Georgia Institute of Technology

Small Wind Turbines Mounted to Existing Structures

Partial Fulfillment of Masters Degree

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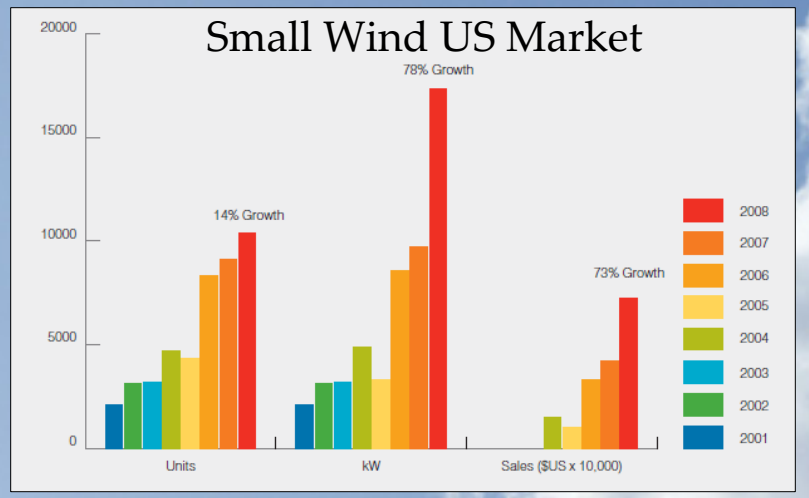
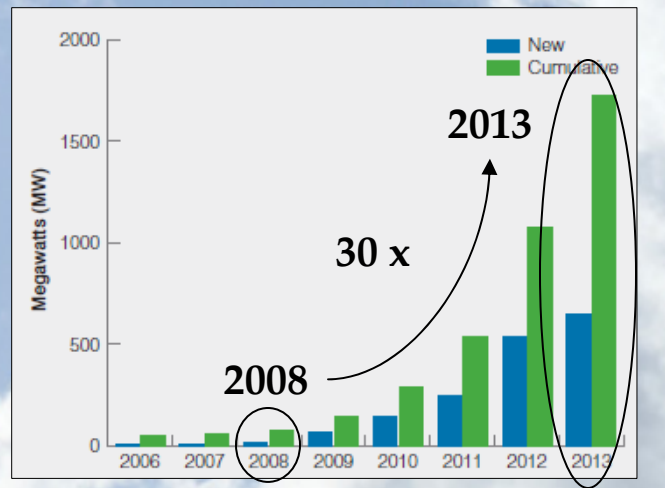
Small Wind Explosive Growth

- Small wind is defined as <100 kW
- The US market for small wind turbines was $77 million in 2008
- Up 73% from 2007
- In 2008 the US Congress introduced a new 8 year 30% federal tax credit for small wind
- American Wind Energy Association (AWEA) predicts a 30 fold growth for small wind from 2008 to 2013



US Small Wind Installed Power



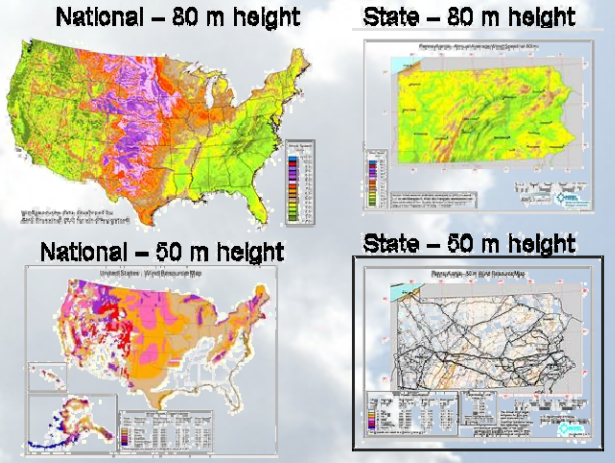
Ref. 1

Current Urban Mounted Small Wind Turbines

- Urban mounted wind turbines have become very popular in recent years
- They do not require a large, dedicated pole
- Large poles comprises 40-50% of the small wind system cost
- Urban mounted wind turbines are easy to install
- However ….
  - Winds in urban areas are generally turbulent and hard to predict
  - Urban wind resources are scattered and hard to find
  - Studies have shown that small wind turbines mounted in urban areas have under performed their rural counterparts

Current Wind Resources

- Current wind speed database is tailored for larger wind turbines at 150-250 ft (>100 kW)
- Low wind speeds in urban areas are hard to predict because of the turbulent urban boundary layer
  - Correction factors for urban mounted wind turbines exist
  - Rules of thumb for mounting small wind turbines in urban areas exist
- Wind measurement is the only way to ensure viability for a given urban location



Wind measurement data:

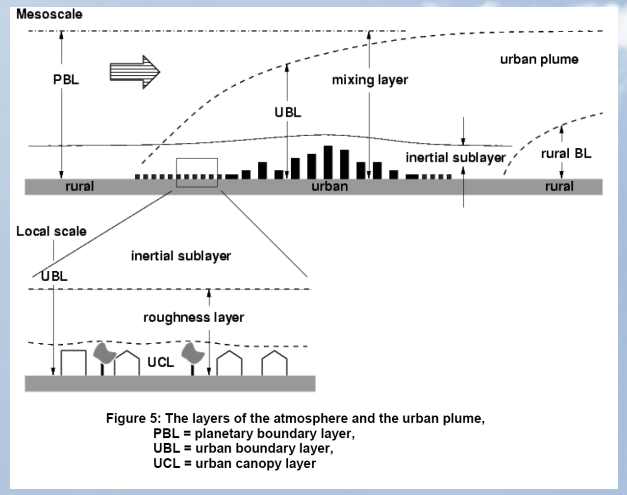
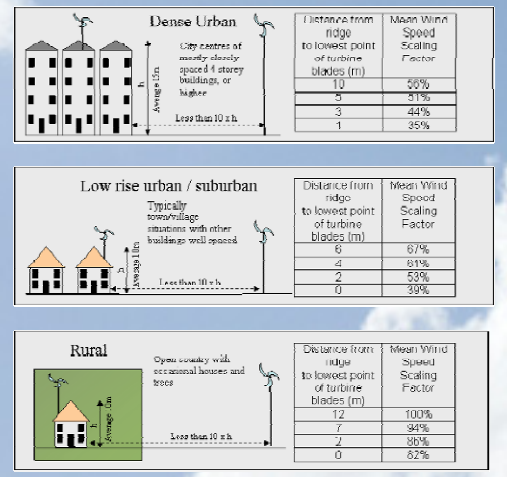
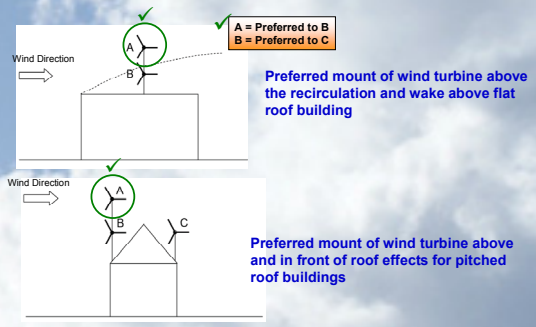


Figure 5: The layers of the atmosphere and the urban plume,
PBL = planetary boundary layer,
UBL = urban boundary layer,
UCL = urban canopy layer

Urban aerodynamics:



Correction factors:



Rules of thumb:

Ref. 3, 5, 8

Current Wind Measurement

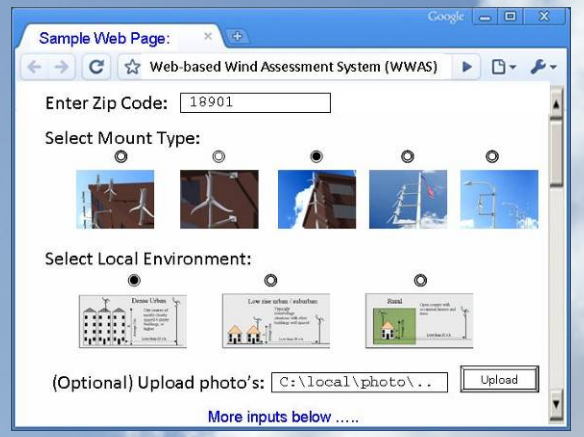
- Pole mounted wind anemometers gather wind speed/direction measurement data
- Raw data is stored and downloaded locally
- User has to analyze raw data on their own
- These systems are tailored for rural areas, typically requiring a large pole and guide wires
- Typical systems are expensive, costing from $600-$2,000
- This cost is justified for larger, more expensive wind turbines (+$10K), but prohibitively high for lower cost urban mounted wind turbines (~$2K)

Ref. 7

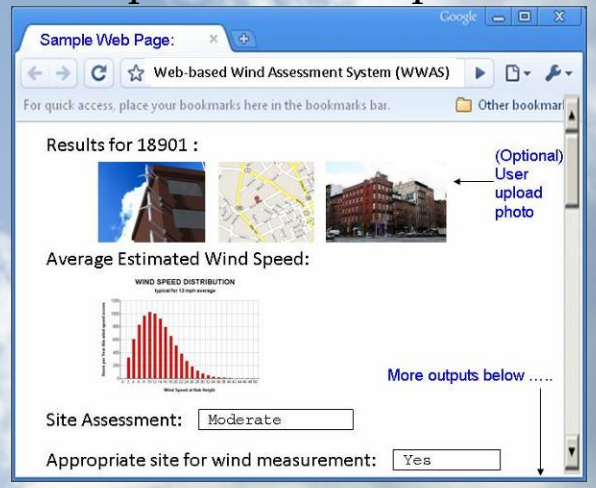
Web-based Wind Assessment System (WWAS)

- Tailored for urban wind assessment
- Combines scattered resources into one location
- Website allows for user inputs: zip code, mount type, local environment, hub height, and upload photos of surrounding area
- WWAS algorithms correct data for height, local environment, and determine overall viability of location
- The WWAS makes an assessment about the sites viability
- Rent modular wind measurement system
- Data is collected and sent through a cellular network back to the WWAS website for data processing
- Data is analyzed for the user
- Presented to the user in a an easy to understand format

Sample WWAS input:

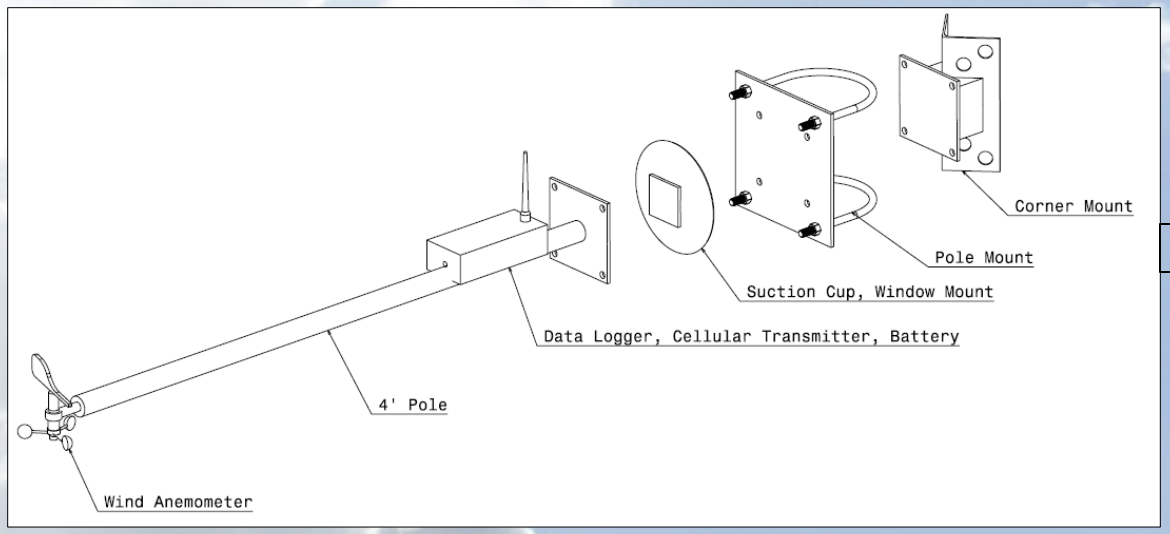


Sample WWAS output:



Modular Wind Measurement System

- Interchangeable mounting hardware allows the Modular Wind Measurement System to mount to various urban structures
- Power, transmitter, and instrumentation are self contained into one unit
- Data is sent through a cellular network and analyzed by the WWAS
- Rentable for a low monthly fee ($30/month) compared to $600-$2,000 to buy

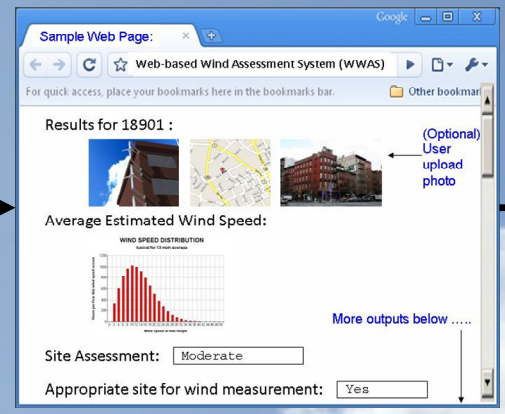


WWAS Architecture

- WWAS outputs:
  - Wind map showing surrounding resources
  - Predicted average wind speed
  - Predicted seasonal variance
  - Site viability for small wind
  - Should wind measurement system be rented
  - Wind measurement system rental cost
  - Estimated wind measurement duration (based on local seasonal data)
  - Projected Annual Energy Production (kWh)
  - Projected number of years for return on investment
  - Available local tax incentives
  - Local government installation requirements/ordinances for small wind turbines
  - Local installers

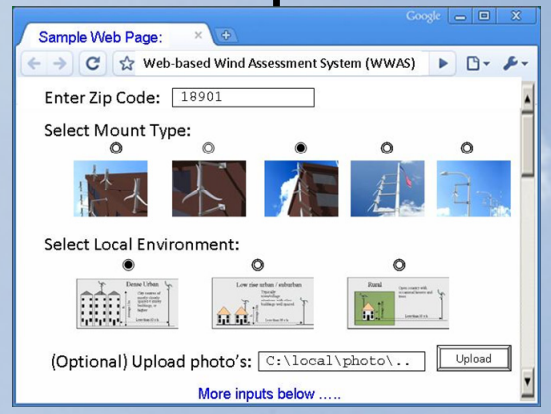
Database is refined overtime as more users join!

Web-based Wind Assessment System (WWAS) Output



Initial Wind Assessment

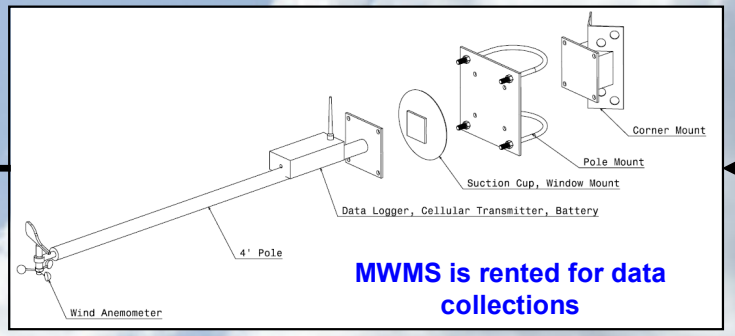
WWAS Input



Data feeds back into WWAS for processing

Based on initial assessment the site is suitable to take measurements

Modular Wind Measurement System (MWMS)



MWMS is rented for data collections

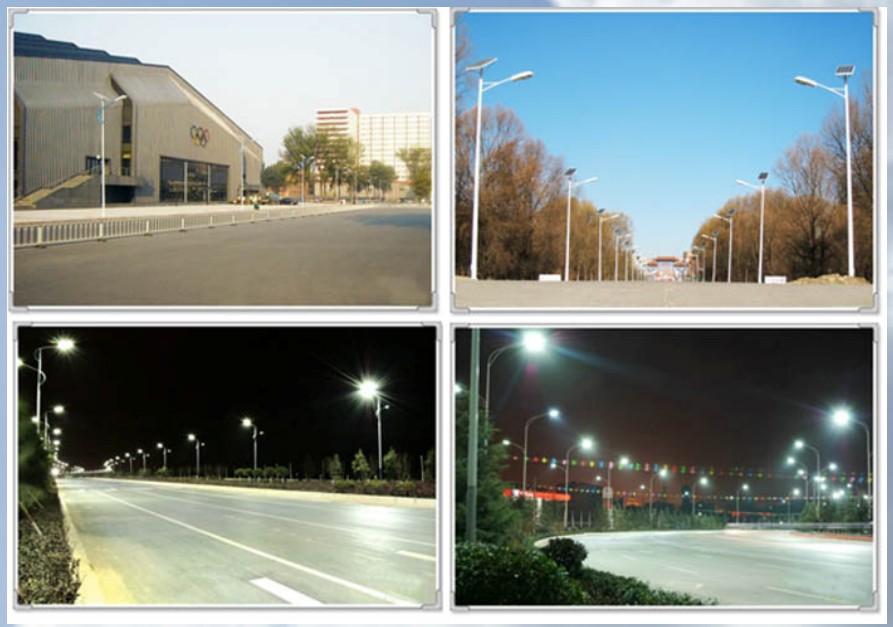
Various Urban Structures Suitable for Small Wind Turbines

- Building corners, walls, roofs
- Bridge support structure
- Light poles
- Power line poles
- Flap poles
- Electrical towers
- Existing wind turbines





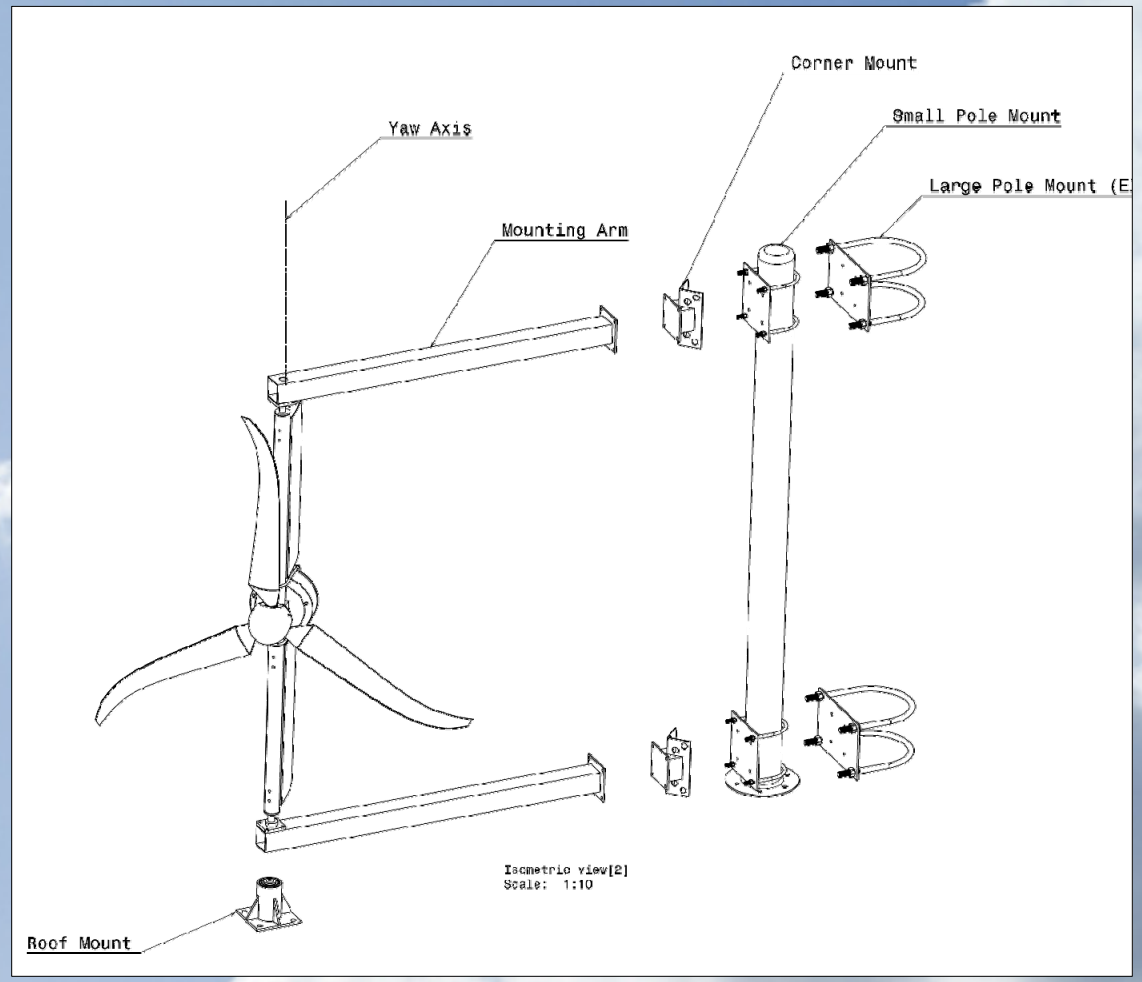




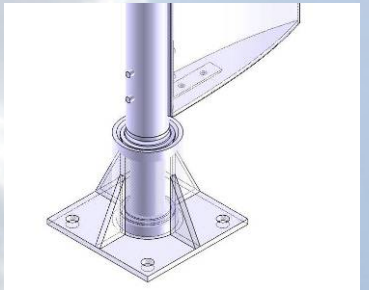
Need a small wind turbine design that can mount to various structures

Modular Mounting System

- Can be mounted to various structures
- Interchangeable mounting hardware
- Same core system can accommodate various mounting arrangements



Roof mount:

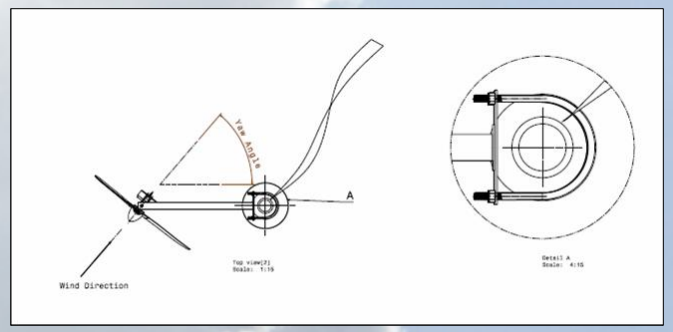


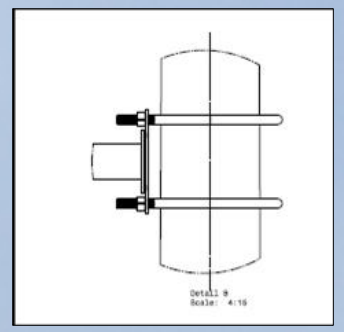
Pole or structure mount:

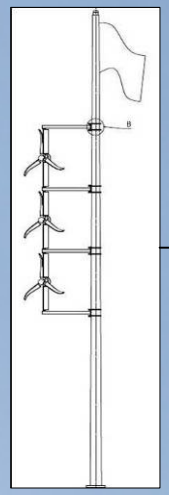
Modular Mounting System – Existing Poles

- Attaches to existing poles using U-bolts
- Does not require drilling or alteration of pole structure
- Various size U-bolts accommodate different diameter poles

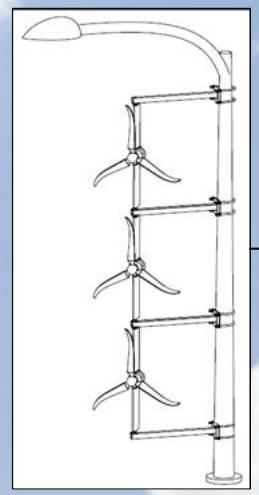
U-bolt attachment:







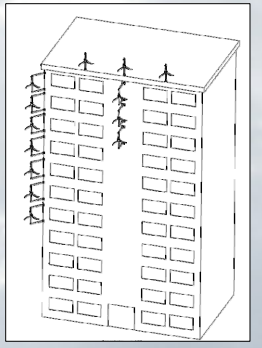
Flag mount:

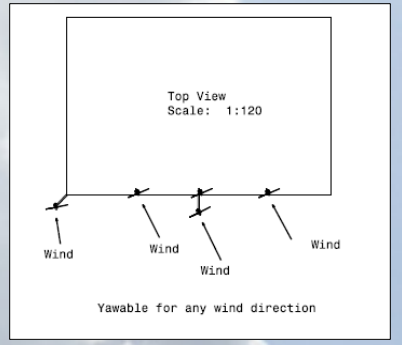


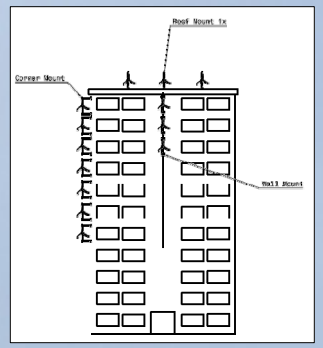
Street light mount:

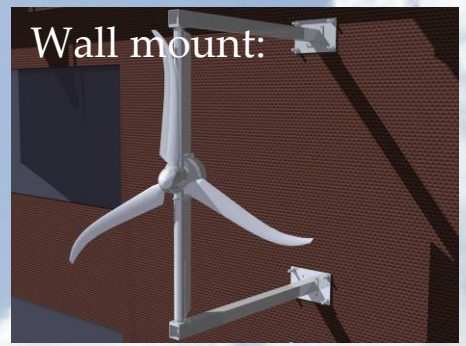
Modular Mounting System - Structure Mount

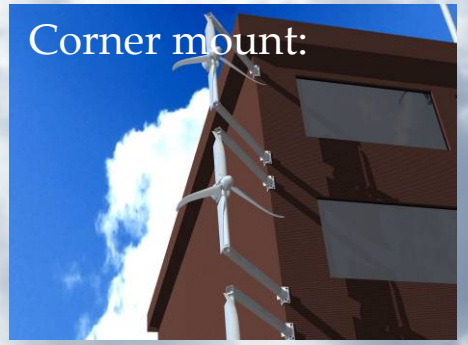
- Bolts into structure
- Similar to satellite dish install
- Can be accessed from windows or roof
- Yaws into wind direction
- Wind can be accelerated between structures





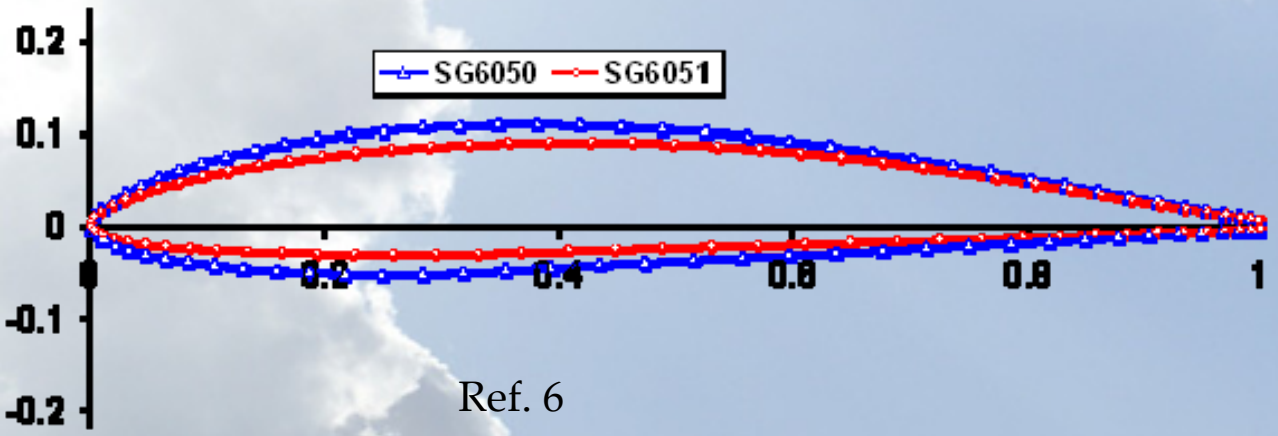




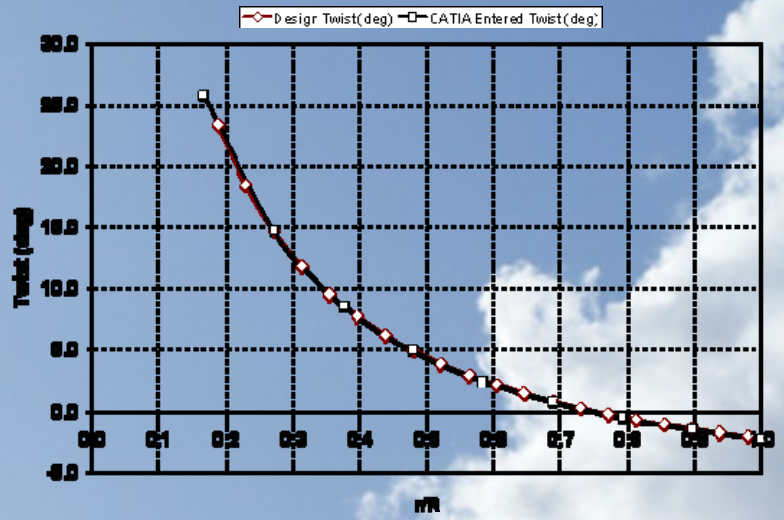


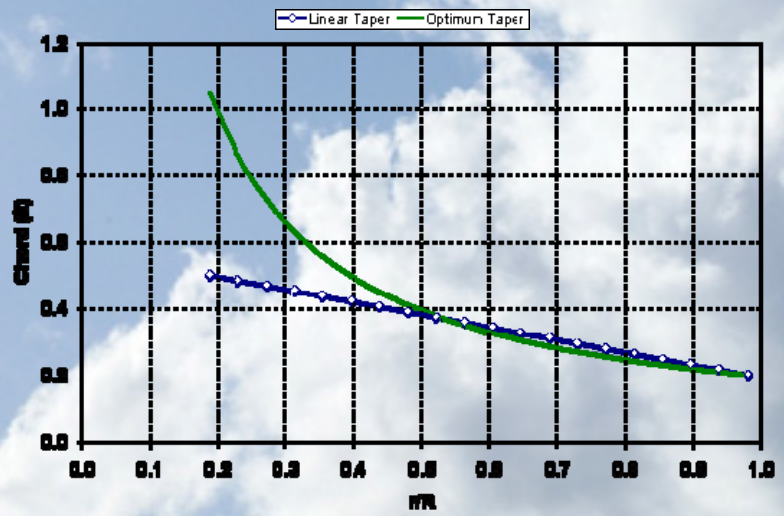
Small Wind Turbine Aerodynamic Design

- 3 bladed - 6 foot diameter, 1 kW rated @ 25 mph
- SG6050, SG6051 Airfoils are tailored for low Reynolds number, used on other small wind turbines
- Twist and taper optimized for low wind speed environment (~10 mph), tip speed ratio of 5.6



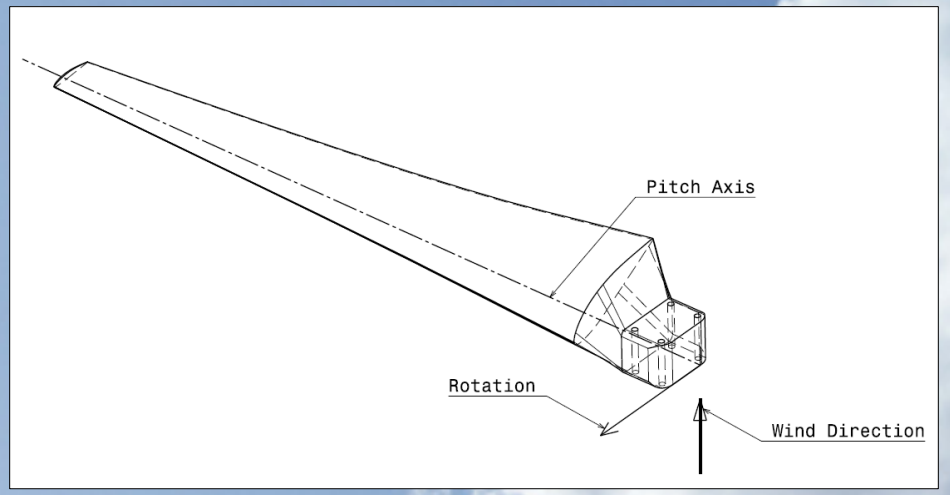
Ref. 6

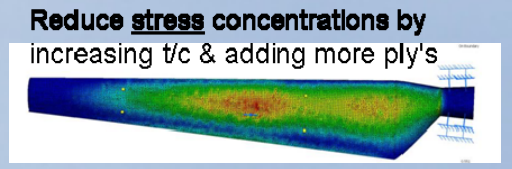


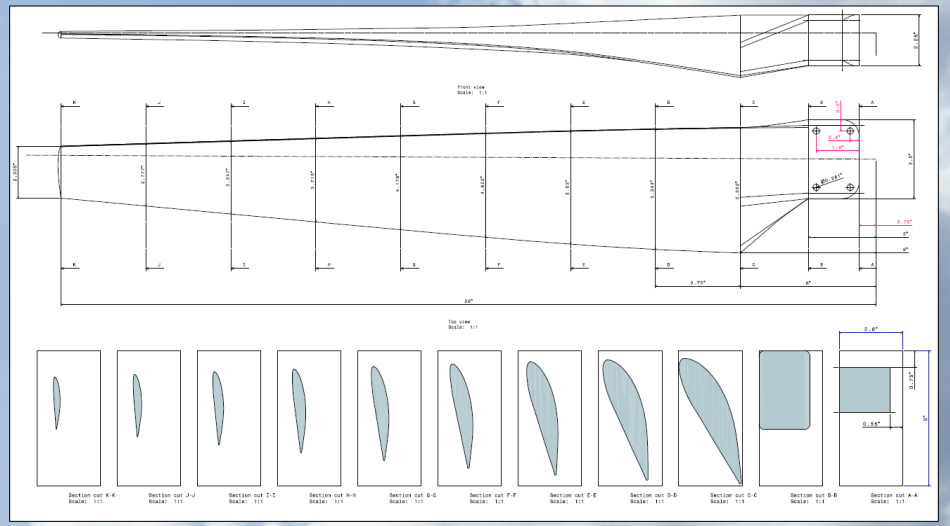


Blade Design

- 6 foot diameter
- Simple 4 bolt attachment
- Light weight Foam Core / Fiberglass Epoxy Skin
- Root airfoils are thicker to react bending moments

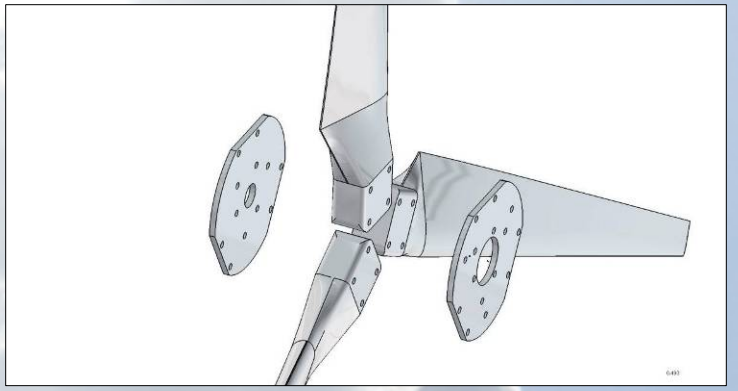


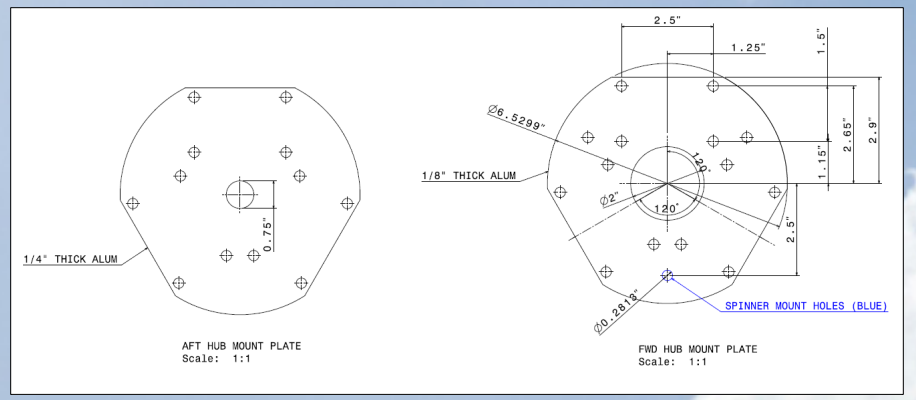




Hub Design

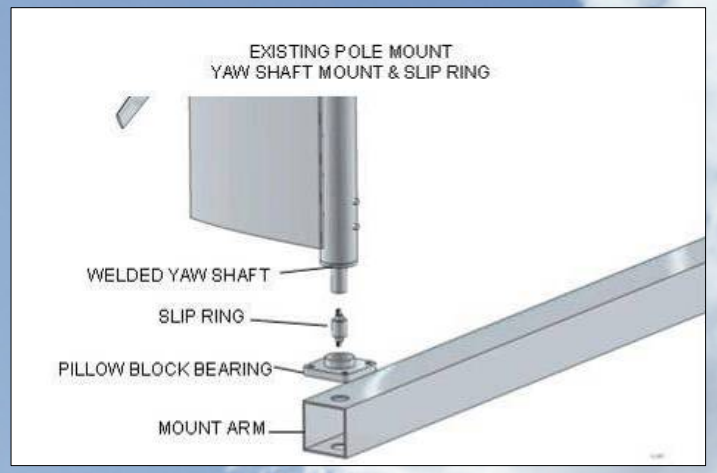
- Simple design, 2-part aluminum hub
- Blades are fixed between two plates
- 4 bolts are used to hold each blade in place
- 3 blades = 12 bolts

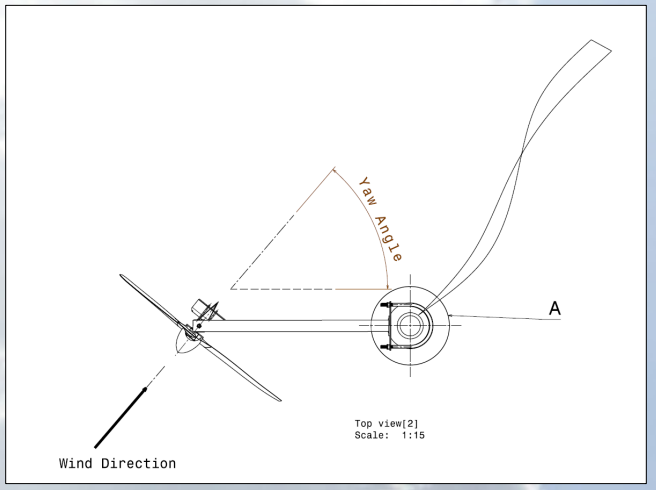


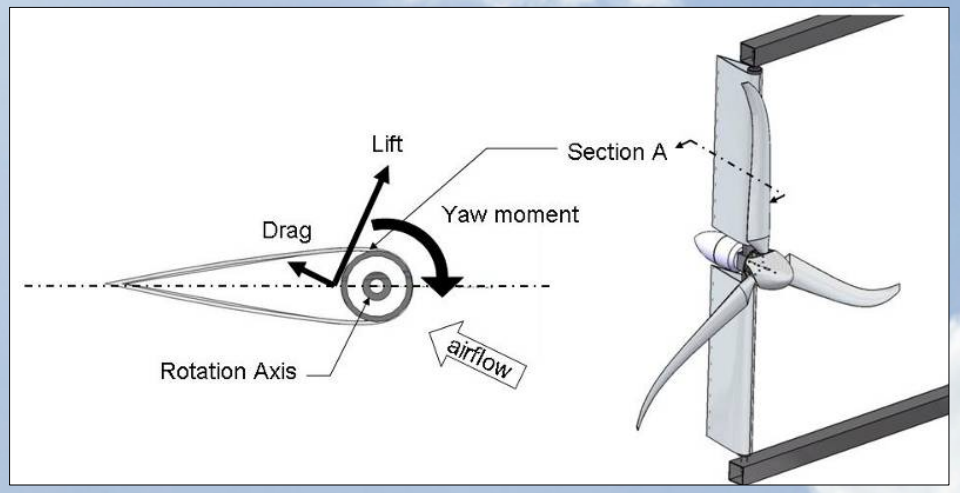


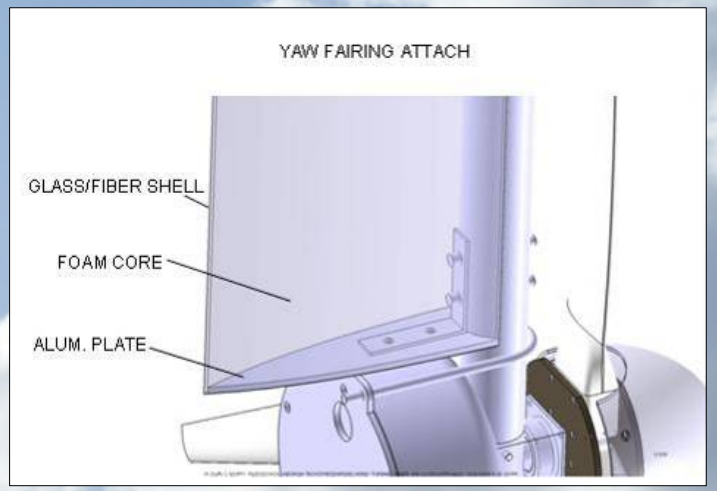
Yaw System Design

- Aligns the wind turbine into the wind direction
- Yaw system integrated into the yaw shaft
- Simple passive design uses airfoil shape fairing to generate lift and yaw the turbine
- Aesthetically pleasing compared to tail and fin design
- Power transmitted though slip ring



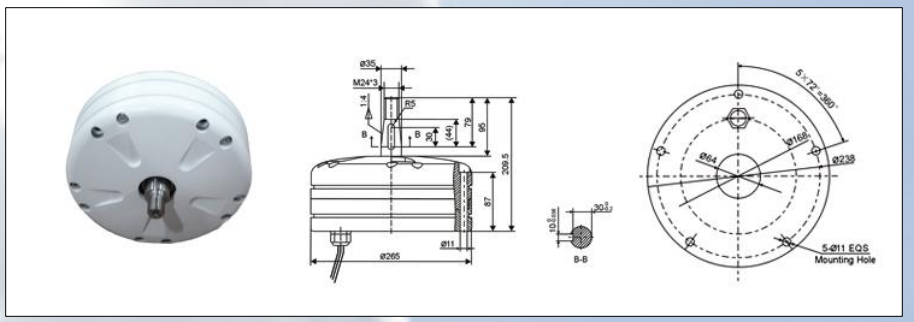






Generator and Mount Design

- Off-the-shelf 1.0 kW GL-PMG-1000 direct drive permanent magnet generator (PMG) manufactured by Ginlong
- PMG requires no gearbox to in increase RPM
- Works at low RPM (many poles)
- Minimal machined parts to reduce cost
- Simple assembly



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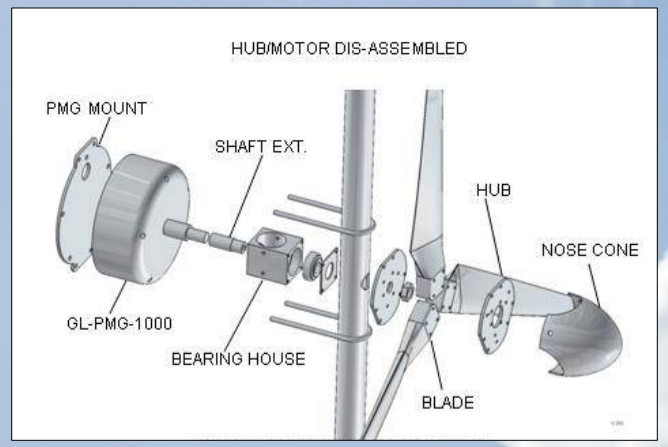
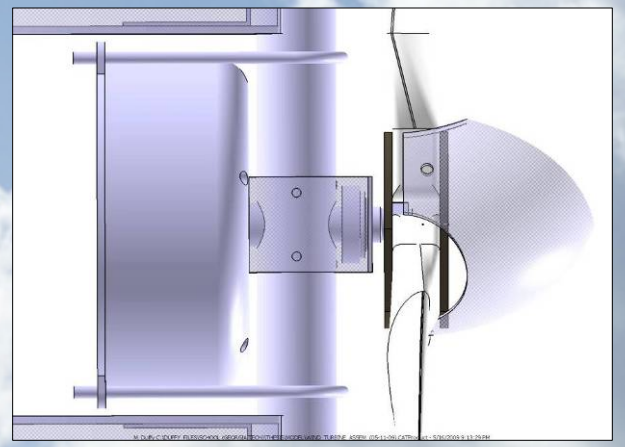
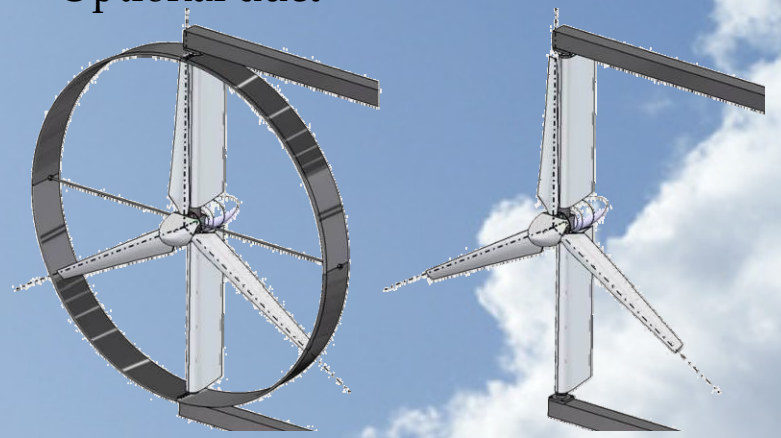




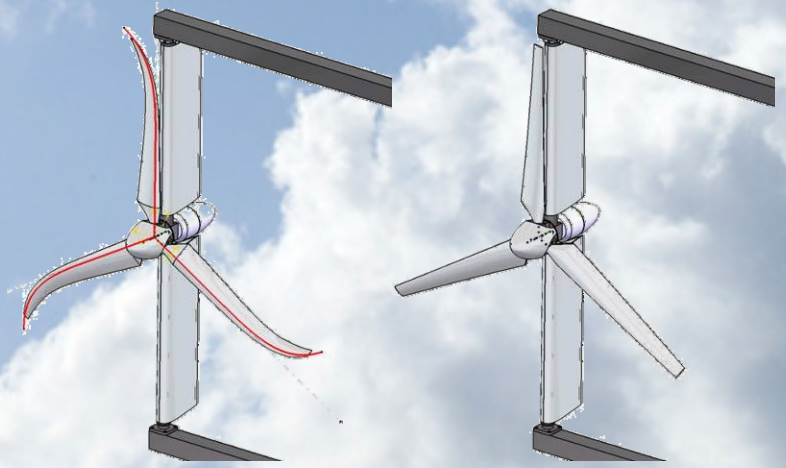
Optional Features for Urban Environments

- Optional duct to protect Avian wild life
- Duct reduces foreign object debris (FOD) from entering the wind turbine
- Optional swept tip blades reduce blade vortex interaction with trailing edge noise
- Swept tip blades are more aesthetically pleasing – Should not under estimate this in a populated area

Optional duct

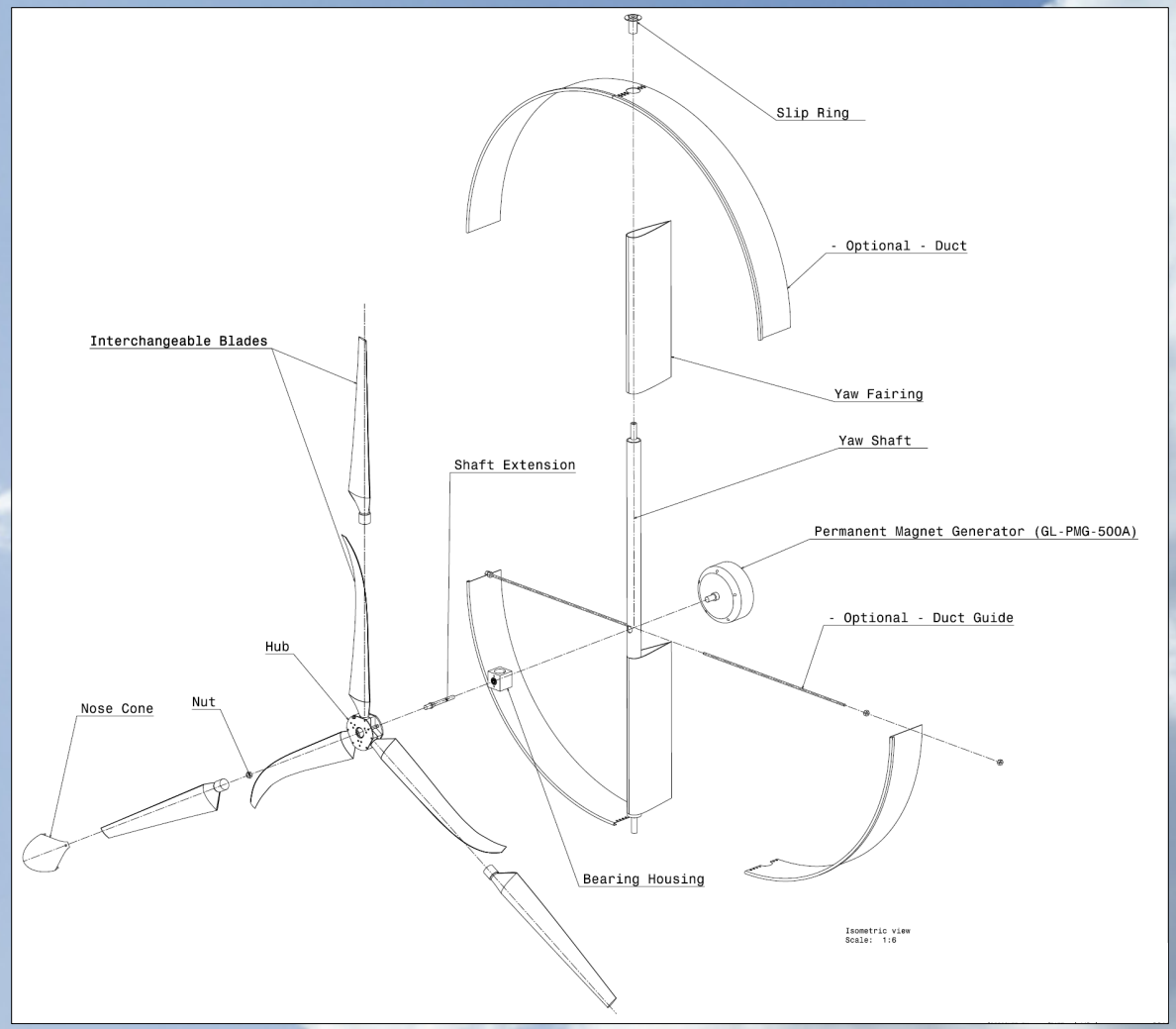


Optional swept tip blades

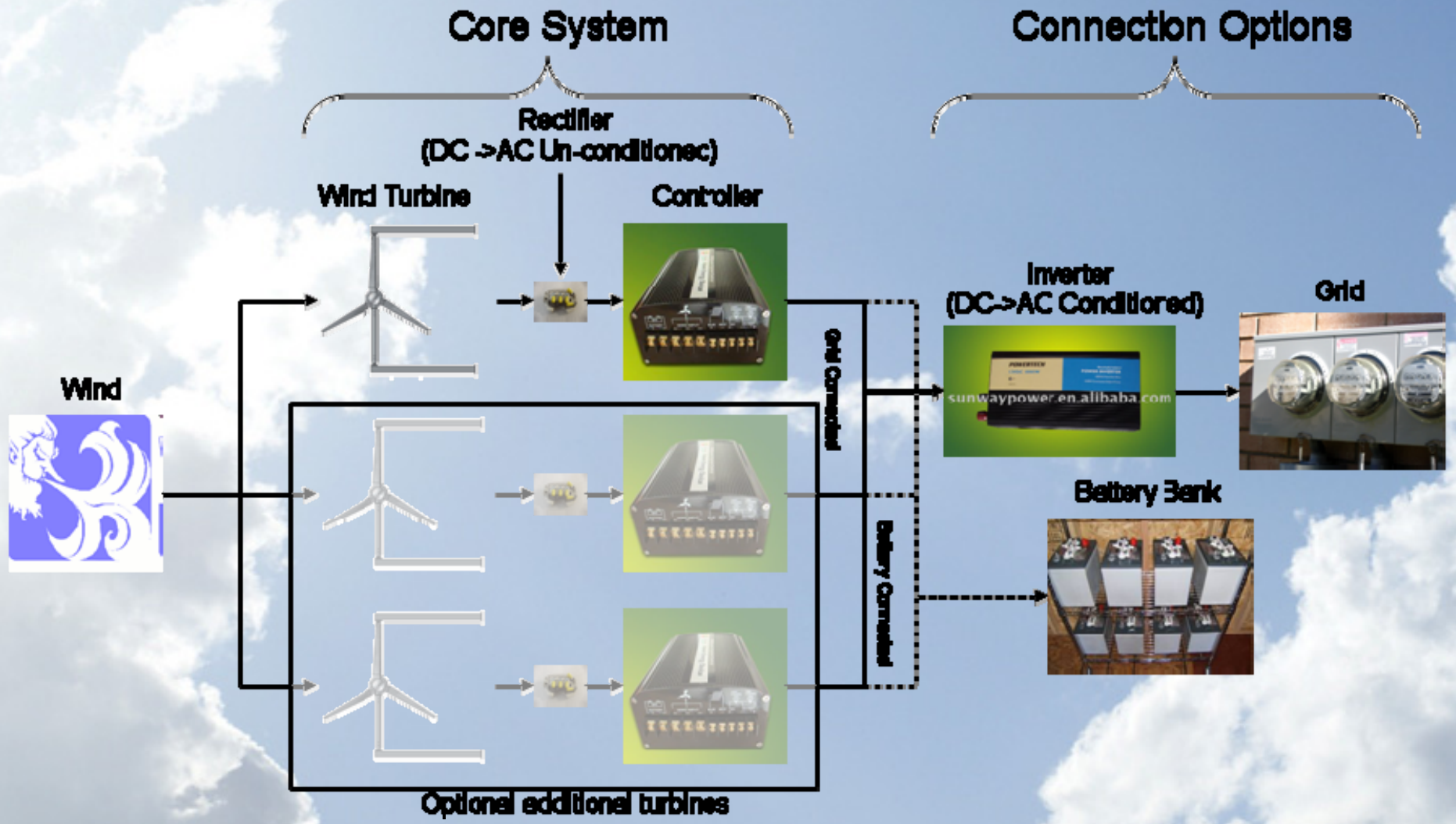


Unique Modularity

- System is easily assembled and disassembled
- Parts are interchangeable:
  - Blades, duct, fairings, PMG
- Interchangeability allows for easy repair
- Optional components allow core system to be lower cost
- Customer can pick and choose options that fit their needs
- Core system can be scaled up for larger models in the future

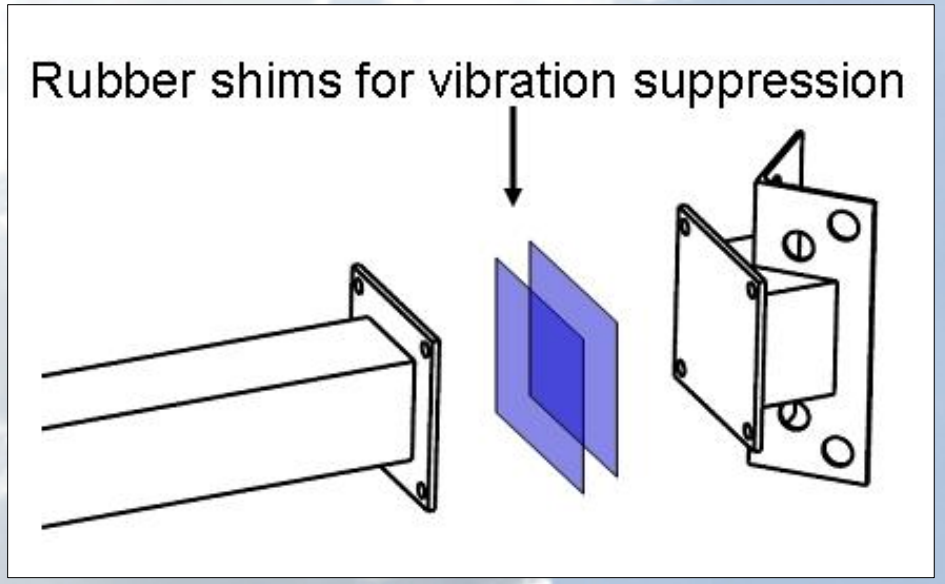


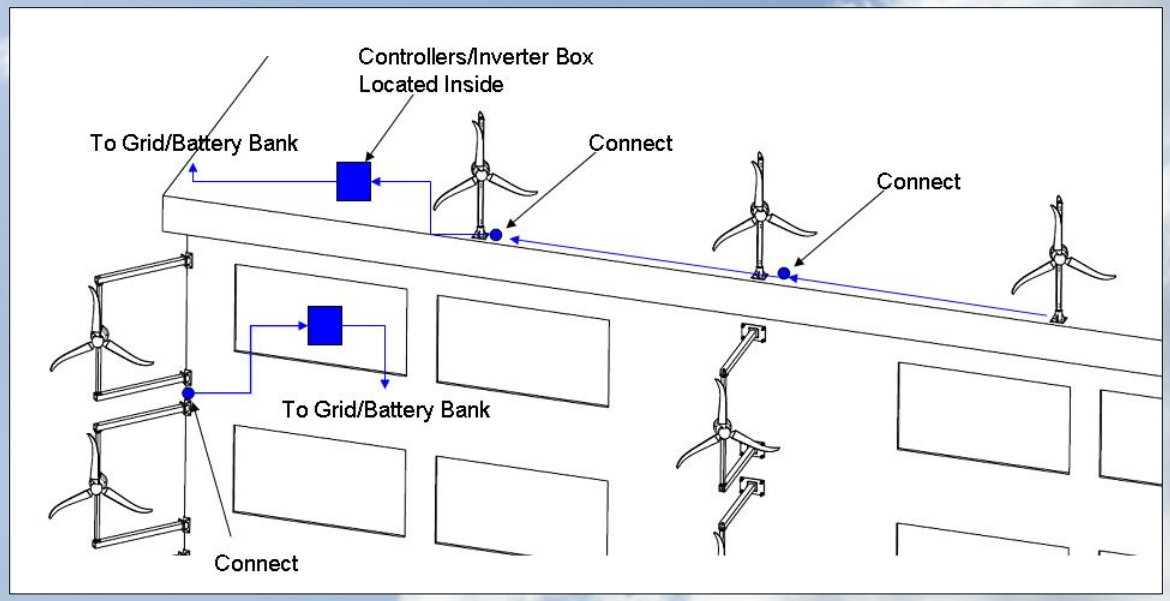
System Architecture



Compatibility with Urban Structures

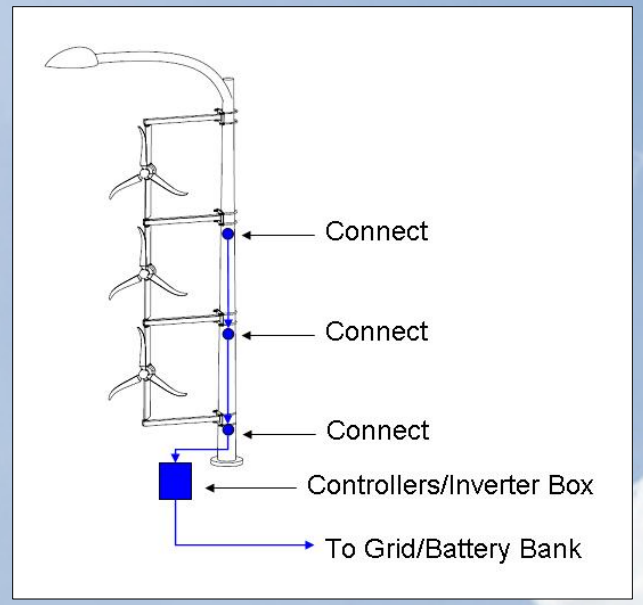
- Building mounted turbines require vibration suppression
- Turbines can be connected together
- Controller and inverter box can be mounted inside or outside

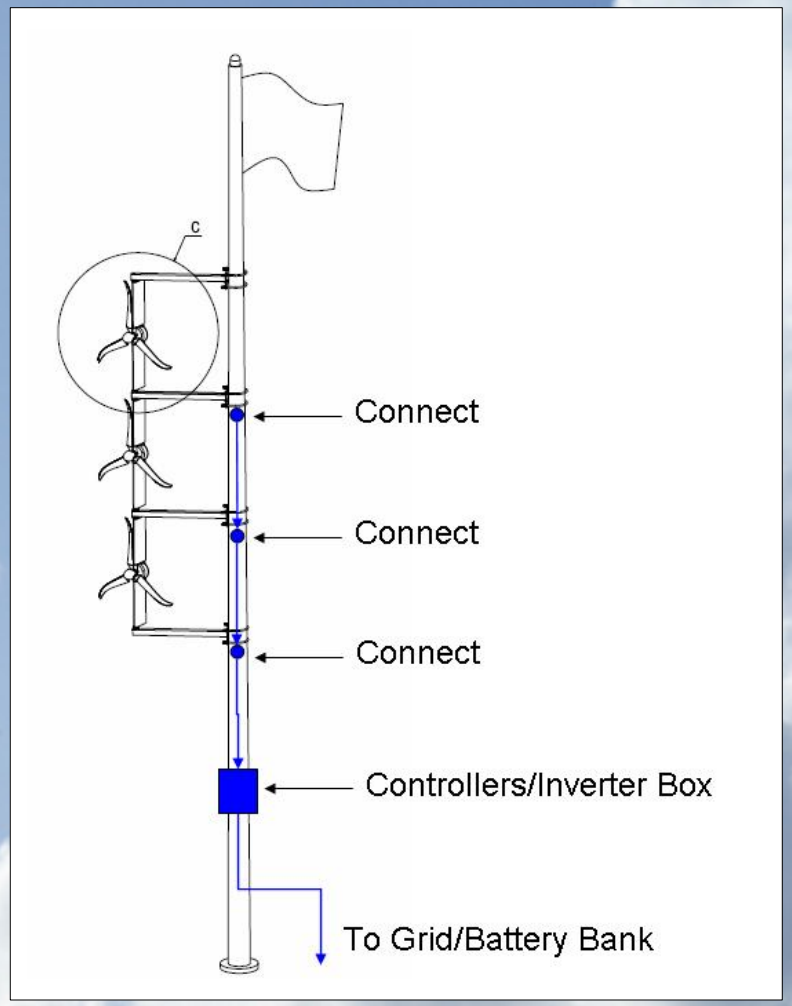




Compatibility with Urban Structures

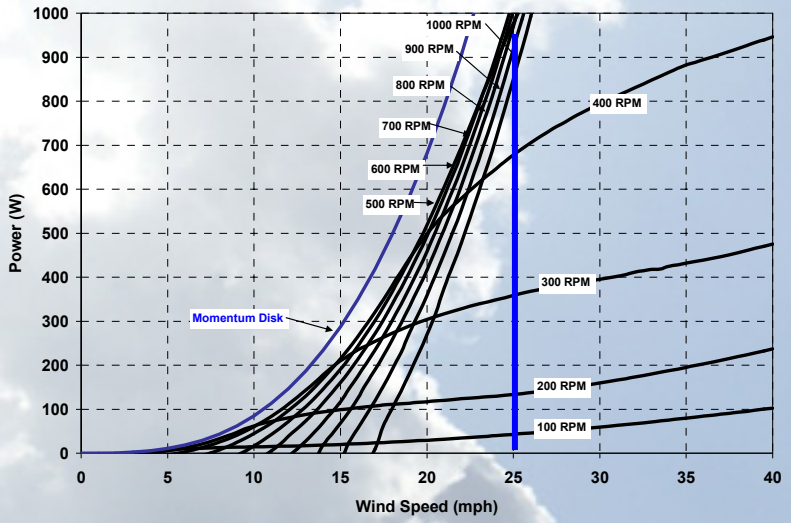
- Pole mounted turbines can be connected together
- Controller and inverter box can be mounted at pole base or underground

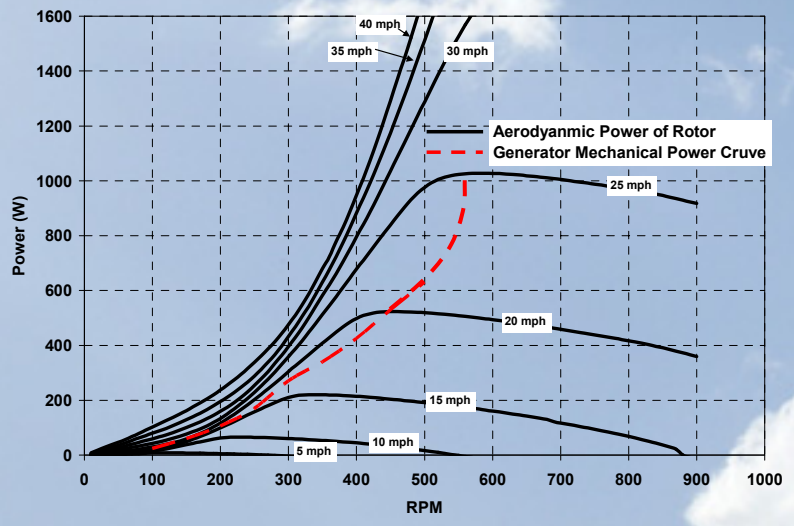


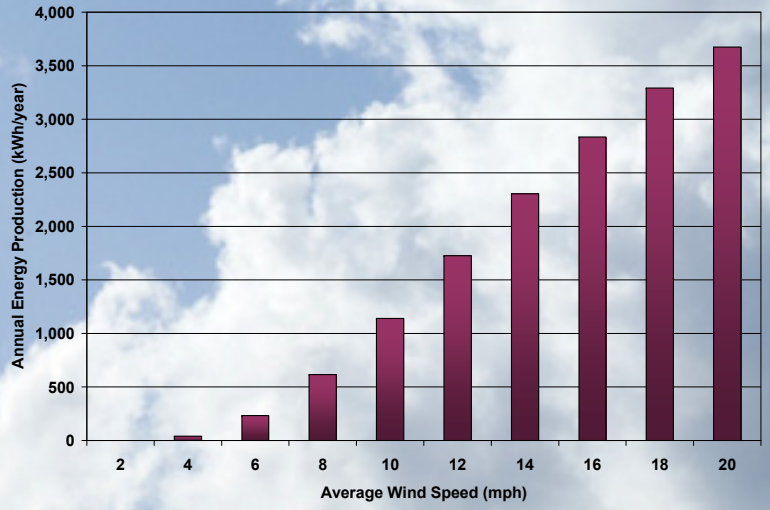


Wind Turbine Performance

- Performance calculated using WT_PERF 3.0, ref. [4]
- 3-bladed 6 foot diameter, rated at 1.0 kW at 25 mph
- Peak power is controlled by RPM
- Annual energy is >1,500 kW/year at 12 mph average wind speed in urban wind environment

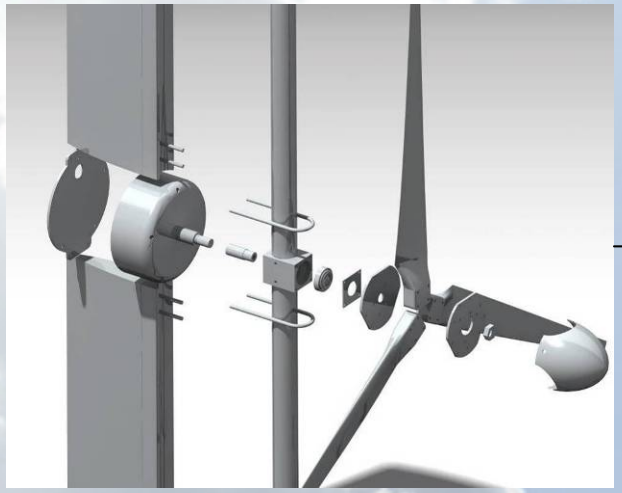






Cost to Manufacture

- Cost is based on 2010 $
- Includes controller and grid-tie inverter
- Cost is calculated assuming 1,000 unit production run
- Total cost to manufacture per unit is $1,899



1000W - 6 Foot Diameter - Structure Mounted Wind Turbine		
Part		Price (Per piece)
Power Components	$	*1,062.54*
Charge Controller	$	97.94
Inverter - Power converter 1000W 12Vdc to 120Vac pure sin	$	170.10
GL-PMG-1000A	$	722.50
Rectifier Kit	$	25.00
Generator Mount Hardware	$	30.00
Slip Ring	$	7.00
50 ft Wire	$	10.00
Machined	$	*530.13*
Yaw Shaft (6', 2.5"OD, t=0.188	$	108.04
Alloy 4130 Steel Precision Shim Bushing Stock 1" OD, 1/2" I	$	54.40
1.00" Propeller Shaft Bearing (Square Mount, Derlin, No mai	$	32.41
0.75" Propeller Shaft Bearing (Square Mount, Derlin, No mai	$	32.41
Bearing Mount 2"x3" Aluminum Block	$	42.50
Hub - 2x 0.125" Aluminum Rounds	$	100.00
Zinc-Plated Steel U-Bolt W/Plate, 3/8"-16X1-1/4" L Thrd, for	$	17.14
Low-Carbon Steel Square Tube 3-1/2" X 3-1/2", .125" Wall T	$	57.92
Low-Carbon Steel Sheet 1/4" Thick, 12" X 12"	$	31.93
Low-Carbon Steel 90 Degree Angle 1/4" Thick, 4" Leg Lengtl	$	53.39
Blades / Fairings	$	*306.00*
Blades (3x set)	$	189.00
Nose Cone	$	36.00
Blade Hardware	$	15.00
Yaw Fairing	$	66.00
Total Hardware (Turbine + Grid Connect) Cost	**$**	**1,898.67**

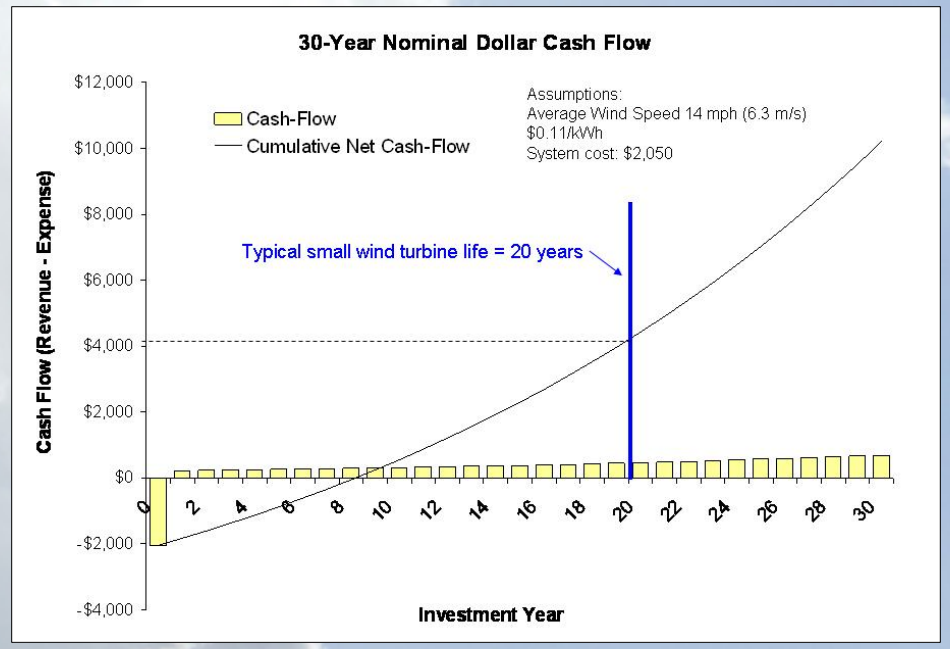
Cost to Customer

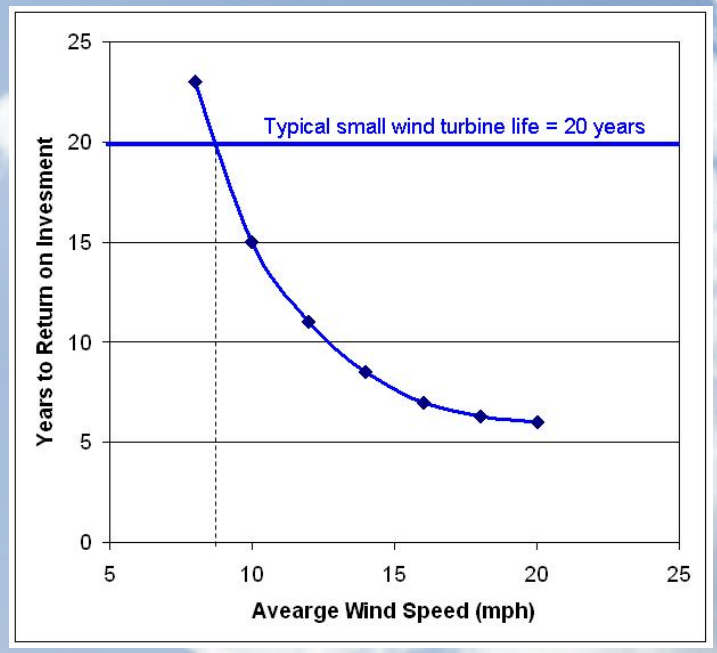
- Operation cost: engineering support (5%), sales (15%), and profit (15%) are added to the manufacturing cost
- Installation Cost (10%)
- A 30% US federal tax credit is applied
- Total cost to customer comes to $2,051 per unit

1000W - 6 Foot Diameter - Structure Mounted Wind Turbine			
	Part		Price (Per piece)
Power Components		$	1,062.54
Machined		$	530.13
Blades / Fairings		$	306.00
	Total Hardware (Turbine + Grid Connect) Cost	$	1,898.67
Operating Cost			
	Engineering Support (5%)	$	94.93
	Sales/Infustructure (15%)	$	284.80
Profit	Profit (15%)	$	284.80
	Total Cost	$	2,563.21
Customer Cost			
	Installation Cost (10%)	$	256.32
	Tax Credit (30%)	$	(768.96)
	Total Customer Cost (System Installed + Grid Connnected)	**$**	**2,050.57**

Return on Investment

- Return on investment at 14 mph (6.3 m/s) average wind speed would be 8 years
- Over the 20 year design life the system would yield a 2x ($4,100) return on investment
- Minimum break even average wind speed must be >9 mph

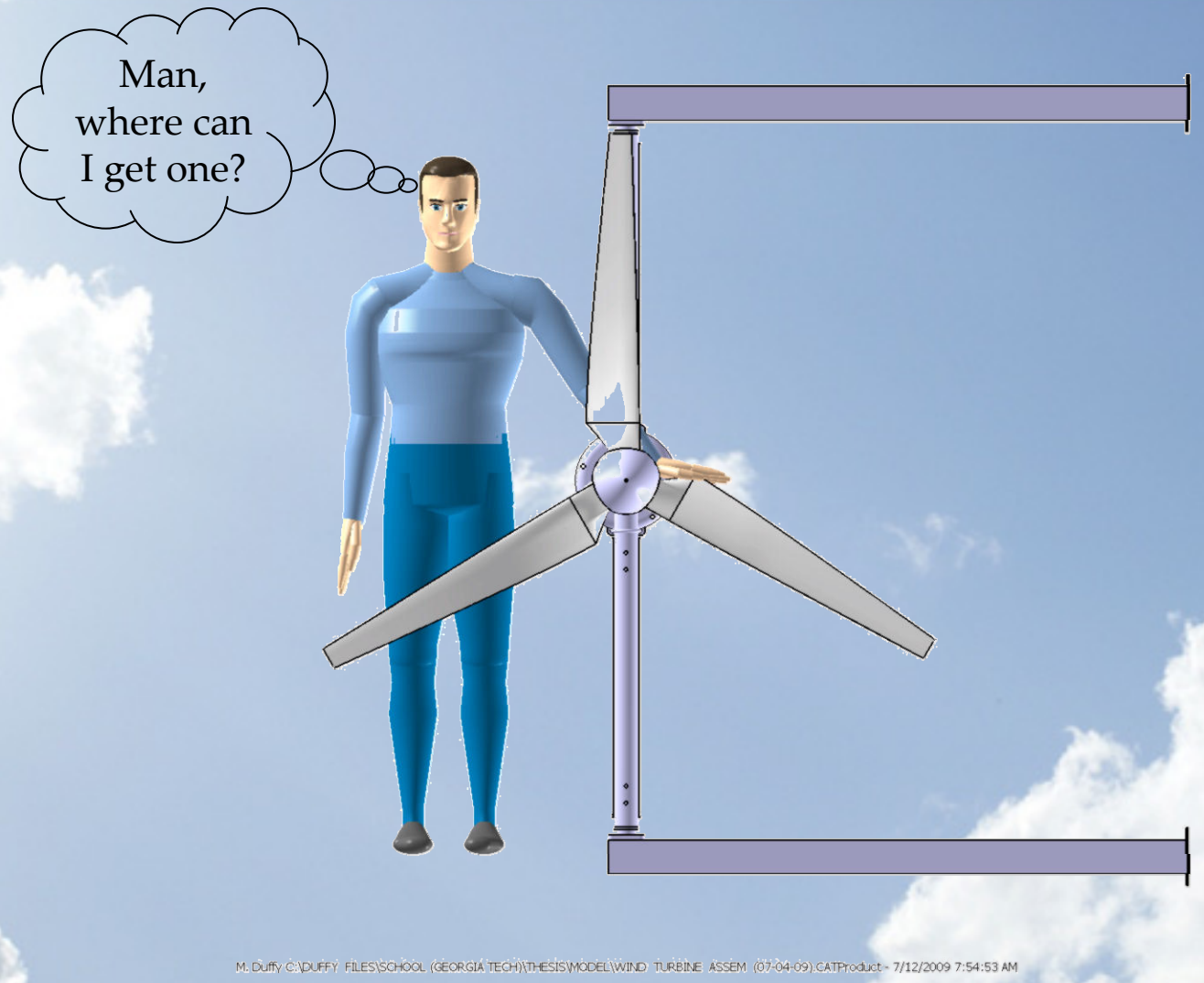


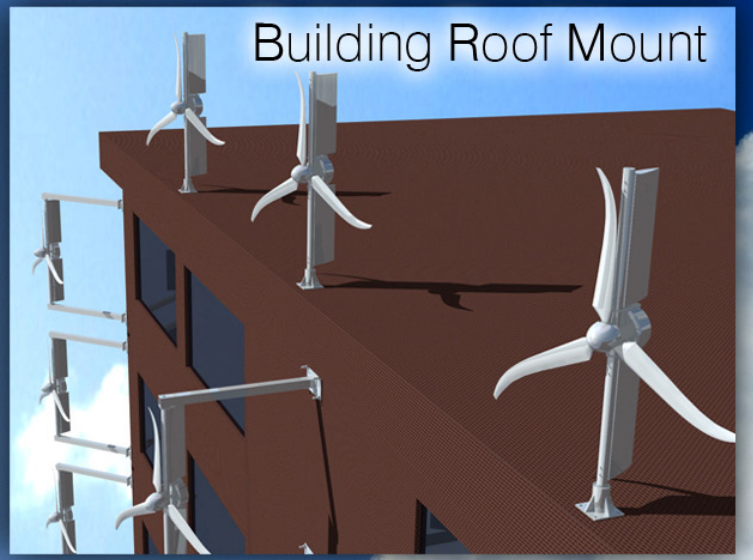


Summary

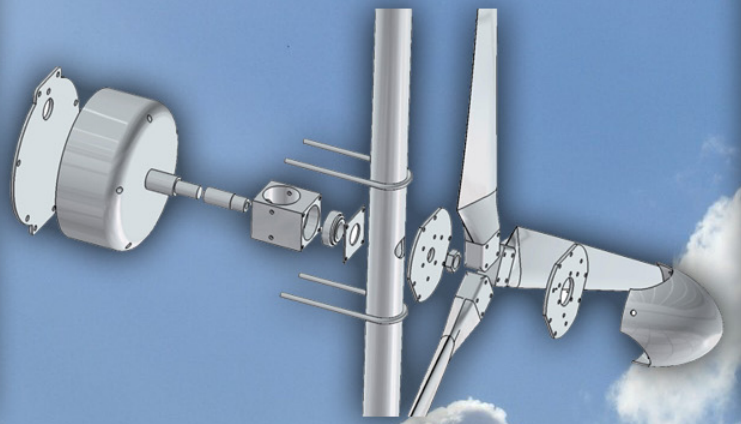
- Urban mounted wind turbine can be economically viable
- To ensure viability, a Web-based Wind Assessment System (WWAS) was introduced
- The proposed system prevents potential small wind turbine customers from over-predicting their local wind resource, thus saving time and labor
- To complement the WWAS a modular mounting system for small wind turbines was designed
- This system allows mounting to various urban structures (via interchangeable hardware)
- These two systems combined can further the viability of small wind turbines mounted to existing urban structures

Questions





Small Wind Turbines Mounted to Existing Structures



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