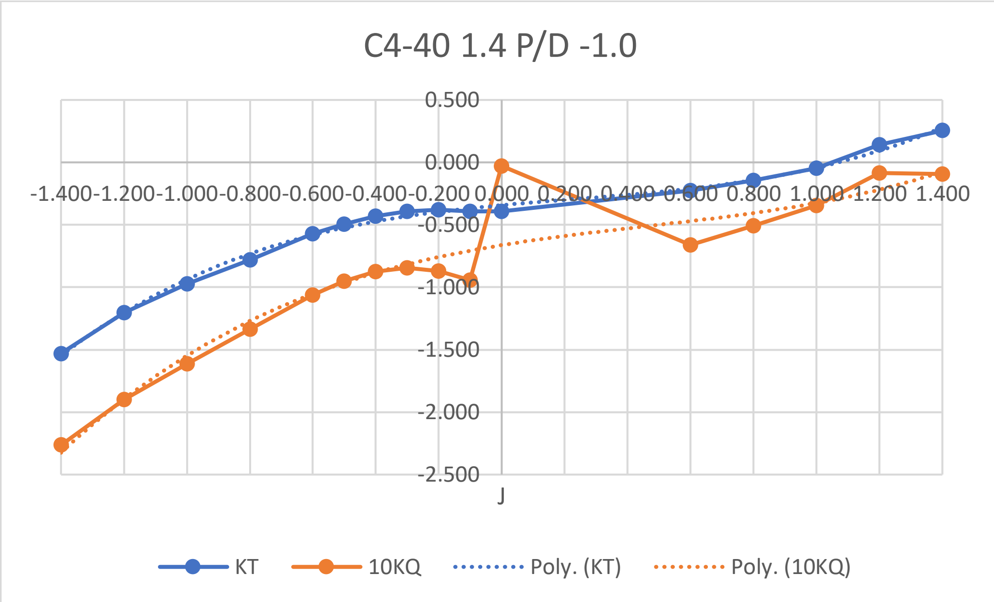


Figure 4. 9 C4-40 P/D -1.0 Propeller Performance

4.4.5. Pitch -1.2

Table 4. 6 Propeller Performance P/D -1.2

Variation		Propeller Performance					
J	Va	T(N)	Q(N)	KT	KQ	10KQ	ηo
-1.400	-6.649	-3334.562	-188.785	-1.438	-0.257	-2.571	-1.246
-1.200	-5.699	-3037.845	-170.641	-1.310	-0.232	-2.324	-1.076
-1.000	-4.749	-2292.735	-141.311	-0.988	-0.192	-1.924	-0.817
-0.800	-3.799	-1815.347	-117.933	-0.783	-0.161	-1.606	-0.620
-0.600	-2.849	-1409.277	-94.731	-0.608	-0.129	-1.290	-0.450
-0.500	-2.375	-1288.234	-76.746	-0.555	-0.105	-1.045	-0.423
-0.400	-1.900	-1139.803	-82.658	-0.491	-0.113	-1.126	-0.278
-0.300	-1.425	-1051.628	-84.685	-0.453	-0.115	-1.153	-0.188
-0.200	-0.950	-1024.730	-82.727	-0.442	-0.113	-1.127	-0.125
-0.100	-0.475	-1053.388	-77.600	-0.454	-0.106	-1.057	-0.068

0.000	0.000	-1059.364	-90.057	-0.457	-0.123	-1.226	0.000
0.600	2.849	-637.247	-63.939	-0.275	-0.087	-0.871	0.301
0.800	3.799	-405.748	-50.619	-0.175	-0.069	-0.689	0.323
1.000	4.749	-224.504	-39.683	-0.097	-0.054	-0.540	0.285
1.200	5.699	62.589	-23.244	0.027	-0.032	-0.317	-0.163
1.400	6.649	583.505	4.421	0.252	0.006	0.060	9.307

Based on table 4.8, The higher thrust is at J1.4 which has thrust 583.505 Newton. The values of thrust are gradually increase from J-1.4 to J1.4. In this case, there are two conditions will happen. First is backing, we can see it on positive J. Second is crashback, we can see it on negative J. The thrust on J-0.5 to J-1.0 are fluctuating. If we see on figure 4.10, the graph looks like figure 4.9.

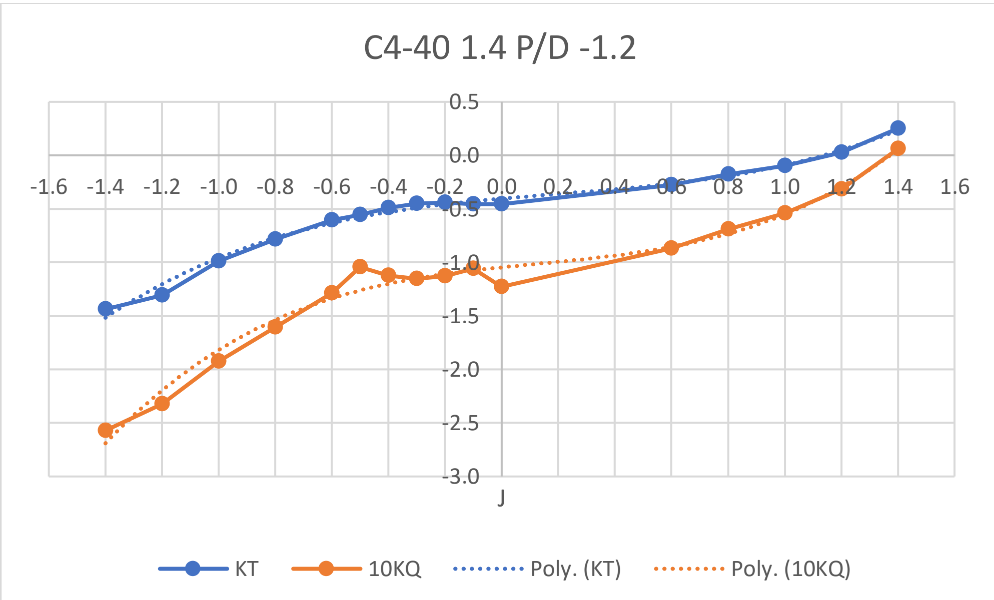


Figure 4. 10 C4-40 P/D -1.2 Propeller Performance

4.4.6. Four Quadrant Properties

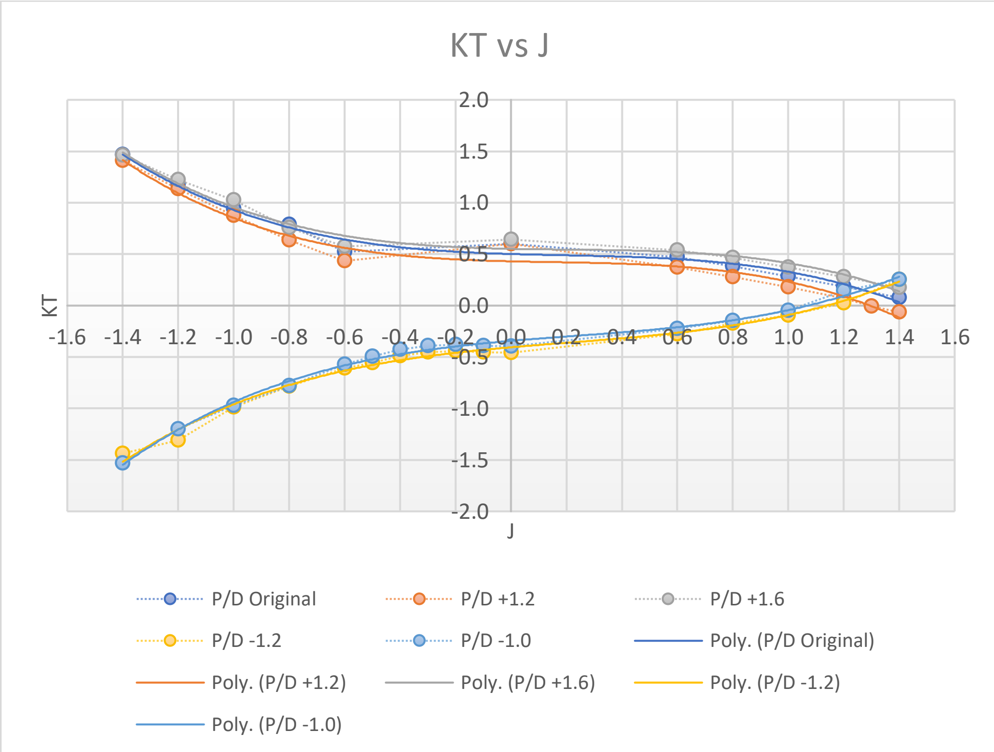


Figure 4. 11 KT vs J Propeller Performance in Four Quadrant

If we see on figure 4.11, the graph is shown on four quadrants. The advanced coefficient (J) started from -1.4 to 1.4. first quadrant is shown as ahead which the current come from ahead and the ship moves forward. In this case, the thrust is gradually decreasing as higher the current is. Then when the current coming from stern, and the ship moves forward, the thrust is increasing significantly as lower negative advanced coefficient, it is shown on the second quadrant. When the ship moves backward and the current coming from stern it will make the thrust, but it slowly goes down at the advanced coefficient getting lower. We can see in the third quadrant, the value is still nearly positive for negative 1.0 and 1.2 propeller's distribution pitch. At the fourth quadrant, we can see that when the ship moves backward, then the current come from ahead will help the propeller gives the higher thrust in to backward or negative direction.

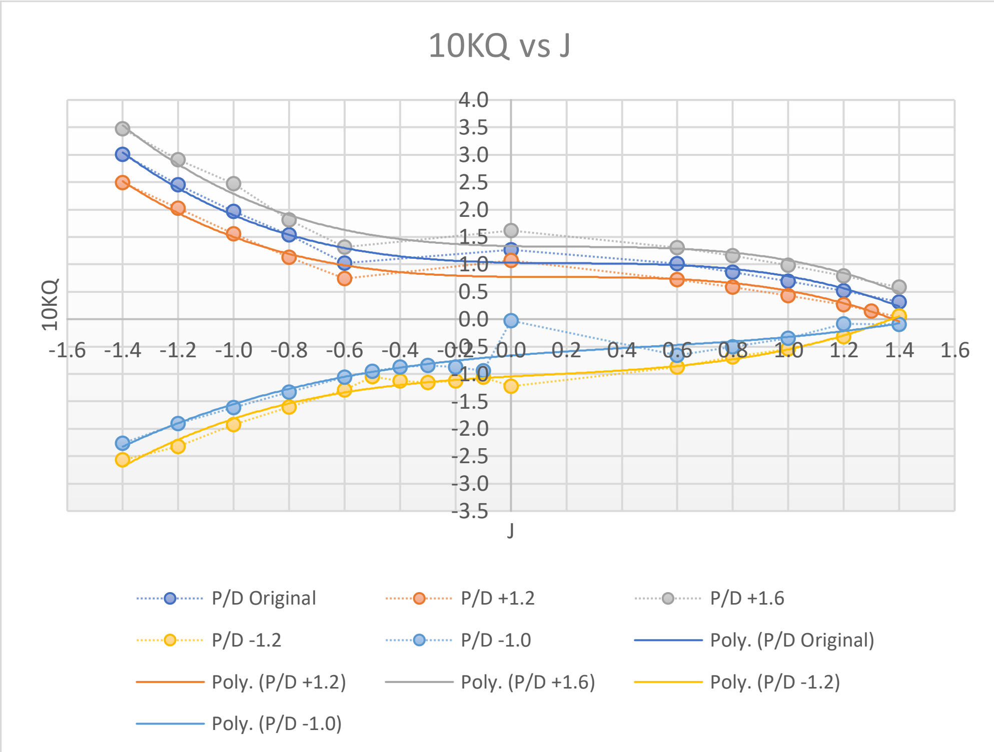


Figure 4. 12 10KQ vs J Propeller Performance in four Quadrant

If we see on figure 4.12, the graph is shown on four quadrants. The advanced coefficient (J) started from -1.4 to 1.4. first quadrant is shown as ahead which the current come from ahead and the ship moves forward. In this case, the moment is gradually decreasing as higher the current is. Then when the current coming from stern, and the ship moves forward, the moment is increasing significantly as lower negative advanced coefficient, it is shown on the second quadrant. When the ship moves backward and the current coming from stern it will make the moment, but it slowly goes down at the advanced coefficient getting lower. We can see in the third quadrant; the value is still nearly positive for negative 1.0 and 1.2 propeller's distribution pitch. At the fourth quadrant, we can see that when the ship moves backward, then the current come from ahead will help the propeller gives the higher moment in to backward or negative direction.

4.4.7. Comparison result between model and published data

The original of propeller type C4-40 P/D 1.4 model already being compared with the published data. It is being compared since the published data has been improved to approach the similar diameter of the propeller. The simulation using fluid model as below:

Table 4. 7 Fluid Model Properties

Fluid Model Properties			
Salt Water	=	15	Celcius
Density	=	1026.021	Kg/m^3
Dynamic Visc	=	0.001	Pa.s
Kinematic Visc	=	1.19E-06	m^2/s

The fluid model is really important as input parameter in the simulation setting, this fluid model is being determined to approach the real situation where the propeller might be used.

The result comparison between published data and simulation we had are consisted of several items such as, propeller performance, and the difference value shown in percentage.

Table 4. 8 Comparison between published data and simulation

Variasi		**Published Data**					**Simulation Data**			
J	**Va**	**KT**	**10KQ**	**KQ**	**T(N)**	**Q(Nm)**	**T(N)**	**Q(N)**	**ΔT(%)**	**ΔQ(%)**
0.8	3.799	0.3478	0.695	0.069	806.700	51.014	885.837	62.926	9.81	23.35
1.0	4.749	0.2636	0.567	0.057	611.403	41.637	658.645	50.849	7.73	22.13
1.2	5.699	0.1716	0.416	0.042	398.015	30.526	425.488	37.984	6.90	24.43
1.4	6.649	0.068	0.231	0.023	157.722	16.963	177.678	23.221	12.65	36.89

From the result above, we can see the different percentage for the thrust is not really big, almost all of them are below 12.65%. but the moment values are quite interesting because they are in the high value of differences which are about 23 – 36 %.

This comparison only for showing comparison in general, it cannot be a parameter because it has different geometry but same type propeller. The diameter which is simulated in this thesis is 316.6 mm, meanwhile the published data has diameter of propeller approximately around 230.37 – 242.81 mm.

4.4.8. Propeller Performance at Extreme Loading

At extreme loading, it happened on the both positive and negative pitch. It has discussed in chapter II which is the literature review telling many researchers found the same case.

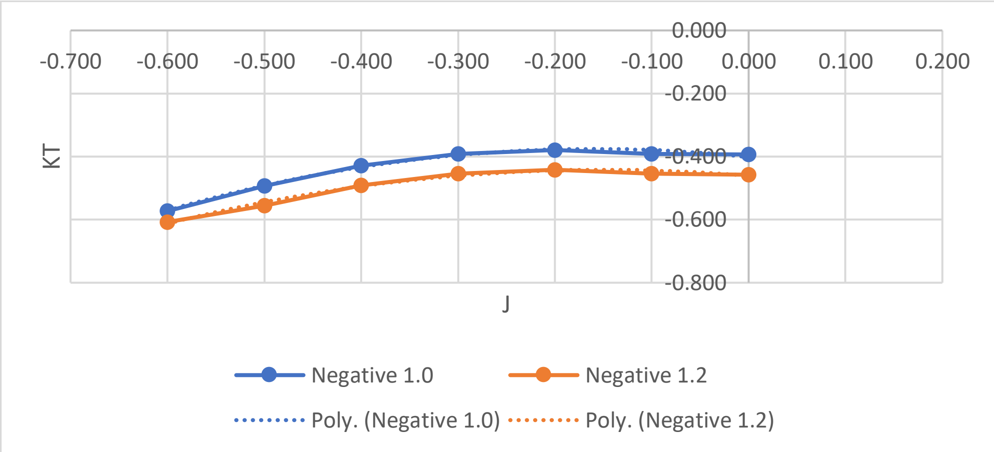


Figure 4. 13 Crashback event while propeller in extreme loads

If we see from *J* -0.6 to -0.2, it is gradually increasing. However, at the next advanced coefficient, it goes down which is shown on *J* -0.1 to 0.0. Propeller properties at normal to extreme loadings in open water and behind conditions for both deep and shallow water also states the peculiarities. In normal loadings represented by higher *J* values, small differences appear for both K_T and K_Q values and different water depths

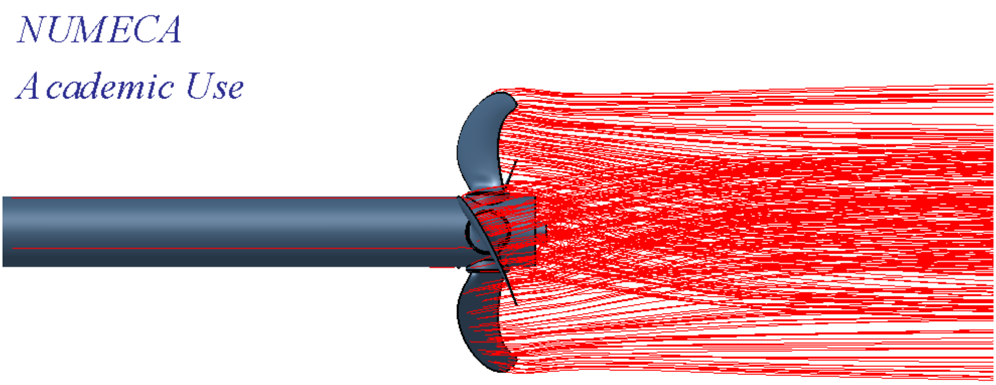


Figure 4. 14 Ahead flow of velocity at J = 0.8

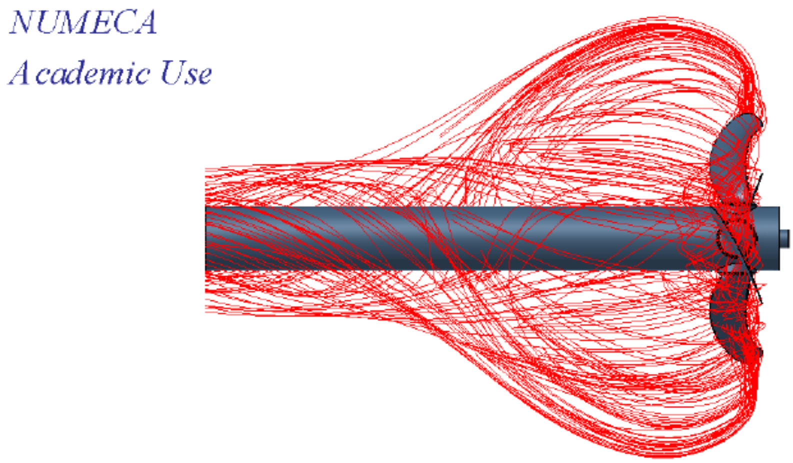


Figure 4. 15 Crashahead flow of velocity at J = -0.8

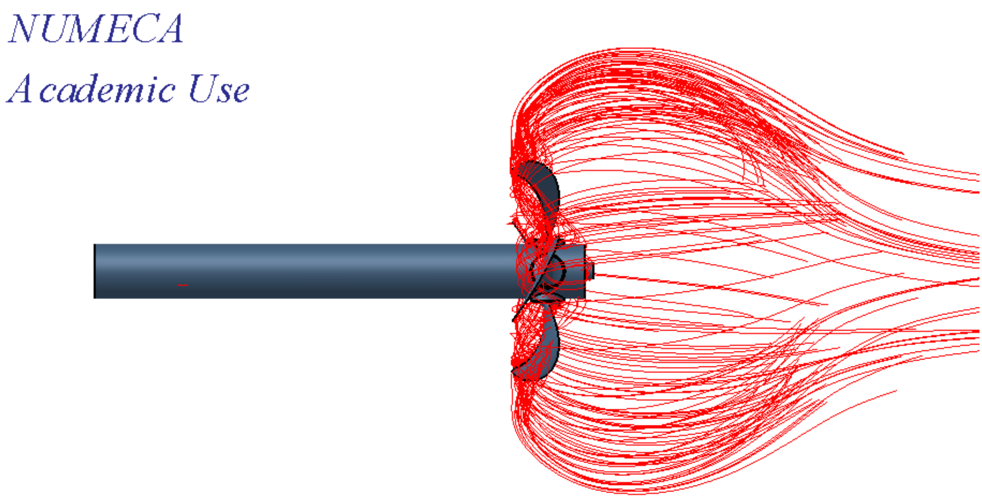


Figure 4. 16 Crashback flow of velocity at J = -0.8

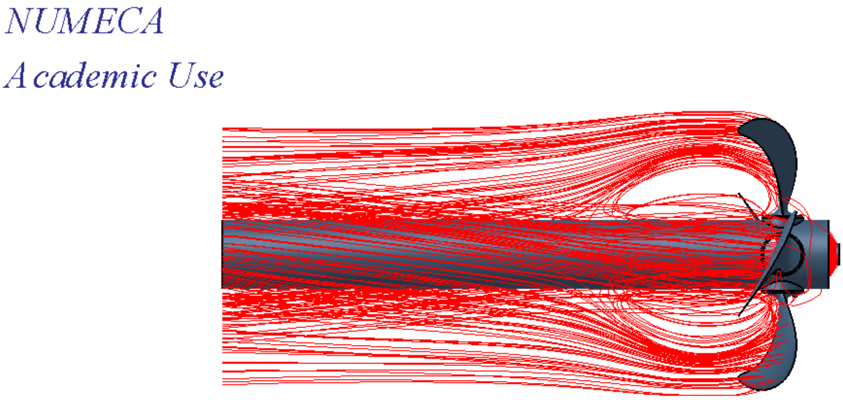


Figure 4. 17 Backing flow of velocity at J = 0.8

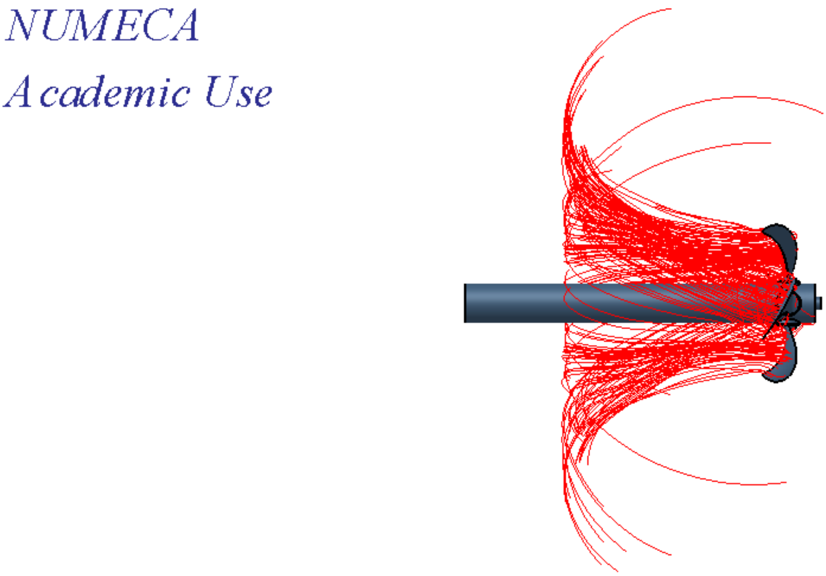


Figure 4. 18 Crashback flow of velocity at extreme loading (J = -0.1)

As observed from the figure, ahead operation at *J* positive for positive distribution pitch propeller creates a streamline flow field. Early phase of crashback operation at *J* negative for negative distribution pitch propeller forms an irregular flow field. At two low J values of -0.2 and -0.1 representing extremely high propeller loadings, the propeller induced velocity changed the flow field to be dominated by reverse propeller inflow.

“this page is intentionally left blank”

CHAPTER V
CONCLUSION AND SUGGESTION

5.1. Overview of Research

This research has been done exactly what it has purposed. Propeller C4-40 Pitch +1.4 has been analysed with different various distribution pitch which are +1.6, +1.2, -1.0, and -1.2. The result which was exist after simulation were thrust and moment. Then, the author processes those data to seek for their performance coefficient. From the graph has made based on that process and calculation, every single propeller distribution pitch gives many explanations.

5.2. Conclusion

The conclusion of this bachelor thesis can be pulled off refer to the result and discussion which has been explain in the chapter before, there are:

1. Controllable Pitch Propeller type C4-40 pitch +1.4 with distribution pitch +1.6 and +1.2 has been simulated at advanced coefficient $J = [-1.4 , 1.4]$. Both coefficients thrust and torque are gradually decreasing as advanced coefficient increased. It shows the event of crashahead in the second quadrant and ahead in first quadrant. Meanwhile, CPP type C4-40 pitch +1.4 with distribution pitch -1.2 and -1.0 gives different result. It is actually giving the same pattern because only the orientation difference. While doing simulation for those distribution pitch, the crashback and backing happened. Crashback in the third quadrant and backing in fourth quadrant.
2. The result data has shown lack of difference when comparing it with the published data, even though diameter of propeller is different.
3. The propeller is operated in reverse rotation while crashback stopping the ship from moving headway as quickly as possible. In such dynamic conditions, propeller properties fluctuate considerably larger than in normal ahead operation most probably due to unstableness of flow field in the vicinity of the propeller. It happened for -1.2 and -1.0 at $J = [-0.6 , 0.0]$

5.3. Suggestion

The suggestion could be given through all the process of making this thesis purposing to whom wants to continue or refer to this thesis, there are:

1. Further studies on the C4-40 experiment series need to be compared with the simulation.
2. Further studies must be done with another propeller original P/D such as 0.8, 1.0, and 1.2.

"this page is intentionally left blank"

REFERENCES

Abidin, M. Z., 2012. Analisa Performance Propeller B-Series Dengan Pendekatan Structure dan Unstructure Meshing.

A, Y., 1962. *Design Diagrams of Modern Four, Five, Six and Seven-bladed Propellers Developed in Japan.* Washington, National Academy of Sciences.

Black, S. & Swithenbank, S., 2009. Analyses of Crashback Forces Compared with Experimental Result.

C. G, Q., 1981. Four Quadrant Open Water Characteristics of Controllable Pitch Propeller 4837 Designed for MCM (Model 5401).

C. L, M. & D. V, L. S., 2006. *Multi-Disciplinary Computational Analysis in Propulsion.* Sacramento, s.n.

Gerr, D., 1989. *Propeller Handbook.* Camden: International Marine.

Holst, C., 1924. *The Geometry of The Screw Propeller.* Delft: Leiden - E. J. Brill Ltd..

J. D, V. M., 1954. Open Water Test Series with Propellers in Nozzle. *International Shipbuilding Progress Vol.1.*

Lee, C.-S.et al., 2010. Performance Optimization of Marine Propellers.

MARIN, 1996. *Resistance and Propulsion.* s.l.:s.n.

Sunarsih, 2018. Four Quadrant Thrust Generation Model with Bounded Dynamic Wake and Thrust Deduction Fraction.

Ueda, T., Sasaki, N., Sugai, N. & Yokoo, N., 1981. Experimental Study on Torque Fluctuation During Crash Stop Maneuver of the Large Tanker with Ducted Propeller.

Chang, P. (2008) 'Propeller Forces and Structural Response due to Crashback' 27th Symposium on Naval Hydrodynamics, Seoul, South Korea

Ye, B., Wang, Q., Wan, J., Peng, Y., & Xiong, J. (2012). A Four-Quadrant Thrust Estimation Scheme Based on Chebyshev Fit and Experiment of Ship Model Open Mechanical Engineering Journal, 6(2), 148-154.

Swithenbank, S., Jessup, S, and Etebari, A.,(2008), 'Measurement of Crashback Loads on a Blade of Propeller 4381 in an Open and Ducted Configuration in the 36-inch Water Tunnel', NSWCCD-50-TR2008/061.

Harvald, S. A. (1977). Wake and thrust deduction at extreme propeller loadings for a ship running in shallow water. Transactions of the Royal Institution of Naval Architects, 119, 213–236

Suranto, Maful. (2018). Analisa Kavitasi Surface Pada Daun Propeller Wageningen Series C4-40 Dengan CFD

Dang, Jie. (2012). Quasi-Steady Two-Quadrant Open Water Tests for the Wageningen Propeller *C*- and *D*-Series. Twenty-Ninth Symposium on Naval Hydrodynamics Gothenburg, Sweden.

Dang, J. (2013). The Wageningen *C*- and *D*-Series Propellers. MARIN, The Netherlands.

Ueda, T., Sasaki, N., Sugai, N., & Yokoo, N. (1981). Survey of torque fluctuation at the time of rapid stop and reverse. Report of Ship Technical Research Institute, 18(1), 35-49.

APPENDIX

“this page is intentionally left blank”

APPENDIX A Main Geometry of C4-40

(Main parameters)

Version 1.1 / 13-06-2012

MARIN

Project: C- and D-series JIP

Client: Participants

Date: 09 July 2019

A_E/A_0	$P_{0.7R}/D_{prop}$	D_{prop}	D_{hub}/D_{prop}	D_{hub}	Z
[-]	[-]	[mm]	[-]	[mm]	[-]
0.4000	0.8000	316.60	0.2527	80.00	4

	r/R	r	C	P	S	X	f_{max}	t_{max}
	[-]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
Blade root	0.2527	40.00	40.87	214.00	-2.22	1.97	1.86	9.76
	0.3500	55.41	51.08	231.23	-5.46	1.87	2.51	8.24
	0.4000	63.32	56.46	238.20	-6.74	1.16	2.74	7.46
	0.5000	79.15	66.75	248.35	-7.27	-1.07	2.99	5.96
	0.6000	94.98	75.30	253.42	-3.74	-3.62	2.95	4.66
	0.7000	110.81	80.45	253.42	5.02	-5.56	2.64	3.57
	0.8000	126.64	79.72	248.33	19.70	-5.98	2.04	2.69
	0.8500	134.56	75.82	243.88	29.32	-5.33	1.64	2.30
	0.9000	142.47	68.06	238.17	40.45	-3.96	1.16	1.92
	0.9500	150.39	53.34	231.18	53.02	-1.74	0.62	1.53
	0.9750	154.34	40.14	227.21	59.82	-0.28	0.32	1.32
	0.9875	156.32	29.54	225.11	63.35	0.54	0.16	1.22
Blade tip	1.0000	158.30	0.00	222.93	66.95	1.43	0.00	1.11
Additional r/R	0.3	47.49	45.75	222.98	-3.82	2.17	2.21	9.03

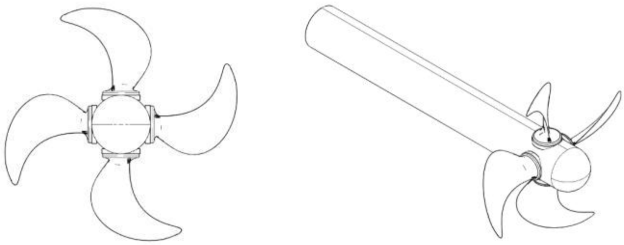
limitations: $0.40 \le A_E/A_0 \le 0.70$

$0.80 \le P_{0.7R}/D \le 1.40$

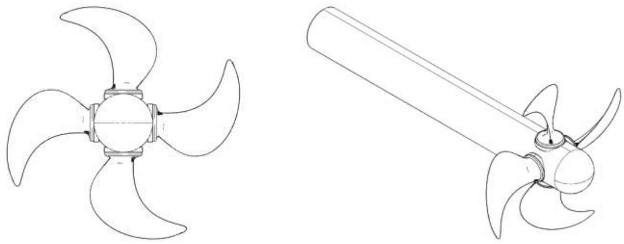
Note: without tip form, anti-singing edge, blade root fillets

“this page is intentionally left blank”

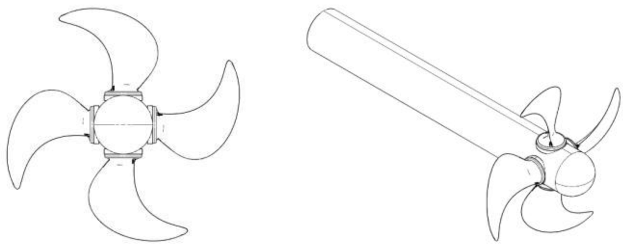
APPENDIX B C4-40 1.4 Propeller Model



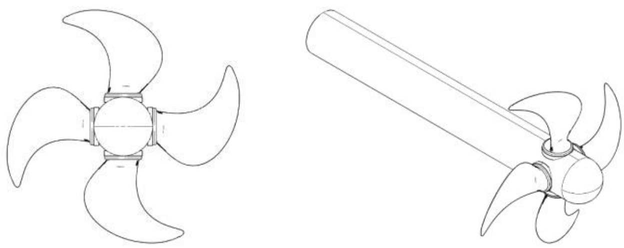
Pitch normal
Original



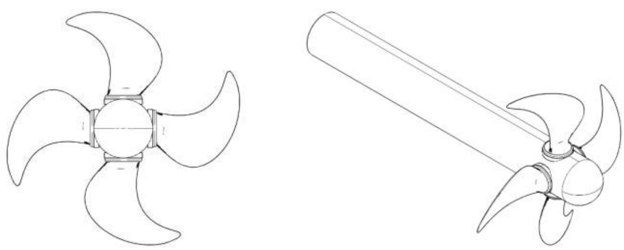
Pitch setting
+1.6



Pitch setting
+0.4



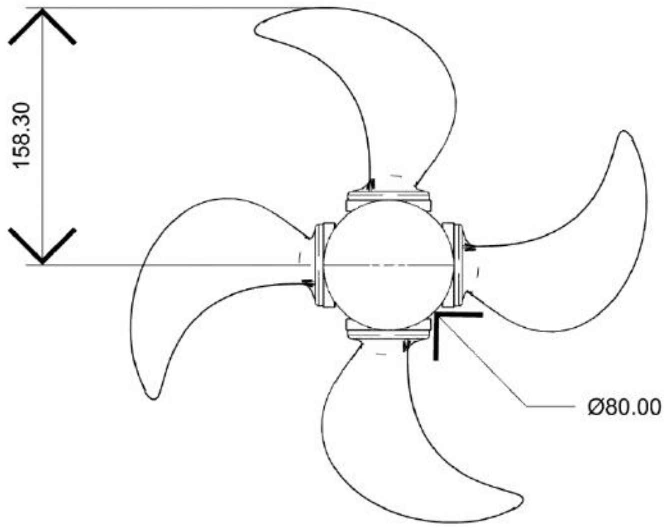
Pitch setting
-0.1

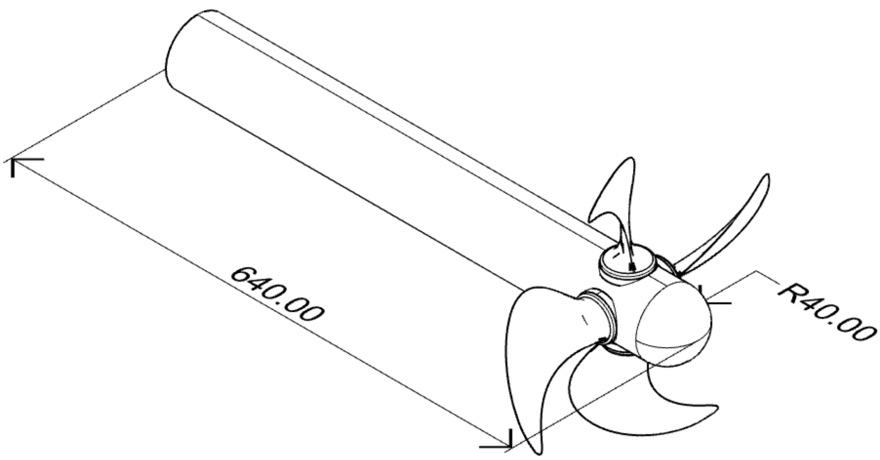


Pitch setting
-0.2

“this page is intentionally left blank”

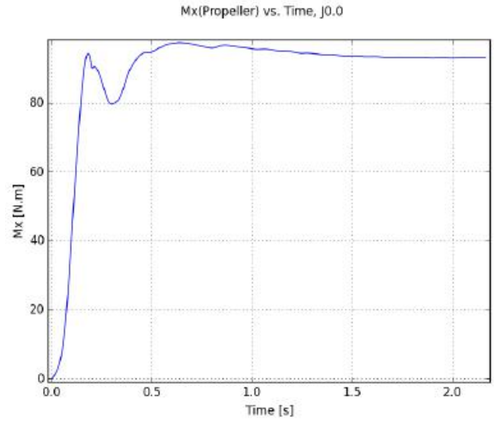
APPENDIX C General Geometry in Model C4-40

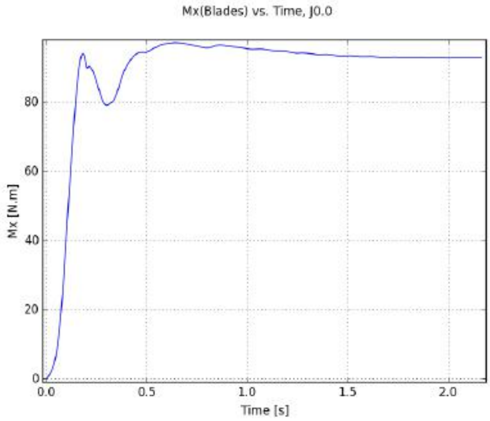


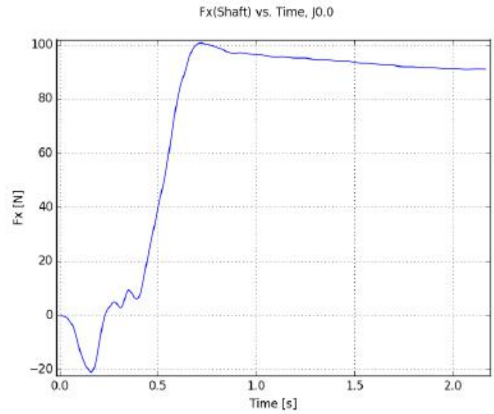


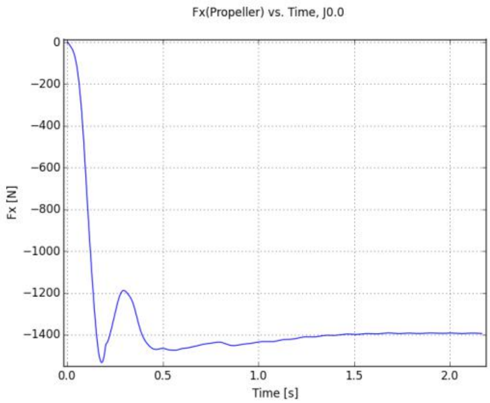
“this page is intentionally left blank”

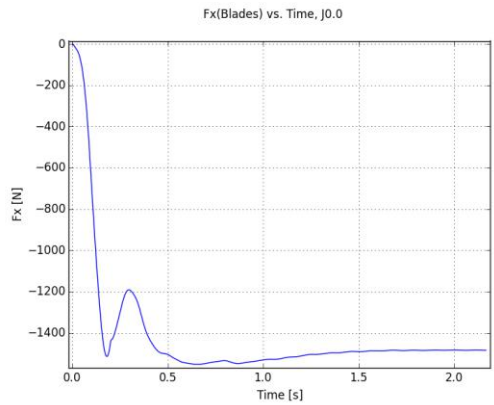
APPENDIX D (Simulation Result) P/D Original J0.0

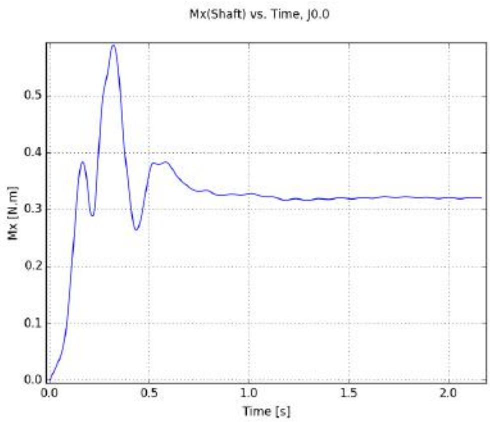




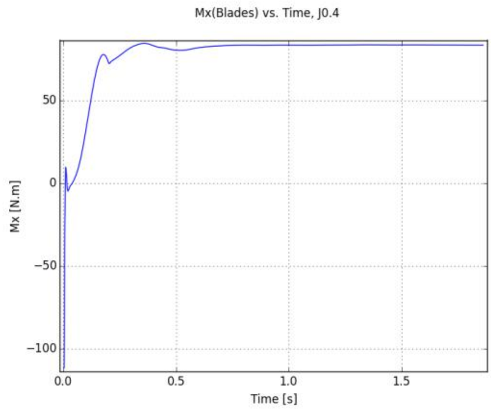


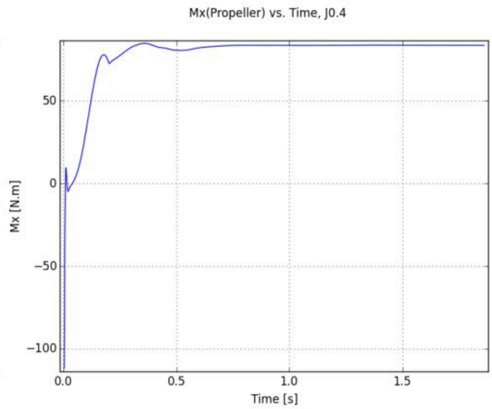


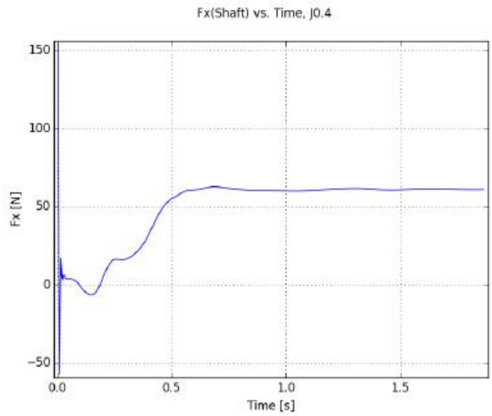


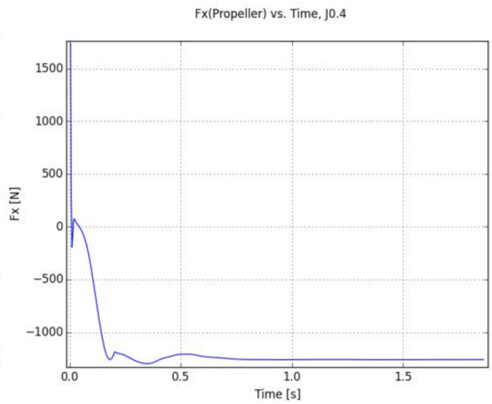


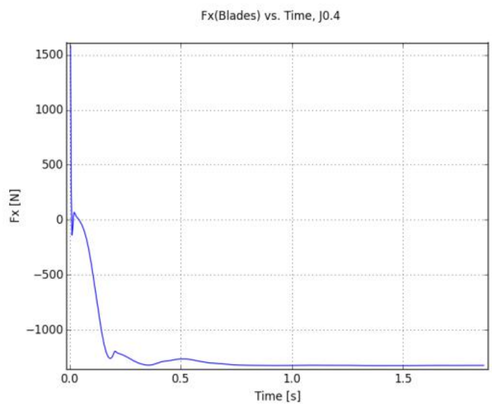
P/D Original J0.4

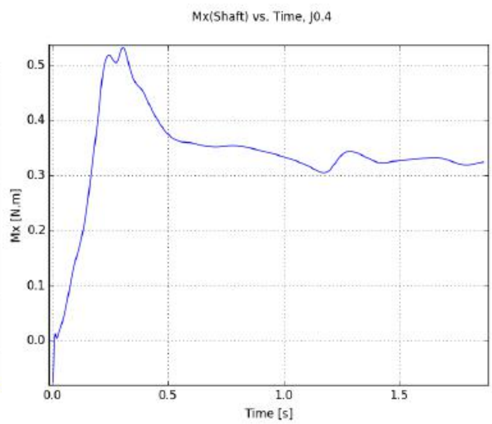




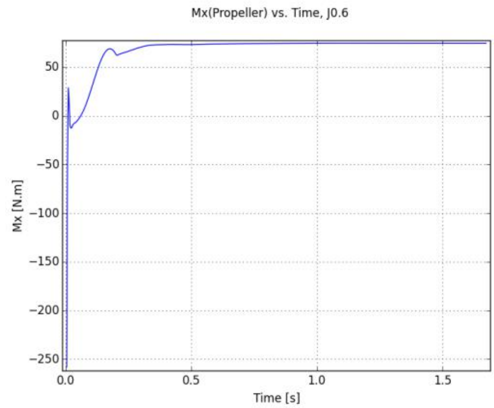


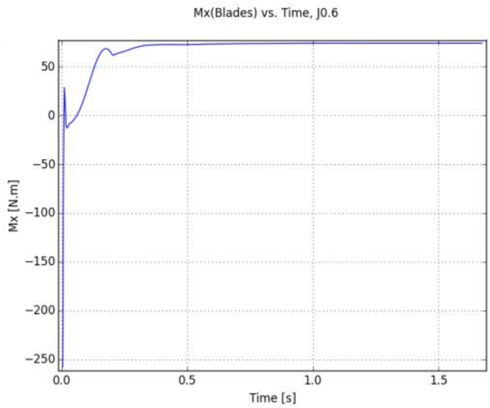


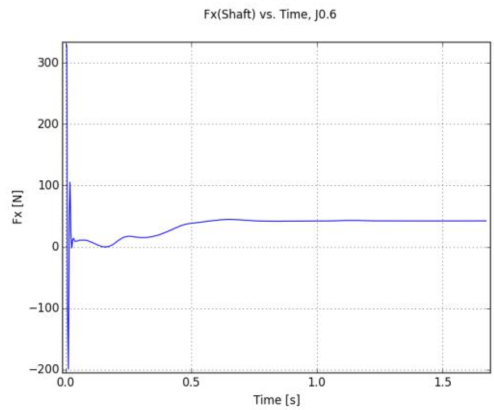


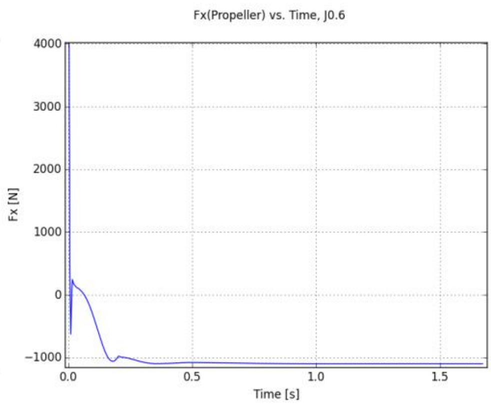


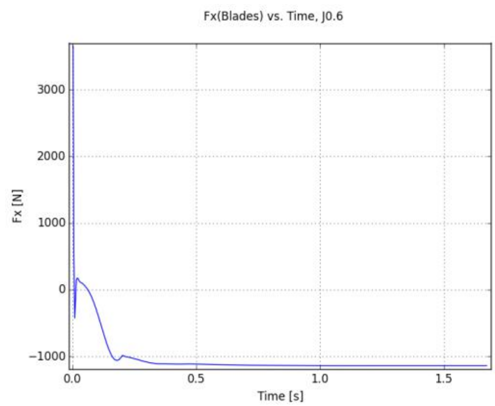
P/D Original J0.6

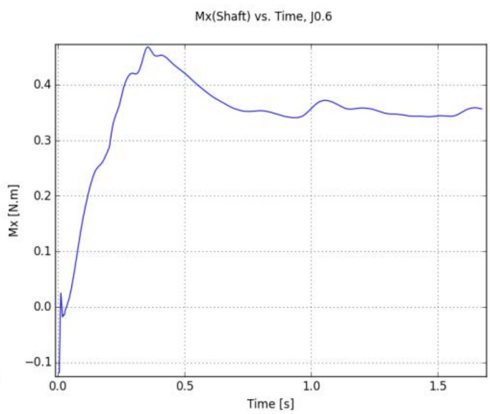




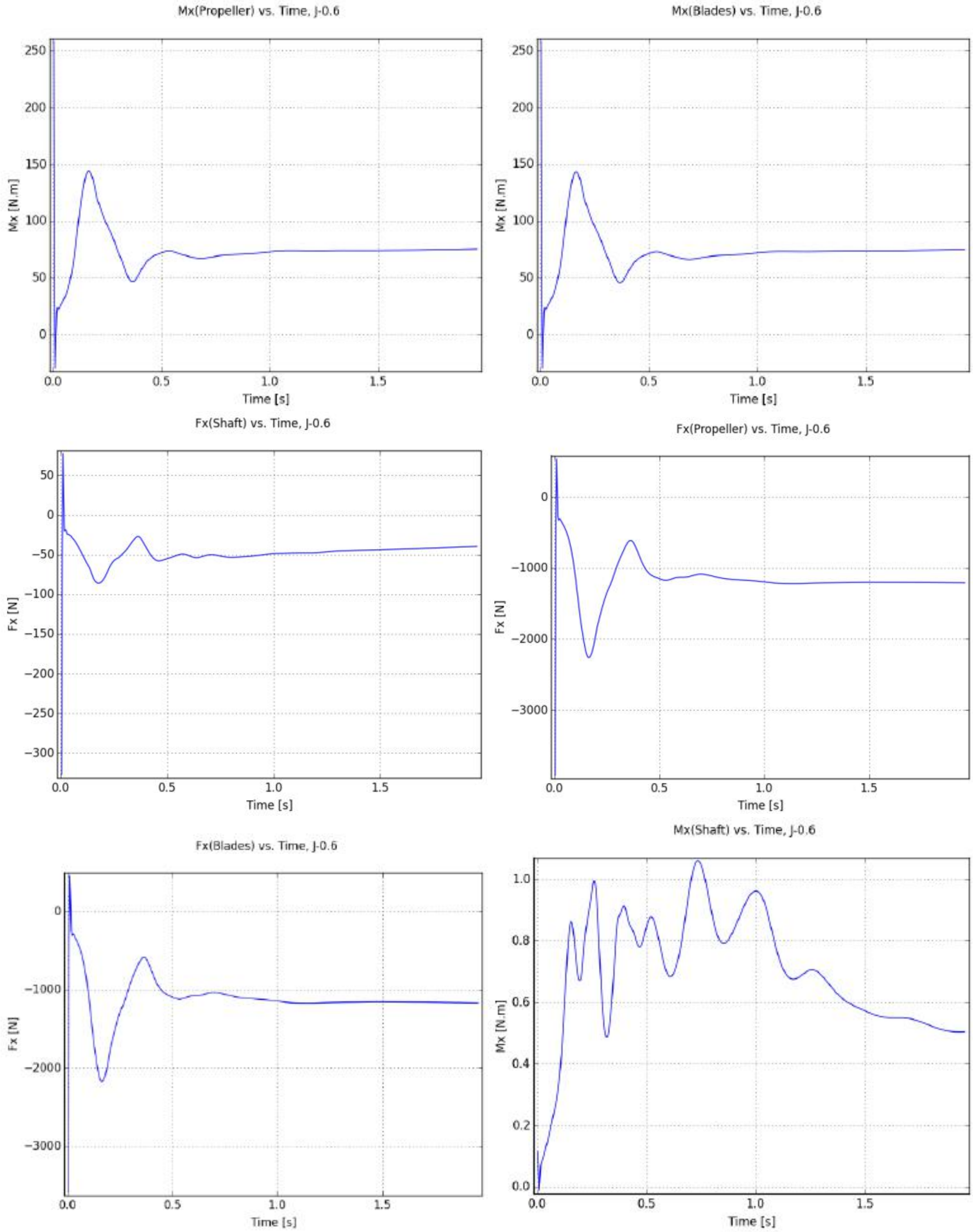




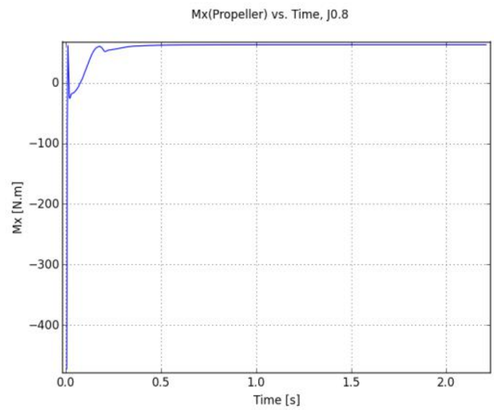


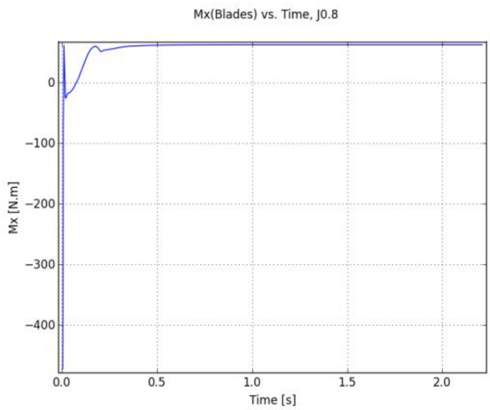


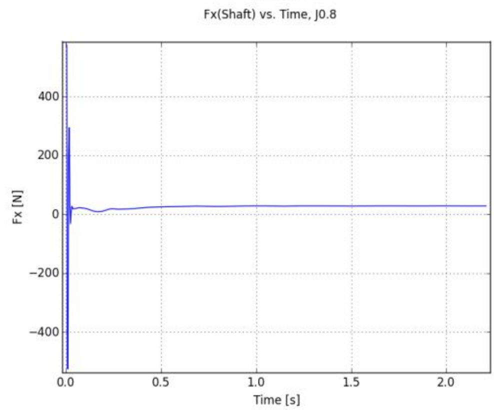
P/D Original J-0.6

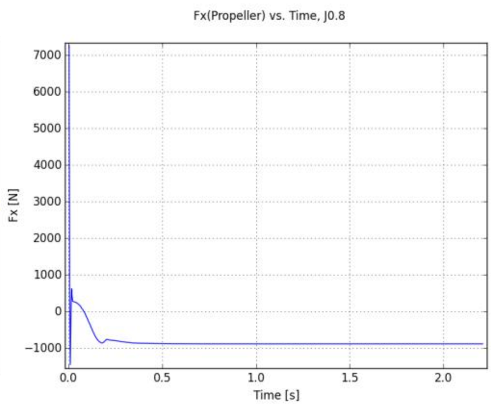


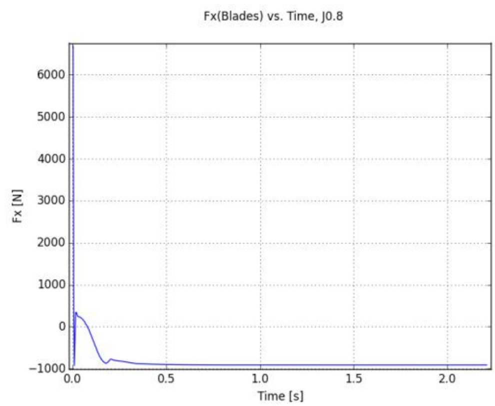
P/D Original J0.8

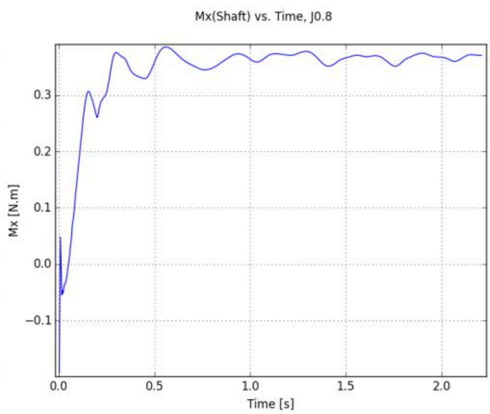




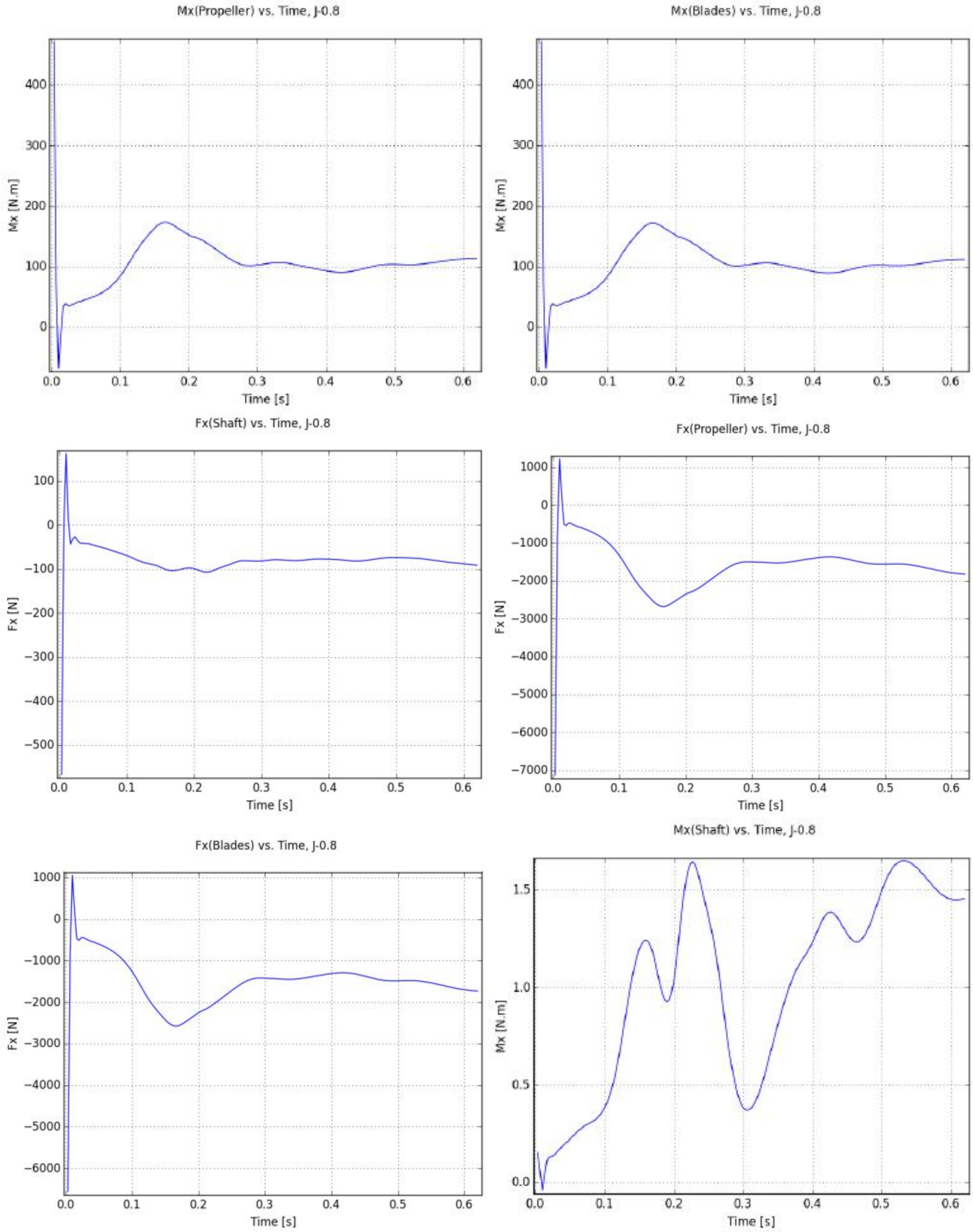




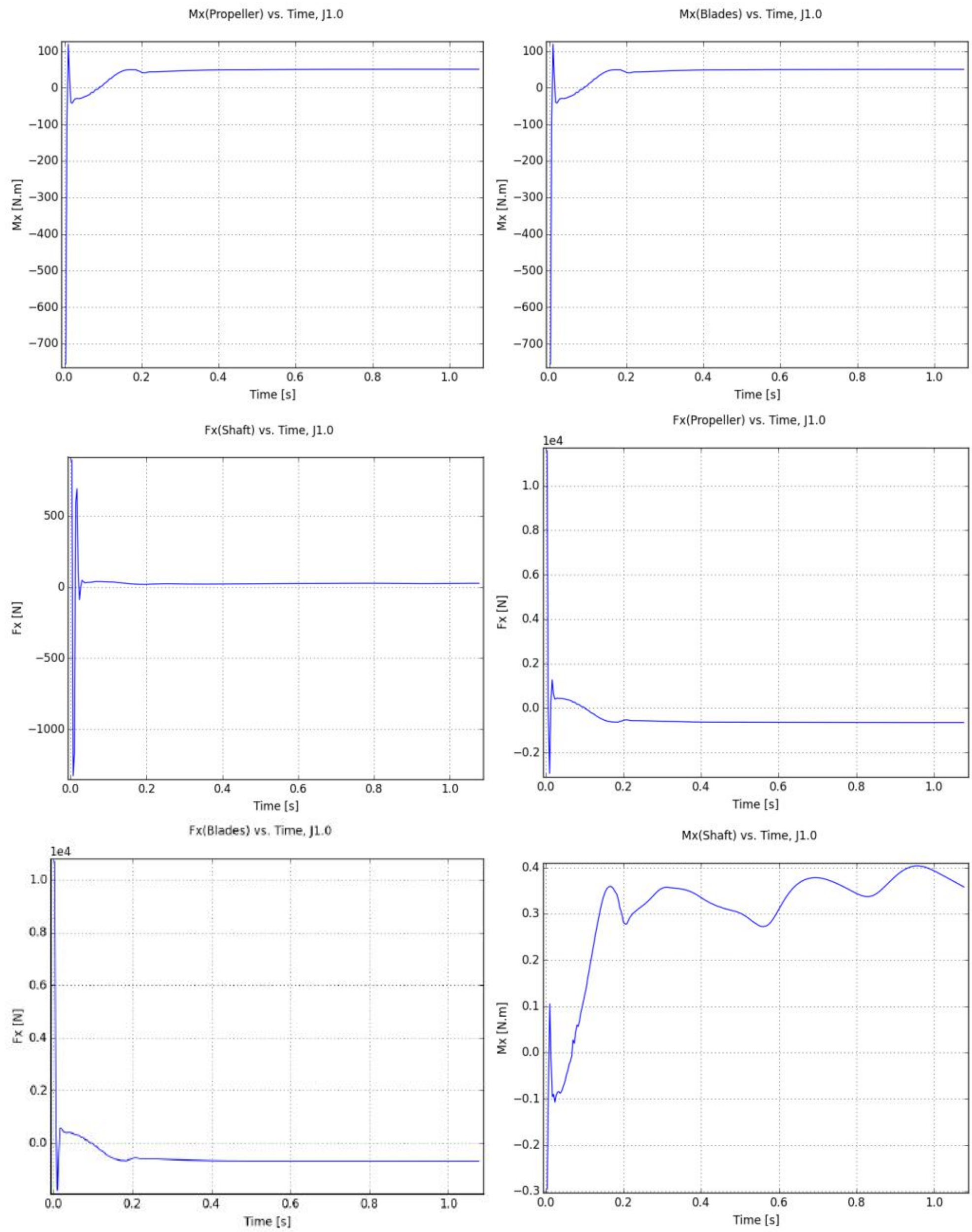




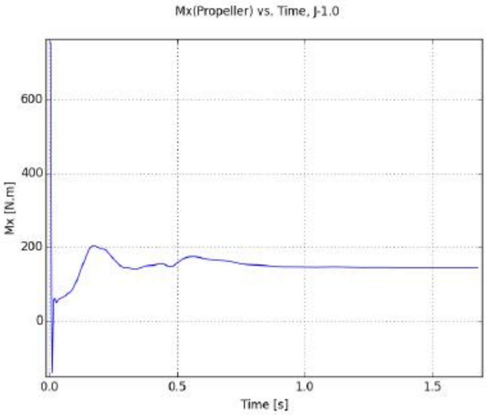
P/D Original J-0.8

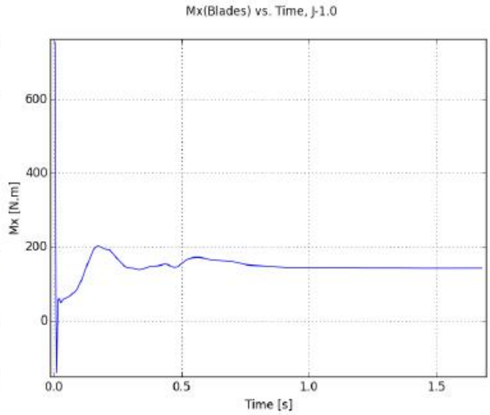


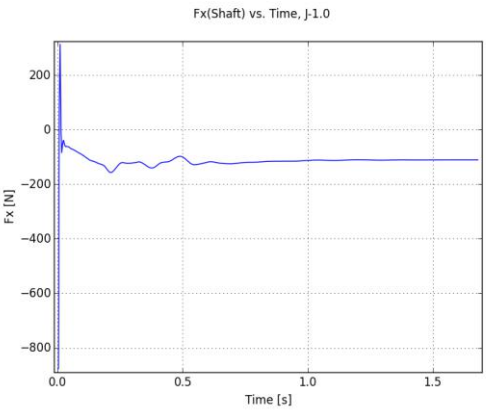
P/D Original J1.0

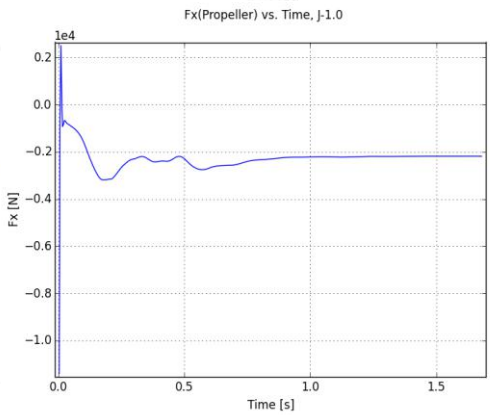


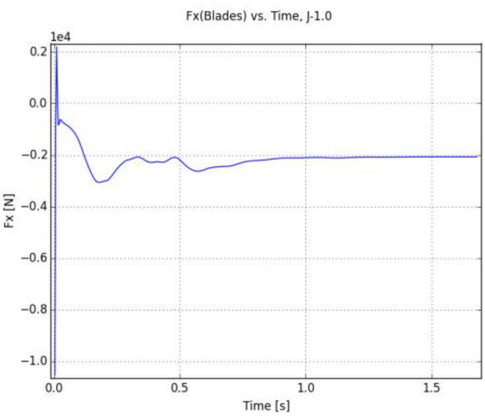
P/D Original J-1.0

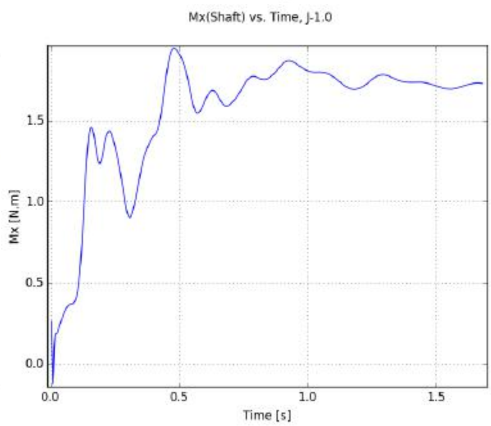




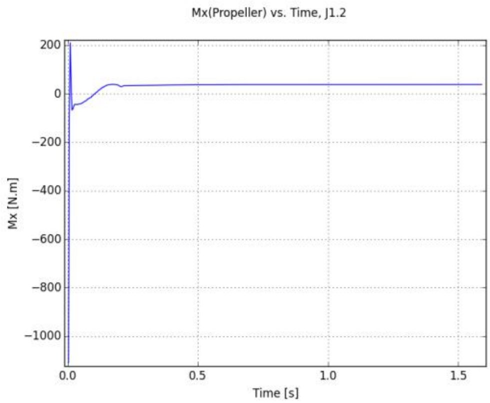


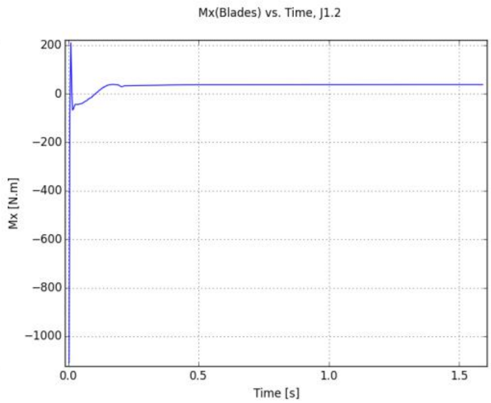


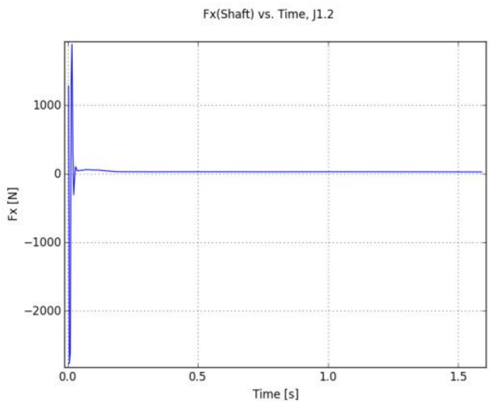


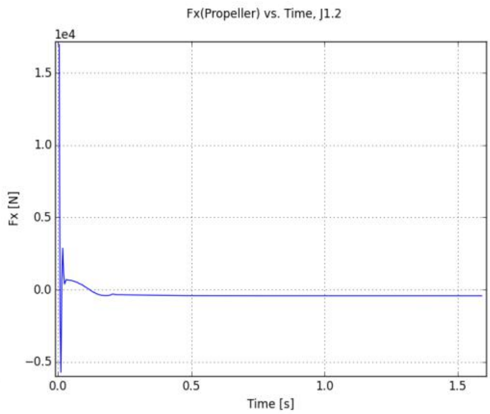


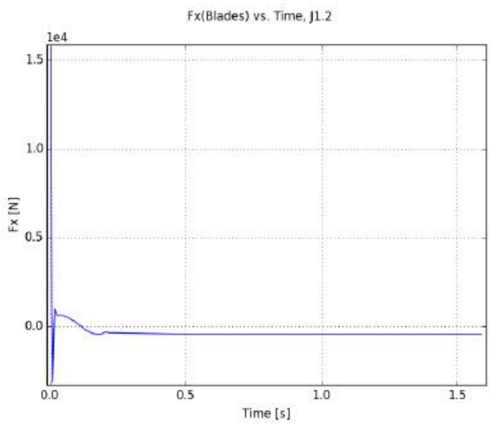
P/D Original J1.2

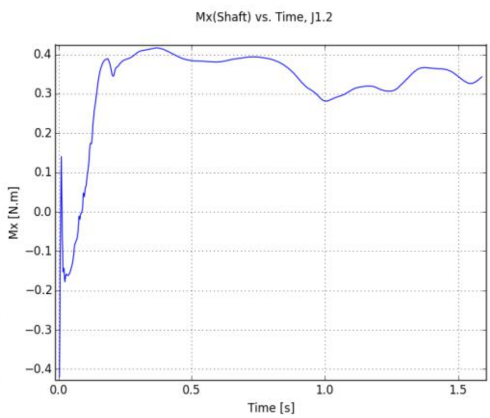




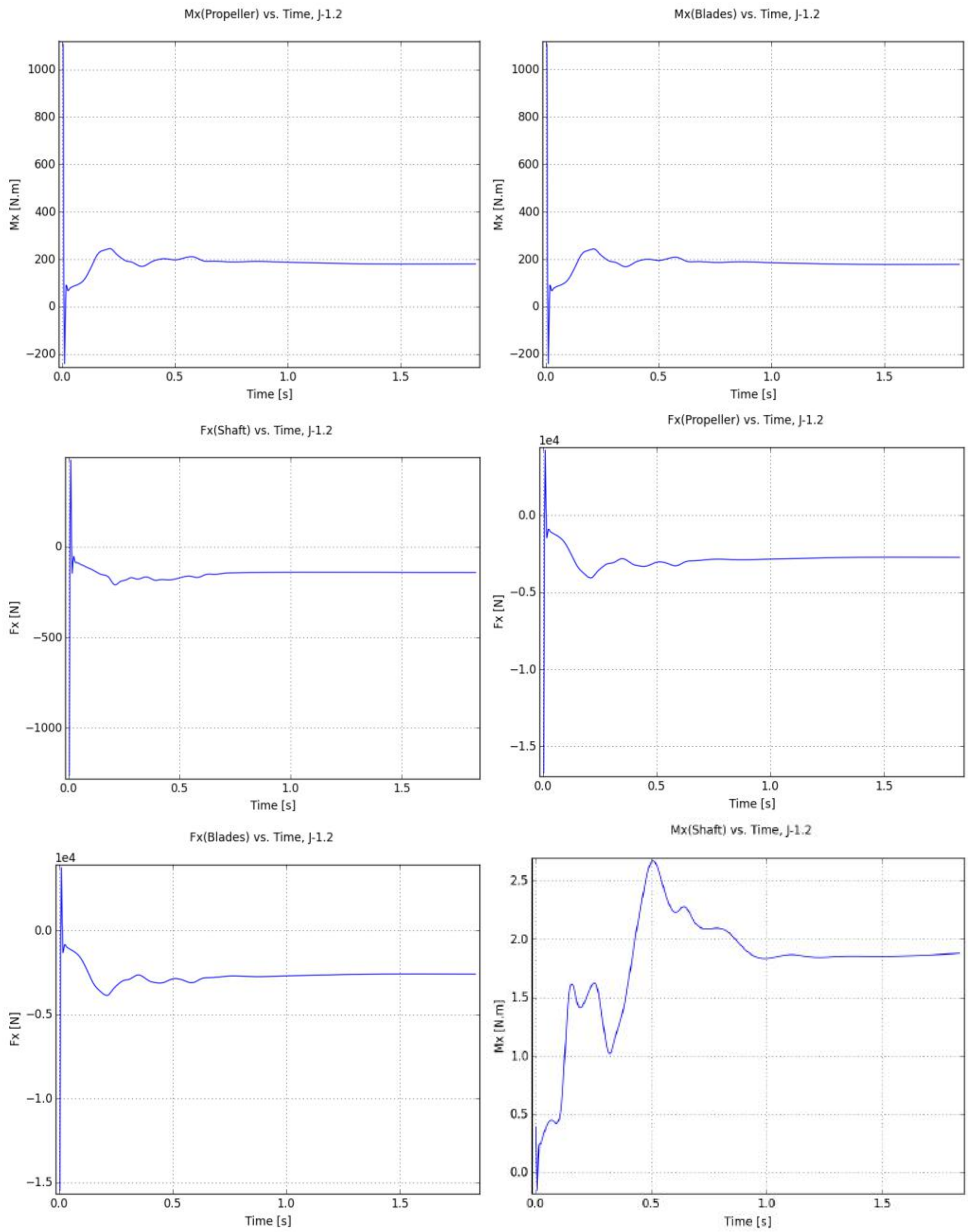




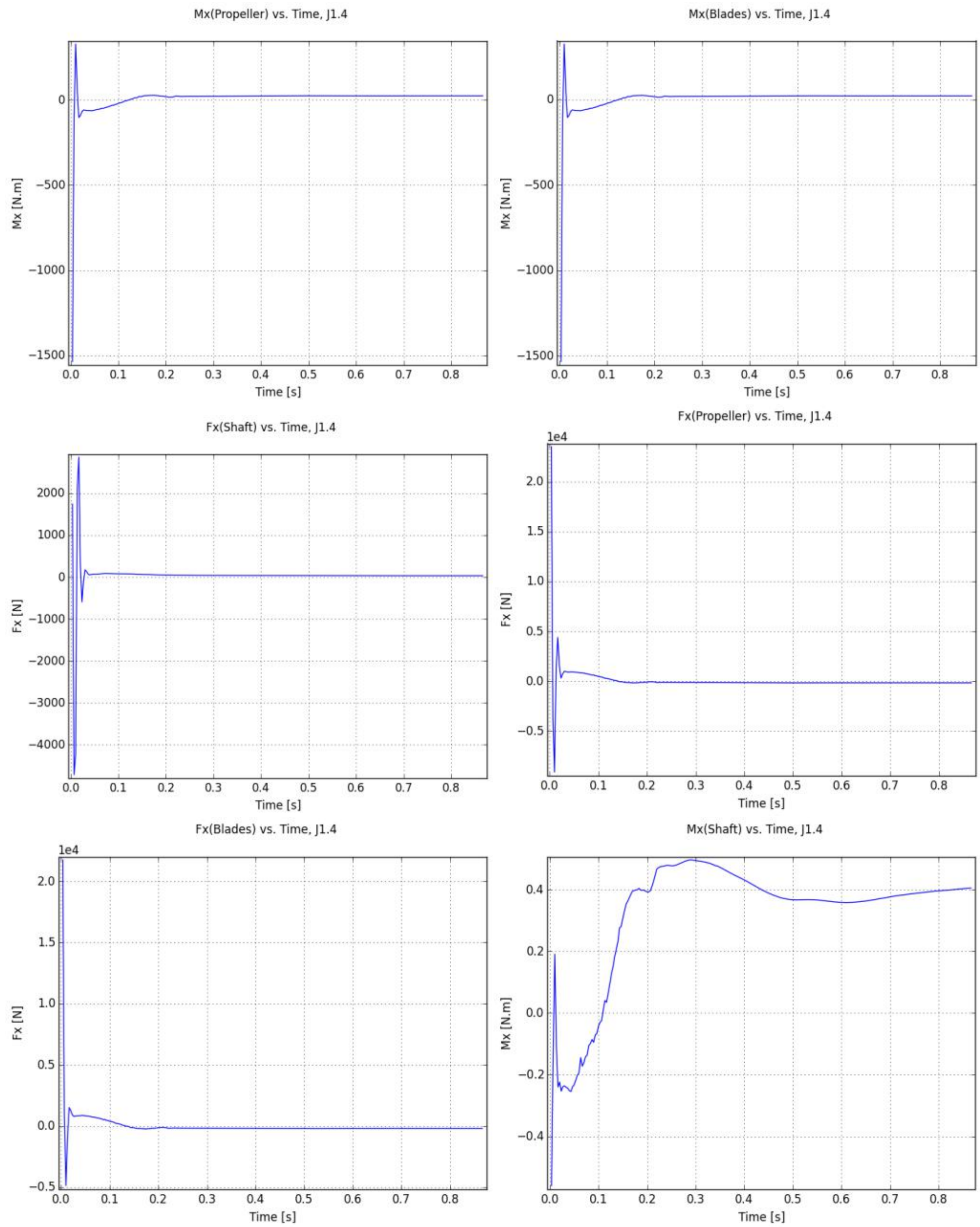




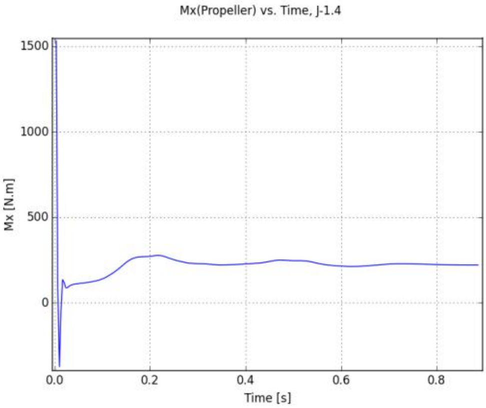
P/D Original J-1.2

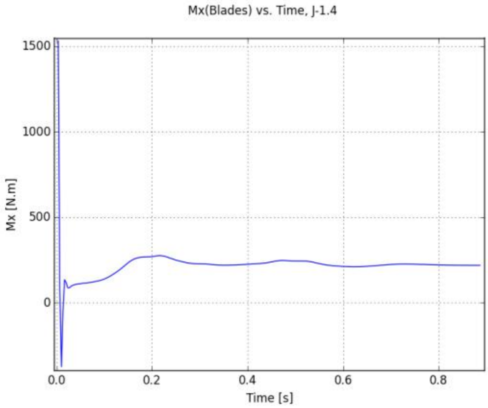


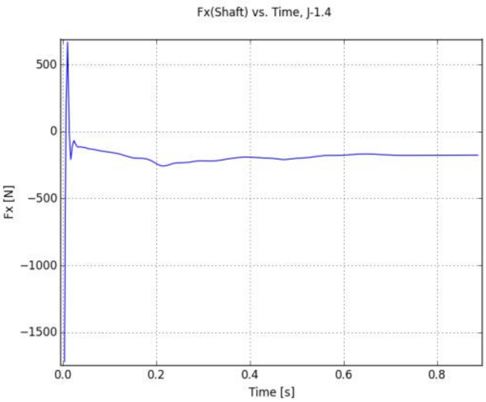
P/D Original J1.4

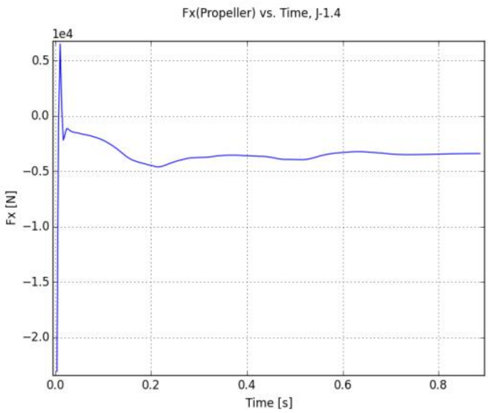


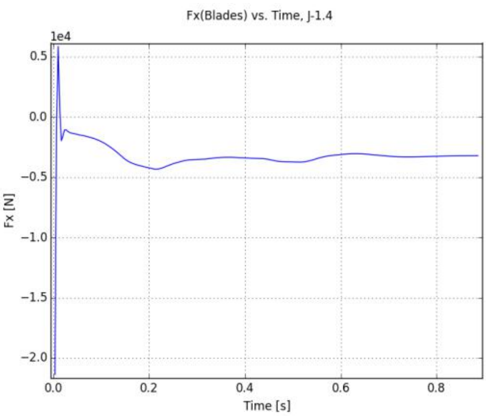
P/D Original J-1.4

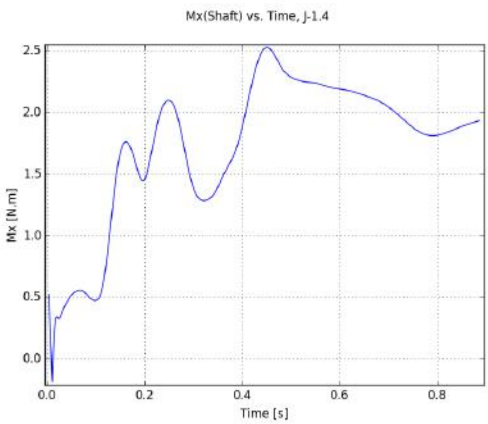




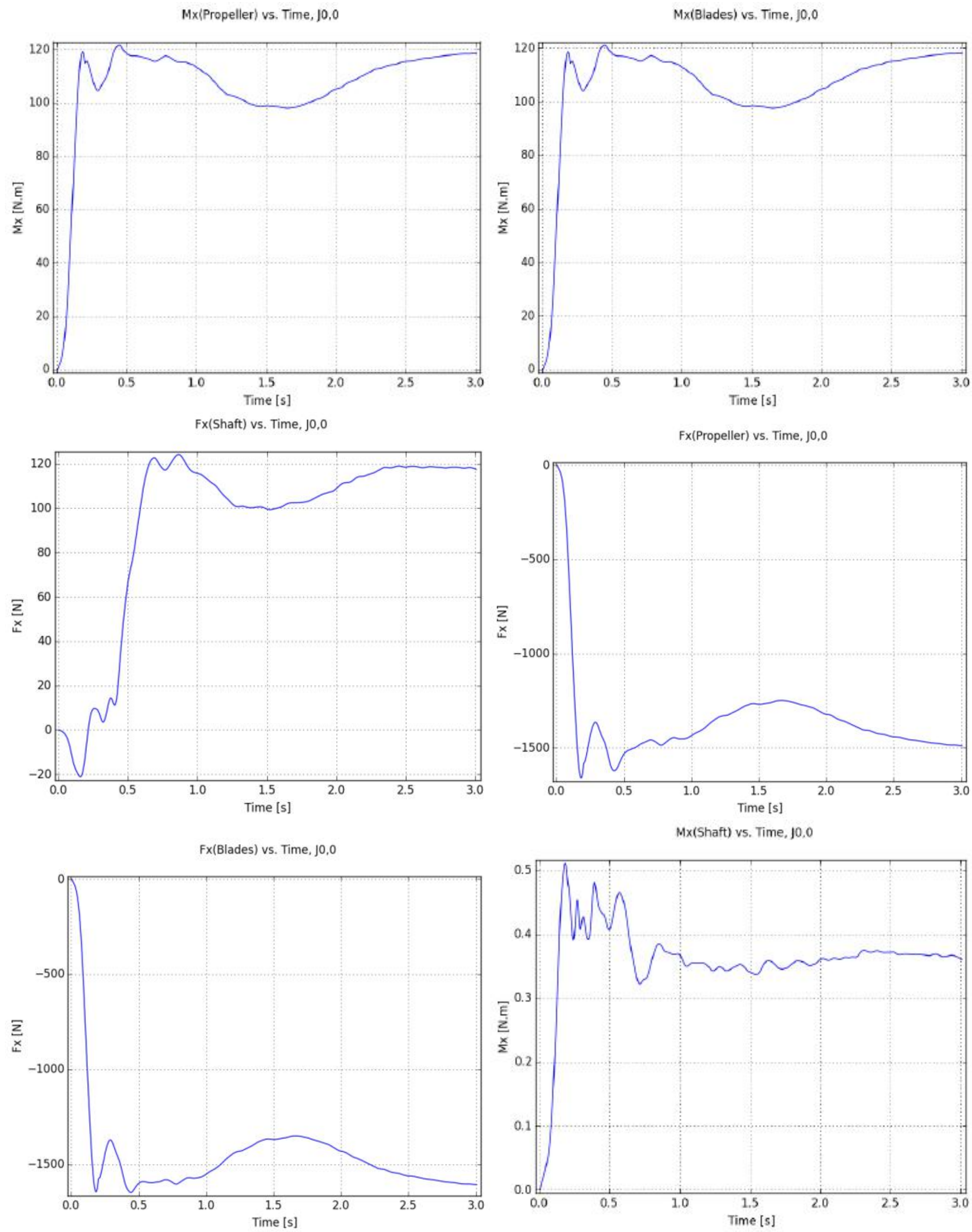




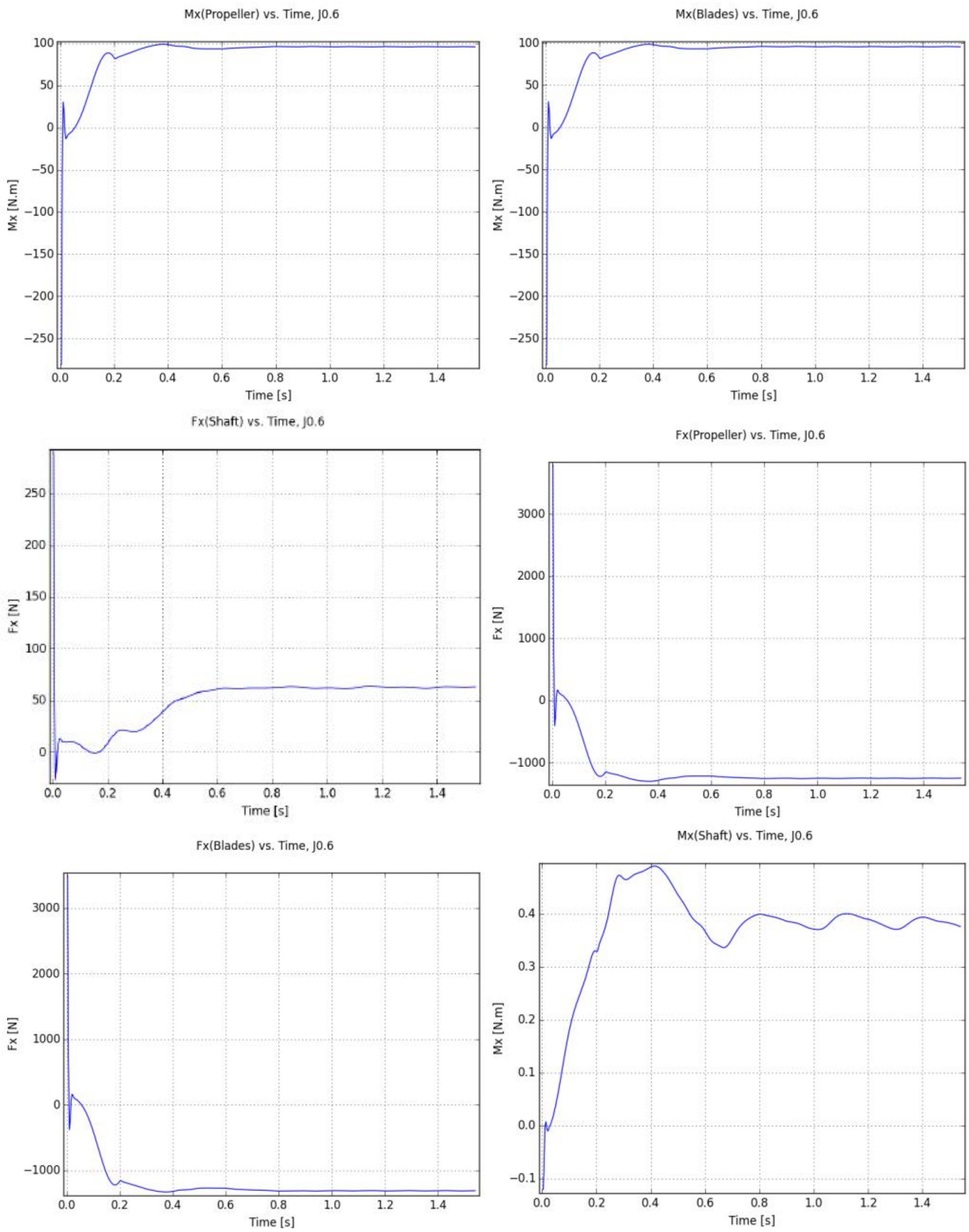




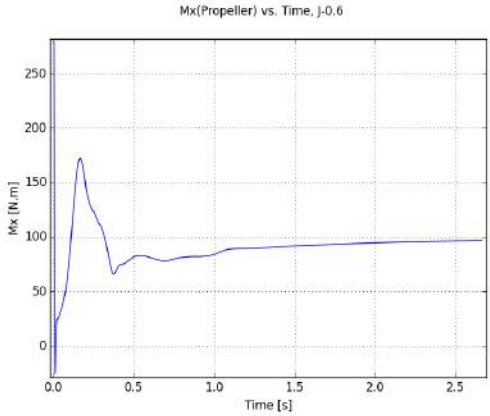
P/D Plus 1.6 J0.0

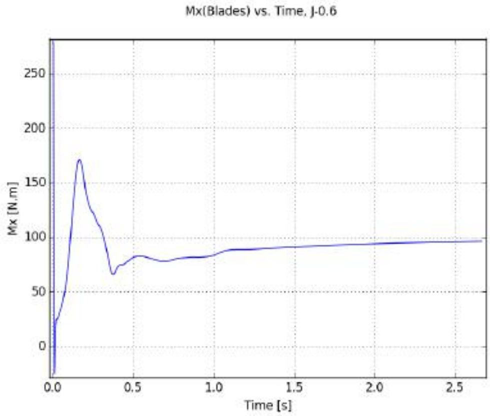


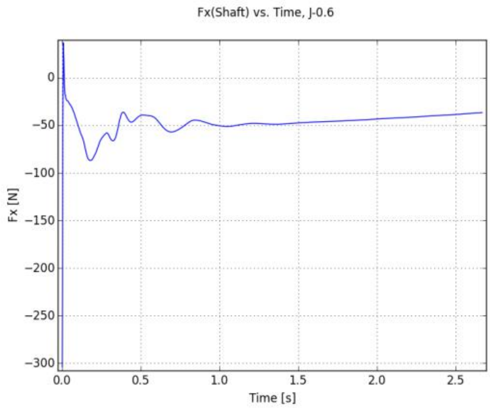
P/D Plus 1.6 J0.6

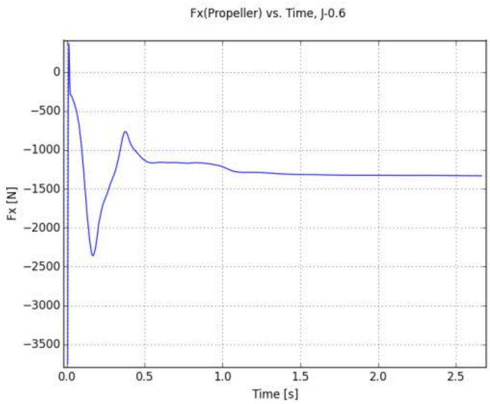


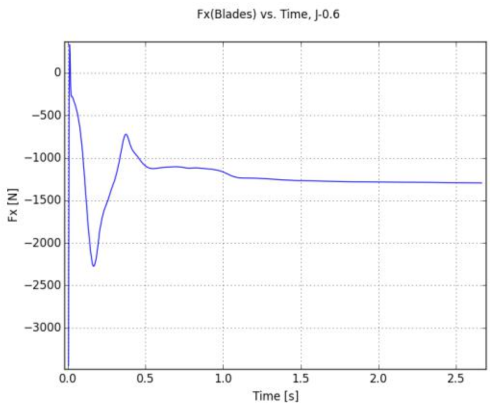
P/D Plus 1.6 J-0.6

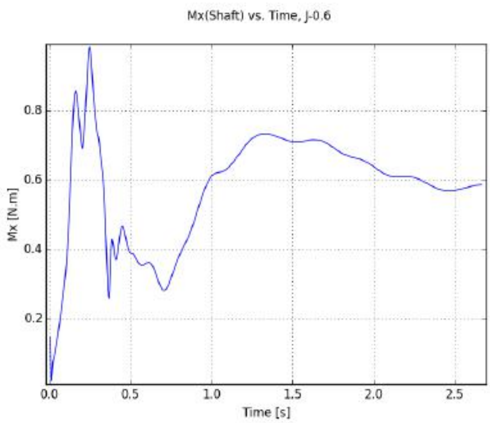




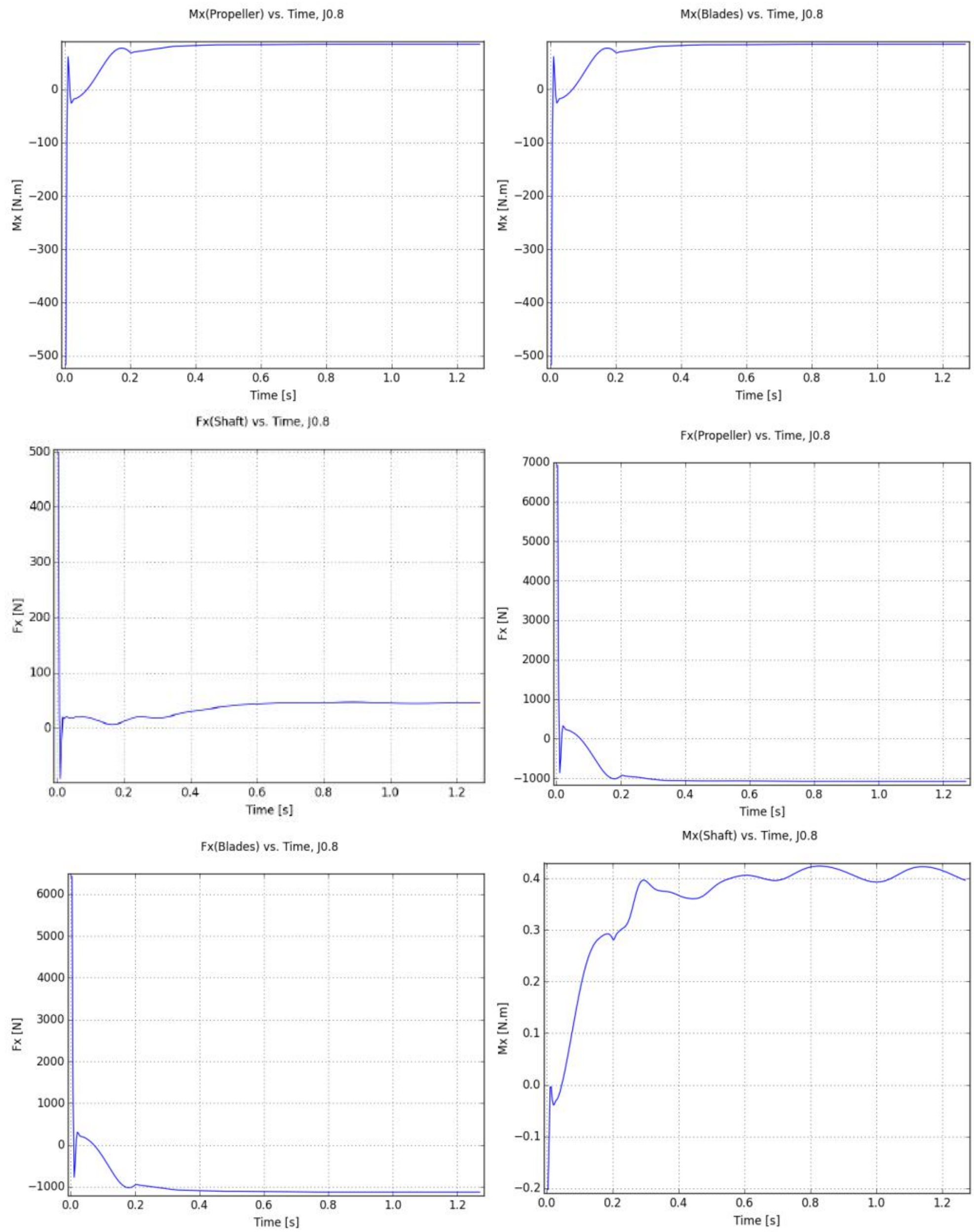




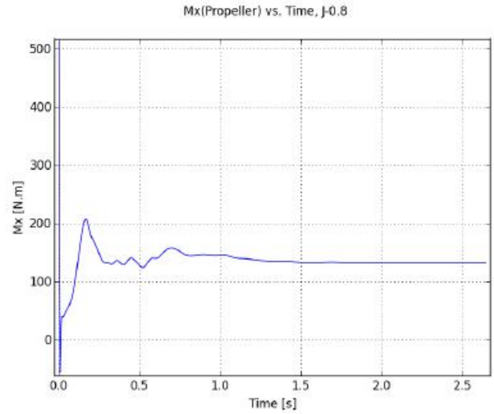


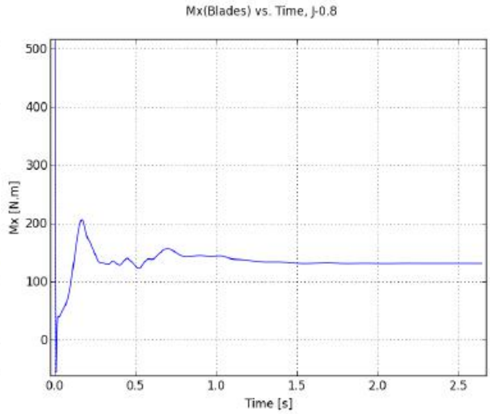


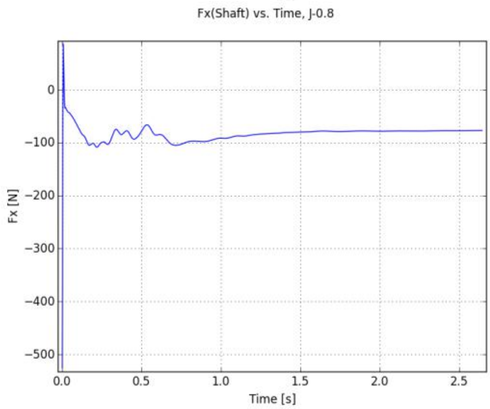
P/D Plus 1.6 J0.8

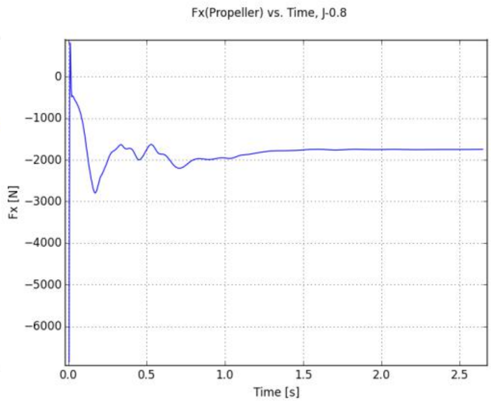


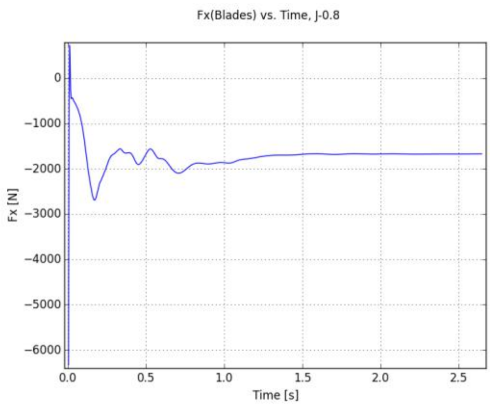
P/D Plus 1.6 J-0.8

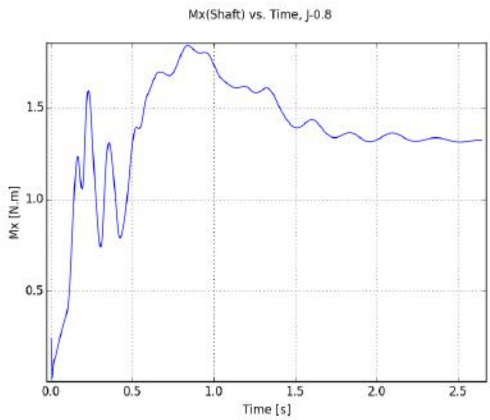




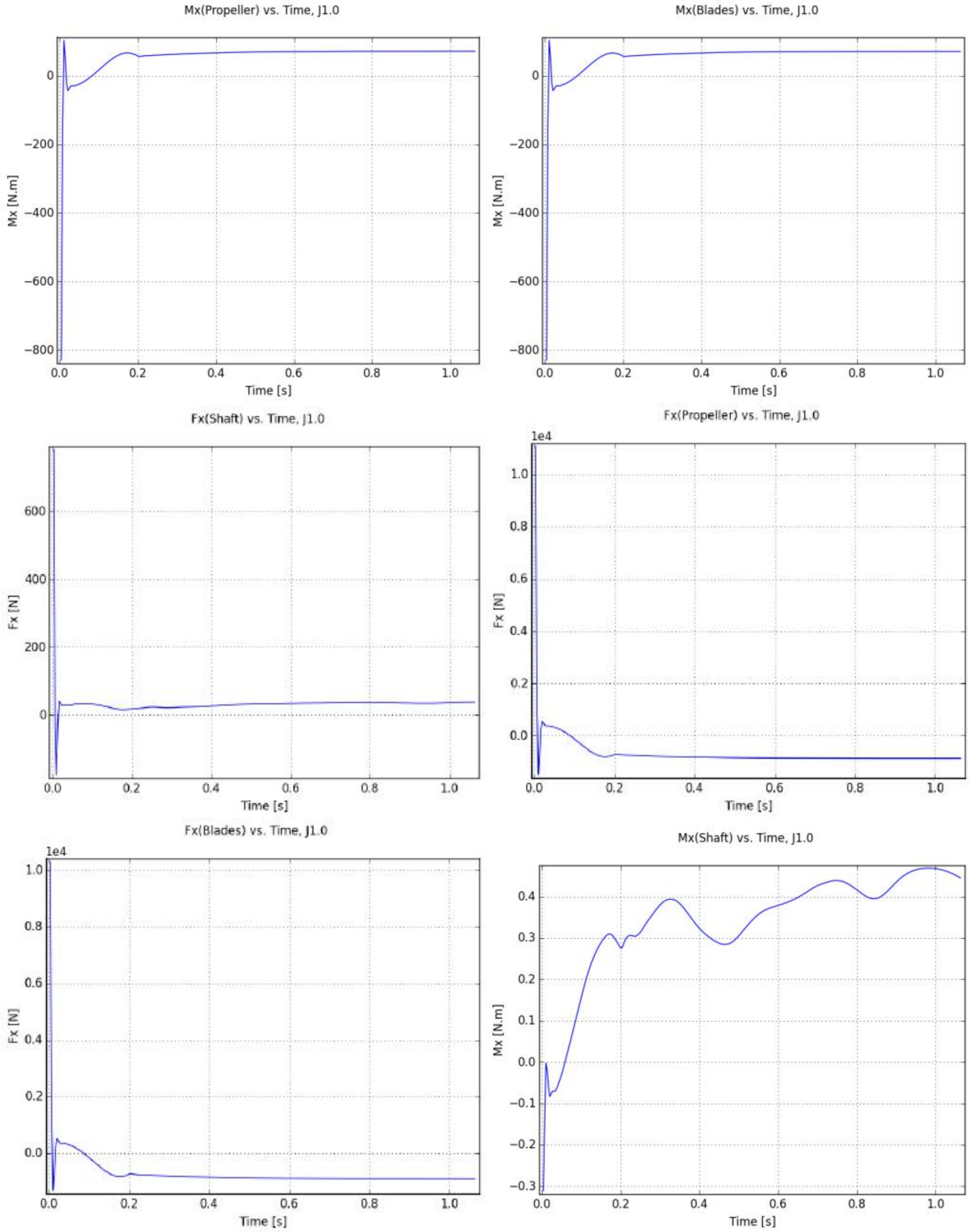




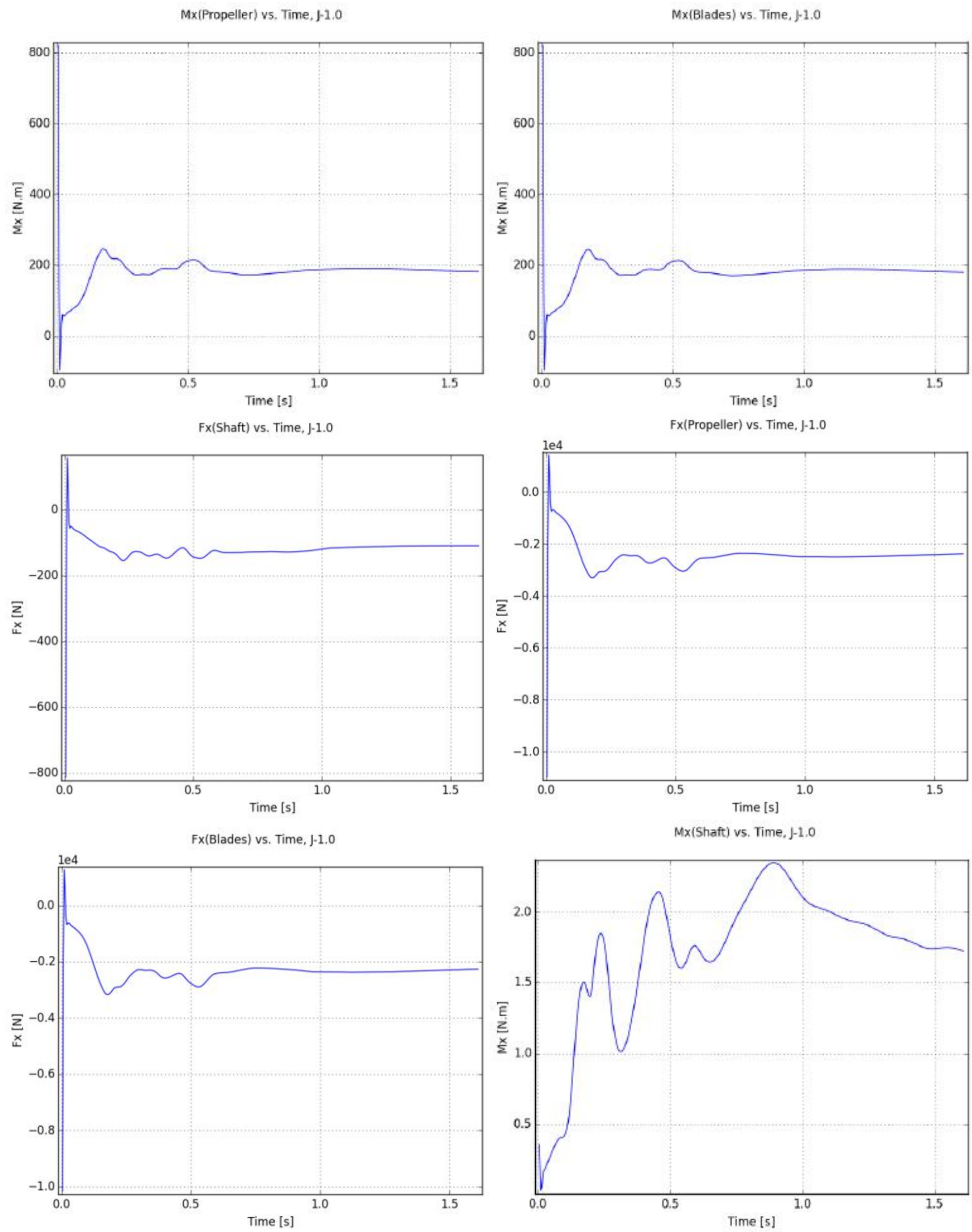




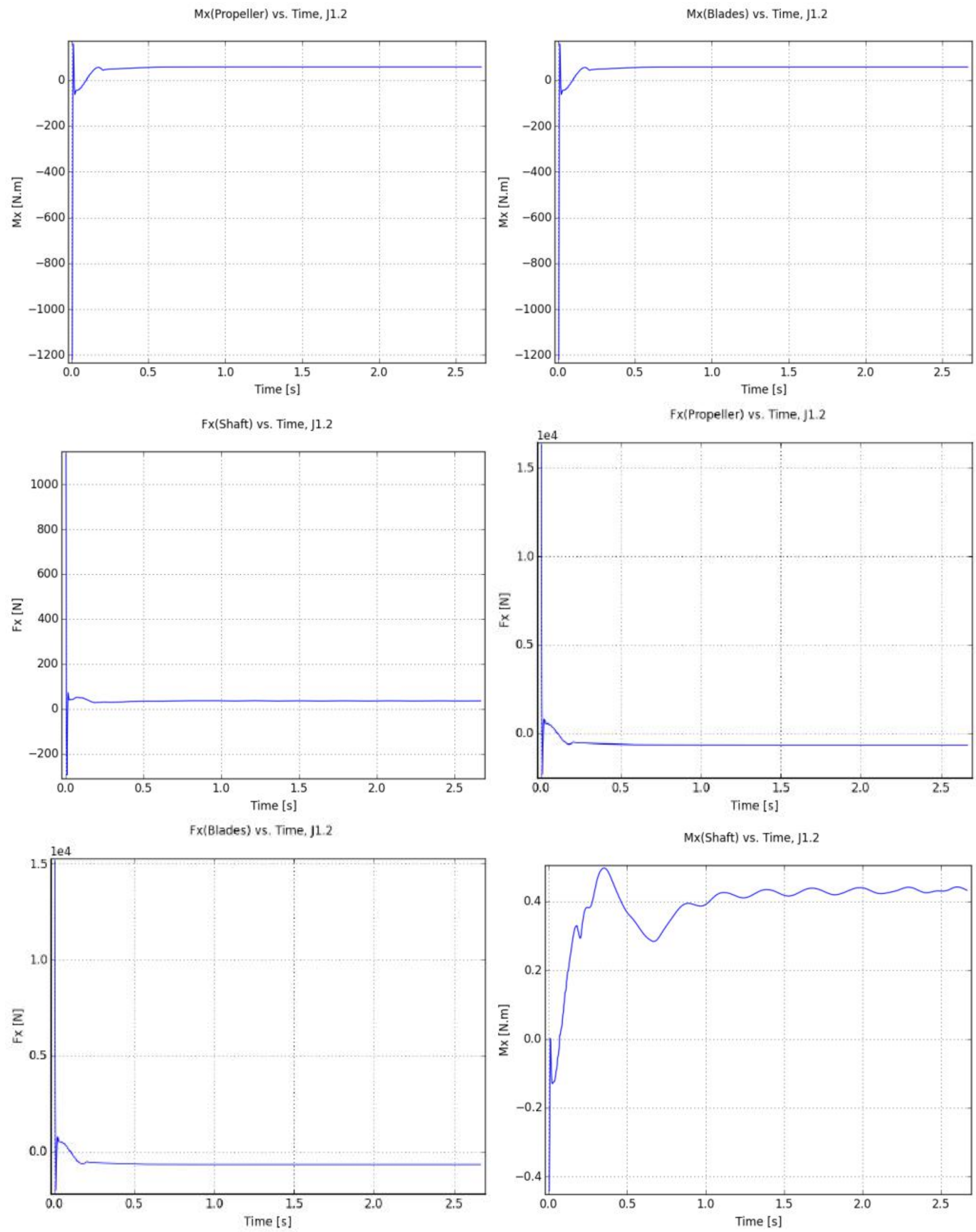
P/D Plus 1.6 J1.0



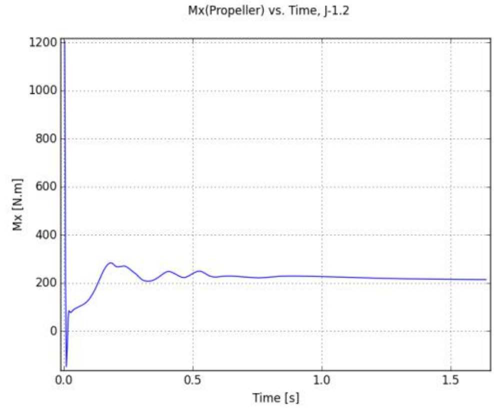
P/D Plus 1.6 J-1.0

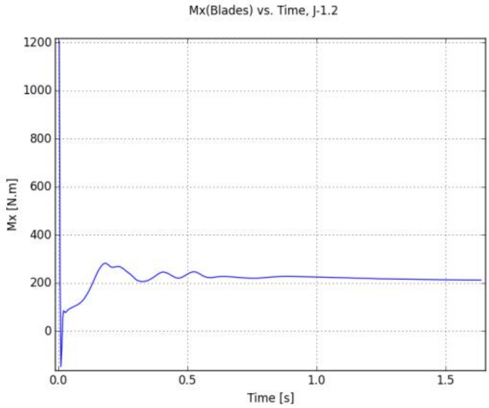


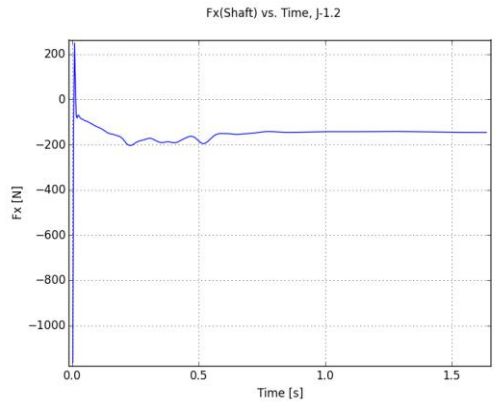
P/D Plus 1.6 J1.2

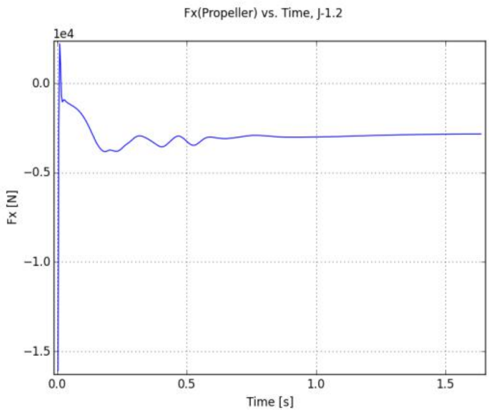


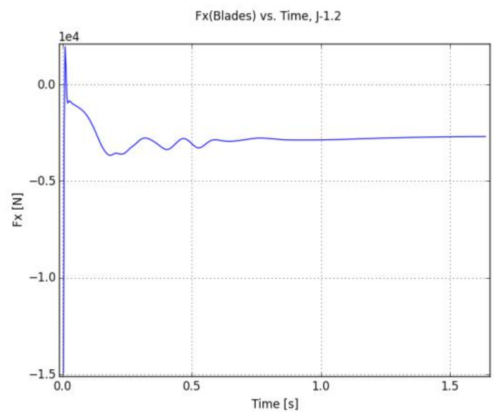
P/D Plus 1.6 J-1.2

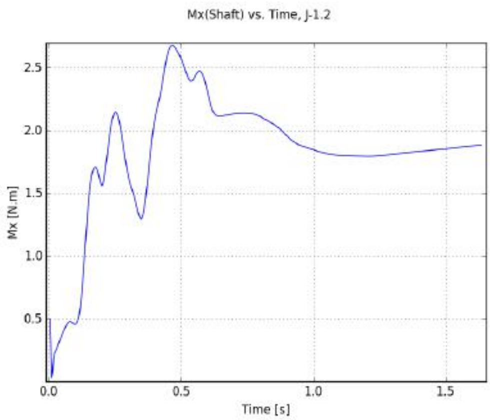




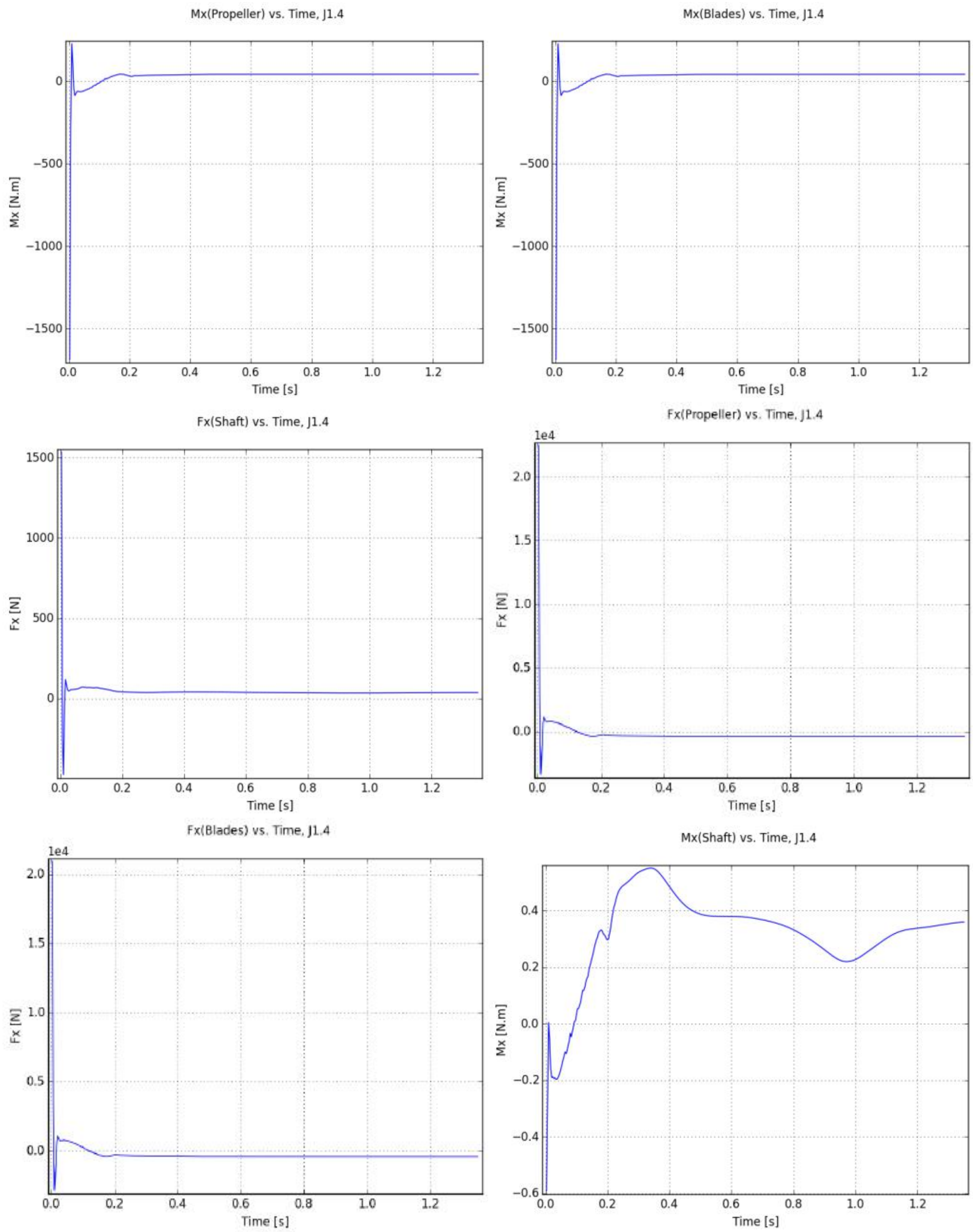




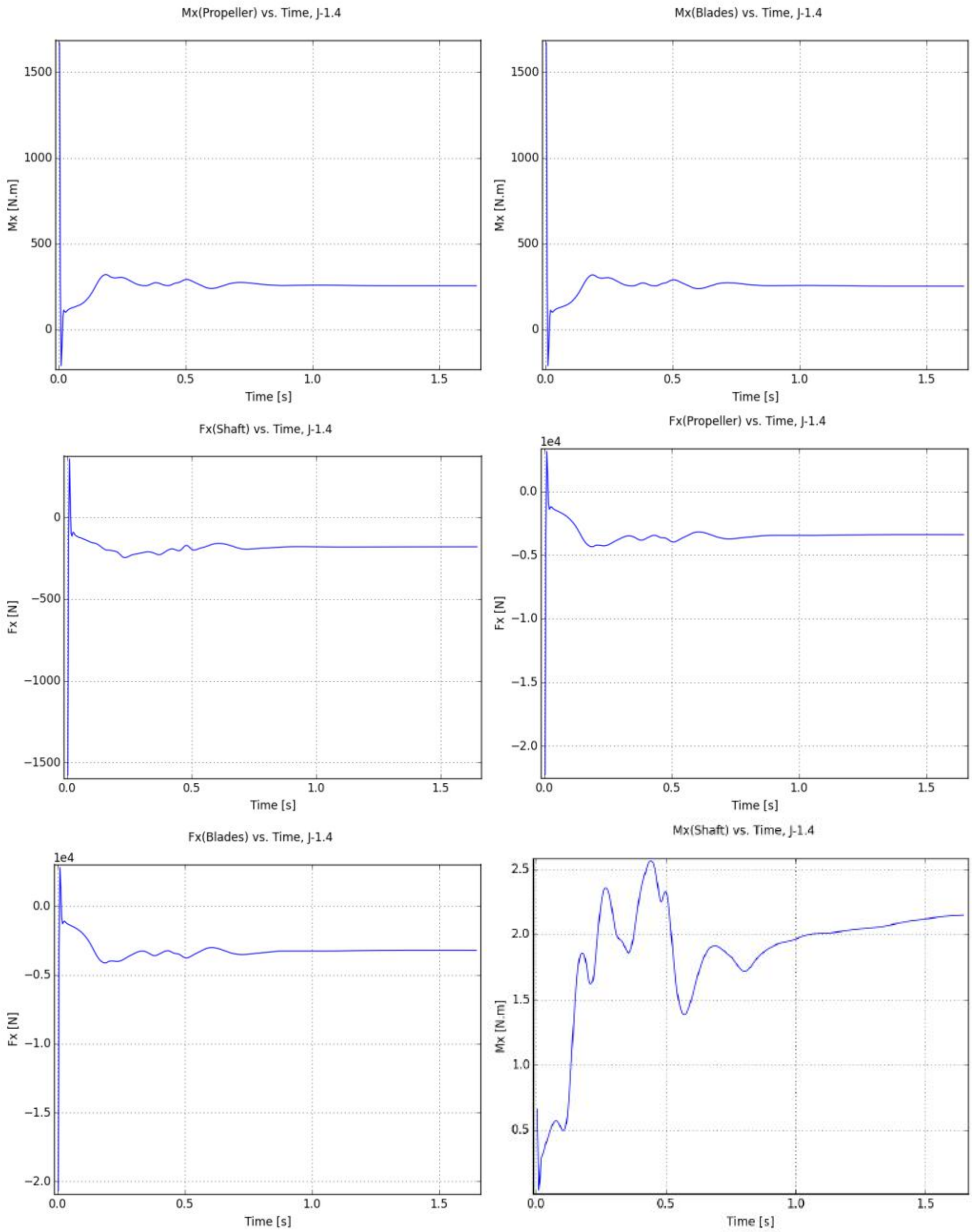




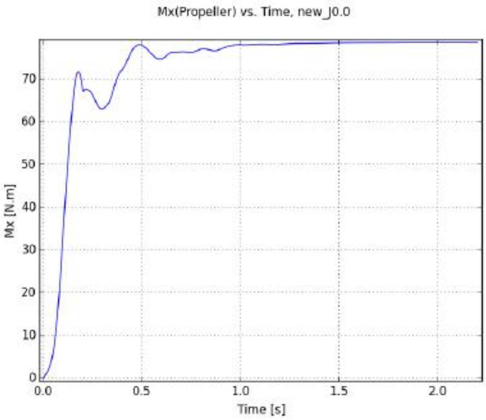
P/D Plus 1.6 J1.4

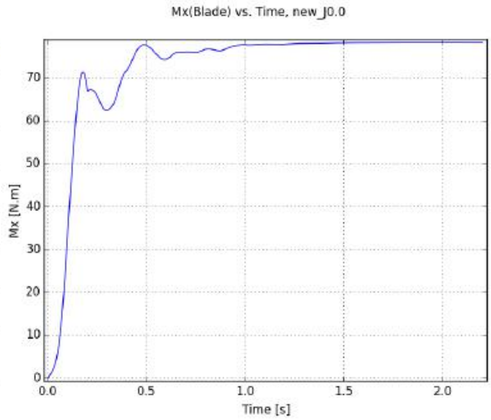


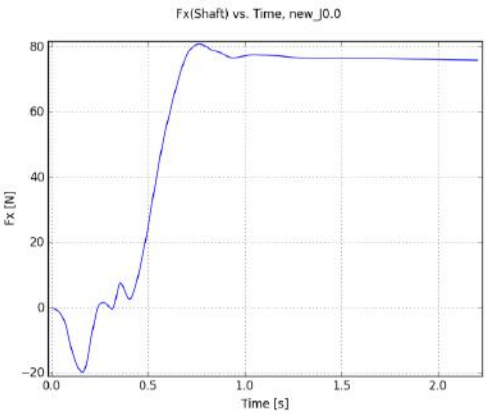
P/D Plus 1.6 J-1.4

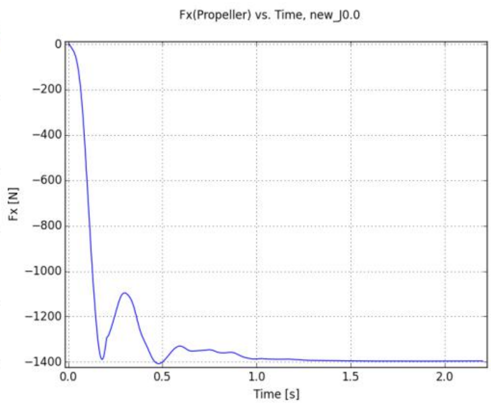


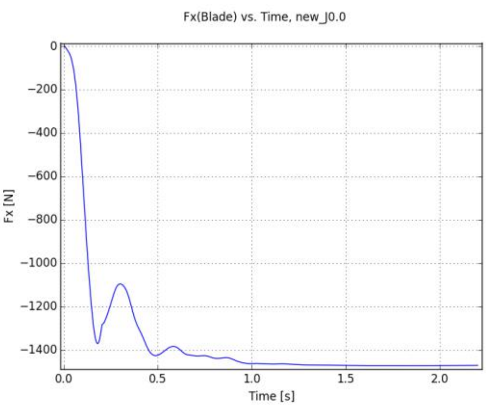
P/D Plus 1.2 J0.0

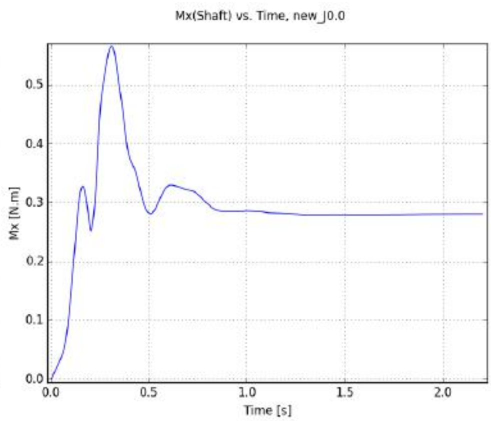




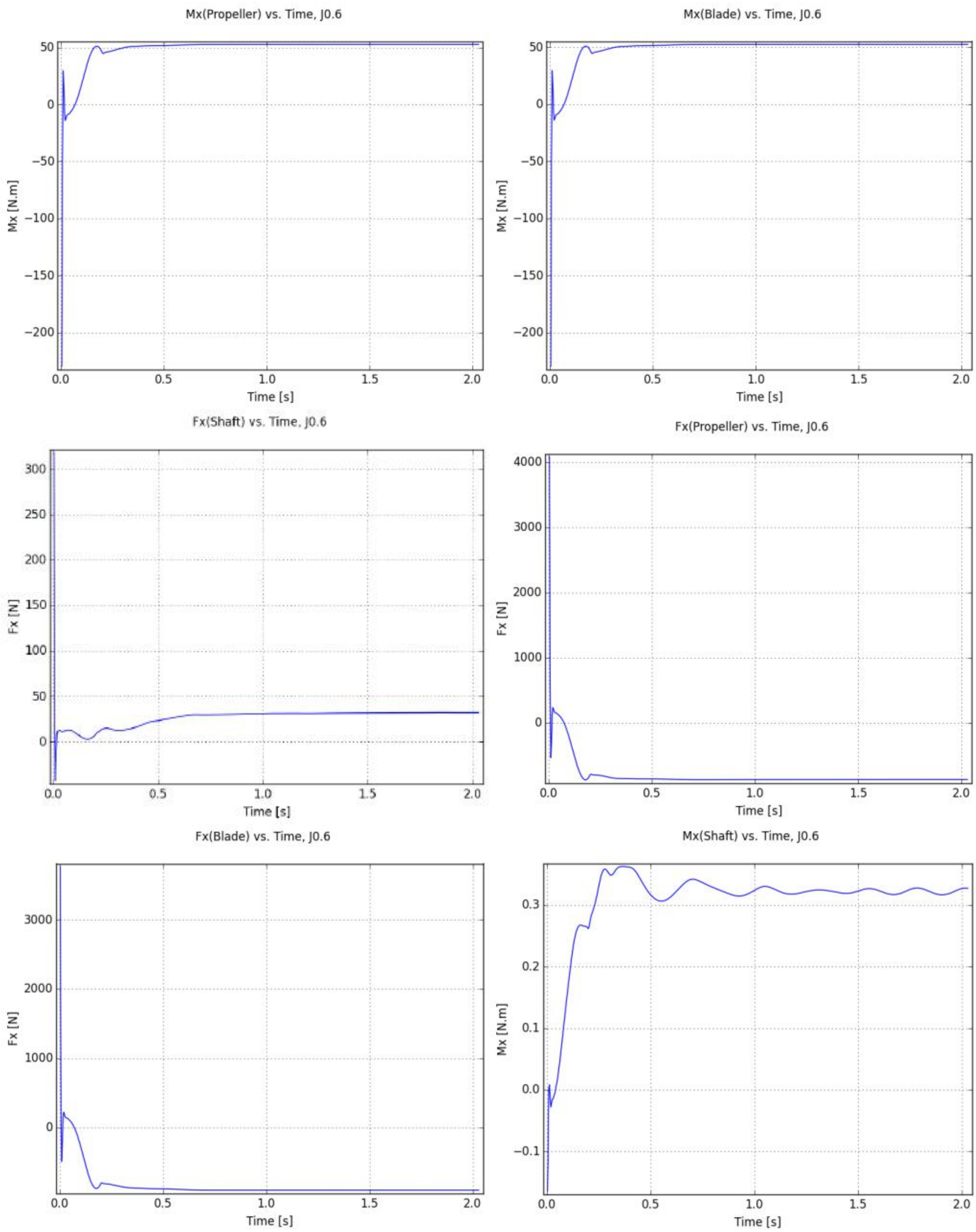




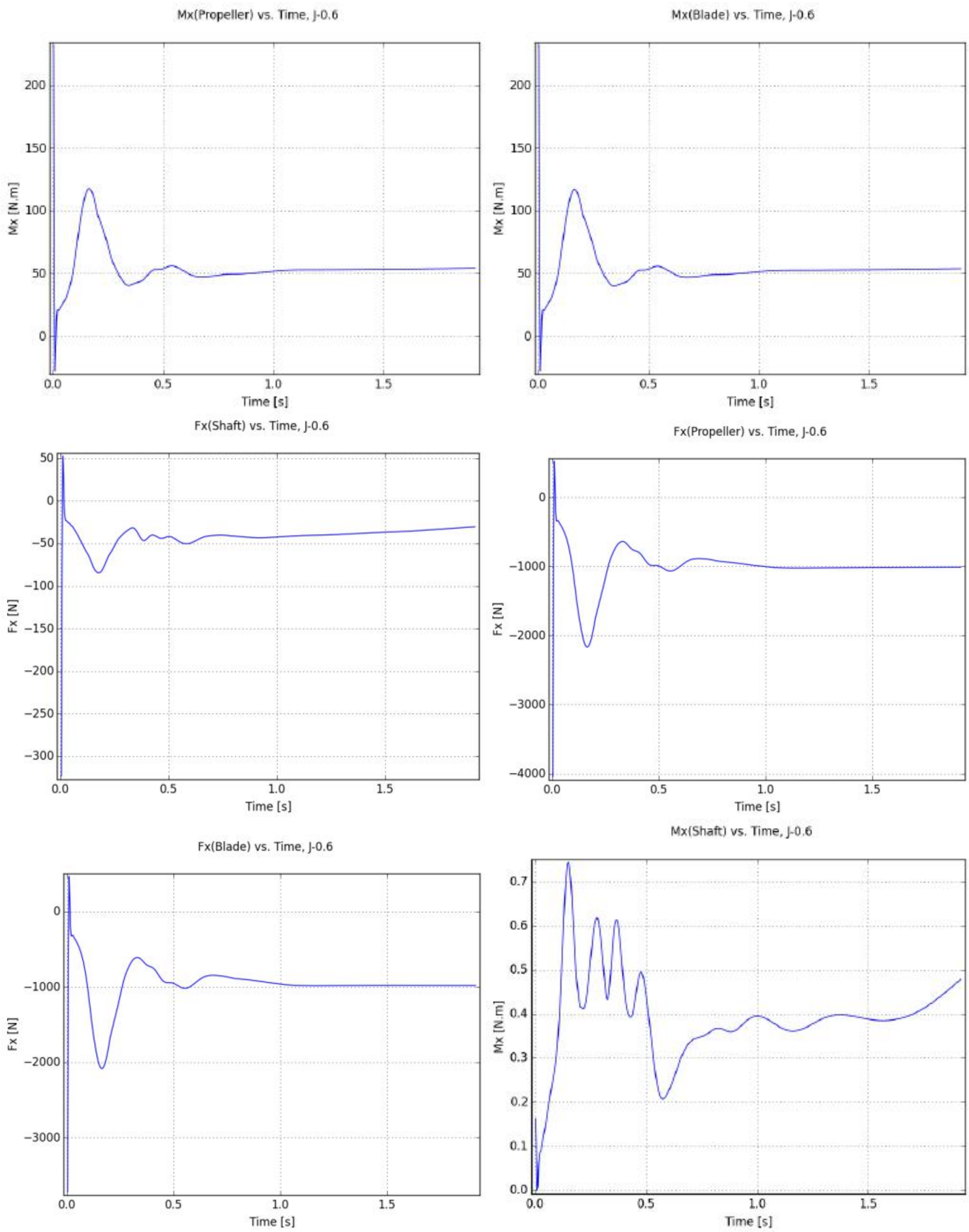




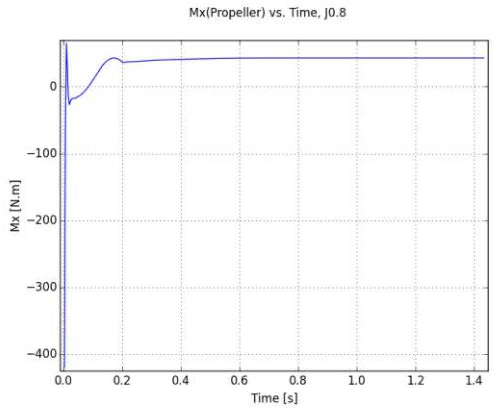
P/D Plus 1.2 J0.6

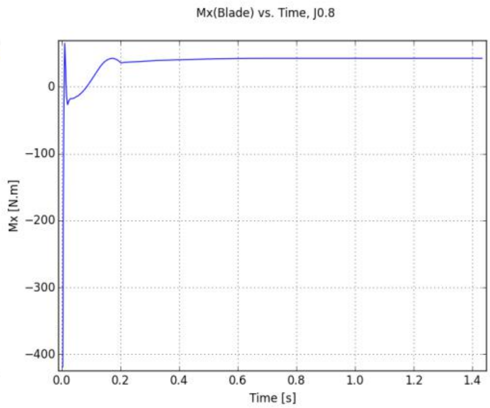


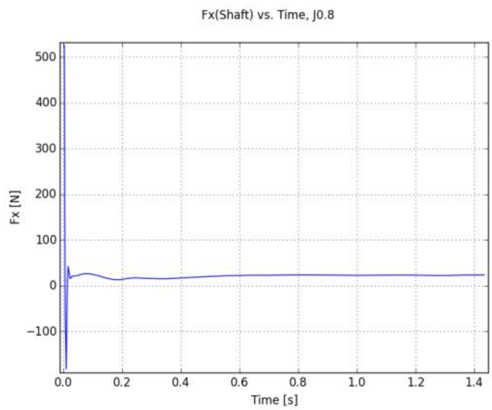
P/D Plus 1.2 J-0.6

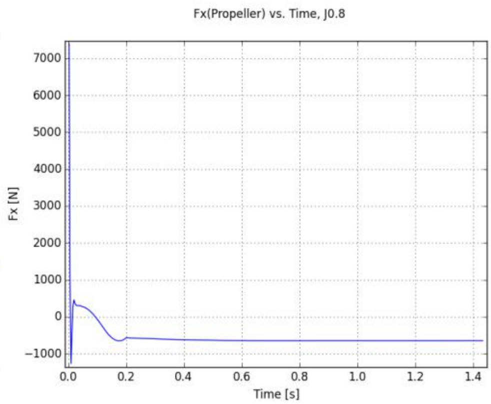


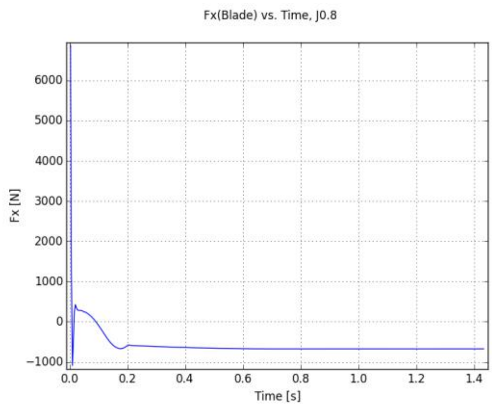
P/D Plus 1.2 J0.8

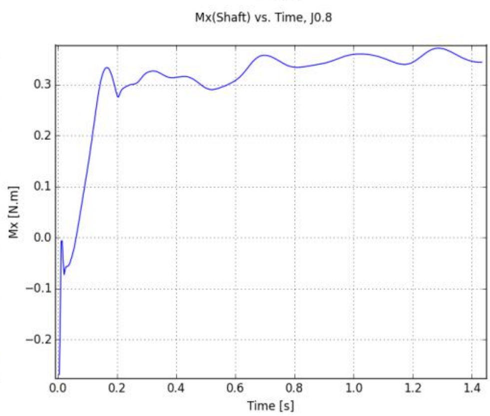




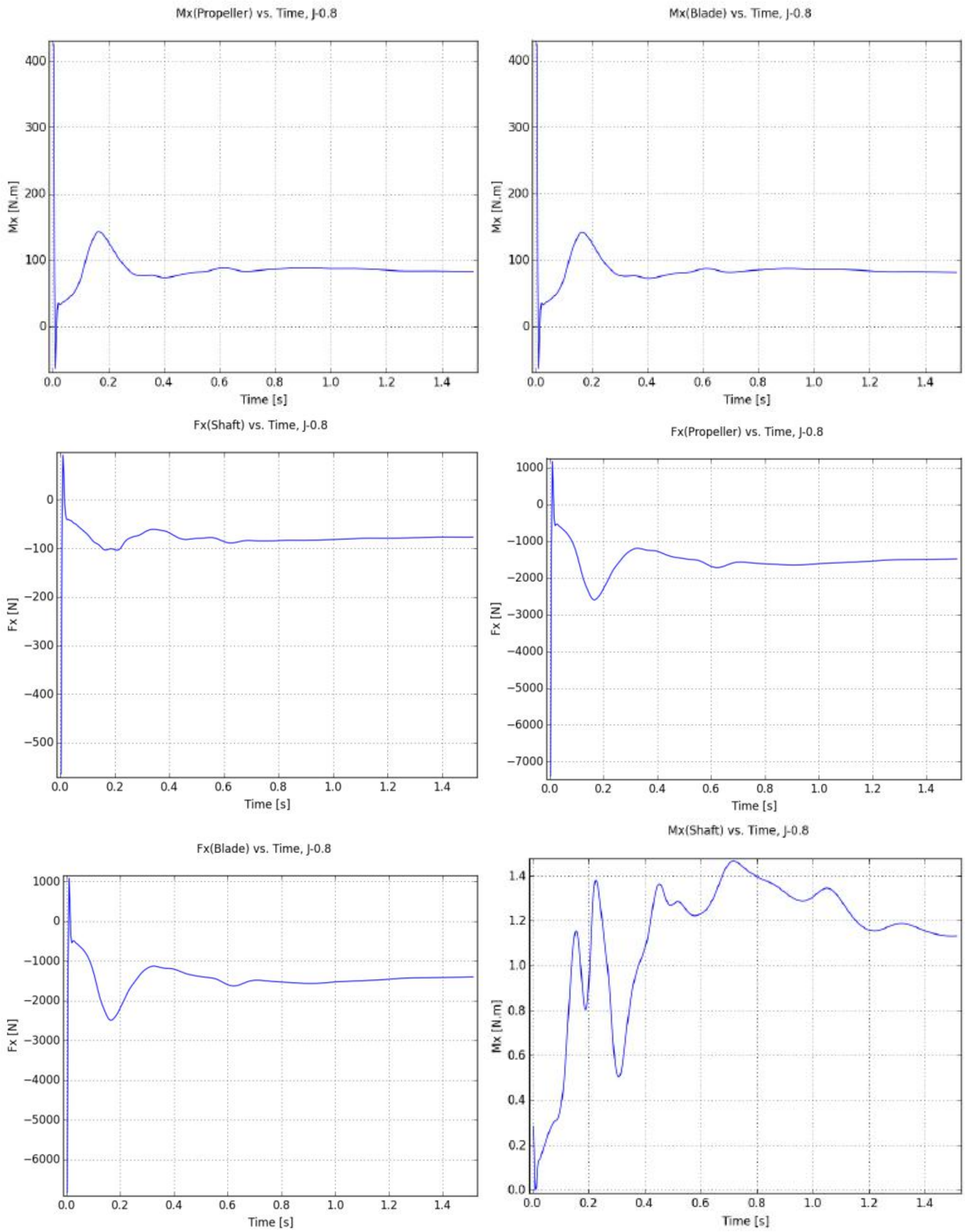




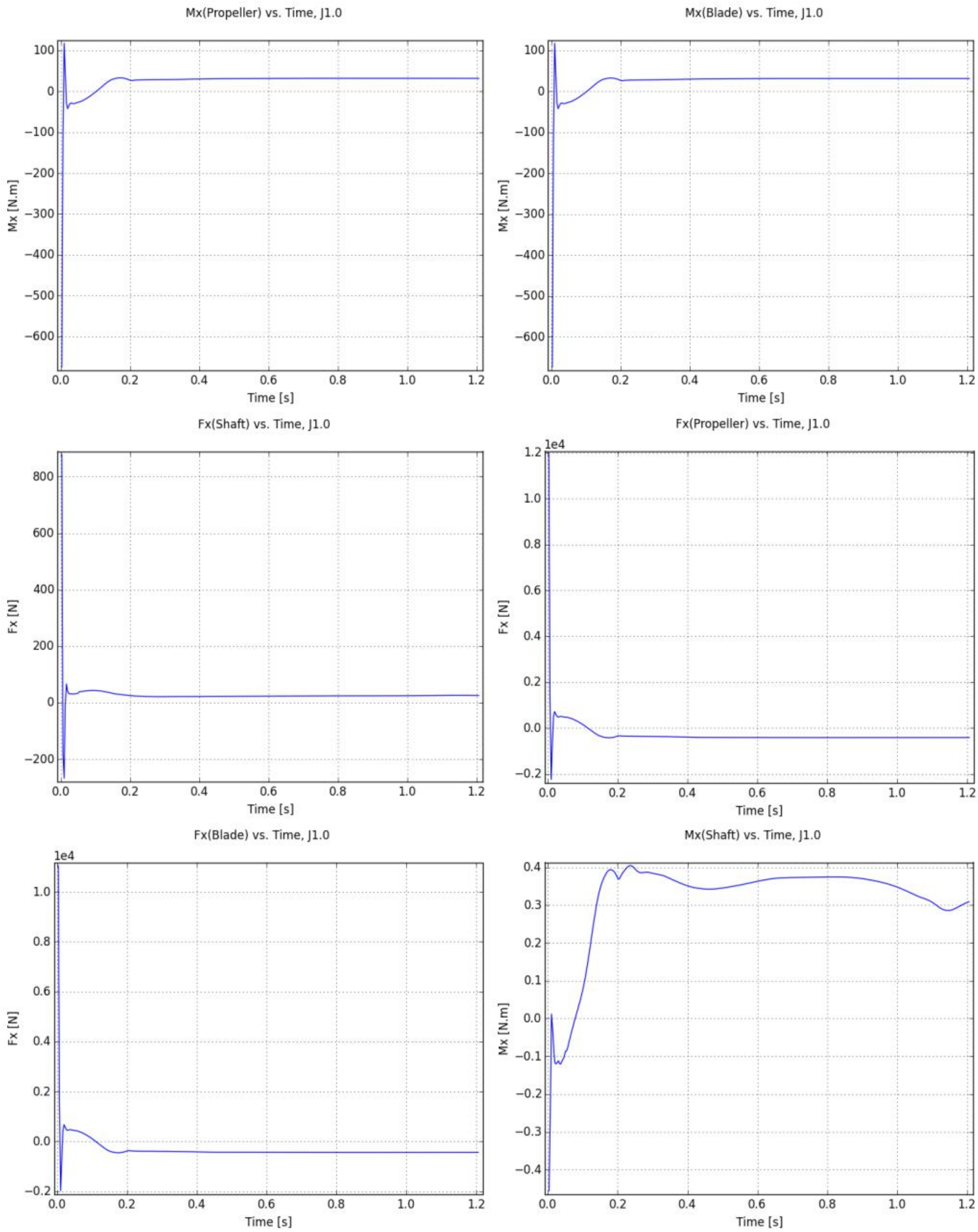




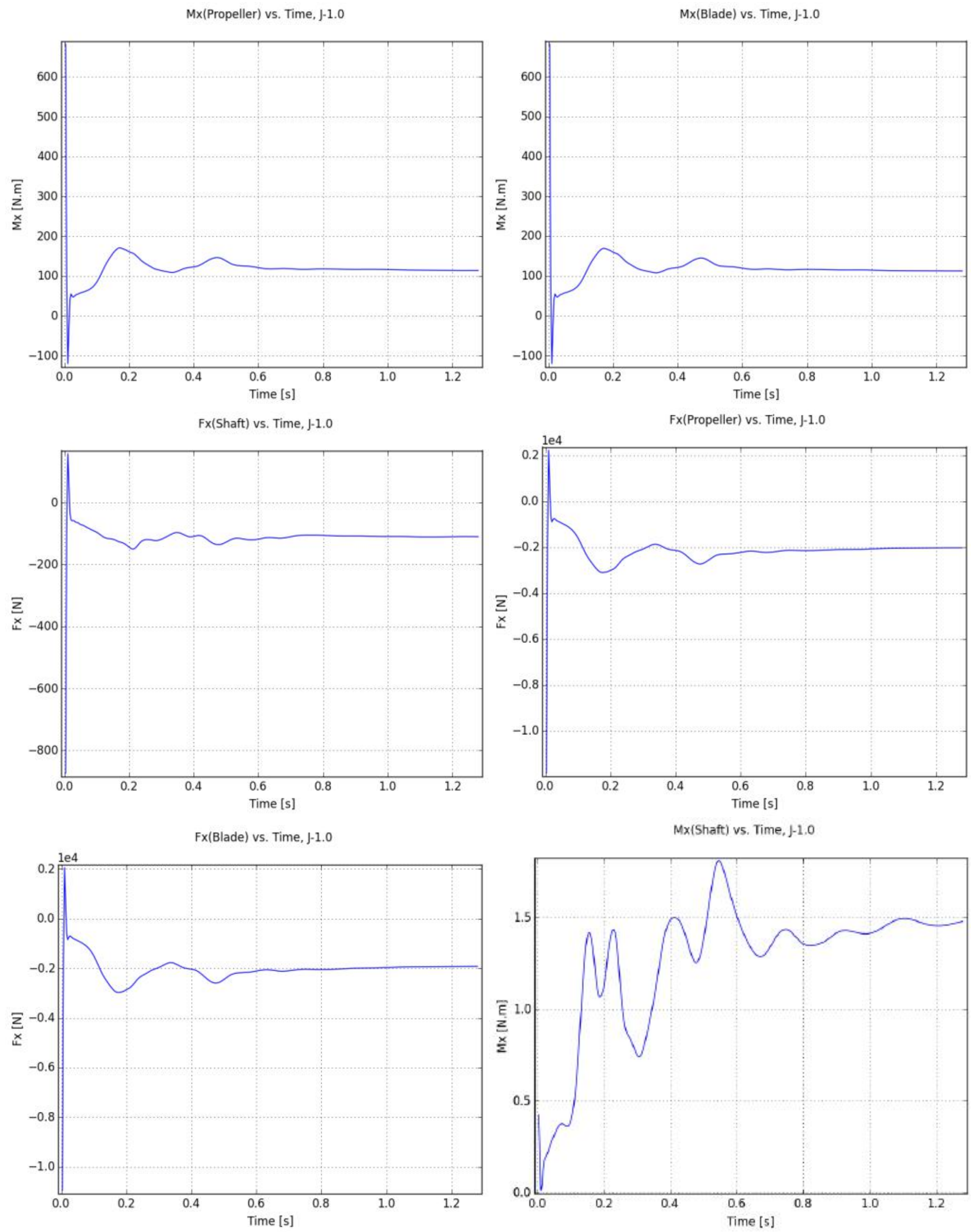
P/D Plus 1.2 J-0.8



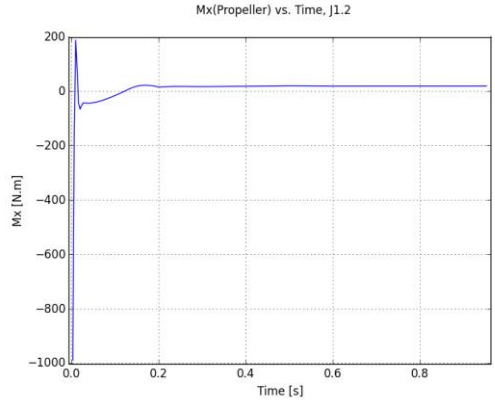
P/D Plus 1.2 J1.0

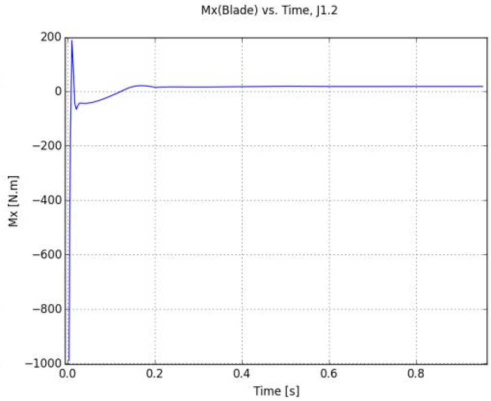


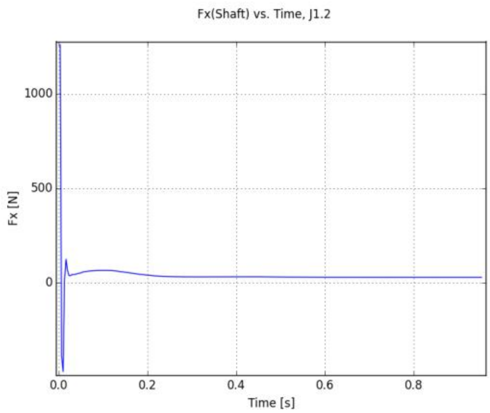
P/D Plus 1.2 J-1.0

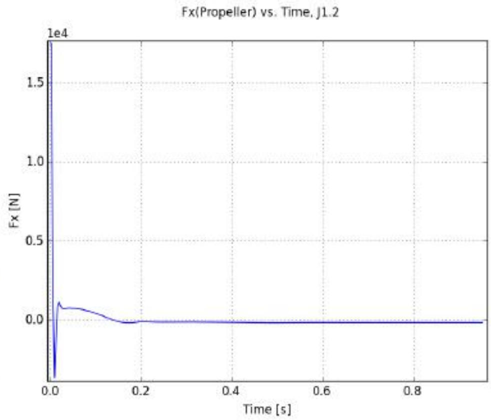


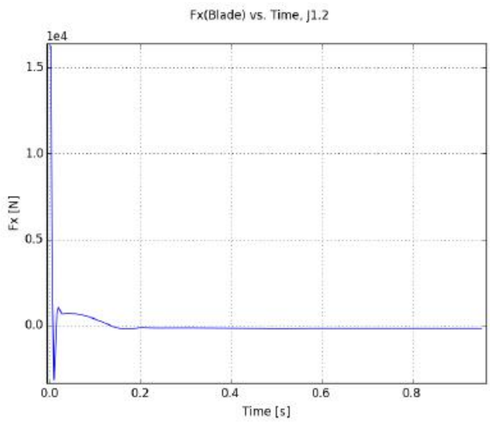
P/D Plus 1.2 J1.2

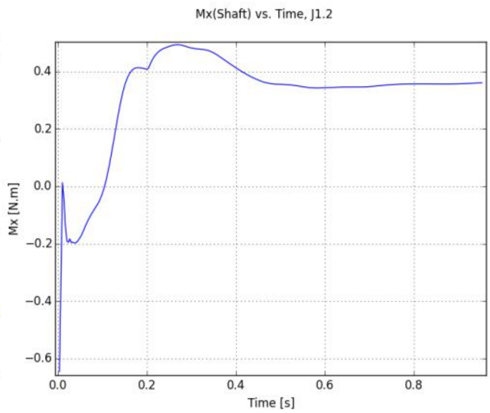




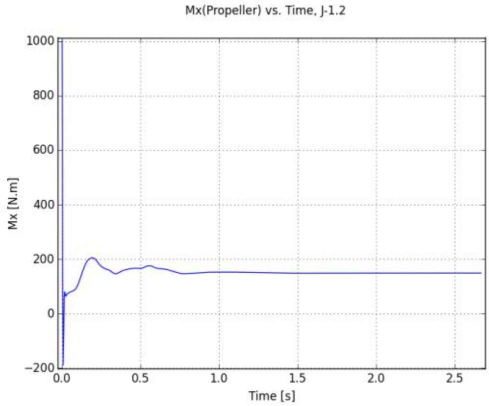


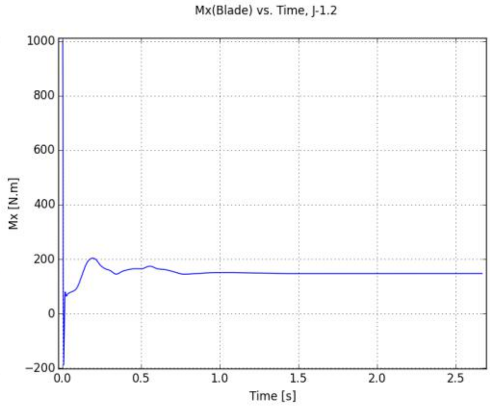


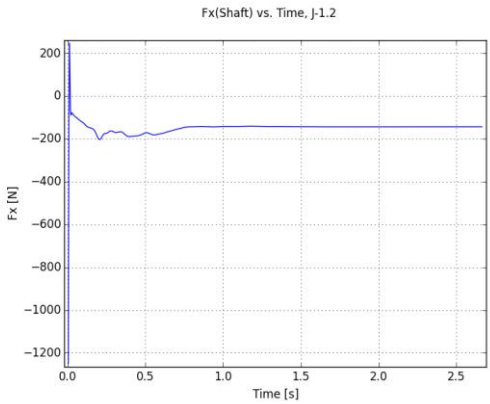


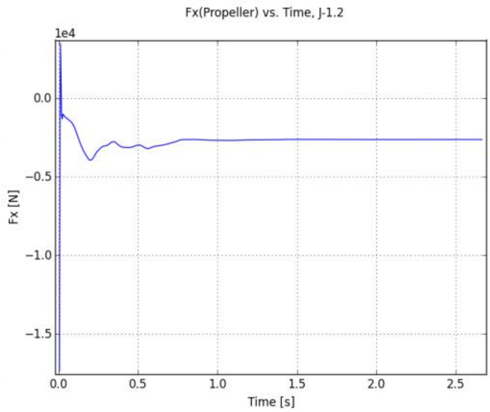


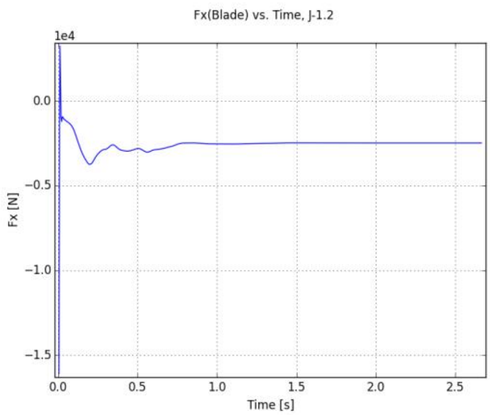
P/D Plus 1.2 J-1.2

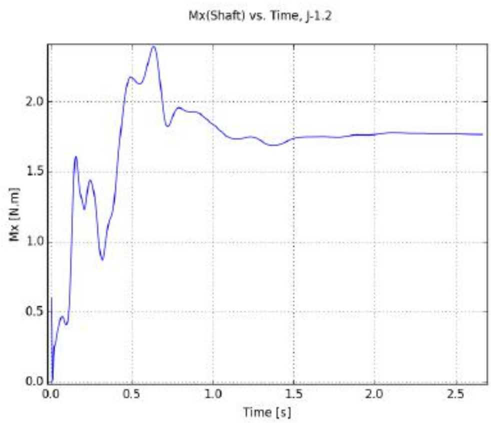




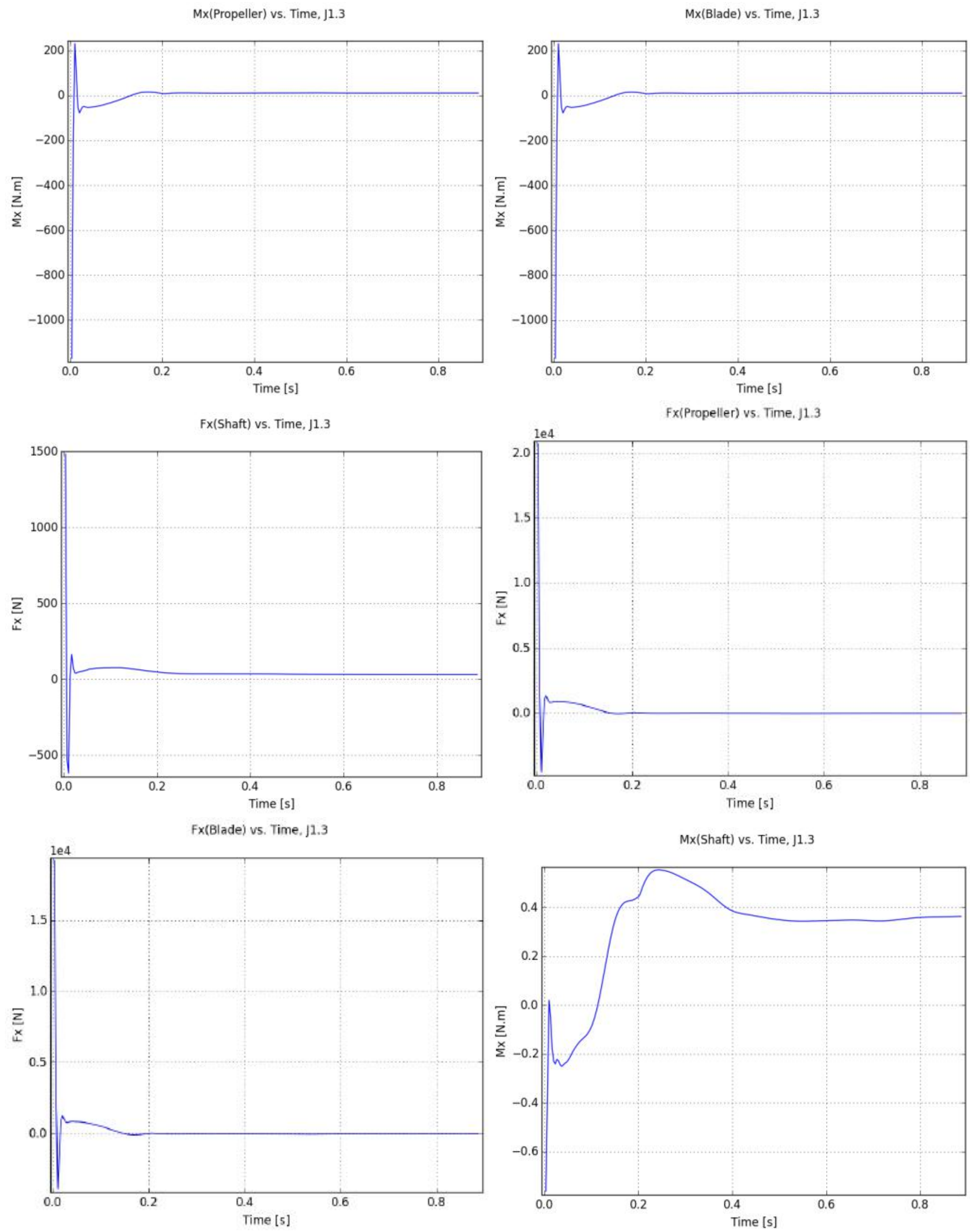




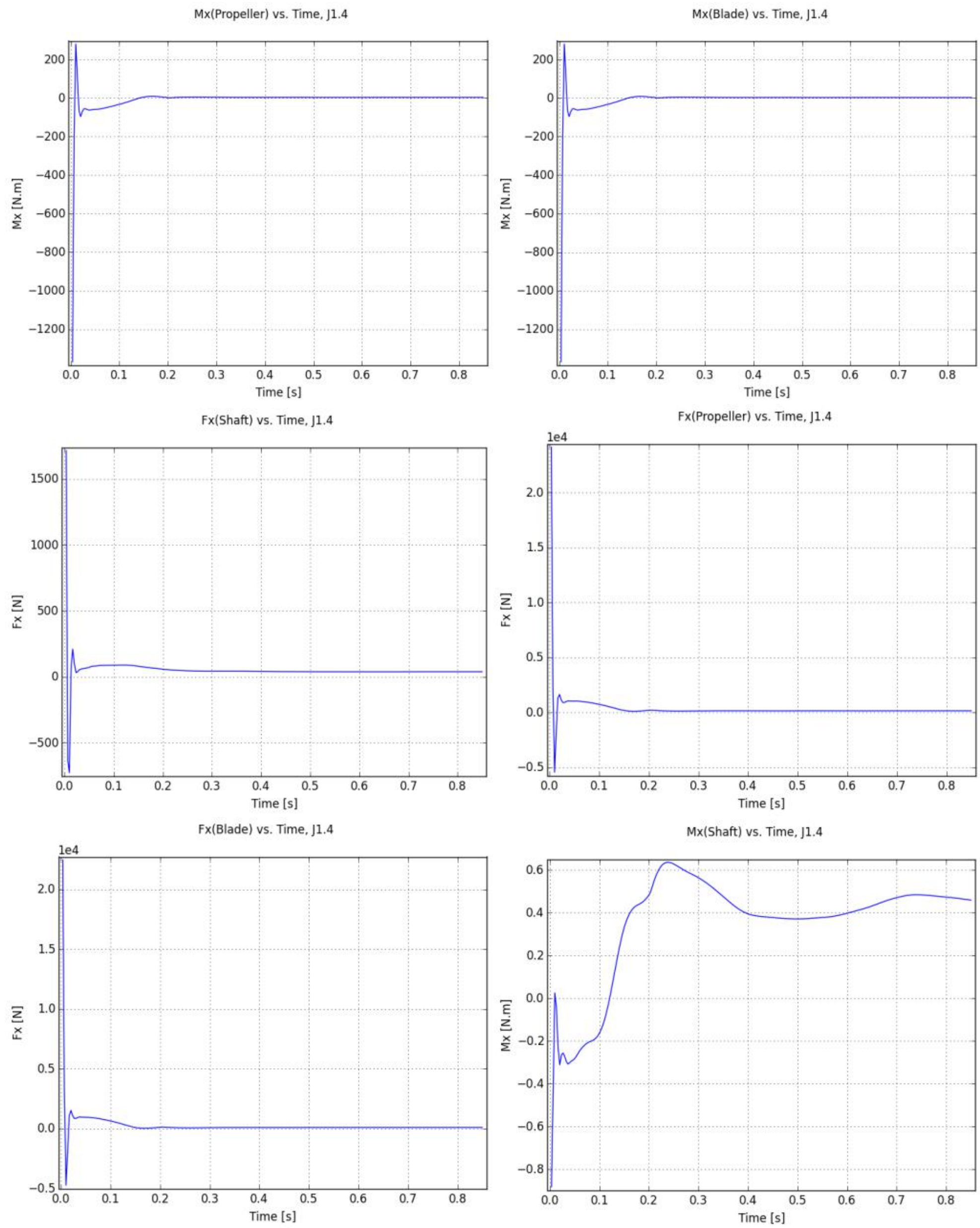




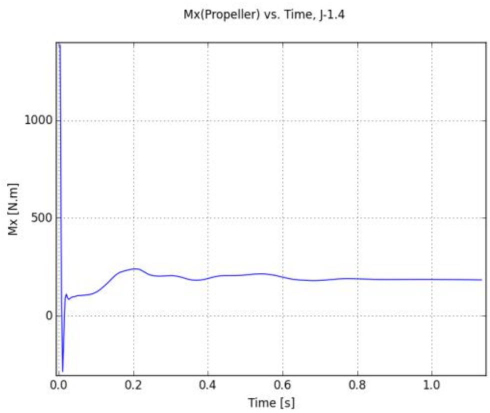
P/D Plus 1.2 J1.3

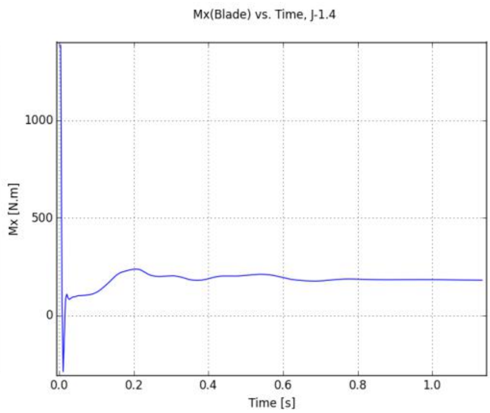


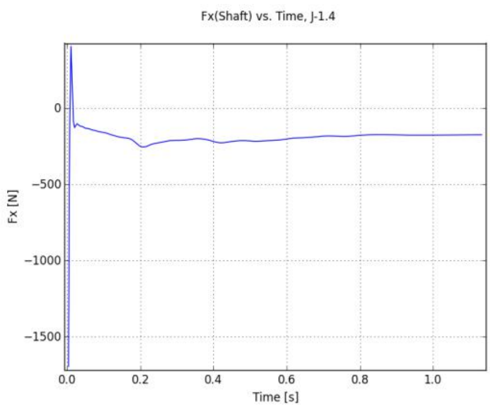
P/D Plus 1.2 J1.4

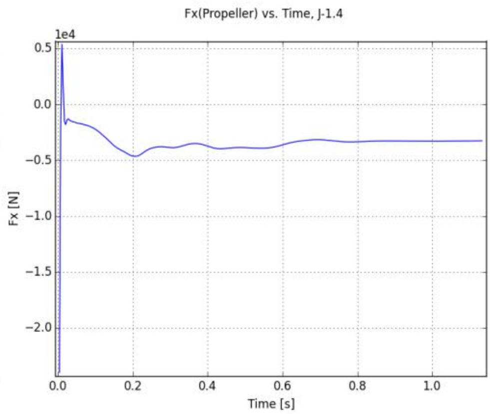


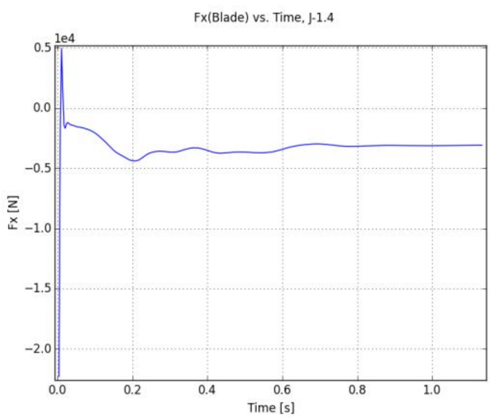
P/D Plus 1.2 J-1.4

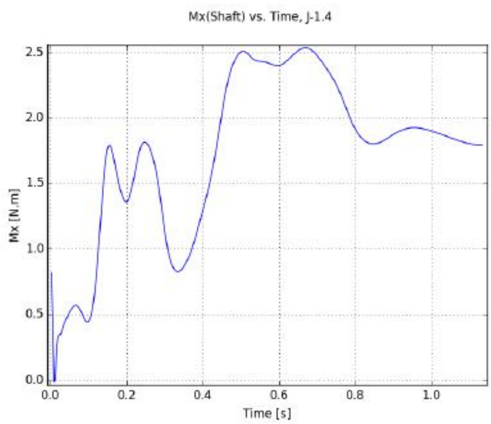




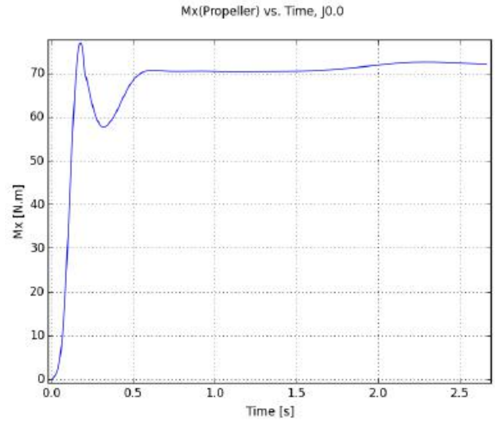


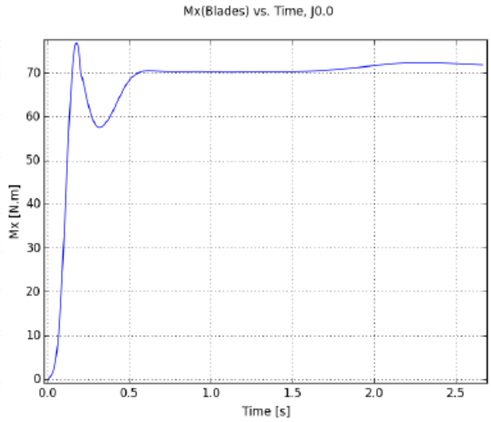


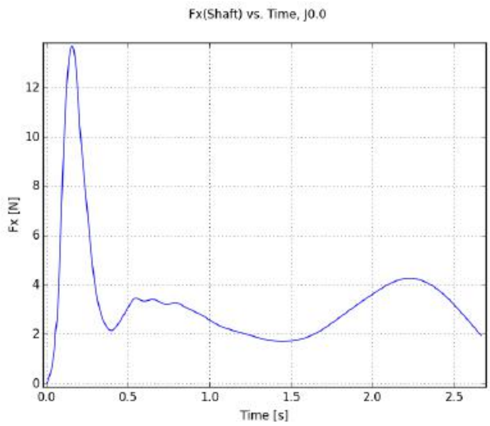


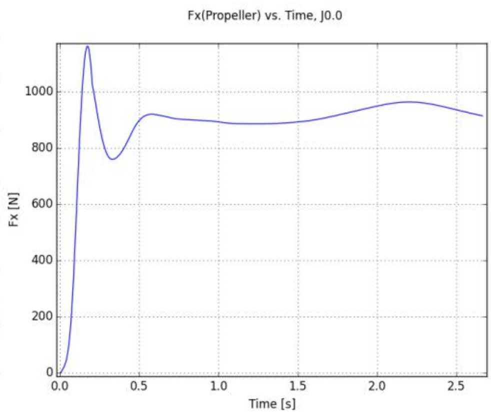


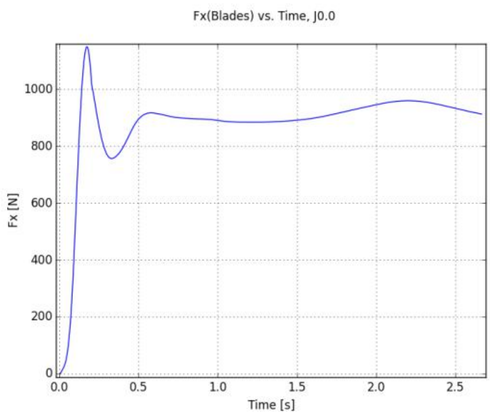
P/D Negative 1.0 J0.0

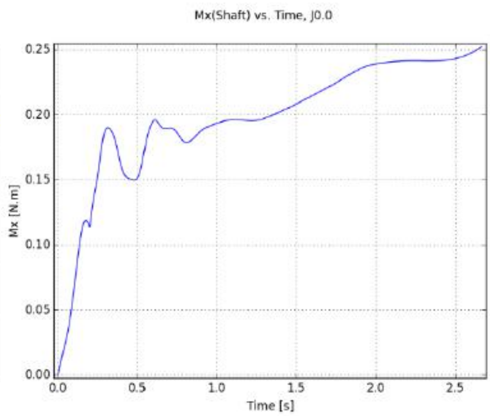




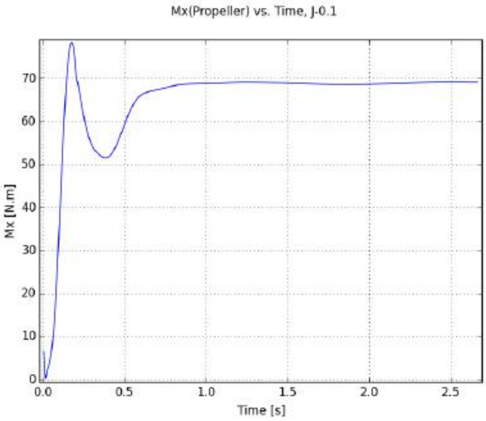


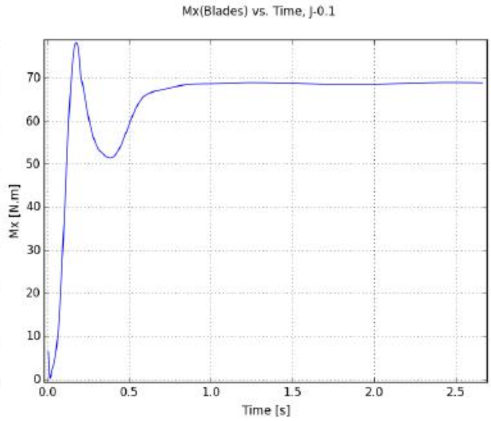


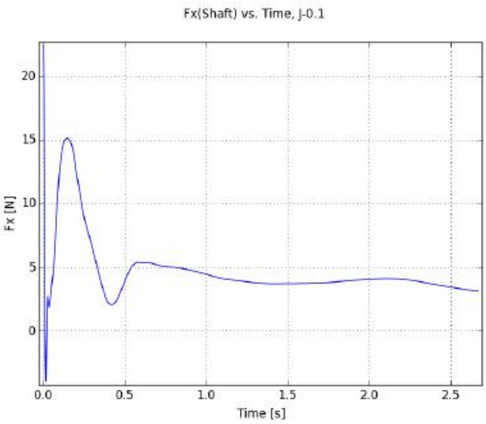


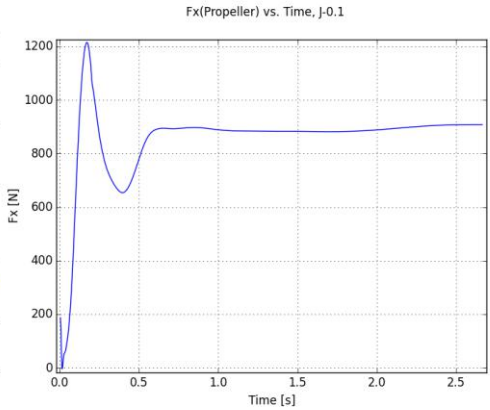


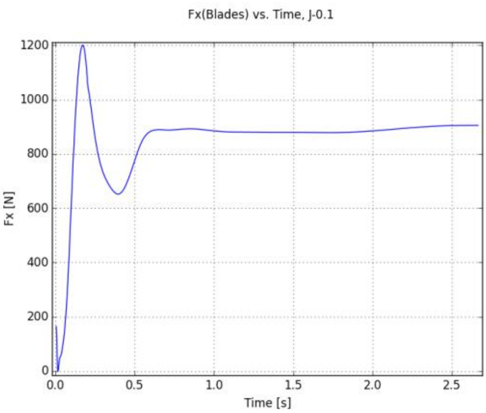
P/D Negative 1.0 J-0.1

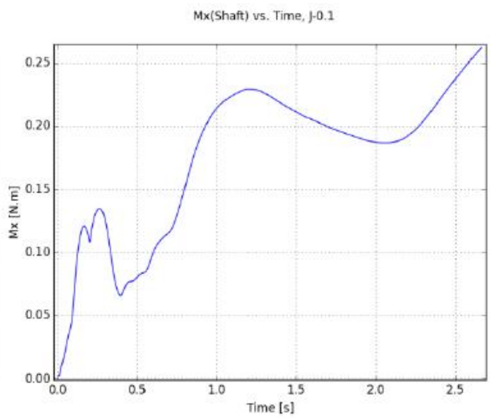




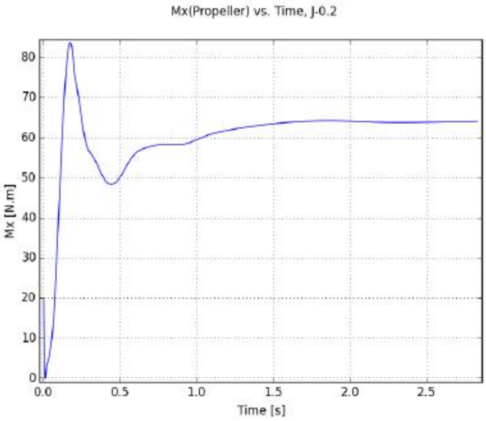


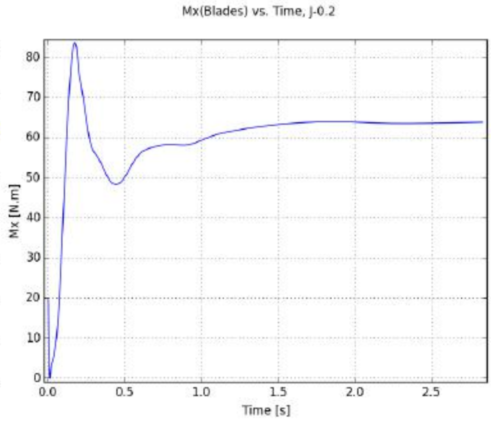


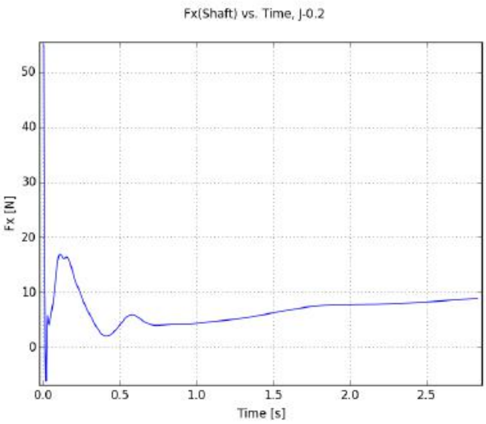


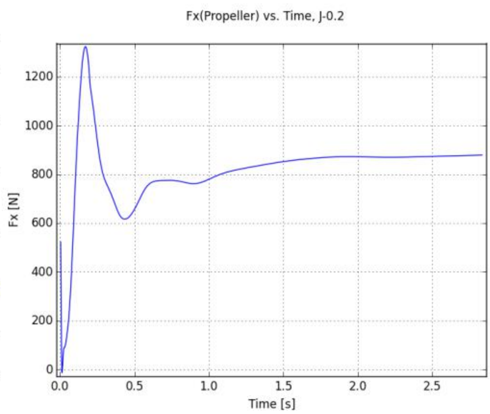


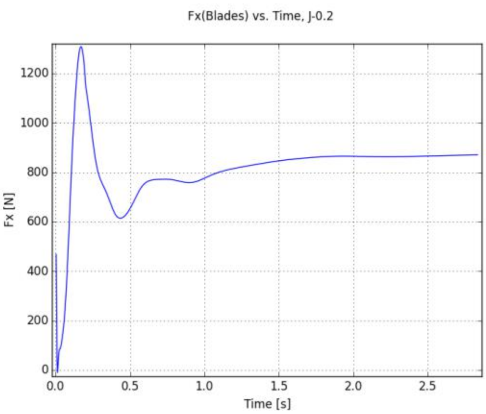
P/D Negative 11.0 J-0.2

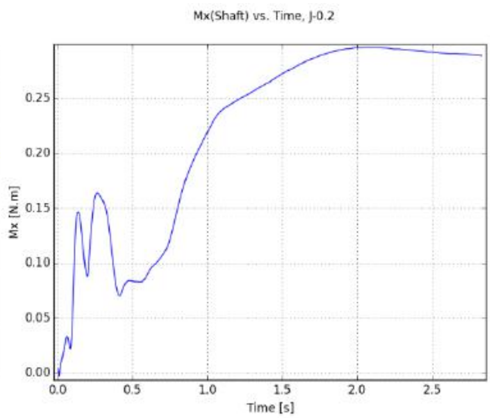




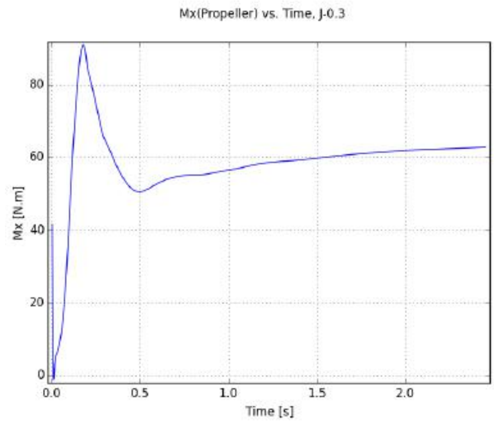


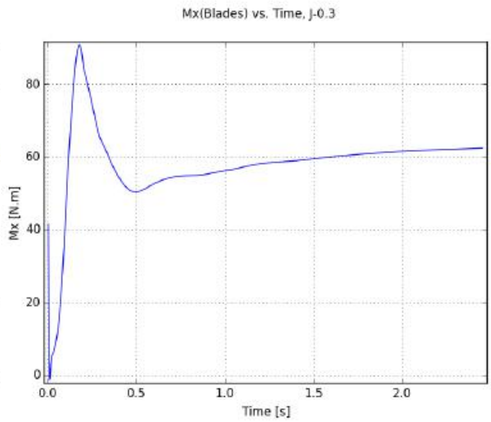


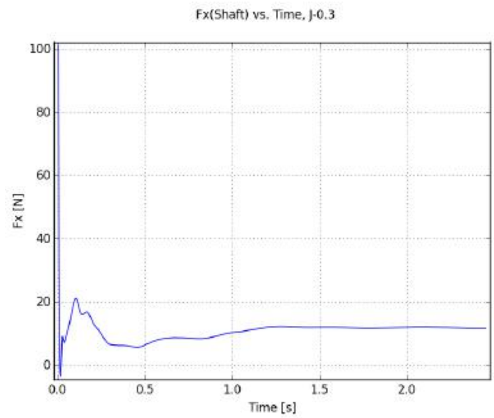


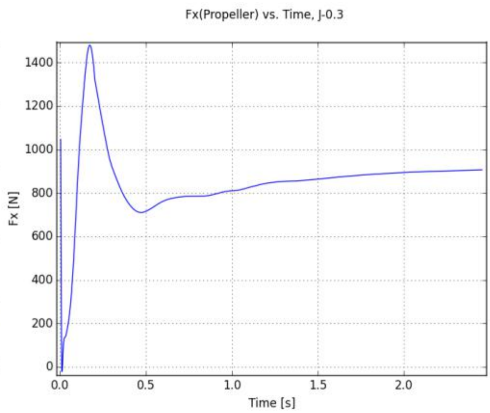


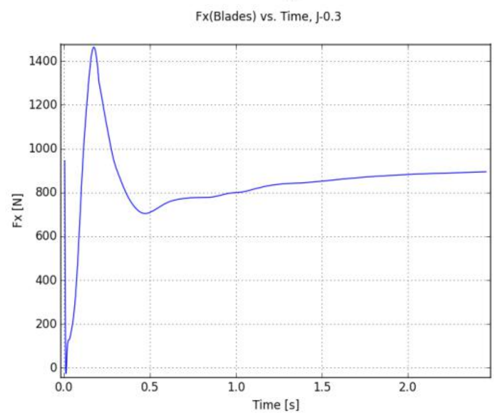
P/D Negative 1.0 J-0.3

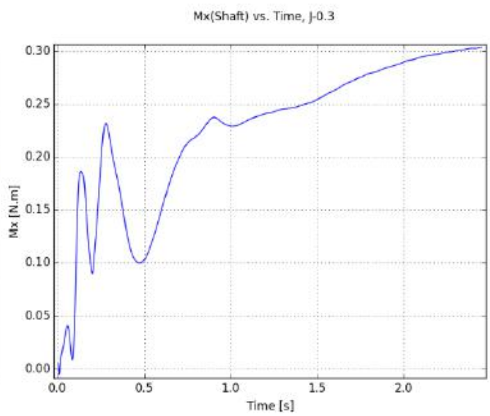




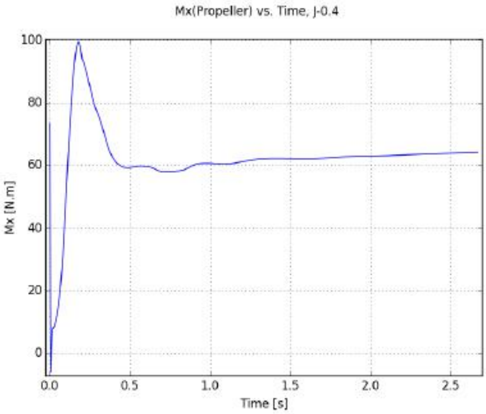


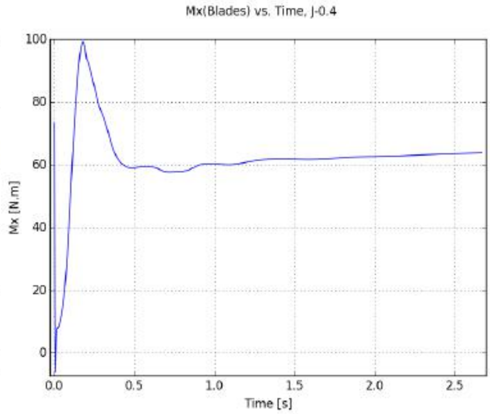


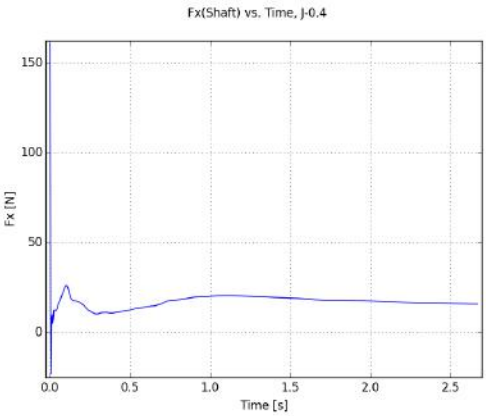


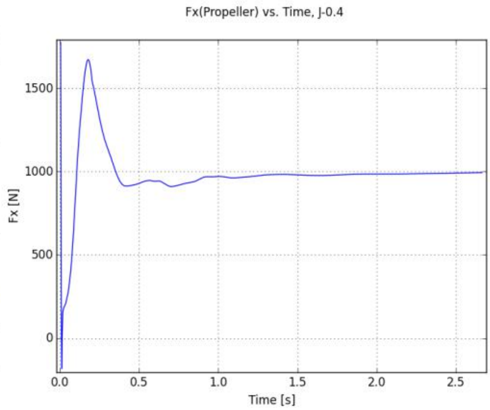


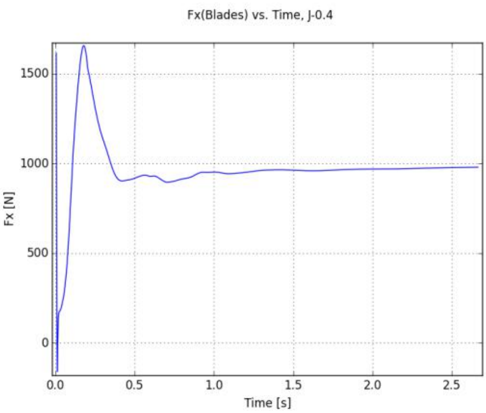
P/D Negative 1.0 J-0.4

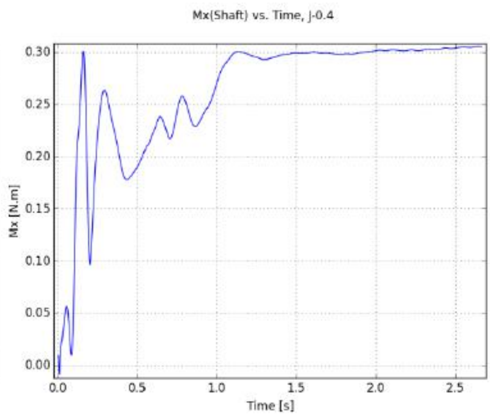




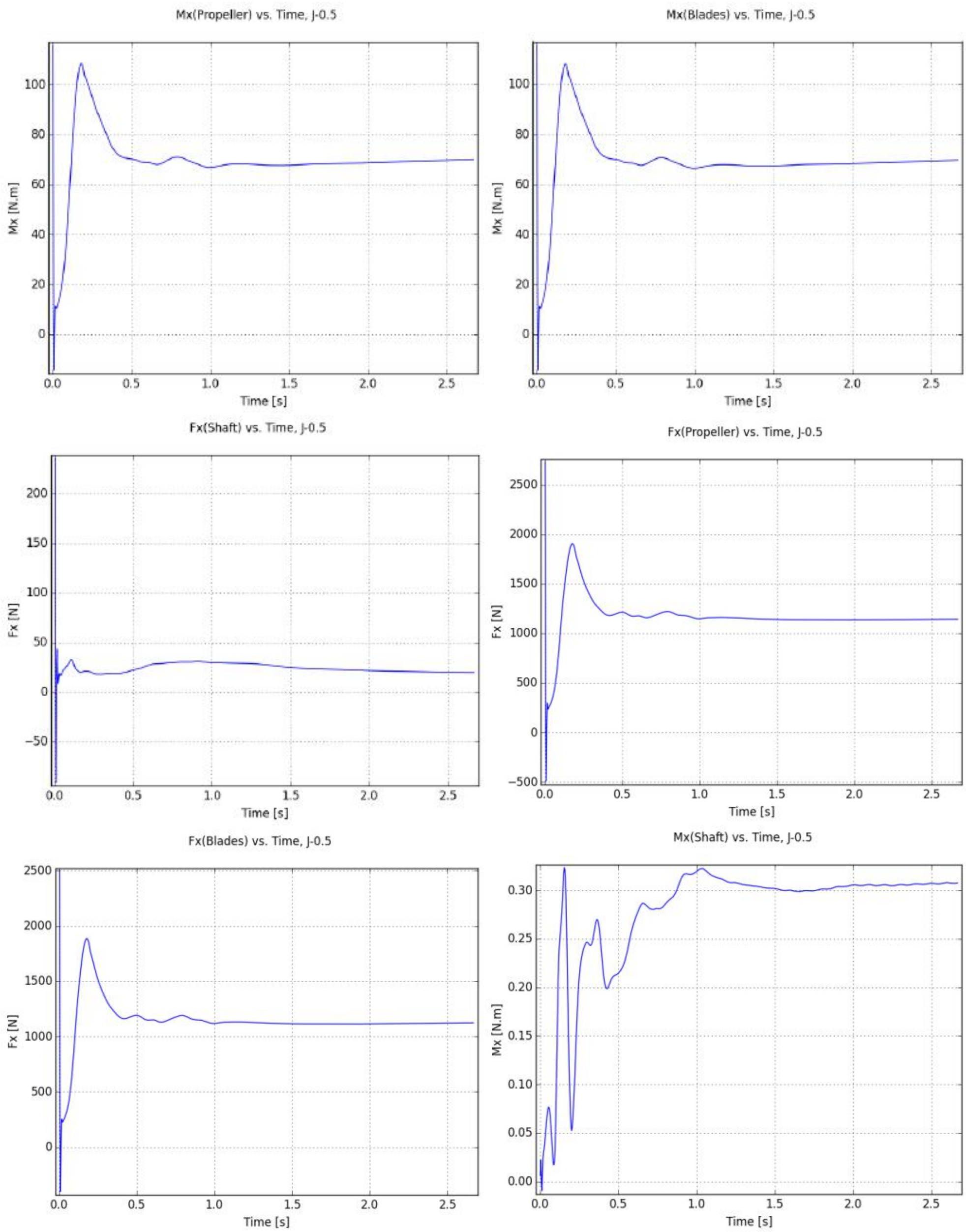




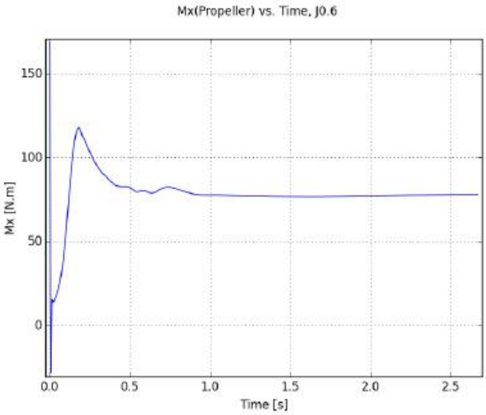


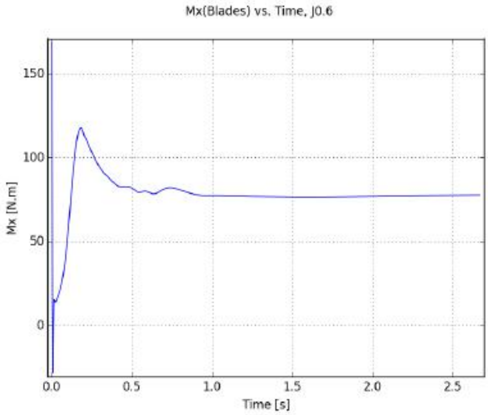


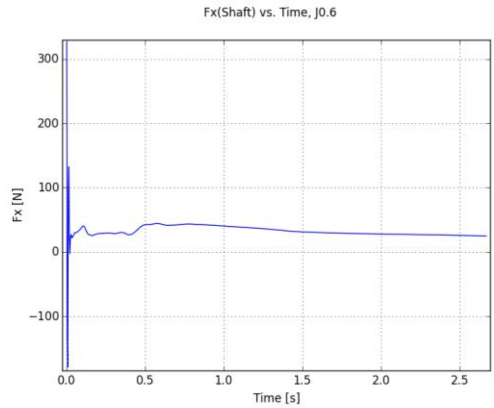
P/D Negative 1.0 J-0.5

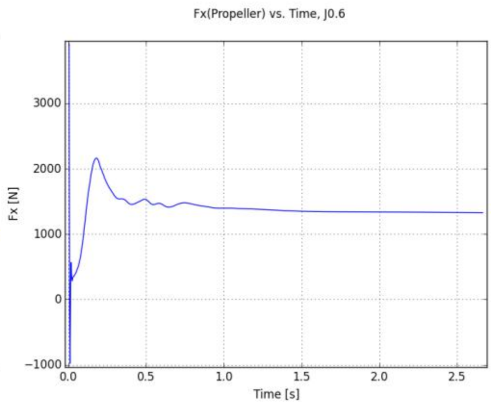


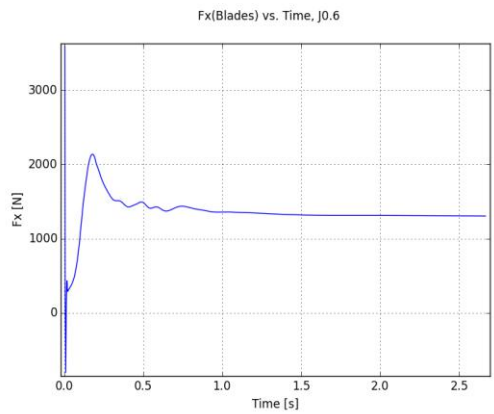
P/D Negative 1.0 J0.6

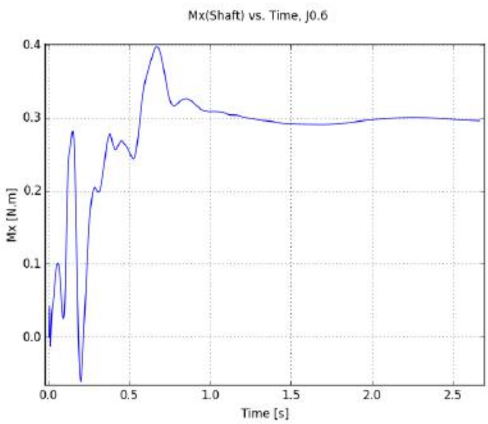




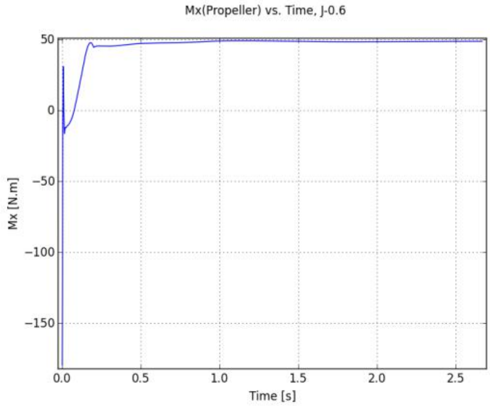


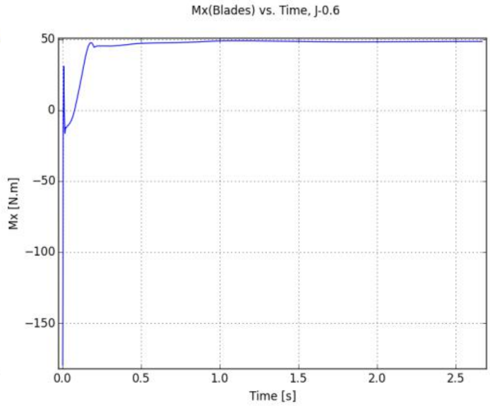


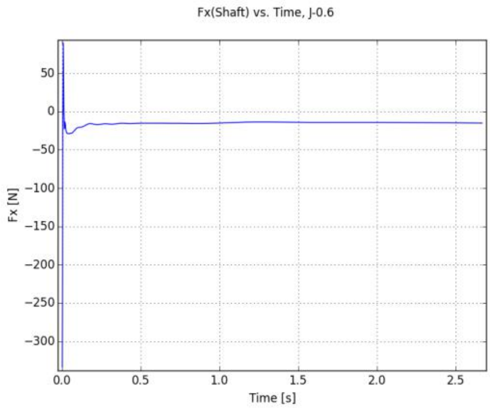


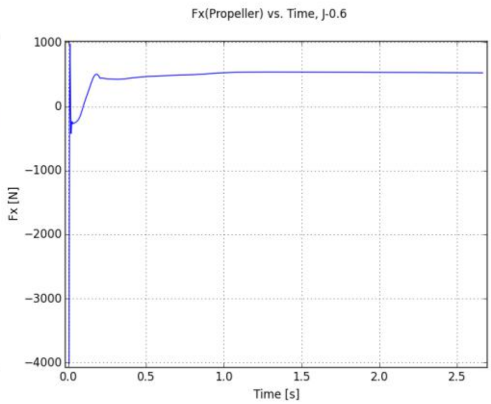


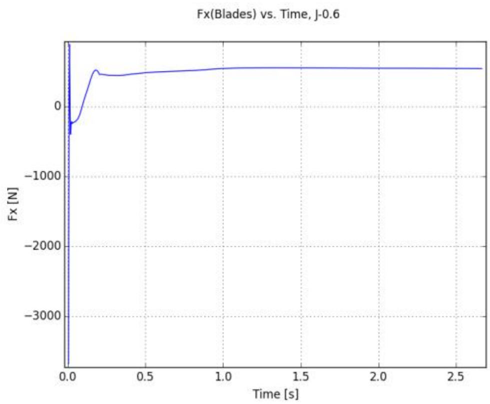
P/D Negative 1.0 J-0.6

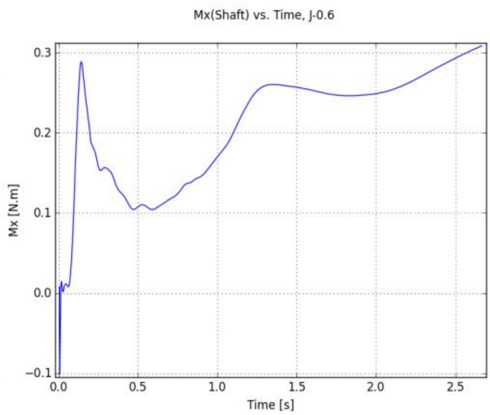




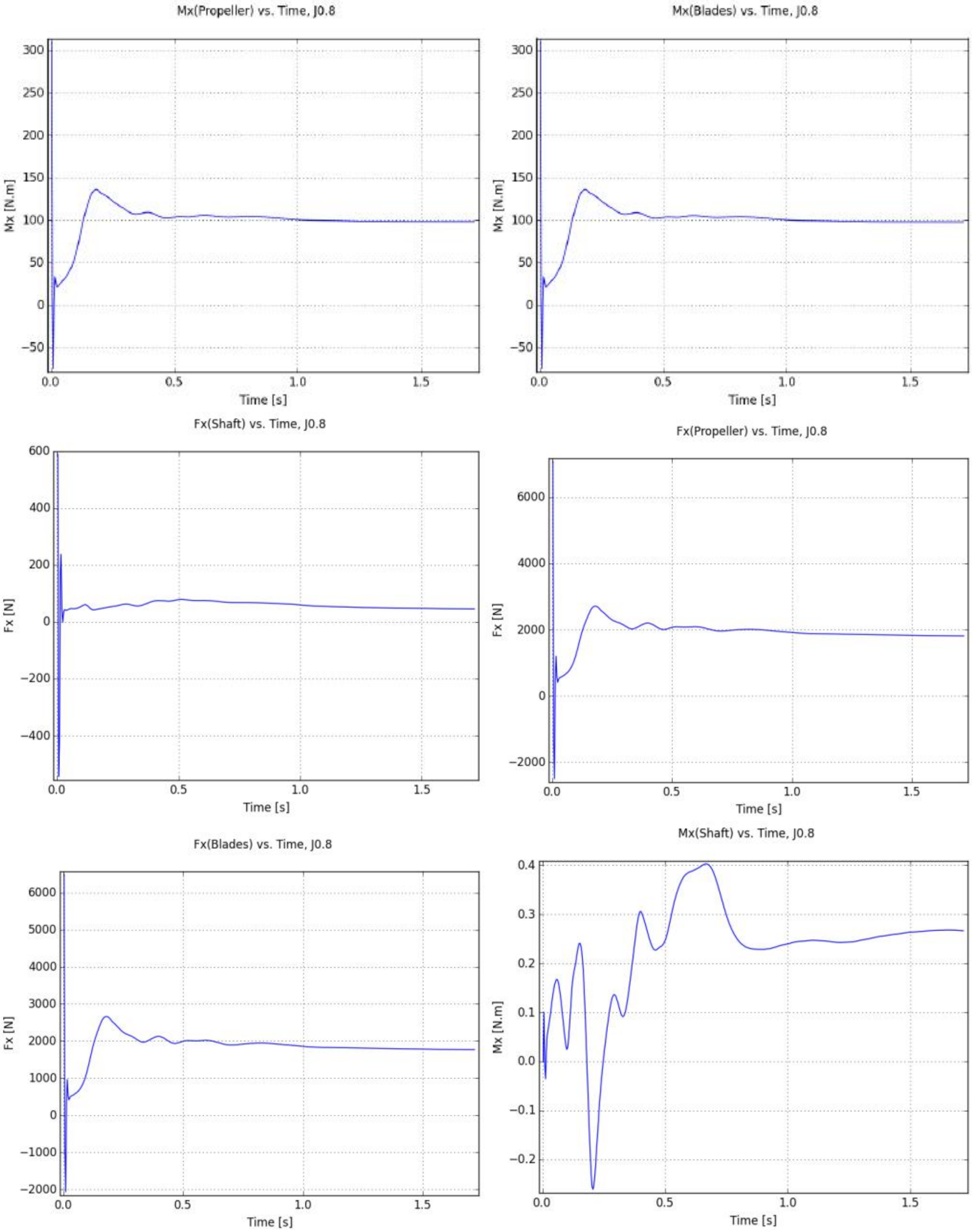




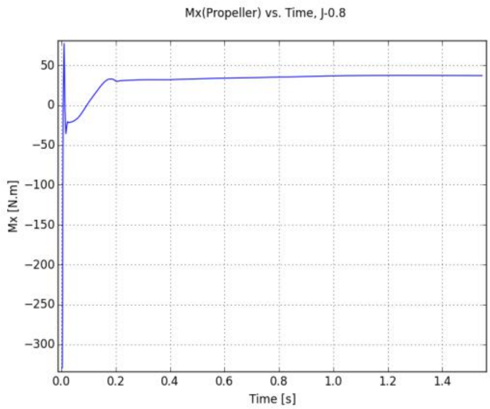


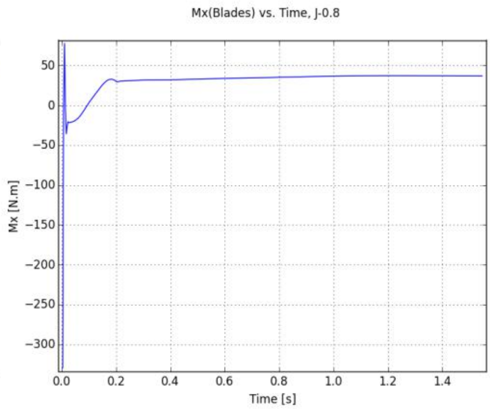


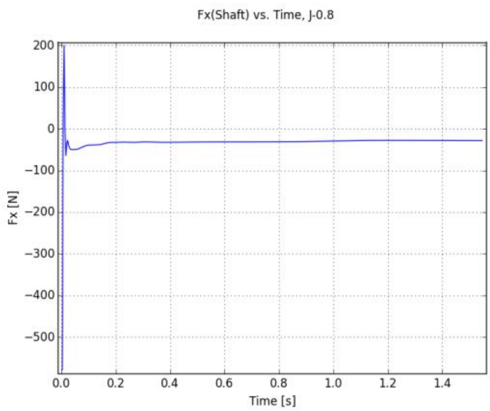
P/D Negative 1.0 J0.8

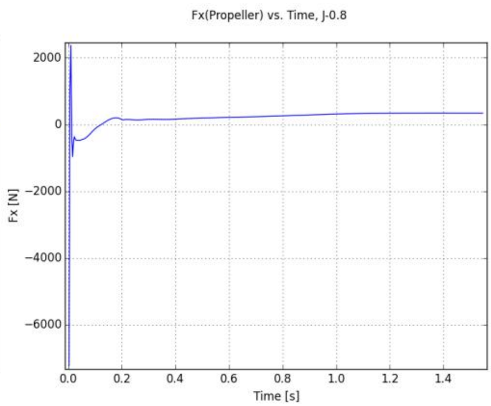


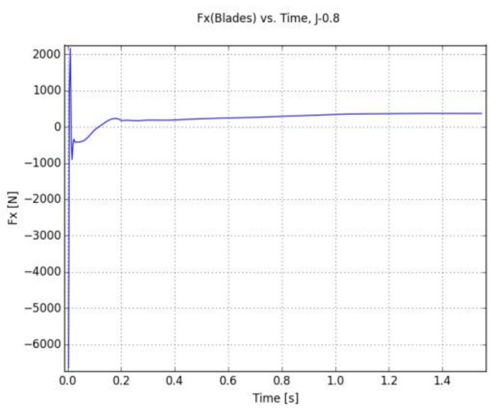
P/D Negative 1.0 J-0.8

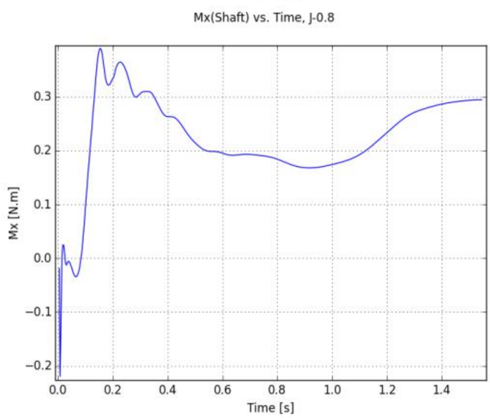




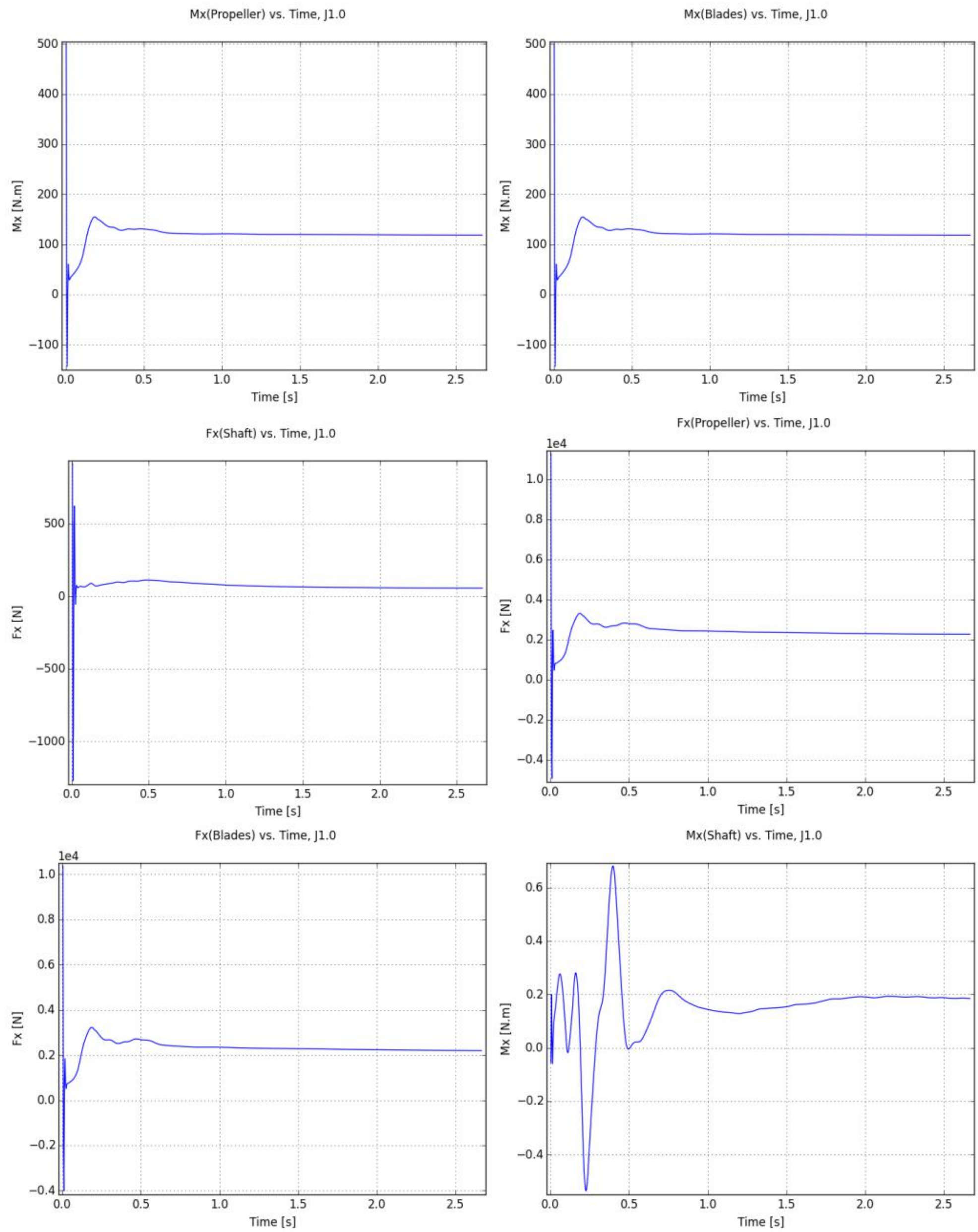




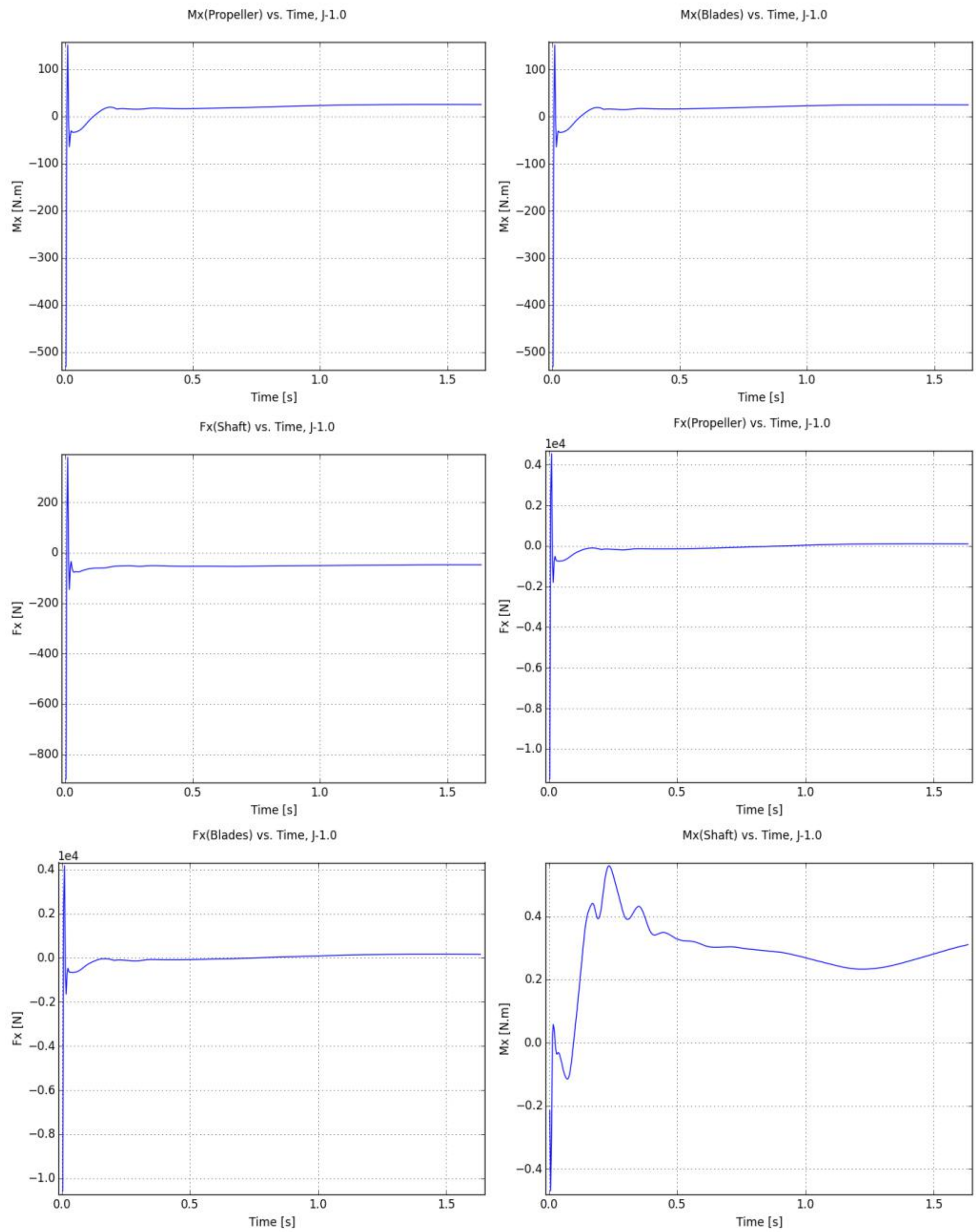




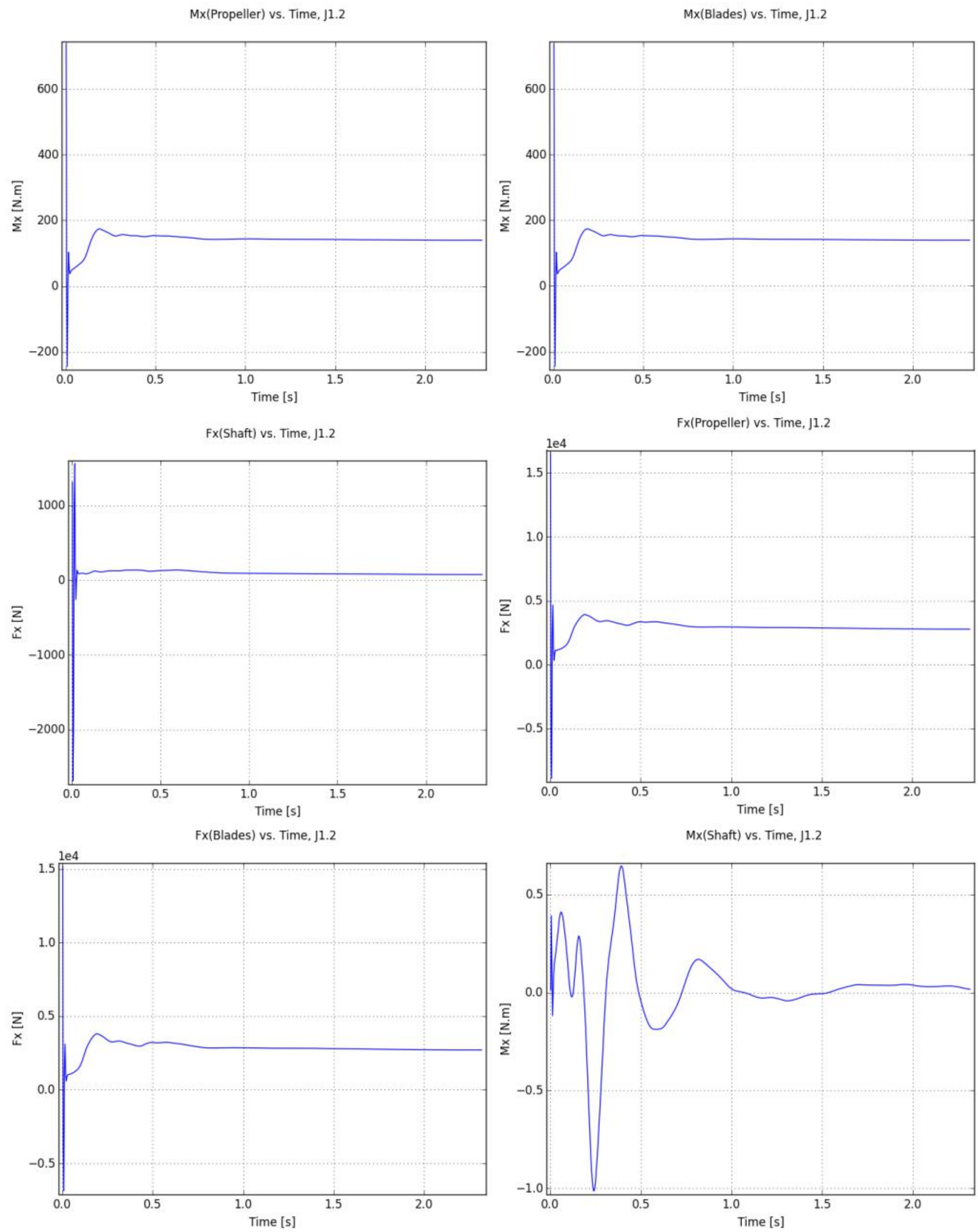
P/D Negative 1.0 J1.0



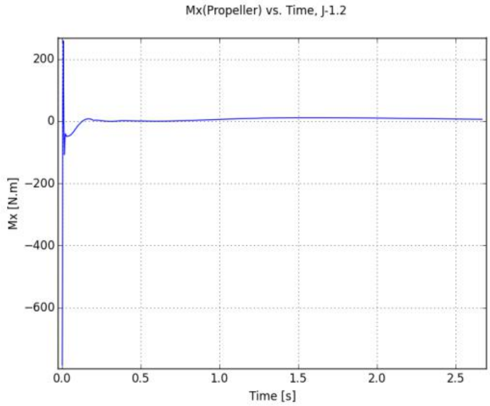
P/D Negative 1.0 J-1.0

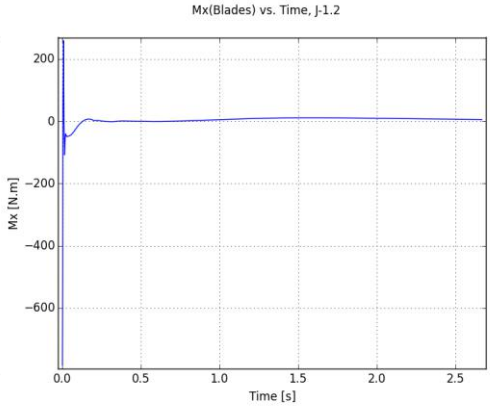


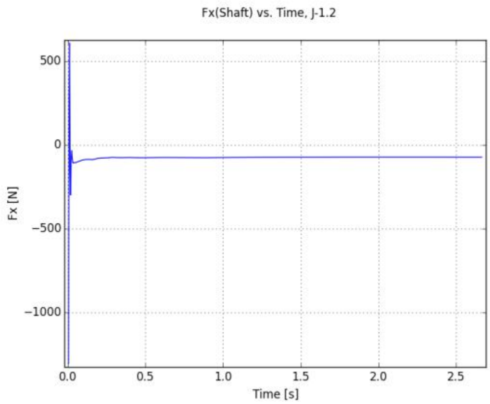
P/D Negative 1.0 J1.2

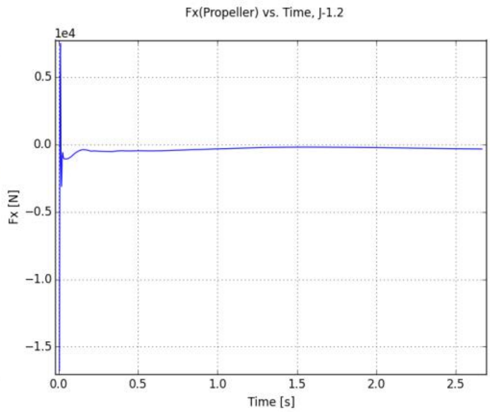


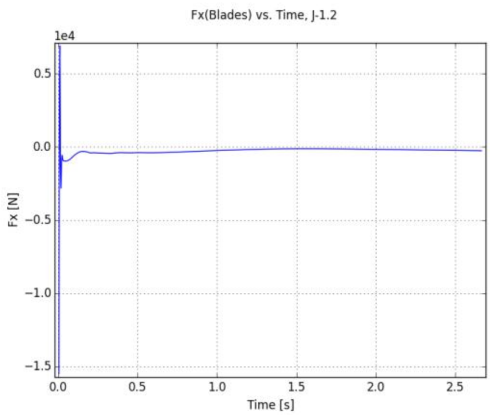
P/D Negative 1.0 J-1.2

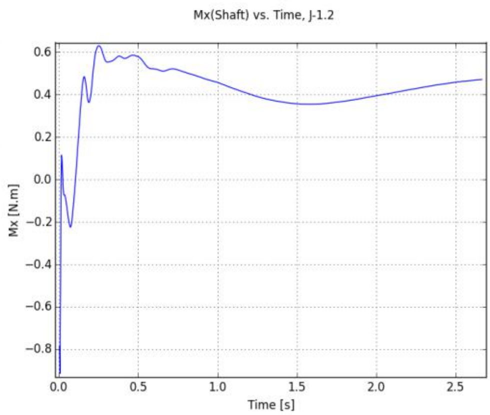




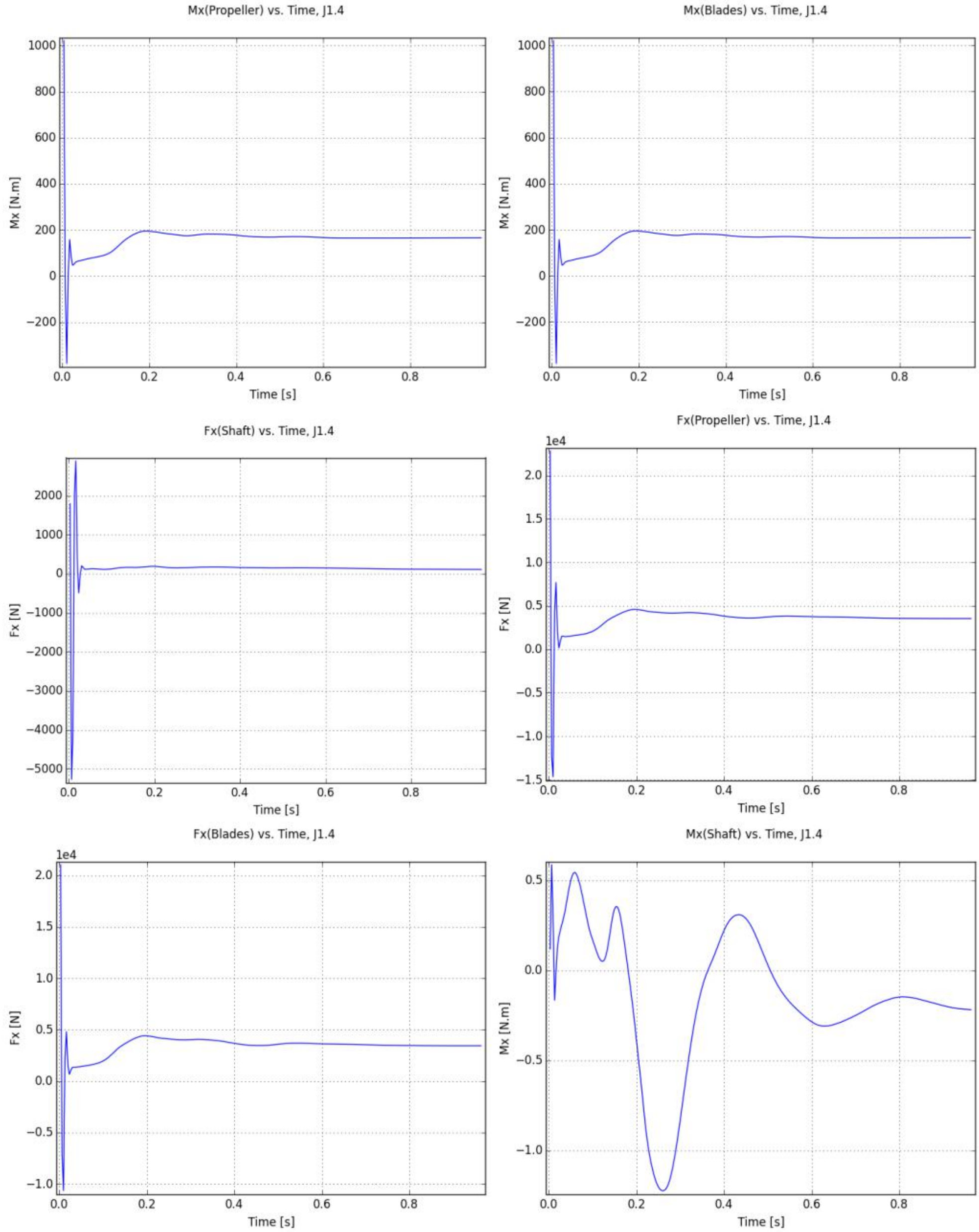




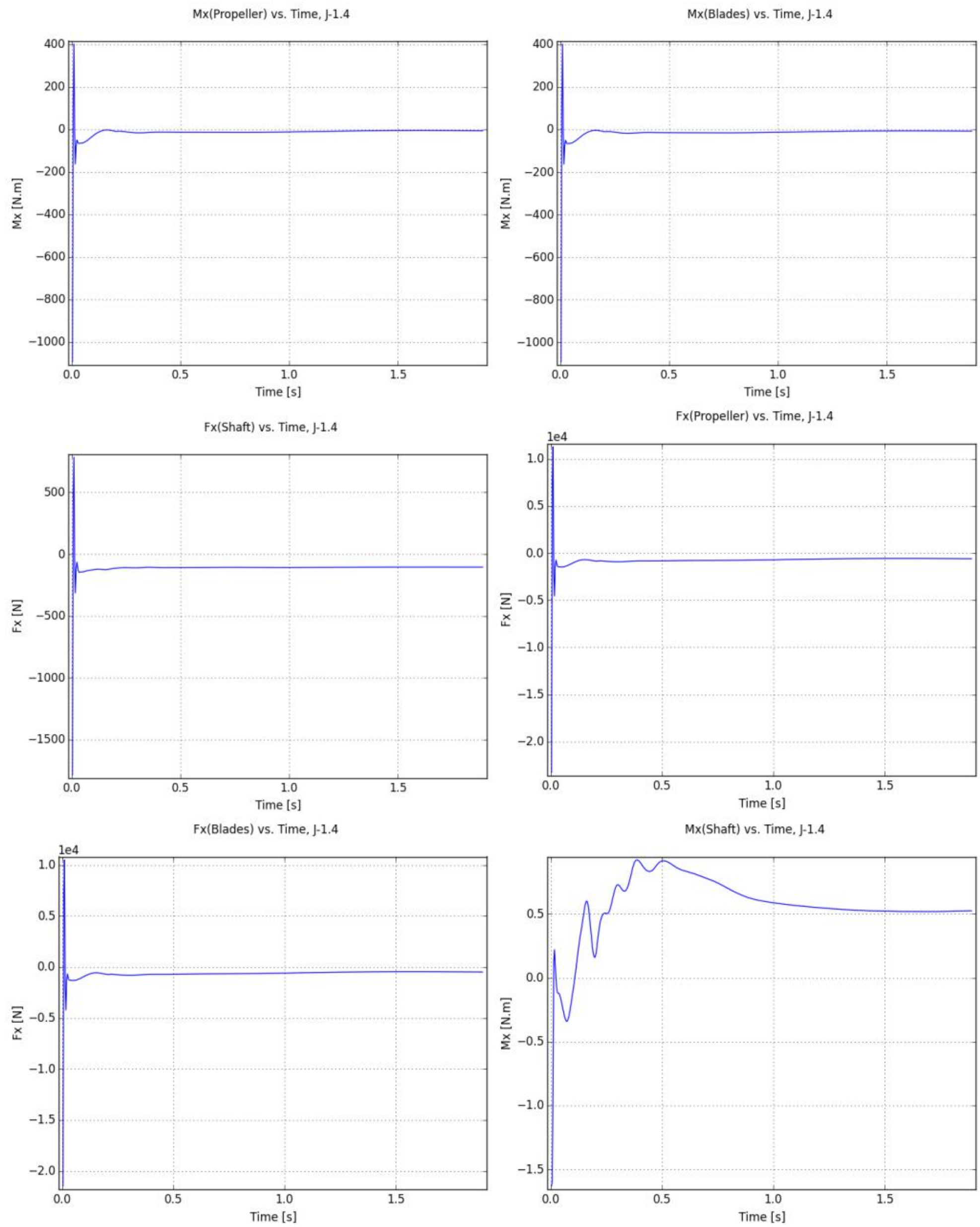




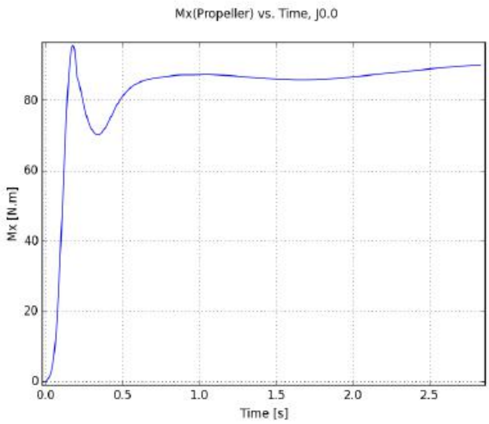
P/D Negative 1.0 J1.4

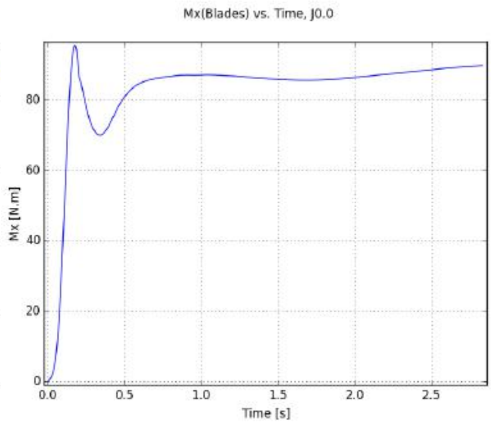


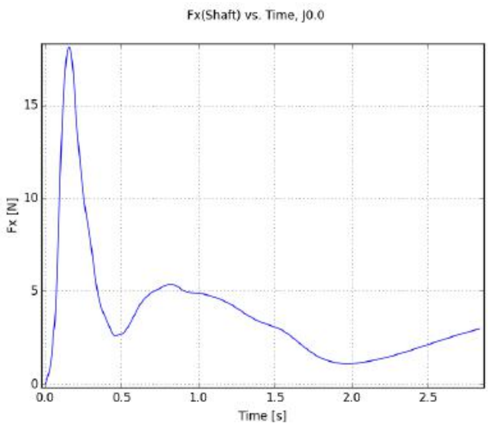
P/D Negative 1.0 J-1.4

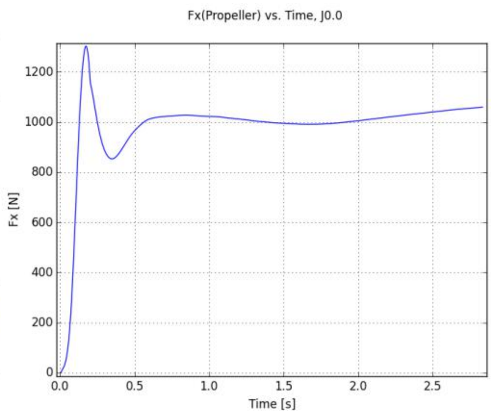


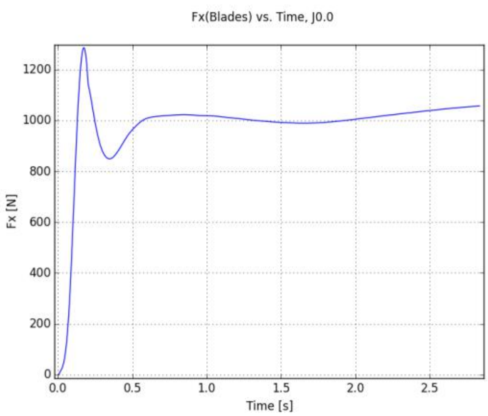
P/D Negative 1.2 J0.0

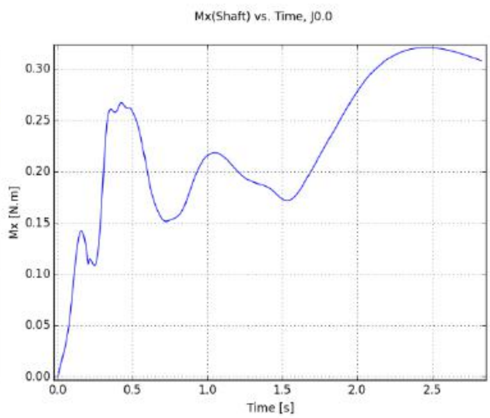




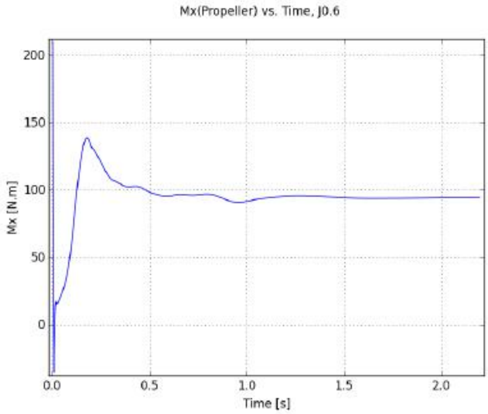


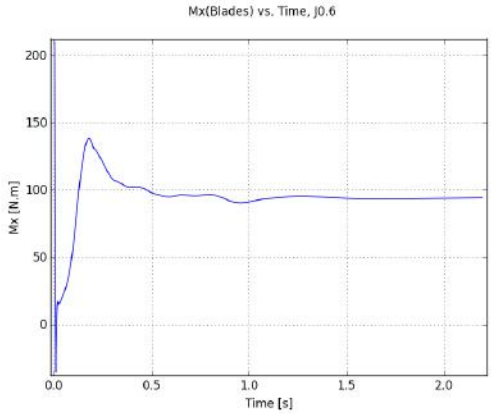


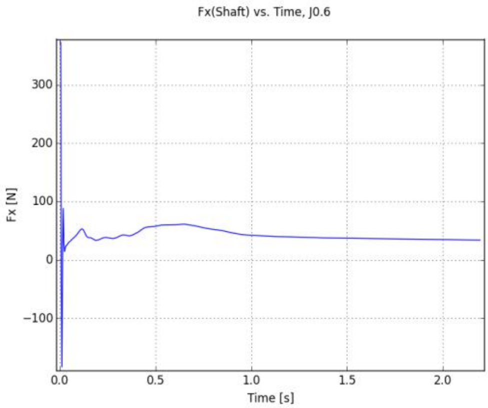


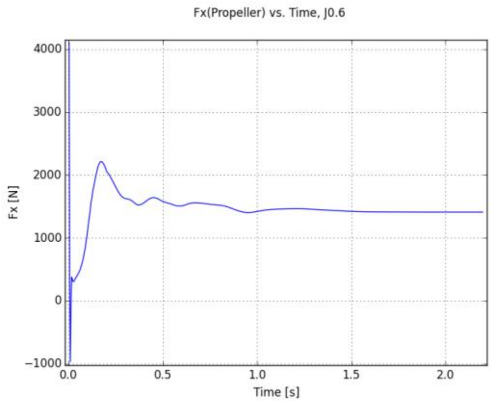


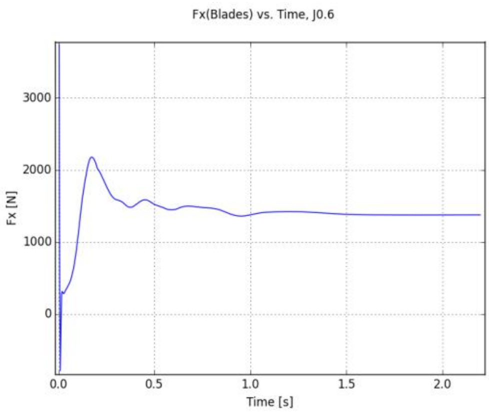
P/D Negative 1.2 J0.6

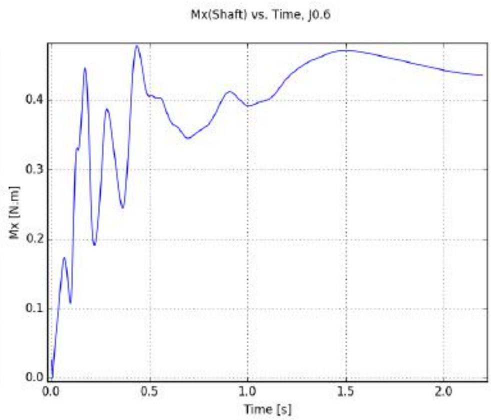




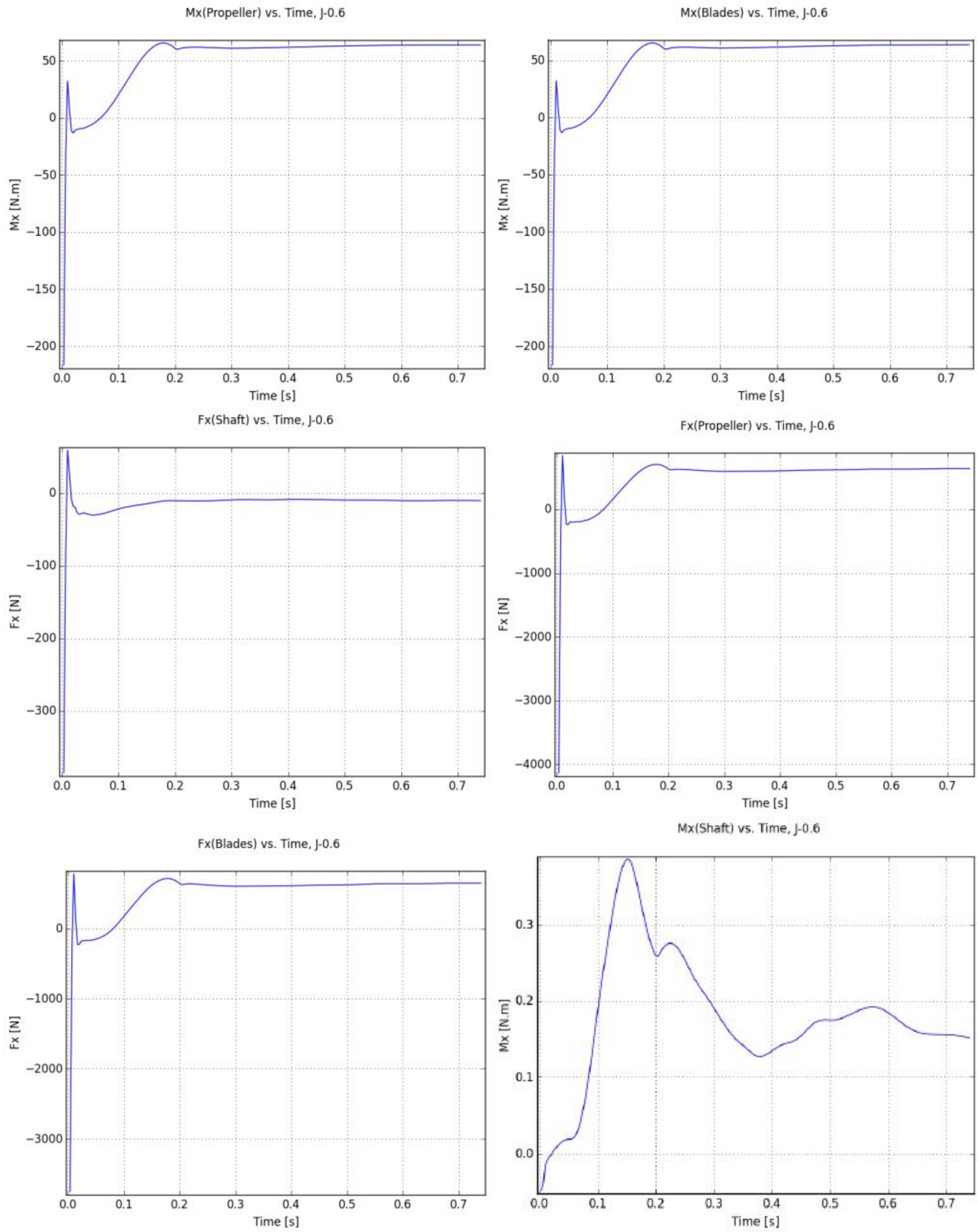




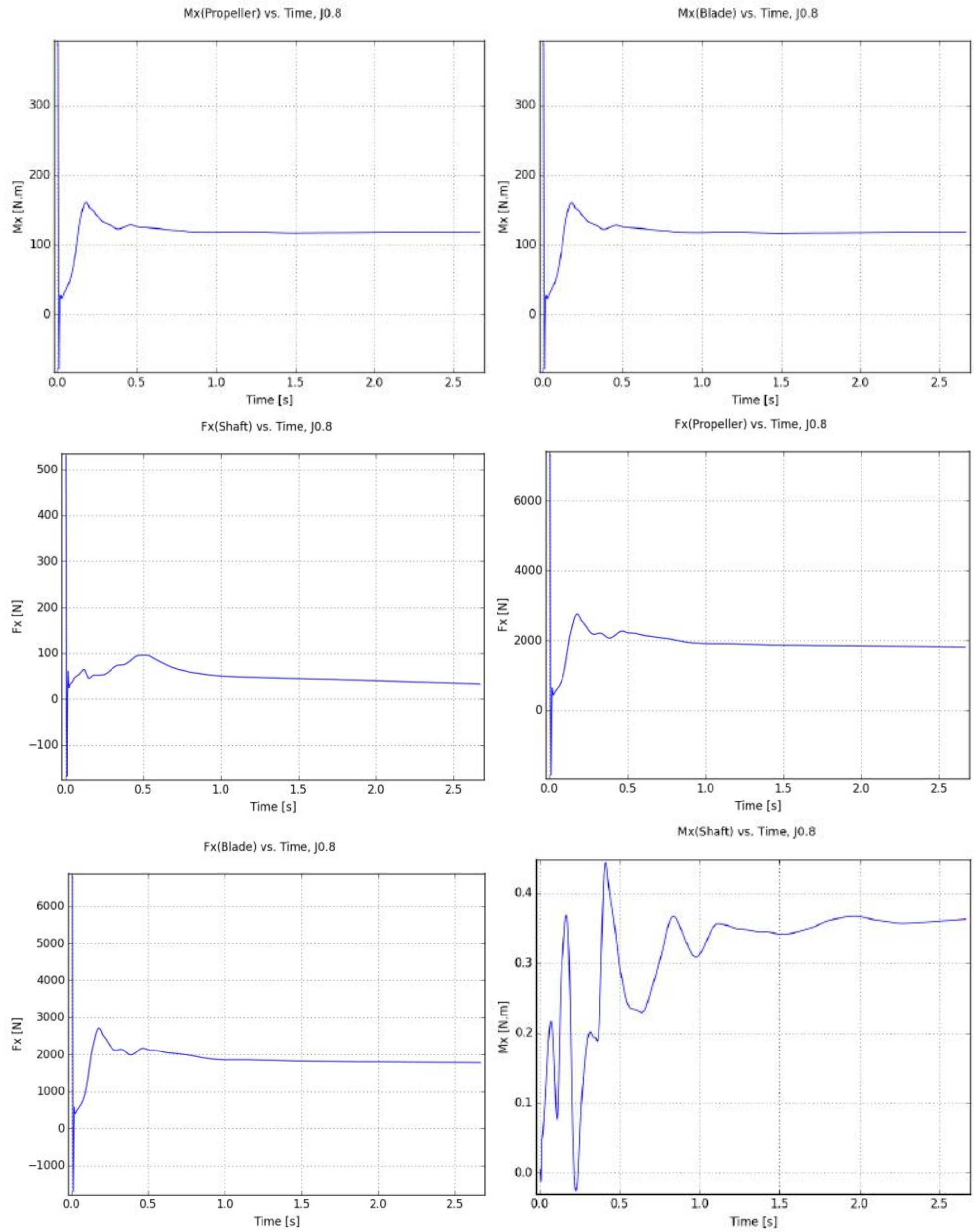




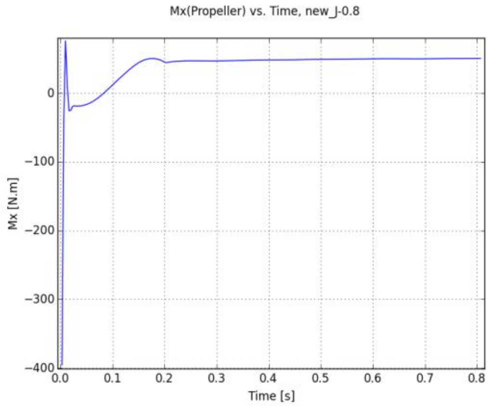
P/D Negative 1.2 J-0.6

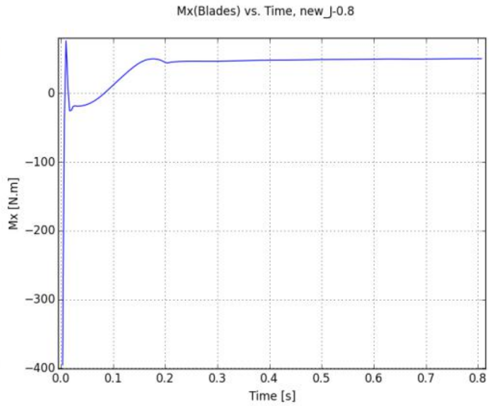


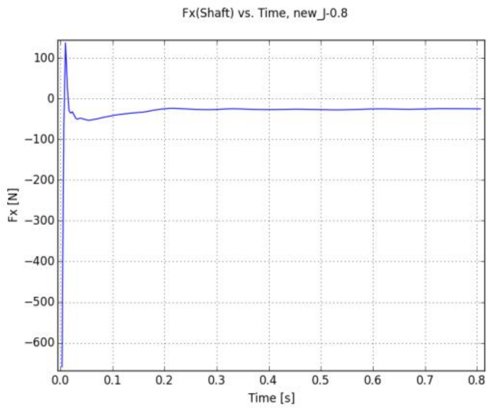
P/D Negative 1.2 J0.8

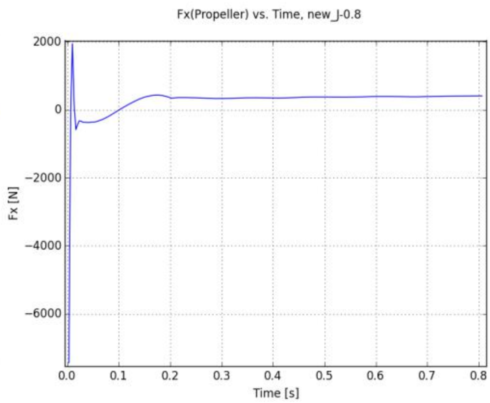


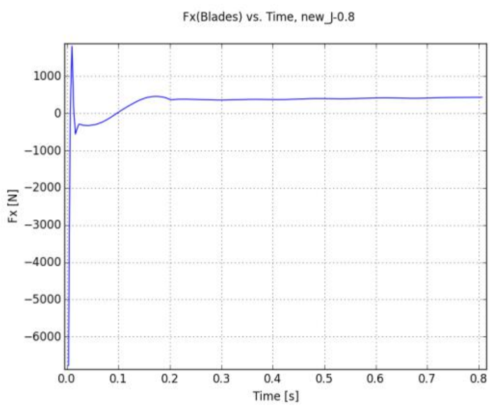
P/D Negative 1.2 J-0.8

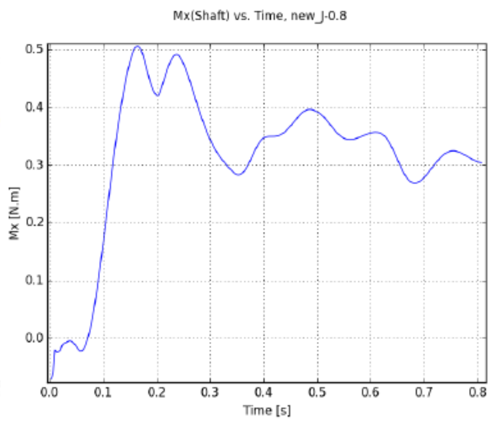




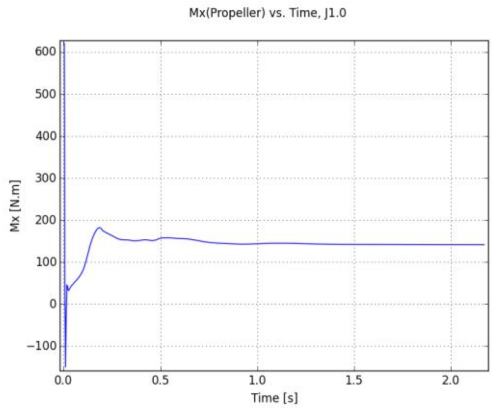


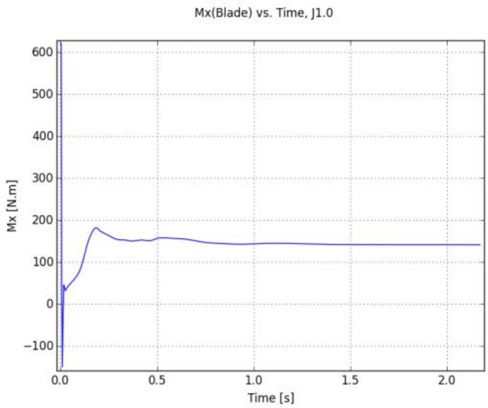


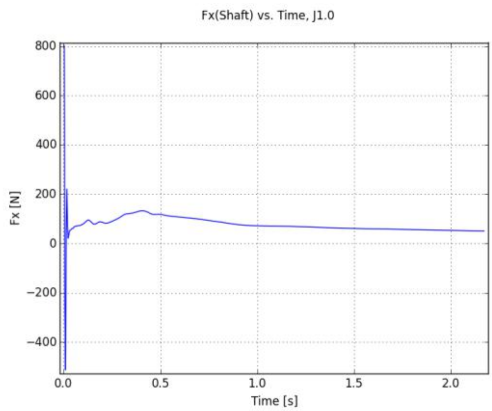


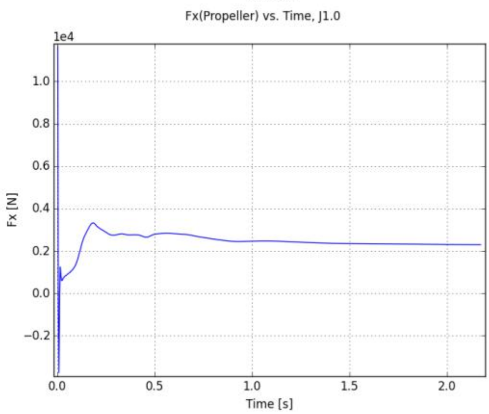


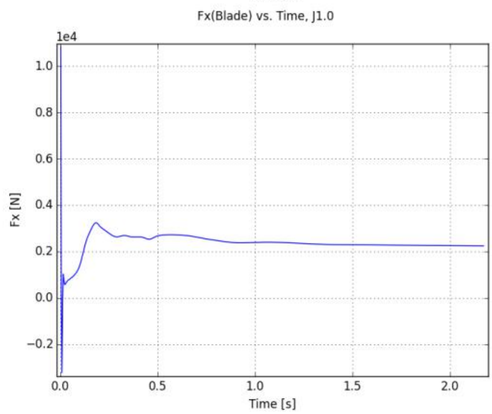
P/D Negative 1.2 J1.0

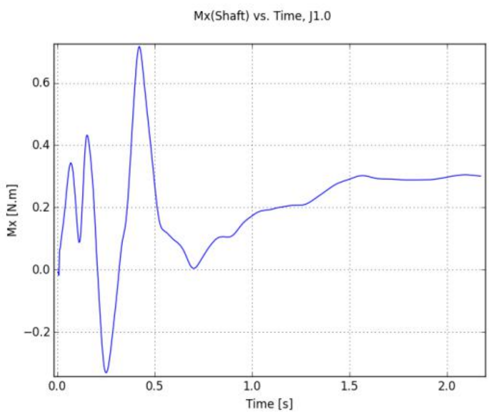




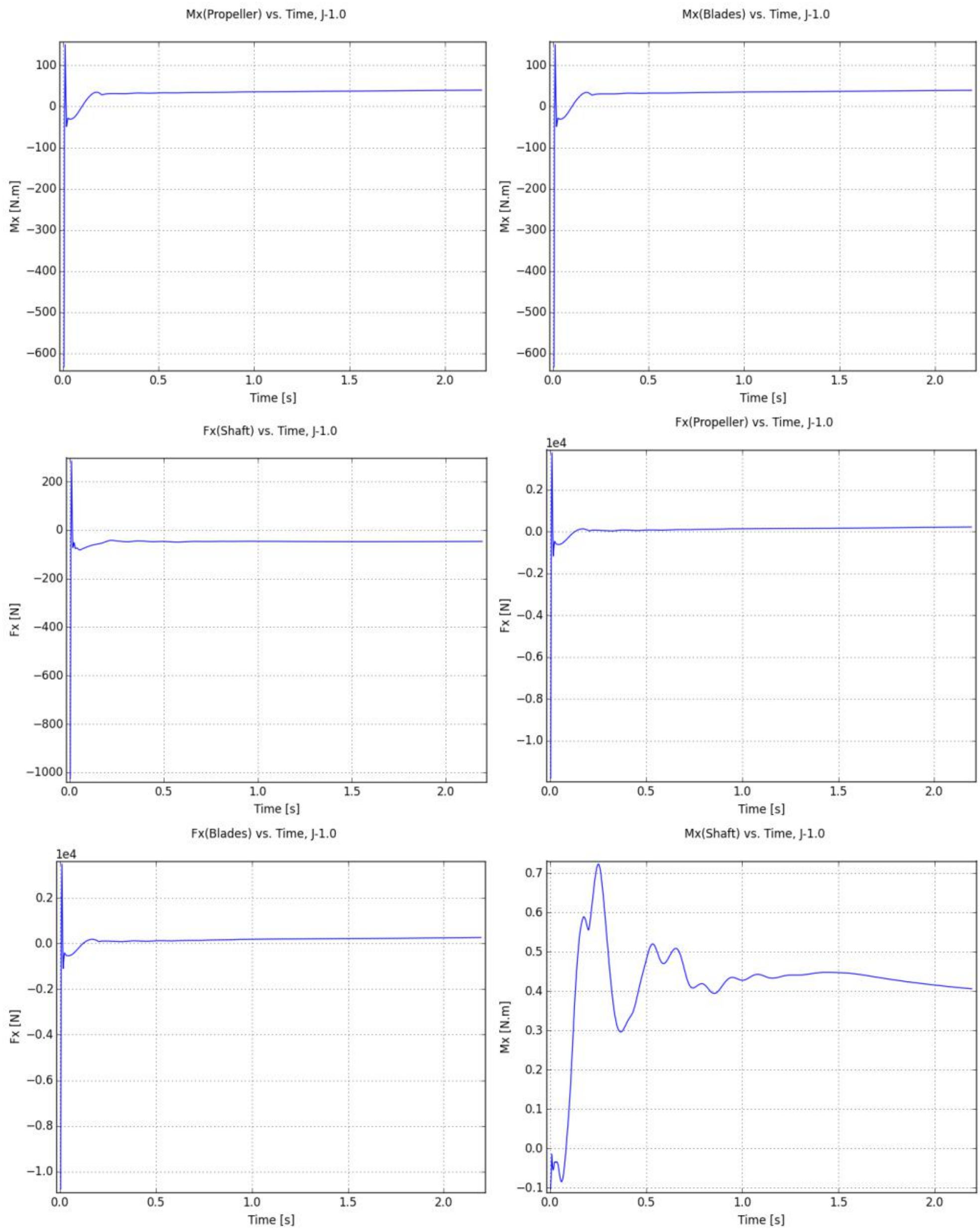




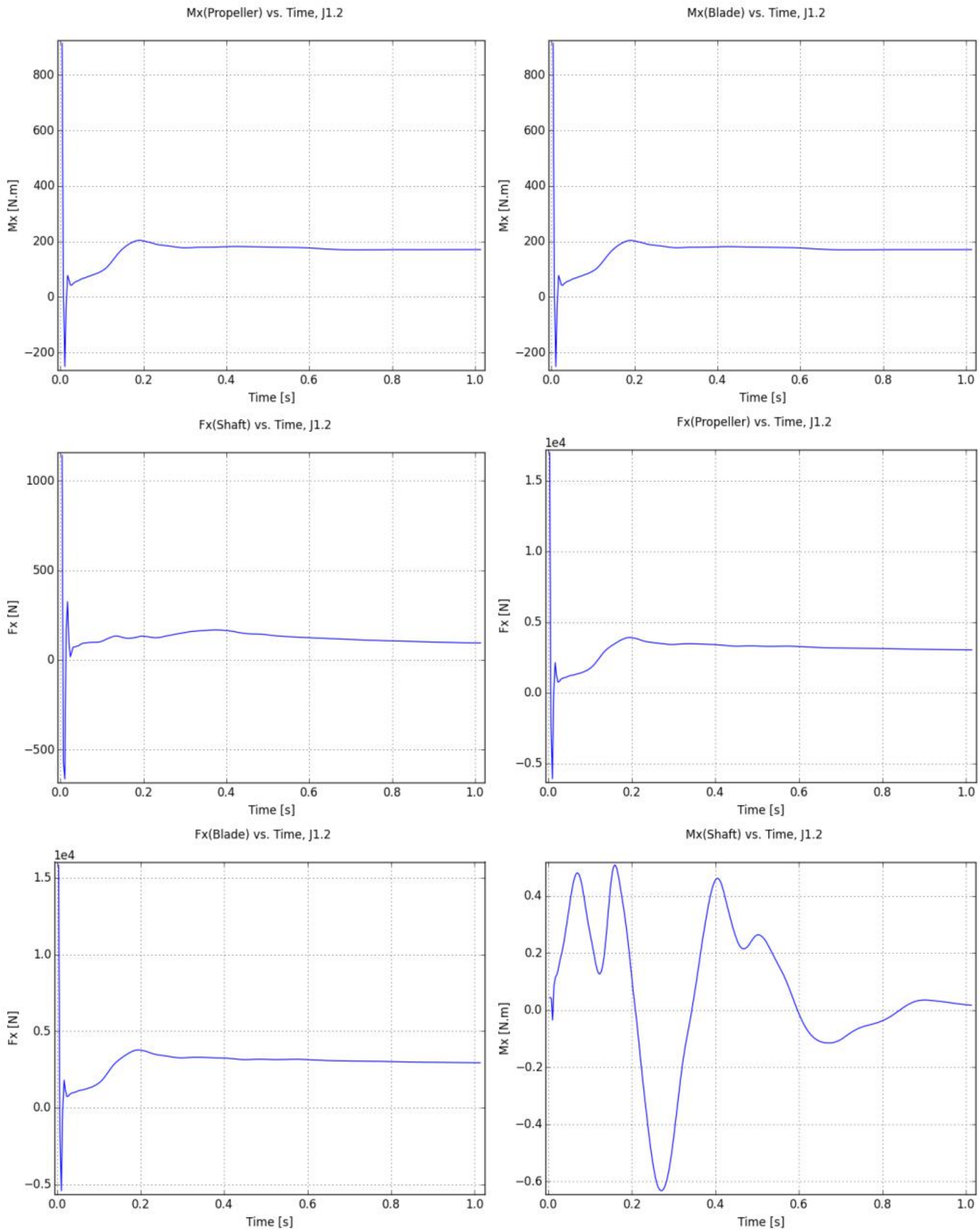




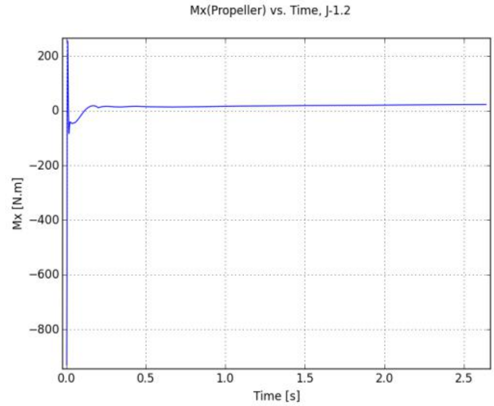
P/D Negative 1.2 J-1.0

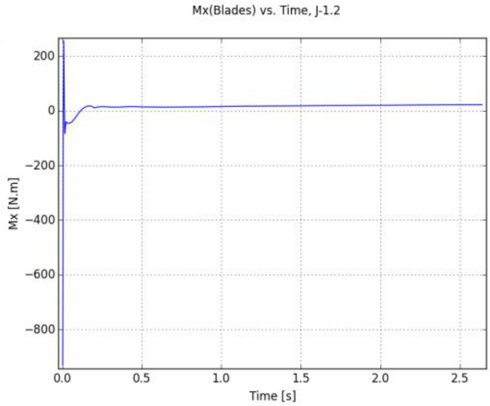


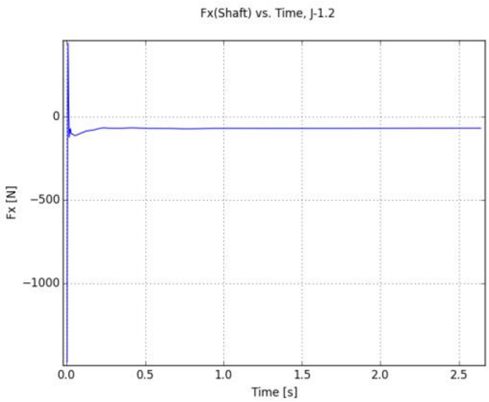
P/D Negative 1.2 J1.2

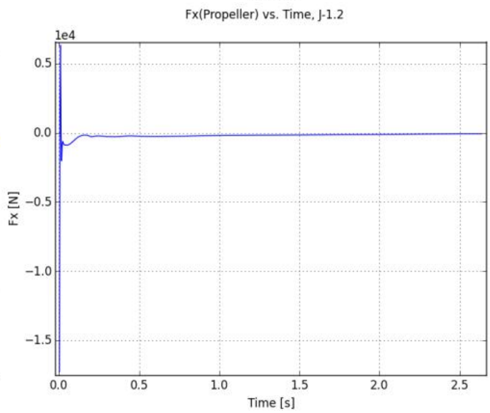


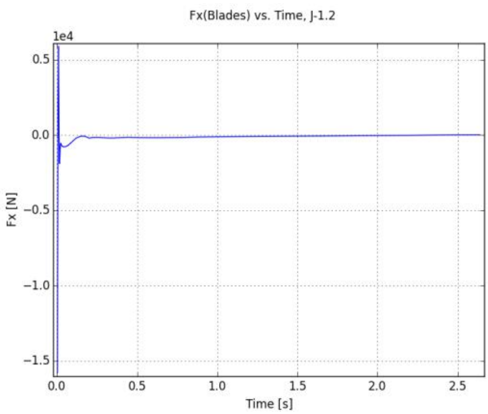
P/D Negative 1.2 J-1.2

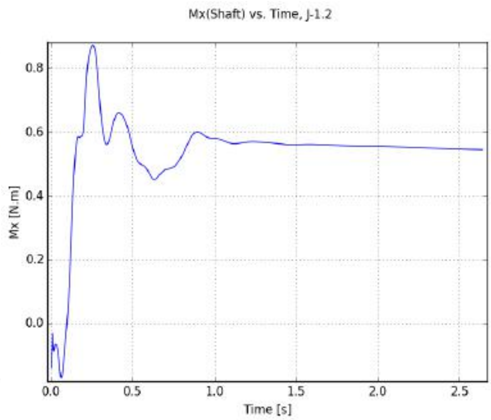




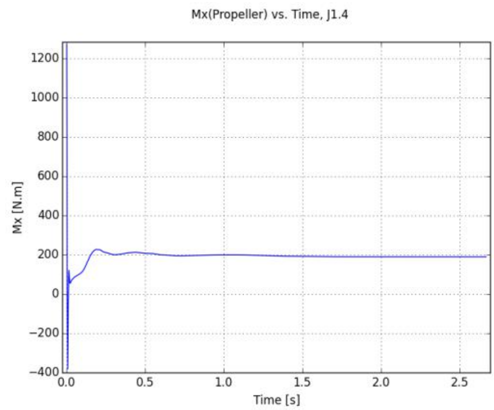


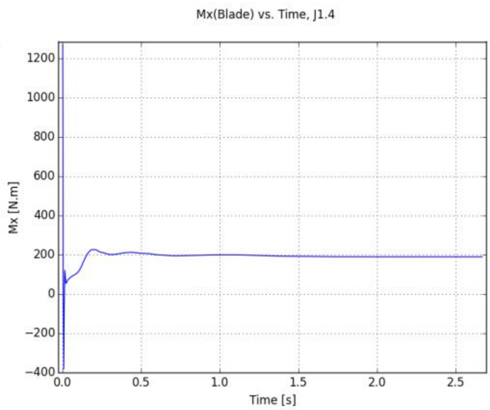


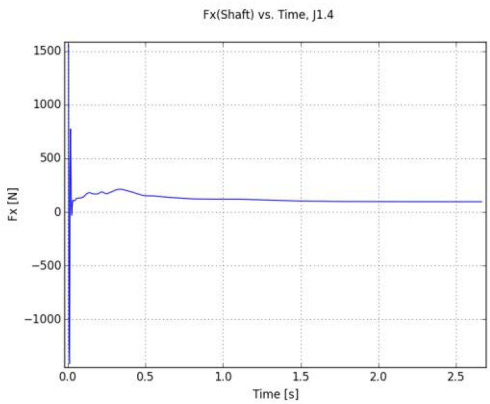


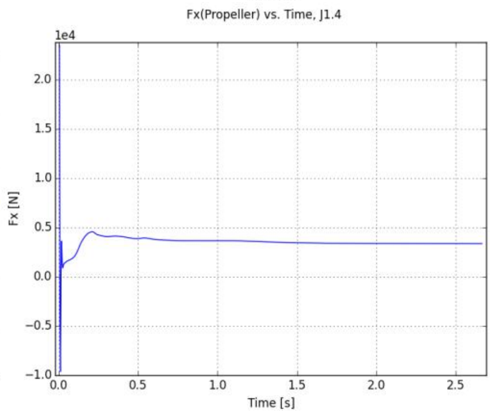


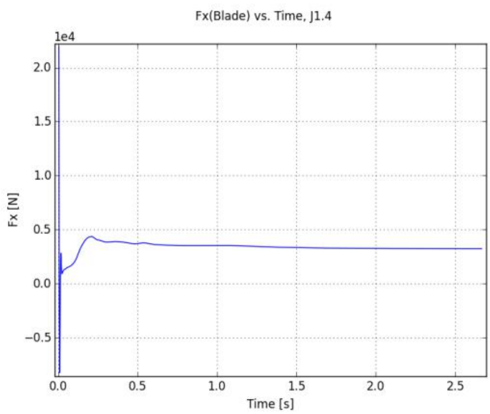
P/D Negative 1.2 J1.4

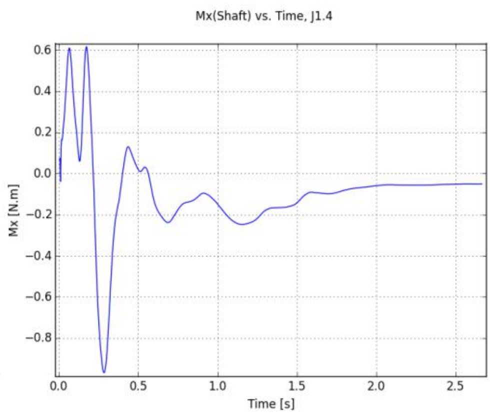




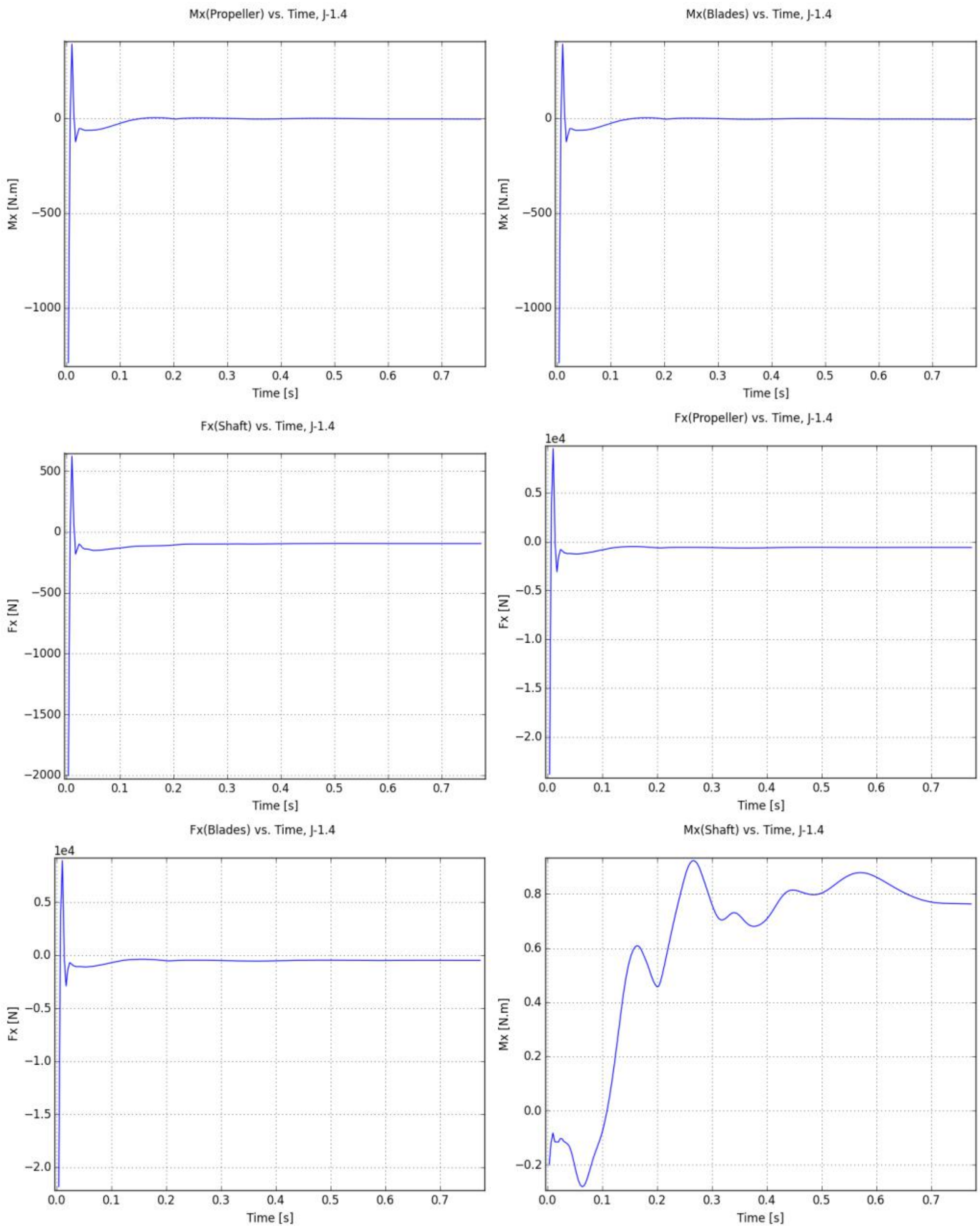








P/D Negative 1.2 J-1.4



APPENDIX E License Numeca FINEMarine

Dear Edli Kemal

Thank you for requesting the marine package in the free student offer.
Please follow these instructions to get started.

1. Download products

a) **Go** to our Customer Area.

b) **Login** with the following credentials:
Username: edli15@mhs.ne.its.ac.id
Password: EKemal2019

c) **Download**

- **FINE™/Marine v7.2-1**
  - Installation archive for the selected OS,
  - Tutorials archive,
  - Democases archive.

2. Installation

a) **Install** FINE™/Marine on the machine: kemal (Windows/Linux).

b) **Ignore** the message to send machine information to NUMECA during installation.

c) **Use** the attached licenses in the **Administration Tool** to activate your license (Windows/Linux)

The attached licenses are only valid on the machine with:

host name	kemal
hostID	1c872ce122ec
vendor defined hostID	a19363cd5a9b8bf7694eac996fd3b096

The licensing is deactivated if the machine configuration is changed (e.g. upgrade OS version, change network card...). Ensure that your hardware address is not generated randomly as this will change the hostID (Windows).
We are unable to issue a new license-file before the current one expires.

For questions related to the installation and use of the software please use the forum (accessible from the Customer Area). Do not hesitate to send us information about your work with NUMECA software if you would like to get featured on our website/blog.
We wish you a pleasant CFD experience with this free student version!

Regards
NUMECA Academic Group

“this page is intentionally left blank”

AUTHOR BIOGRAPHY

Edli Kemal Mahadika was a student of double degree program in Marine Engineering Department, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember. He is the second child of dr. H. Elfiedi Sofyan and Hj. Mastalinda, S.E. He was specialized in Marine Manufacture and Design Laboratory. He was born on June 20th 1997 in Padang. She completed his 12 years of formal education in Duri, Riau. He started his journey in ITS be the staff of IMarEST Indonesia and then joining the UKM Maritime Challenge and had position as public relation staff. He also participates as the committee of its big event called Indonesia Maritime Challenge 2016 in Bawean. He trained his capabilities by joining leadership program and design skill such as AutoCAD and Maxsurf. In the end of December 2016, he also be a global volunteer to over come the SDG about education in Denizli, Turkey for about 6 weeks which were teaching the culture and English. When he was returned to Indonesia, he gave a talk in some forum as speaker telling about his experience and knowledge. He participated many seminars and forum discussion for getting more understanding. He already did internship three times in different companies which were PT. Citra Shipyard (2017), PT. Biro Klasifikasi Indonesia (2018), and PT. Pratiwi Putra Sulung (2018). In the end of 2018, he also get awarded as excellent student on 1st Ocean Education College International Student Innovation Course Program in Tianjin, China.