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Computational Investigation of Oil Film Pressure Profile in Journal Bearings

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ABSTRACT

Lubrication of journal bearing in ship shafting systems is facing a problem in the slow speed range, where oil film created pressure depends on shaft speed, among many other factors. Hence, the slower the speed the lower the pressure will be, which shifts lubrication from hydrodynamic to boundary one. An experimental journal bearing test rig (JBTR) has been designed and established to simulate typical journal bearing for ship's shafting system. A theoretical validation study has been undertaken and good agreement with the test rig pressure readings was found. The test rig is capable of carrying out wide range of tests to investigate oil film pressure profile dependence on many parameters regarding design modification, oil properties, material properties, and many other factors. A new Computational Fluid Dynamic (CFD) model has been built for the sake of coupling future experimental investigations with computerized ones. The CFD model was created using the well-known CFD package Ansys ver. 15.0. The effect of shaft speed on oil film pressure profile was studied using the CFD model as a verification test. The model results were contrasted to the experimental results and an acceptable deviation range was found.

Keywords: CFD analysis, hydrodynamic lubrication, boundary lubrication, experimental test, journal bearing (JB), propulsion shafting system.

INTRODUCTION

Journal bearings are one of the important shafting elements in ship shafting propulsion systems. The design of journal bearings is considered important to avoid boundary lubrication problems. A number of design constraints have been studied through the last decade experimentally and numerical. Fluid film journal bearing is a mechanical element designed to support a load while permitting relative motion between journal and bearing surface.

The fluid film bearing is also called hydrodynamic journal bearing. An effective fluid film ought to be applied with the aim of separating the journal and bearing wall. Generally, radial clearance is very small in order of 15/10000th of journal radius. The failure of fluid film could possibly result in notable problems in the bearing during working conditions. Complicated obstacles could emerge and might lead to undesirable failure and losses, among of which include the metal-to metal contact that could increase with the result of reaching the hazardous boundary lubrication area with its negative consequences on the bearing performance.

It's significant to mention that factors such as the friction as well as the power loss may ultimately result in a power loss in addition to a tangible reduction in the life of the bearing. Hence, researchers have conducted versatile investigations concerning the numerous parameters of the journal bearing.

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The endeavours have culminated in the discovery of the great impact of load capacity as one of the foremost parameters affecting load capacity estimation as well as dynamic analysis.

Problem statement; For the final aspired goal of promoting the thrust force relating to ships, it is so instrumental to reduce the speed of the propeller, in spite of the undesirable consequences of that reduction on the effective performance of the lubrication oil film resulting from the reduced speed in the journal bearing. Hence, the urgent need to investigate the other factors affecting the pressure profile that work in lieu with the speed factor strongly arises. Those other factors would comprise the viscosity, the density and the temperature characterizing the journal bearing lubricating oil. Moreover, there ought to be a thorough investigation into that issue for the sake of reducing and overcoming the negative impacts incurred as a consequence.

2. LITERATURE REVIEW

An experimental study was carried out by Valkonen in 2009, with the aim of determining the oil film pressure in hydrodynamic journal bearings under realistic operating conditions. The relation between the oil film pressure and the other operating parameters was given great attention. The author conducted a new method for determining the friction using a heat flow analysis. Optical pressure sensors were inserted in the bearings for measuring the oil film pressure. He pointed out the key operating parameters in that study which comprised the oil film temperature, the oil film pressure and the oil film thickness. Valkonen, 2009, participated, to a great deal, in developing journal bearing tribology research methods. The author had a great effect on developing measuring and simulation methods. The author suggested using optical pressure sensors, as other developed sensors were not available or guaranteed (Valkonen, 2009).

Shahu et al, 2012, have launched a numerical study with the aim of realizing the effects of the frictional force and the temperature fluctuations on the bearing temperature and viscosity profiles. It has presented thermodynamic study of the 3 dimensional plain journal bearing using CFD. They recorded the pressure distribution on journal surface, not only circumferentially but also axially, with and without considering temperature effect. The researchers have made use of the 3–dimensional bearing geometry and meshing generated in Gambit, with view to investigating the performance of bearing using fluent 6.3.26 software. From this it is clear that increasing the frictional force increases the temperature and reduces the viscosity, as well as the maximum pressure of the lubricant present inside the plain journal bearing (Shahu et al, 2012).

In 2013, Aher et.al, studied the pressure distribution of plain journal bearing with lobe journal bearing. The authors stated that the plain hydrodynamic journal bearing was the most basic hydrodynamic bearing with cylindrical bore. The oil whirl came to represent the problem hindering the required effective performance, as it caused high vibration amplitudes, forces, and cyclic stresses on the shaft bearings and machine creating the instability of bearing. The result showed that lobe bearing had a higher load carrying capacity with good stability. Load carrying capacity of lobe manufactured bearing was observed to be higher than the plain bearing. Thus, the stability of lobe bearing was better than that of plain journal bearing, and consequently, is more stable at higher speed as well as lower speed (Aher, et al, 2013).

Analyzing the performance of infinitely long journal bearing using CFD and FSI approach was the main concern of Tiwari, 2014. Critical data concerning the analytical calculation are considered from the design data book. The objectives of this research aimed at realizing the effect of pressure and temperature variations of journal bearing under steady state condition. It was found out that maximum pressure tended to occur more often nearer to the region of minimum film thickness. During analysis, developed analytical model had to be compared with simulation results of ANSYS. It was found out that CFD results validated with analytical solution (Tiwari, et al, 2014).

In 2015, Binua et.al, performed an experimental study of hydrodynamic pressure distribution in oil lubricated two-axial groove journal bearing. Newly developed test rig was used to measure hydrodynamic pressure in oil lubricated two-axial groove. They held a comparison between the maximum pressures obtained using the second approach and those obtained by theoretical values. The difference between the maximum experimental pressures and theoretical ones was 20%. There was a difficulty in measuring hydrodynamic pressure by means of the sensor shaft approach as it failed to work. The reason was that it didn't have the ability to measure dynamic pressure variation. The experimentally recorded pressures using the conventional approach were lower than the theoretical pressures by 20% (Binu, et al, 2015).

Calculating the pressure distribution and load capacity of journal bearing by analytical method and finite element method was implemented by researchers among them were Nuruzzama et al, 2010. To check the validity, the results were compared. Also calculation isothermal analysis was considered. Comparing the results have shown that low eccentricity ratio would result in a notable steady rise in the dimensionless load and also a similar rise with high eccentricity ratio (Nuruzzama et al, 2010).

Unsteady analysis for thin film lubricated journal bearing with different L/D ratios such as 0.25, 0.5, 1, 1.5, and 2 was performed by Panday et al, 2012. During the analysis, authors have observed maximum pressure that was present at minimum oil film thickness. Also it was found out that shear stress on surface of bearing and journal was reduced with the increase in L/D ratio, but the turbulent viscosity of lubricant tended to rise with the increase in L/D ratio (Panday et al, 2012)

Among the latest researches, Zhang, et.al, 2016, investigated the tribological applications of high strength, tin-based overlay for medium and high speed diesel engine bearing. That structure comprised a combination of electroplating and thermal annealing, as well as a top and a bottom tin-copper sublayer, with a tin-nickel intermetallic sublayer in the middle. The results showed significant improvement in the fatigue, in as much as the multilayer was concerned compared to its monolayer counterpart. There was also a notable increase in the seizure resistance for the multilayer structure. Wear resistance was enhanced, if compared to the wear resistance of the monolayer structure. The wear amount of the monolayer overlay was more than five times the wear amount of the multilayer, under the same conditions. Moreover, the tin-nickel intermetallic sublayer combined the properties of friction and hardness, a quality which improved seizure resistance on bearing exposed to the steel shaft (Zhang, et.al, 2016).

The pressure and temperature effects on viscosity were the target of the investigations carried out by Panthi et al, 2015. They have ascertained the effect of L/D ratio, rotational speed and eccentricity ratio on pressure distribution on bearing. The analysis has been done using computational fluid dynamic "CFD" tool. Results obtained from the software validated with numerical results reached using Raimondi and Boyd chart methods. Results have indicated that increasing temperature raises the pressure but would lead to considerable decreases in the altitude angle (Panthi et al, 2015).

A CFD analysis of hydrodynamic journal bearing was conducted by Kumar et al, 2015. During the analysis it was stated that oil film pressure was one of the important parameters describing the working condition of hydrodynamic journal bearing. They have focused on the modeling of journal bearing for various L/D and eccentricity ratios, where the analysis was done by using fluid structure interaction "FSI" approach to find out pressure, stress and deformation of hydrodynamic journal bearing. Authors have recorded the pressure distribution by means of sending the lubricant in between the bearing and the journal. FSI technique was made use of so as to identify stresses and deformation of the journal bearing. The technique has thus been effectively used for finding out the performance of the bearing (Kumar et al, 2015).

3. EXPERIMENTAL TEST RIG SETUP

Figure (1) shows the journal bearing test rig (JBTR), designed by the authors, with its different components used in the experiments, where its main dimensions are given in Table 1. The upper part of the test rig bearing is provided with an oil inlet port, which allows supplying lubricating oil from the oil inlet port into the bearing clearance. The lubricant is supplied to the bearing at an inlet port located on the vertical center line of the bearing. On the rotation of the journal, the pressure created inside is measured via the ten pressure transmitters, distributed around the circumference of the plain bearing and is hence displayed on PLC. The validity of the journal bearing test rig experimental results was ensured via numerous comparisons that were continuously held and that proved their consistency and accordance in relation to those previously derived theoretical results. Hence, the journal bearing test rig has proved valid for the experiments that are to be conducted on it in the future, as illustrated in Reference (Marey. Nour, et al, 2018):

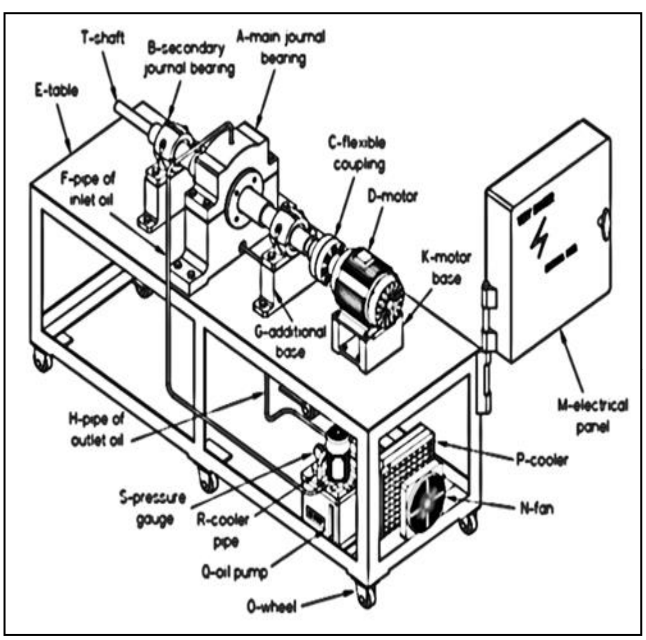


Figure 1: The Journal Bearing Test Rig (JBTR) by which the experiment was conducted

Table [1]: The dimensional data concerning the journal bearing as well as the lubrication oil properties.

L, bearing length	58 mm
d, inner diameter for plain bearing	105.05 mm
Φs shaft diameter	104.97 mm
W, Weight of journal shaft	727.65 N
C_0, total clearance	0.08 mm
C, radial clearance	0.04 mm
Operating speed	50:400 rpm
Lubricant density	862 Kg/m^3
Lubricant viscosity	0.0967 Kg/ms

4. CFD MODEL- ANALYSIS

In this study, ANSYS FLUENT 15.0. was used to investigate the journal bearing behavior. The model is designed in "AUTOCAD" 2018, and is then imported in ANSYS for meshing and analysis. Furthermore, the CFD model is characterized by a predetermined number of cells amounting to 1165416 cells.

A symmetry condition is applied on the mid-plan of the bearing in order to simulate only half of the domain. On the side of bearing, the pressure is set at the ambient value, i.e. the relative pressure is set to zero. For the boundary conditions, the operating pressure is set to 101325 Pa. To simplify the geometry, one side of the clearance is used as a lubricant inlet and the other as an outlet. The boundary condition at the lubricant inlet was set as pressure inlet with an appropriate value, leading to the right-side lubricant flow rate. For the outlet, the boundary condition was set as pressure outlet with gauge pressure at zero Pascal. The bearing shell and the journal were set as a wall; the journal was defined as a moving wall "with different angular velocities", while the bearing shell was defined as stationary. No slip wall was to be used in the simulation.

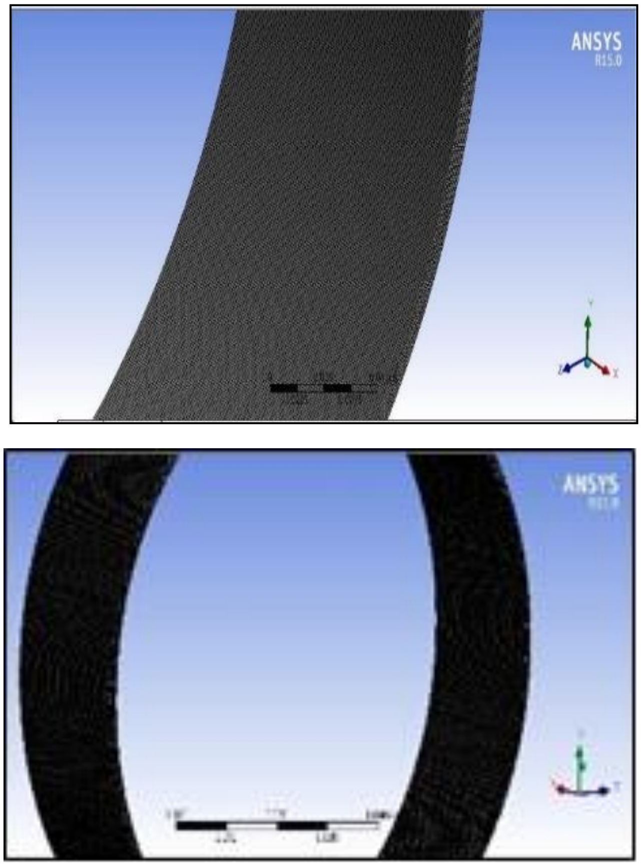
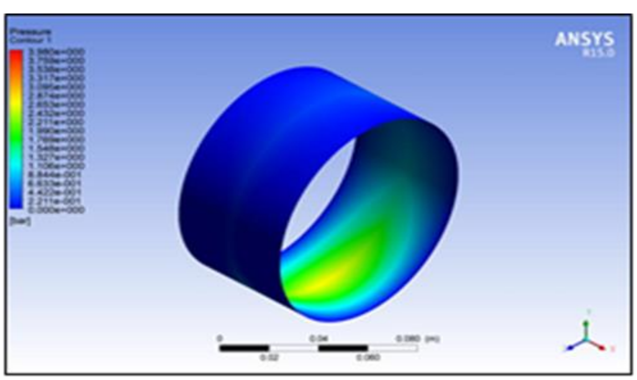


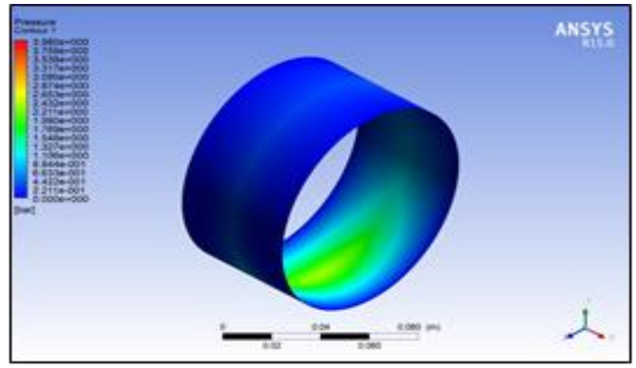
Figure 2: Meshed Model

5. CFD MODEL- RESULTS

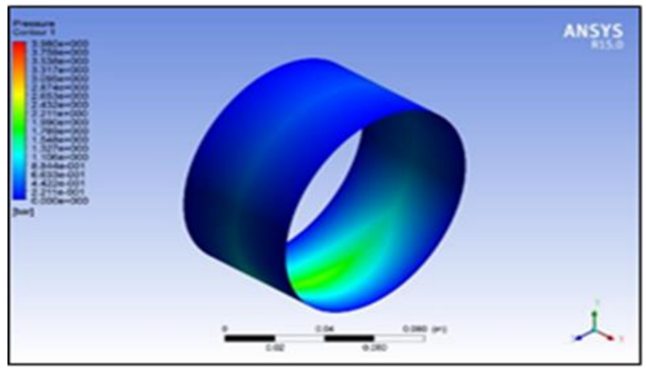
The above mentioned CFD model has been utilized to further study of the pressure distribution relating to the 3-dimensional lubrication oil film. For investigating the impact of speed on the 3-dimensional oil film, the CFD model was run at various speeds of rotation (50, 100, 150, 200, 250, 300, 350 and 400 RPM). The results were to be individually recorded and they were drawn by means of the post processor, as illustrated in Fig (3).



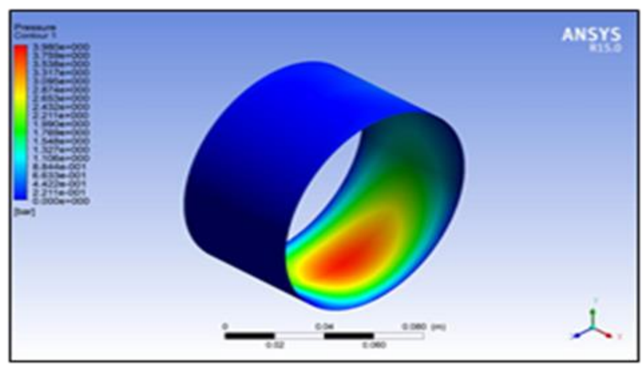
50 RPM



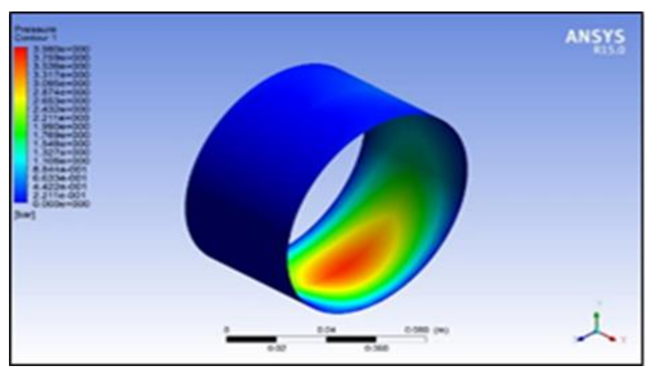
100 RPM



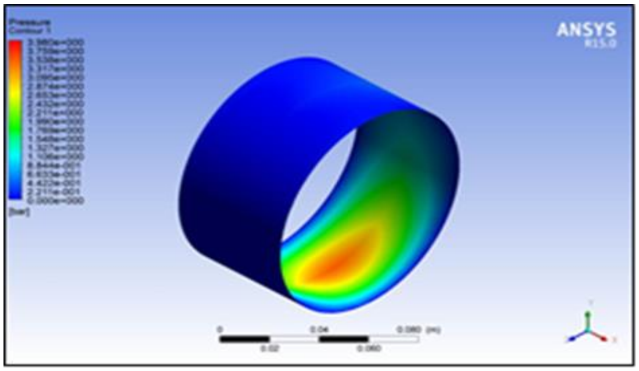
150 RPM



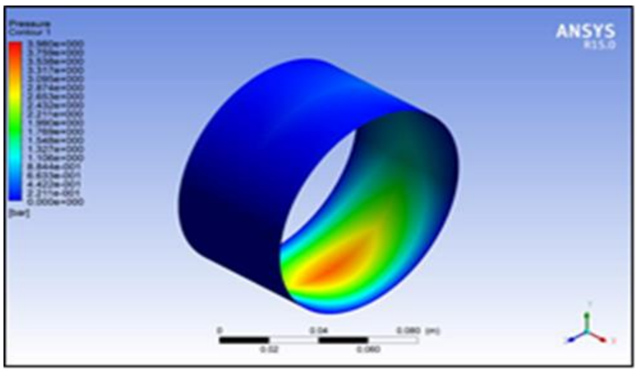
200 RPM



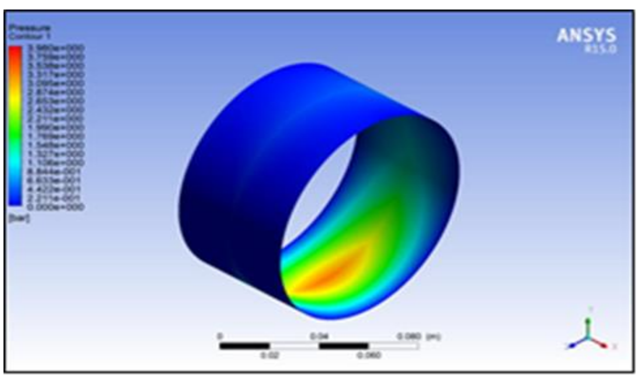
250 RPM



300 RPM



350 RPM



400 RPM

Figure 3: Pressure distribution at different speed rotations

Table 2: The CFD model maximum film pressure ratio

Parameter	RPM			
	50	100	150	200
P_0/P_{max}	0.447	0.489	0.519	0.527
Parameter	**RPM**			
	250	300	350	400
P_0/P_{max}	0.556	0.559	0.618	0.655

6. VALIDATION OF CFD MODEL

Table (3) gives a comparison between the maximum film pressure ratio (P_0 / P_{max}, where P_0 is terminating film pressure, P_{max} is maximum film pressure) as obtained by CFD model and those results obtained experimentally using the above mentioned journal bearing test rig JBTR and theoretically as recorded in reference (Marey. Nour, et al, 2018). The same comparison is shown on figure (4).

Table 3: CFD model results as compared to both of JBTR experimental and theoretical results.

RPM	CFD	Experimental [7]	Theoretical [7]
	P_0/P_{max}	P_0/P_{max}	P_0/P_{max}
50	0.447	0.500	0.47
100	0.489	0.504	0.51
150	0.519	0.507	0.52
200	0.527	0.512	0.53
250	0.556	0.52	0.532
300	0.595	0.528	0.534
350	0.618	0.53	0.536
400	0.655	0.619	0.54

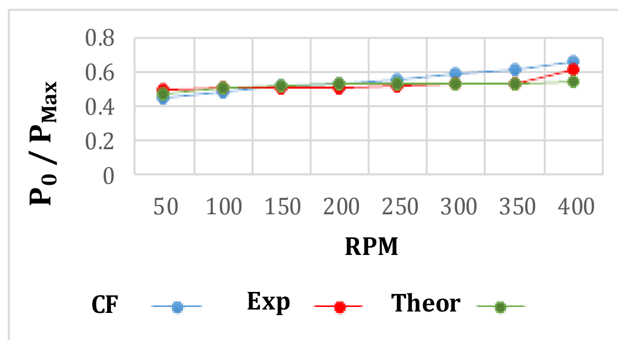


Figure 4: CFD model results as compared to both of JBTR experimental and theoretical results.

7. Conclusion

By examining the results given in table (3) and figure (4) it is clear that there is a good agreement between the results obtained experimentally as well as the results calculated theoretical and numerically using CFD model. This conclusion has proofed the validity of the purposed CFD model to be used for further and deep investigations of the behavior of the oil film in journal bearing.

Nomenclature

C	Radial Clearance (mm)
C_0	Total Clearance (mm)
CFD	Computational Fluid Dynamics
d	Inner Diameter For Plain Bearing
L	Bearing Length (mm)
P_0	Terminating Film Pressure (Pa)
P_{max}	Maximum Film Pressure (Pa)
P_0/P_{max}	Maximum Film Pressure Ratio
W,	Weight of Journal Shaft (N)
Φs	Shaft Diameter (mm)

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دراسة حاسوبية لضغط غشاء زيت التزييت في أعمدة المحامل

تواجة عملية تزييت أعمدة المحامل نقل الحركة في السفن ذات السرعات البطيئة مشكلة مهمة حيث يعتمد ضغط غشاء زيت التزييت علي سرعة العمود، علاوة علي العديد من العوامل الأخري. ومن ثم كلما كانت السرعة أبطأ كلما إنخفض الضغط، مما يؤدي إلي الأنتقال من نطاق التزييت الهيدروديناميكي إلي نطاق التزييت الحدي. تم تصميم وتجهيز منصة تجريبية لإختبار المحامل من النوع (JBTR) لمحاكاة أحد أنواع أنظمة نقل الحركة في السفينة. وتم إجراء دراسة نظرية تحققية ومقارنة نتائجها بالنتائج العملية وقد كان الأنتفاق بينهما جيدا. وتعتبر هذة المنصة التجريبة قادرة علي تنفيذ مجموعة واسعة من الإختبارات لدراسة إعتماد ضغط غشاء الزيت علي العديد من العوامل المرتيطة بتصميم المحركات وتطورها علاوة علي خصائص زيت التزييت، خصائص المواد والعديد من العوامل الأخري. أيضا تم بناء نموذج جديد من نماذج ديناميكا الموائع الحاسوبية (CFD) من أجل ربط الدراسات التجريبية المستقبلية مع الدراسات الحاسوبية. وقد تم بناء هذا النموذج بإستخدام حزمة ديناميكا الموائع الحاسوبية المعروفة بإسم (Ansys Ver. 15.0) تمت دراسة تأثير سرعة العمود علي شكل غشاء زيت التزييت بإستخدام النموذج المنشأ كأختبار لتحقق. وتم مقارنة نتائج النموذج بالنتائج التجريبية وكان الأختلاف بينهما في حدود المقبول .