A Study on the Powering Performance of Drillship in Transit Mode with Azimuth Thrusters

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ABSTRACT

As a special case of multi propulsion ships, a study on the powering performance prediction for drillship in transit mode with 6 and 3 azimuth thrusters is presented in this paper. Azimuth thrusters installed in drillship are used not only for the thrust acting device in dynamic positioning mode when wind/current/wave load are applied but also used for the propulsion system in transit mode from drilling site to site.

The conventional method for treating 3 and 6 azimuth thrusters in propulsion test and extrapolation to full-scale value is to take average of each thruster's thrust and torque and summation. However, this method does not consider each thruster's inflow condition. In this study, an alternative method dividing 6 azimuth thrusters into several groups considering each thruster group's longitudinal/transversal position is presented. Wake fraction of each group and its effect on the propulsion efficiency are investigated. Considering the difference of wake along with position, the variation of propeller revolution for keeping constant power of each thruster is applied and compared with constant revolution mode.

Comparative model test results are presented for 6 and 3 azimuth thrusters operation (forward group of 3 thrusters retracted into the hull) and overall propulsion efficiency is compared. Some special concerns for the model testing technique for the drillship propulsion test are also presented.

Keywords

Drillship, Powering performance, Azimuth thruster

1 INTRODUCTION

Offshore market is booming these days in contrast with declining trend in commercial ship market and major ship yards in South Korea are focusing research and development in offshore plants including drillship.

In exploration project for natural resource especially in sea, a drillship is a very attractive one and many exploration companies have ordered new building of drillship nowadays. Azimuth thrusters are used for dynamic positioning work for drilling with wind/wave/current loading applied, but also used as main propulsion system in transit mode from site to site. Drillship operating companies requested authors to make enhancement in fuel efficiency in transit mode, because oil price is still high and expected to be increased. By this reason, drillship design aims at the workability in harsh environment mainly, but also should take the focus to improvement in propulsion efficiency.

Model test campaign to assess powering performance of drillship has more complexity in test apparatus itself, because of many points of measurement in propeller, duct and whole unit. And also analysis procedures should consider the wake effect due to each thruster's position (longitudinally and transversally), and also each thruster unit's loading to the overall efficiency pointed out by authors' previous work [1].

In this study, powering model test was carried out for drillship equipped with 6 and 3 azimuth thrusters. Conventional way to treat multiple propulsors having identical dimension and power is to take average and summation of each thruster's thrust and torque value. But in this method, the wake effect due to different position in hull form might be disregarded and predicted power and revolution of each thruster unit in full scale can be deviated from true values. By grouping thrusters as positional similarity, each group's powering performance is evaluated separately and can be merged all together.

Some azimuth thruster design has a retractable feature and part of azimuth thrusters can be retracted into the hull. By model test program for 6 in forward/after part and 3 azimuth thrusters in after part only, overall propulsion efficiency is thoroughly compared.

In this paper, test equipment for measuring several forces and moments around azimuth thruster to assess powering performance of drillship is briefly introduced and a control device of yaw angle adjustment also.

2 MODEL SHIP AND TEST SETUP

A subject hull form for this study is newly developed Hyundai HD12000 drillship with main particulars as Table 1. As normal drillship design, our prototype design has central moon. For DP and propulsion purposes, 6 azimuth thrusters with retractable canister type are positioned at forward and after part of hull form. Model azimuth thruster has MARIN 19A duct and Ka4-70 series propeller. Detail dimension is presented at Table 1.

Table 1 Main particulars of ship and azimuth thruster

Ship Main Particulars		
Item	Ship	Model
Scale	28.926	
LBP(m)	abt. 223.0	abt. 7.71
B(m)	38.0	1.31
T_operating(m)	11.5	0.40
Displ.(m^3)	abt. 80,000	abt. 3.31
Azimuth thruster		
Prop. Dia.(m)	4.1	0.1417
No. Blades	4	
P/D(mean)	0.8	
EAR	0.6532	
Hub ratio	0.243	

Housing and strut of azimuth thruster are manufactured with similar dimension of commercial thruster and duct is installed with tilting angle 5 deg. The perspective and 3 dimensional views are presented at Figure 1.

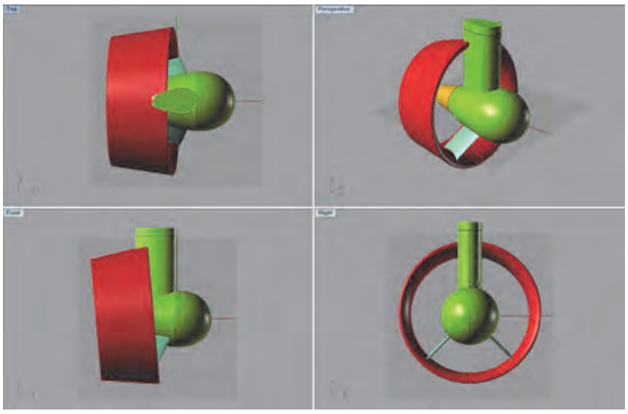

Figure 1 Duct/housing/strut of azimuth thruster

For the open water test of azimuth thruster, ITTC Recommended Procedures and Guidelines 7.5-02-03-01.3 “Podded Propulsor Test and Extrapolation” is referenced and general test setup for podded propulsor is used.

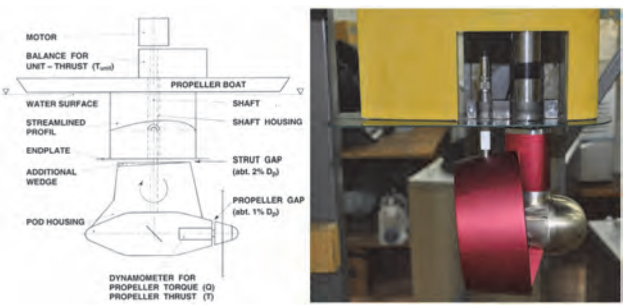

Figure 2 Test setup for open water test of azimuth thruster

In addition to general test set-up of podded propulsor (left side of Figure 2), force sensor for duct thrust measurement (right side of Figure 2) is installed along with vertical shaft of thruster body like Figure 2. Pulling and pushing type are two versions of podded propulsor by the position of propeller with respect to body and the current azimuth thruster is a pusher version.

Figure 3 Overall view of model azimuth thruster

Model azimuth thruster for open water test and propulsion test is manufactured like Figure 3. On the horizontal end of thruster body, a propeller shaft with thrust/torque sensor exists for propeller thrust/torque measurement directly. For the measurement of duct thrust which is important for the validation of duct design, a one component force sensor between vertical driving axis and duct is installed. Overall and effective thrust of azimuth thruster is unit thrust summarizing the effect of propeller thrust, duct thrust and resistance of housing/strut of thruster body. To measure this unit thrust, a two component balance is installed on the upper part of thruster where stationary part of balance is fixed on the open water test rig or model ship and force absorbing part is connected to the vertical shaft including thruster body. For the yaw angle adjustment of thruster, the outside of force absorbing part of balance is connected to the gear teeth with step motor to control the yaw angle. Driving motor for propeller revolution is installed on the upper end of vertical shaft of thruster.

As mentioned before, each model azimuth thruster has five measurement points, those are thrust/torque of propeller, duct thrust and unit thrust by 2 component balance (in some yaw angle, unit thrust and side thrust value should be considered). For the propulsion test, 6 model azimuth thrusters are installed in model ship, so many signal cables and power/encoder cables for motor and power/control cables for step motor of yaw angle control are laid between model ship and motor drive/data acquisition system. If motor drive and data acquisition system are located outside model ship, many cables may interfere with towing force measurement (in captive propulsion test which is a HMRI towing tank standard).

For the countermeasure of this circumstance, motor driving system and data acquisition system is installed inside model ship and the number of cables can be minimized(one main power line and one communication line from data acquisition system to data collecting computer). Overall view of propulsion test and forward/after bottom view are presented at Figure 4.

Figure 4 Overall and forward/after bottom view for propulsion test setup

In propulsion test of drillship with 6 or 3 azimuth thrusters, an integrated system for AC servo motor control of propeller driving and step motor control of azimuth thruster yaw angle simultaneously is developed and main screen of the system is presented at Figure 5.

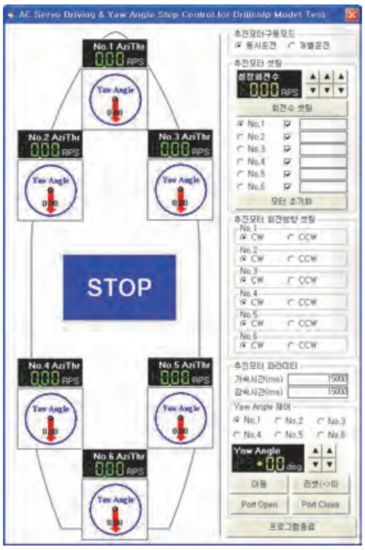

Figure 5 Integrated system for controlling propeller revolution and yaw angle of azimuth thruster

All sensors for measuring thrust/torque of propeller, duct thrust and unit thrust are calibrated before model test and the quality of sensors is checked and confirmed within HMRI towing tank standard (e.g linearity error within 0.2% F.S.).

3 TEST DATA AND ANALYSIS

Like a standard procedure of powering performance of conventional ships, a resistance test without azimuth thruster and open water test in unit configuration are carried out, then propulsion test. In this chapter, test data and analysis result for open water test and propulsion test only are presented and discussed here.

3.1 Open Water Test of Azimuth Thruster

As mentioned before, our stock azimuth thruster has MARIN 19A nozzle and Ka-4 70 series propeller. Authors select these geometries primarily because these are commercially used with wide application and also has validation data published by MARIN, so our developed test equipment can be validated with the published experiment data.

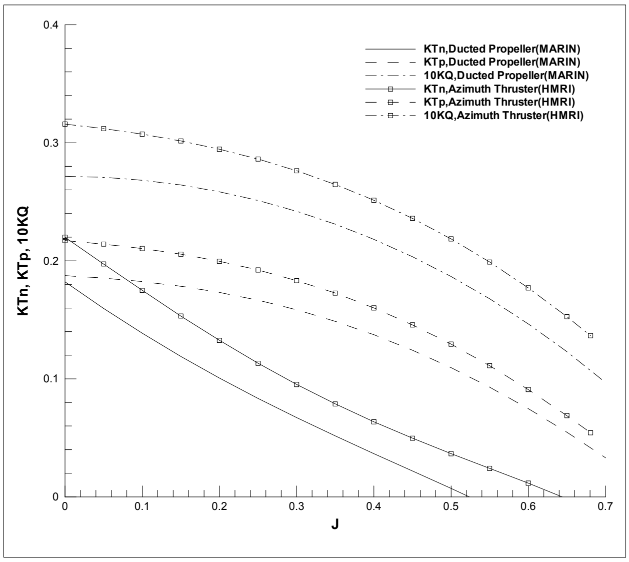

Figure 6 Open water characteristics of azimuth thruster

A published data for Ka4-70 with 19A nozzle (P/D=0.8) is for ducted propeller and current work is for azimuth thruster with same geometry of propeller and duct (nozzle). By this reason, we need to consider the wake effect by thruster body (propeller is located behind body, pusher version), so propeller thrust/torque and duct thrust in azimuth thruster configuration is a little higher than ducted propeller configuration like Figure 6. If using K_T identity methodology in self-propulsion factor of ship, the wake fraction of thruster body is around 0.2, which means the inflow speed behind thruster body is 80% of upstream velocity. Considering current thruster geometry, this value is within a reasonable range.

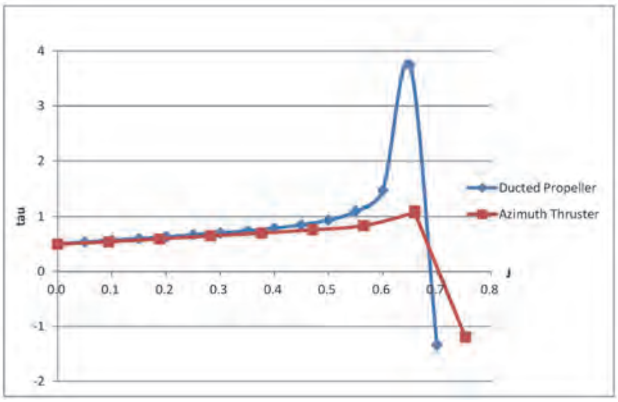

Figure 7 Ratio of propeller & nozzle thrust

Again, comparing tau(τ) defined as below between ducted propeller and azimuth thruster like Figure 7, a similar trend is presented except for high J range where strong effect of wake behind thruster body exists. From this, we can conclude the developed test equipment as validated.

$$\tau = Tp/(Tp+Tn) \quad (1)$$

Where, Tp is a propeller thrust and Tn is a nozzle thrust.

3.2 Propulsion Test with 6 Azimuth Thrusters

For current subject vessel, 6 azimuth thrusters are located forward and after part of the hull like Figure 8 considering DP performance. From the propulsion point of view, these thrusters can be separated as 4 groups with longitudinally different position.

Figure 8 Arrangement of 6 azimuth thrusters

Conventional way to treat multi-propulsors is averaging of each propulsor's performance. From the measured value of unit thrust and torque of each thruster, taking average of all thruster's values and then analysis of propulsion factors and full scale power and revolution. Details of propulsion factors are like Table 2.

Second way of analysis for multi-propulsors is to consider each group's performance separately and then take summation of power of each group. 4 groups of thrusters are selected considering their longitudinal location such as No.1 group(#1), No.2 group(#2 & #3), No.3 group(#4 & #5) and No.4 group(#6). For the measured value of unit thrust and torque of each thruster, the propulsion factors of each group are derived and then take summation of each group's propulsion power. Details of propulsion factors of each group are like Table 2.

Table 2 Propulsion factors of subject vessel (@13kts)

Method	#	wtm	t	etaR	etaD	Total Power
Averaging	#1~#6	0.016	0.064	0.993	0.393	100.0%
By group	#1	-0.067	0.064	0.963	0.299	100.1%
	#2 & #3	-0.049	0.064	0.970	0.322	
	#4 & #5	0.123	0.064	1.038	0.498	
	#6	0.027	0.064	0.963	0.390	

In calculating of thrust deduction factor and thrust loading of each thruster, an assumption is applied that each thruster burden resistance of subject vessel according to the thrust ratio of each with respect to total thrust, so thrust deduction factor of two methods is identical. The more interesting is the wake fraction of each thruster. Minus value of wake fraction of forward thruster group No. 1 and No. 2 means an accelerated flow passing through bulbous bow and bilge regime and the effect of acceleration is stronger at the position of No. 1 group thruster than No. 2 group.

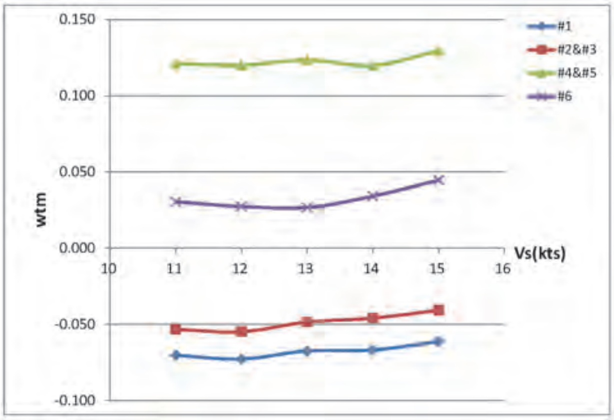

Figure 9 Wake fraction of each thruster's group

For No.3 and No. 4 group, their longitudinal positions are very similar with respect to the midship, but the wake fraction values are quite different. The wake fraction value of No. 3 group thrusters can be seen from conventional ship having similar afterbody by the boundary layer development. But for No. 4 group, quite small wake fraction is derived and this is caused by several phenomena. First of all, the boundary layer development can be disturbed by the presence of moon pool located forward of No. 4 group(#6 thruster), and the boundary layer restart at the end of moon pool or retarded boundary layer flow can be somewhat accelerated by internal whirling motion of moon pool. Variation of wake fraction along with speed is like Figure 9.

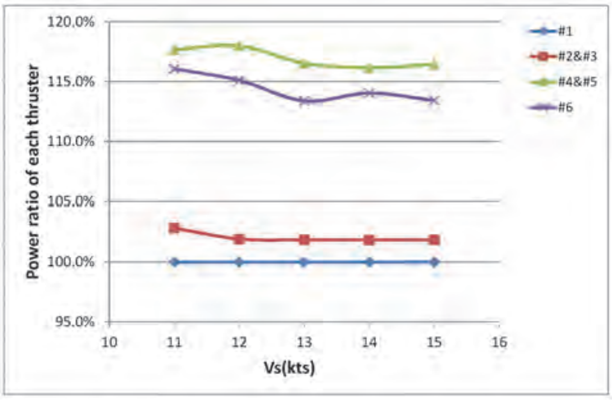

Figure 10 Power ratio of each thruster group (in constant revolution mode)

Final and overall performance derived with 2 methods is very similar, where mean value of each thruster's performance is very close to the one from averaging method. But, by separated method, more details of each thruster's characteristics can be derived. First of all, propulsion efficiency can be different according to it's longitudinal position, so we can try to study another operating option for slow steaming of drillship having more propulsion efficiency. (3 azimuth thruster operating mode in after part, and more detail in next chapter)

Until now, model test data was for the constant RPM mode of azimuth thruster which means when operating azimuth thruster, the revolution of each thruster is kept constant in model test. But as seen above, the wake fraction of each group is quite different and final delivered power of propeller could be different like Figure 10. As seen from Figure 10, each thruster has different power with constant propeller revolution and some thrusters might encounter power limitation in higher revolution regime. For real operation in group of azimuth thrusters, the constant power mode or any ratio of power between thrusters should be tested, and this is another topic of next chapter.

3.3 Propulsion Test with constant power mode

As described in previous chapter, the inflow velocity to each azimuth thruster is different by the boundary layer development around hull form and moon pool like Figure 9. For the combination of different wake velocity and constant revolution of propeller of each thruster, the delivered power can be different like Figure 10.

Table 3 Propulsion factors of subject vessel (@13kts) for test mode(constant revolution vs. constant power)

Method	#	wtm	t	etaR	etaD	Total Power
Constant revolution	#1	-0.048	0.122	0.930	0.295	100.0%
	#2 & #3	-0.029	0.122	0.957	0.325	
	#4 & #5	0.161	0.122	1.018	0.494	
	#6	0.111	0.122	0.993	0.451	
Constant power	#1	-0.044	0.152	0.941	0.313	103.5%
	#2 & #3	-0.025	0.152	0.964	0.337	
	#4 & #5	0.150	0.152	1.019	0.471	
	#6	0.102	0.152	0.986	0.426	

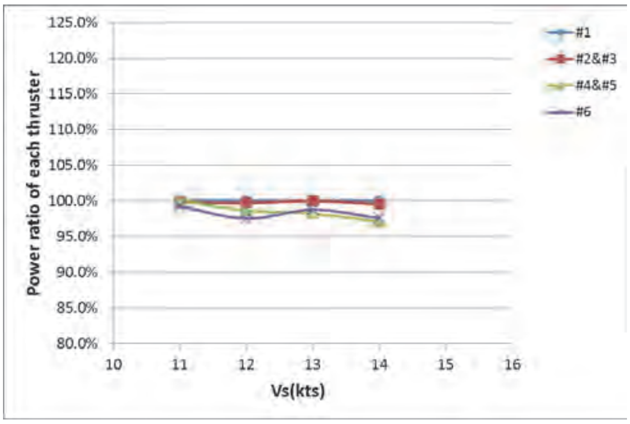

Figure 11 Power ratio of each thruster group (in constant power mode)

As additional model test program, the variation of revolution of propeller is tried to keep the each thruster's power constant and the final delivered power is compared with constant revolution mode. For these test campaign, another propellers are designed and tested, so the test result of constant revolution is different with Table 2.

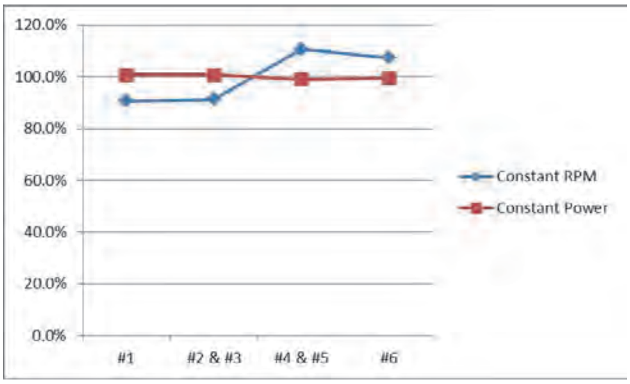

Figure 12 Power ratios of each thruster group in two test modes (@13kts)

Delivered power of each thruster's group is like Figure 11 and the power ratio is almost same as contrary to Figure 10. Interesting point of the result is the total power of two different test methods is very similar. This is because if the variation of propeller revolution along with different wake velocity is applied, the forward thrusters' power increases and after thrusters' power decreases. For the given wake velocity around hull form and moon pool, the controlled revolution of propellers can give more even ratio of each thruster's power like Figure 12.

3.4 Propulsion Test with 3 Azimuth Thrusters

As discussed in previous chapter, after group of azimuth thruster has more higher propulsion efficiency, further experimental work scope was added to investigate new operational alternative to improve propulsion efficiency.

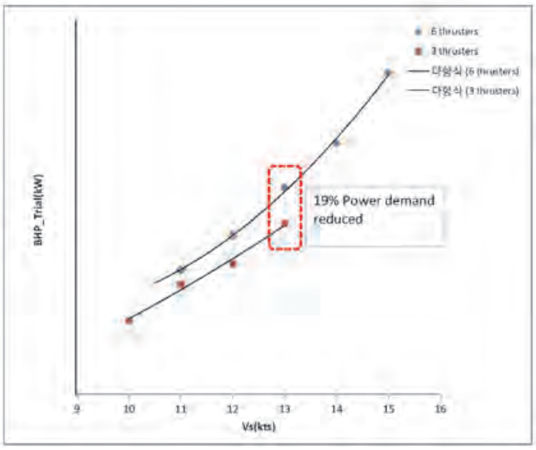

Figure 13 Comparison of power in 6 & 3 thruster mode

Current design of azimuth thruster has a retractable feature, propulsion test with forward 3 thrusters retracted into the hull was carried out. Analysis was used for averaging method.

Overall propulsion efficiency for 3 thrusters mode is more higher than 6 thrusters mode, mainly due to the increase of hull efficiency defined by (1-t)/(1-wtm) and it's physical meaning is that hull resistance increase with accelerated flow by thruster can be minimized by eliminating of forward group of thrusters.

Table 4 Propulsion factors 6 & 3 thruster mode (@13kts)

Mode	#	wtm	t	etaR	etaD	Total Power
6 thruster	#1~#6	0.016	0.064	0.993	0.393	100.0%
3 thruster	#4~#6	0.133	0.095	1.021	0.481	81.0%

By 3 azimuth thrusters operation, power reduction for constant speed can be acquired like Figure 13 even though maximum speed become lower by 3 thruster usage and this can be considered as slow steaming.

4 CONCLUSIONS

For the powering performance prediction of drillship in transit mode, towing tank model tests for the drillship equipped with azimuth thrusters are carried out. Hull form of the subject vessel is newly developed Hyundai HD12000 deepwater drillship and azimuth thruster is modeled with MARIN 19A nozzle, Ka4-70 propeller and commercially used body shape of azimuth thruster.

For the open water test of azimuth thruster and propulsion test, a new test device is carefully designed for measurement of propeller thrust/torque, duct thrust and unit thrust. For the validation purpose, an open water test in unit configuration with propeller and duct having experimental data published such as MARIN 19A nozzle and Ka4-70 propeller. For propulsion test, yaw control mechanism and servo driving system was developed.

For the propulsion test, two analysis methods were investigated such as averaging and grouping analysis. Each method shows a very similar overall performance, but grouping method gave us different wake velocity along with each thruster's longitudinal position by the boundary layer development and moon pool effect. By this, additional operating alternative for improvement of propulsion efficiency is presented with 3 azimuth thruster mode when forward 3 thrusters retracted into the hull.

For considering wake difference, the two test approaches for the constant revolution of each propeller and constant power of each thruster. The total power of two methods shows very similar value, this is because for the different wake velocity, forward groups' power and after groups' power show more balanced ratio of each thruster group.

For final assessment of delivered power of drillship, two alternative analysis methods (averaging and separate/grouping) and two alternative test procedures shows a very similar result. So we can conclude the constant revolution procedure and averaging analysis method can be enough to assess overall powering performance of drillship, but for real operating information of each thruster, the constant power procedure and separate/grouping analysis can be applied as additional approach.

Further studies are strongly requested on the effect of scaling and more sea trial data of drillship should be collected and compared for improvement of model-ship correlation of drillship.

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