USING TOLERANCE ANALYSIS SOFTWARE TO EXPLORE MANUFACTURING ALTERNATIVES

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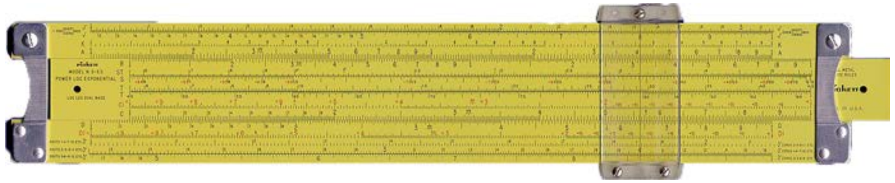
VESTAS BACKGROUND

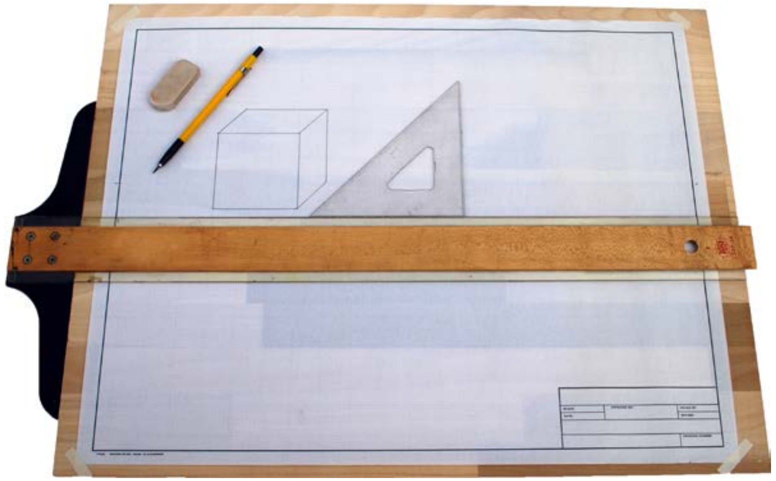
- "World's largest producer and manufacturer of wind turbines … Providing the world with much more green energy production than what we've seen in the past."
- Offshore industry with turbines has been growing over the last 15-20 years. Vestas is one of the pioneers in this area.
  - It's like sending something into space – it must work the first time
  - Going "really, really large scale" and have a lot of good expectations in the offshore industry in the next year or so

HISTORICAL PRACTICES

HISTORICAL DESIGN PRACTICES

- Experienced engineers using “gut feel”
- They did some analyses with spreadsheets but “didn’t really do a lot of documented analyzing. It was very much trial and error.”
- Design engineers define tolerances for new designs based on what was on the drawings for the old.
- Many other companies have similar practices.





RESULTS

RESULTS OF THE LEGACY PRACTICES

- Significant production inefficiencies:
  - Assembly and onsite teams had to do a lot of rework to make things assemble.
  - Manufacturing expectation when setting up the production line for a new design was that a lot of rework and “fiddling” would be needed in the beginning.
  - Cost estimates and schedules were padded to account for expected problems
- Previous issues resolved in manufacturing reencountered when a 2nd source for the the component(s) reintroduced the problem
- Inappropriate reuse - reapplied “legacy” small tolerance caused over ½ year of effort trying to achieve good quality parts before everyone realized that it wasn’t necessary

MOTIVATION FOR CHANGE

- Increased competition mandates that Vestas does not continue to plan around production inefficiencies stemming from details missed during design.
- Vestas is required to use local manufacturing resources when entering new markets.
- New assembly personnel are unfamiliar with the designs and don't have the benefit of years of experience to know how to deal with problems.

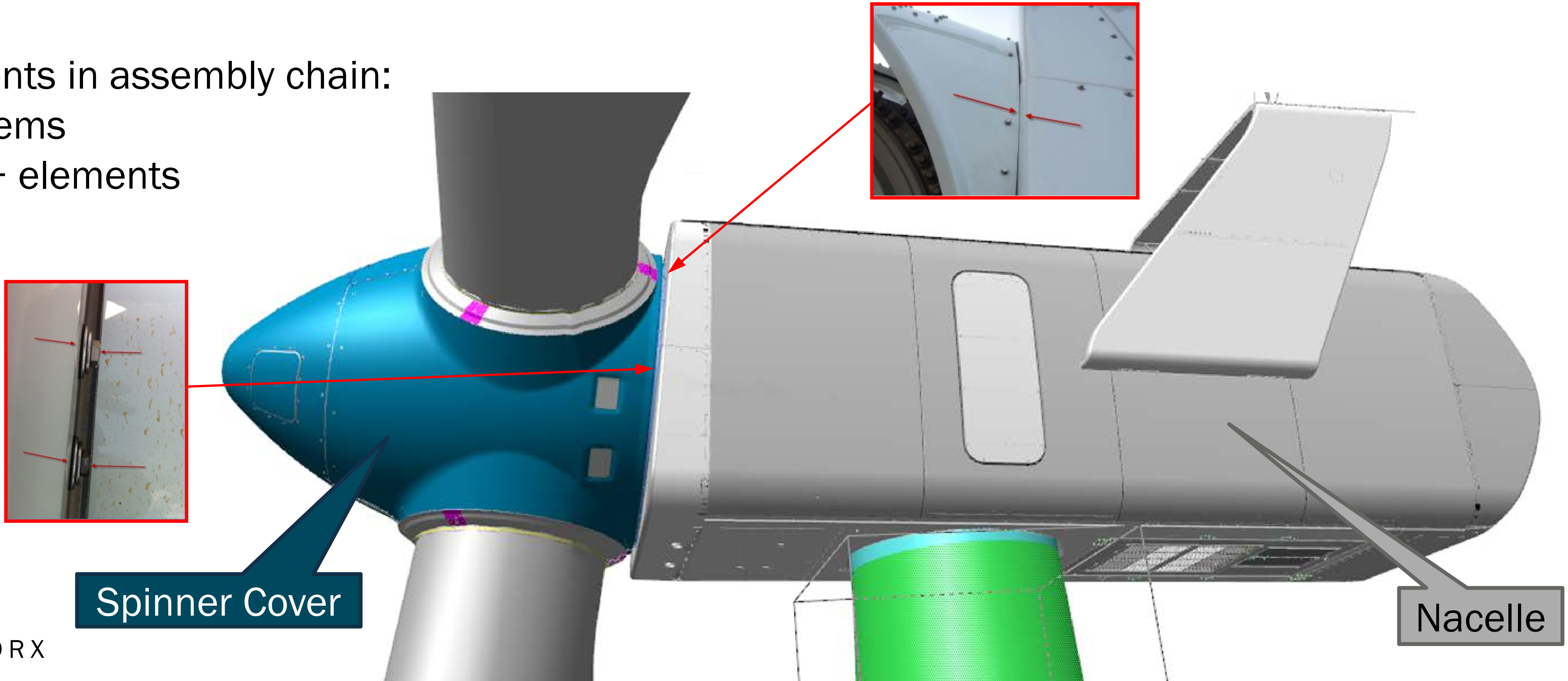
CASE STUDY – SPINNER COVER REDESIGN

Prototype test: Cover assembly of Hub and Nacelle were tested for fit in Lyon.

- When assembled, a collision between Spinner cover and Nacelle covers appeared.
- CETOL 6σ was acquired and used to understand and document the robustness of the spinner design against the intended functionality.

Elements in assembly chain:

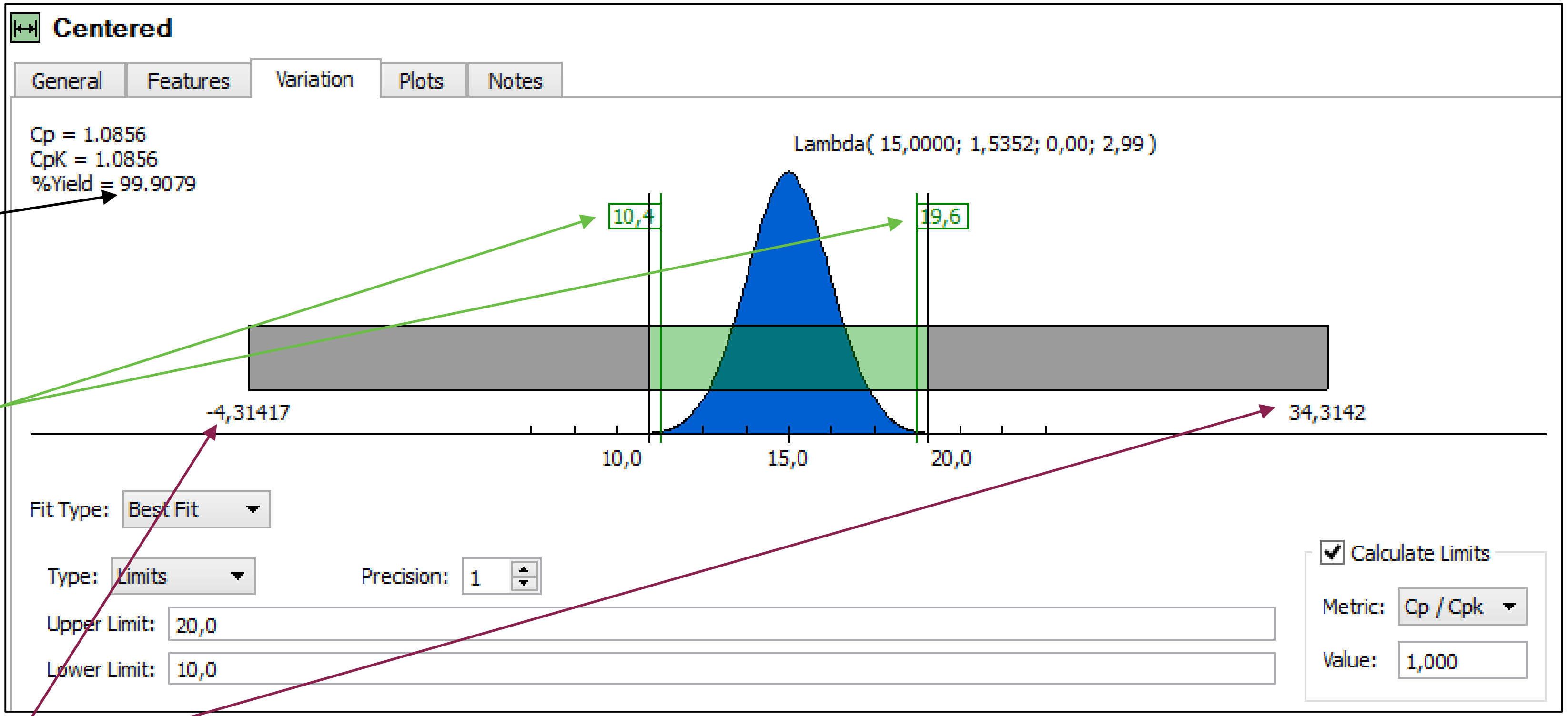
- 7 items
- 15+ elements



FIRST ANALYSIS OF GAP – DESIGN APPEARS ACCEPTABLE

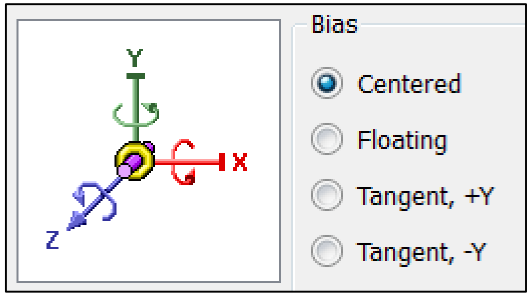
Results:

- Design will achieve requirements of 10-20 mm 99.9% of the time
- Statistical variation is estimated to be between 10,4 and 19,6 mm, or 15 ± 4,2 mm, 99,7% of the time (C_p=1)
- Worst-case variation is between -4,3 and 34,3 mm or 15 ± 19,3 mm



Q: But why did the first assembly have interference (gap < 0)?

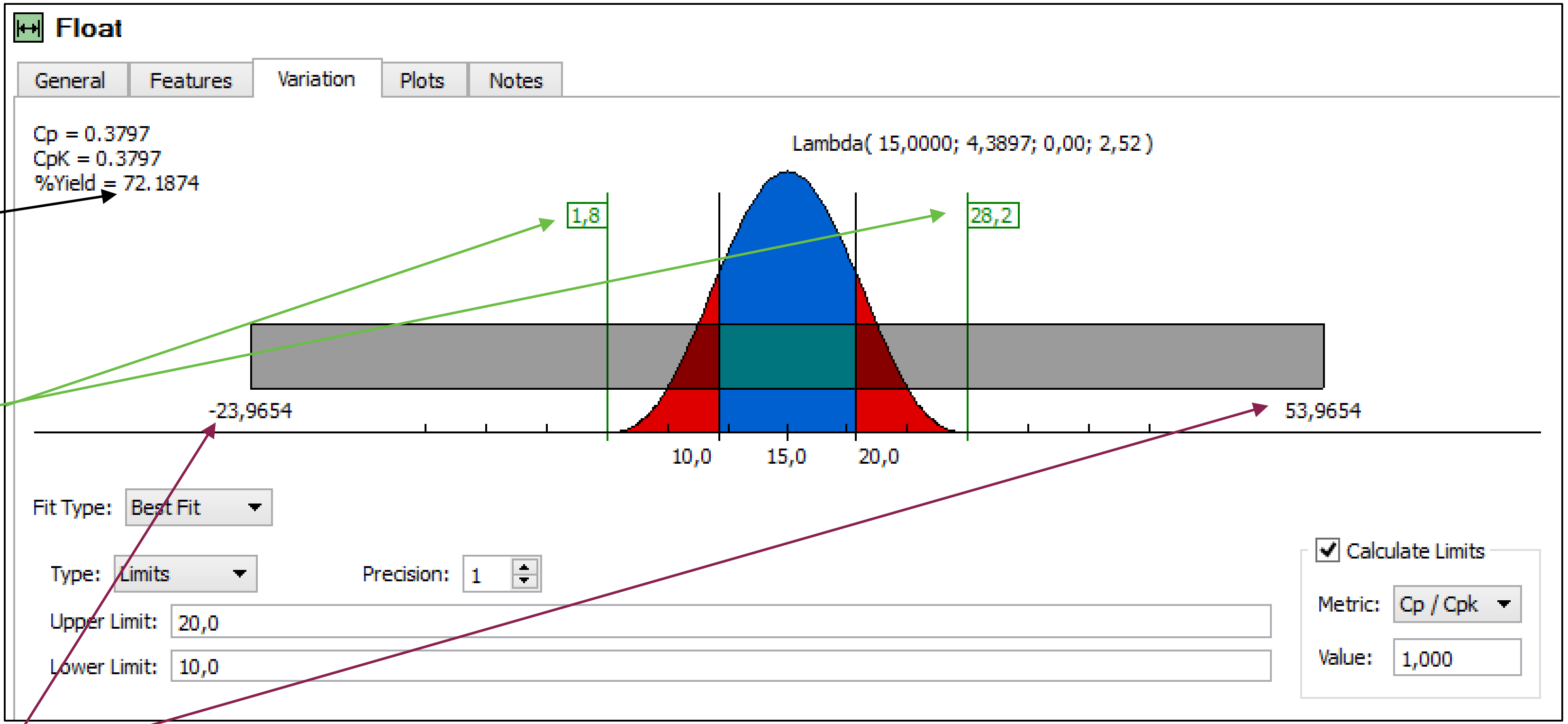
A: Clearances between bolt and holes not considered.



GAP ANALYSIS UPDATED WITH FLOAT OF BOLTED INTERFACES

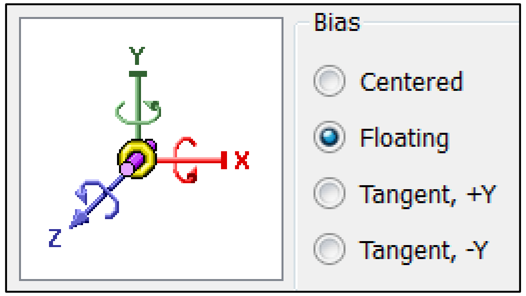
Results:

- Design will achieve requirements of 10-20 mm 72.2% of the time
- Statistical variation is estimated to be between 1,8 and 28,2 mm, or 15 ± 13,2 mm, 99,7% of the time (C_p=1)
- Worst-case variation is between -24,0 and 54,0 mm or 15 ± 39,0 mm



Q: But why did the first assembly have interference (gap < 0)?

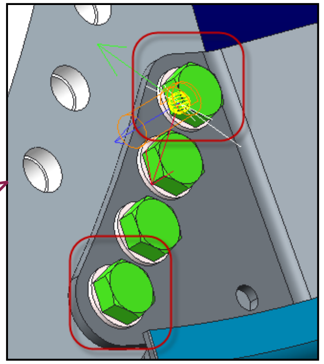
A: More investigation needed.

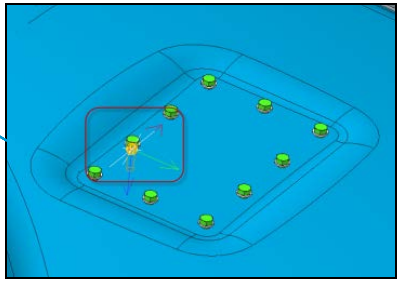


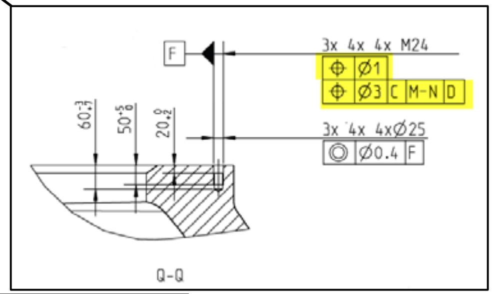
TOP CONTRIBUTORS TO ASSEMBLY VARIATION

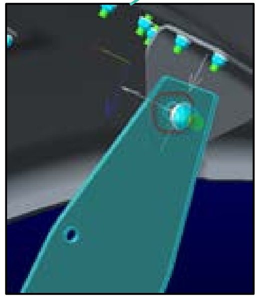
'Float NoSlot' Statistical % Contributions

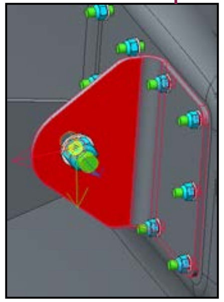
Name	Contribution
Float NoSlot / [illegible]_SPINNER_SHELL_[illegible];1 to [illegible]_SPINNER_SHELL_[illegible];1,3 TY	19,83 %
Float NoSlot / [illegible]_SPINNER_SHELL_[illegible];1 to [illegible]_SPINNER_SHELL_[illegible];1,5 TY	13,19 %
[illegible];1 / [illegible]Hub;1 / Hole1 to C_BracketMate|M|N	10,46 %
Float NoSlot / [illegible]_SPINNER_SHELL_[illegible];1 to [illegible]_SPINNER_SHELL_[illegible];1,6 TY	9,70 %
Float NoSlot / [illegible]_SPINNER_SHELL_[illegible];1 to [illegible]_SPINNER_SHELL_[illegible];1,4 TY	9,60 %
[illegible]_SPINNER_SHELL_[illegible];1 / [illegible];1 / [illegible];1 / [illegible]HubBracket;1 / Hole1 to D|B|C	5,46 %
Float NoSlot / [illegible]_SPINNER_SHELL_[illegible];1 to [illegible]_SPINNER_SHELL_[illegible];1,1 TY	4,46 %
Float NoSlot / [illegible]_SPINNER_SHELL_[illegible];1 to [illegible]_SPINNER_SHELL_[illegible];1,2 TY	4,37 %

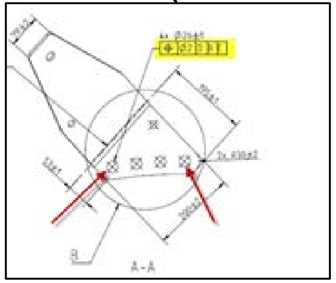


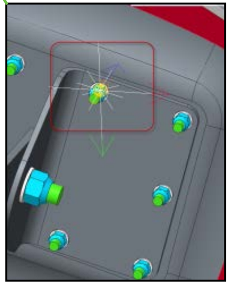








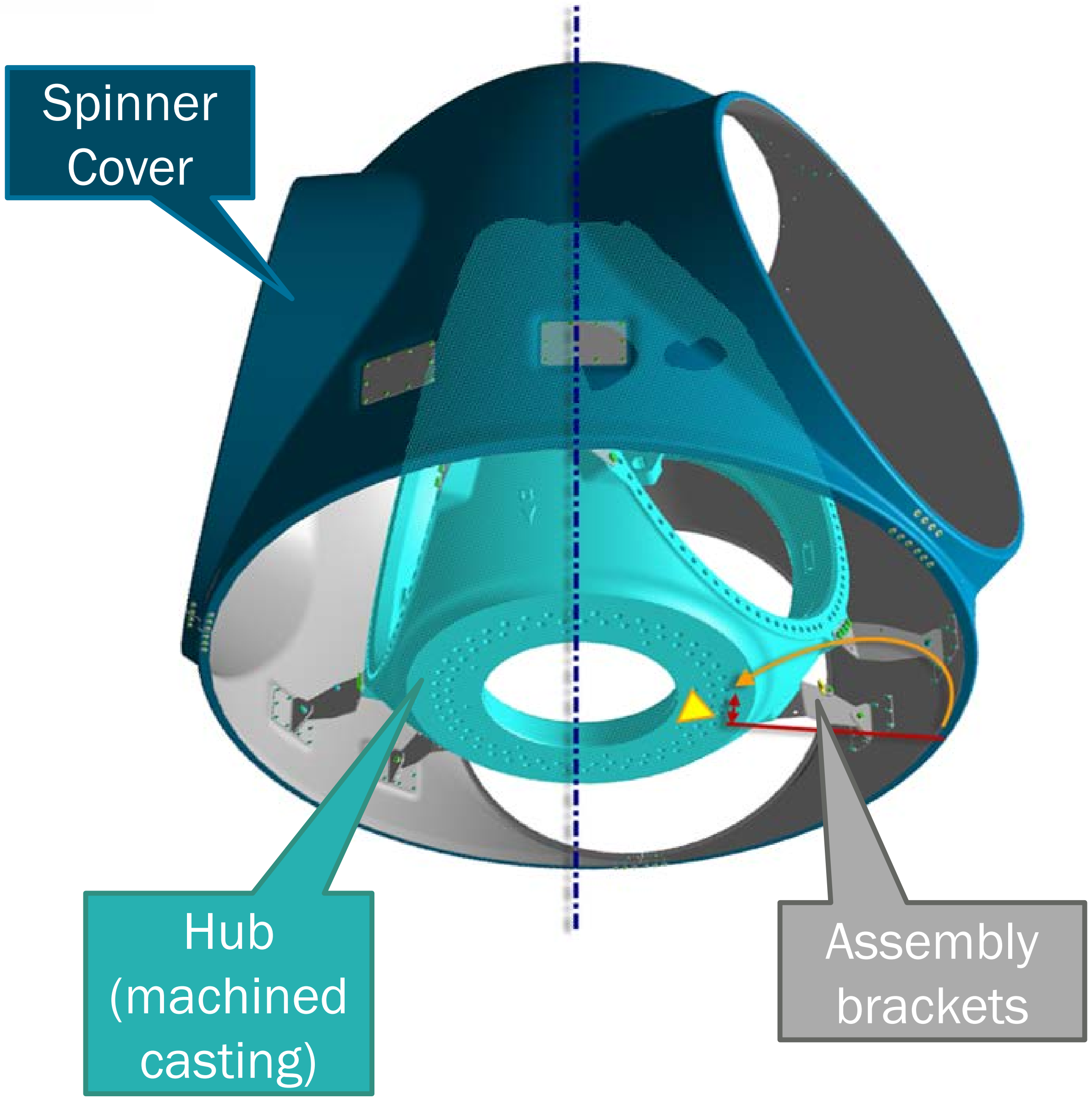




6 of the top 8 contributors to variation in the gap are due to “float” between bolts and holes

INVESTIGATIONS INTO ASSEMBLY TECHNIQUES

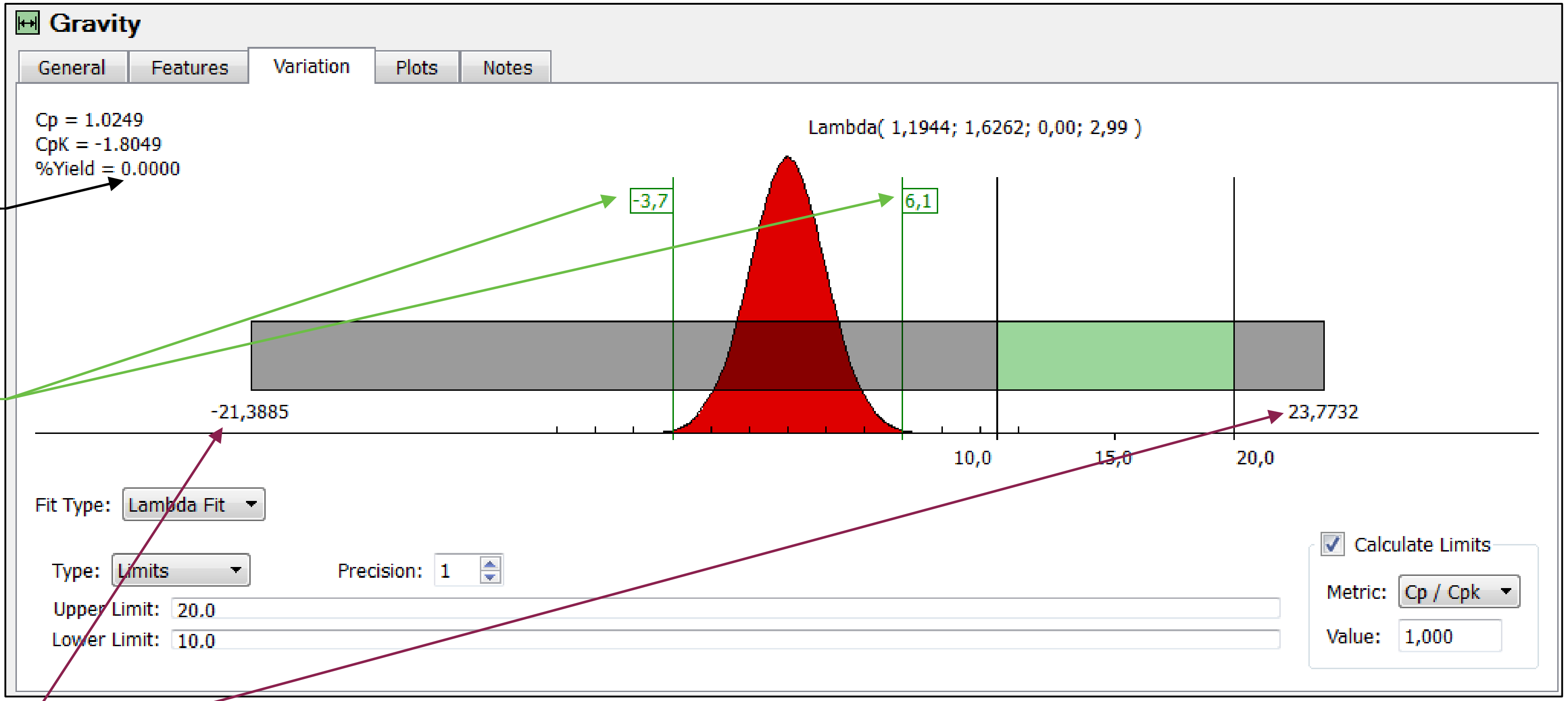
- The spinner cover is assembled to the hub with both in the vertical position as shown.
- Gravity pulls the cover downward during assembly.
- This bias is in the direction of the Nacelle when assembled thus minimizing the gap.



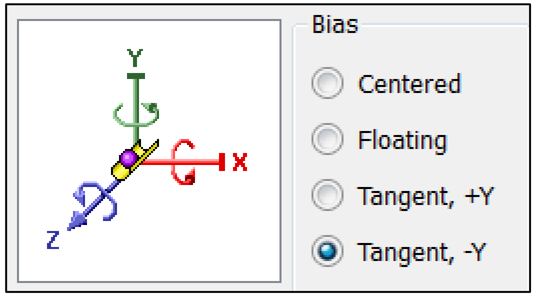
GAP ANALYSIS UPDATED WITH ASSEMBLY BIAS CONSIDERED

Results:

- Design will not achieve requirements of 10-20 mm
- Statistical variation is estimated to be between -3,7 and 6,1 mm, or 1,2 ± 4,9 mm, 99,7% of the time (C_p=1)
- Worst-case variation is between -21,3 and 23,8 mm or 1,2 ± 22,6 mm



Conclusion: Assembly technique is causing 13,8 mm bias in average gap leading to very high probability of interference!



OVERALL ACTION LIST FROM CETOL 6σ ANALYSIS

- 4 parameters considered for actions:
  1. Sensitivities
  2. Contributions
  3. Tolerance cost/size
  4. Chain robustness

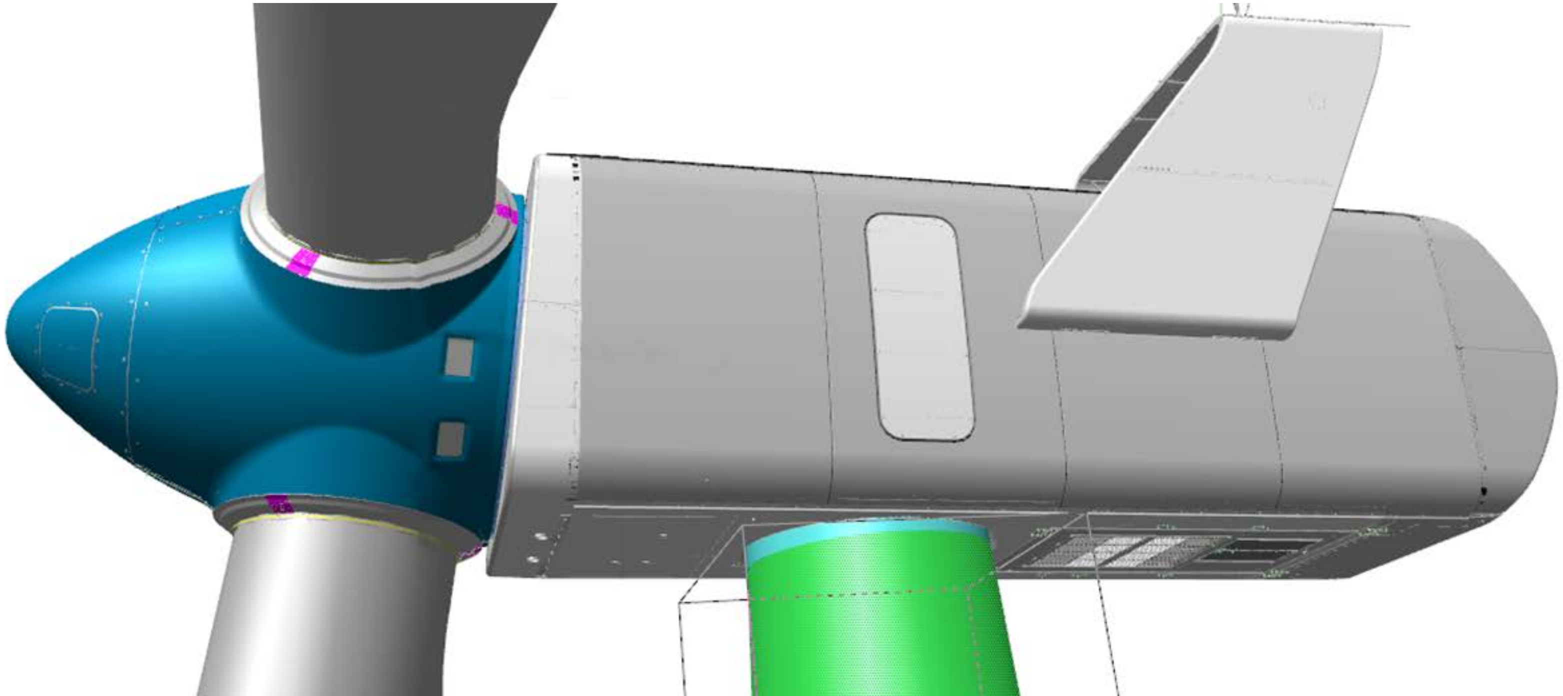
- Actions included both monitoring some dimensions more closely as well as removing CTQ[1] flags

Input				Output
Sensitivity	Var. Contri.	Tolerance size	Tol Chain robustness	Action
High	Low	Cheep (Large Tol)	Poor	Check for errors in model
High	Low	Cheep (Large Tol)	Solid	Check for errors in model
High	Low	Expensive (Small Tol)	Solid	Cost out potential. Evaluate need for CTQ.
Low	Low	Expensive (Small Tol)	Solid	Cost out potential. Evaluate need for CTQ.
Low	High	Expensive (Small Tol)	Solid	Cost out potential. Evaluate need for CTQ.
Low	Low	Expensive (Small Tol)	Poor	Cost out potential. Remove CTQ if any.
High	High	Expensive (Small Tol)	Solid	Monitor to keep quality performance. Consider CTQ
High	Low	Expensive (Small Tol)	Poor	Monitor to keep quality performance. Consider CTQ
High	High	Expensive (Small Tol)	Poor	Monitor to keep quality performance. Consider CTQ
High	High	Cheep (Large Tol)	Solid	No action. Consider CTQ
Low	Low	Cheep (Large Tol)	Poor	No action. Remove CTQ if any.
Low	High	Cheep (Large Tol)	Solid	No action. Remove CTQ if any.
Low	Low	Cheep (Large Tol)	Solid	No action. Remove CTQ if any.
Low	High	Cheep (Large Tol)	Poor	Tighten tol to improve robustness of chain. Consider CTQ.
High	High	Cheep (Large Tol)	Poor	Tighten tol to improve robustness of chain. Consider CTQ.
Low	High	Expensive (Small Tol)	Poor	Tighten tol to improve robustness of chain. Consider CTQ.

[1] *Critcal to Quality*

VESTAS'S CONCLUSIONS

- The design is robust with Centered analysis Cp ≥ 1.
- The major variation giving trouble will come from assembly float under gravity influence.
- As long as assembly happens in vertical position, an assembly fixture is needed to bring spinner cover in nominal position before tightening the bolts.



QUESTIONS?

All images courtesy of Vestas Wind Systems A/S

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