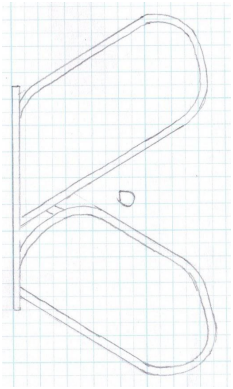
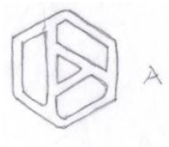
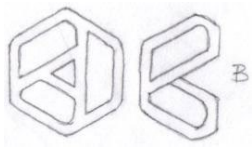
Spokane Butterfly 2021-22 Phase I -Design Report 7/28/21

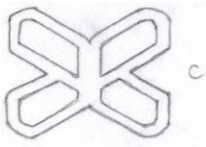
Honoring the Past Frame Approach

Following **feedback** it is clear that a more safe and stable solution is needed while honoring the **original intent and design** of the '74 butterflies while bringing the butterfly into the **2020's and beyond**!

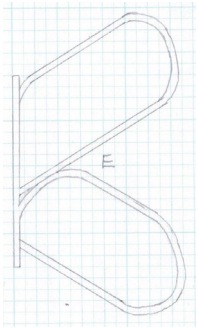


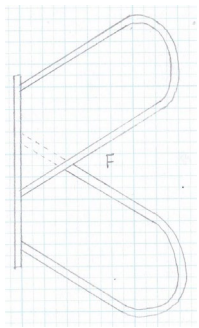


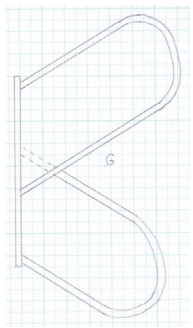


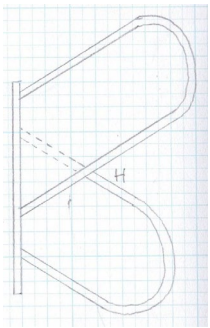


The following sketches show the progression of the '74 Butterfly design and development from the logo (A, B, C), through the original frame (D) which to note does not exactly follow the logo and puts space between the wings. We then move into a proposed evolution of the frame (E-M) in order to gain stability while retaining and moving closer to the original look and feel.



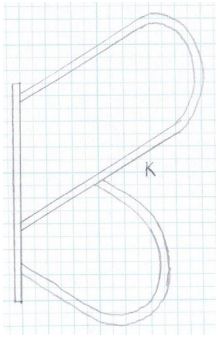


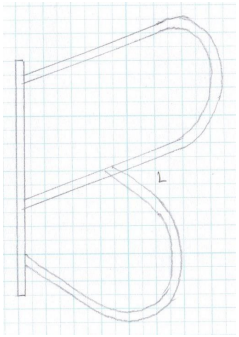


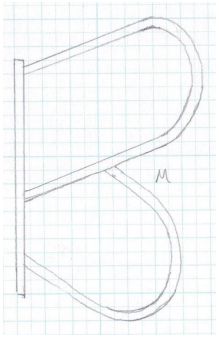


Finalizing a Proportion

Sketches K, L, and M show slight adjustments to the wing angles which will provide even more movement toward adapting the ‘74 logo and merging it with a true butterfly proportion.







Free Bottom Edge

If we view the original butterfly from 1974 there was no heavy spar on the bottom edge of the structure holding the bottom (trailing edge) of the wing.

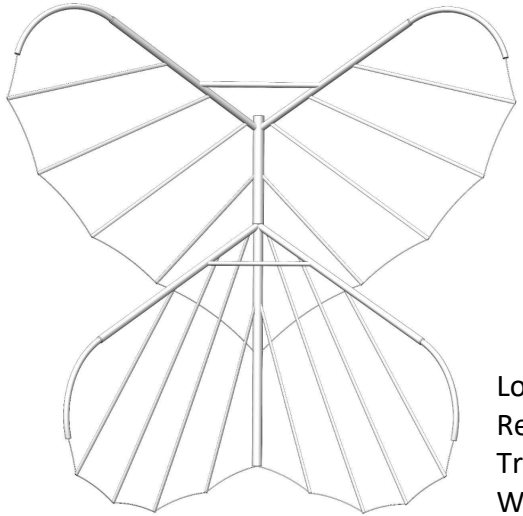
Advantage - Reduce Wind Loading

Batten Wing Approach

Windsurfing sails use **battens** to give the sail anchor points as well as catch the wind safely while holding the trailing edge and stiffness of a sail.

Advantages

- Less Aluminum fabrication
- Flexible wing reduces load
- Having battens allows going back to original unsupported design
- Produces a kinetic visual effect



Upper/ Leading Wing

Lower/ Rear / Trailing Wing

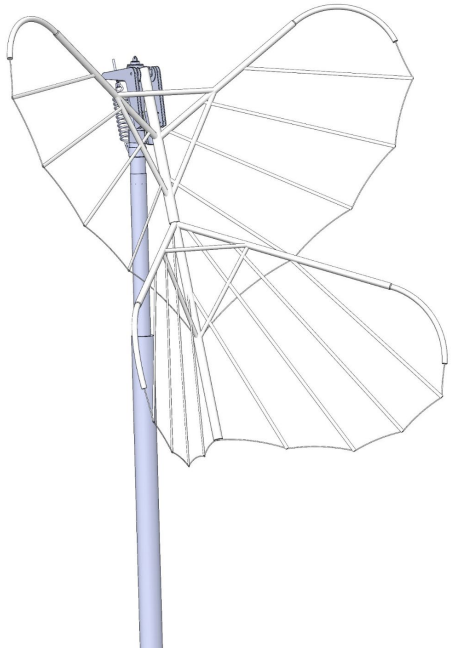
Lower Wing Behind and Steeper Angle (dihedral) see page 7

Advantages

- Reduced side and torqued loading on full system
- Increased stability in wind

2021-22 Butterfly Frame Proposed Structural Updates and Advantages

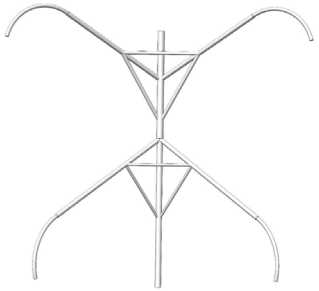
- Non-Framed Trailing Edge / Batten Design
- Increased Wing Support Tetrahedral Bracing
- Torsion Joint Allowing Spinal Twisting
- Bolted Connections
- Less aluminum bending
- Reduced wing loading
- Updated/ reinforced top assembly
- Failsafe lanyard connecting frame to mast



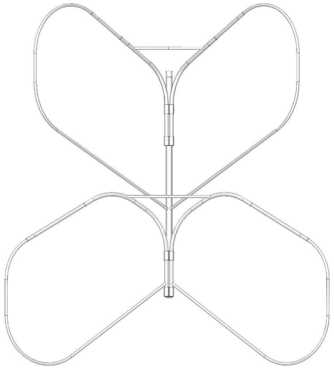
Proposed New Frame Compared to Old

Features of new vs. old:

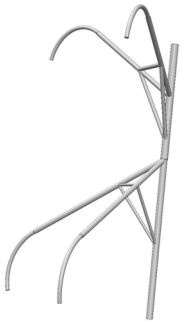
- Less overall framing
- Less custom curved frame
- Additional Arm Supports/ Stiffeners
- More compact mass for installation



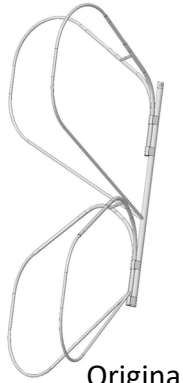
New



Original



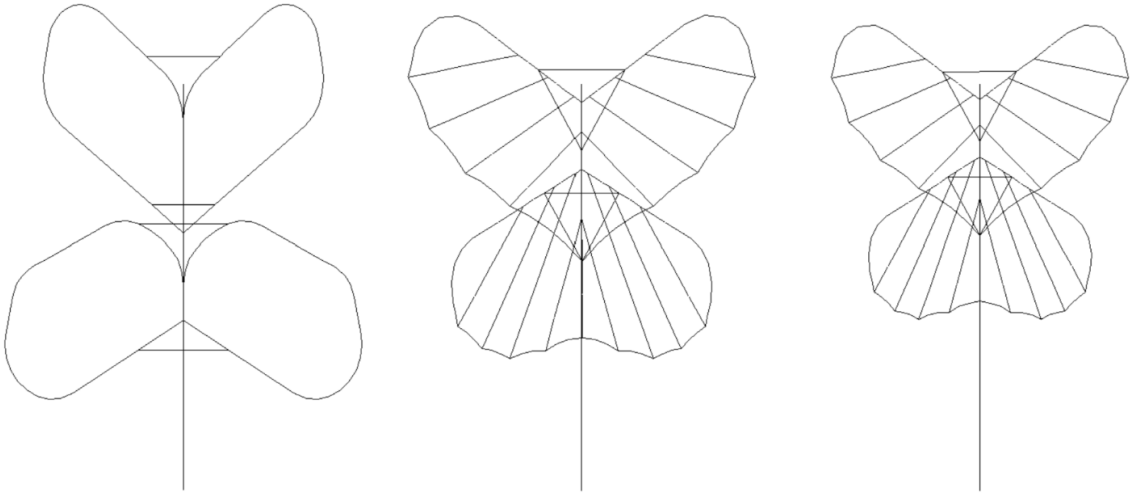
New



Original

Proposed New Wing Compared to Old

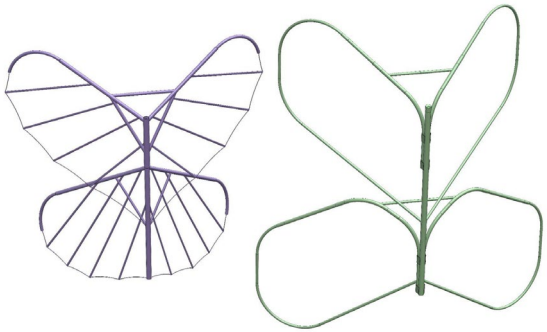
Comparison of overall shape and wings from original to new to a **15% reduced scale** version being considered for reducing loading on structure



Original **Preliminary** **Preferred**

Proposed New Frame Compared to Old

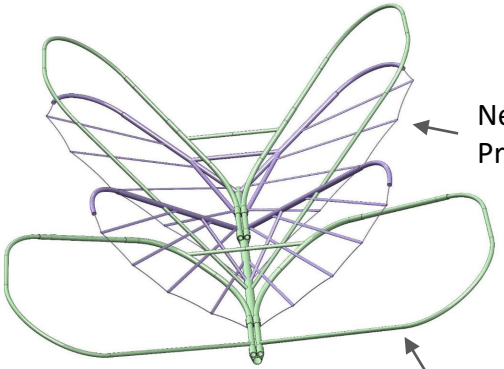
Visual Butterfly Comparison



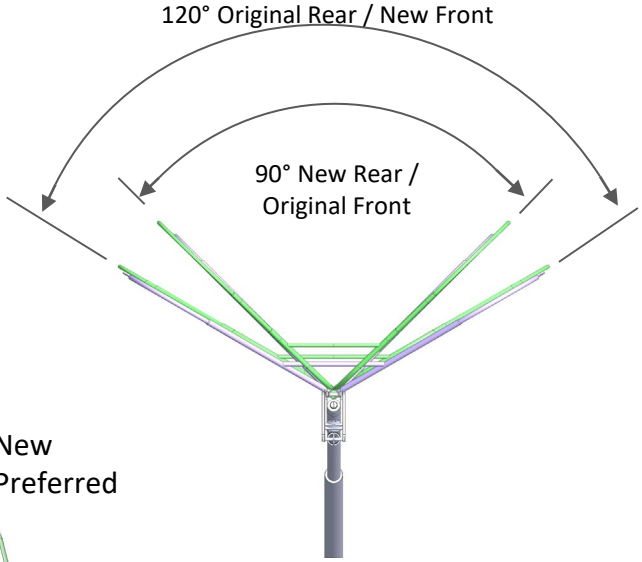
New Preferred

Original

Side by Side Comparison



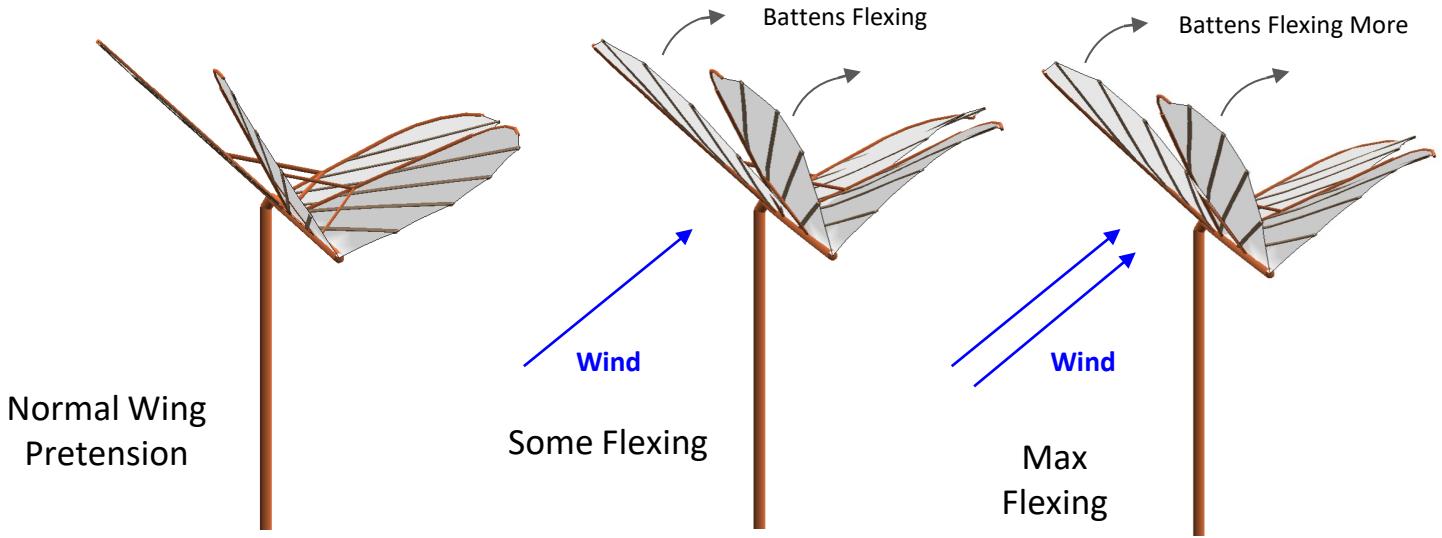
Overlaid Comparison



Inverted Dihedrals New / Original:
Narrow Rear Wing helps tracking to wind
And reduces overall loading

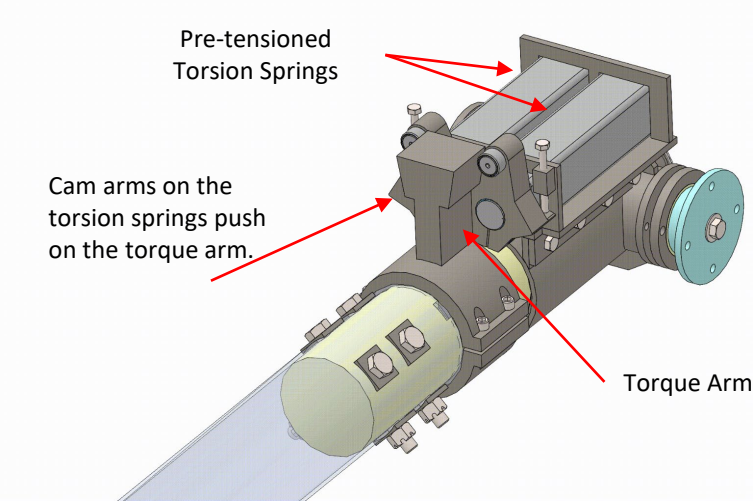
New Frame Batten Design and Wind Flex

Fiberglass sail battens provide flexibility in wind, reducing wind loading and adding visual dynamics.

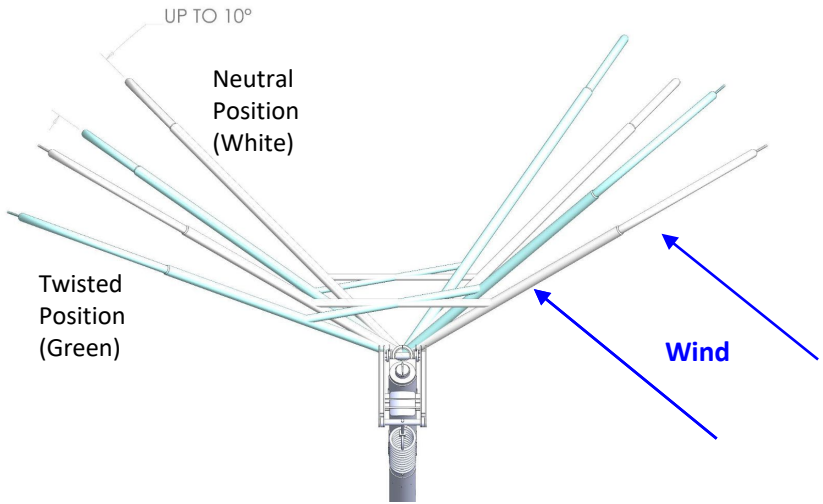


New Frame - Torsion Joint Twist Ability

- Dual, adjustable, torsion axles allow limited rotation at spine mount to reduce moment in the wing frame members under unbalanced wind loading.
- The new joint will return wings to neutral position at rest.



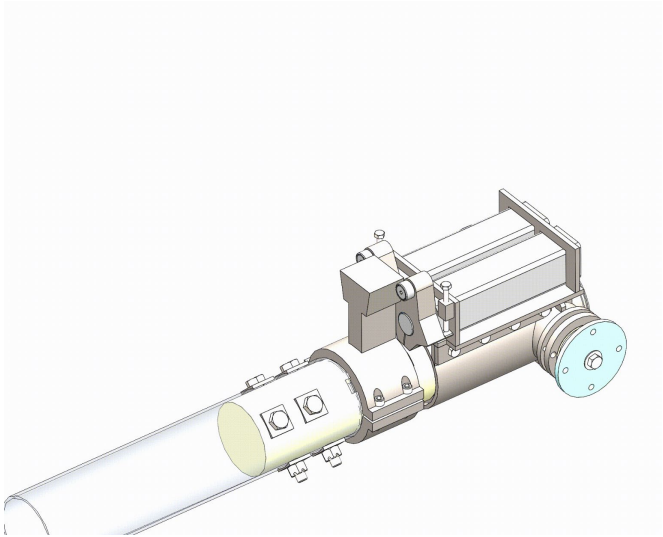
One twist direction shown based on wind direction indicated



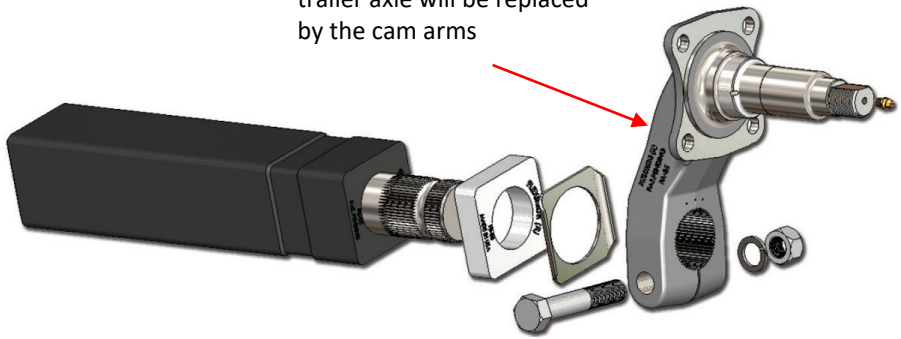
- The original butterfly didn't have a way to accommodate the twisting motion created by unbalanced wing loads.
- This was a primary contributor to the failure of the last butterfly.

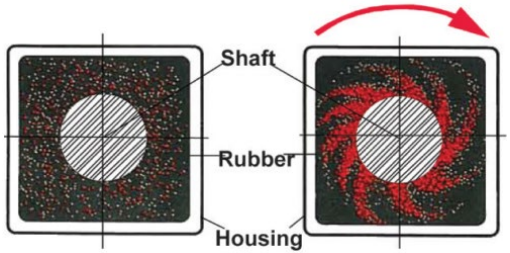
Torsion Joint Detail and Engineering

- The torsion joint utilizes two off-the-shelf trailer torsion axles to absorb the twisting motion of the butterfly.
- The axles use rubber bonded to a center, splined shaft to resist twisting and are very corrosion resistant.
- The cartridge style torsion axles can be easily replaced and serviced.
- The force provided by the axles can be adjusted by changing the starting angle of the arms.
- Torsion sled can be easily removed for rare maintenance (see animation on the right).



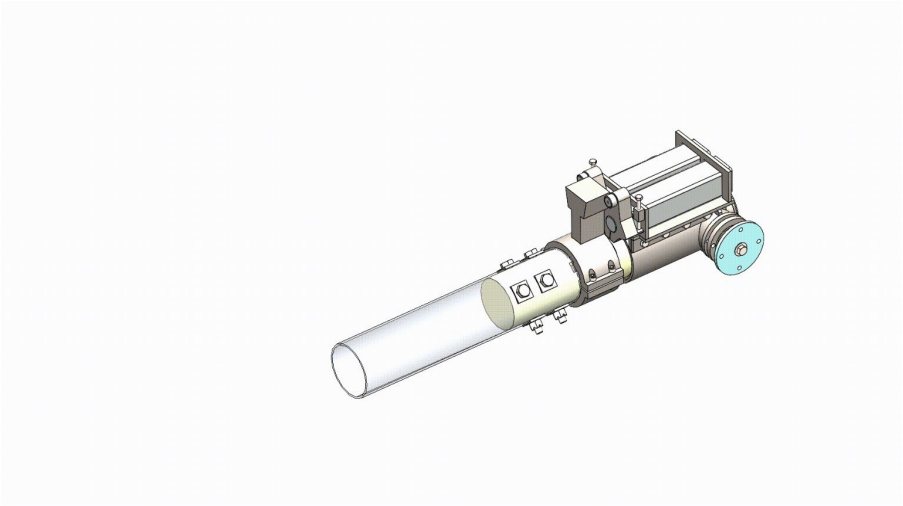
This part on the original trailer axle will be replaced by the cam arms

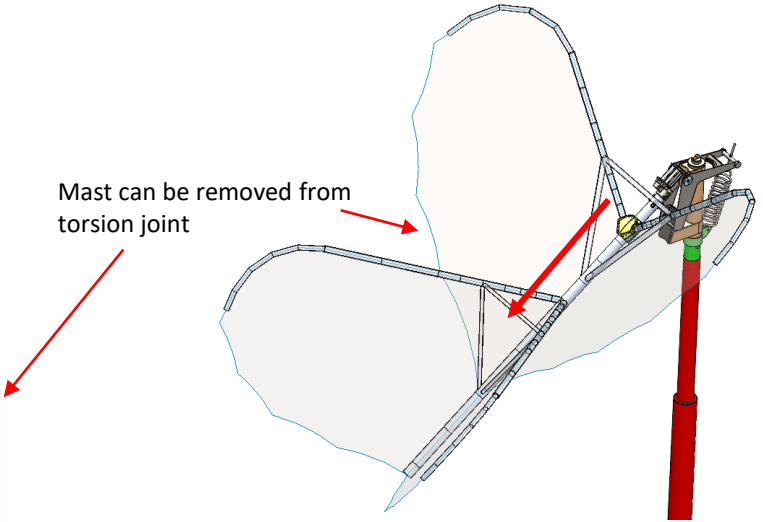


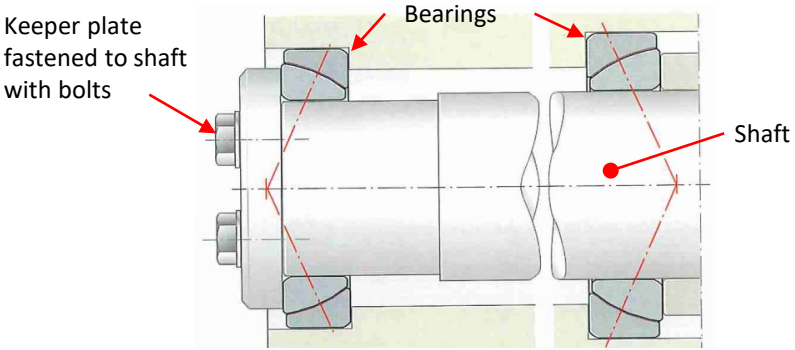


Torsion Joint Detail and Engineering

The new torsion joint uses an arrangement of maintenance free bearings that allows the mast (or main shaft) to be removed by unscrewing a cover and unbolting a keeper plate.



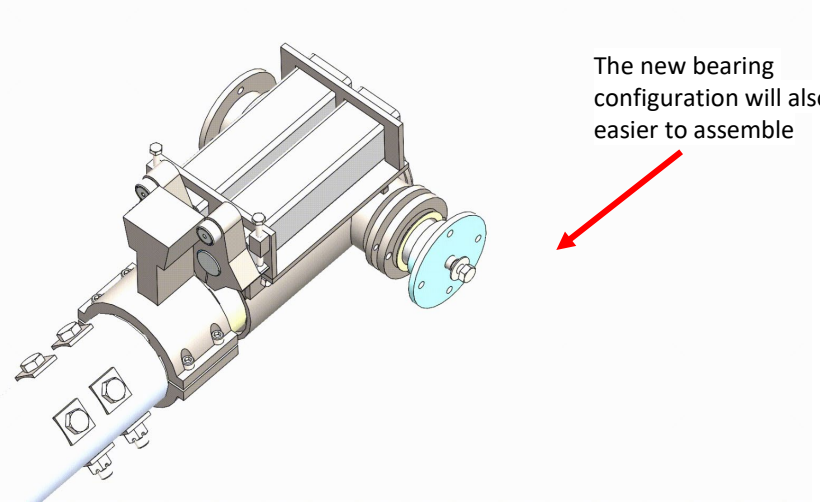




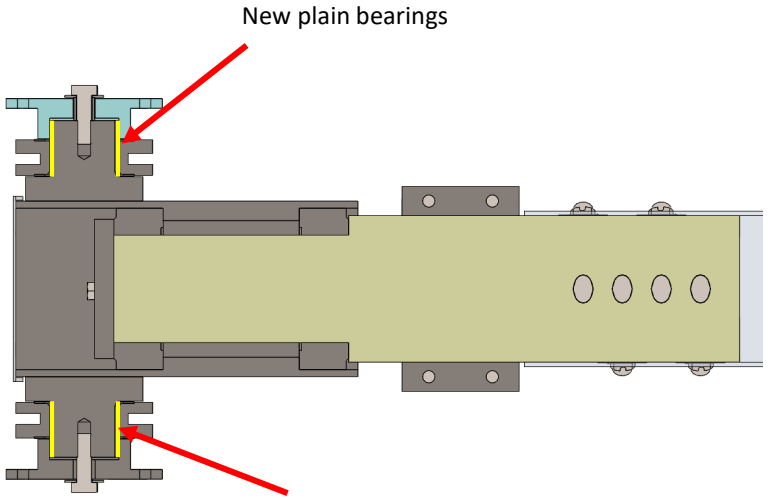
Bearing and cap arrangement similar to what is used on butterfly joint

New Pivot Bearings and Stub Shafts

- The old 2” steel pin and the old ball bearings that allowed the butterfly to swing up and down will be replaced by stronger, more supportive shafts and modern, maintenance free, plain bearings (similar to those utilized in the 2018 cap redesign).
- These bearings have no moving parts, have a longer service life, can handle higher loads, and require no lubrication.

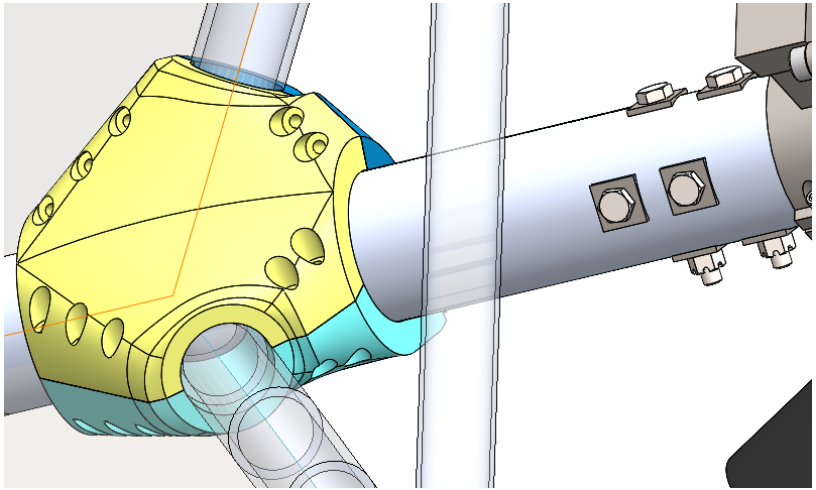


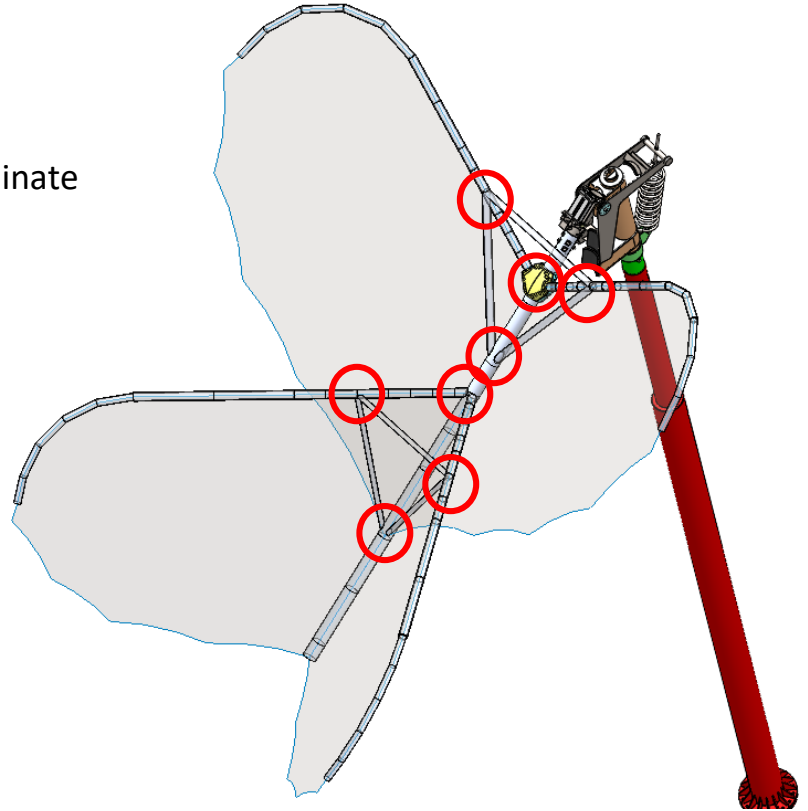
The new bearing configuration will also be easier to assemble



Frame Connections (Bolted not Welded)

The wing joints will be bolted, clamp-on connections to eliminate strength reductions created by welds at key stress areas.

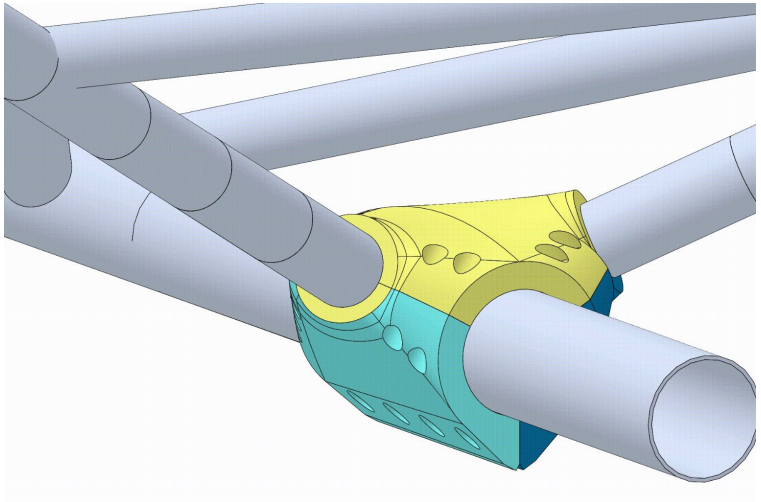




(Joints circled in red)

Frame Connections

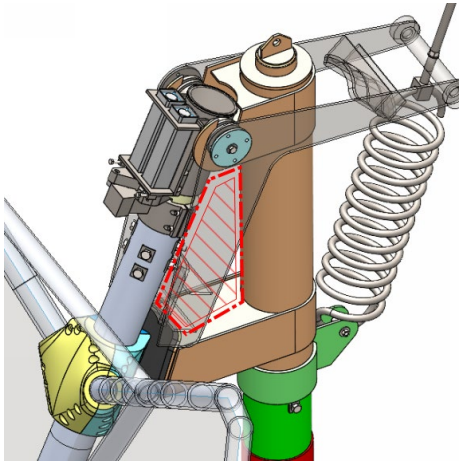
- Each bolted wing joint will consist of three or four parts that clamp onto the wings and main shaft.
- These connections will allow the wings to individually disconnect from the main shaft.

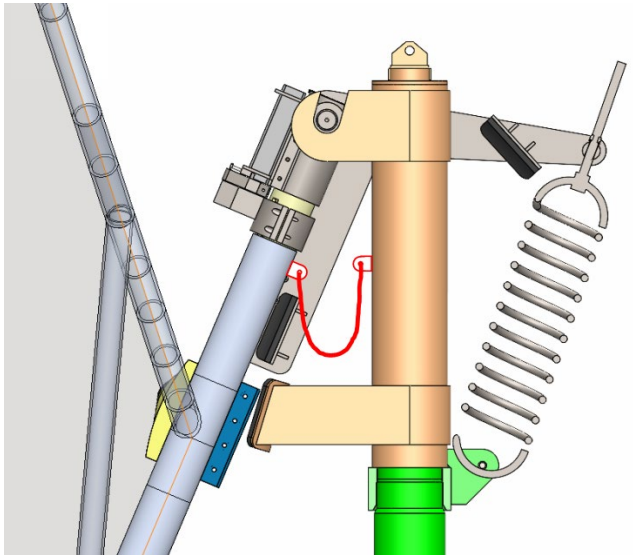


Note: only one wing joint has been mocked up at this time.

Backup Lanyard

- A steel lanyard will connect the mast assembly to the butterfly's main shaft to prevent the butterfly from falling to the ground in case of a worst case scenario detach.
- The lanyard will be nested within the boomerang to be less visibly obtrusive.



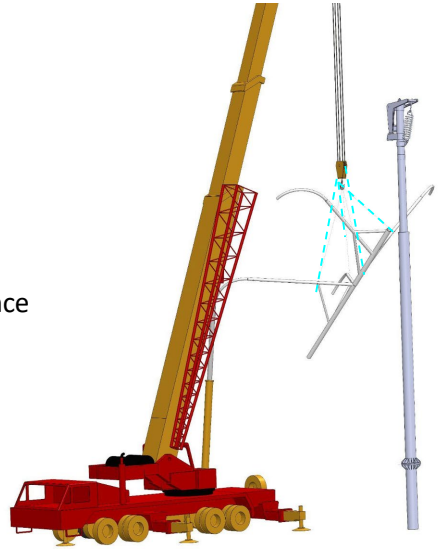


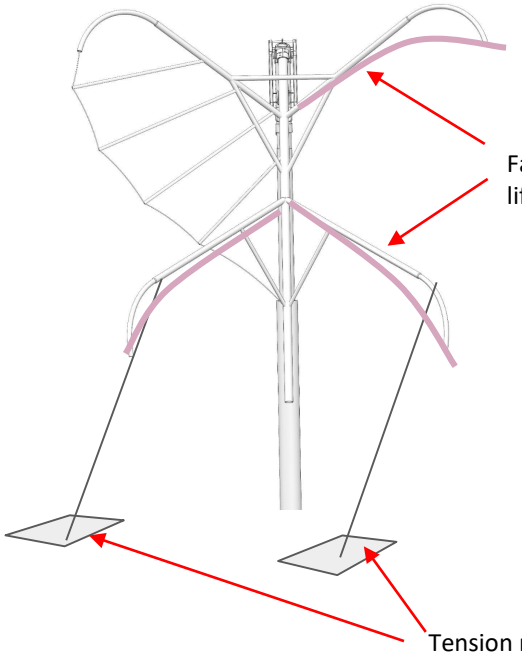
Installation Process

Frame can be lifted assembled with wing membranes bound to reduce wind loading then unfurled and secured once frame is up

Advantages:

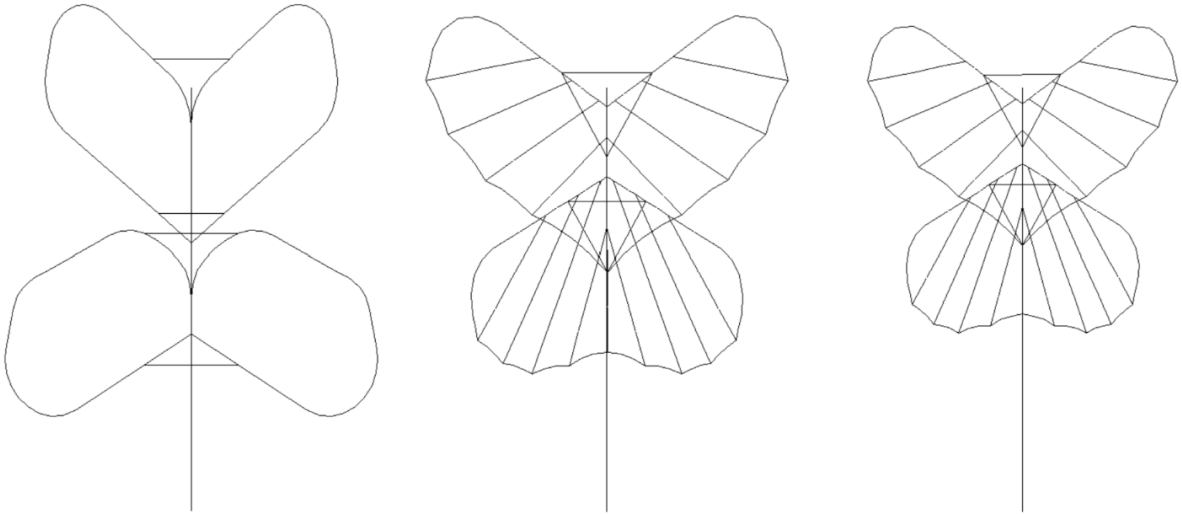
- Greatly reduce installation time
- Less time in lifts for fabric installation
- Easy repair and maintenance as needed





Wind Loading Studies

While looking at Wind loading force analysis we studied a 15% reduction in scale of the new Butterfly design, this has become our preferred size and solution.



Original Preliminary Prefered

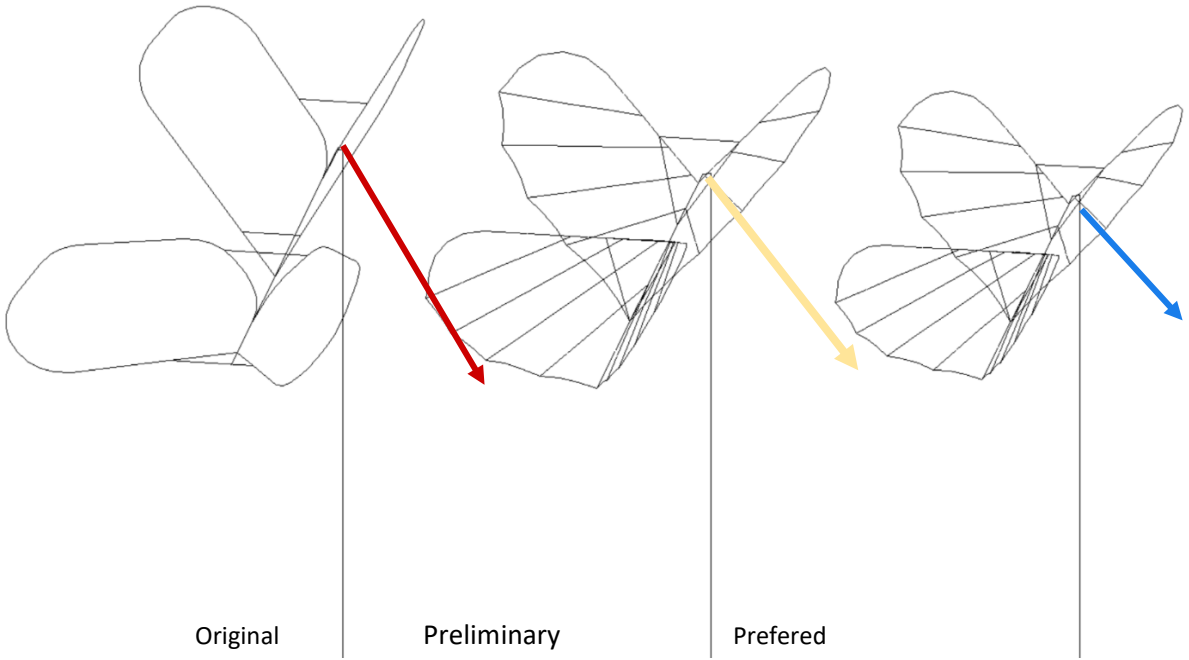
Wing Design and Size- Wind Loading Studies Results

Average wind load reaction to design and scaled models

*engineering results simplified for overall ease of reference

Reaction (kip)

9.0
8.0
7.0
6.0
5.0
4.0



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Spokane Butterfly 2021-22

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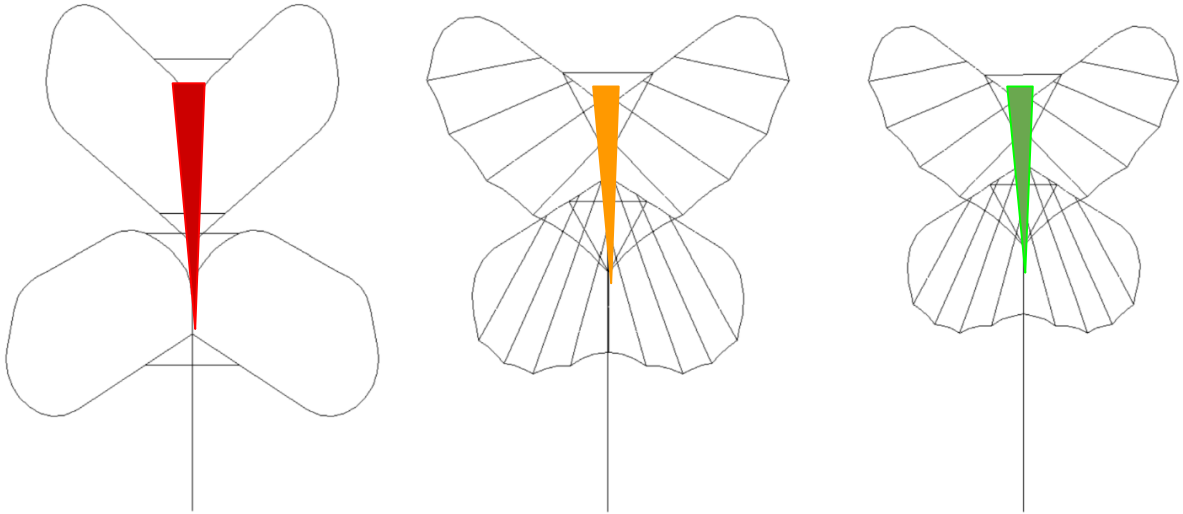
Loading Comparisons on Torsion

(twist in spine not including torsion bar)

*engineering results simplified for overall ease of reference

Beam Torsion (kip-ft)

- 27
- 22.5
- 18
- 13.5
- 9
- 4.5



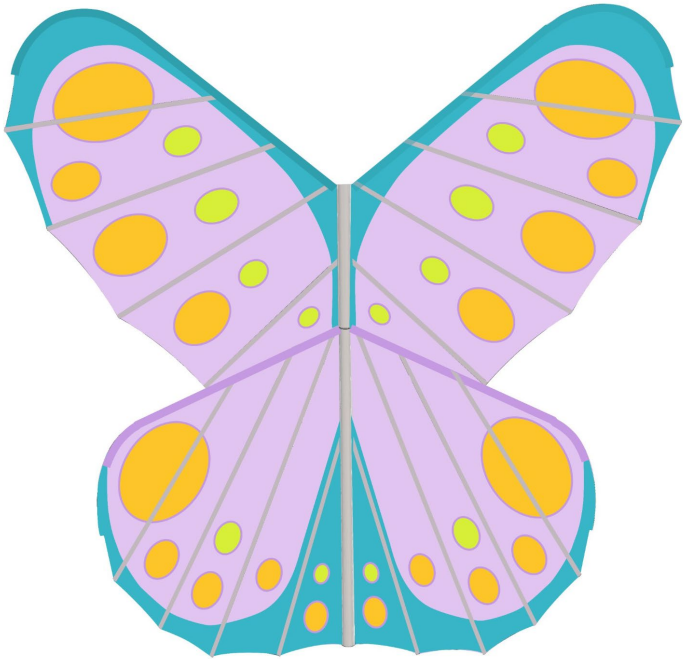
Original Preliminary Prefered

New Preferred Frame at 15 % Reduced Scale

Member Sizing based on loading analysis

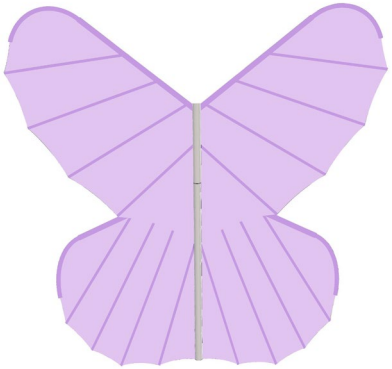
Wing VIsual Design

The battens give us a new visual feature to work with in the design process. The following are a mix of options in design and colors and are only the beginning of what is possible.



The following pages have a number of options, as stated these are not a final selection but a starting point for feedback. In phase II further refinement of these will happen

Wing VIsual Design - Basic Colors



a

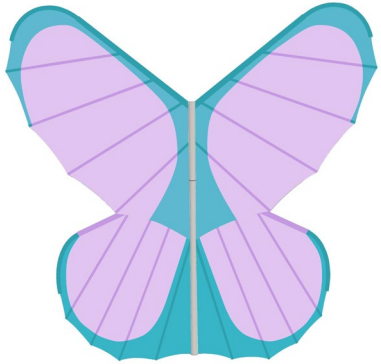
b

c

d

e

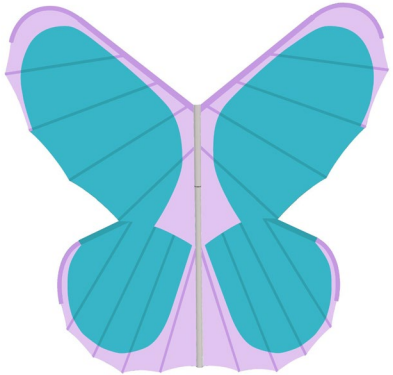
Wing VIsual Design - Basic Colors with Border



a

b

c

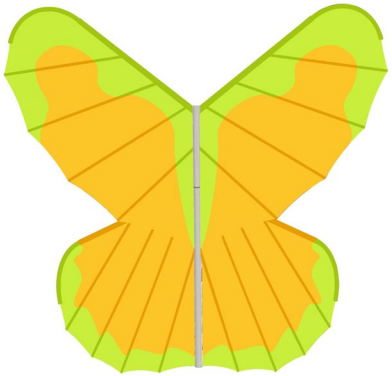


d

e

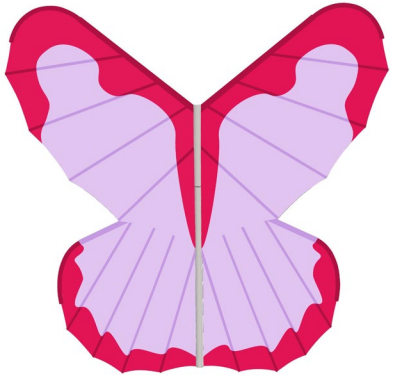
Wing VIsual Design - Basic Colors with Fancy Border

a



b

c



d

e

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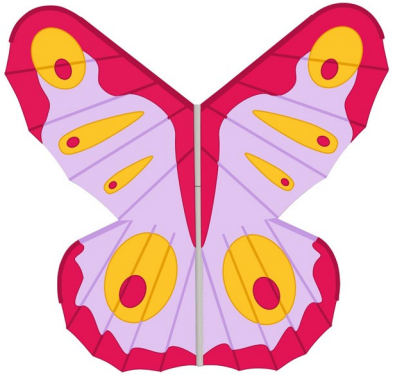
Wing VIsual Design - Fancy Border and Dots

a



b

c

d

e

f

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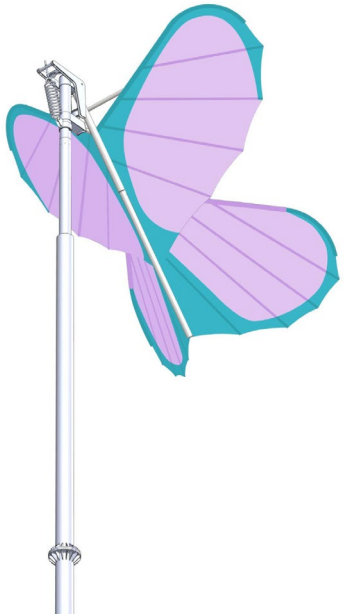
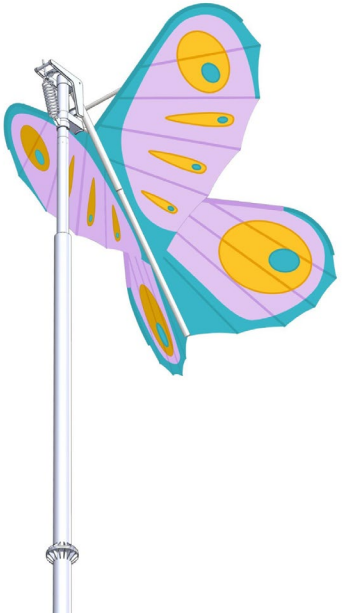
COFFMAN ENGINEERS

Wing Visual Design- side views





Phase II - Moving Forward

Phase 2 will turn these concepts into the New Butterfly. It includes:

- Evaluation and repair of the existing rotor, spring capacity check, and previous top assembly work.
- Detailed Design for construction & fabrication of new components, including:
  - Aluminum tube frame development
  - Machined frame joints
  - Batten fixtures and batten testing
  - Torsion joint assembly
  - Fabric wings connection details
  - Fabric wing patterning with final new design
- Materials and supplier sourcing
- Installation planning
- Lighting design

Budget

2020-21 Design, Fabrication and Construction estimated budgets

As Phase 1 design did not include construction quotable drawings, the budget needs for constructions contain a wide range of estimation at current moment

Design			
Pre Design		**low**	**high**
Failure Assessment and Next Step Planning/ Coffman		$6,000	$6,000
	subtotal	**$6,000**	**$6,000**
Design Fees- Phase 1			
Coffman		$14,000	$14,000
Guildworks		$13,500	$13,500
	subtotal	**$27,500**	**$27,500**
Design Fees- Phase 2			
Coffman		$36,000	$46,000
Guildworks		$21,000	$25,000
	subtotal	**$57,000**	**$71,000**
Design - Construction Support			
Coffman		$1,500	$2,500
Guildworks		$0	$1,500
	subtotal	**$1,500**	**$4,000**
Total Design Budget		**$92,000**	**$108,500**

Construction	low	high
Repair old rotor and boomerang	$5,000	$7,500
Butterfly Material-Aluminum	$1,500	$22,700
Butterfly Fabrication- Wing Joints	$20,000	$29,450
Butterfly Fabrication- tube bending (wing tips)	$2,000	$4,000
Butterfly Fabrication- Torsion Assembly	$15,000	$20,000
Misc. Butterfly Connections	$5,000	$13,000
Nickel Plate Steel Components	$800	$2,000
Assemble Frame	$4,500	$7,000
Install Service Ballast	$3,500	$4,500
Frame and wing assembly cradles	$2,000	$3,000
Erect Frame	$4,500	$6,800
Supply Fabric	$16,000	$20,000
Install Fabric	$12,000	$14,000
Ground based Up-lighting	$1,500	$4,000
frame transportation	$1,000	$3,000
Construction contingency	$14,145	$24,143
Tax (8.9%)	$9,652	$16,473
Total Construction Budget	**$94,300**	**$160,950**

Total Budget 1st Butterfly*	**$186,300**	**$269,450**

*Design effort + construction of first butterfly

Budget

Second, New Butterfly		
Construction	**low**	**high**
New Foundation	$15,000	$18,000
New Mast	$25,000	$28,000
Butterfly Material-Aluminum	$1,500	$22,700
Butterfly Fabrication- Wing Joints**	$20,000	$29,450
Butterfly Fabrication- tube bending**	$2,000	$4,000
Butterfly Fabrication- Torsion Assembly**	$15,000	$20,000
Misc. Butterfly Connections**	$5,000	$13,000
Nickel Plate Steel Components	$800	$2,000
Assemble Frame	$4,500	$7,000
Install Service Ballast	$3,500	$4,500
Erect Frame	$4,500	$6,800
Supply Fabric**	$16,000	$20,000
Install Fabric**	$12,000	$14,000
frame transportation	$1,000	$3,000
Reduction for making at same time as 1st Butterfly	**-$14,000**	**-$30,135**
Construction Contingency	$16,770	$24,347
Tax (8.9%)	$11,443	$16,613
Total Construction Budget*	**$125,800**	**$192,450**

* Total calculated as if done at same time as replacement butterfly for fabrication savings

** Line items decreased fabrication costs due to duplicated parts between butterflies.

A revitalized Expo ‘74 Butterfly design integrates Spokane’s historic past and bright future- The World’s Fair with a modern flair.

New engineering tech ensures the long term safety and reliable functionality of this dynamic art piece at home only in Riverfront Park.

Locals and visitors alike will enjoy and appreciate this 21st century treatment of a 20th century icon.