# Model Rocket Helicopter (Gyrocopter) Duration for U.S. and International Competition

**Trip Barber**

**NAR 4322 L3**

**January 2022**

# Definitions

- An “autogyro” or “gyrocopter” uses an unpowered rotor in free autorotation to develop lift

- A “helicopter” uses a powered rotor to develop lift and thrust

- Our ”helicopter” models are actually “gyrocopters”!

# Competition Rules

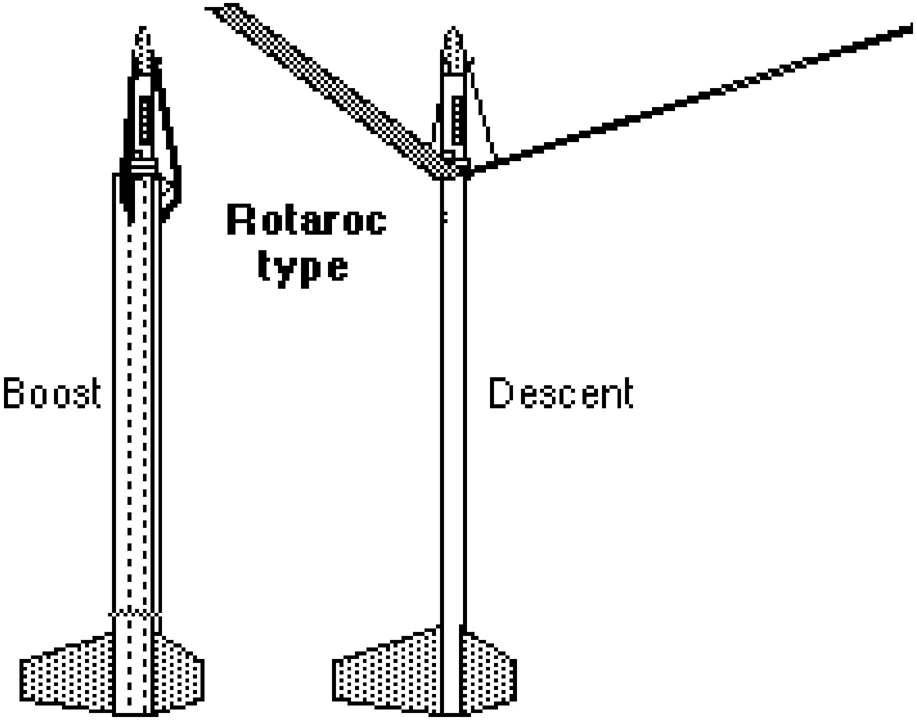
## NAR and International

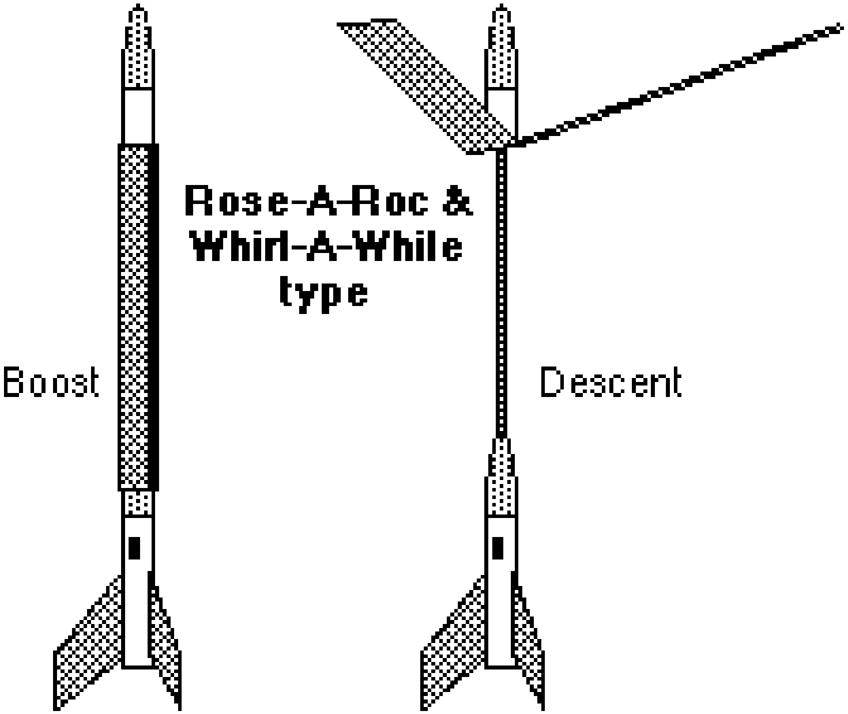
- Each entry must be decelerated during descent by its autorotating recovery device. The resulting autorotation must be around the vertical (roll) axis.
- A model that descends nose first, or flips over during descent is permitted under NAR rules. FAI (international) rules require “proper deployment and operation of the recovery system”.
- The recovery system may not be constructed of flexible materials and rigging (e.g. folding rotors of flexible materials between rigid stringers) and cannot act in a manner similar to a parachute – it has to rotate.
- FAI Gyrocopter (S9) models must be contained in a body that is at least 500 millimeters long, and that is at least 40 mm in diameter for at least half of its length.

# Design Approaches

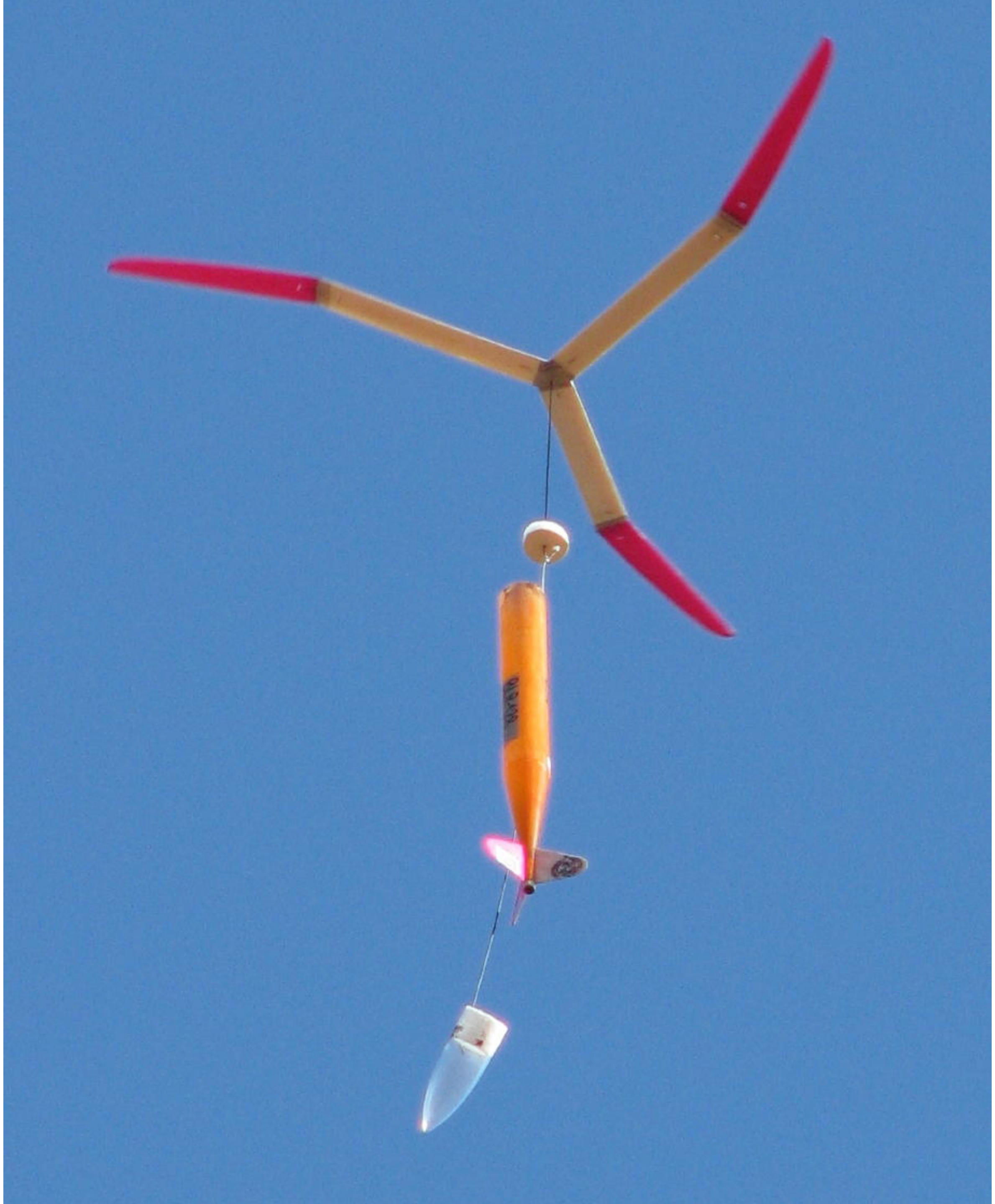
- External blades – blades are attached to and fold along an engine-diameter body – widely used for NAR
  - Fit between fins during boost
  - Burn-string holds them closed until ejection
  - Easy to build, but high boost drag
  - Must be tail-heavy in order to come down right-side-up
- Internal blades – blades fold inside a body that is larger than the engine in diameter – <u>must be used for FAI</u>
  - Piston ejects the blades, which are attached to a hub
  - Blade hub is attached to booster body by a Kevlar cord and descends with the body dangling under it – make the body <u>light</u>
  - Harder to build (complex) and heavier, but higher boost altitude offsets this in A and higher power classes
- Folding blades – can be used with either approach
  - Folded part can either lengthen the internal blade, or can increase an external blade's width and add camber with a flap

# External Blade NAR Designs





**Good NAR external blade competition kits on the market:**
**Apogee Heli-Roc**



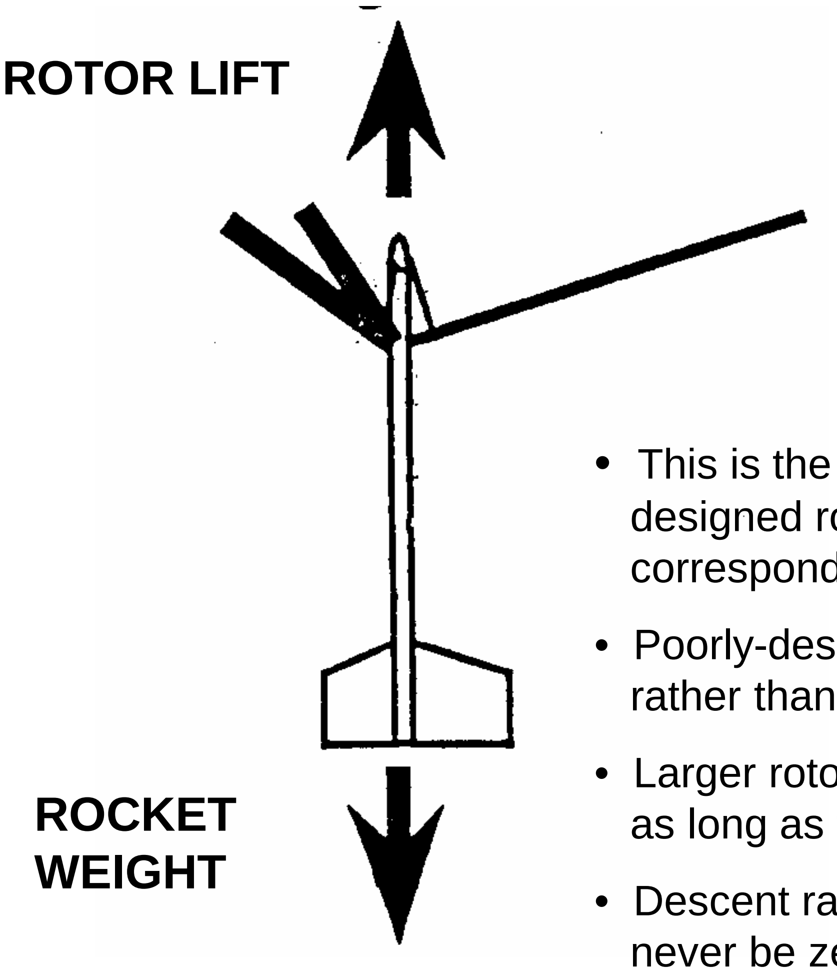
# Internal blade FAI design

Note the two-section blades;
a cool design, but
not a winning one

# How These Models Work

- Multiple blades, symmetrically arranged around the model’s roll axis, deploy at apogee.
- The airspeed from the model’s initial descent creates airflow over the deployed blades, inducing lift.
- The component of blade lift perpendicular to the long axis of the model causes rotation of the blades.
  - The inner part of the blade’s span creates most of this torque
- The component of blade lift parallel to the long axis of the model offsets its weight, slowing its descent.
  - The outer part of the blade’s span, where airspeed across the blade is highest, creates most of this lift

# Descent Rate



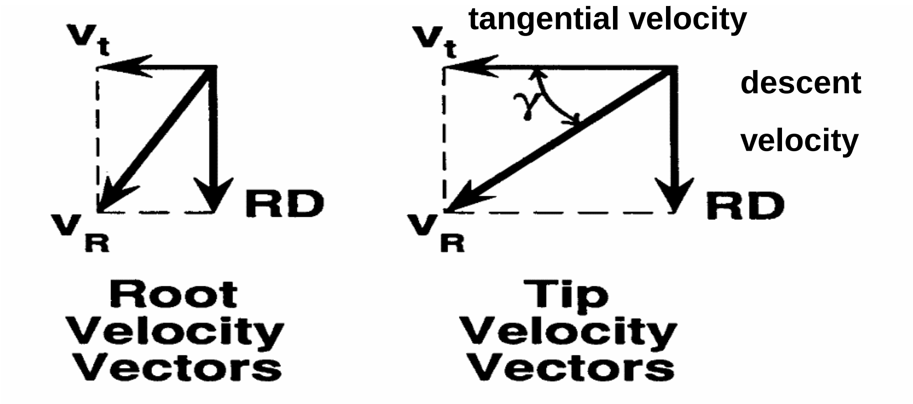
**BEST POSSIBLE DESCENT RATE (m/sec)** = $\mathbf{3.6}\sqrt{W / S}$

W = rocket mass (kg) : **minimize**

S = rotor disc area ($m^2$) : maximize

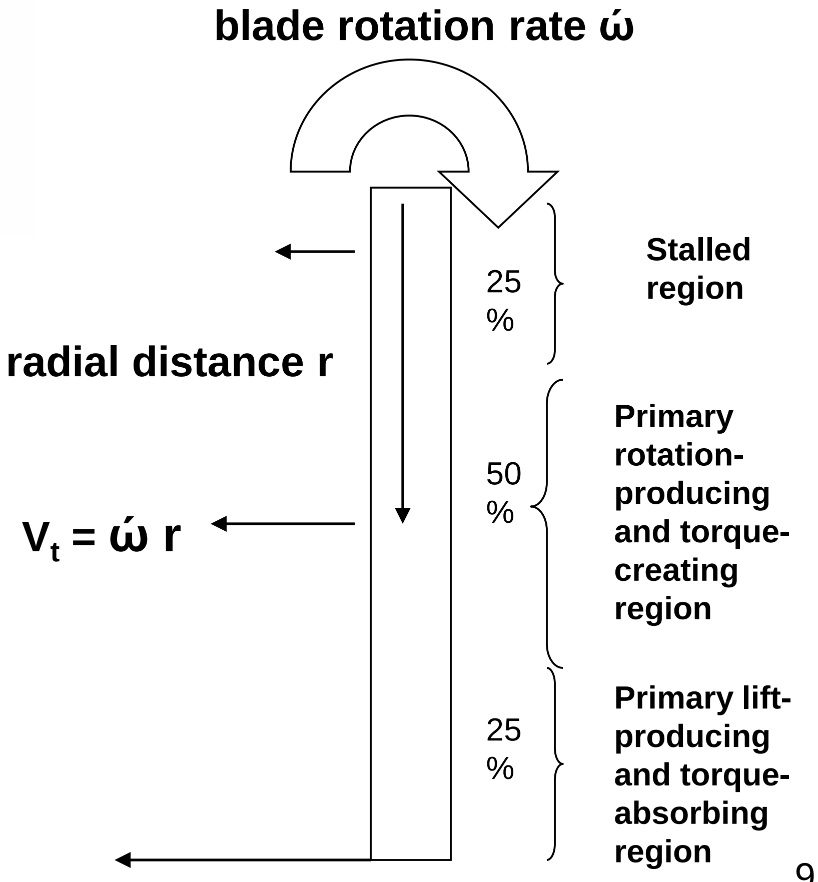
- This is the lowest possible descent rate for a well-designed rotor stably spinning at high speed; it corresponds to ~85% of the $C_D$ of a spherical parachute
- Poorly-designed rotors behave as 3 individual blades rather than a disc and cannot match this descent rate
- Larger rotor disc areas (blade span) descend slower as long as they can reach high rotation rates (100’s rpm)
- Descent rate relative to the surrounding air mass can never be zero –there would be no pressure difference across the rotor disc and the blades would stop rotating

# Blade Twist



- Blade twist keeps each part of the blade flying at its best angle of attack relative to the blade's net velocity $V_R$ at that local point along its span
- The best local angle of attack is the one that minimizes $C_L^{1.5} / C_D$, typically ~5-8°
- Twists of 30 degrees between hub (most pitch) and tip (least) are typical
- Curved blades that are wider at their root than at their tip have aerodynamic "twist"

- Lift increases with the square of the distance r along the blade until the tip area, where it goes to zero



**blade rotation rate ώ**

**radial distance r**

**$V_t$ = ώ r**

25 %

**Stalled region**

50 %

**Primary rotation-producing and torque-creating region**

25 %

**Primary lift-producing and torque-absorbing region**

# Blade Rotation

- Rotation rate should be as fast as possible to create maximum blade lift

- In order to get fast rotation, pay attention to:
  - Blade drag: keep them thin and smooth
  - Body/fin drag: only seen if the blades' rotation makes the body rotate – use a free-spinning hub to avoid
  - Rotational moment of inertia: longer, thicker, and/or heavier-material blades spin up to speed slowly
  - Stability: use 10-15$^o$ dihedral angle in mounting the blades to the body or hub, and keep overall model's descent center of gravity low or it will oscillate
  - Stalling (rotation stops then restarts): result of excessive blade pitch angle

Model that won an FAI Bronze Medal at the 2014 World Space Model Championships

Championship

Diploma

*Fédération Aéronautique Internationale*

FAI

**FAI World Championships**
**for Space Models**

**Kaspichan, Bulgaria**

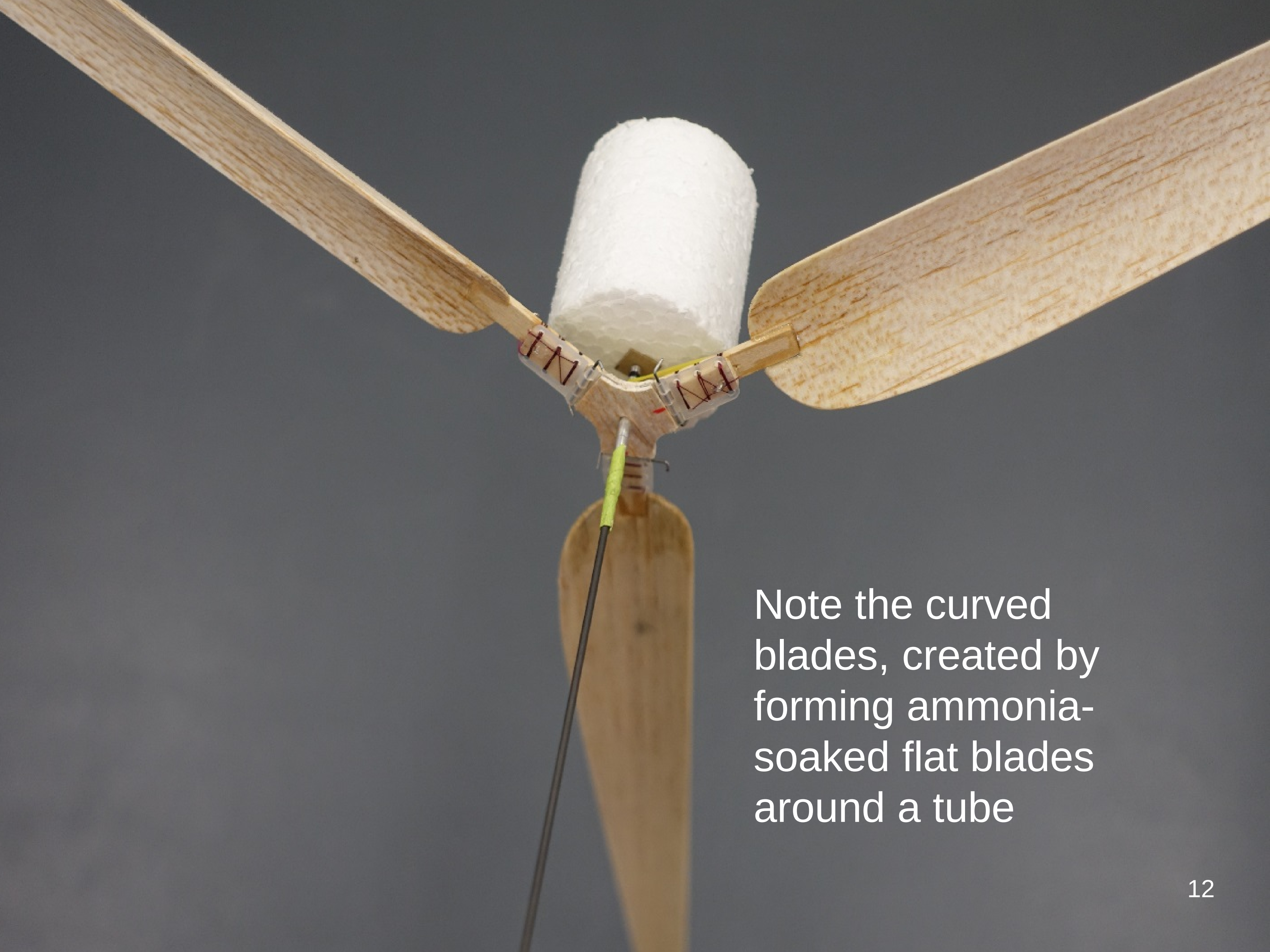
Name Barber Arthur

Position 3rd place in class S9 A

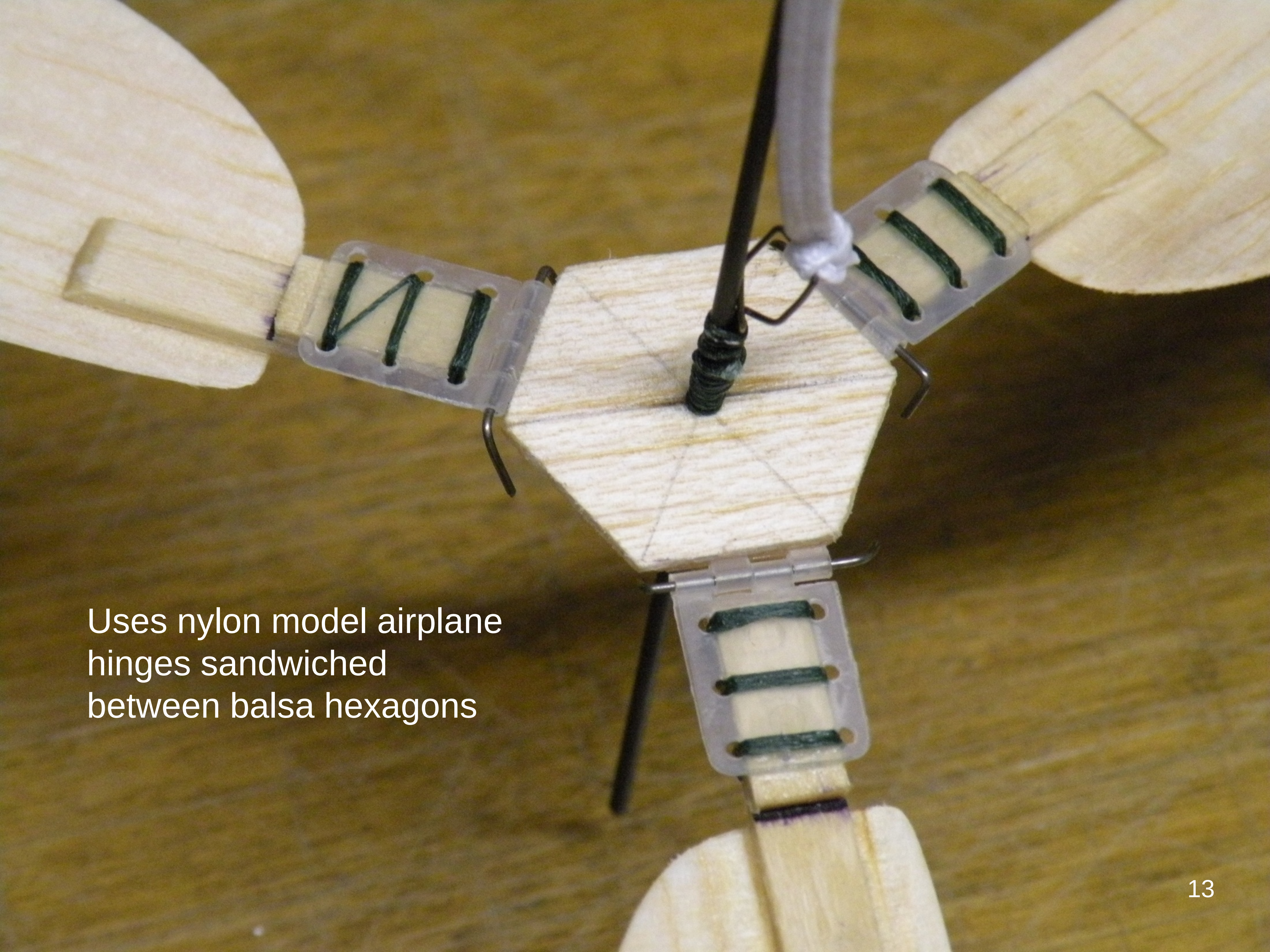
Date 27 August 2014

FAI President

FAI Secretary General



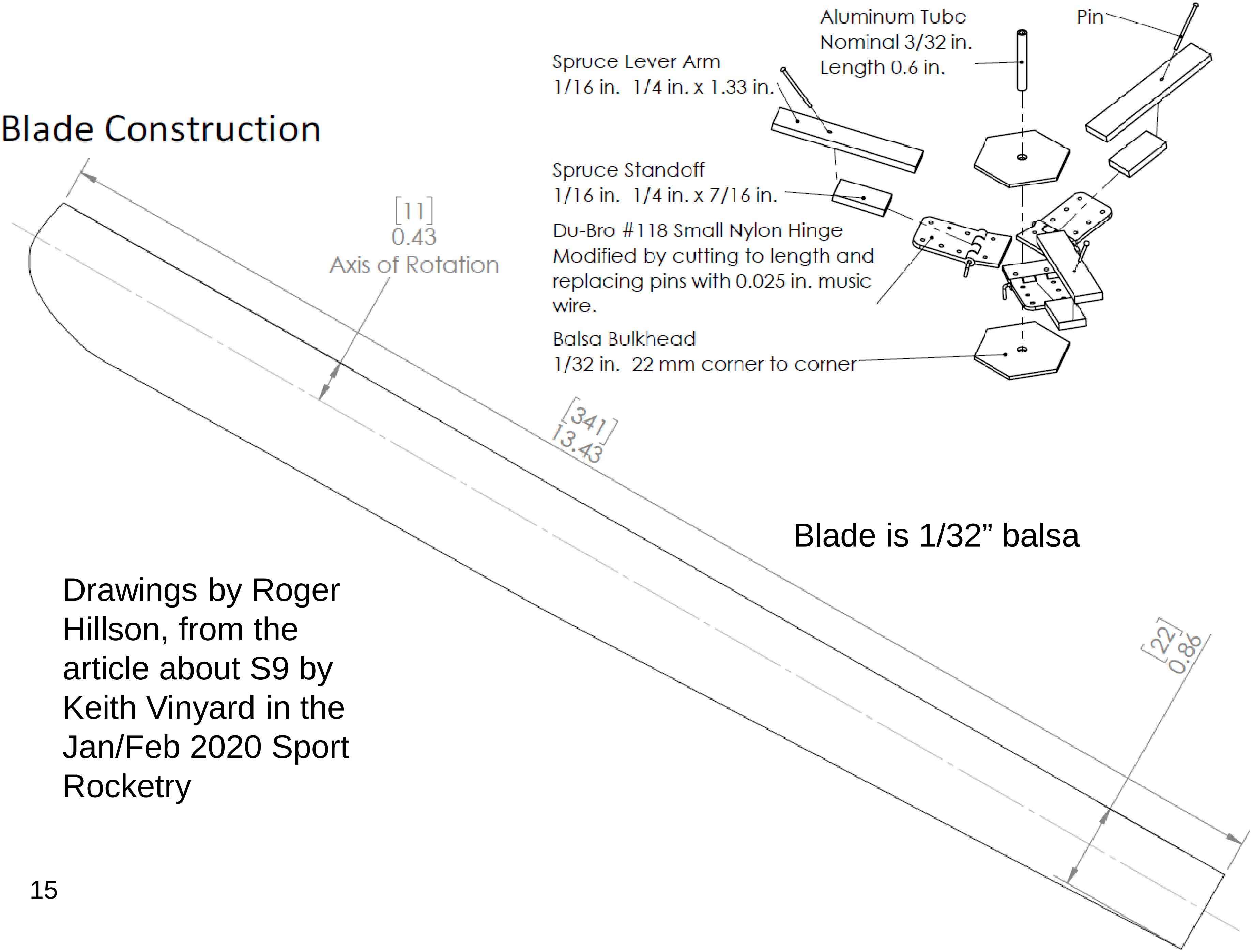
Note the curved blades, created by forming ammonia-soaked flat blades around a tube



Uses nylon model airplane hinges sandwiched between balsa hexagons

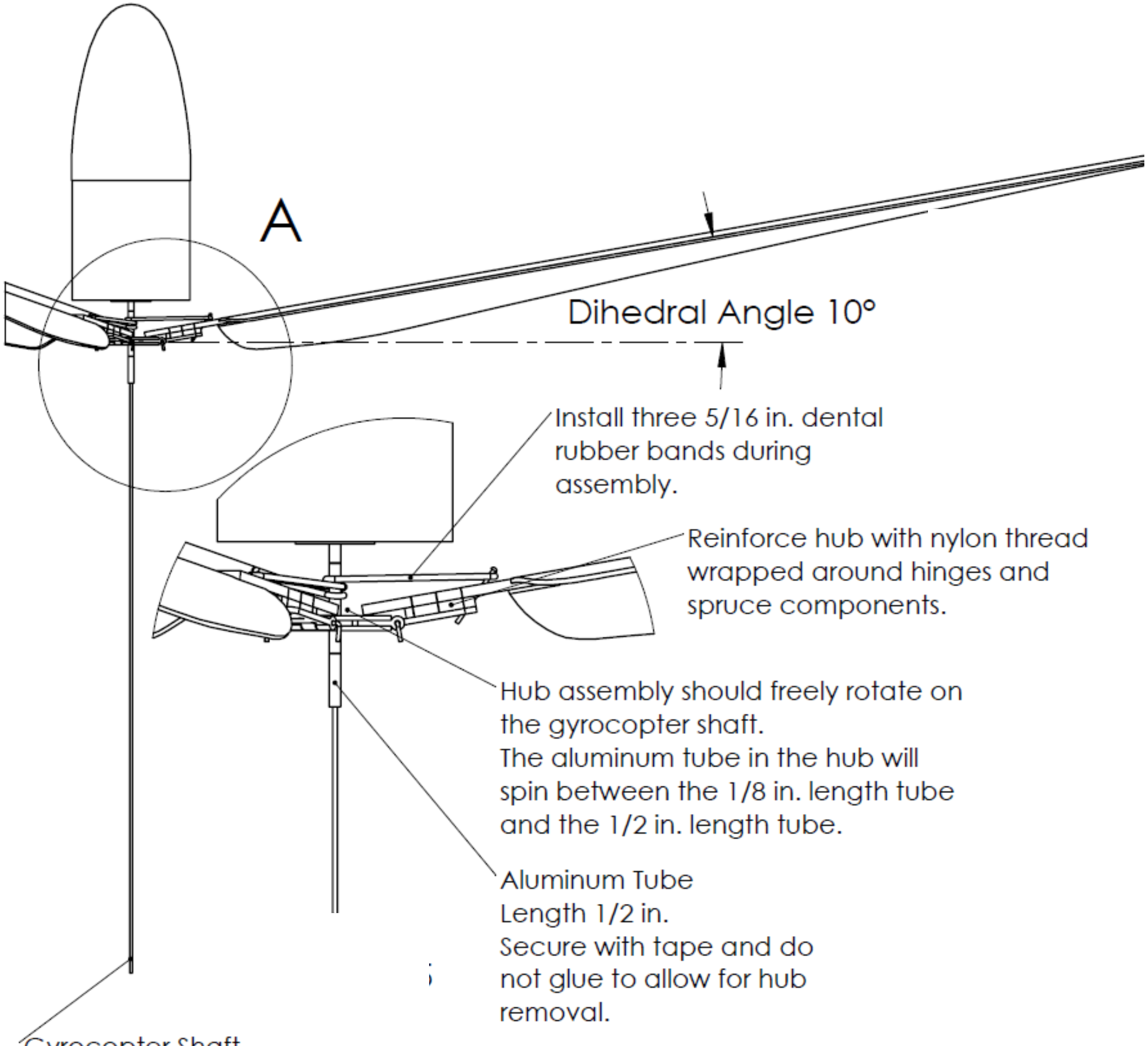
Another approach:
Apogee “Rotary
Revolution” kit hub

# Blade Construction



Blade is 1/32” balsa

Drawings by Roger Hillson, from the article about S9 by Keith Vinyard in the Jan/Feb 2020 Sport Rocketry



Install three 5/16 in. dental rubber bands during assembly.

Reinforce hub with nylon thread wrapped around hinges and spruce components.

Hub assembly should freely rotate on the gyrocopter shaft.
The aluminum tube in the hub will spin between the 1/8 in. length tube and the 1/2 in. length tube.

Aluminum Tube
Length 1/2 in.
Secure with tape and do not glue to allow for hub removal.

Gyrocopter Shaft
0.06 in. nominal diameter carbon fiber, length is 12 in.
Some fliers use 0.04 in. nominal diameter.
Wrap shock cord around carbon fiber and glue with cyanoacrylate.

# Summary

- Keep the model light
- Minimize both boost drag and rotation drag/friction
- Get the blade pitch angles right – a twist with more camber at the root and zero at the tip
- Make the blades long and thin, and put dihedral in their attachment to the hub
- Use strong elastic to open the blades right before apogee