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DYNAMIC POSITIONING CONFERENCE
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**Design and Control Session**

# Dynamic Positioning Control Augmentation for Jack-up Vessels

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## 1 Introduction

Specialized Dynamic Positioning (DP) System augmentations are assisting self-propelled jack-up vessels as they move into deeper and harsher environments. The features of one such system are described here along with simulation results to demonstrate the performance improvements when the new control modes are enabled.

Jack-up vessels are platforms with three or more legs that can be extended to the seafloor to lift the vessel's hull above the sea surface. Once deployed, the jack-up vessel offers a stable and sturdy platform for performing offshore jobs such as drilling platforms and wind farm service platforms. Most jack-up vessels are not self propelled. Tugs or heavy lift vessels are used to move the jack-up from place to place and are again used, along with anchoring systems, to precisely position the vessel over the sea floor. The jack-up's work site is often alongside other structures, such as oil drilling platforms, complicating the positioning process. Precise positioning may be important to avoid pipelines or other structures on the seafloor. There is a trend toward self-propelled jack-ups which avoid the cost of the additional vessels needed for transport and positioning associated with un-propelled jack-up vessels. Even more recently, self-propelled jack-ups are being equipped with Dynamic Positioning Systems to further reduce operational costs and risks (Figure 1).

Standard Dynamic Positioning Systems are valuable to jack-up vessels, allowing independent and precise positioning. There are issues associated with the interaction of DP systems and jack-up systems, however, which are discussed in the next section.


**Figure 1. High Lift Jack-up Vessel Innovation**

# 2 Issues Associated with DP and Jack-up Operations

Jack-up equipment and operations can influence a vessel's dynamics (aerodynamics, hydrodynamics, thruster operations, and bottom forces) and therefore the DP system performance. Likewise, the operation of the DP system can generate forces detrimental to the jack-up system.

## 2.1 Aerodynamics

### 2.1.1 Legs

Jack-up legs are large structures that can be significant contributors to the overall wind drag on the vessel and must be accounted for in the DP aerodynamic model, especially when in the full up position. This can be handled by standard DP systems. Unfortunately for a standard DP system, the contribution of the jack-up legs to the overall aerodynamic drag varies as the legs are deployed below the keel. The legs are usually lowered all at about the same time and rate, simplifying the aerodynamic model. If the legs are deployed individually, the aerodynamic model, especially yaw moment, becomes more complicated as the overall shape varies depending on the order of deployment.

### 2.1.2 Cargo

Many applications for DP controlled jack-ups include deployment of large structures (such as windmill structures, drilling equipment, etc.) on and off the vessel which can affect the aerodynamic drag. Cargo can vary in size, shape, and location on the deck.

## 2.2 Hydrodynamics

Similar to the aerodynamic effects discussed above, the jack-up legs contribute to the overall hydrodynamic drag on the vessel as they are deployed below the keel. The legs may remain partially deployed between work sites to minimize the time required for extension and retraction and affect the transit as well as the on-site hydrodynamics.

## 2.3 Variable Added Mass/Inertia

The added mass and inertia of the jack-up legs also vary with deployed length and could be included in the dynamics model, but unless the legs are quite large in diameter, their added mass and inertia are generally negligible compared to the mass and inertia of the hull displacement and its added mass and inertia.

## 2.4 Bottom Force Effects on Environmental Model

The DP system interacts with the bottom during touchdown and liftoff of the jack-up legs.

When the jack-up legs contact the bottom, it is desirable that the vessel have near zero velocity over the ground to limit the horizontal reaction forces and possible damage to the legs. It is also preferable that thruster forces exactly balance the wind drag and current drag on the vessel so that no net horizontal force or moment is transferred from the vessel through the legs to the seafloor. Most DP control systems include an integral factor that grows over time as a function of position error in order to eliminate steady state errors. If the touchdown of the jack-up legs lock the vessel into a position away from its goal position, the integral term will continue to grow resulting in increasing thruster forces beyond that required to properly balance the wind drag and current drag. The force imbalance is then carried by the legs to the seafloor, risking damage to the legs. The increase in power demand by the DP system may also interfere with the jacking system leading to a power cutback situation during the critical jack-up operation.

Similarly, during liftoff, it is desirable to have the DP system balance the wind drag and current drag on the vessel so that only vertical forces are carried by the legs.

## 2.5 Model Development at Liftoff

If no source of ocean current vector information is available, the DP system will frequently develop a calculated estimate of the current based on the thrust required to hold the vessel's position beyond what is required for wind compensation and a hydrodynamic model of the vessel. This calculated value generally requires time to develop as the vessel must first settle into a steady state. When a jack-up vessel lifts off the seafloor, the current drag is no longer being reacted by the legs against the bottom and begins to push the vessel off position while the current estimate develops and begins to be compensated for.

# 3 Jack-up Augmentation System Description

In this section are described the specialized features added to the L-3 Communications DP system to aid jack-up operations.

## 3.1 Deployed Leg Length

The first element of the augmented DP system is the input of the deployed leg so the DP operator has visibility of the jack-up progress and for jack-up compensation (described below). The primary source of the leg length input is from the jack-up system. To mitigate the risk from non-redundant measurements, we have included the option of entering the leg deployment manually.

## 3.2 Jack-up Compensation

Jack-up Compensation uses the deployed leg length input above to scale additions to the base vessel aerodynamic and hydrodynamic models.

### 3.2.1 Aerodynamics

We were fortunate to have scale model test results with which to develop a variable aerodynamic drag model dependent on the deployed leg length, the form of which is shown below. The test data was taken with leg lengths approximately at the midpoint of the maximum length to obtain the per-length scale factors used in the DP system.

$$F_{i=surge,sway} = \sum_{l=1}^{NUM_{LEGS}} \left(\frac{Pos_l}{Pos_{l,max}}\right) * FACTOR(i) * TABLE(i, dir) * V^2(-SGN(V))$$

where $Pos_l$ is the current extension of leg $l$,

$Pos_{l,max}$ is the max modeled leg extension of leg $l$,

$FACTOR$ returns the scale factor for a given axis index ($surge$ or $sway$), and

$TABLE$ represents a table lookup based on axis index and relative angle ($dir$).

### 3.2.2 Hydrodynamics

Similar to the aerodynamic model, we developed modifications to the base vessel hydrodynamic drag model from test data. As expected, jack-up legs were shown to have a significant impact on the total drag force. A typical effect is shown in Figure 2.

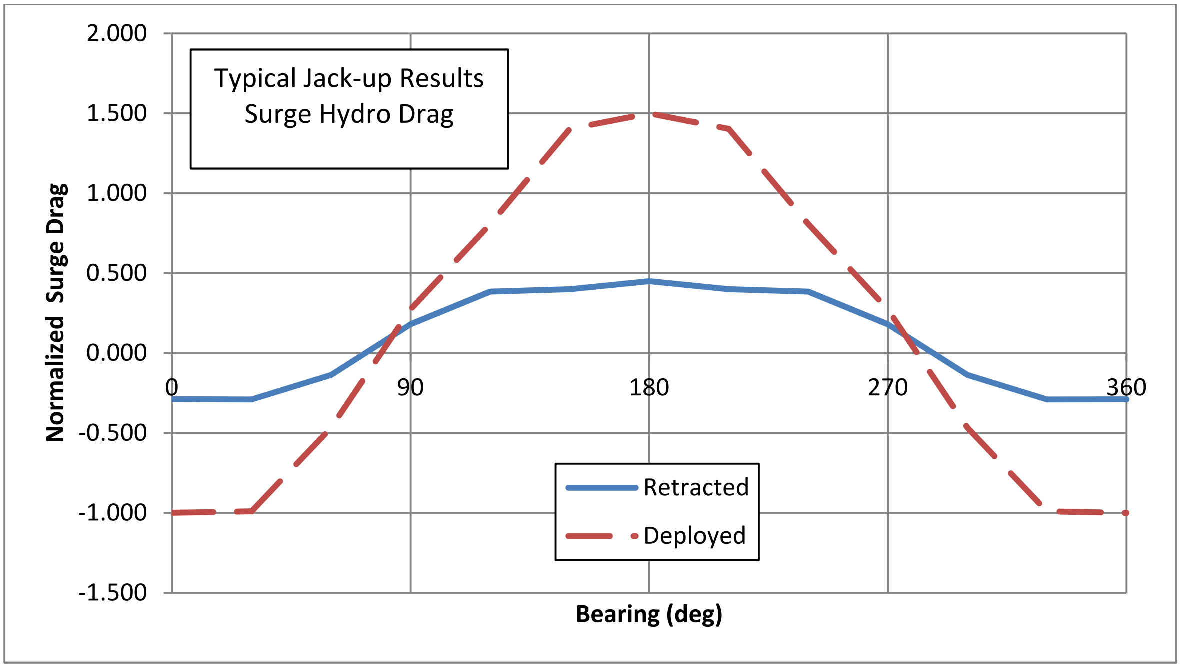


**Figure 2 Typical Leg Drag Effect**

## 3.3 Auto Freeze Integrals

To deal with the issue associated with touchdown and escalating integral thrust forces, we provide the operator with the capability to freeze the environment integrals. The operator enables the Auto Freeze Integrals mode after which a steady bottom contact signal from the jack-up system (or contact input overridden by the operator) begins a 10 second timer after which the environment integrals are frozen. The vessel can then sit at a touchdown position other than the DP goal position without increasing thrust levels.

### 3.3.1 Contact

To automatically trigger the Auto Freeze function without further operator intervention, we input signals from the jack-up system indicating whether a leg load threshold (set by the jack-up system) has been exceeded indicating touchdown of that leg. Similar to the leg length input, we allow the DP operator to set the contacts manually to mitigate the risk from non-redundant measurements.

### 3.3.2 Locked

Many jack-up systems include a method to lock the extended leg positions to the hull. We input a signal from the jack-up system for each leg indicating when the jack-up leg has been locked into position as an indication to the DP operator.

### 3.3.3 Data Checking

We process the jack-up related inputs in various ways to filter out erroneous information including de-bouncing and comparisons with other data. Depending on how the leg contact signal is generated in the jack-up system, it is possible for the signal to give false positives when, for example, the leg hits the bottom temporarily due to vessel heave motion. We therefore implement both a de-bounce timer and a longer duration timer between the first leg contact sensed and the freezing of the environmental model. We also validate signals by comparing the measured deployed leg lengths with the operator input water depth and provide a warning if the received length is too much greater than the water depth or if false positive or false negative contact signals are likely.

## 3.4 Manual Freeze Integrals

To further mitigate the risk of non-redundant contact signals, we provide the operator with the option of immediately invoking the integral freeze regardless of the contact signals. This was also useful during trials while the contact signal threshold levels were being calibrated.

## 3.5 Current Compensation

We provide the capability of feeding forward predicted forces due to operator-input current velocities. The operator can input the current measured with the current sensor or input values from other sources, like nearby platforms. This allows a rapid settling of the DP system after liftoff since it is not necessary to wait for the slow buildup of a calculated current estimate, as well as improved performance at other times such as during heading changes. We mitigate the risk of an inaccurate current sensor by requiring the operator to assess the current before entering it manually. If Current Compensation is invoked while in Joystick Mode (not Holding Position or Holding Heading), the operator is provided a warning that the change may not be bump-less and that rapid increases in thrust are possible. This is the expected case when lifting off the bottom. If Current Compensation is invoked while in Hold Position/Hold Heading, or if the operator changes the current estimate while in Hold Position/Hold Heading, the change in the Current Compensation forces are offset by changes in the Environmental forces for a bump-less change since the Environmental forces will have accumulated the forces due to an incorrect current estimate over time. When Wind Compensation and Current Compensation are both enabled, there should theoretically be no steady Environment forces. Any Environmental force buildup is due to inaccuracies in the vessel models (such as thrusters, aerodynamics, and hydrodynamics, or sensor errors) or an inaccurate current vector input by the operator.

## 3.6 Cargo Aerodynamics

The aerodynamic changes associated with changes in deck cargo can be handled by the operator through inputs of individual cargo size, location, and drag characteristic. The aerodynamic effect is quickly turned on and off as the cargo is loaded or unloaded from the deck. The effect of cargo weight is handled through the standard operator input of vessel draft.

## 3.7 Rapid Model Development

Quick Current is a feature useful for systems in addition to jack-up vessels in which the operator can choose to speed up the environmental model development for a limited period of time. An example is when a vessel is operating in an area subject to current changes over short periods of time or over short distances. For a jack-up system, the Quick Current function is provided for the liftoff situation in which current vector information is not available due, for example, to a faulty current sensor. By speeding up the rate at which Environmental forces are incremented, the vessel can reduce the peak position losses due to the sudden introduction of forces that had been carried by the legs against the seafloor. The trade-off is a reduction in the gain margin of the DP system and is therefore limited in level and duration.

## 3.8 User Interface

The User Interface (UI) with the Jack-up Compensation tab selected along the right hand side is shown in Figure 3with Current Compensation enabled and Jack-up Compensation disabled in the middle pop-up.


**Figure 3 User Interface**

The Jack-up Compensation User Interface (UI) tab, shown in the screen shot in Figure 4, gathers the principal elements of the jack-up operation as it affects the DP system.

The upper graphic within the tab shows the general arrangement of the jack-up legs around the hull with indications of the deployed leg length, bottom contact input, and locked status. The operator can configure, for each leg independently, whether the measured input or an operator input is used for these three values in the Jack-up Leg Input Configuration as shown lower section in Figure 4. The configuration section allows the operator to specify an estimated leg length which can also be modified on the Jack-up Compensation tab using the up and down arrowheads with each push modifying the estimate by the amount preset in the Jack-up Leg Input Configuration section. From the tab, the operator can also configure what information is displayed on the UI page (measured/estimated/all).

Buttons are provided on the middle section of the tab for the operator to either manually enable the Freeze Integral function or to enable the Auto Freeze mode which causes the Freeze Integral to be enabled once one of the leg contact inputs (or operator estimates) signals touchdown. A 10 second countdown to the actual implementation of the Freeze is displayed beside the buttons.

Another section of the UI provides access to the Quick Integral function. The operator can preset the multiplication factor on the model build rate and the duration the function will be in effect before automatically returning to normal operation. Once the Enabled/Disabled button starts the Quick Integral, a countdown of the time remaining is provided to the operator.

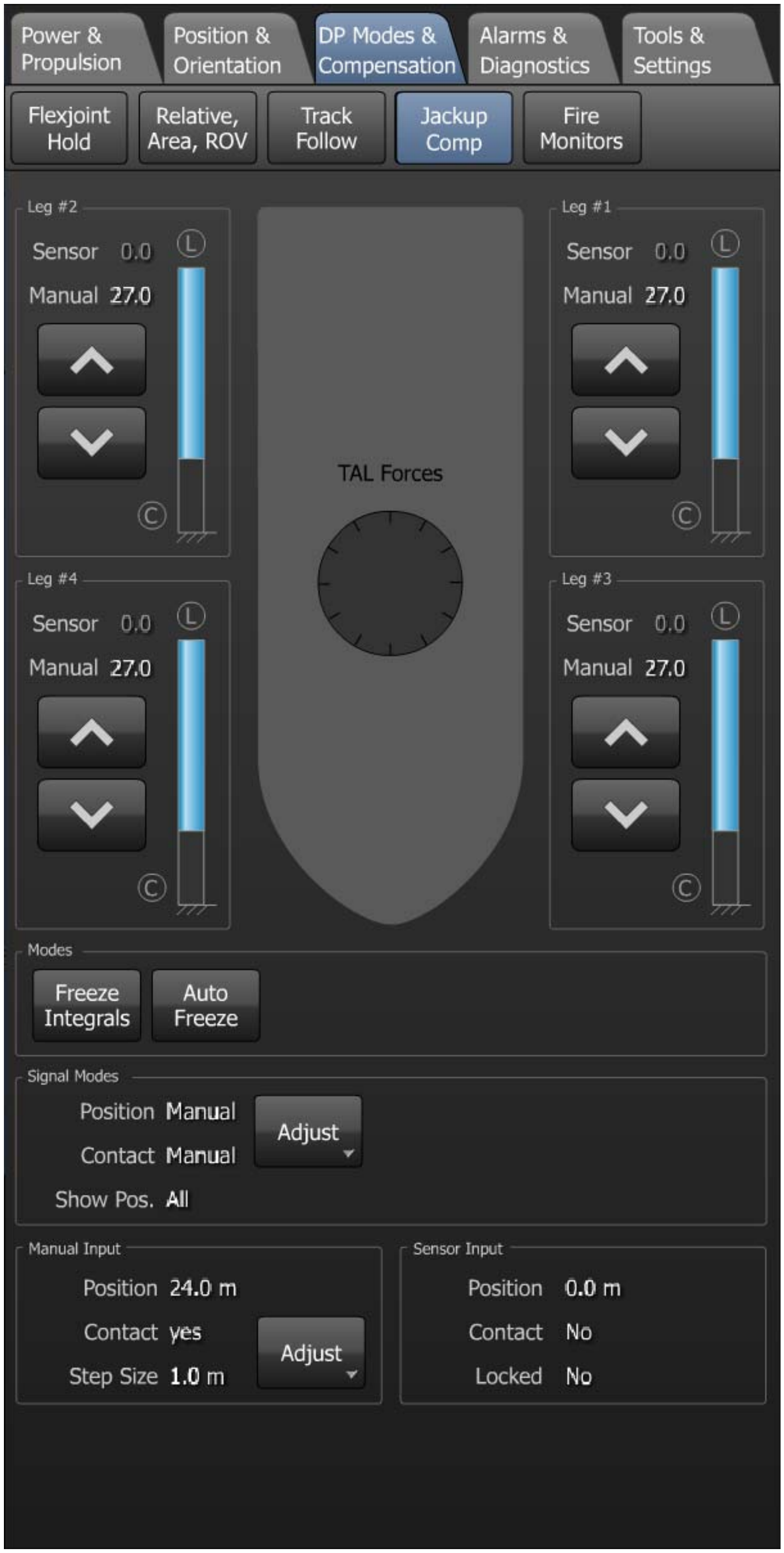


Figure 4 Jack-up Compensation User Interface

# 4 Performance Improvements

How important are these features (Jack-up Compensation, Integral Freeze, Quick Current, and Current Compensation) to the performance of the DP system during jack-up operations? Simulation allows us to compare apples to apples, the results of which are discussed below.

## 4.1 Jack-up Compensation

In Jack-up Compensation mode, the models within the DP system tracks the changes to the aerodynamic and hydrodynamic characteristics of the vessel as the jack-up legs are extended. The more accurate model improves the calculated current estimate and improves positioning performance, especially during a heading change. Figure 5 shows the results of a simulated 20 degree heading change (such as might be encountered while repositioning the vessel between tasks) with and without Jack-up Compensation enabled in a 2 knot current. Without an accurate model of the current forces acting on the vessel, a large position loss occurs. With Jack-up Compensation enabled, the position loss is much reduced.

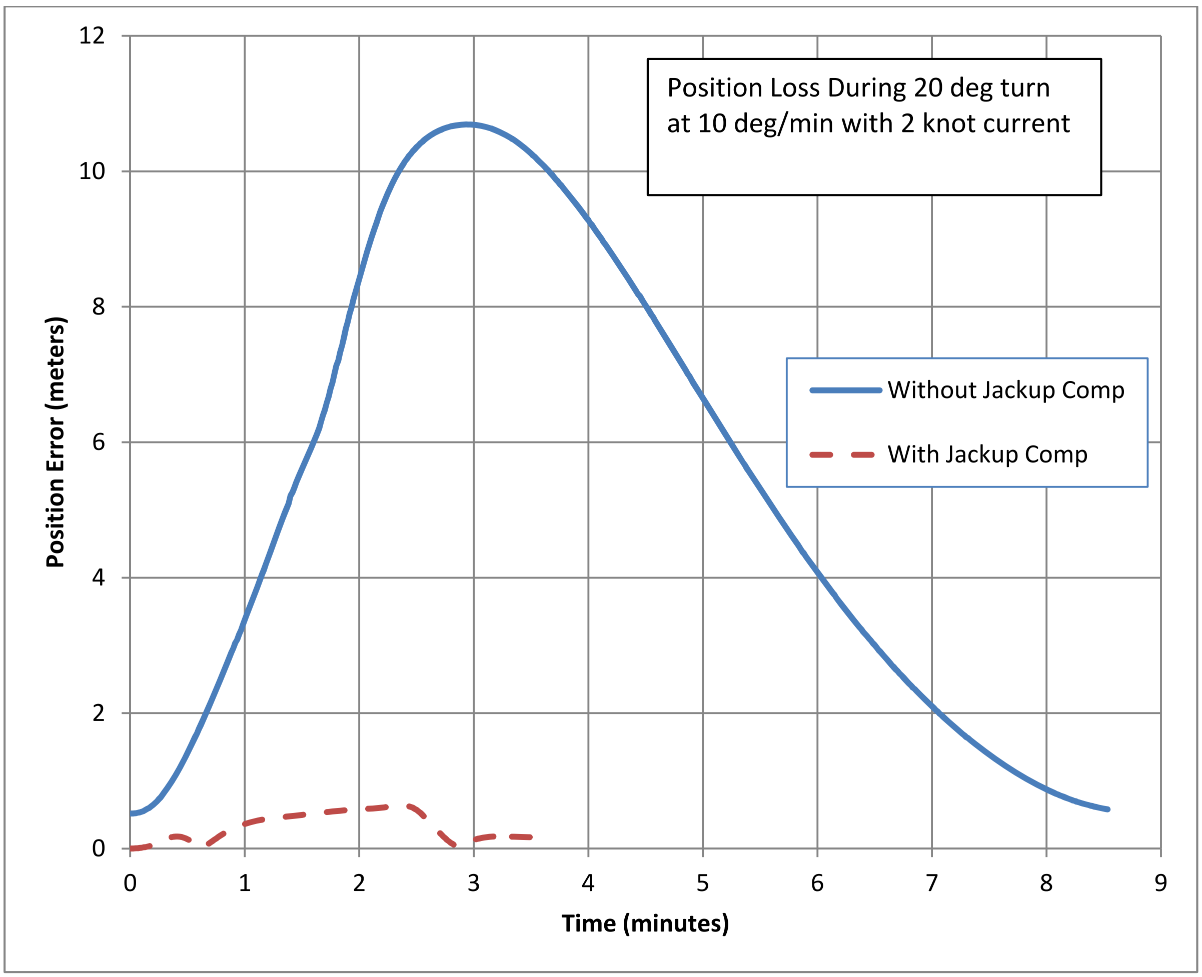


**Figure 5. Jackup Compensation Reduces Position Loss During Turn**

## 4.2 Integral Freeze

In normal operation, a position error will result in a slowly increasing environment model and compensation thrust as shown in Figure 6 where a simulated touchdown locks the position error at 1. The Freeze Integral function, if enabled, eliminates the erroneous Environment buildup.

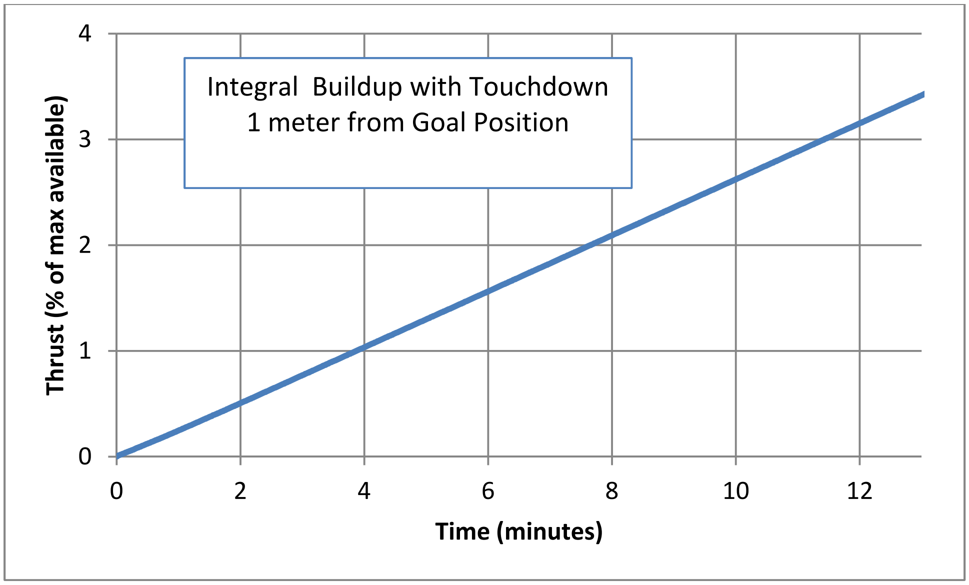


**Figure 6. Thrust Climbs without Environmental Model Freeze at Touchdown**

## 4.3 Quick Current

Liftoff can be a difficult phase of a Jack-up operation for the DP system as the vessel loses the support of the jack-up legs and must react to the current forces. Figure 7 shows the large position loss that can occur after liftoff in a 2 knot current when the DP system has no knowledge of the current and using nominal operator gain settings (control bandwidth). Increasing the operator gain would also reduce the deviation. The Quick Current function, which allows a faster Environmental model buildup, can reduce the peak position loss, but at the cost of less stability margin.

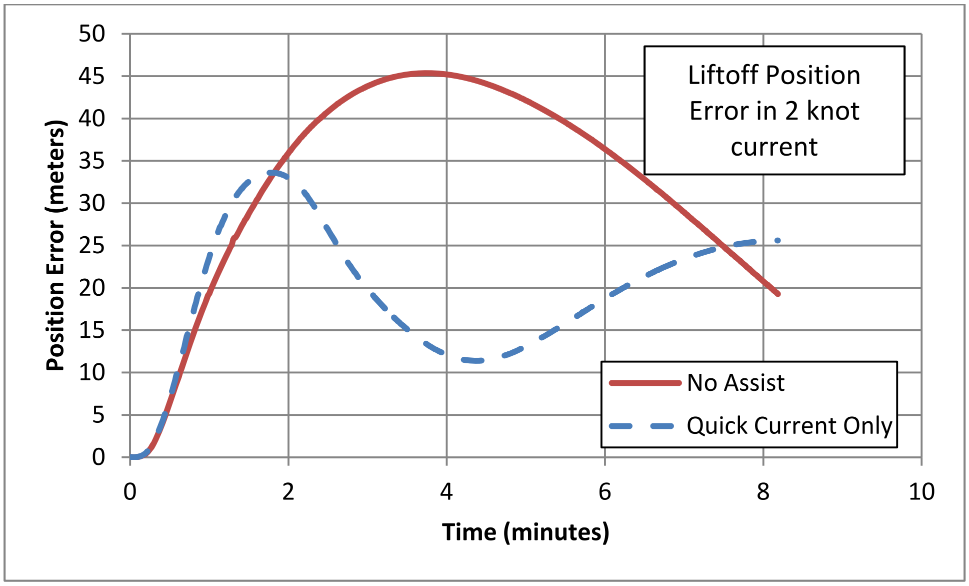


**Figure 7. Large Position Losses Possible Without Current Compensation**

## 4.4 Current Compensation

The position loss with Current Compensation during liftoff is a function of the accuracy of the hydrodynamic model, the current information, the thruster model, etc. Figure 8 shows the position loss at liftoff as a function of the current input accuracy assuming perfect current direction information.

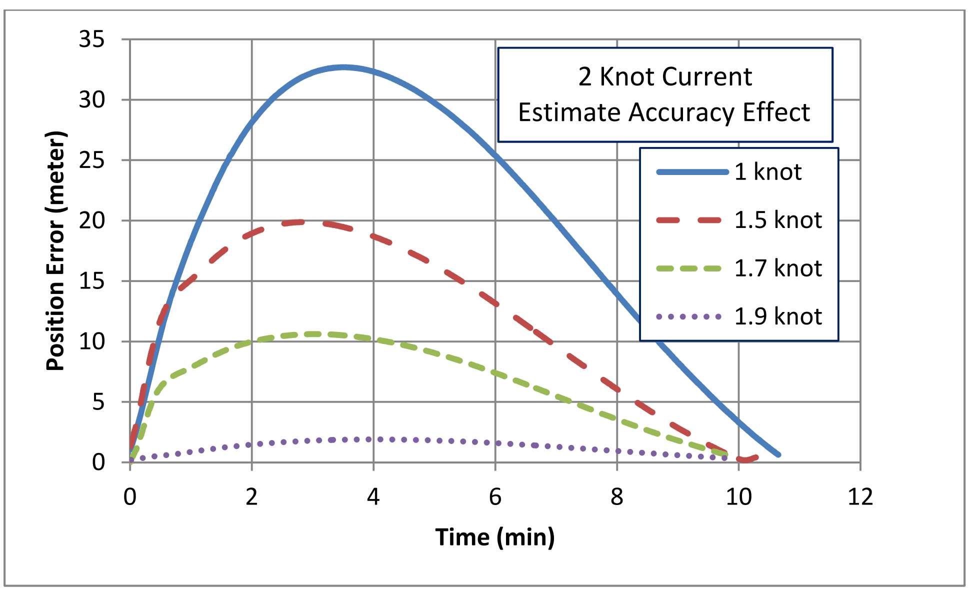


**Figure 8. Effect of Current Estimate Accuracy**

## 5 Summary

We found three significant issues with standard DP systems when operated on self-propelled jack-up vessels and augmented the system to solve the potential problems and provided backup solutions for the new, non-redundant inputs.

**Table 1. Jack-up DP Issues and Solutions Summary**

| Issue | Solution | Backup |
|---|---|---|
| Variable Aerodynamics and Hydrodynamics | Jack-up Compensation based on leg length input | Manual leg length input |
| Integral windup due to bottom forces at touchdown and prior to liftoff | Auto Integral Freeze at first contact | Manual contact input and Manual Integral Freeze |
| Drift-off during model development at liftoff | Current sensor input, operator assessment of currents, Current Compensation | Quick Current |