What's New in Designing for Helicopter Duration

Prepared for

NARCON-2017

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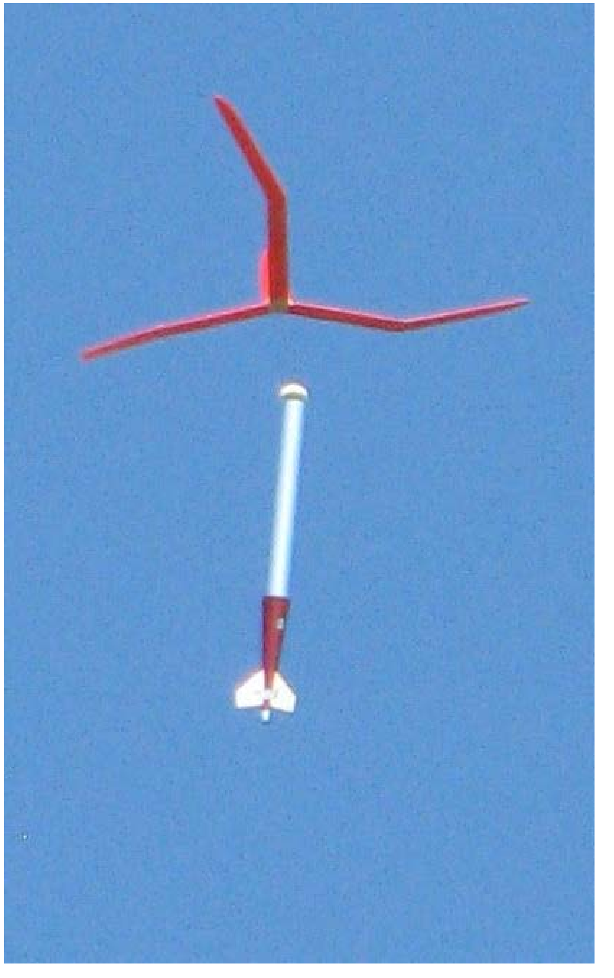
NAR 17540 L1

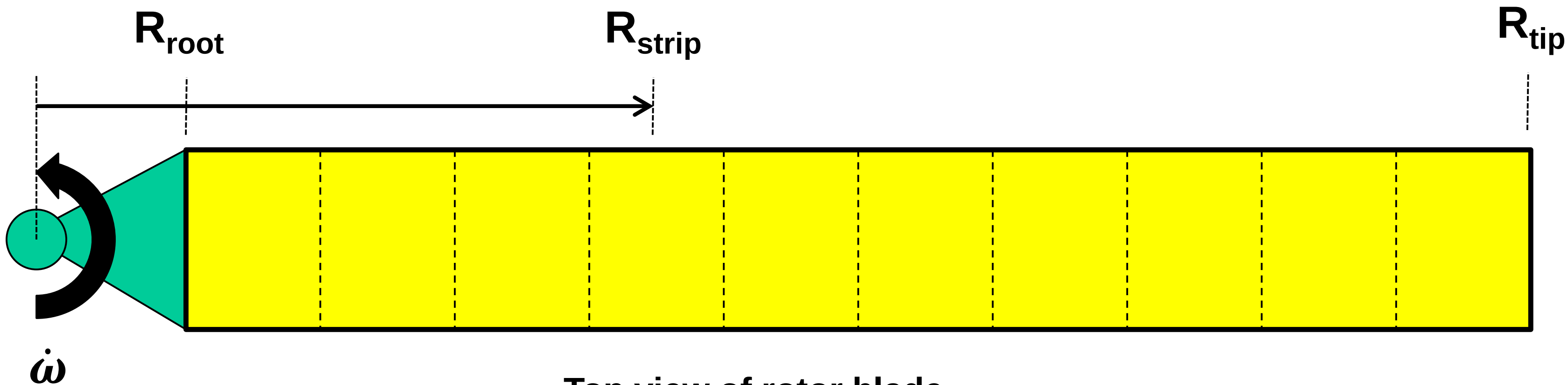
Topics

- Quick review of theory
- Blade design & airfoil selection
- Hub construction
- Internal or external rotor
- Spin-up requirements
- Analysis software
- Popular designs
  - Rota-Roc, Rose-a-Roc, Apogee
- G HD at NARAM-59
- Summary



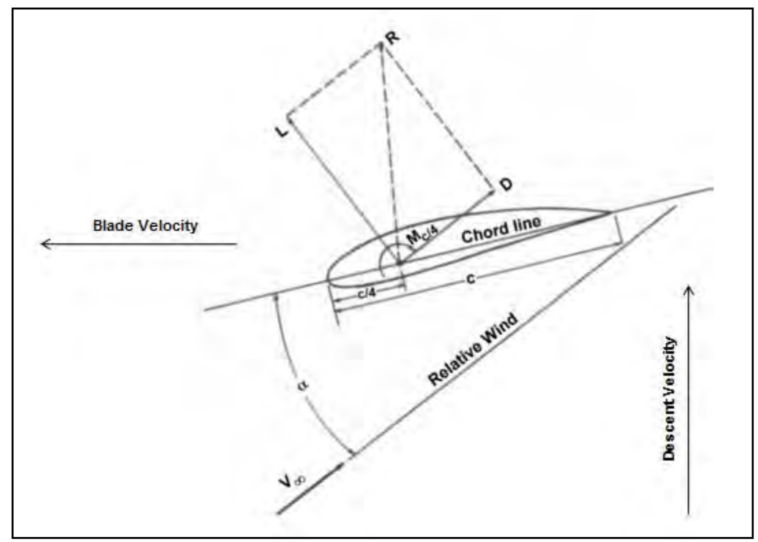
Helicopter Blades Have Unique Aerodynamics

Efficient Blade Angle Depends on Radius

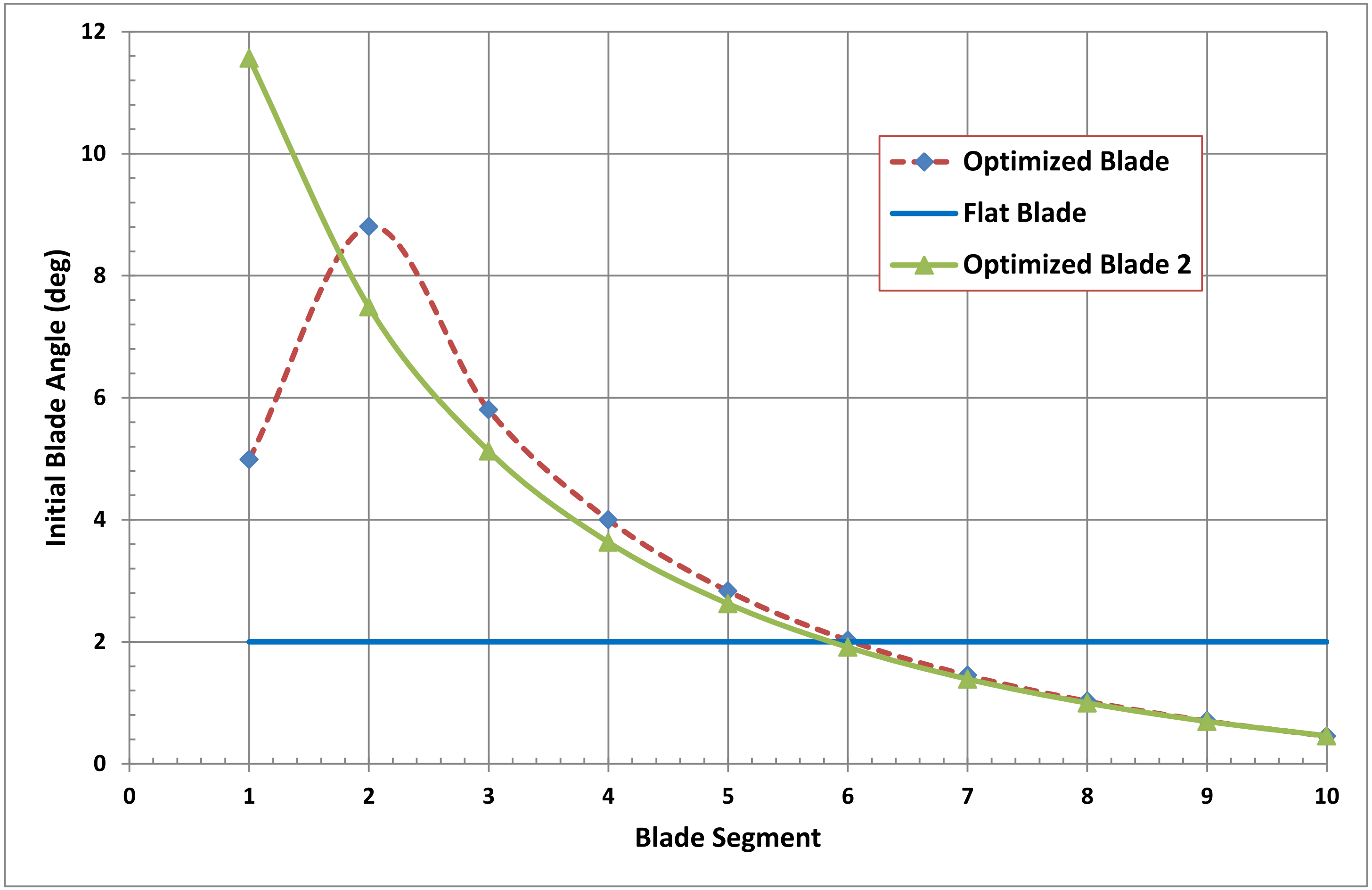


Top view of rotor blade

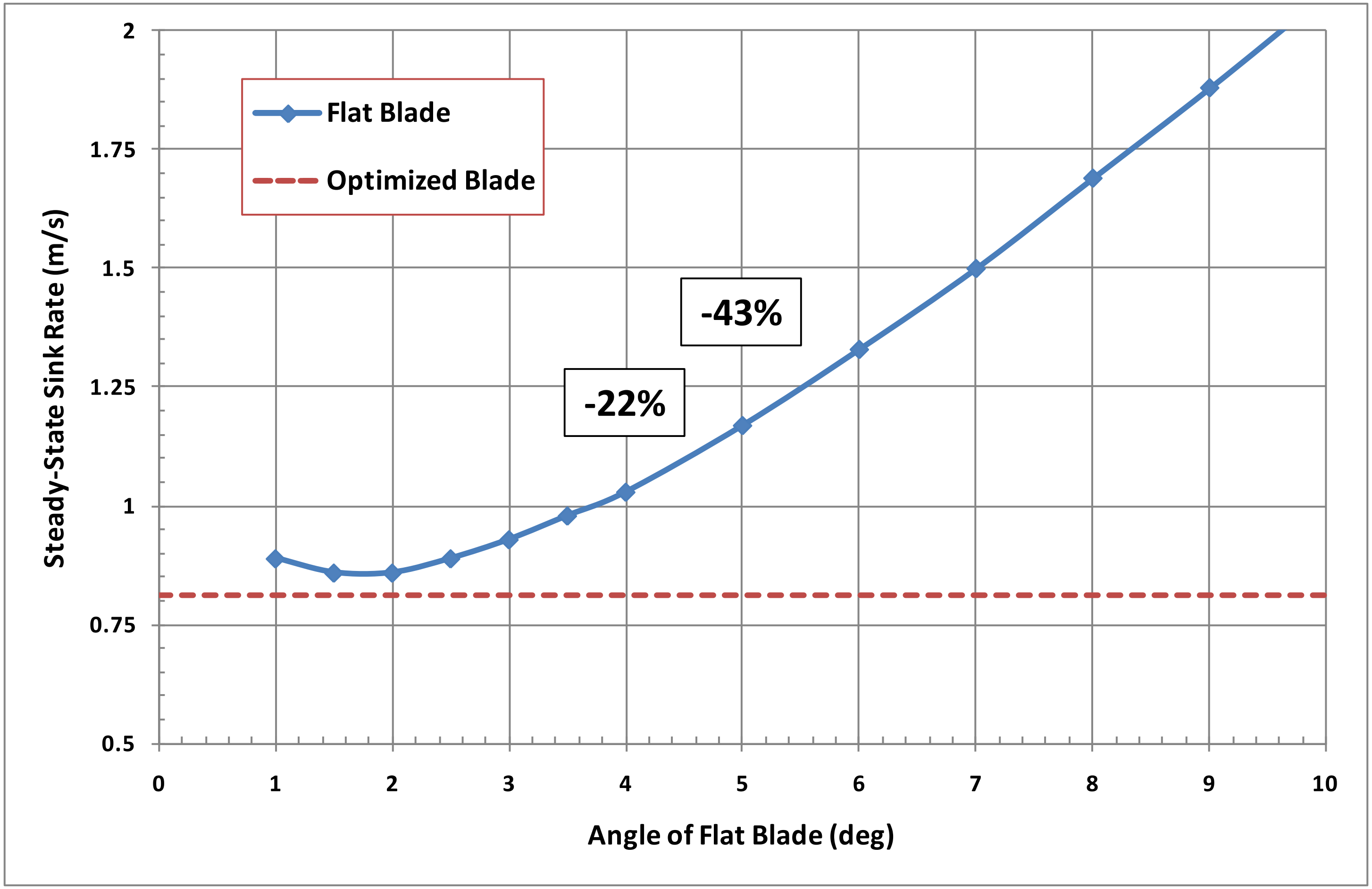
- **Blade rotary velocity = $\dot{\omega}$**
  - $V_{strip} = \dot{\omega}\, R_{strip}$
- **Descent velocity same for all strips**
- **Calculate lift & drag of each strip based on local aero and blade angle**



Optimum Blade Uses Twisted Profile

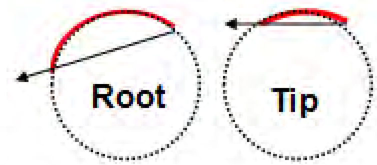


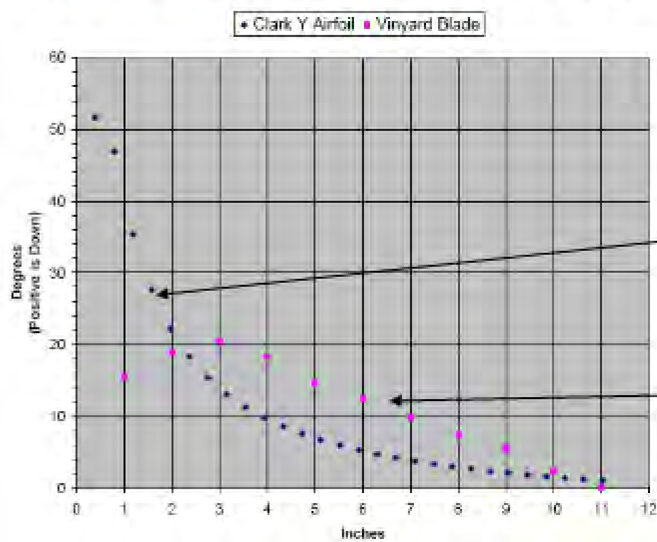
Flat Blades Have Lower Performance



Technique To Make a "Twisted" Blade

- 3 non-folding balsa blades with curved airfoil generated by forming chord around 40mm diameter cylindrical mandrel
- Change in blade pitch vs span along the blade is created by change in blade chord with span
- Semi-circular airfoil produces lift over a very wide range of angle of attack (+ or – 20 degrees) so it spins up quickly and handles both calm and wind





Clark-Y airfoil produces lift over limited range of "negative" angle of attack, so the twist angle must carefully follow effective air stream direction

Curved plate produces lift from -20 to +20 degree angle of attack, so optimization of twist angle with respect to air stream is not as critical

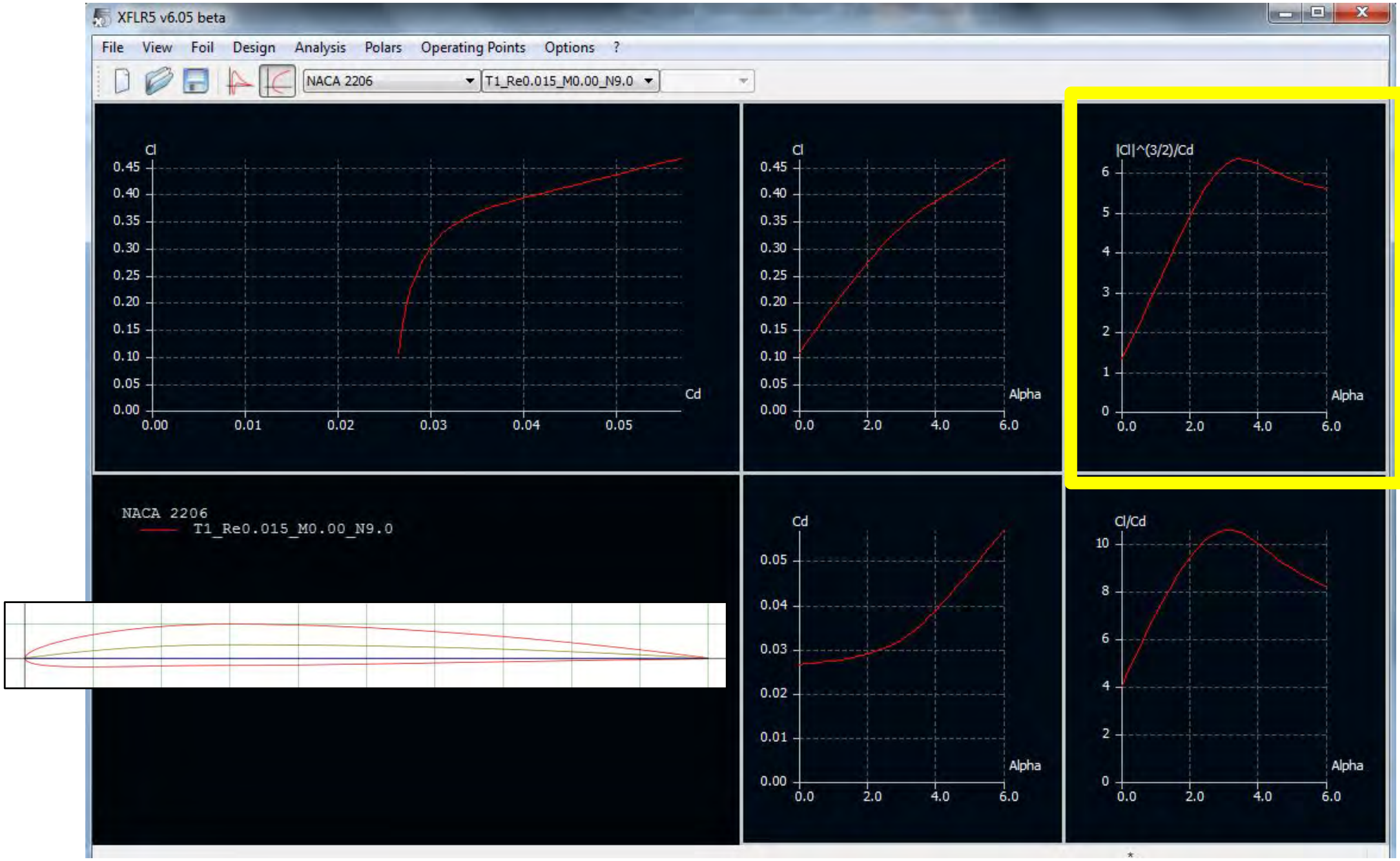
Two-Segment Blades Approach Performance of Optimally Twisted Blades

- Two segments of straight blades
  - Inboard segment at "steep" angle
  - Outboard segment at "shallow" angle
- Used HD spreadsheet to calculate best angles

Carbon rod and CA at joint

Blade Description	Sink Rate (m/s)	Ratio	Angle 1 (deg)	Angle 2 (deg)	Spin-Up Torque
Optimized	0.90				2.5
20/80	0.95	-5.6%	14.0	1.6	2.3
30/70	0.94	-4.4%	8.5	1.5	2.3
40/60	0.93	-3.3%	6.0	1.3	2.4
50/50	0.92	-2.2%	4.4	1.1	2.5
60/40	0.92	-2.2%	3.4	1.0	2.3
70/30	0.93	-3.3%	2.7	0.9	2.7

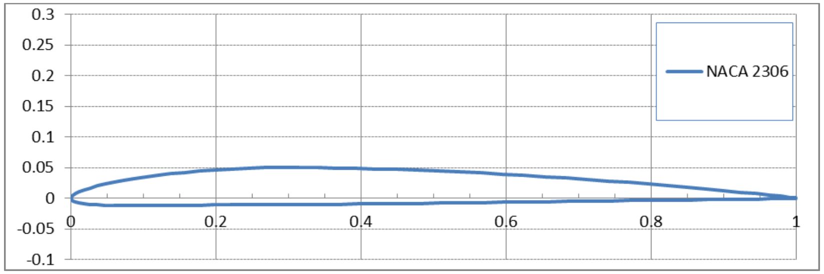
Used XFLR5/XFOIL to Calculate Airfoil Performance

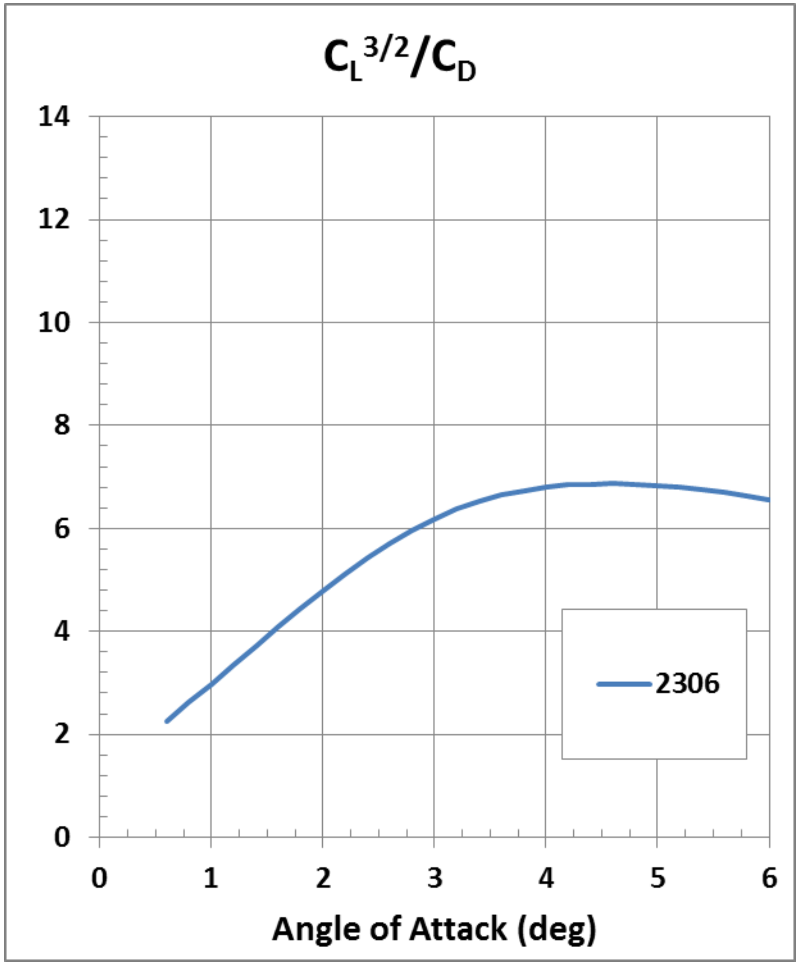


NACA 2306, RN = 15,000

Duration Is proportional to $C_L^{3/2}/C_D$

Thin Cambered Airfoils Proved Better Aero Performance for HD Blades





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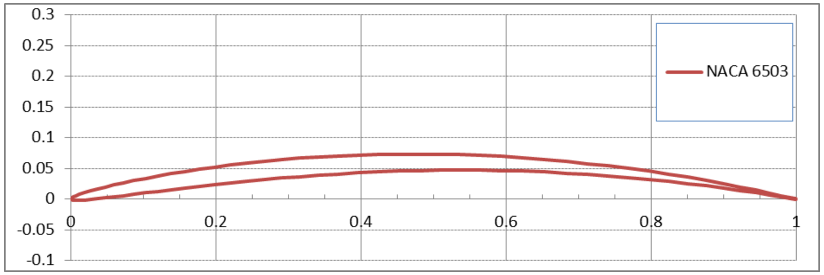

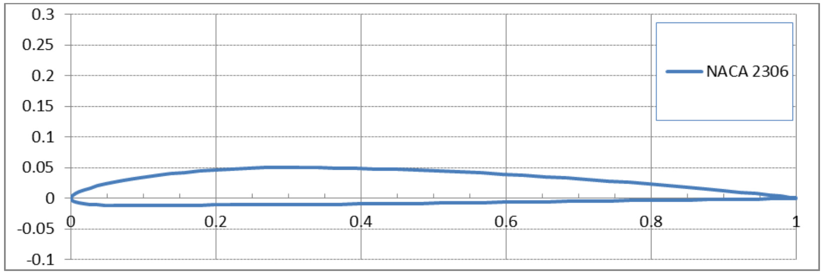

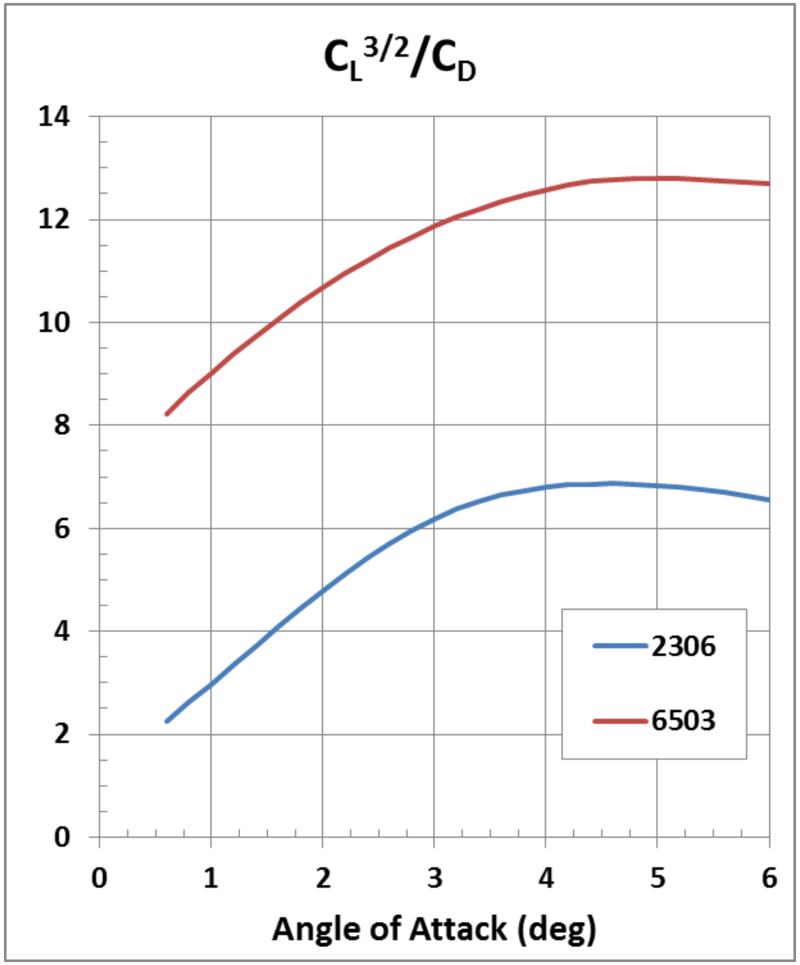

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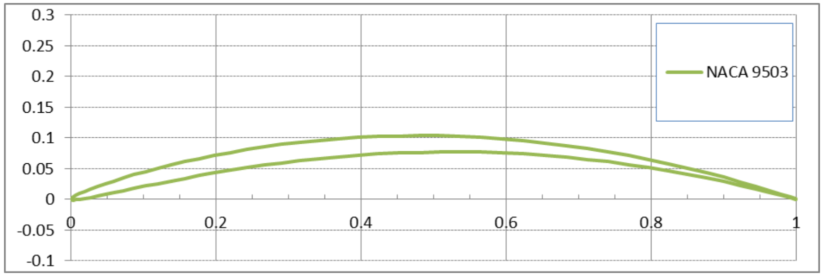
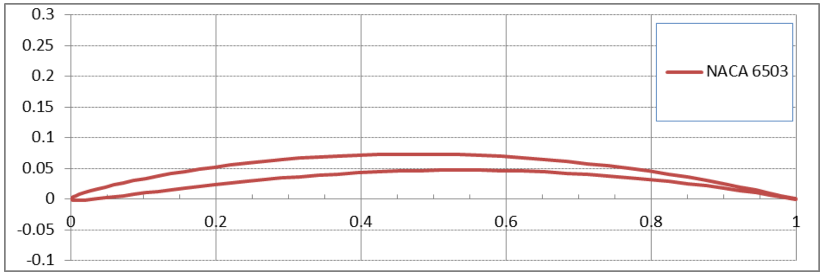
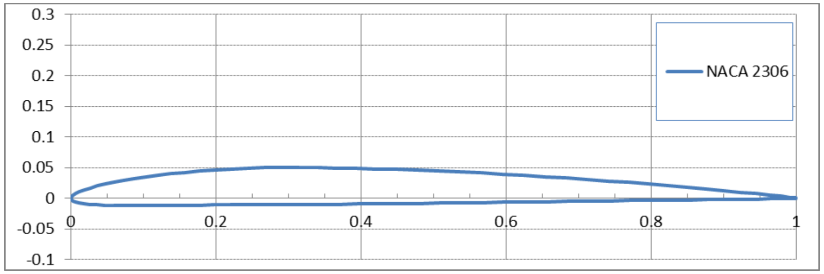
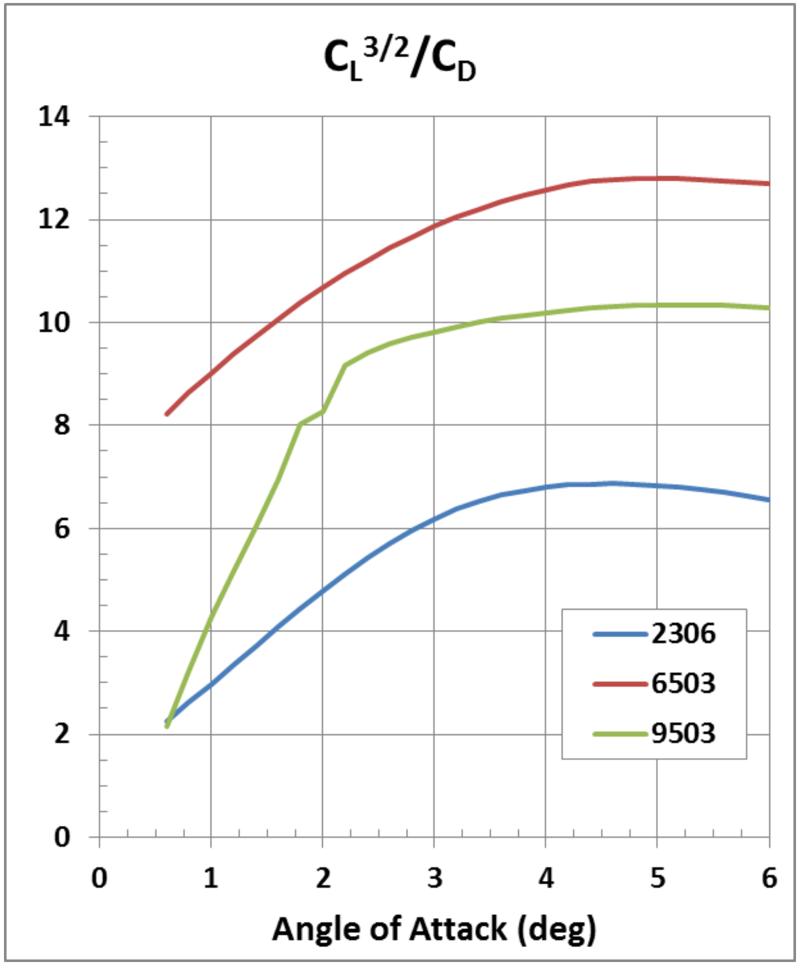
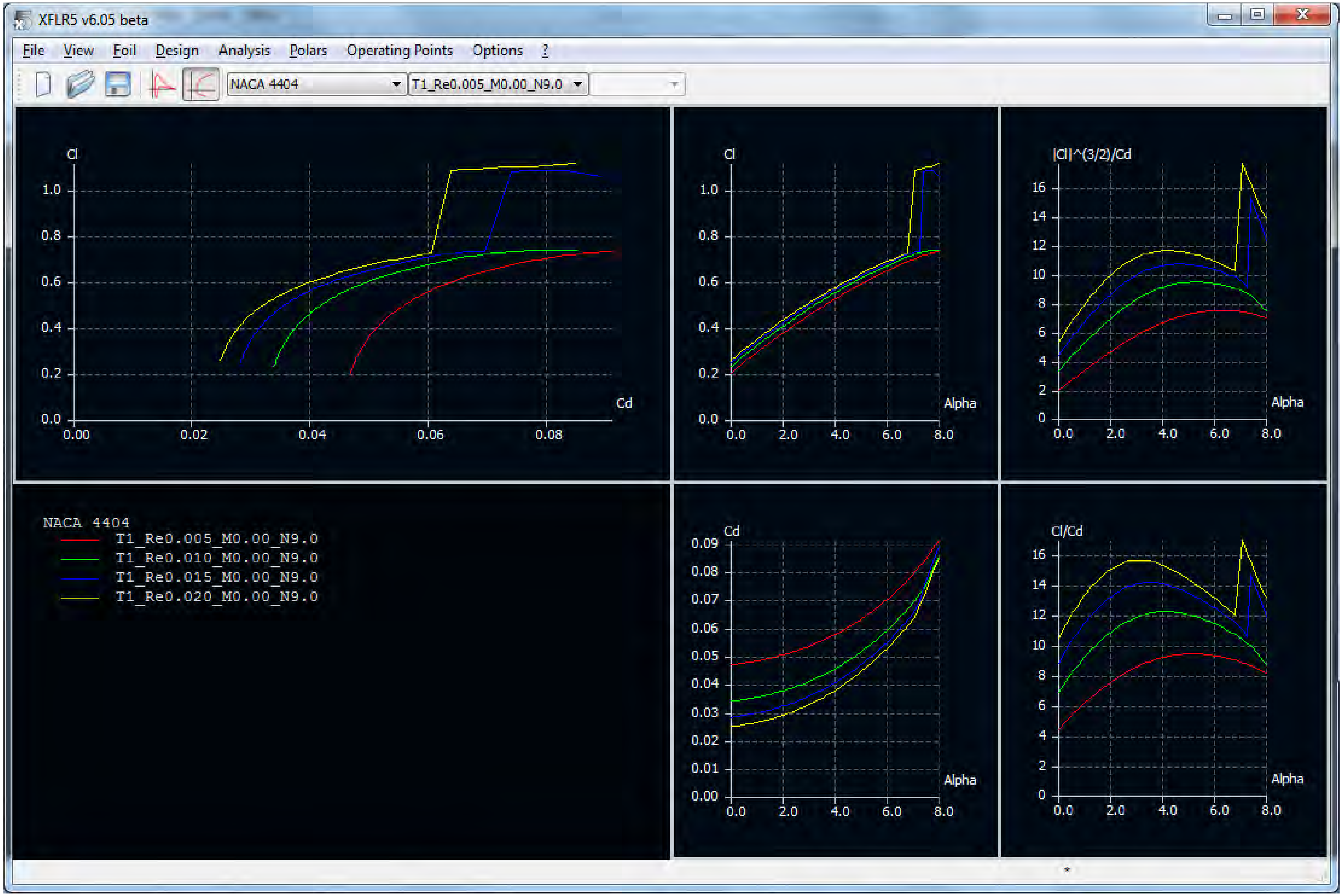






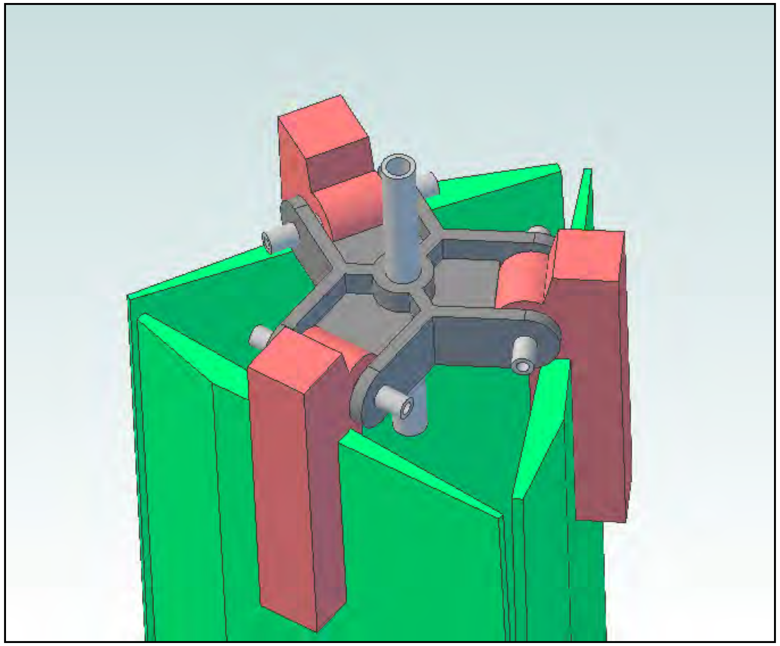


Reynolds Number Variation Affects Airfoil

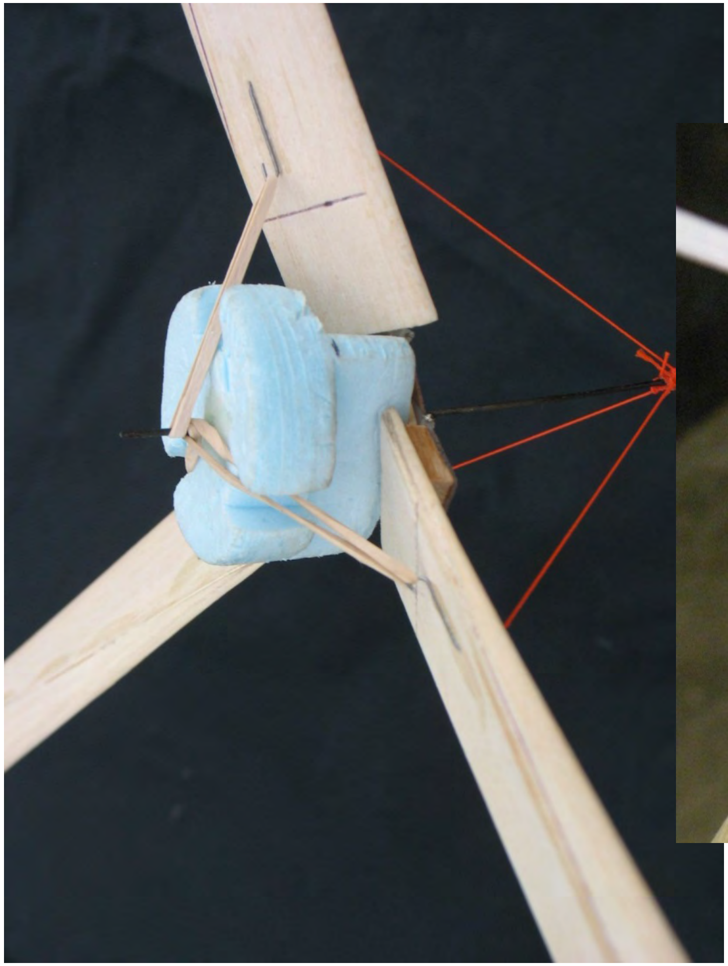


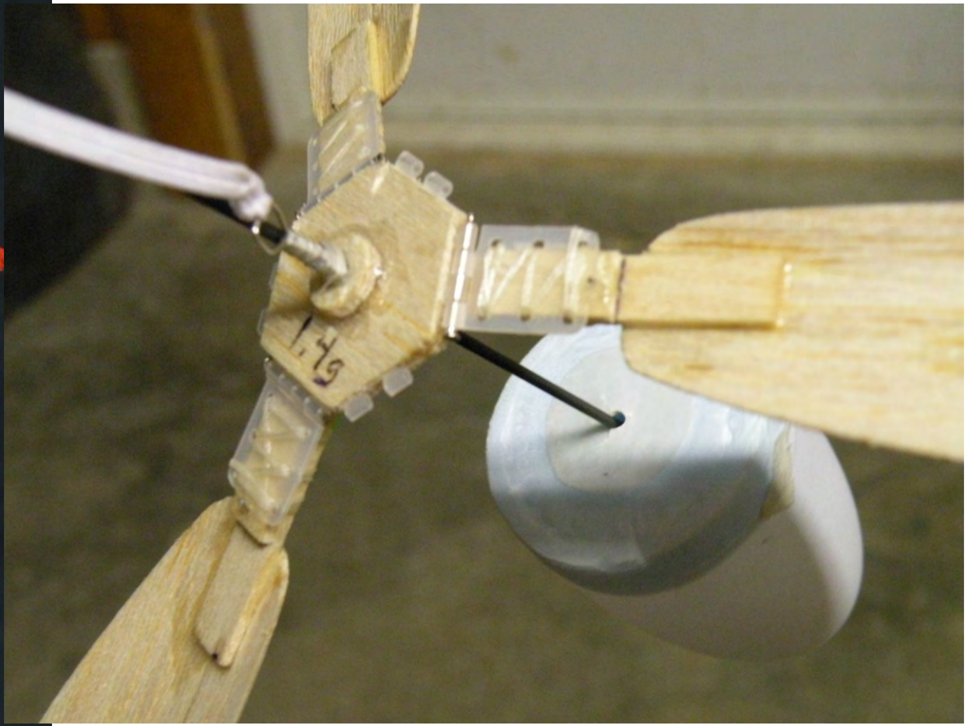
Laser Cutters and 3D Printers Improving Hub Design

- **Traditional hub**
  - Dubro or Klett hinges and plywood hub plate
  - Manually intensive
- **Laser cutter (Apogee)**
  - Thin, light plywood parts
  - Precise sizing
  - Simplified assembly
- **3D printing**
  - Precise sizing
  - New design is very light
  - Simplified assembly

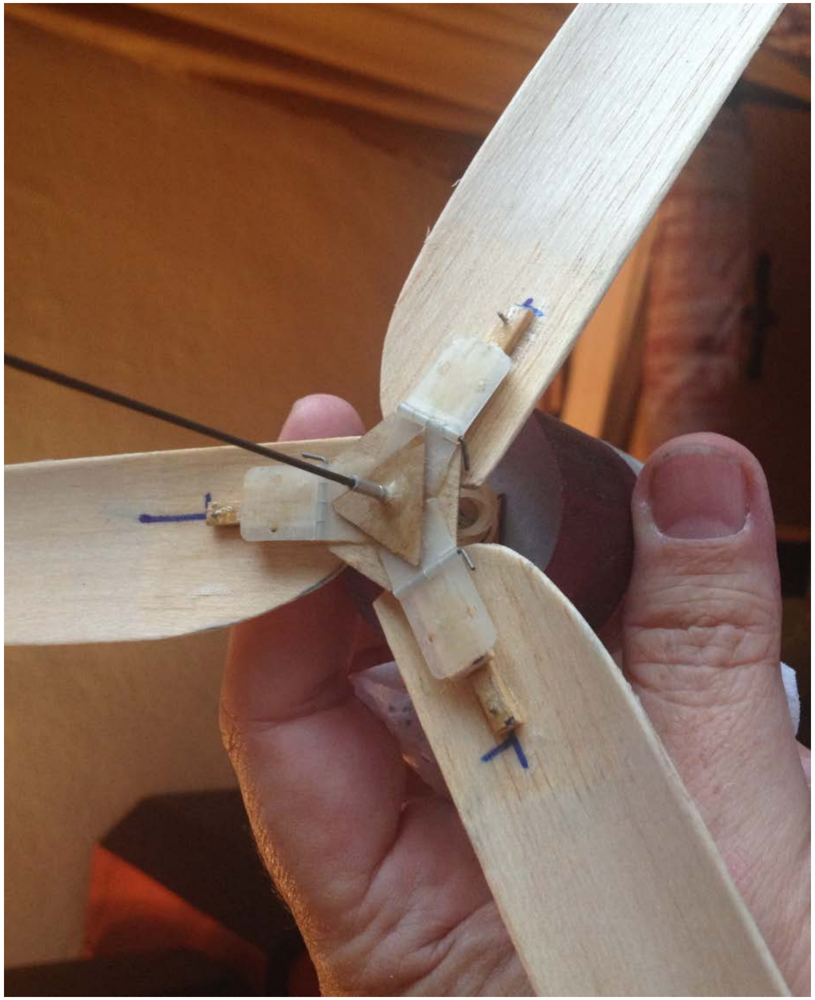


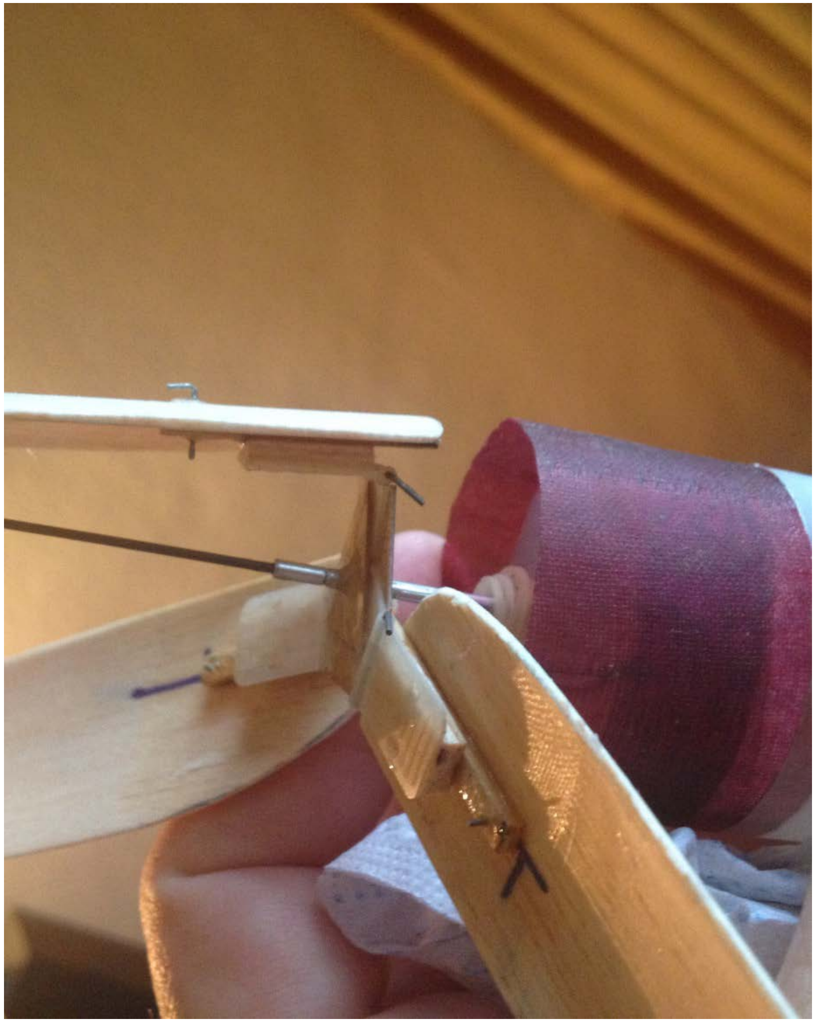
S9 Hub Designs





Vinyard/Barber Hub Design

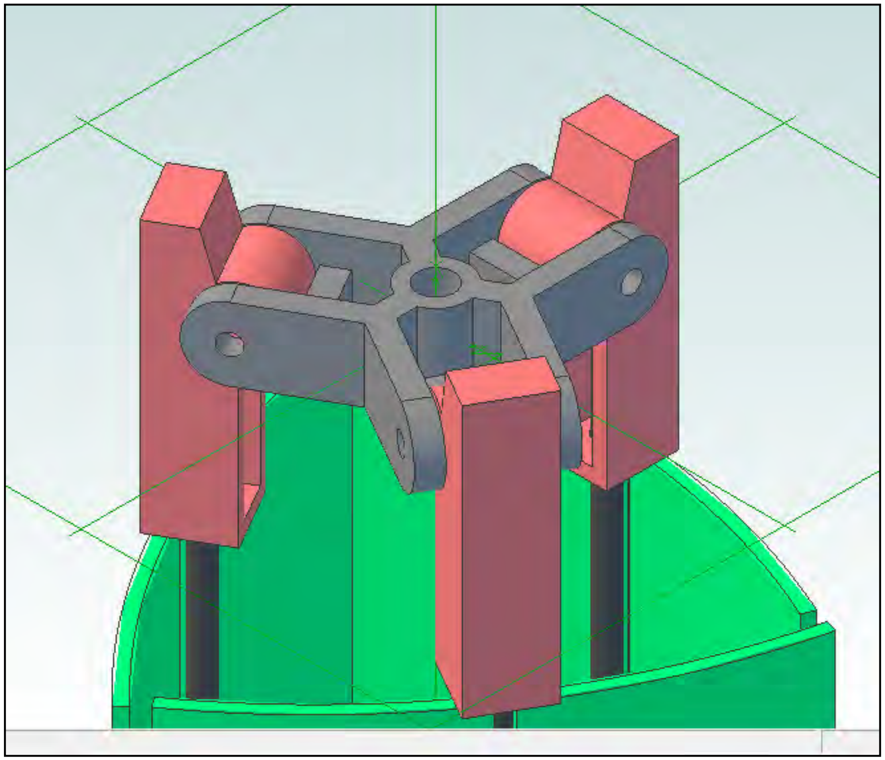


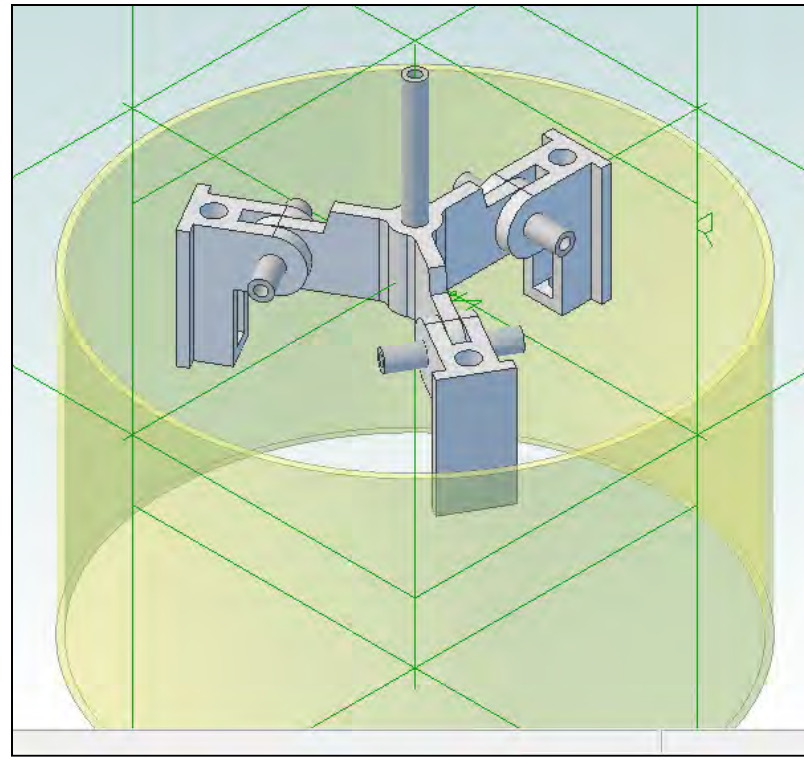


Tim Van Milligan Hub Design

Antonio Mazzaracchio (Italy) Hub Design

Flanigan 3D-Printed Hub Designs





Internal Blade Designs Are Very Competitive

- **S9A (FAI) all use internal blade design**
- **US competitors use both external and internal blade designs**
  - **External blade: Rotaroc, Rose-a-Roc, Whirl-a-While, etc.**
  - **Internal blade: FAI variants (typically 40 mm diameter bodies)**
- **External blade designs are simpler (ejection)**
- **Internal blade designs usually achieve higher ascents**
- **Internal blade designs successful at recent NARAMs**
  - **A HD at NARAM-58: 1^{st} in B Div, 1^{st}, 2^{nd}, & 3^{rd} in C Div, 1^{st} & 2^{nd} in T**
    - **FAI 40 mm designs**
  - **B HD at NARAM-57: 1^{st} place in A, B, and C divisions**
    - **Gyro Chaser by Apogee**

Spin-Up Requirement

- **Flat blades use 3-5 deg angle**
  - 3 deg = 13% performance loss
  - 4 deg = 22%
  - 5 deg = 43%
- **Twisted blades have start-up torque with minimal performance loss**
- **For internal rotor design, it's critical that rotor assembly is significantly lighter than body**
  - Can be challenging when using lightweight "fiberglass paper" for body

Software for Helicopter Design

- No general purpose HD model rocket design program
  - No RockSim or OpenRocket for HD
- Rotor/propeller codes (strip theory, blade element theory)
  - Helicopter Duration (S9) spreadsheet by Chris Flanigan
  - "Java Prop" by Dr. Martin Hepperle
    http://www.mh-aerotools.de/airfoils/javaprop.htm
- Airfoil programs
  - XFOIL
  - XFLR5 (includes XFOIL with GUI)
- Programs by academia
  - XROTOR, QMIL, and QPROP by Prof. Mark Drela (MIT)
- Industry programs
  - Windmill design and performance
  - CFD (Ansys FLUENT, Siemens STAR-CCM+, etc.)
  - $$$

Popular Designs

- Apogee carries five HD models!
  - Rotary Revolution (FAI style, 40 mm body, A motors)
  - Gyro Chaser (24 mm body, 18 mm motors)
  - Mini-copter (18 mm body, 13mm motors)
  - Heli-Roc (rotaroc style)
  - Texas Twister (Gyroc style)
- Plans on NAR web site
  - http://www.nar.org/contest-flying/competition-guide/duration-events/helicopter-duration/
- Semroc (eRockets.biz) Heli-Roctor
- Fliskits Tiddlywink
- QCR not currently operating

Approaches to Improve Designs

- More blades
- More blade chord
  - Wider blades, chordwise folding blade
- More blade span
  - Longer blades, spanwise folding blade
- Improved boost aerodynamics
- Lighter, lighter, lighter
- Betz limit
  - https://en.wikipedia.org/wiki/Betz%27s_law

Thoughts on G HD for NARAM-59

- High boost…
  - Internal blades
- … but not too high!
  - Have to be able to observe blade rotation to get qualified flight
  - Recoverable
  - Max impulse, max altitude may not be desirable
- Rugged and reliable
  - High boost acceleration and probably high velocity at deployment
  - Need strong design (but not too heavy)
  - Score is sum of two flights (need two qualified flights)
- A very challenging set of design options!
- Winners will set long-standing records
  - Current NAR records: 105 sec (A), 156 sec (C), 242 sec (T)

My Approach for G HD

- Internal rotor
  - Avoids excess loads during ascent
  - Use chord-wise folding blades to increase blade area
  - Heavy duty 3D-printed hub and arms
- Large diameter model (BT-80)
  - Room for rotor
  - Controls altitude
  - Lightweight tubing (not BT-80H)
- Minimum G motor
  - Control altitude
- *What's your approach? Discussion?*

Summary

- **Twisted blades are good**
- **Thin, cambered airfoils are good**
- **Laser cut and 3D printed hubs provide new options**
- **Light, light, light for best performance**
  - **For “small” models**
  - **G HD might win by being rugged and working**
- **Always look for thermals**

Backup Slides

INTRODUCTION

Prior Work …

- Flanigan (2012)
  - Excel spreadsheet based on strip theory aerodynamics
  - Simulates initial startup through steady-state descent
- Peterson, et. al. (2012)
  - Examined standard and “spill hole” designs
- Prior work in HD methodology
  - Overview by Trip Barber (NAR web site)
  - Gassaway, Steele, McCarthy (NARAM, 1983)
  - Tim Van Milligan (NARAM, 1991)
  - Professional and academic programs
    - XROTOR, QMIL, QPROP programs by Prof. Mark Drela (MIT)

Blade-to-Hub Attachment Methods

- Vinyard/Barber design
  - Dubro hinges
- Tim Van Milligan design
  - 1/32” plywood arm
- Single spar connection
  - Graphite rod with plywood hinges – similar to Robart Hinge Point
- Wide arm design
  - Similar to TVM design but using Gatorfoam for greater AOA control
- Two arm design
  - Similar to TVM design but with two arms for greater AOA control
- Vinyard/Barber design with custom “C” channel
  - Use “C” channel to accommodate attachment of rotated blade
- Butt splice joint with reinforcement
  - Simple