Wind Turbine Blade Workshop
SNL, DOE, NREL

24 Feb 04

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Proof-of-Concept Manufacturing and Testing of Composite Wind Generator Blades Made by HCBMP (High Compression Bladder Molded Prepreg)

DE-FG36-03GO13140

Alaska Applied Sciences, Inc. (AASI)

Prime subcontractor:
Quatro Composites, Poway, CA (QC)

DE-FG36-03GO13140

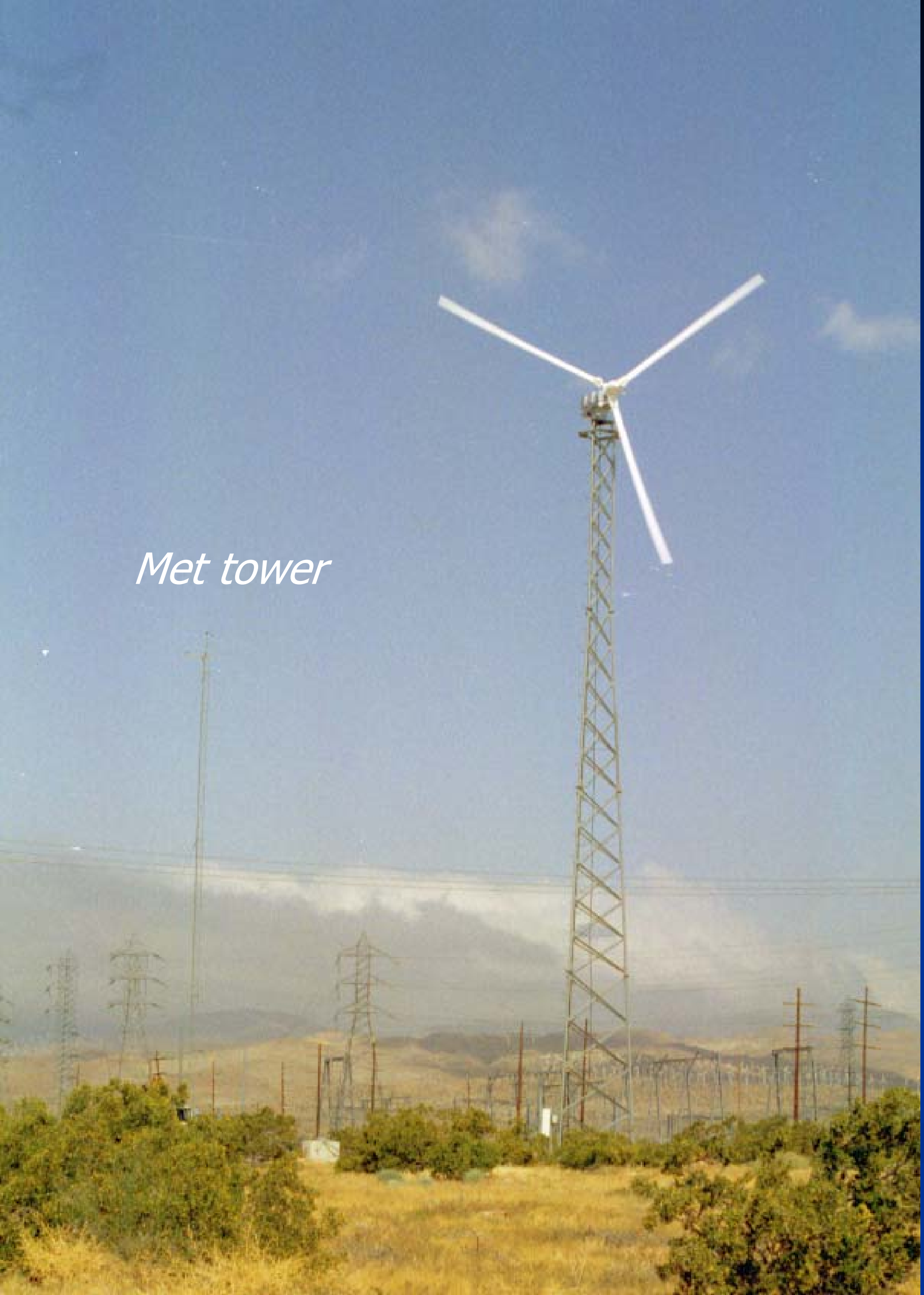
- Goal: Lower long-term COE
- Small wind turbines
- Low windspeed: Class 3
- 1 Oct 03 – 1 Oct 04
- Mfg proof-of-concept, not blade design or performance
- Lower cost, high quality blades
- $ 118K = $78K DOE + $40K AASI
- New blade design: 12m diam;
  Salter & Associates, via royalty
- Tooling design and fab: QC
- Blade fabrication: QC
- Field testing, San Gorgonio Pass, CA:
  AASI windplant, short-term and long-term

DE-FG36-03GO13140

- Produce several sets 12m diam blades by HCBMP: QC prime sub
- Test at AASI Palm Springs windplant
  - Short term: dynamics, power curve, survival
  - Accelerated fatigue life test
  - Long term: survival, degradation
- Document tooling and production costs
- Develop cost model for HCBMP process
- Poster at Global Windpower 2004: Ken Gamble, QC principal, presenting

AASI windplant, Palm Springs, CA

14 wind gen's, fixed speed, 50 kW drivetrain, downwind, free yaw, 26 m hub height

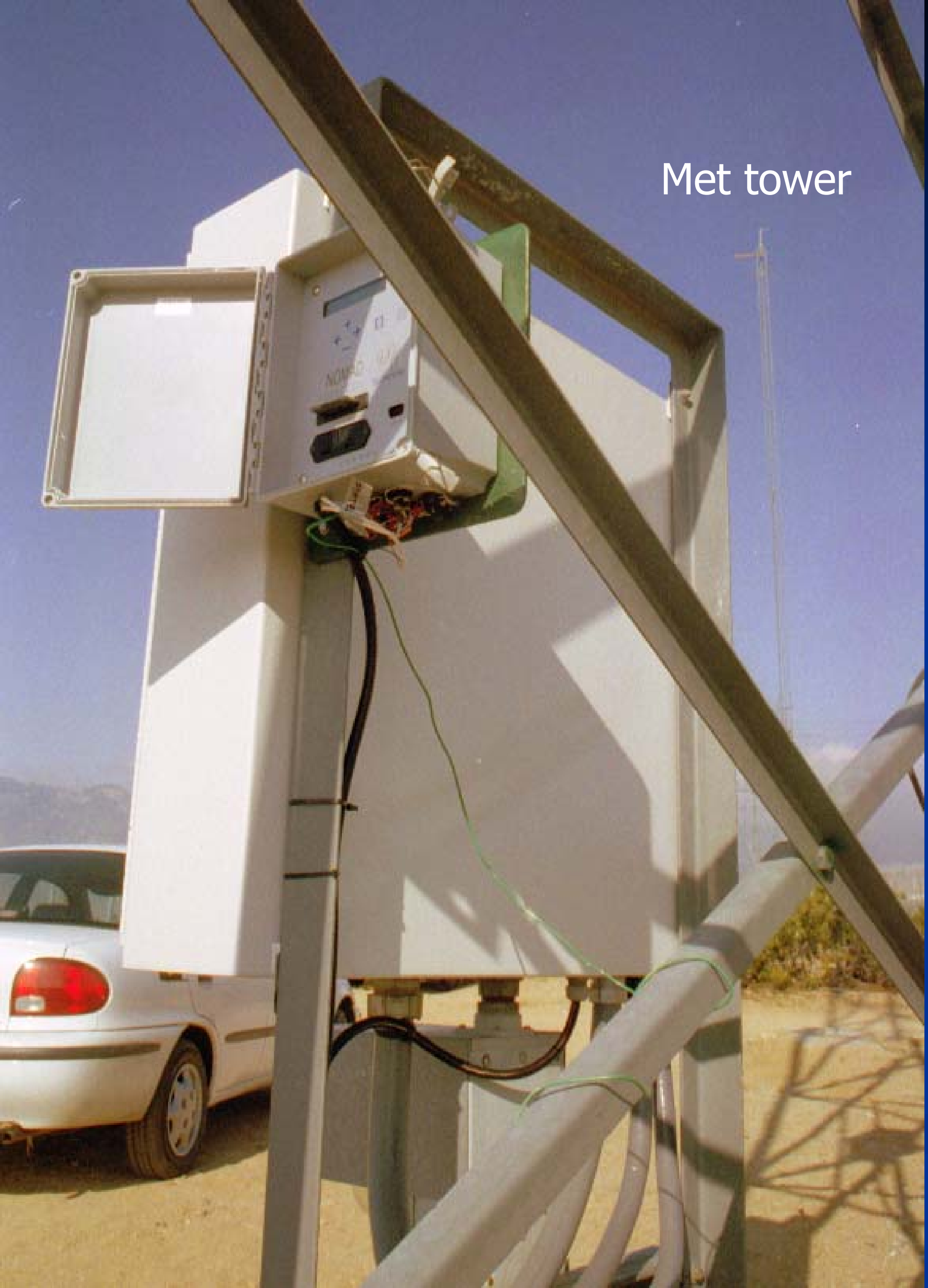


Instrumented, unobstructed test site

AASI windplant, Palm Springs, CA

13m diam blade set installed

View to WNW



NOMAD datalogger, on wind generator control cabinet

- Anem 1
- Anem 2
- Wind direction
- Wind slope
- kW (OSI precision xducer)
- State: on-line
- Tracking yaw error

Preliminary cost model :

5.6 m LOA blade; 1000 per year

- Tooling design and fab $30 K
  - Aluminum mold to cure blade; 1 K blade life
  - Airspring press constrains and heats mold
- Amortization in first year = $30 per blade

Preliminary cost model :

5.6 m LOA blade; 1000 per year

Turbine diameter:	*12m*	*13m*	*14m*
■ Carbon prepreg: 35 lbs @ $12 / lb @ 12 m diam	$ 420	$ 500	$ 650
■ Other material:			
■ LE mass	$ 50	$ 70	$ 85
■ Paint, primer, supplies	$ 60	$ 70	$ 85
■ Root box fill, SS washer plates	$ 60	$ 70	$ 85
■ Prepreg cut, assemble, layup:			
■ 4 man-hours @ $25 / hr (burdened) =	$ 100	$ 125	$ 150
■ Demold, prep for paint:			
■ 2 man-hours @ $25 / hr (“) =	$ 50	$ 50	$ 60
■ Prime and paint:			
■ 1 man-hour @ $40 / hr (“) =	$ 40	$ 40	$ 50
■ Fill + drill root box, install washer plates:			
■ 2 man-hours @ $25 / hr (“) =	$ 50	$ 50	$ 50
■ Balance:			
■ ½ man-hour @ $25 / hr (“) =	$ 13	$ 13	$ 13
TOTAL MATERIAL AND BURDENED LABOR	$ 743	$ 988	$ 1,228
TOOLING AMORTIZATION	$ 30	$ 40	$ 60
MARKUP @ 20% (on total M+L+TA)	$ 150	$ 198	$ 250
SELLING PRICE	$ 923	$ 1,068	$ 1,538
PRICE PER SQUARE METER	$ 7.90	$ 7.73	$ 9.72

Tooling Design Team, with Tip Mold Sections, 20 Feb 04, at QC

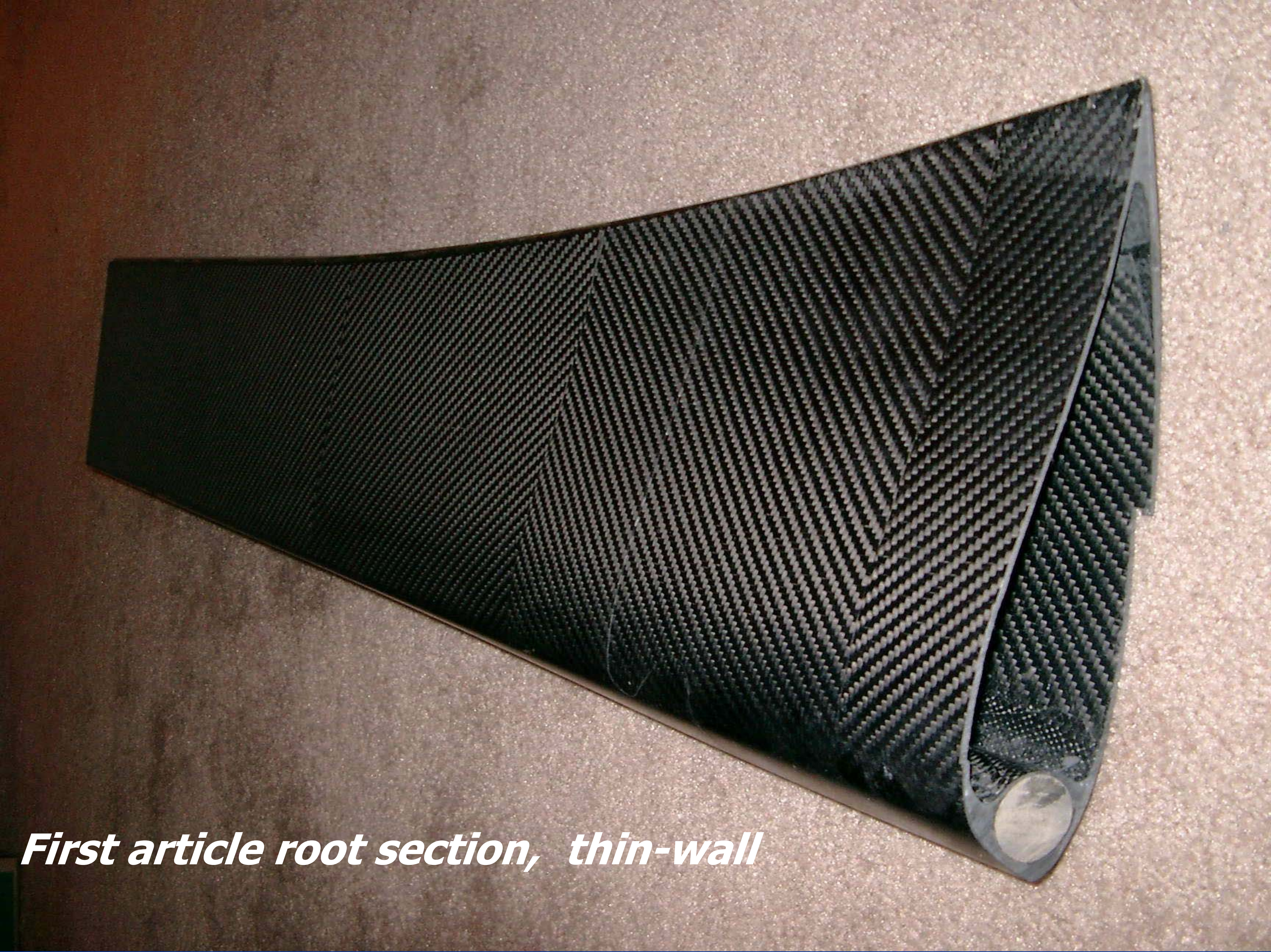
- Jason Nelson, QC, blade project manager (L)
- Ed Salter, S&A, blade shape design (C)
- Ken Gamble, QC, principal (R)

QC: Quatro Composites, Poway, CA

S&A: Salter and Associates, Oceanside, CA

First article root section, thin-wall

Root box end: 2.25" x 7"



First article root section, thin-wall

First article root section mockup on turbine hub

Note 6-bolt pattern

Blade Design Criteria

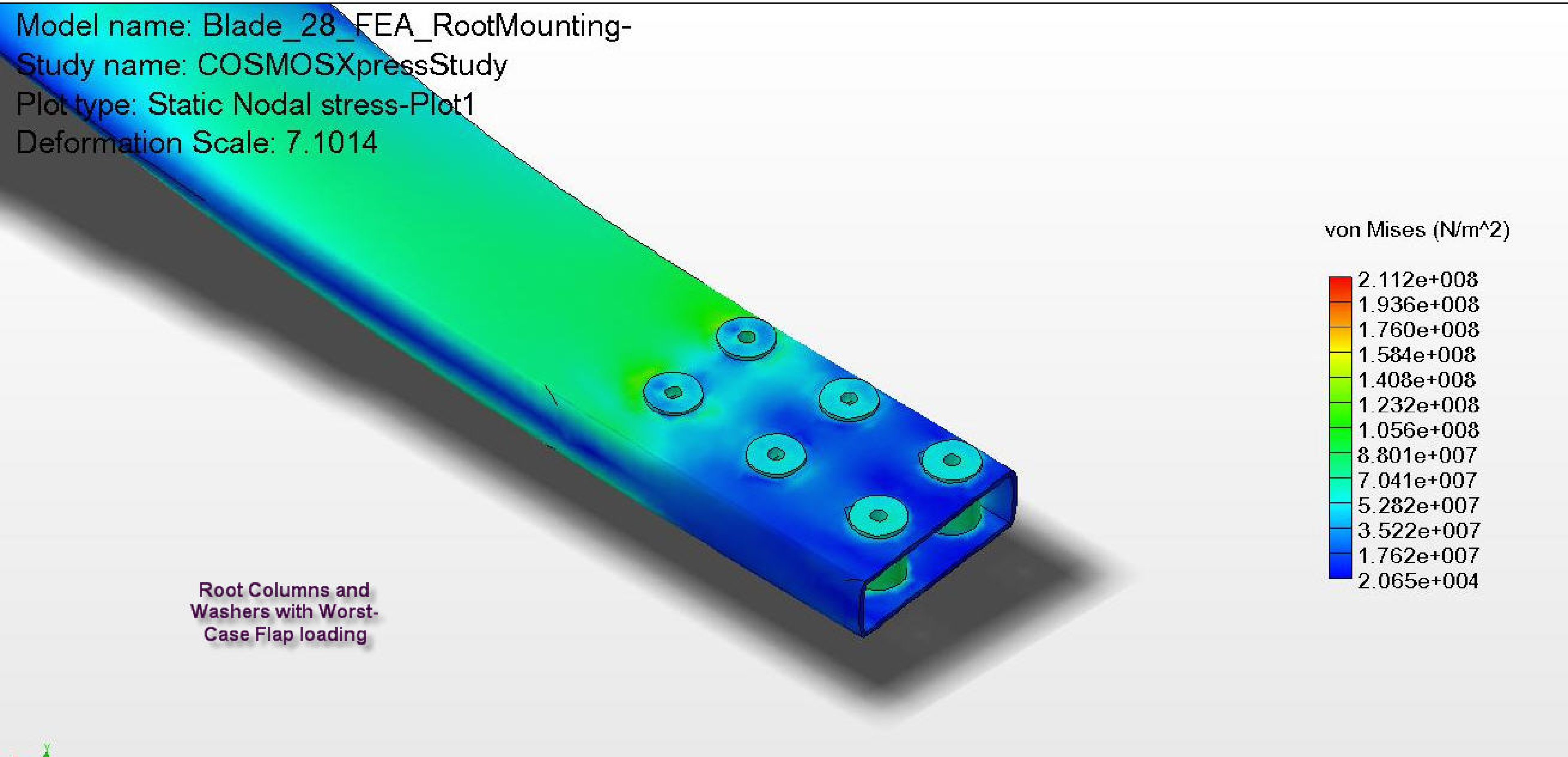
- Low-cost, high-quality manufacturing
- Modest chord: mold and press cost
- Power curve: stall-regulated
- Startup in light winds
- LE dirt degradation relief
- NREL 822, 823 airfoils

Blade Design

- 12 m diameter, 130 rpm, AASI Palm Springs windplant
  - Fixed-speed
  - Downwind, 3-blade, free-yaw
  - Root box bolts to extant hub: 6 @ ½" bolts
  - 225" LOA
  - Chord 10" max, 9" for ~60% of span, 7" tip region
  - Preliminary wall thickness: .300" root, .065" tip region
  - 35 lbs prepreg, ~ 50-60 lbs total
- Salter & Associates: NREL 822, 823 airfoils
- Ideal flap stiffness
  - "soft" turbine
  - Centrifugally-stiffened
  - Avoid tower
- Flutter - free: stiffness, quarter-chord mass-balance

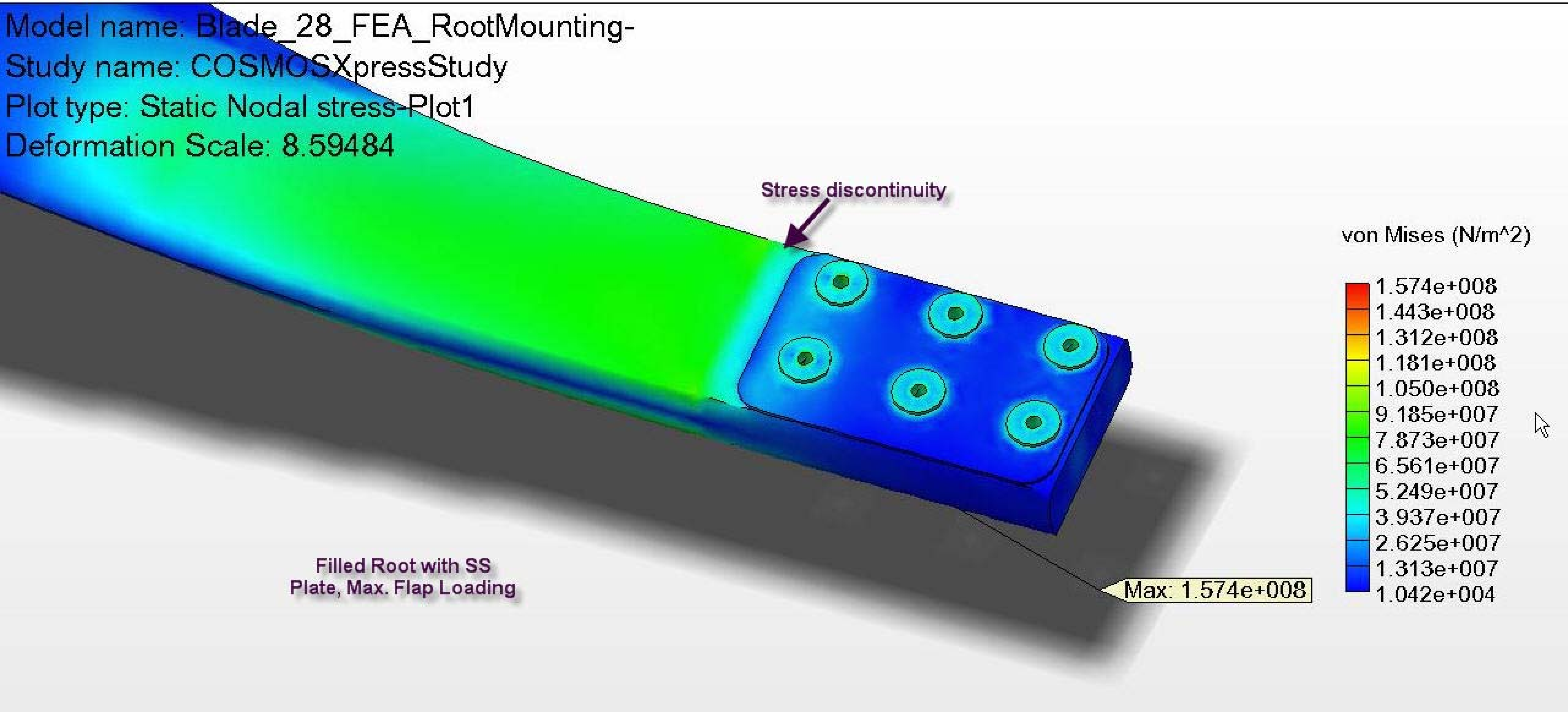
FEA analysis of root box stress
COSMOS, in SolidWorks, by Salter & Associates

Case: Columns and washers

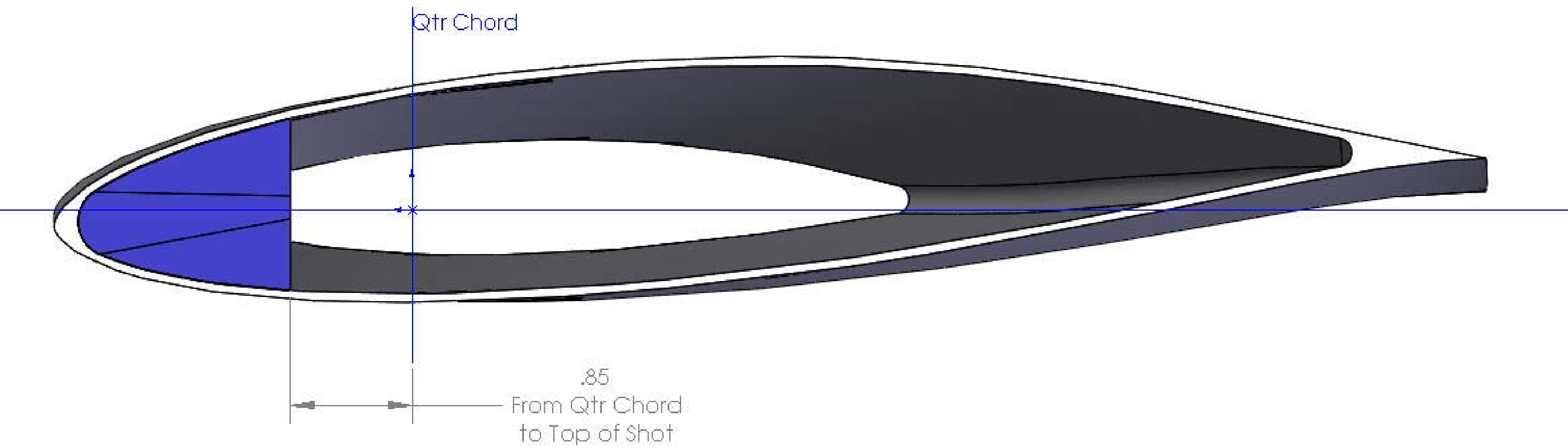


FEA analysis of root box stress
COSMOS, in SolidWorks, by Salter & Associates

Case: solid fill with washer plates



Tip region mass balance ahead of quarter-chord point
Blue: Leading Edge D-Spar (LEDS), steel shot + epoxy



Flap and torsional stiffness test fixture

Torsional Stiffness Test

Incentives for this project

- Class 3 wind: higher ratio of turbine swept area to drive train power rating
- Blades larger fraction of total wind turbine system capital cost
- Emphasize low-cost, high-quality blade production methods
- Need high quality composite for long blade service life
- Requires proof-of-concept blade fabrication + extensive field testing
- Capitalize on recent advances:
  - Solid modeling CAD – CAM software tools
  - CNC machining facility, lower cost
  - HCBMP process
  - Prepreg availability, cost: carbon and glass “tape”

HCBMP advantages

- No liquids
- Good process control
- Modest mfg skill level; die cut plies, layup
- Controlled high fiber : resin ratio
- High quality:
  - High compaction, minimum voids
  - Little variation in parts
  - Seamless blade
- Short production cycle time per part
- Easy to build entirely of “tape “
- Modular tooling: easy to modify, move, store
- Easy to vary lamination schedule
- High HDT: cure at 285 F
- Foam filling optional

HCBMP limitations

- Hollow, single-cavity part
- Limited structural enhancements
- Root attachment finished post-molding
- Foam filling required ?
- Limited size ? Blade length 10 – 15 m ?

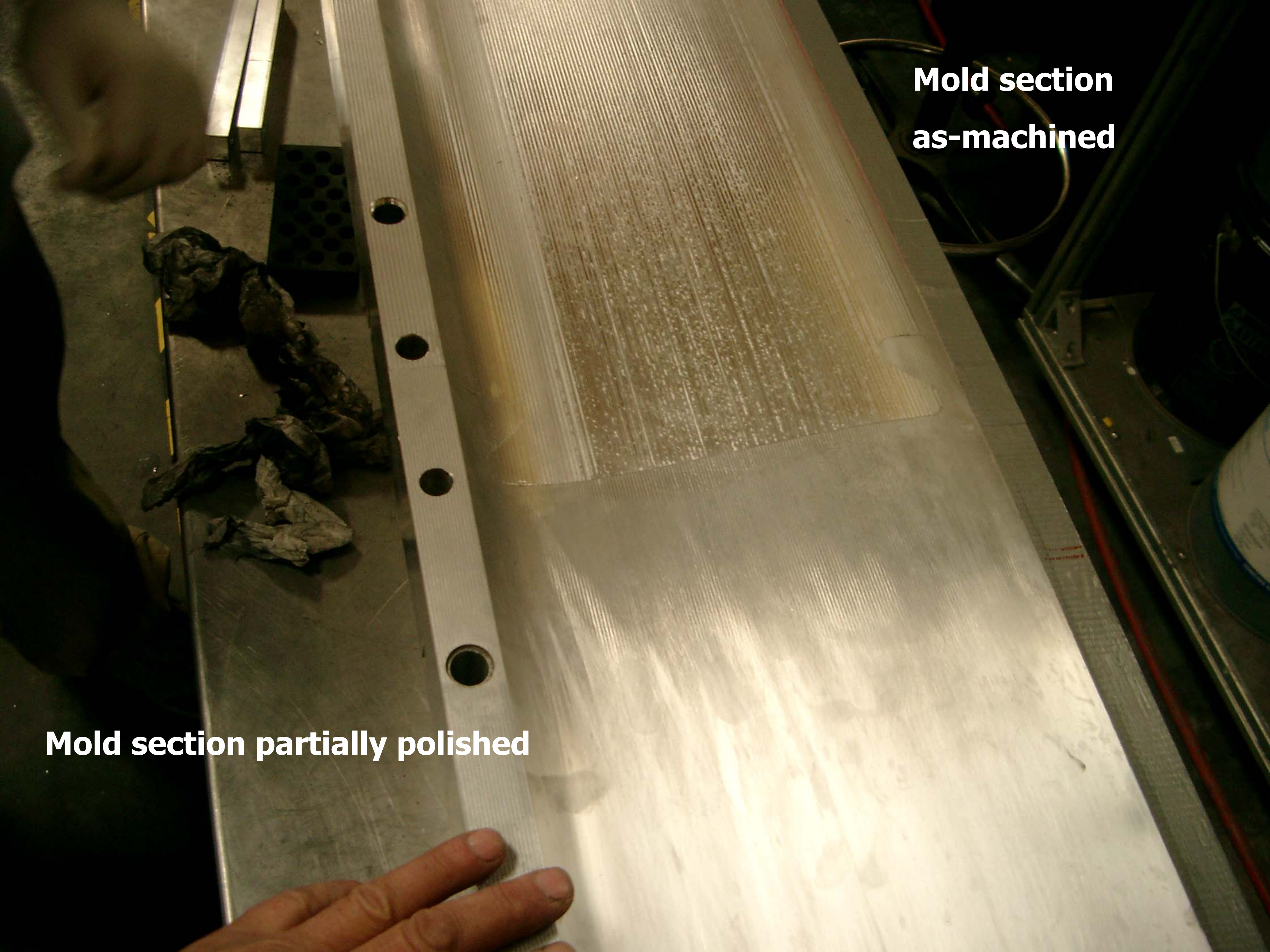
Prepreg

- Fiber pre-impregnated with catalyzed resin; dry, slightly sticky to touch (see sample)
- Activated at automated 250 F cure; freezer storage; room temp working
- Well-controlled fiber : resin ratio
- Wide variety material available:
  - Fiber-resin ratio
  - Tape, stitched, woven; tape lowest-cost
  - Carbon, glass, Kevlar
  - Roll width standard
- Assemble lamination schedule dry, at room temp:
  - Cut + stack tape: ply orientation
  - Vacuum consolidate, de-air
  - Die cut
  - No liquids
  - Minimum material waste

Blade quality

- Process control
- Uniform properties, weight (balancing)
- Freedom from defects, voids
  - Macro
  - Micro
- Infinite fatigue life
- SR+T expertise: adjunct to contract
  - SNL, NREL, NWTC
  - Blade design review
  - NDE, ultimate strength, failure modes
  - Test to failure; failure modes
- AASI windplant accelerated lifetime testing


CNC machining mold section


Mold section
as-machined
Mold section partially polished

Mold

Sanding

and

Polishing

Mold sections showing dovetail joints

Blade Mold Sections, QC, 20 Feb 04

JiJoe, CNC Manager, QC (L)

Ken Gamble, Principal, QC (R)


Prepreg cutting

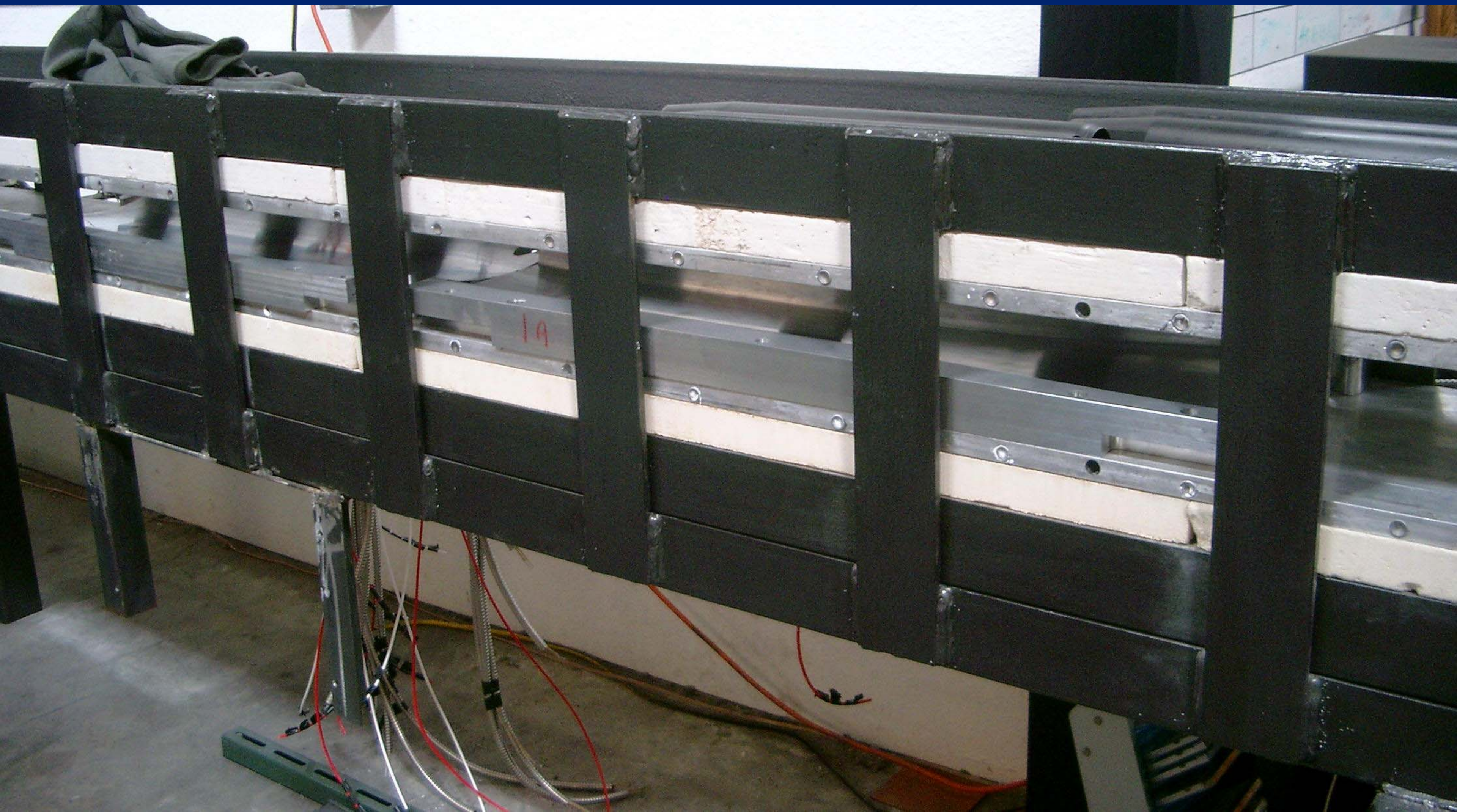
Complete Mold Section Half (right)

Mold Segments (left)

QC, 20 Feb 04

Closed mold rolls into the airspring press, at rear

Heated airspring press



Tentative project schedule Rev 20 Feb 04

- Tooling completed: mold, airspring press, at QC
- First article blade mold, prep for test: 23-26 Feb
- Properties test; root box fill + drill develop;
  revise design (lam schedule and LE mass): 27-29 Feb
- Second article blade mold, prep for test: 2 Mar
- Properties test; approve design (lam schedule and LE mass)
  for first blade set: 2-4 Mar
- Mold blade set 1; document time + material: 5-10 Mar
- Finish blade set 1: 10-13 Mar
- SR+T blade (SNL?): _____
- Install set 1 at Palm Springs test site: 14-16 Mar
- Test fly set 1; power curve; video; accel fatigue test: 16-30 Mar
- Revise design, if necessary: 1-5 Apr
- Build, install, test fly set 2: 6-15 Apr
- Build, install __ other test sets: Apr-May
- Long-term monitoring and reporting to DOE (NREL, NWTC, SNL)

Optional HCBMP concept

Test specimen: HCBMP with spanwise-sawed pultruded core

GO798 airfoil; 19 cm chord

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