A Functional Method for the Optimization of a Tension Leg Offshore Platform Orientation Utilizing CFD

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Introduction

Technical safety in the oil and gas industry is of paramount importance. With most Tension Leg Platforms (TLP) being geographically remote, costing upwards of $3.5 billion, containing a multitude of process and operational hazards, and crowding personnel onboard, it is crucial to minimize the risks to people and assets. This can be achieved through the process of Inherently Safe Design (ISD), in which technical safety has direct influence on the design, from concept through to commissioning. The platform orientation is one design aspect that can play a significant role in the ISD process, limiting the adverse effects should an incident occur. Traditionally, the platform orientation has been determined by engineering judgment, heavily weighted by past experiences. While this approach initially appears to be cost- and time-effective, it has the potential to lead to a non-ideal design solution which could cause safety and operational issues to go unaddressed and increased costs in later design stages.

This article will discuss how the orientation and layout of an offshore platform can have a significant impact in developing a better and more informed design, keeping with the ISD principles. A case study will be discussed where STAR-CCM+® was integrated with additional analysis tools to optimize the orientation of a fixed offshore platform. It will demonstrate a technique to find the optimum platform orientation, i.e. the platform orientation which results in the best design compromise between specified parameters.

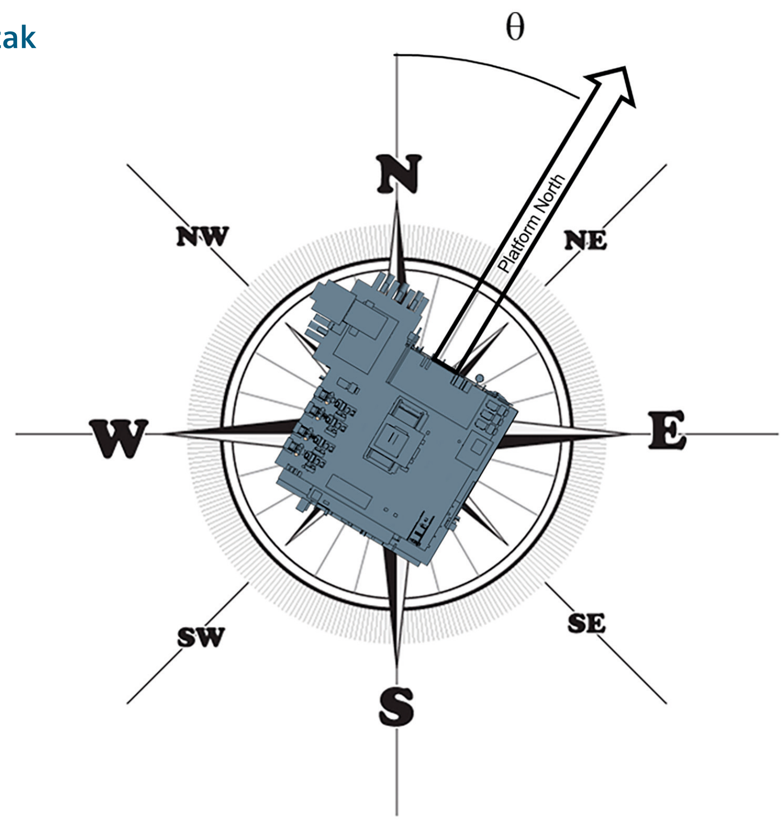


Figure 1: The aim of this study was to find the optimum theta, angle between True North and Platform North, based on a set of parameters.

Optimization Parameters

The parameters considered for the optimization study were as follows:

- The natural ventilation (wind), which can reduce the potential accumulation of toxic and flammable gases as well as provide indications of potential vapor cloud explosion consequences.
- The helideck impairment, which can impact helicopter operations due to hot turbine exhaust gases, affecting both general operations and potential emergency operations.
- The wind chill, which can affect the ability for personnel to work on the platform. This is particularly important in cold climates and extreme weather areas where working conditions can influence the number of personnel required for operation.
- The lifeboat drift-off direction, which can impact the safety of the crew in an emergency situation.
- The hydrodynamic drag, which can affect tendon fatigue life, hull integrity, and structural design requirements.

Natural Ventilation (Wind)

Guidance for ventilation rates is contained in the Institute of Petroleum (IP) 15 document. In the event of an unintended hydrocarbon release, higher ventilation rates typically translate into the formation of smaller flammable gas clouds. This parameter is therefore intended to be maximized.

Exhaust

The Civil Aviation Protocol (CAP) 437 dictates that restrictions be put in place to the helicopter operations if there is a temperature increase of 2 °C above ambient within the operational zone above the helideck. Temperature rise is used to define potential impairment to operations, in some cases this may limit operations altogether or require adjustments to payload weight, approach paths, etc. For many offshore facilities, particularly in extreme weather areas, helicopters are used as the primary means of transportation and evacuation during an emergency. Thus, it is imperative that the helideck remains available through as many expected weather conditions as possible. Additionally, platforms look to minimize exhaust impacts to drilling, crane, and elevated deck operations. The helideck impairment from exhaust fumes is therefore intended to be minimized.

Wind Chill

Wind chill is quantified by the perceived decrease in temperature felt by the body won exposed skin and is regulated by NORSOK S-002. Wind chill can impact the number of personnel required to operate a facility. In some cases, environmental effects such as wind chill have been known to increase the potential for operator error. In order to provide personnel with acceptable working conditions and maximize safety, wind chill effects are intended to be minimized. It is important to note that this can be counter to increasing ventilation for the reduction of flammable clouds during an unintended release of hydrocarbons. One intent of the optimization approach is to find a balance between these two potentially competing goals.

Lifeboat Drift-off

If a lifeboat is deployed during an emergency, it is imperative to maximize the potential survival of the craft by limiting exposure to potential hazards. A lifeboat deployment may also suffer from loss of power, thus left to environmental effects to reach safety. To maximize the potential for survival, the lifeboat should drift safely away from the platform, assisted by the current. Adverse drift-off, the length of time to reach a safe area, and potential drift back into the

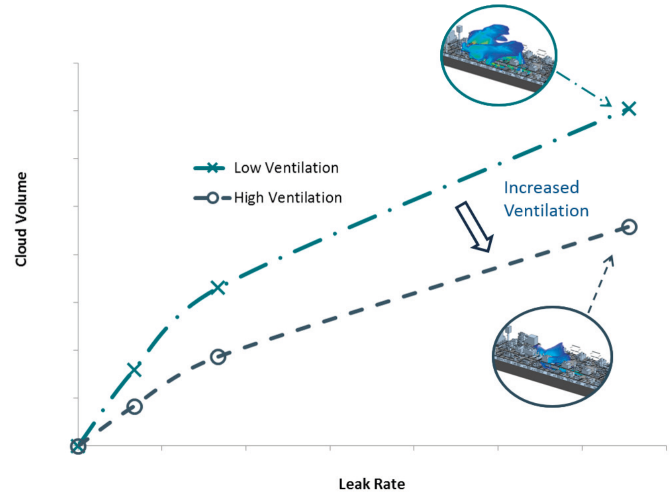


Figure 2: For a given hydrocarbon leak rate, increasing the ventilation rates aids in dispersing the flammable gas cloud, typically producing smaller explosions in case of ignition, and less probability of fatality and damage to the structure.

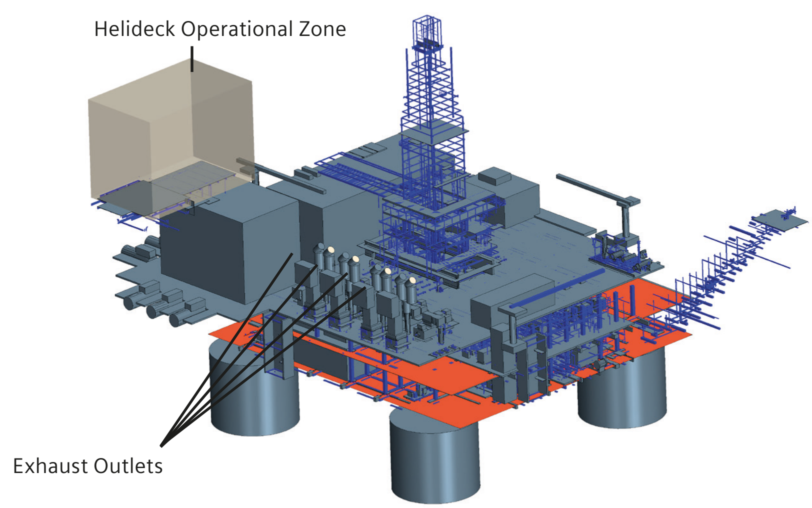


Figure 3: The offshore platform is powered by burning some of the gases it produces. The exhaust outlets need to be positioned in such a way that the exhaust fumes minimize potential impairment to the helideck operational zone throughout the year.

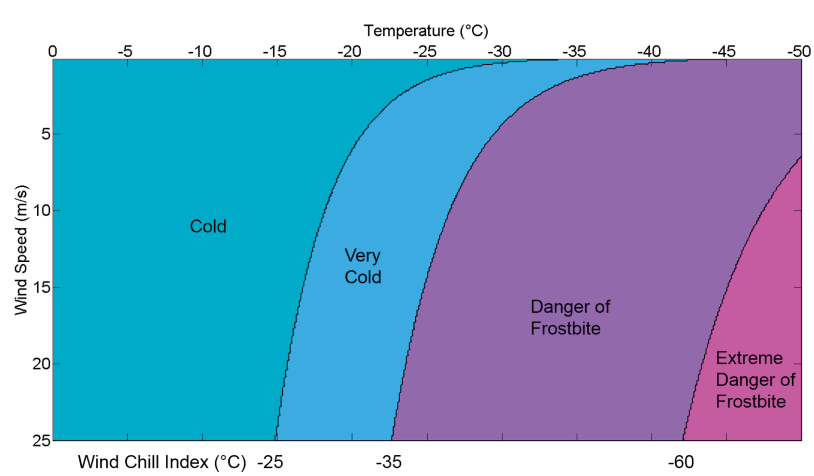


Figure 4: Wind chill index map showing the danger of frostbite to personnel

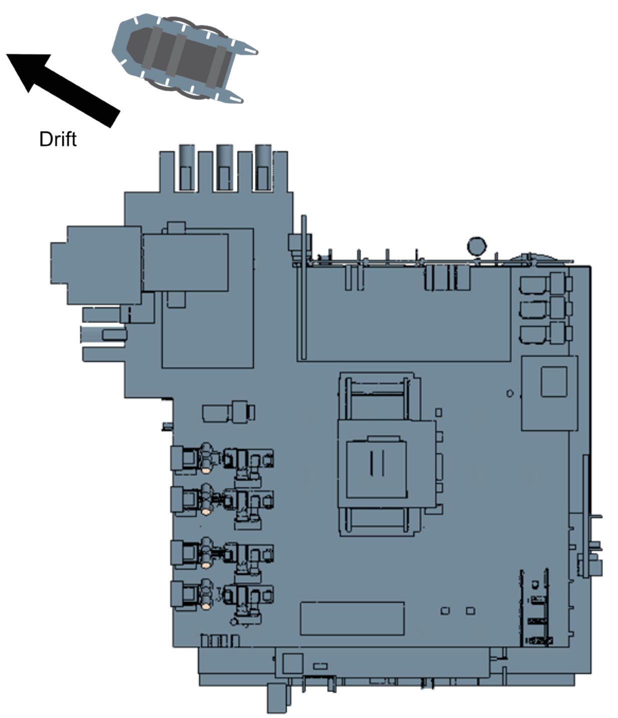


Figure 5: In case of emergency, lifeboats should drift away from the platform rather than into or underneath the platform.

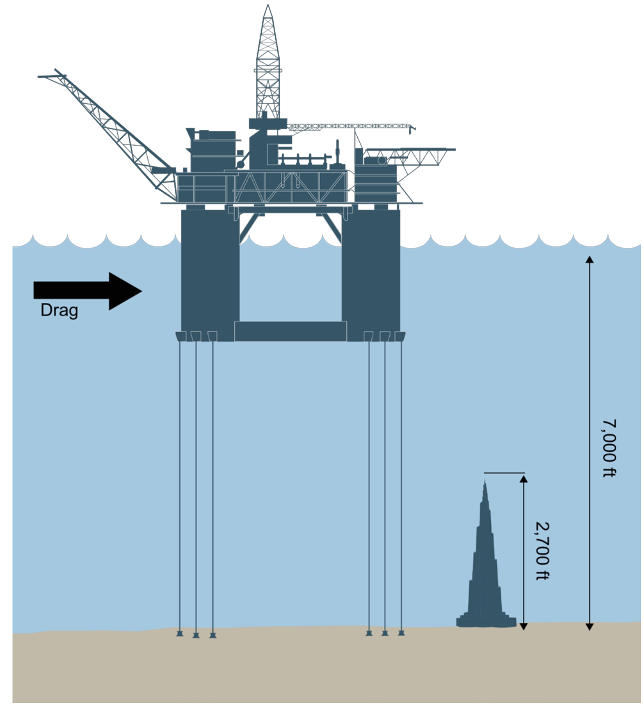


Figure 6: With water depths reaching up to 7,000 ft, the tendon fatigue resulting from wave impact and drag loading is a significant cost factor. Here, the platform depth is compared to the height of the Burj Khalifa, which is the tallest building in the world.

facility is intended to be minimized.

Tendon Stress

TLP platforms are typically used in water depths reaching up to 7,000 ft. To be cost-efficient and comply with the American Petroleum Institute (API) Recommended Practice (RP) 2T, the stress in the tendons resulting from maintaining the platform in place despite wave impact and drag loading from the current needs to be minimized. Tendon requirements can lead to weight and structural design limitations, as well as require unnecessary buoyancy complications during operations.

Why Use CFD?

Good judgement is fundamental in solving any engineering problem. However, numerical simulations can help in making a good design even better. In his book Expert Political Judgment: How Good is It? How Can We Know?, social scientist Philip Tetlock shows how solutions derived from formal models such as CFD consistently outperform decisions based solely on expert judgement. Today, with powerful Multidisciplinary Design Exploration (MDX) and Multidisciplinary Design Optimization (MDO) tools such as HEEDS, it has never been easier to make a design reach its best potential.

In the oil and gas industry however, decisions relating to the platform orientation are still typically made solely based on previous experience and qualitative judgment, which can lead to unintentional biases. This study aims at improving the accuracy of experts' predictions through the use of numerical tools in order to meet the following design objectives:

- Maximize ventilation
- Minimize helideck impairment from exhaust
- Minimize wind chill effects
- Minimize tendon stress
- Minimize adverse lifeboat drift-off

Of course, using formal models doesn't come without limitations. There are a few challenges associated with using CFD to resolve issues related to offshore platforms:

- Firstly, from a technical point of view, offshore platforms are very large and have extremely complex geometries. This makes it difficult, if not impossible, to explicitly resolve all objects within the available time frame.
- Secondly, from a project management point of view, projects are strongly schedule-driven: stakeholders want their platform to start running as early

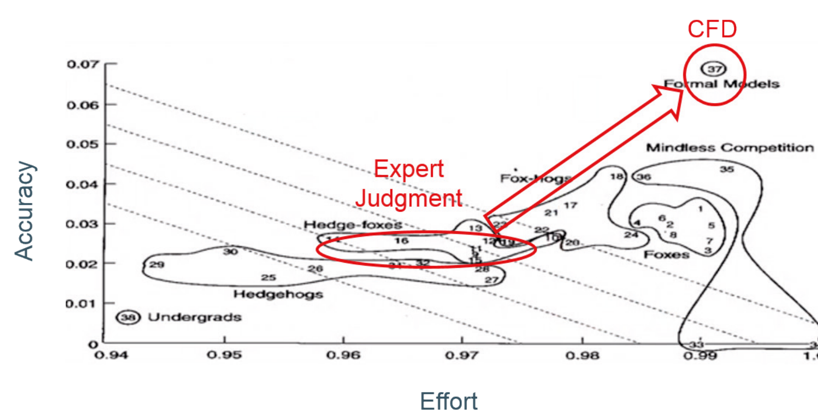


Figure 7: Social scientist Philip Tetlock [1] compared 20,000 predictions made by experts in their fields with the predictions given by formal models, such as CFD. Every time, the formal models outperformed expert judgment.

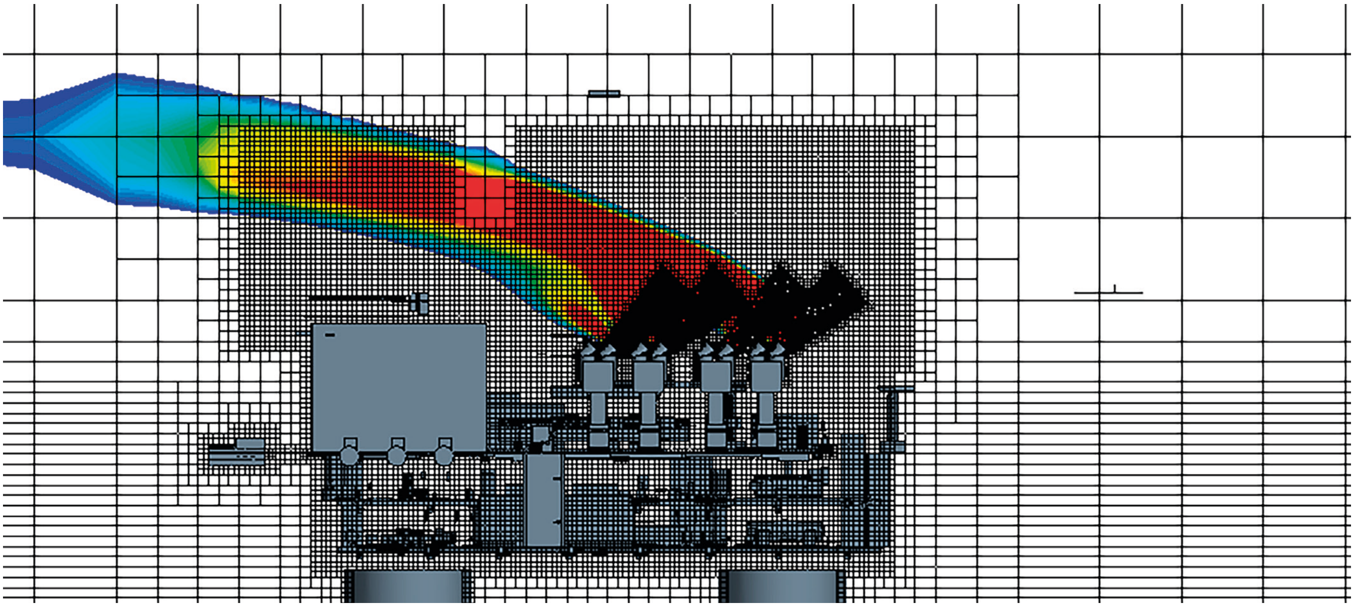


Figure 8: Mesh on the platform, showing local refinements around the exhaust outlets and the helideck

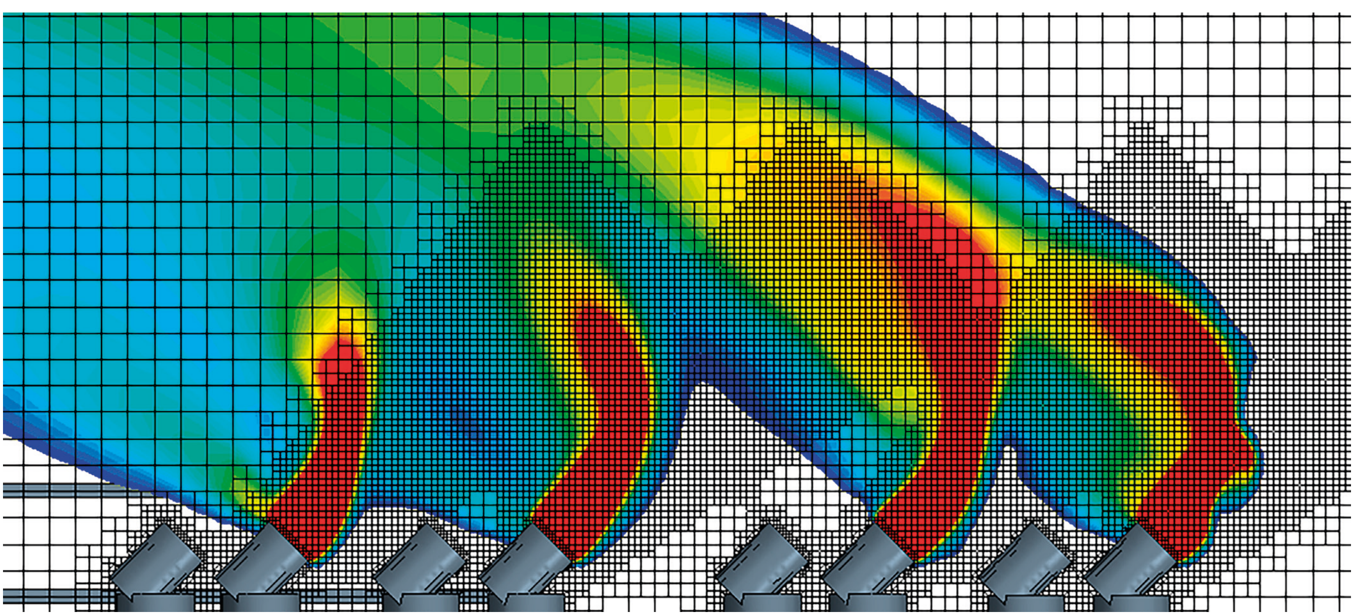


Figure 9: Mesh refinement around the exhaust outlet

as possible since each day of delay will cost upwards of $10 million in deferred revenue.

- In addition, the platform orientation is one of the first design aspects to be decided. However, in very early design stages, information is scarce. Many uncertainties need to be dealt with regarding the location of the equipment, etc.
- Finally, the budget allocation for Health and Safety is usually around 1% of the total project cost, which greatly limits the amount of influence technical safety bears on the final design.

The physics parameters used in STAR-CCM+ to represent the exhaust are as follows:

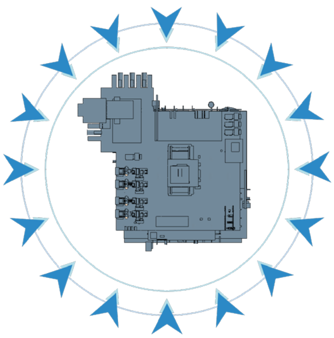
- Steady-state
- Two-layer realizable k-epsilon turbulence model
- Segregated multi-component gas model
- Gravity model to deal with the buoyancy-driven exhaust flow

The mesh parameters were set as follows:

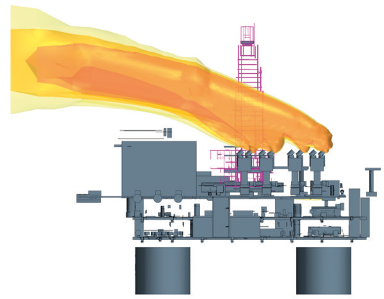
- Large scale objects are explicitly resolved
- Small scale objects are represented by sub-grid drag terms
- Two to five million hexahedral cells
- Locally refined on platform and helideckRefined exhaust outlets

Methodology

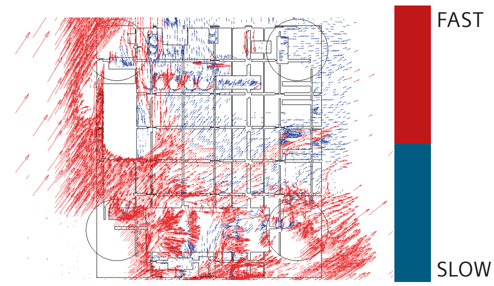
The methodology is summarized in the table below:



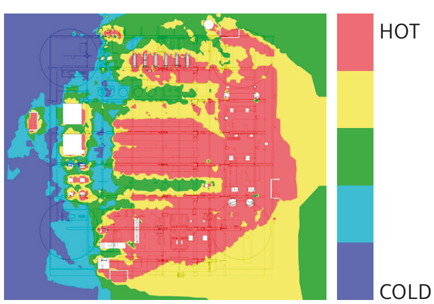
Step 1: Simulate wind from 16 direction and 2 wind speeds



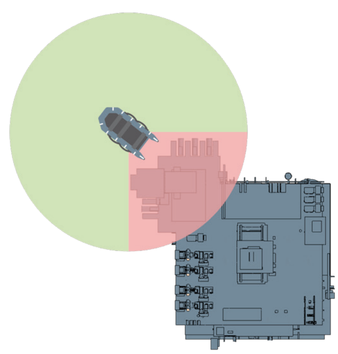
Step 2: Calculate helideck impairment from exhaust for each scenario



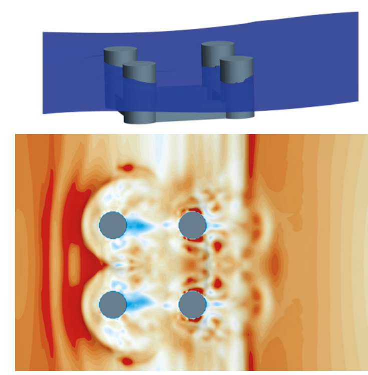
Step 3: Calculate mean air speed through the platform



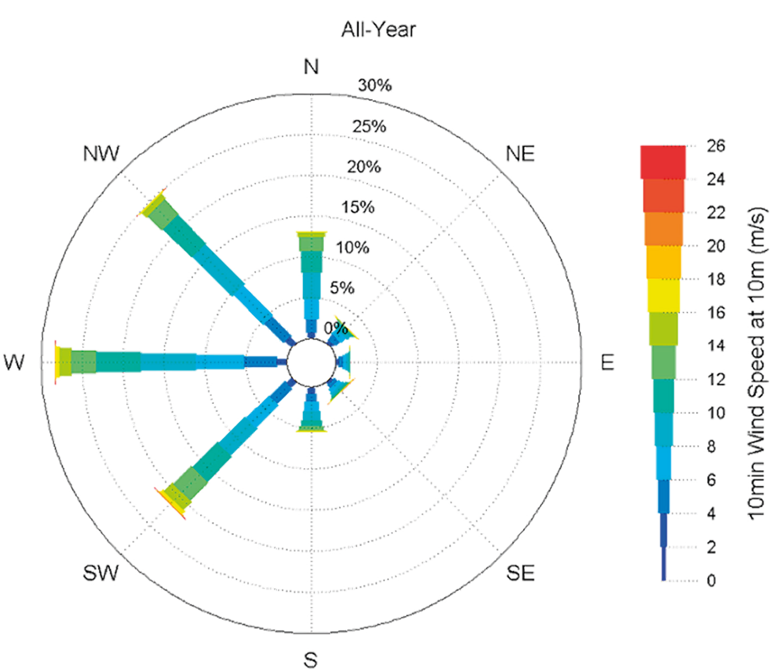
Step 4: Calculate wind chill on the platform



Step 5: Determine lifeboat drift collision probability



Step 6: Calculate drag loading on hull as a surrogate for tendon stress



Step 7: Combine all results using annual wind and current probability distributions

Results

The cost functions for each individual design objective were calculated and are illustrated in Figures 10 to 14. Figure 15 shows the linearly weighted cost function for the combined objectives. The combined cost function shows that the optimum orientation of the platform, once all objectives are taken into account, is for its North to face True East-Southeast. This result does not coincide with any of the ideal orientations found for the individual design objectives, but is the best compromise between all these objectives.

Conclusion and future considerations

The optimum orientation of the platform, with Platform North facing True East-Southeast, was obtained using simulation tools based on five design objectives: ventilation, exhaust, wind chill, lifeboat drift-off and tendon stress. The approach taken in this case study considers an early stage of design, with parameters covering both safety and operational issues. As the design progresses, the number of parameters considered is expected to change, as will

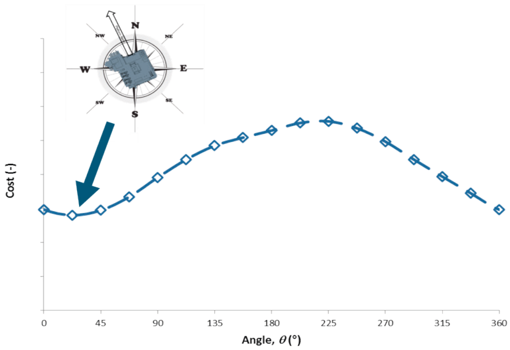


Figure 10: Cost function for the ventilation objective, showing that the ideal orientation from a ventilation perspective is for Platform North to be aligned with True North-Northwest

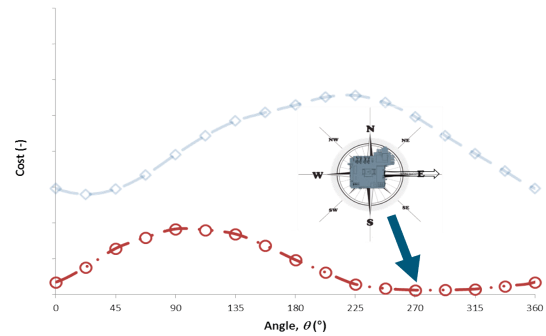


Figure 11: Cost function for the exhaust objective, showing that the ideal orientation from the exhaust perspective is for Platform North to be aligned with True East. However, results would be acceptable anywhere between θ = 250 and 330 degrees.

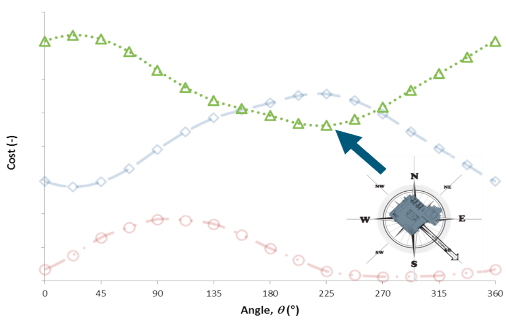


Figure 12: Cost function for the wind chill objective, showing that the ideal orientation from a wind chill perspective is for Platform North to be aligned with True Southeast. Note that the cost function curve is the opposite of the one obtained for the ventilation. This is explained by the fact that the wind chill is driven by the air speed in the same way as the ventilation, as well as temperature. In this specific case, the temperature was not cold enough to have much of an effect.

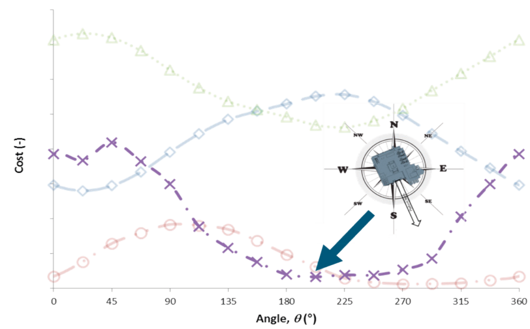


Figure 13: Cost function for the lifeboat drift-off objective, showing that the ideal orientation from a lifeboat drift-off perspective is for Platform North to be aligned with True South-Southeast, although any orientation θ between 180 and 260 degrees would be equally acceptable.

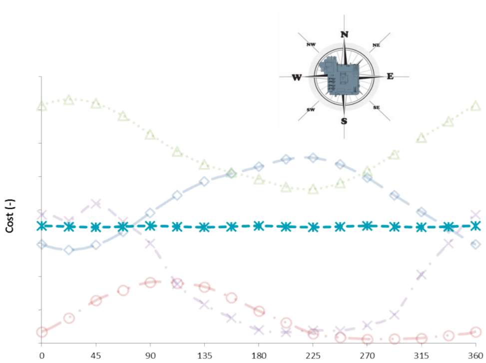


Figure 14: Cost function for the tendon stress objective, showing that the orientation doesn't have any real influence on the tendon stress. This result may be explained by the symmetrical nature of the platform.

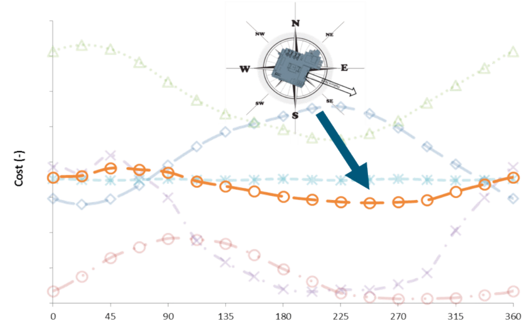


Figure 15: Cost function for all combined objectives obtained by linear weighting of the individual cost functions. It shows that the optimum platform orientation is facing True East-Southeast.

Legend ▶ Ventilation | Exhaust | Wind Chill | Drift-Off | Tendon Stress

their weighted contribution. The idea is that the orientation can be further optimized as the design process progresses or in some cases completely alter the selection based on safety and operational prioritizations.
If a proper balance of previous experience, qualitative judgement, and the use of formal models such as CFD are deployed, this function method can be used to achieve an Inherently Safe Design. Further work could involve optimizing the facility layout based on: turbine stack design and positioning, helideck positioning, module placement, flare tower design, etc.

References

[1] Philip E. Tetlock: Expert Political Judgment: How Good is It? How Can We Know?

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