

# **Development of a TLP/TLB for Large MW Floating Offshore Wind Turbines**

**Technical Leader Coordinator - Offshore Substructures**

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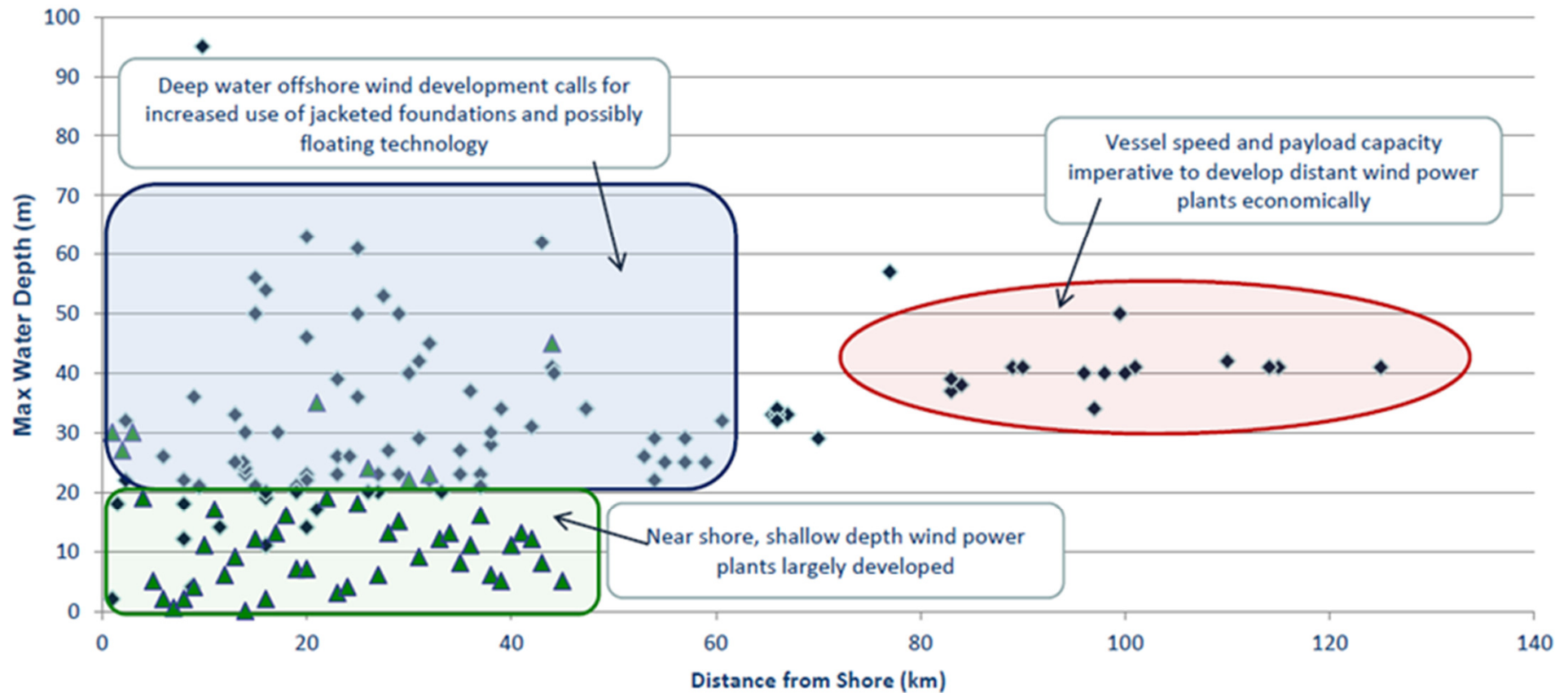


- Brief Overview
- Qualitative Assessment
- Sensibility Analysis & Optimization
- ALSTOM Floating Haliade 150-6MW
- Summary & Conclusions

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# Current and Future Offshore Project Characteristics **ALSTOM**

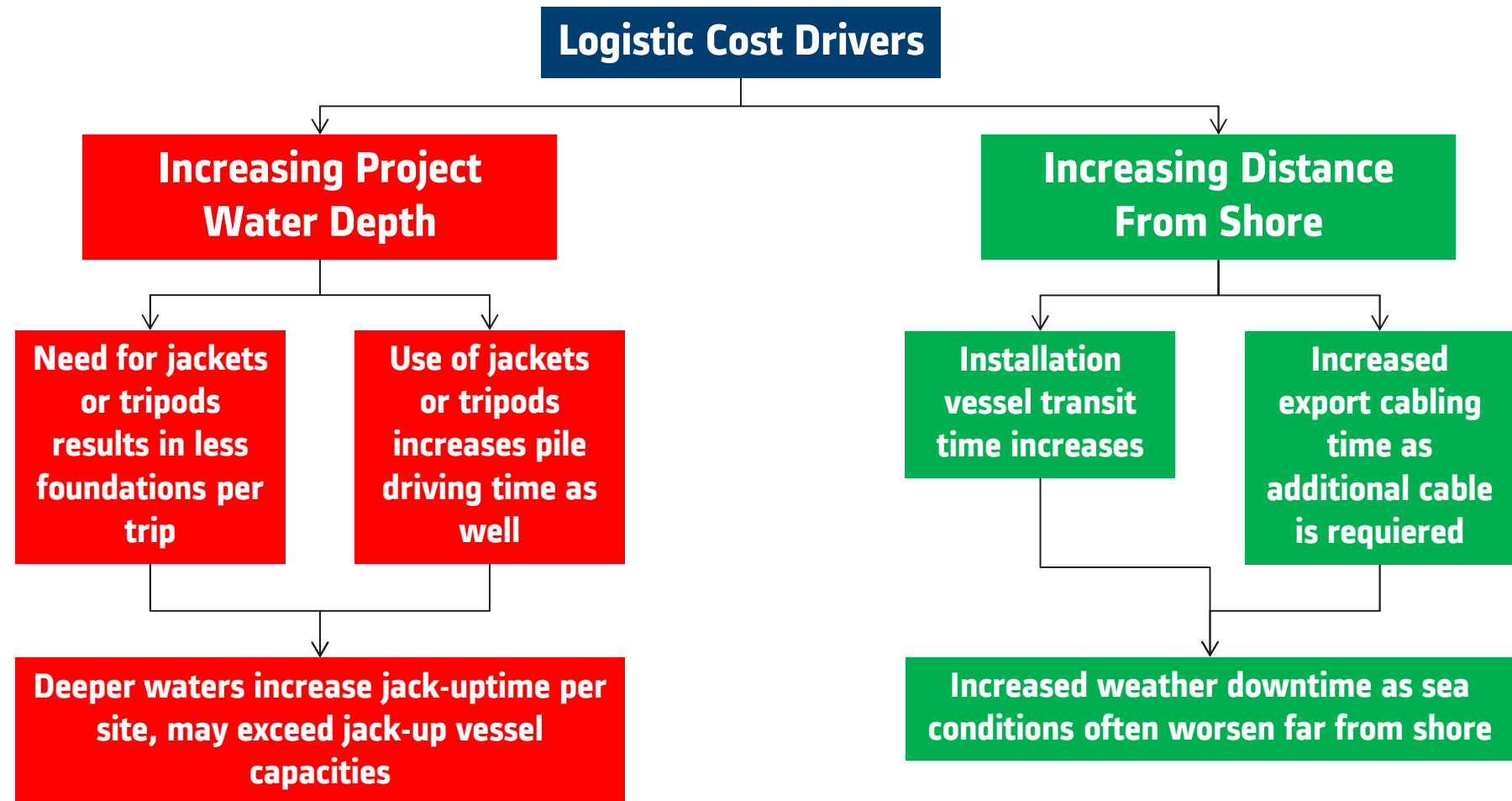
Source: MAKE Consulting



NOTE: Water depths based on max water depth, not average water depth at site

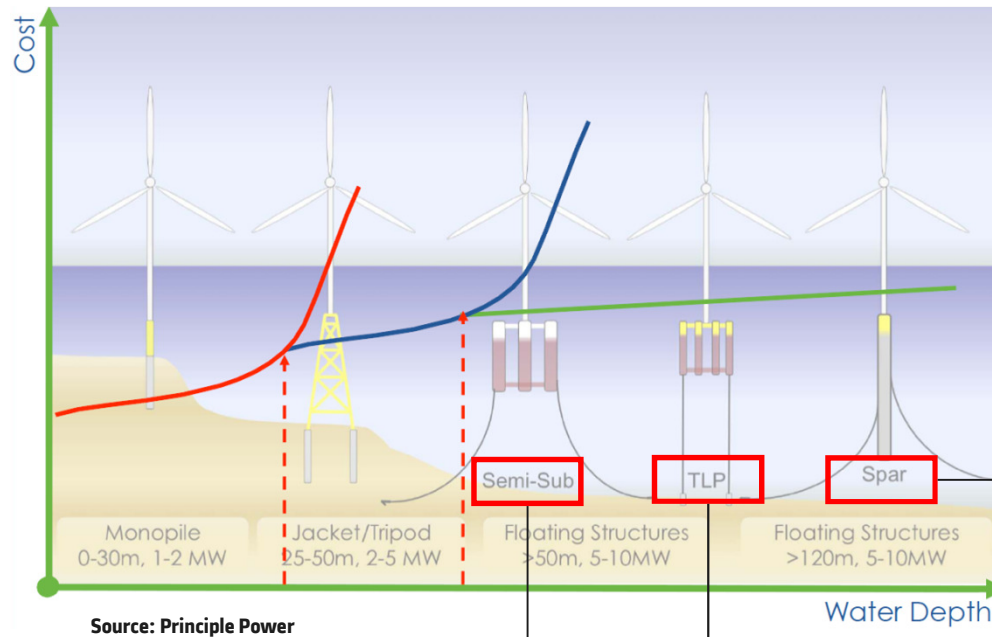
Source: MAKE Consulting

Clear trend in going further and deeper to find available sites



**Greater depths require (i) larger and faster vessels & (ii) new substructure concepts**

# Water depth economics



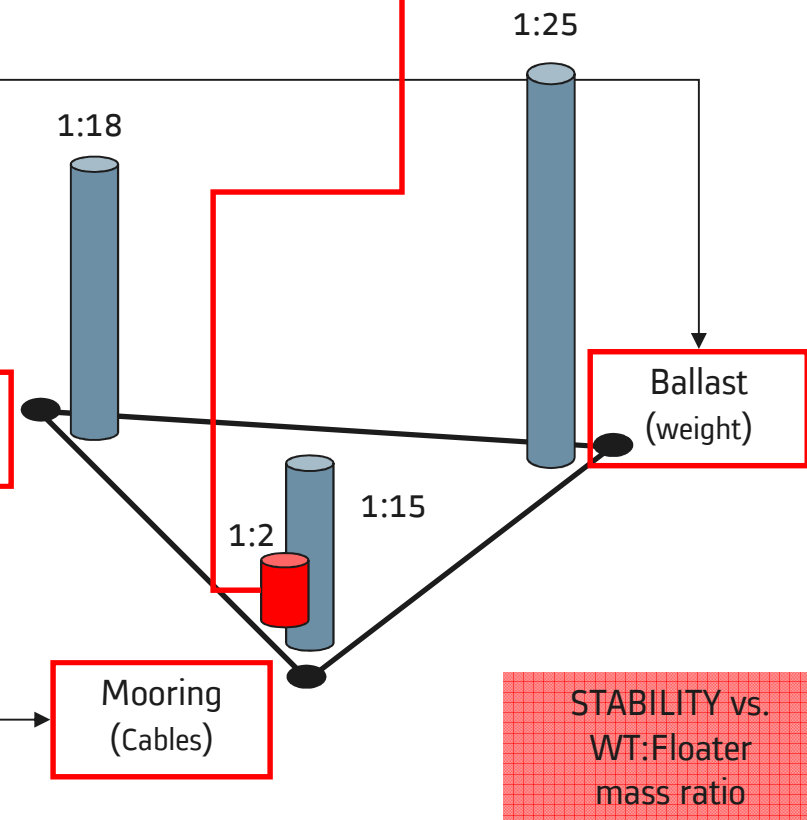
## ALSTOM concept:

- Water depth range [50m to 300m]
- O&M, manufacturing, and transportation design

## Global potential for offshore wind projects with water depths >40m



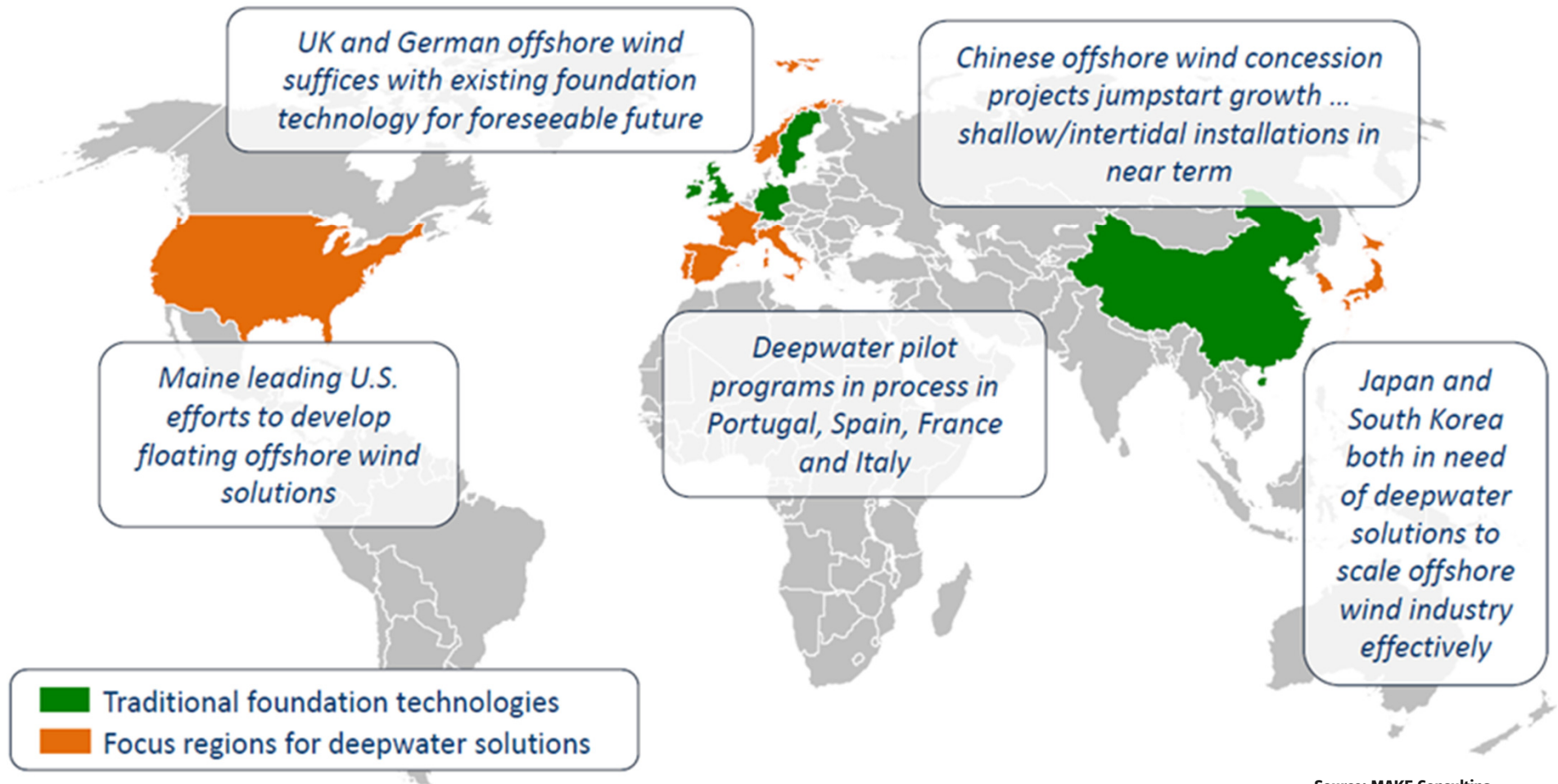
Buoyancy (hydrostatics)



# Global Market



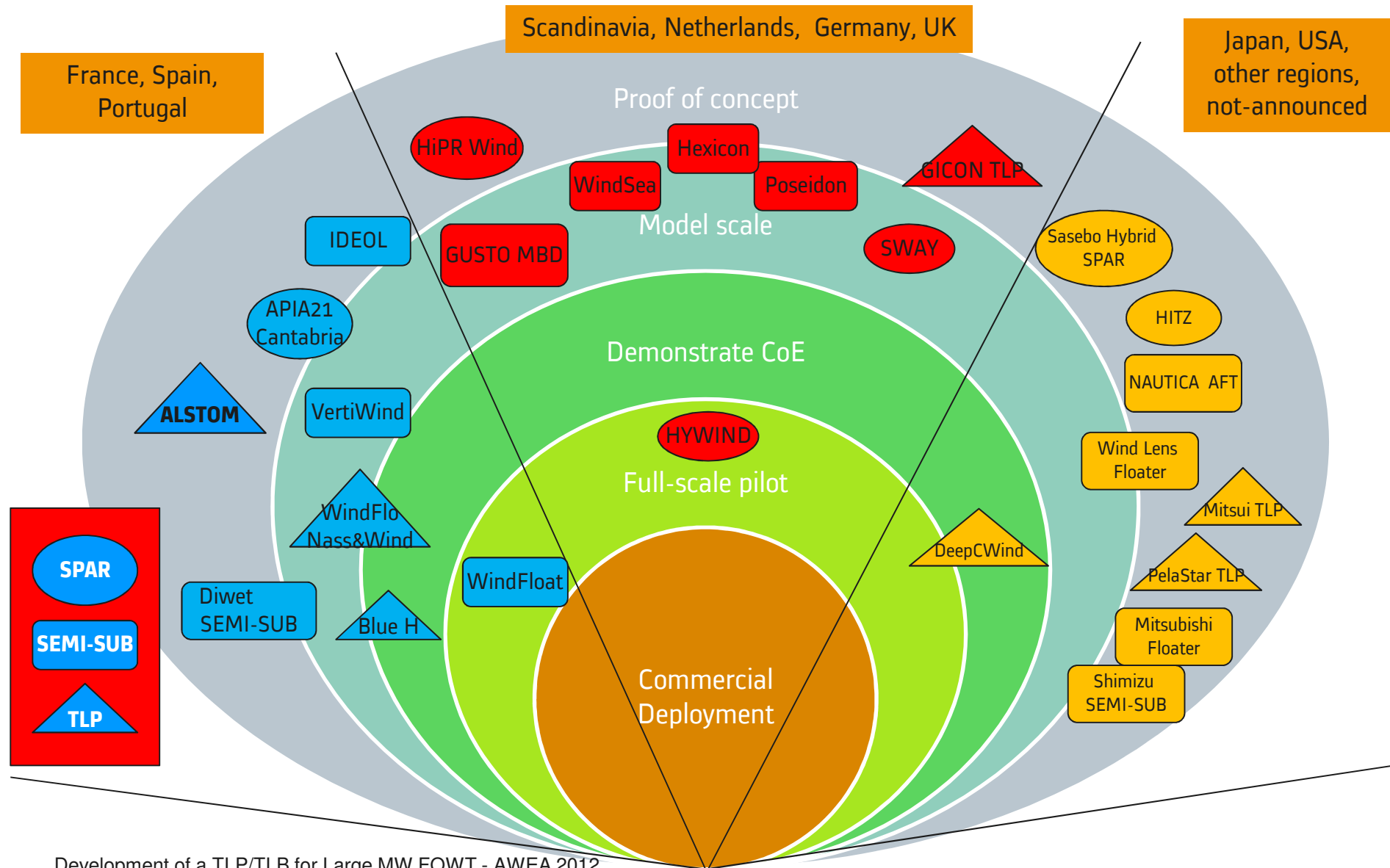
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# Path-to-Market

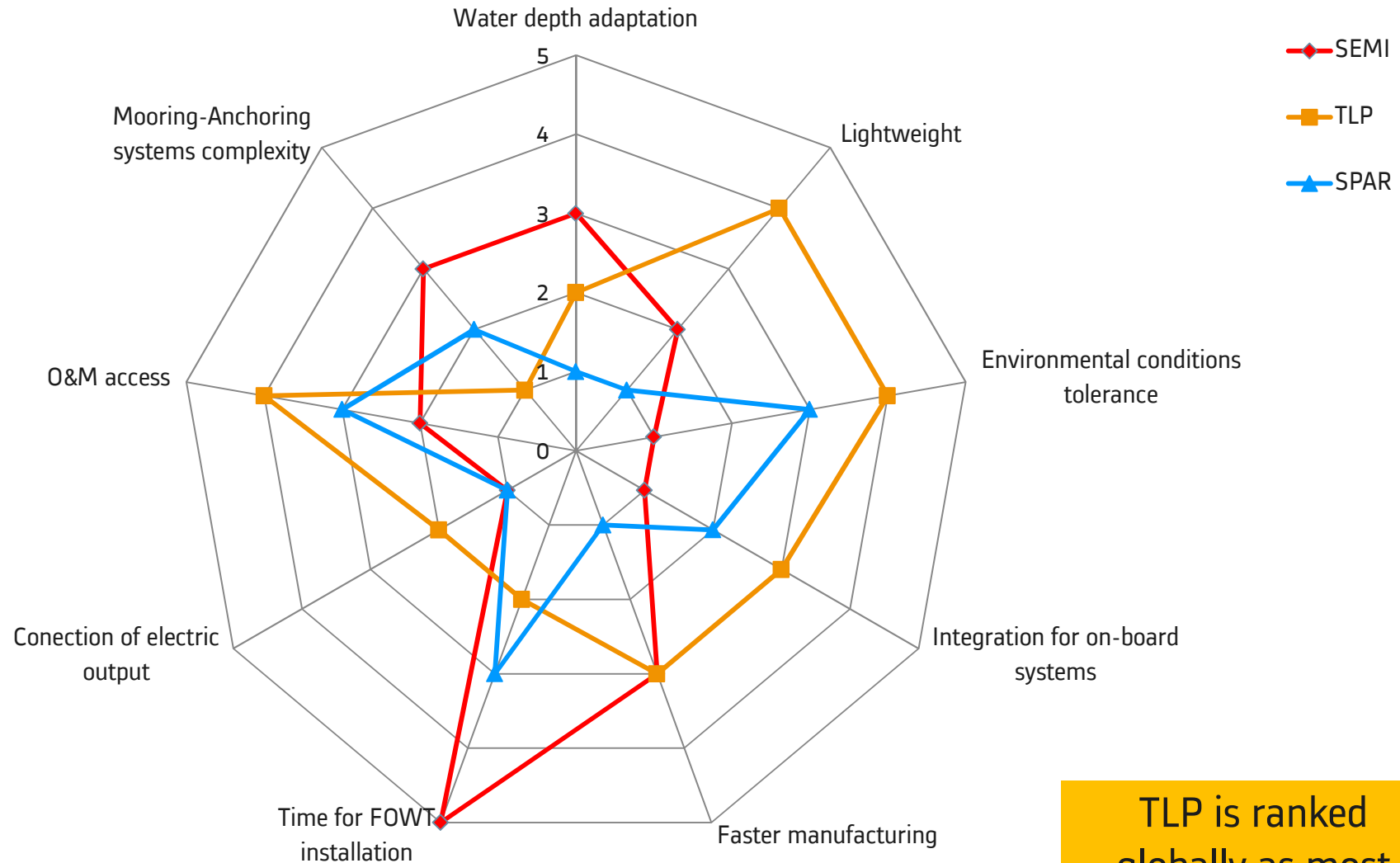
ALSTOM





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# Global Qualitative Assessment



TLP is ranked globally as most feasible & cost competitive

# Key Areas of Concern for Floating Technology



## Heave, Pitch & Roll

- Consider massive forces from turbine pitching, rapid acceleration / deceleration,
- WT compensated by pitch controls, may undermine power production,
- Drive train bearing failure concerns,

## Major Component Service

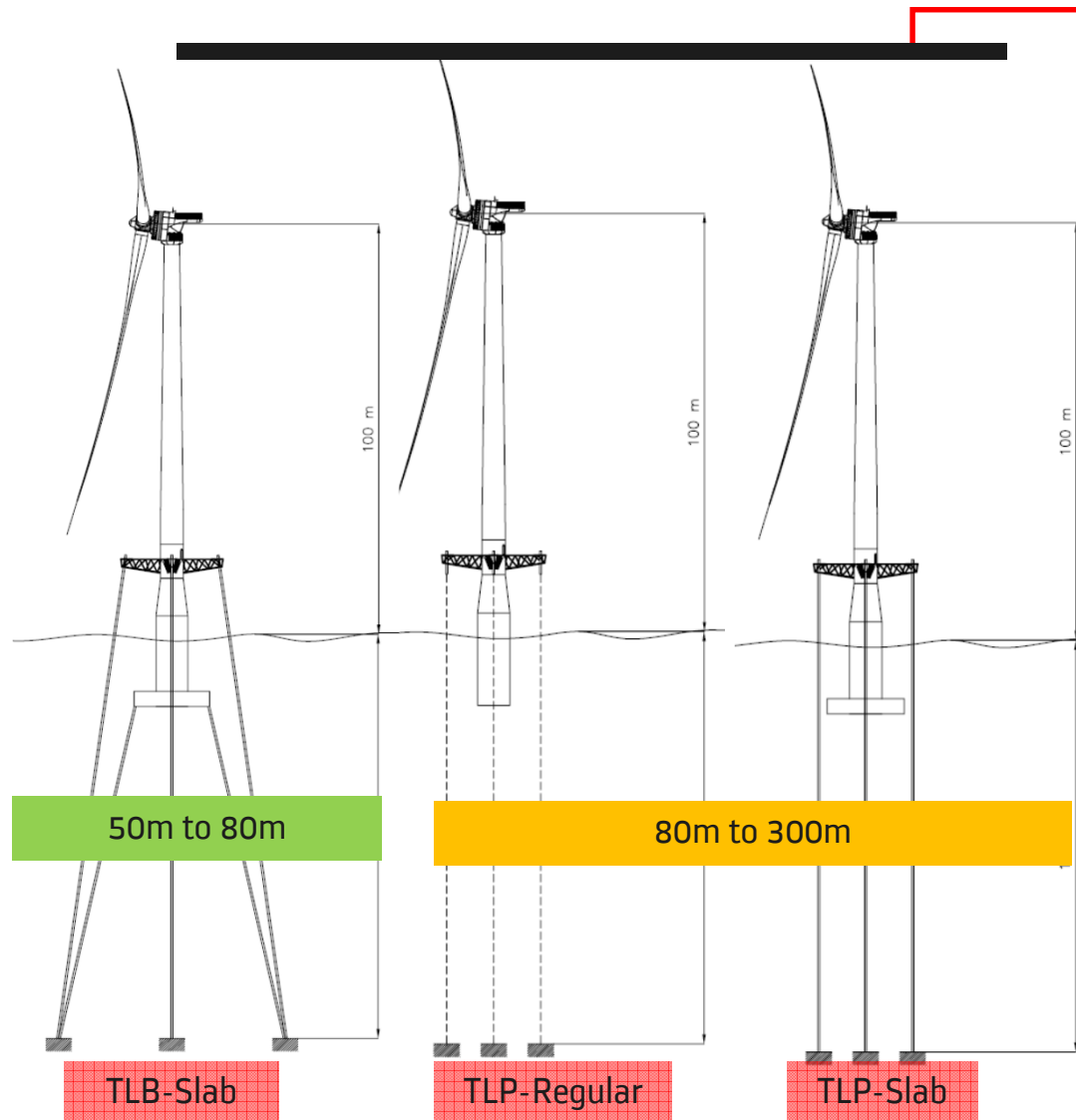
- Servicing a pitching and bobbing platform from jack-up barge,
- Towable platforms may be more advantageous to tackle this issue,
- Increases the criticality for onshore service facilities,

## Logistical Concerns

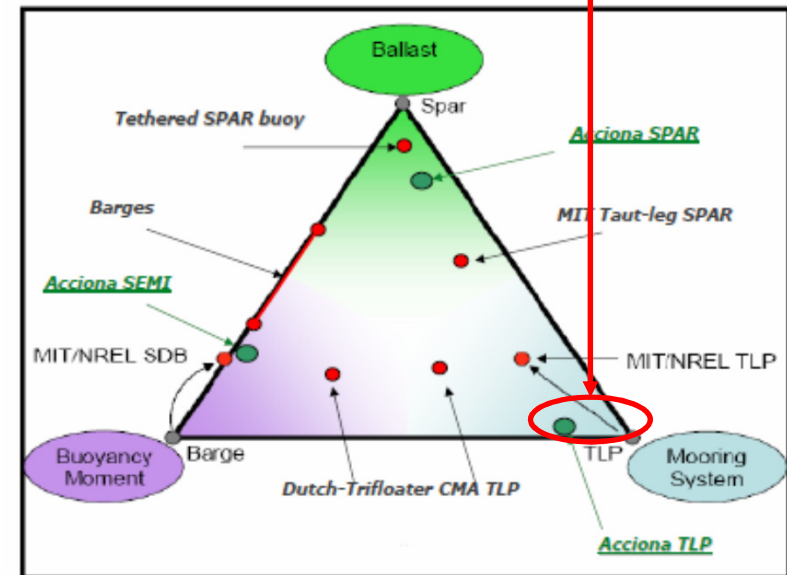
- Need of understanding the weather windows required for towing fully assembled units,
- Blades and drive shaft are fixed, and unable to pitch to compensate loads
- Distance from onshore facility may play a critical factor

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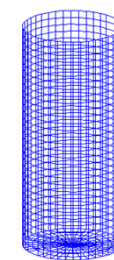
# ALSTOM - Studied floating concepts



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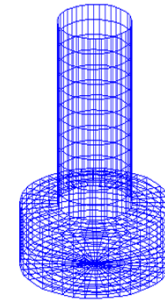


Ternary Stability (Picth- C55) Plot



TYPE-I

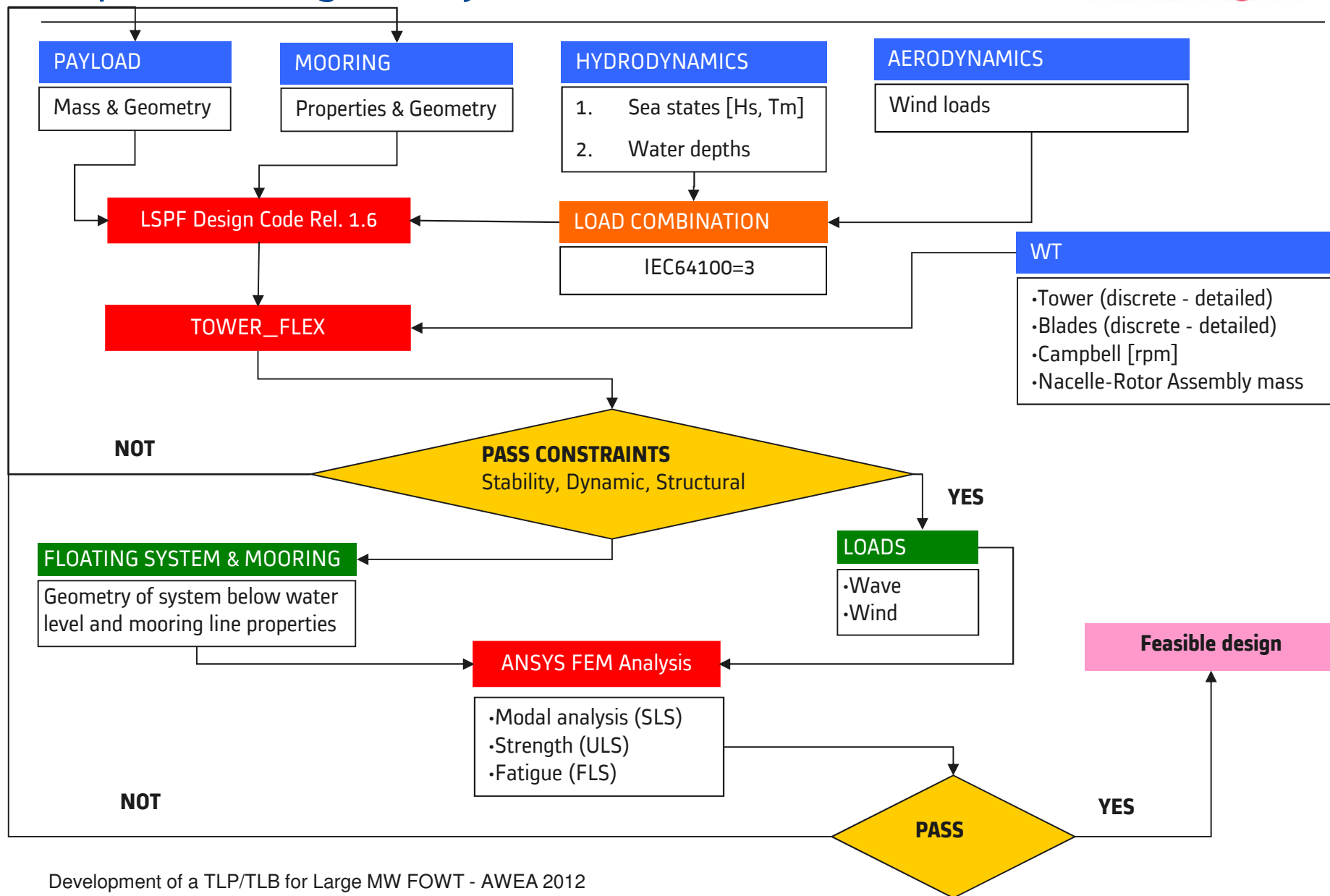
REGULAR CYLINDER



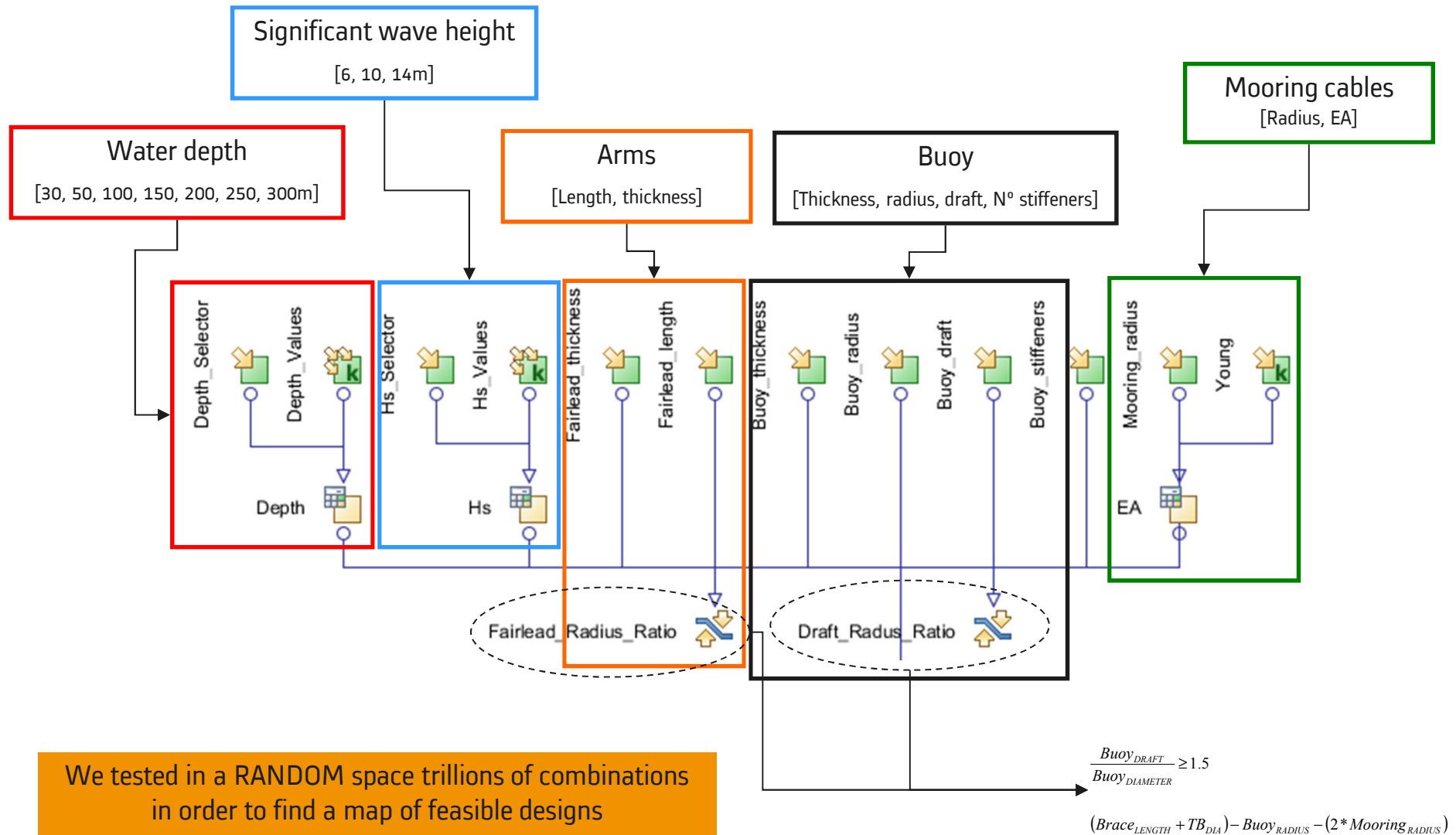
TYPE-II

SLAB CYLINDER

# Optimal Design Analysis Workflow



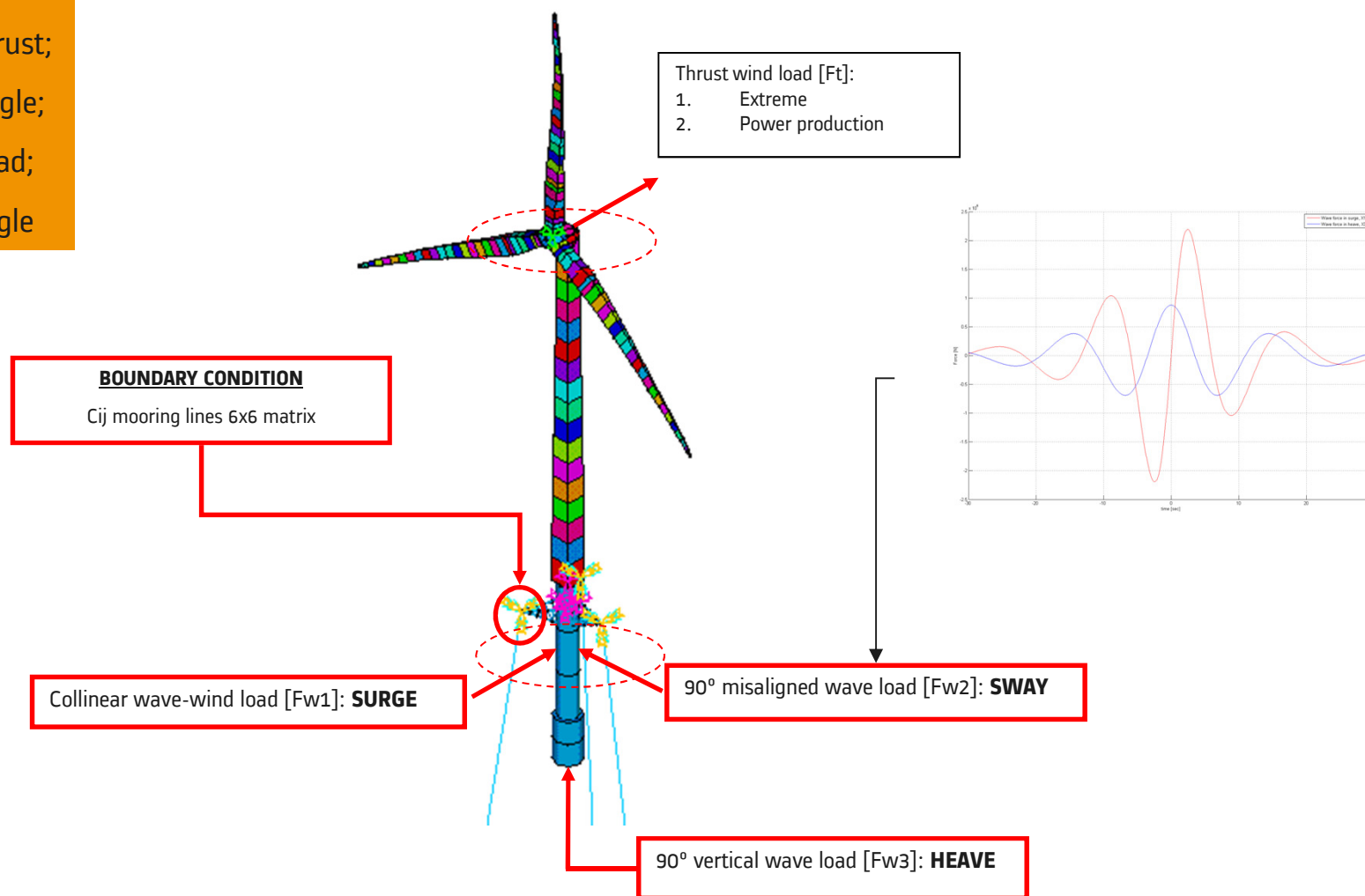
# Sensitivity analysis inputs vectors



# Application of TLB/TLP Design Loads

The DLC's varied:

1. Wind thrust;
2. Wind angle;
3. Wave load;
4. Wave angle



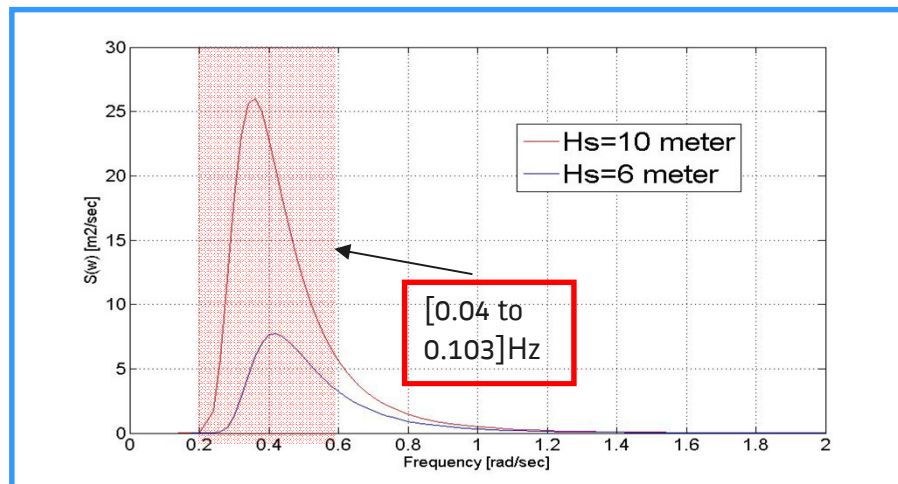


# Constraints and/or restrictions for a feasible design **ALSTOM**

$$Buoy_{DISPLACEMENT} = M_{WT} + M_{BUOY} + M_{TP} + M_{MOORING} + \sum_n T_{mooring}^{vertical}$$

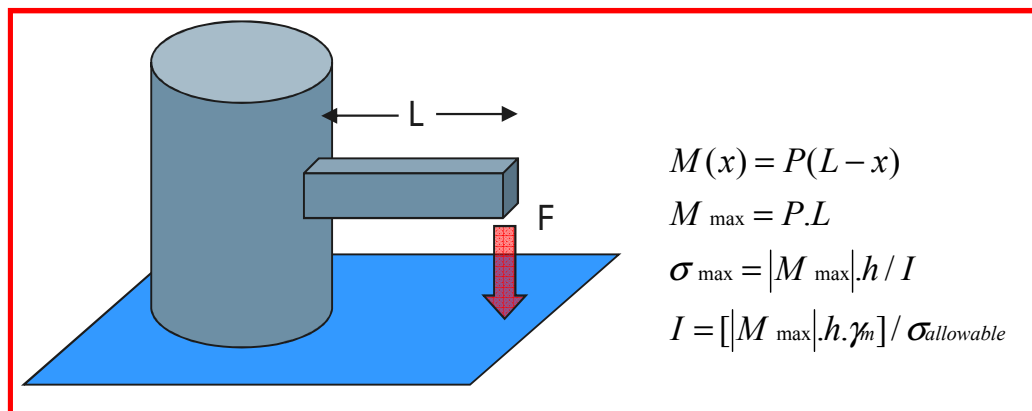
$$\min T_{PRETENSION} = -\min[\Delta T_{WIND} - \sigma * T_{RMS}]$$

Stability criterion



Dynamics criterion

1. Wave spectrum
2. Rotor harmonics (+/-10% apart from 1P, 3P...min & max bands)



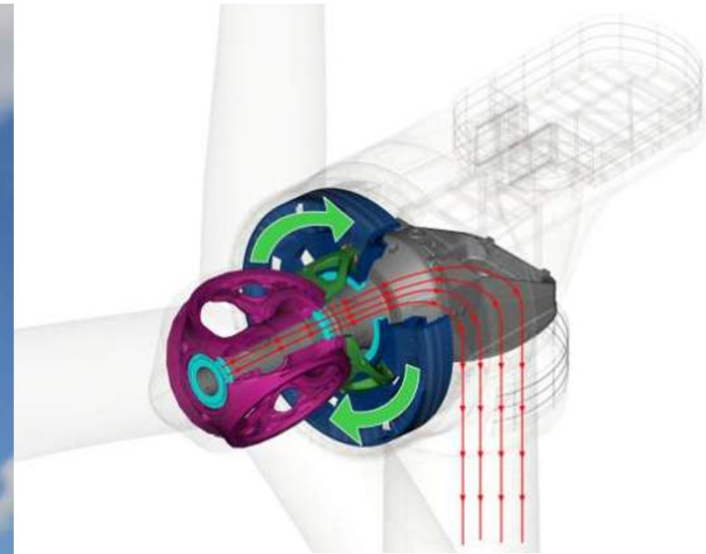
Structural brace criterion

- ***LSPF-DESIGN-CODE Rel.1.6*** (Lee, 2012)
  - Computational package:
    - Evaluates a coupled dynamic response analysis of the wind turbine, floating platform and mooring line systems in a given wind and wave condition in the frequency domain.
  - Analytical hydrodynamic analysis methods based on:
    - McCamy & Fuchs theory and Kramer-Kronig relations
- ***TOWER\_FLEX*** (Luypaert, 2011)
  - Multi-body, frequency-domain code:
    - Tower is modeled as a series of uniform Timoshenko beams connected to each other.
    - It couples 3D flexural motions of the turbine, the floating platform and the mooring system.
    - The mass, damping and stiffness coming from the rotor, the floating platform and the mooring lines are taken into account via generalized boundary conditions from LSPF-DESIGN-CODE-Rel. 1.6.

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# Haliade 150 – 6MW

## New generation offshore turbine

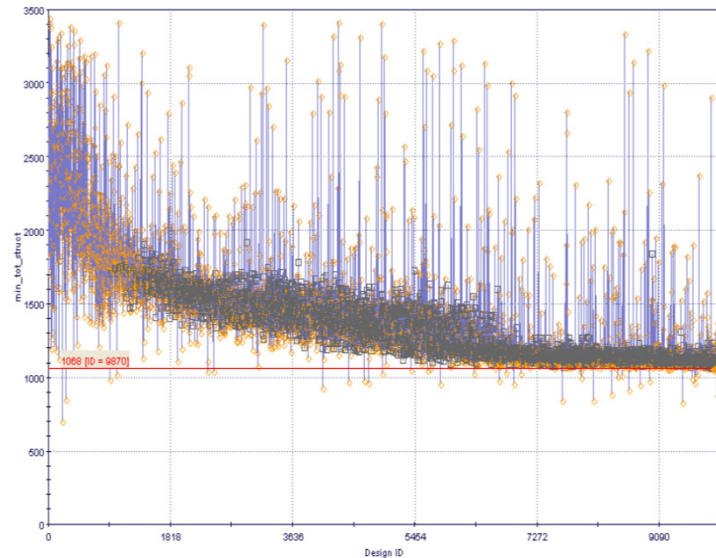


### **Haliade 150**

- Robust - ALSTOM PURE TORQUE®
- Simple - Direct drive permanent magnet generator
- Efficient - High yield and low weight

# Results comparison between TLP and TLB

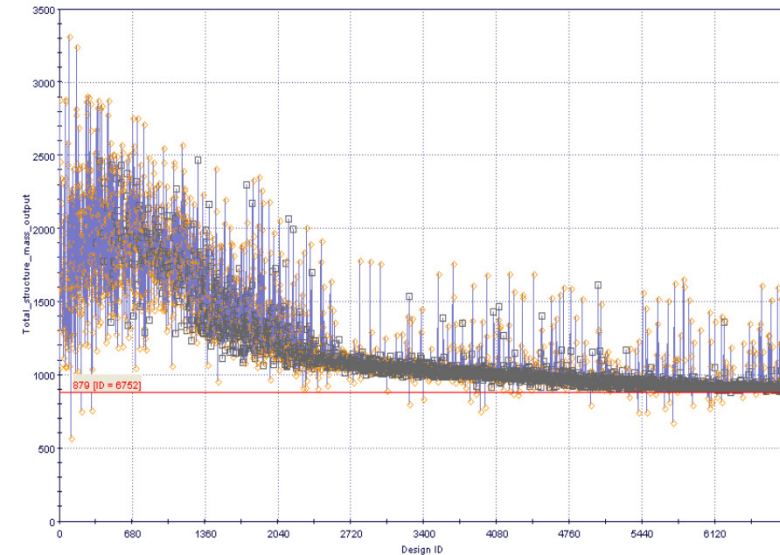
## TLB



Min. Floater Mass



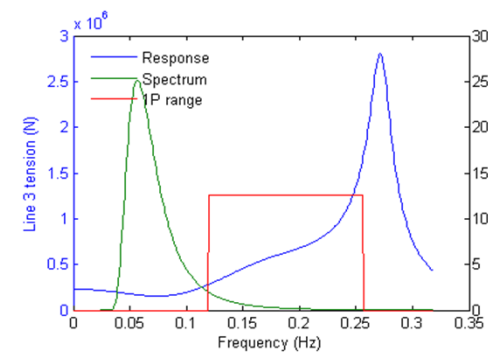
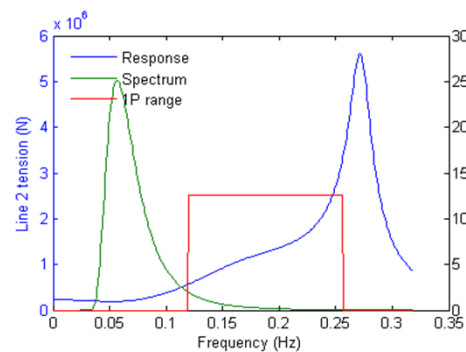
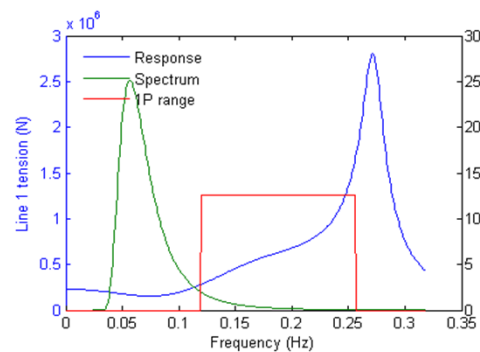
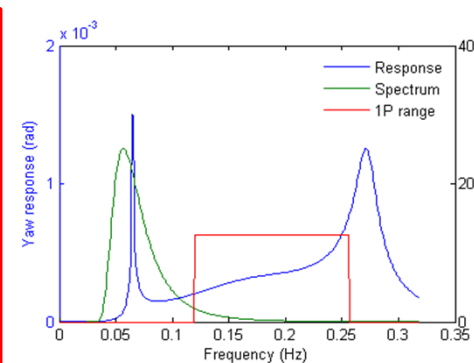
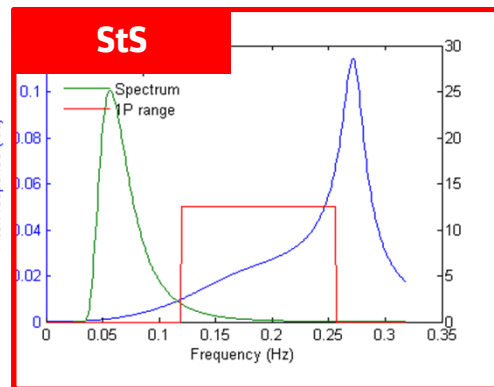
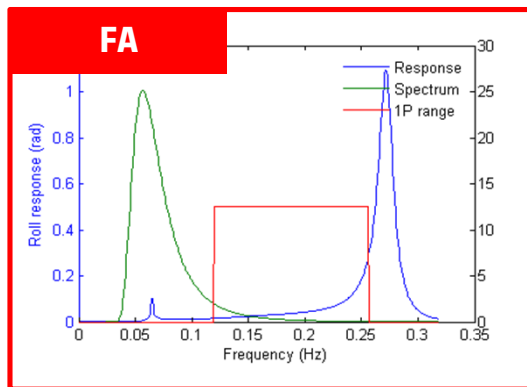
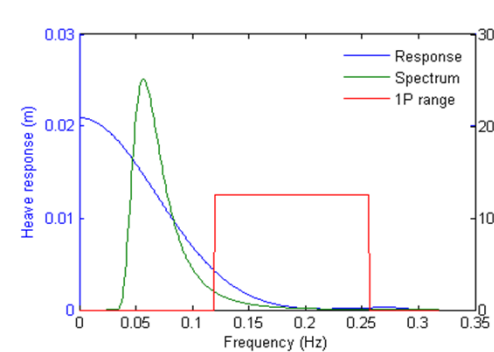
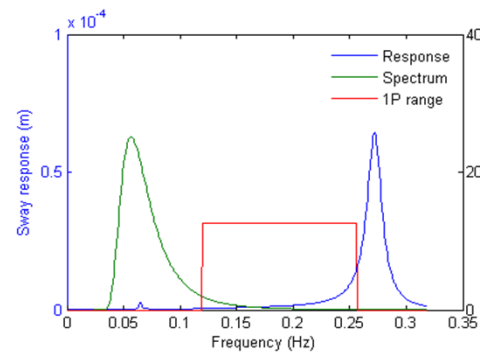
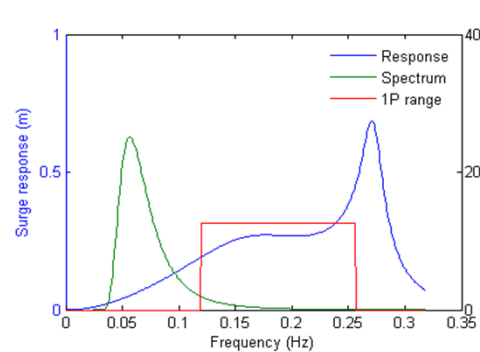
## TLP



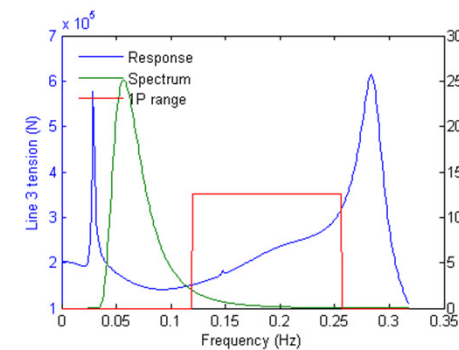
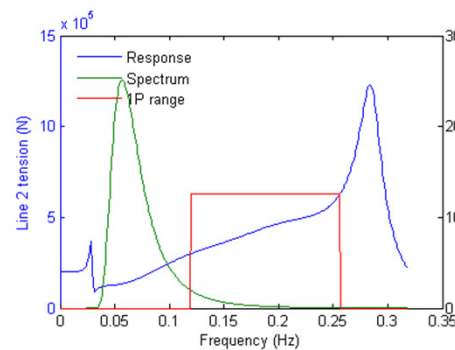
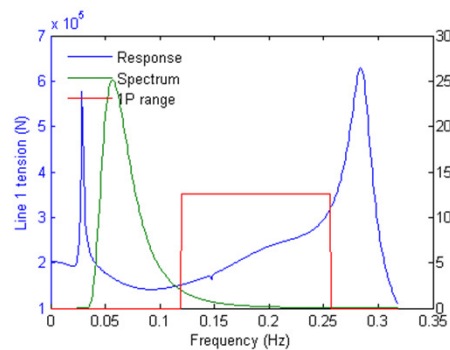
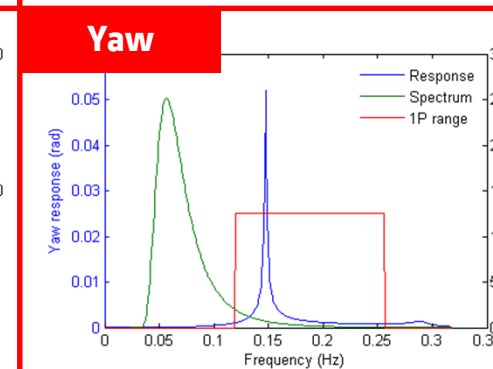
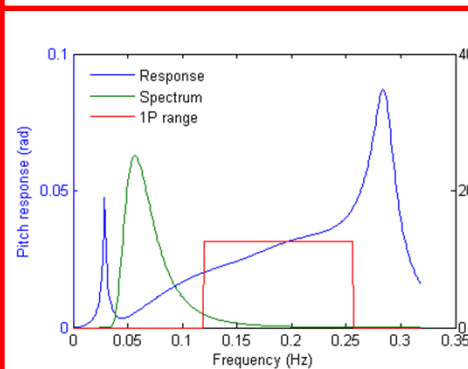
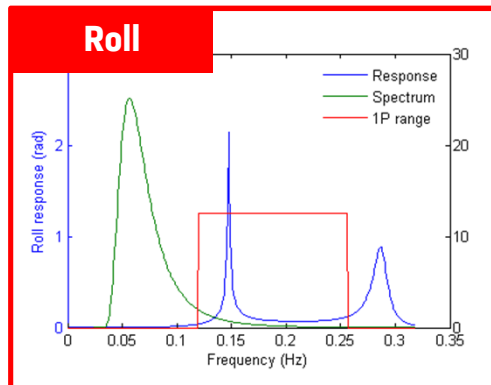
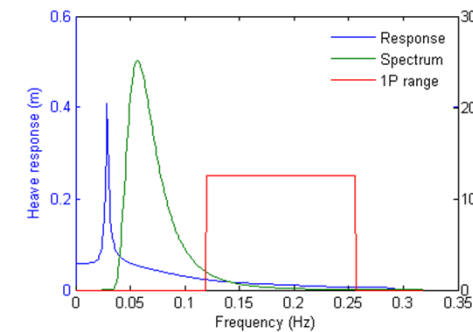
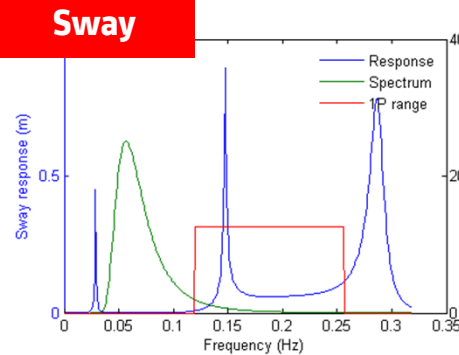
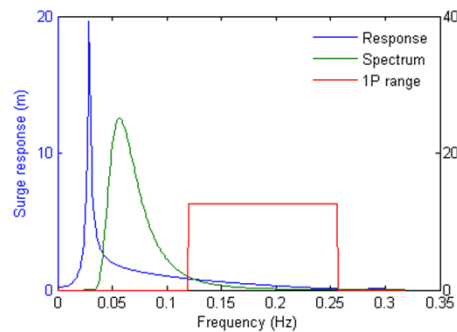
Min. Floater Mass



# Flexible Dynamic Response - TLB @ 60m

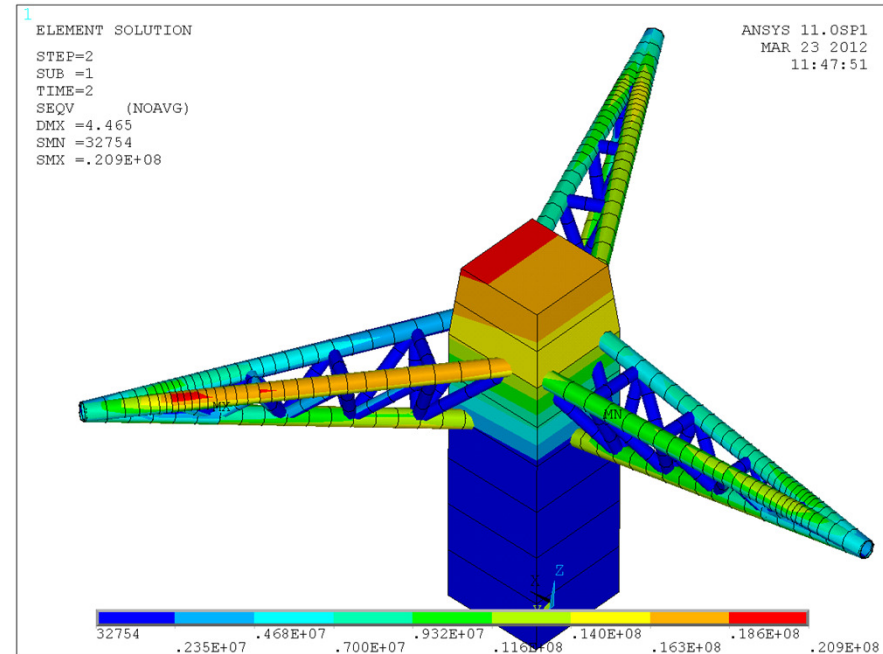
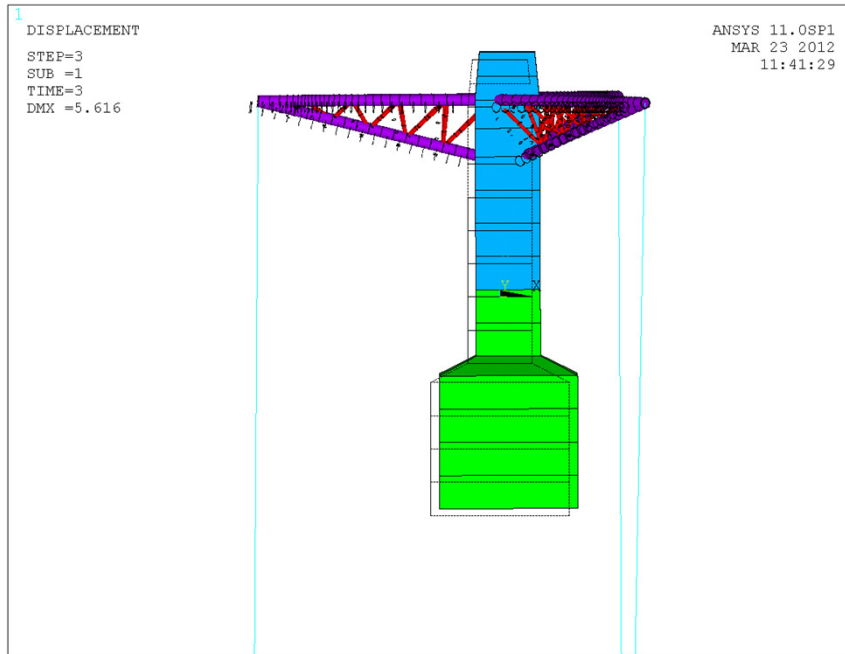


# Flexible Dynamic Response - TLP @ 100m





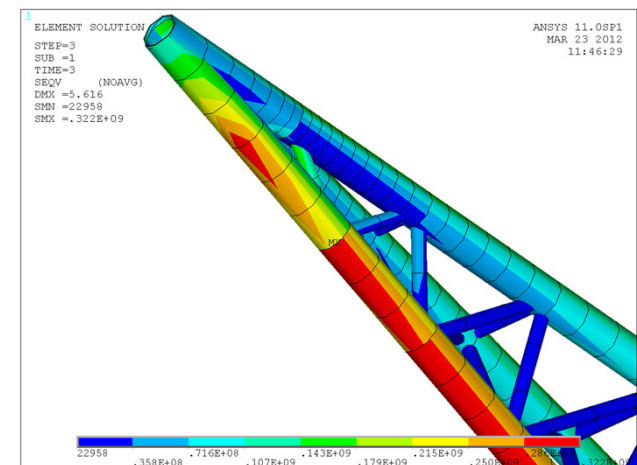
# Structural Analysis (SLS, ULS, FLS)



## A structural analysis using a parametric FEM model (ANSYS) has been employed to:

- Dimension appropriately the fairleads due to WT loads (Extreme& Fatigue) and cable tension,
- Following DNV-OS-J101 Structural Standard & new DNV FOWT Standard recommendations

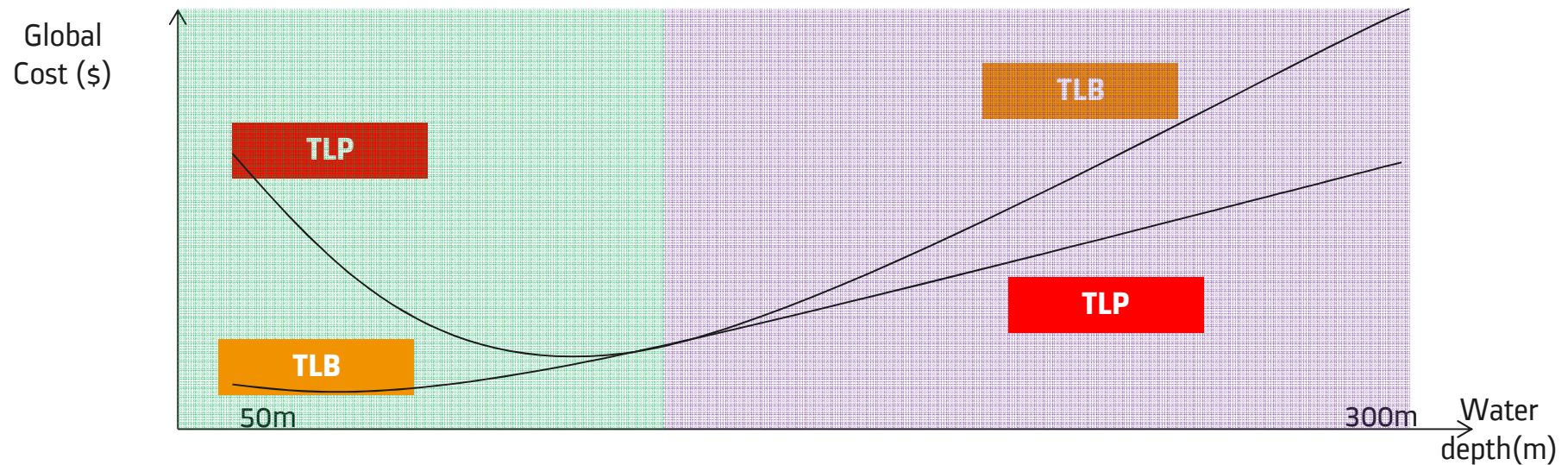
Development of a TLP/TLB for Large MW FOWT - AWEA 2012





# Results

- Two design have been explored, and the results converged to:
  - **Low water** → 50m to 80m (TLB or TLB\_Slab)
  - **Deep water** → 100m to 300m (TLP and TLP\_Slab)



**Strong focus on a simple geometry with tunable standard structural components, moorings & anchors tuned to site conditions:**

- Logistically better,
- Less manufacturing complexity,
- Installation controlled cost

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- An analysis scheme that couples **robust analytical tools** to model waves and the dynamic response of a floating system, accompanied by a **structural design methodology**, have been completed successfully.
- ALSTOM has chosen a tension-stabilized system for its WT as it guarantees its global structural integrity, while only changing the tower and control systems. The most suitable configurations are:
  - TLB for water depths between 50 to 80m,
  - TLP for water depths between 80 to 300m,

**This project has outlined a robust and reliable concept for floating offshore wind turbines and paves the way for the design phase of the next generation Haliade 150-6MW floating system.**

- **DESIGN:**
  - **Time-domain fluid impulse theory wave analysis** in order to capture non-linear effects,
  - **2<sup>nd</sup> order frequency domain analysis** to capture ringing and springing effects,
  - Coupled **wind and wave fatigue assessment**,
- **VALIDATION:**
  - **Model testing** to validate whole floating system,
- **UNCERTAINTY ASSESMENT:**
  - Perform a thorough **Risk Assessment** on design development, based on interface with Designer, Manufacturer, Transport, and Installation contractor.



Thank you for  
your attention !

*Acknowledgements:*

**Elena Menéndez, Jordi Ollè, Jose-Luis Roman, Manel Martin, Albert Fisas,  
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