Tower Systems for Small Wind Turbines

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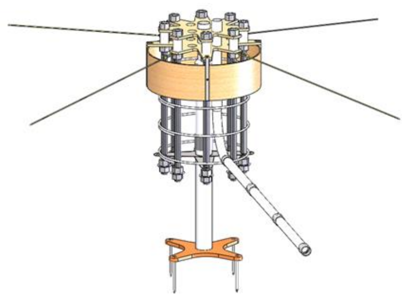
AnemErgonics … about us

- Taken from the Greek language "AnemErgonics" literally means "wind energy."
- Company established in 2005 to assist Skystream beta customers with foundation needs.
- Subsequently commissioned to develop innovative foundations to reduce installation costs.
- Commercialized SMarT Foundations to serve the U.S. small wind turbine industry.
- Received DOE SBIR support to develop innovative SMarT Towers.
  - ✓ *SMarT = Simple Modular Technology.*
  - ✓ *SMarT Foundations™ and SMarT Towers™ pre-date the SMART Wind Consortium!*

What we do

- Only monopole towers.
- To date, only SDWTs (small DWTs) up to about 5 kW.
- Sell, ship and support SMarT Foundations.
- Sell, ship and support SMarT Towers.
- Developing a family of steel towers for those turbines whose dynamics require that solution.

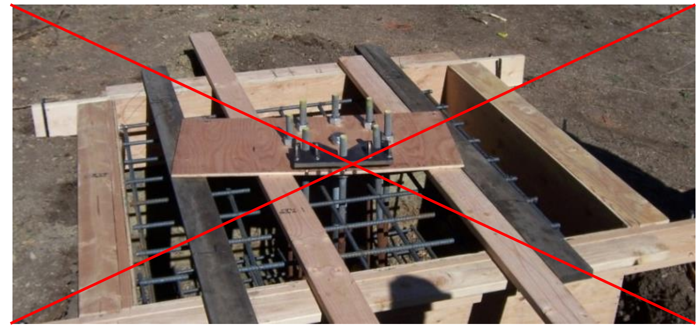


Why we do it

- Monopole tower systems, including assembly and erection, can easily be 50% of the Initial Capital Cost for a small wind turbine.
- Examples of significance.
  - ✓ Wind load on 60' Skystream 3.7 tower is 37% to 52% of the total tower base moment.
  - ✓ Wind load on 60' Pika T701 tower is 53% to 68% of the total tower base moment.

Manufacturing
SMarT Foundations™ (U.S. patented)

- Why?
  - ✓ Mat foundations viable almost anywhere.
  - ✓ Traditional construction is tedious and expensive.
- Features of this solution.
  - ✓ No forms are needed.
  - ✓ Eliminates rebar mats.
  - ✓ Uses fiber-reinforced concrete.
  - ✓ Convenient kits ship UPS or FedEx.
  - ✓ Pre-engineered and readily stamped.
  - ✓ Detailed instructions and drawings provided.
  - ✓ Small footprint and easy re-vegetation.
  - ✓ 120 mph design for 97% of U.S. locations.
  - ✓ Adaptable to all frost depths in the U.S.
  - ✓ Installed in 40 U.S. states & 10 offshore locations.
  - ✓ Saves at least 20% materials and 50% labor.
  - ✓ Saves $1,100 for Skystream 3.7 on 45’ tower.
- Barrier: foundation size is currently limited!



Manufacturing SMarT Towers™

- Specialized, "imported" manufacturing technique.
- Composite shafts + ductile iron castings.
- Less expensive than made-in-the-USA steel towers.
- Considerably lighter than steel monopoles.
- Easier and less expensive to ship, install and erect.
- Tilt-up with inexpensive gin pole and winch.
- Lower drag coefficient.
- Any color any time.

AnemErgonics test site at NWTC

Manufacturing Challenges (not barriers)

- Simple, reliable and precise slip fits of tower joints.
- Good quality hot-dip galvanizing of castings.
- Dependable manufacturing quality.

Non-Manufacturing Challenges

- Acceptance of non-traditional deflections.
- Overcoming entrenchment by DWT manufacturers.

Skystream Tower Deflections During Operation

More on Manufacturing Challenges
Quality Assurance by Non-Destructive Inspection (NDI)

- Nominal cost of effective NDI system is $50,000.
- Requires special training.
- Requires routine calibration and maintenance.
- Several hours to inspect typical structure.
- Unknown probability of “misses” – perhaps 25%.
- Reality: what to do about the inevitable deflects.
- Conclusion: not really practical for composite towers (or blades???).

AnemErgonics’ manufacturing issues are “challenges” not barriers.

Many such “challenges” are unique to a specific manufacturer.

I find it difficult to inform the development of a roadmap for addressing <u>generic</u> manufacturing gaps and barriers.

But, while I have the podium ….

- Let’s inspect the elements of a DWT support structure.
- Let’s scrutinize the critical issues regarding DWT support structures.
- Let’s see which of these critical issues affect all stakeholders.

Elements of a DWT support system

- Tower and foundation.
- Erection equipment.
- Maintenance system.
- Manufacturing processes.
- Quality assurance processes.
- Convenient, affordable tool set.
- Availability solution.
- Shipping solution.

Needs a "System of Systems" Solution

Critical DWT support system issues

- Getting the design right.
  - ✓ Do I have the correct loads?
  - ✓ Do I know and understand the applicable standards?
  - ✓ Have I modeled the interface between the tower and turbine?
  - ✓ Do I correctly understand the system dynamics?
  - ✓ Have I accommodated the system dynamics?
- Design for manufacturing.
  - ✓ Do I have the right vendors?
  - ✓ Can components be economically shipped?
  - ✓ Can the tower be effectively installed and maintained?
  - ✓ Is my quality assurance system workable?
- Have all the logistics issues been addressed and resolved?
- Can I deliver it in a reasonable time and at a reasonable price?

Gaps & Barriers Affecting All Stakeholders – Standards

With respect and gratitude to the folks at Rohn and other TIA-222-G committee members that labored on the proposed standard …..

- Note: tower systems are governed by civil-structural standards, not IEC 61400-2.
- IBC, TIA, ASCE, AISC, AASHTO, ACI ...
- These were developed without much input from wind-energy experts.
- May be unaware of our unique issues.
- May be unaware of insights, approaches and solutions developed by others over decades.
- May be unnecessarily conservative.
- Leave little room for innovation (P.E.s are not risk takers).
  - ✓ What industry prospers without innovation?
- Are difficult to change; they have a long cycle time.
- From my perspective:
  - ✓ DOE, NREL, AWEA and the DWT industry have not sufficiently engaged in DWT support-structure standards development.
- **Action opportunity** for SMART Wind Consortium.
  - ✓ Have the right people on the standards committee.
  - ✓ Have a harmonized IBC/AWEA Small Wind Turbine Support Structures standard.

Connection between Manufacturing and Standards
AnemErgonics Innovative Manufacturing of Composite Towers

- Case Study #1: Tower top deflection.
- Standards attempt to ensure adequacy by specifying maximum tower top deflection.
- The two critical criteria, strength and system dynamics, are not directly addressed.
- Metric can be false positive (standard says YES but structure fails.)
- Metric can be false negative (standard says NO but structure performs safely).
  - ✓ Example: AnemErgonics SMarT Towers are proven but may not meet deflection criteria.
- Furthermore …
  - ✓ What method is used to calculate deflection? Is that method accurate?
  - ✓ Suppose I have field measurements? Do field measurements prevail or the prescribed calculation method?

- Case Study #2: Tower self-load (wind load on the tower).
- TIA 222-G (ASCE) specifies tower drag coefficient based on cross sectional shape.
- Wind tunnel tests of SMarT Towers indicate 33% reduction in drag coefficient compared to galvanized steel towers. But the standard does not allow
- Therefore, tower and foundation are overdesigned by approximately 15% and ….
- Gotcha! We can't use the demonstrated lower drag coefficient calculate tower top deflection.
- So …. we add more material ($$$) to meet unnecessary constraint.

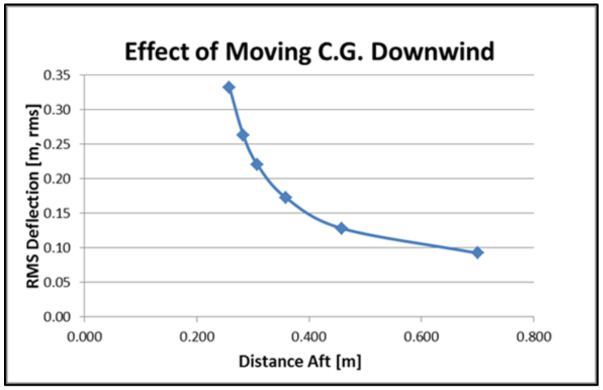
Innovative manufacturing can be thwarted by other considerations.

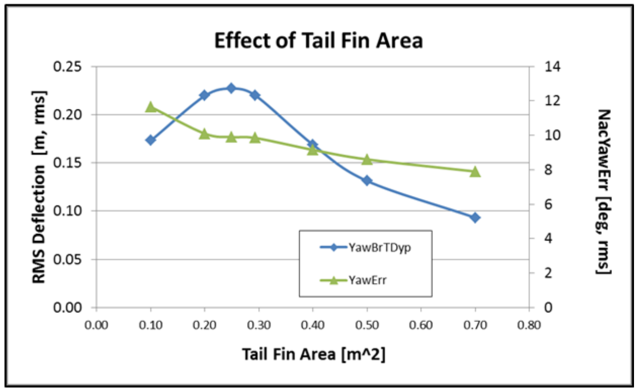
Gaps & Barriers Affecting All Stakeholders – System Dynamics

- Some designers use IEC simplified loads with large safety factors.
  - ✓ May be overly conservative (IEC x IBC Safety Factors = 3.0 x 1.6 = 4.8 on loads).
  - ✓ No assurance that system dynamics and fatigue life are acceptable.
- Aero-elastic modeling, typically FAST, is much preferred, but:
  - ✓ Requires skilled user and detailed, accurate input data.
  - ✓ Still, no assurance that system dynamics and fatigue life are acceptable.
- Typical approach – tower natural frequency must avoid rotor forcing frequency.
  - ✓ Predicting tower natural frequency is not a slam dunk.
  - ✓ Different methods yield disparate results.
  - ✓ Incongruous results with and without head weight.
  - ✓ Incongruous results for 1st and 2nd modes.
  - ✓ Typical 10-15% exclusion from blade forcing frequency may be insufficient.
  - ✓ Yawing, furling and tower wake may also be forcing issues.

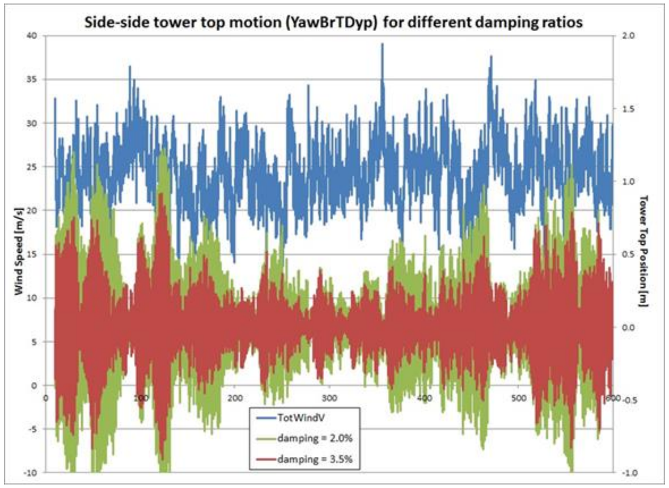
Examples of system-dynamic modeling (but are predictions accurate?)

- Tower top RMS deflection depends on tail geometry (courtesy of Pika Energy)





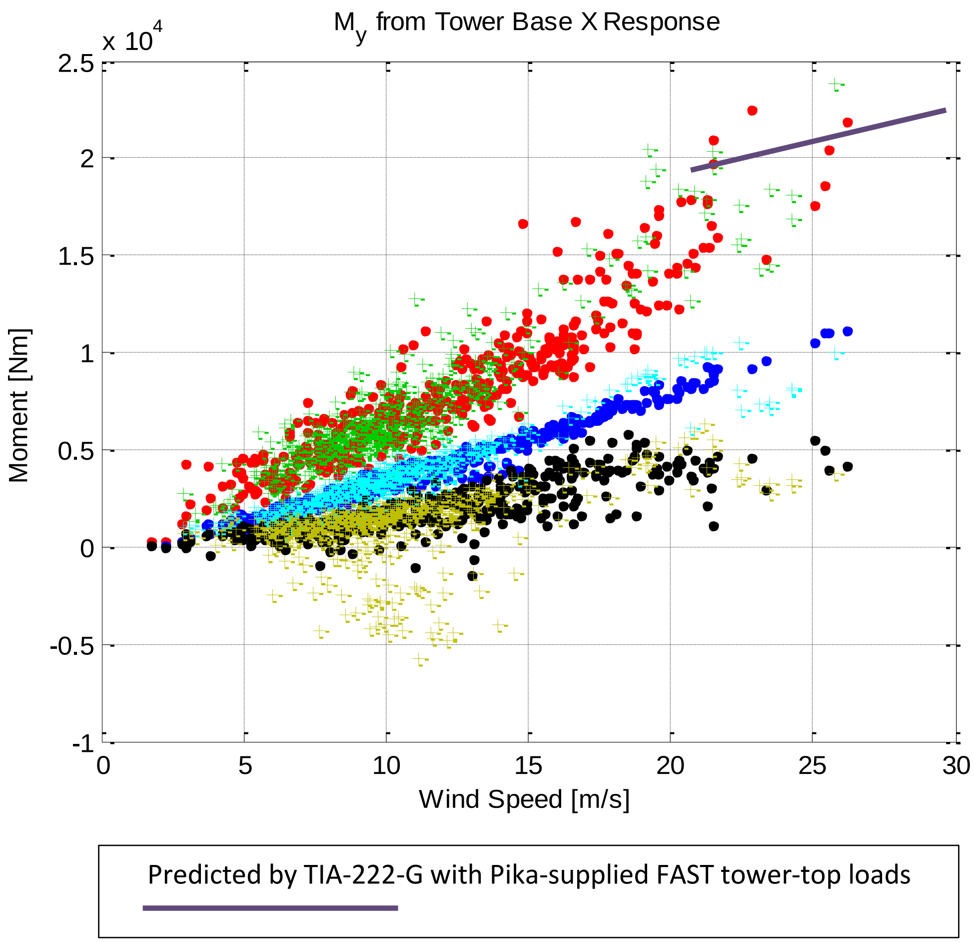
- Tower top RMS deflection depends on damping ratio (courtesy of Pika Energy)



Gaps & Barriers Affecting All Stakeholders – More on System Dynamics

- FAST disparities.
  - ✓ With better information than most designers our design team still has troubling issues.
  - ✓ No FAST version models both tower self-loads and tail behavior.
  - ✓ Uncertain prediction of tower natural frequencies (BMODES).
  - ✓ Disagreement between predicted and observed side-to-side deflections.
  - ✓ Uncertainty regarding predicted and measured tower base moments.
- What we can and cannot do.
  - ✓ Cannot test every tower + turbine combination – too time consuming and expensive.
  - ✓ Can model proposed tower + turbine combinations if designers develop FAST models and these models are reliable.
- **Action opportunity** for SMART Wind Consortium.
  - ✓ Promote development of better FAST models that are inclusive of anticipated DWT designs.
  - ✓ Promote a robust NREL validation study comparing predicted to measured structural performance; disseminate guidelines for the use of improved FAST models.
  - ✓ Promote the development of a fatigue analysis method that does not break the bank of DWT developers.

Illustration regarding loads prediction; <u>we need more of this</u>!



Comparison of NWTC-Measured Tower Base Moments to Calculations According to TIA-222-G

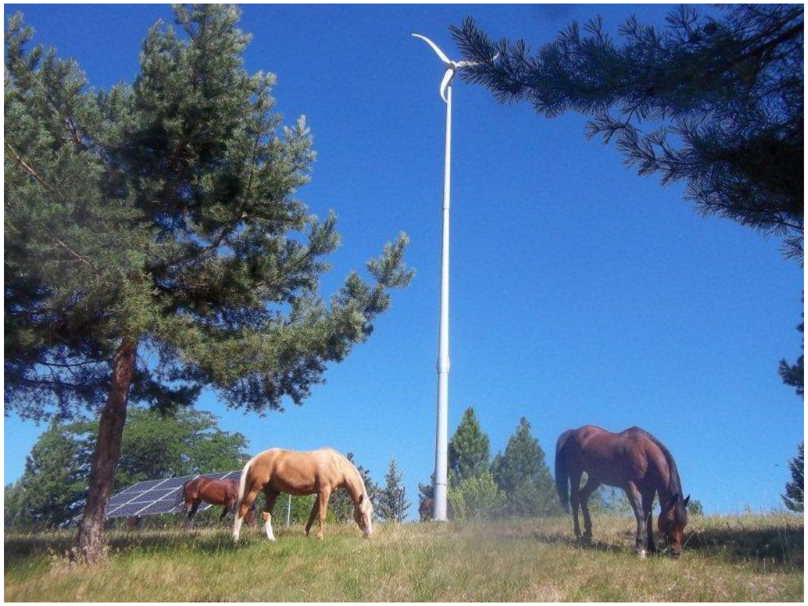
Gaps & Barriers Affecting All Stakeholders – Fiber Reinforced Concrete

- Fiber Reinforced Concrete (FRC) has significant cost-saving potential for DWT foundations.
  - ✓ How large can the foundations be?
- FRC is on a path to greater acceptance.
  - ✓ Tunnel linings.
  - ✓ High-strength airport runways.
  - ✓ Blast-protected bunkers.
  - ✓ Very large building slabs.
- Why not also DWT foundations?
- **Action opportunity** for SMART Wind Consortium.
  - ✓ Identify the obstacles to expanded use of FRC.
  - ✓ Work with P.E. community to identify a path to greater acceptance.
  - ✓ Engage industry trade groups and standards-writing committees.
  - ✓ Fund the necessary analyses and tests.



Summary of Gaps, Barriers and Actions Affecting All Stakeholders

- More extensive use of fiber-reinforced concrete can benefit the industry.
- Suitable standards are very important.
- Reliable system-dynamic modeling capability is crucial.
- If these two last issues are dealt with poorly, then advanced and improved manufacturing of DWT support structures is not going to matter.



Skystream 3.7 on 51’ SMarT Tower, Nolan Wind, Colfax, WA

Pika T701 on 70’ SMarT Tower, Pika Energy, Westbrook, ME