Welcome to

IFAI EXPO

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Technology Behind Shade Sails

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Introduction

Shade Sails are engineered structures however, the technology is often misunderstood and underestimated.

The result are that many shade sails fail long before their normal life expectancy and they often don't look great.

In this session we'll learn to avoid this by understanding:

1. The differences between the right and wrong design
2. How a catenary works and why it's so fundamental
3. How patterning affects shade sail

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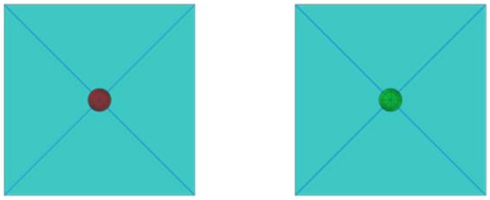
Top View



2 Cubes – same size in all 3 dimensions
2 Balls – held in the middle of the cube by blue ropes
Like many sails other than the color everything **looks** the same

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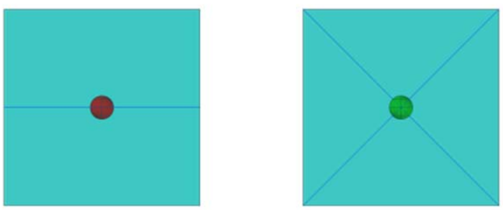
Front View



From the front we can see some difference
Balls are still held in the middle of the cube by blue ropes
Red ball held in place from sides – Green ball from the corners

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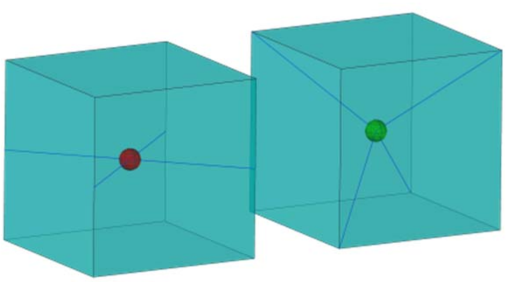

Fabric has little out of plane stiffness
So a sail design shown by the red ball can move up and down
But the green ball sail design is restrained

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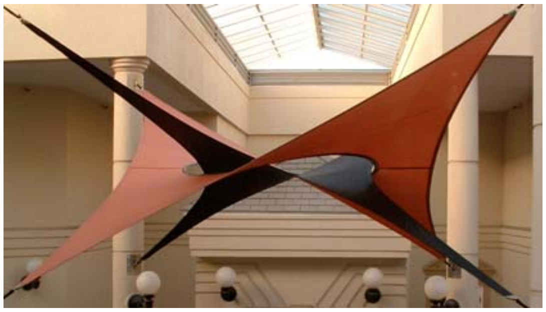

Green Ball shows why 3D form is so important

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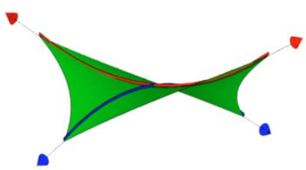
3D SAILS

The basic "Hypar" sail demonstrates an "Anti-Clastic" double curved shape.

2 opposing radii (arcs)

- between the 2 low points (blue)
- between the 2 high points (red)

Built in stiffness <u>resists loads</u>, <u>reduces deflection</u> and <u>prolongs service life</u>



All this **AND** they look great

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Other double curved shapes

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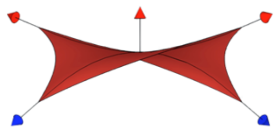
3D SAILS

- A load will cause the sail to change shape until it finds a new "Force Balance" shape.
- A Hypar subjected to uplift, has increased tension in the low arc and decreased tension in the high arc allowing the fabric to change shape.



8p #vdlo#z lwk#31 6nSd#dssolhg#
Ghiohfwlrq#583p p

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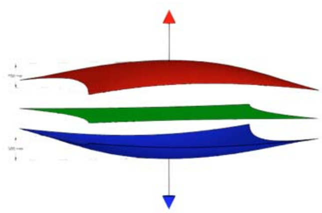
FLAT SAILS

- In contrast, a flat sail subjected to the same load has no opposing curvature to help resist the force.
- Total deflection is larger leading to:
  - stretching
  - the "saggy-baggy" look
  - early failure/shorter life



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FLAT SAILS

Large deflections result in edge cables working like hacksaws on the fabric edges

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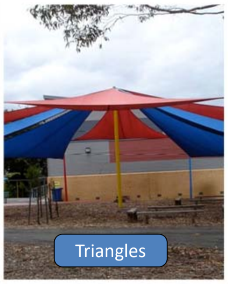
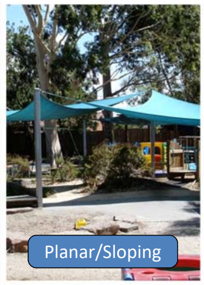
FLAT SAILS





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Design Summary

Good Design requires a double curved surface

There must be height differences

For a hypar aim for a range of 20-30% of span

so for a 30ft span the height difference between high poles and low poles should be between 6 and 9 feet.

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CATENARY

What is it:

Idealized shape of a chain held at the 2 ends

In our industry it's a term used to describe the edge of the sail.

What does it do:

- Pre-Stress – converts cable tension into work to tension the fabric
- Under load – collects all the loads from the fabric and directs them to the sail fixing points then (via the posts) to the ground

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T = Work x Radius

Radius (R) = $((Span^2)/(8xDip))+(Dip/2)$

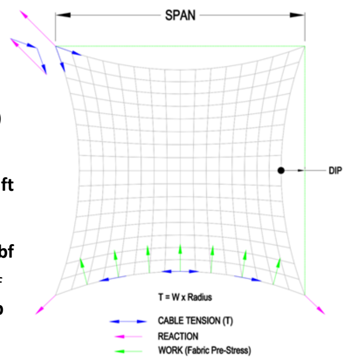
For Span 30ft, Dip 2ft

R = 57.3 ft

For W of 10lb/ft

T = 573 lbf

Reaction = Vector sum of the cable tensions = **1 kip**



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Fabric Pre-Stress w	10.00	lb/ft
Sail Edge Span	30.0	ft
Corner Angle	90.00	degrees (post to post)

Cable T (lbf)	Radius (ft)	Dip (ft)	Dip (%)	Reaction kips	kN
390.0	39.0	3.00	10.0%	0.72	3.27
430.2	43.0	2.70	9.0%	0.78	3.55
480.8	48.1	2.40	8.0%	0.86	3.89
572.5	57.3	2.00	7.0%	0.99	4.51
634.0	63.4	1.80	6.0%	1.08	4.91
757.5	75.8	1.50	5.0%	1.26	5.73
943.5	94.4	1.20	4.0%	1.53	6.94
1254.5	125.5	0.90	3.0%	1.97	8.95
1878.0	187.8	0.60	2.0%	2.86	12.97
3751.5	375.2	0.30	1.0%	5.51	25.01

BIGGER DIP = LESS T + SMALLER RADIUS = LOWER REACTION FORCE

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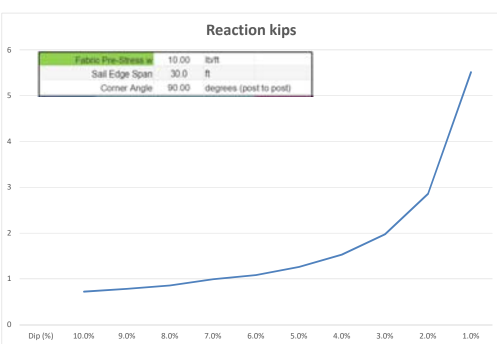

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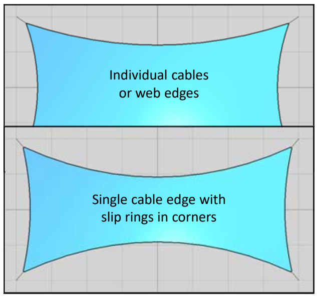
Catenary Shape – 8 x 4 sail with 8% dip/span



8% dip means different tensions on each side.

Reaction angle tends in the direction of the long span with highest tension

Single edge cable by definition means a single tension therefore different radius on each side.

Reaction angle bisects corner angle

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Catenary Summary

Sales-person and client want min catenary dip / more shade:

- We can see changing dip from 7% to 3% doubles reaction
- In real life installers don't double pre-stress tension so in fact the W (pre-stress) is halved or less.
- The sail is therefore allowed to deflect, flog, stretch and sag

Critical – Edge Shape:

- Not a dip/span percentage if single cable

Critical – Site Measure:

- Measure from post connection points – don't include corner hardware and take site measurements from ends of turnbuckles for example.

Critical – Edge Cable must be:

- Correct length
- Locked off at correct length before installing
- Adequate tensile strength so it will not stretch/fail

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MAKING 3D SAILS

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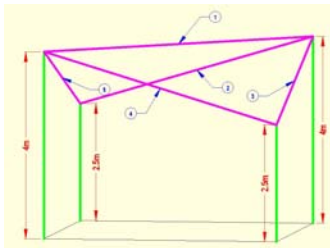
OLD PROCESS

(1) Site measured - often only 5 dimensions

(2) No checks for measurement errors

(3) Sail patterns “worked out” by averaging diagonals



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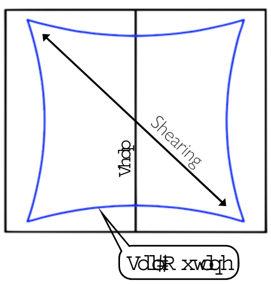
OLD PROCESS

(4) Flat fabric joined to form a large flat panel

(5) Sail pattern marked onto flat fabric

(6) Fabric cut and hemmed

(7) Sail forced into 3D form by “Shear” during installation



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THE RESULT

- Forcing flat fabric into 3D forms result in uneven stress and zones of:

  (a) low tension = wrinkles

  (b) high stress and stretching = shorter product life

- Consequently sails tend to be made too flat to avoid these problems

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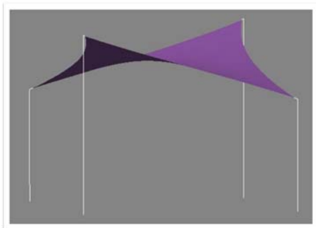
MODERN PROCESS

1. Site measure - 10 dimensions for Hypar (ensures accuracy of site measurements)
2. Model sail as 3D mesh
3. Panel by splitting mesh into multiple "shaped" panels – when joined will form a 3D shape



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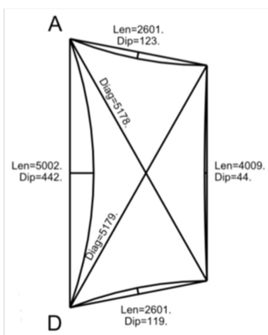
MODERN PROCESS

(4) Join shaped panels – note dip in seam removes loose fabric

(5) Hem

(6) Sail fabricated into a 3D shape (it will not lay flat on the floor)

(7) Low shearing stress during installation



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OUTCOME

Correctly formed sails result in even stresses:

(a) less wrinkles

(b) longer product life

(c) better looking product

(d) increased inherent stiffness

(e) less deflection

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Summary

- Properly designed and patterned shade sails will last longer, look better and your best advertising are ecstatic customers
- Understanding the basic math of tensile architecture will help improve your decisions about how to make a sail, communicate better with your clients, and head off problems before they occur
- Low cost software now allows all fabricators to design and pattern shade sails and other 3D forms in the same way as professional suppliers
- If you'd like to see the software in action or have more questions please visit us at booth #1563

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Thank You

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