OFFSHORE WIND TURBINE

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OUTLINE

- Brief Overview
- Component Costs
- Turbine Concepts
- Power Generation Concepts
- Foundation Concepts
- References
- Q&A

BRIEF OVERVIEW (JASON DAVIS)

Identification of Need

Transform wind energy into electrical energy offshore in deep water (>60m).

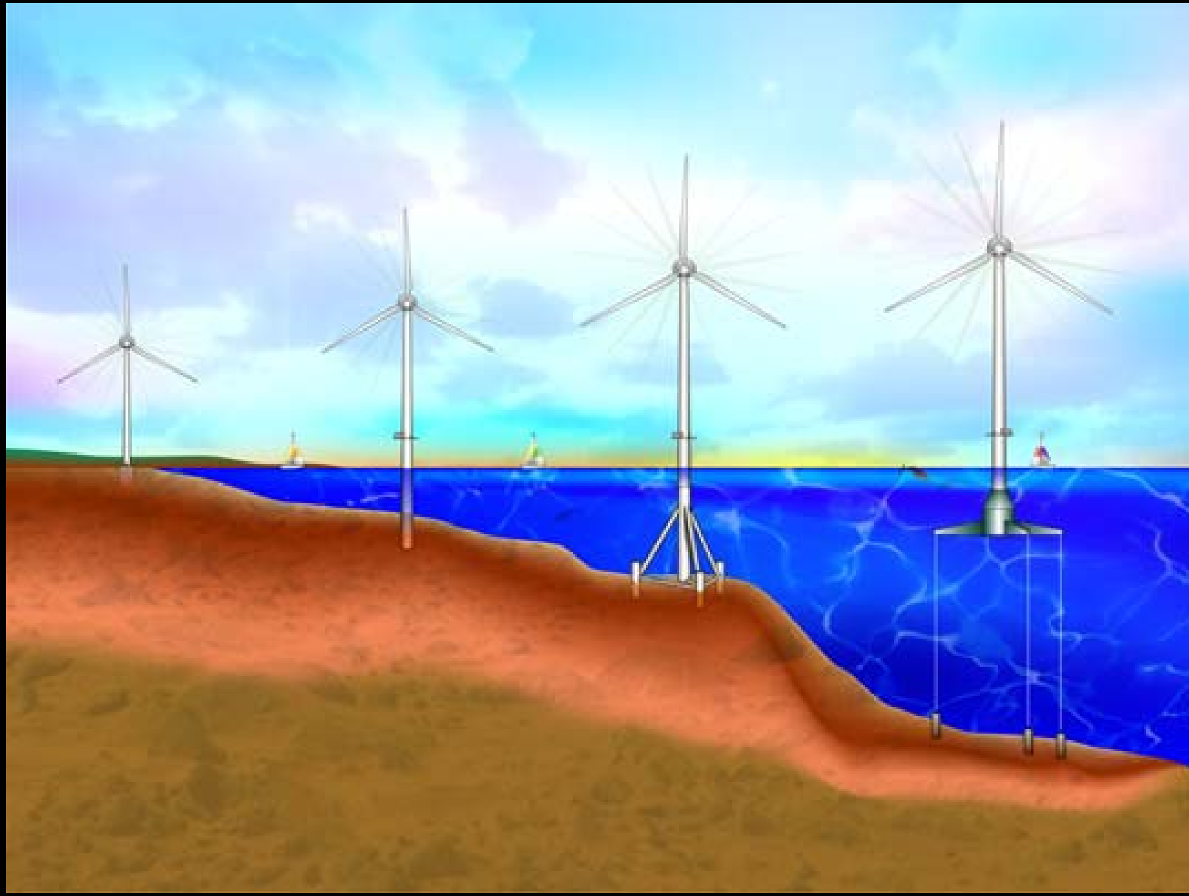
Background

Traditionally accomplished using wind turbines.

Overall costs increase dramatically with offshore turbines v. onshore turbines.

Goal Statement

Reduce the cost of offshore wind turbines in deep water.



COMPONENT COSTS (JASON DAVIS)

CAPEX

Offshore:

Turbine 33%

Balance of Plant 37%

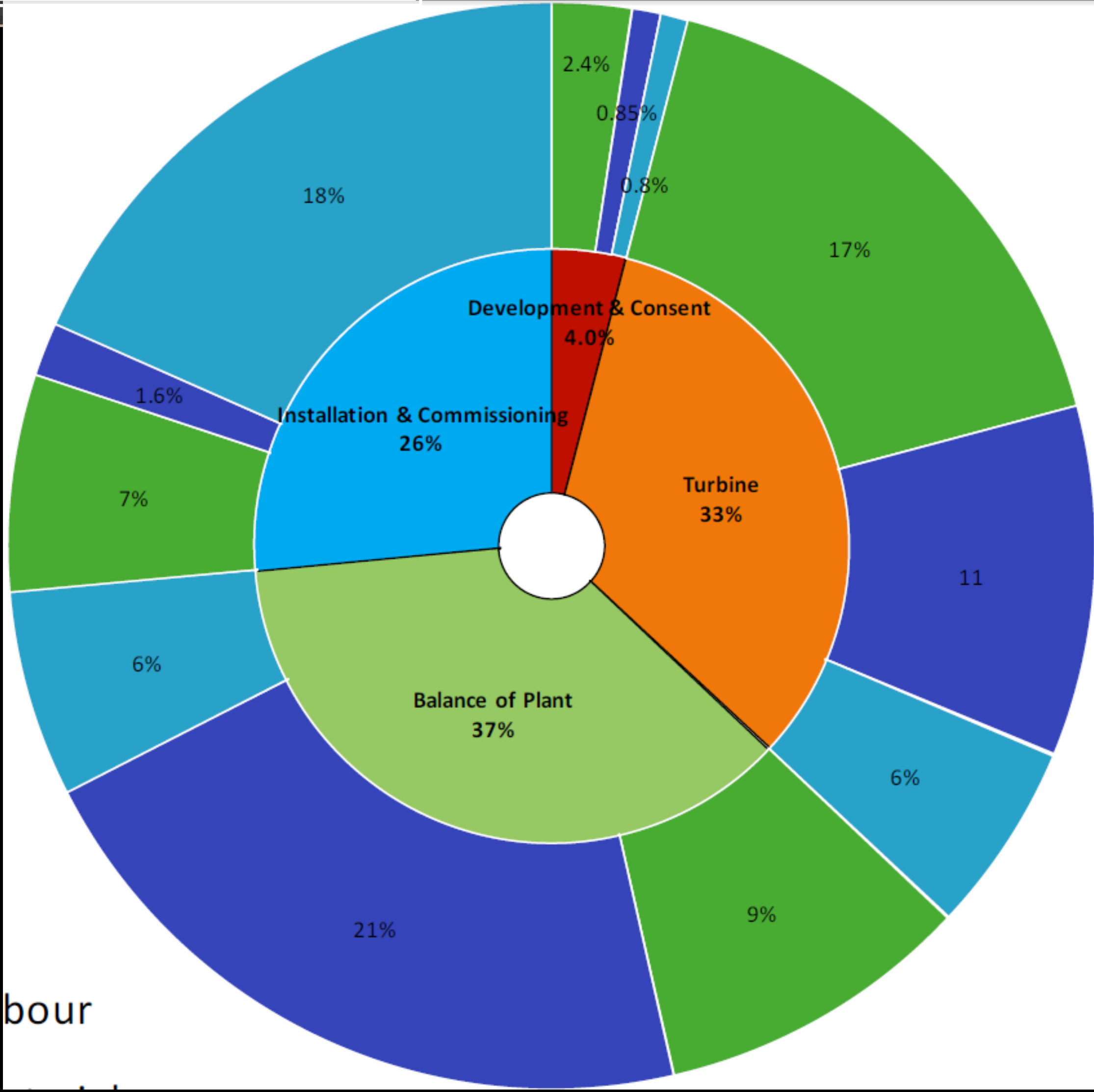
Installation and 26% Commissioning (1)

Onshore:

Turbine 70%

Balance of Plant 18%

Installation and 12% Commissioning (1)



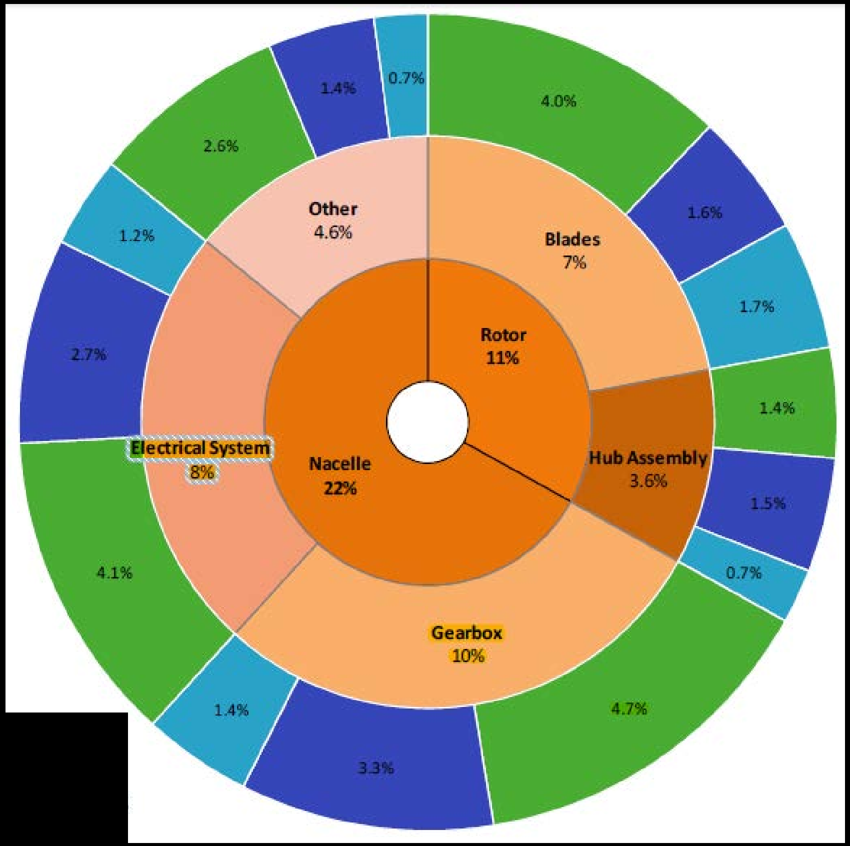
Offshore Wind Sector CAPEX Component Costs (1)

Jason Davis

COMPONENT COSTS (JASON DAVIS)

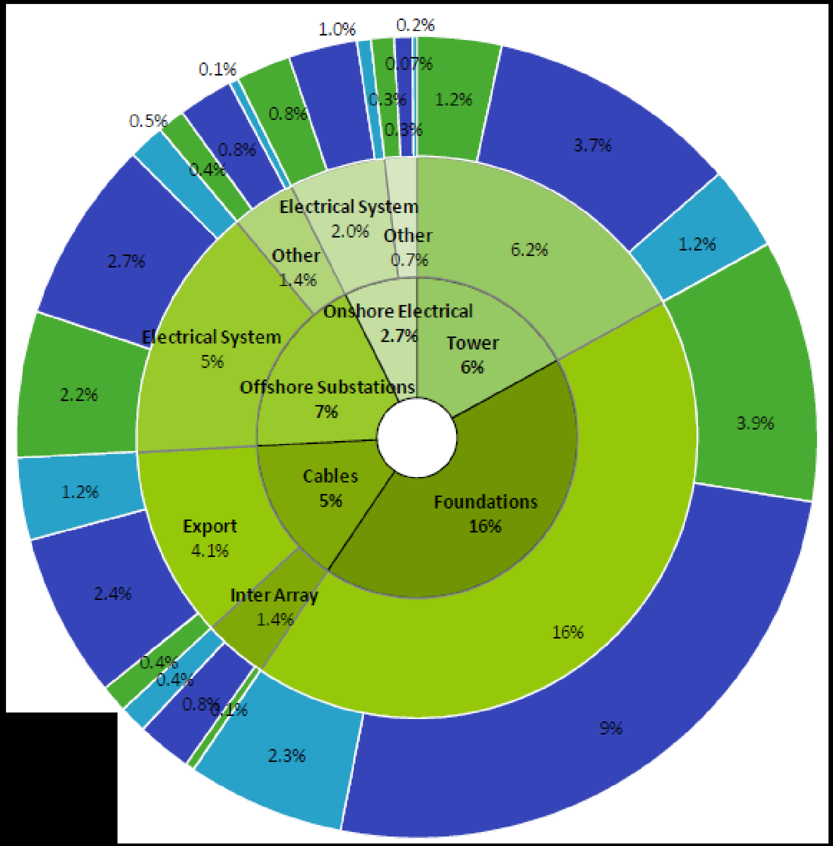
Turbine (33% of Total)

Gearbox 30%



Offshore Wind Sector Turbine Component Costs (1)

- Balance of Plant (37% of Total)
  - Foundation 43%



Offshore Wind Sector BoP Component Costs (1)

TURBINE CONCEPTS

Horizontal Axis:

Rotating axis is horizontal axis is horizontal/parallel to the ground.

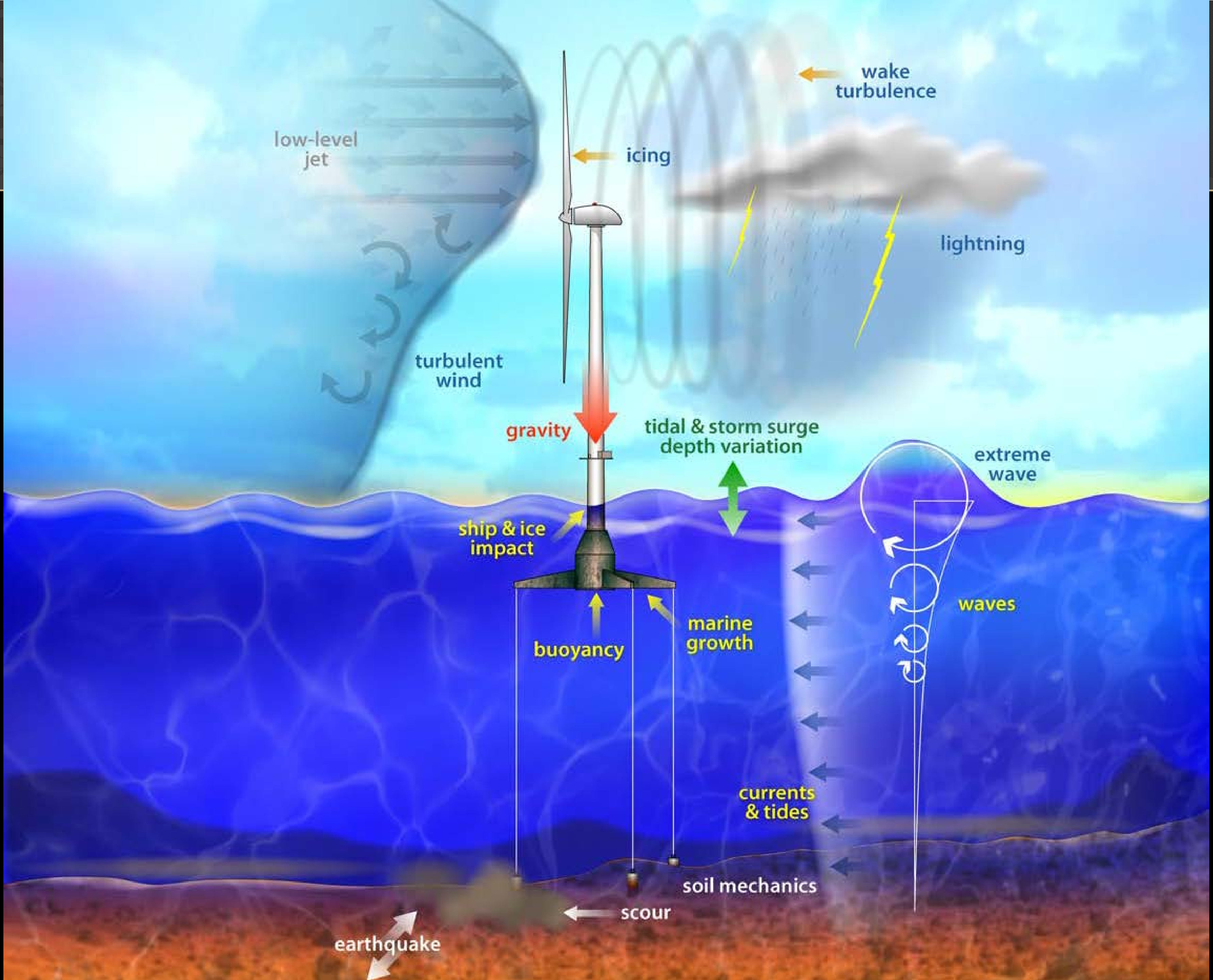
Majority of industry.

Mostly seen in big wind applications (2).

Vertical Axis:

Rotating axis stands vertical or perpendicular to the ground.

Used in small wind projects and residential applications (2).



wake turbulence
low-level jet
icing
lightning
turbulent wind
gravity
tidal & storm surge depth variation
extreme wave
ship & ice impact
waves
marine growth
buoyancy
currents & tides
soil mechanics
scour
earthquake

ADVANTAGES & DISADVANTAGES

Horizontal Axis

Pros

- Able to produce more electricity from a given amount of wind. Ideal for producing as much wind as possible at all times (2).

Cons

- Generally heavier and does not produce well in turbulent winds (2).

Vertical Axis

Pros

- Produces well where wind conditions are not consistent because it can take wind from any direction (2).

Cons

- Cannot be placed high enough altitude to benefit from steady wind (2).

POWER GENERATION CONCEPTS

Direct Drive vs. Gearbox

Direct Drive

Pros

Less cost on Maintenance (Long Term)

Reduce weight on load

Operates in Lower RPM

Cons

Cost more on front end (PM Generator)

Produces less power

Gearbox

Pros

Cheaper initial cost on generator

Increases rpm

Cons

Significantly higher cost on Maintenance

Heavier Nacelle

External power source

LARGE VS SMALL

Large

Higher and more consistent wind capability

Operate at wider range of rpm

Cons- More expensive

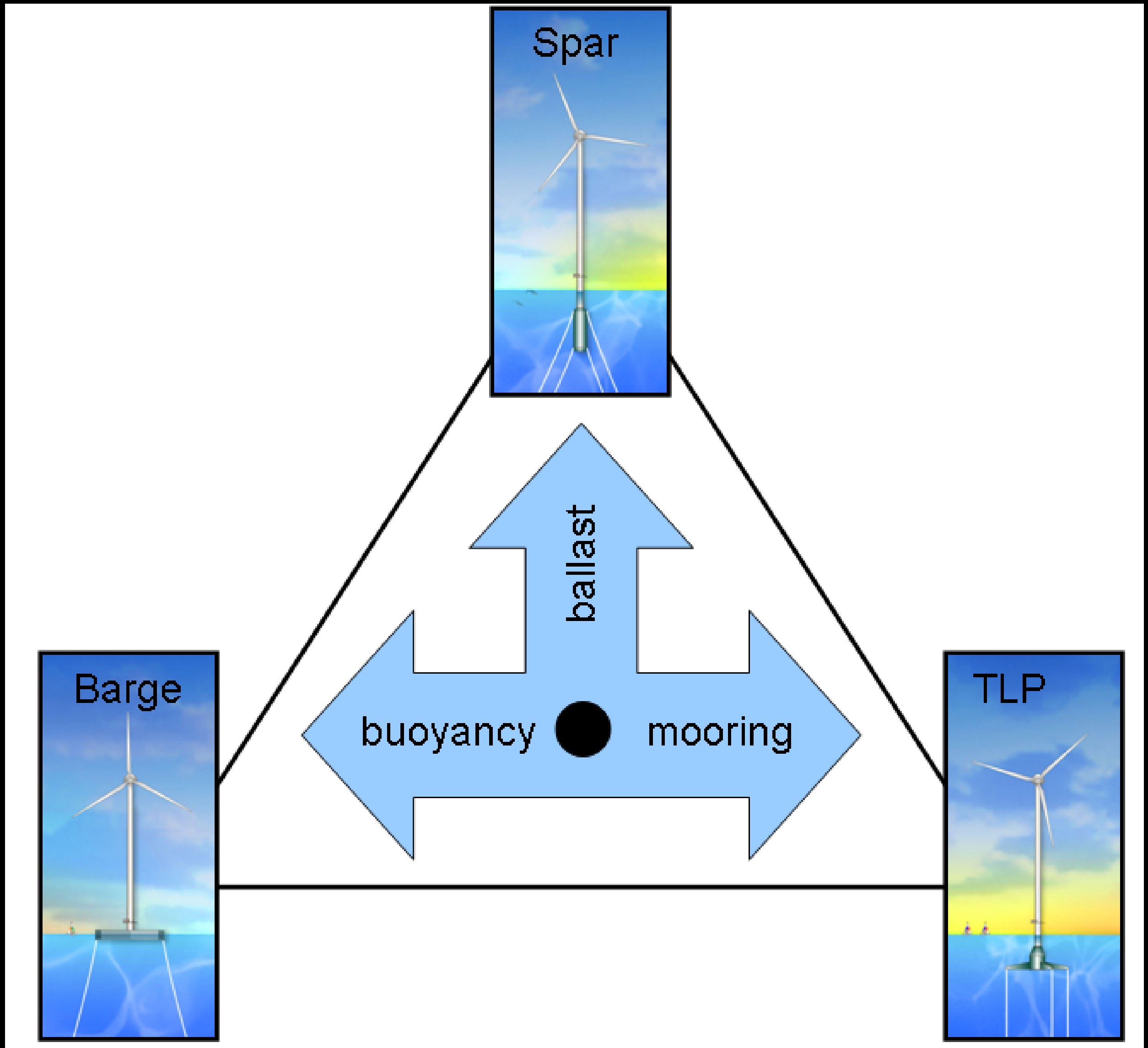
Small

Cheaper to produce

Easier to Maintain and life expectancy longer

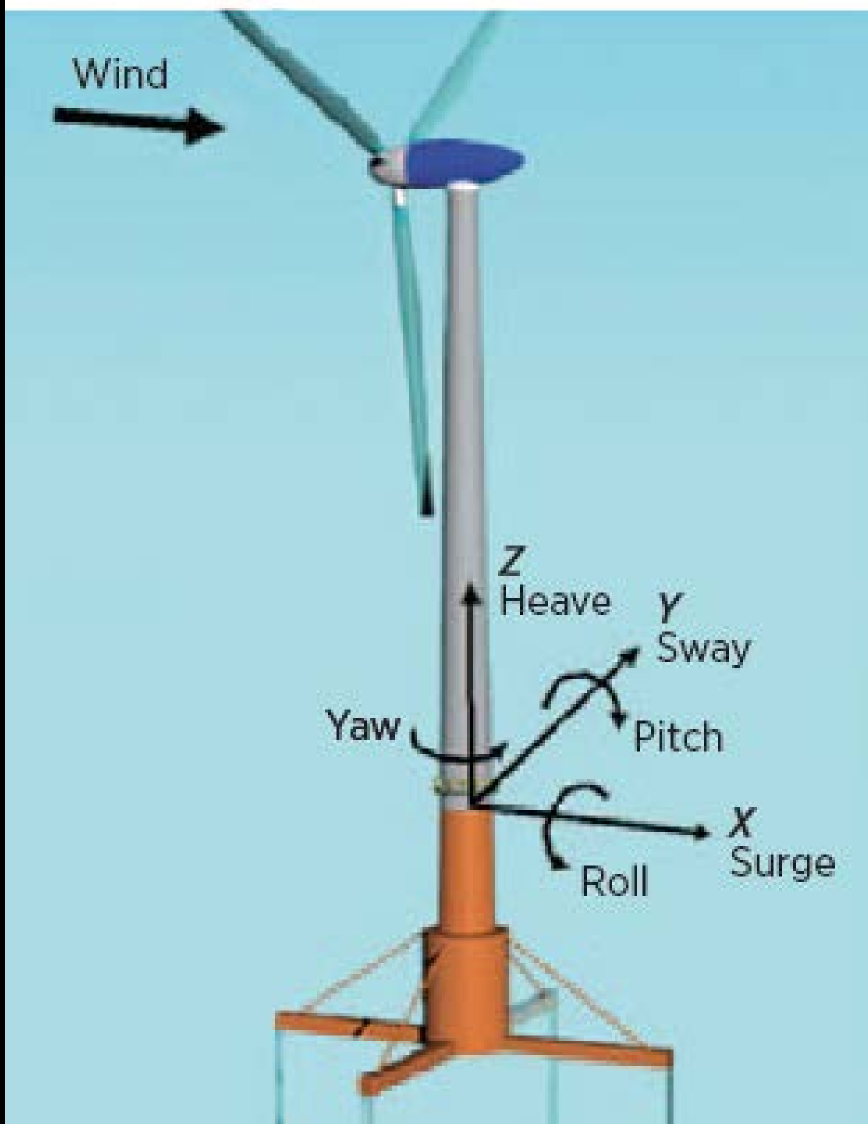
Cons- Lower wind speeds, lower power generation

FOUNDATION CONCEPTS

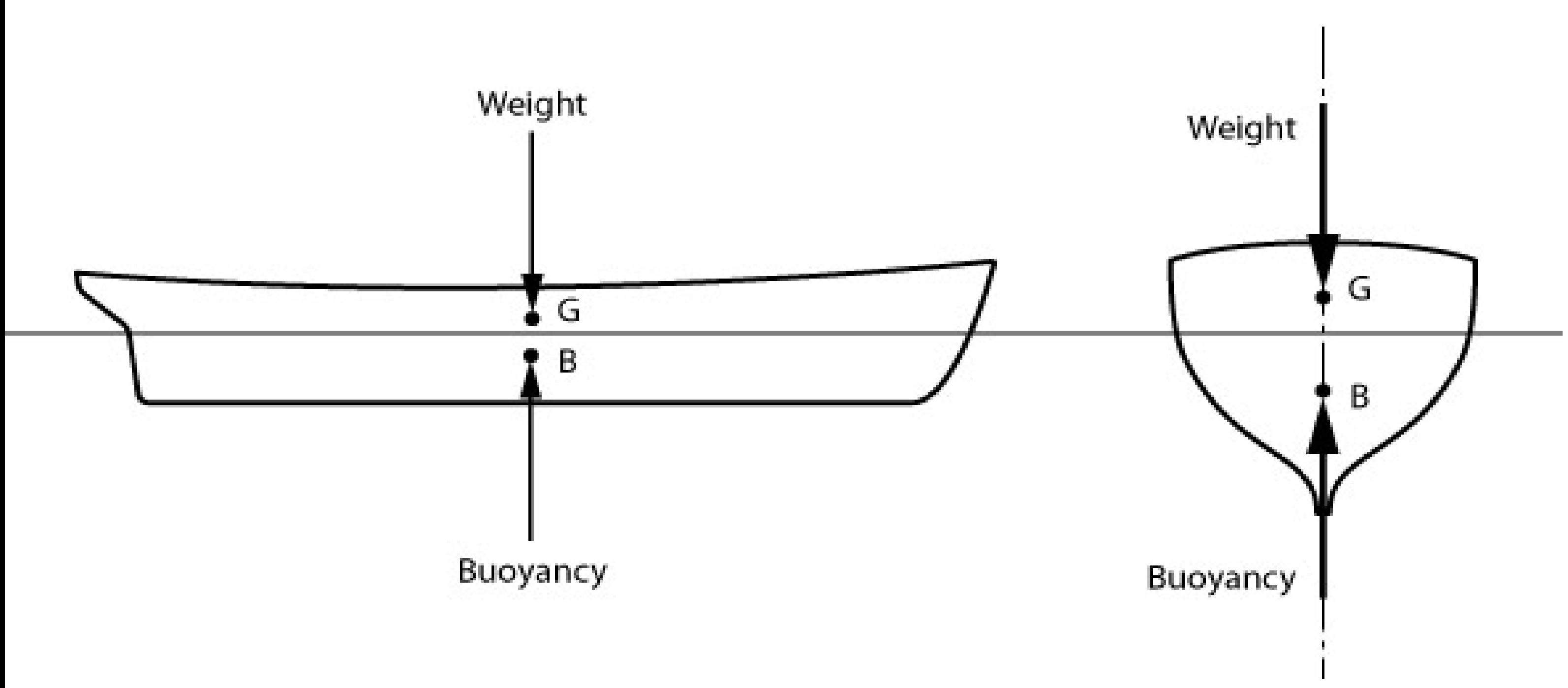


CONSIDERATIONS OF ANY FLOATING FOUNDATION

- Modes of Motion:
- Surge
- Sway
- Heave-up down motion
- Rotational Roll- motion about platform longitudinal axis
- Pitch-the rotational motion about the platform lateral axis.
- Yaw –rotational motion about tower axis

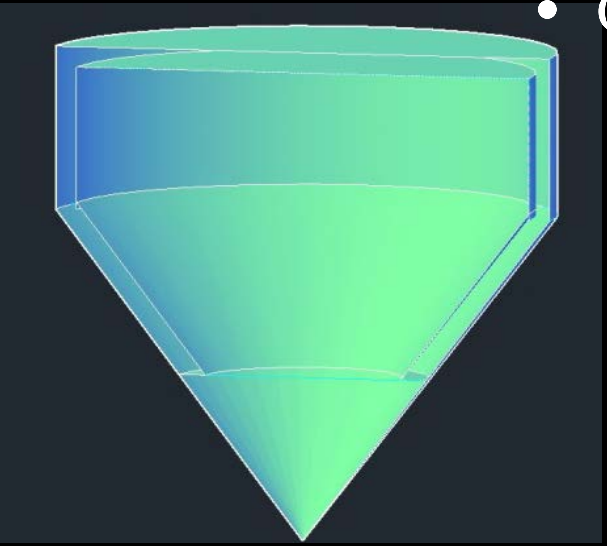


SPAR BUOY



The two forces are equal and opposite for a floating object. For a vessel floating at an even keel or upright, G and B are in the same vertical line from either horizontal axis

SPAR BUOY IDEAS



The profile view displays the cavity, solid base and wall thickness.

- Corrugated Base:
  - Improve stability
  - Reduce lateral movement
  - Allow water to flow through the structure
  - Decreases the effect of waves and tide
  - Anchor system not required to maintain the position
  - Reduce the construction cost.

- Traditionally stabilized by a heavy ballast
- Idea of pendulum to counteract external forces

BARGE CONCEPT

- Ballasted with sea water.
- Moored by a system of eight catenary lines,
- Two of which are 45° apart at the corner.
- Stabilized by buoyancy
- large water-plane area
- resulting great restoring moments when the platform is displaced in heave, pitch, and roll.
- Shallow draft and square shape of the support platform enable easy, inexpensive onshore assembly of the system.

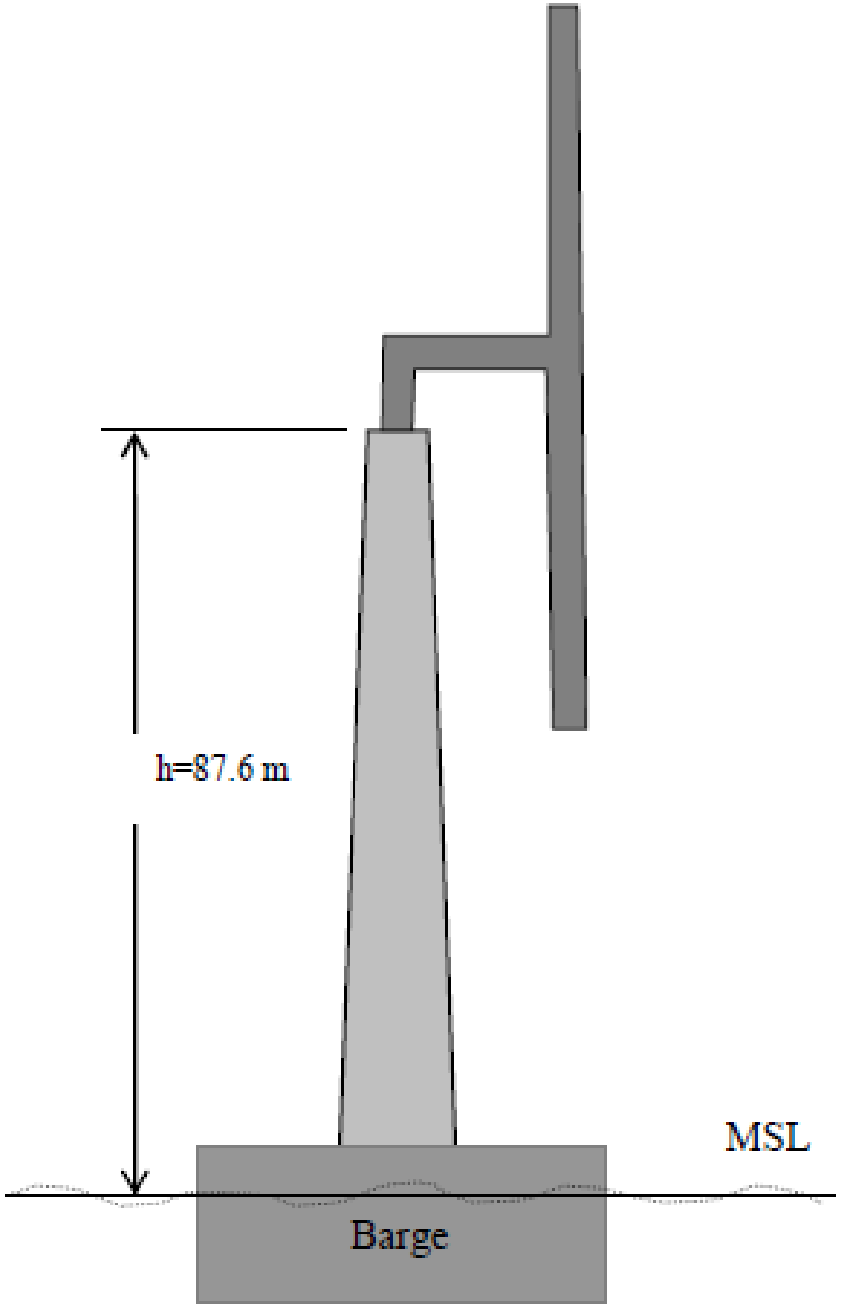
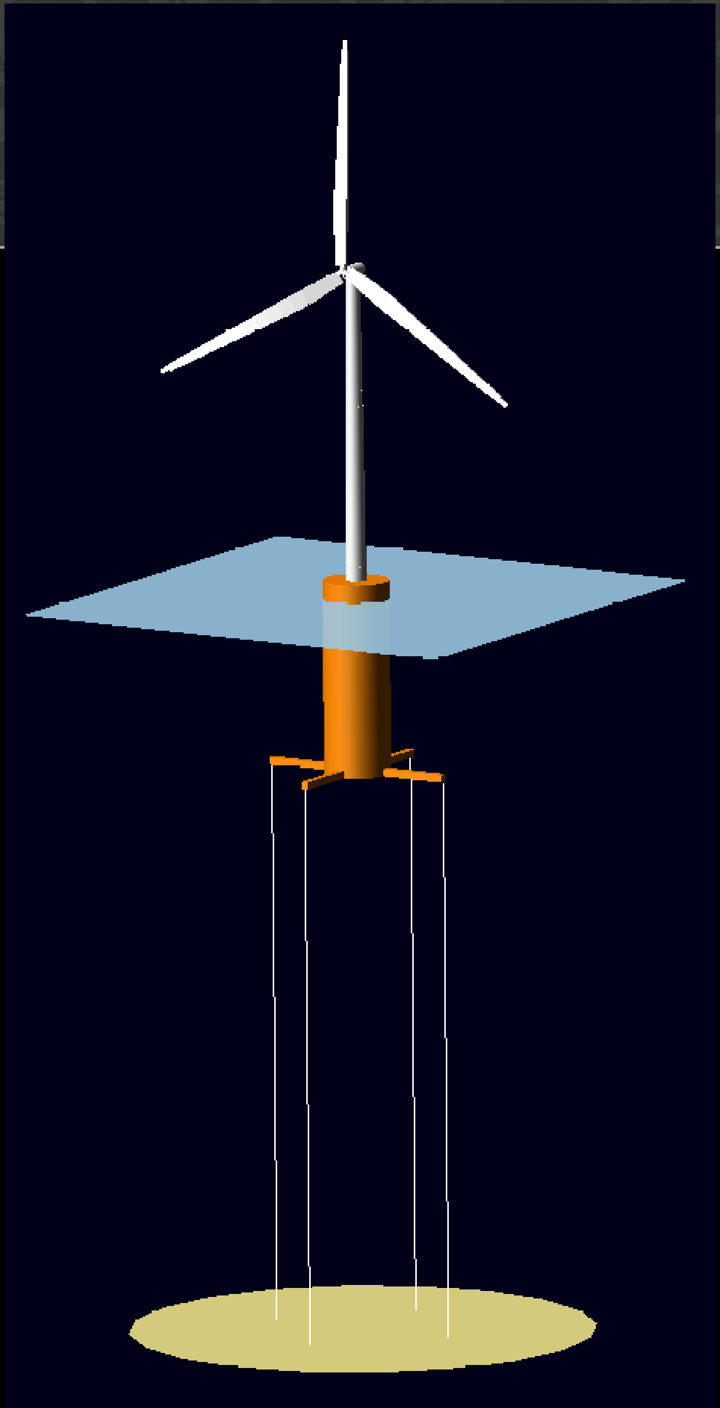


Figure 2. Floating-platform-supported turbine.

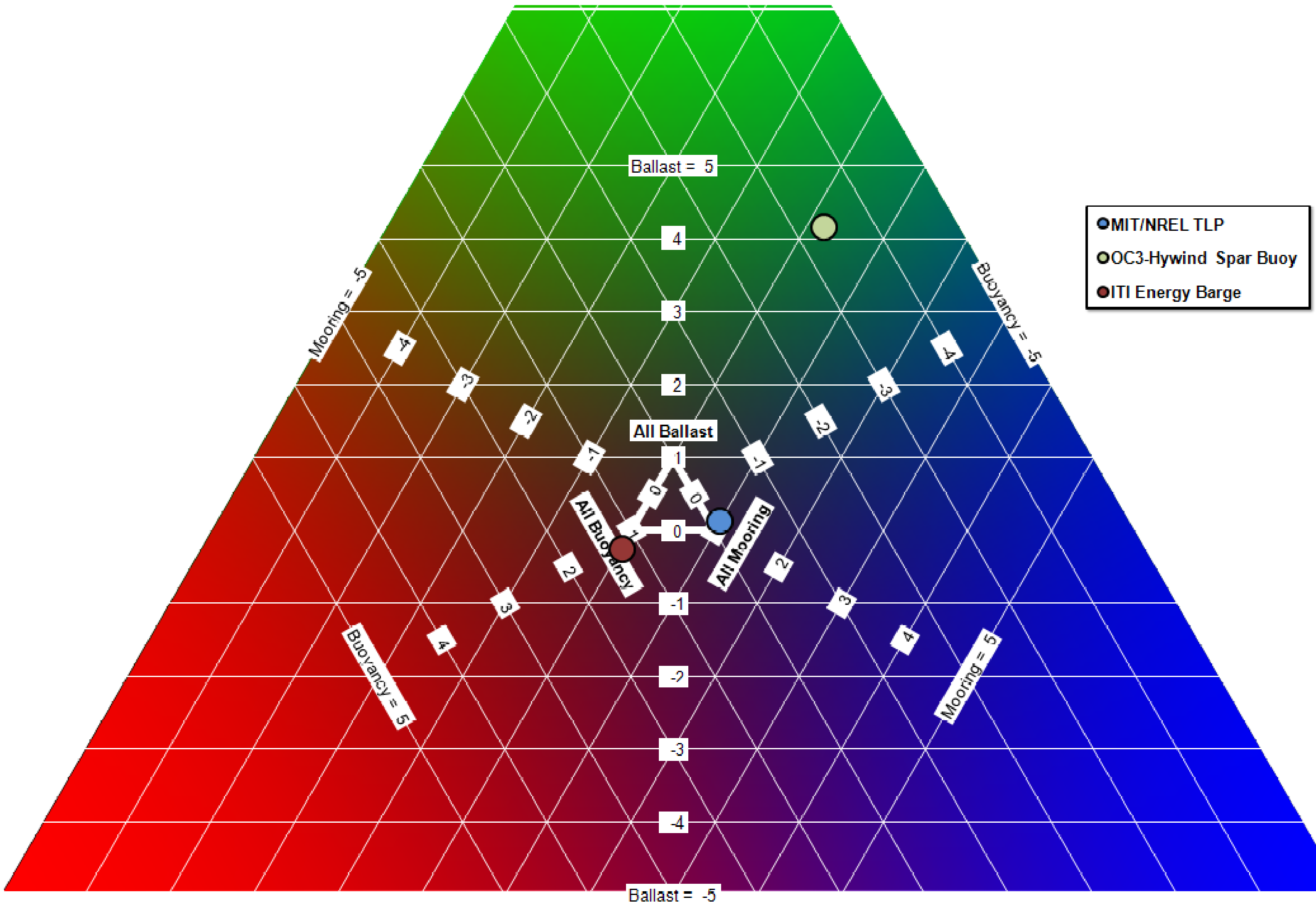
TENSION LEG PLATFORM

System in which which restoring mainly is provided by the mooring system. Therefore, must be equipped with taut mooring lines

TLP has low root mean square (RMS) accelerations and negligible heave and pitch motions.



COMPARISON



Ballast = 5
4
3
2
All Ballast
1
0
-1
-2
-3
-4
Ballast = -5
Mooring = -5
-4
-3
-2
-1
All Buoyancy
2
3
4
Buoyancy = 5
Buoyancy = -5
-4
-3
-2
-1
All Mooring
2
3
4
Mooring = 5
MIT/NREL TLP
OC3-Hywind Spar Buoy
ITI Energy Barge

COST COMPARISON

barge primarily has the advantage that the platform design is easy to manufacture and install. It consists mainly of inexpensive off-the-shelf flat steel panels and can be assembled in almost any coastal facility due to the shallow draft. The slack catenary mooring system allows for a simple inexpensive anchoring system. The stability analysis also showed fewer instabilities for the barge than for the other two concepts.

Spar The analysis of the ultimate and (especially) the fatigue ratios however indicate that the concept, although experiencing significantly less loads than the ITI Energy barge, meets a strong challenge posed by the investigated TLP design. The fatigue ratios—which differ up to one order from the TLP—indicate a great need for improvements in the tower strength or the control system. Additionally, the spar buoy has the disadvantage that it is very deep drafted and could require deep-water harbors for manufacturing and assembly. The amount of ballast needed also adds to total costs. Compared to the TLP, the design has the advantage of a simpler anchoring system, due to the slack catenary mooring and the slender cylindrical body, which results in a small cross-section at MSL, it also has advantages regarding drag forces. The spar's natural frequencies also are very well placed out of the energy-rich wave spectra. Further iterations, economic design analysis, and experimental data will help to clarify the pros and cons of the spar concept, particularly as compared to the TLP.

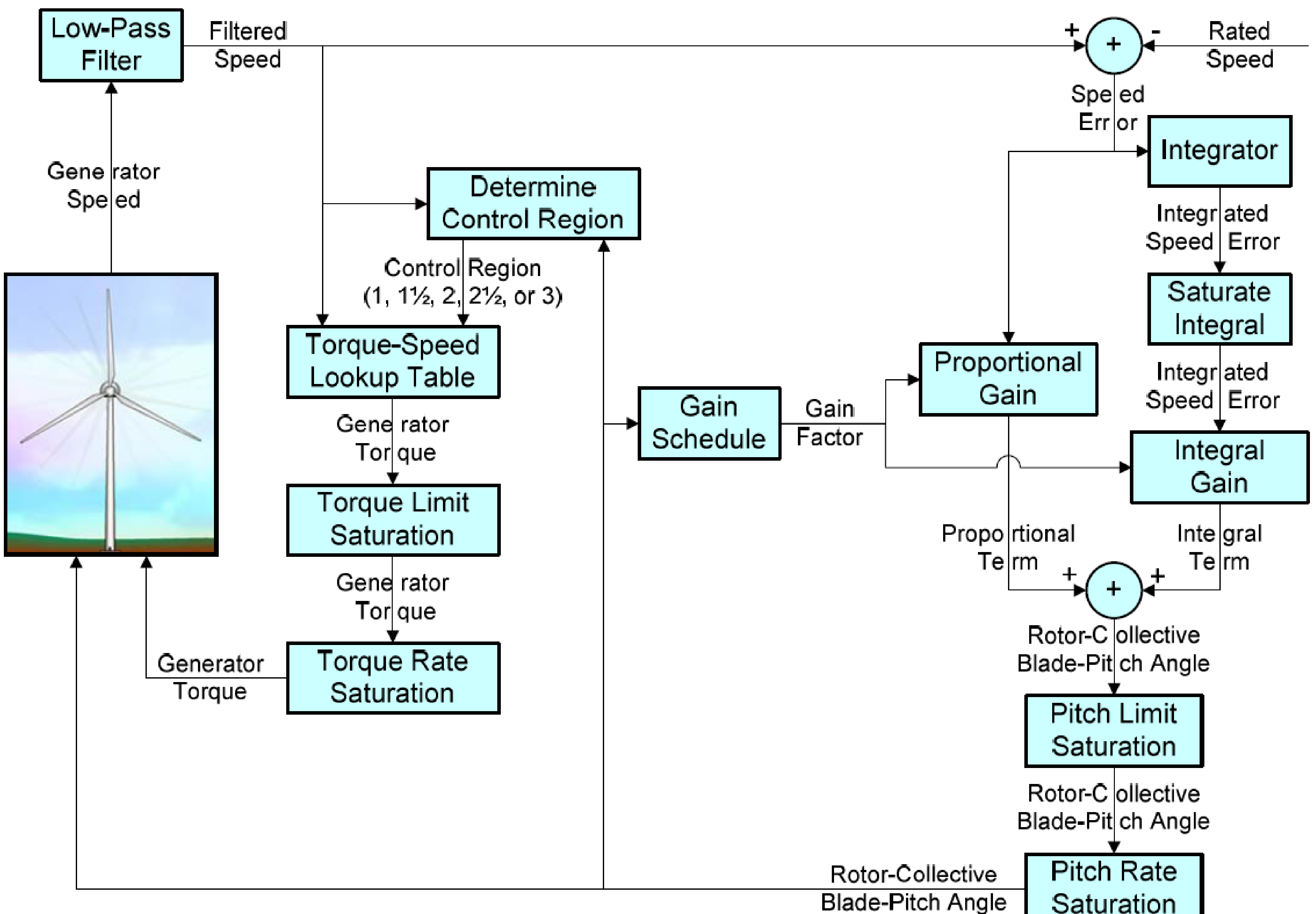
tension leg platform showed the best ratios for ultimate and fatigue loads of all investigated concepts. It is the floating concept closest to the land-based system and therefore requires the least effort for strengthening the turbine, which saves costs. A disadvantage of all TLP designs is the expensive tension leg mooring system and expensive anchors needed. This particular TLP also has the disadvantage of a large amount of ballast and a very high volume of the platform—the largest of all three concepts. The big cross-section at mean sea level also poses a significant obstacle for incident-waves and adds to drag. The long spokes are a source of failure; to build them with the necessary strength requires additional costly material and manufacturing work. Installation also is the most difficult of the three designs because the design is fairly deep drafted, the tension leg anchors are difficult to install, and without adding additional ballast the design is quite unstable without a mooring system (which makes the towing-out process challenging)

TENTATIVE DECISION

Corrugated Spar Buoy

Optimized Tension Leg Platform

Control Systems to Reduce Loads



Low-Pass Filter
Filtered Speed
+
+
-
Rated Speed
Speed Error
Integrator
Generator Speed
Determine Control Region
Integrated Speed Error
Control Region (1, 1½, 2, 2½, or 3)
Saturate Integral
Torque-Speed Lookup Table
Proportional Gain
Integrated Speed Error
Gain Schedule
Gain Factor
Integral Gain
Generator Torque
Torque Limit Saturation
Proportional Term
Integral Term
+
+
+
Generator Torque
Rotor-Collective Blade-Pitch Angle
Generator Torque
Torque Rate Saturation
Pitch Limit Saturation
Rotor-Collective Blade-Pitch Angle
Rotor-Collective Blade-Pitch Angle
Pitch Rate Saturation

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Q&A