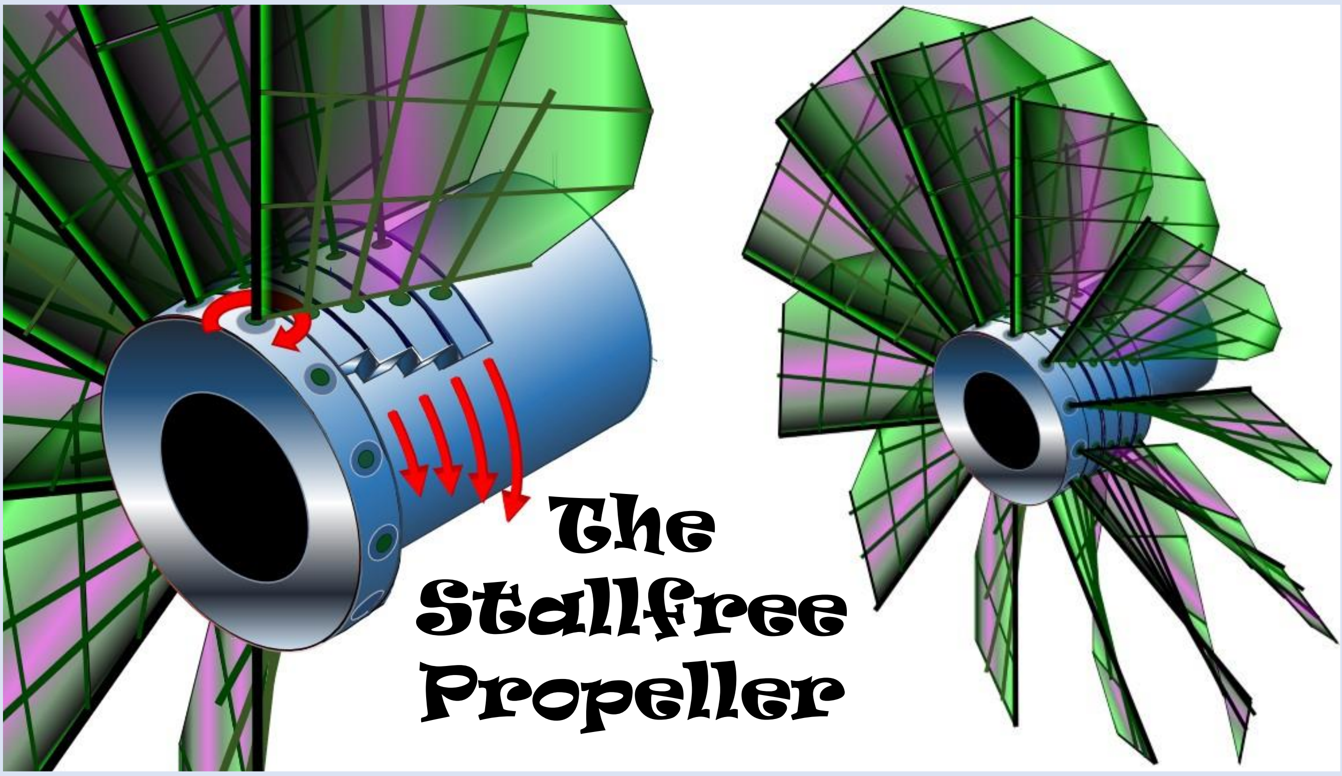
ADVANCES IN BLADE GEOMETRY



The Stallfree Propeller

Wide-range
Variable Pitch
Fans & Propellers
with
Torsional Blades

Concept & Design

By
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April 2021
Budapest, Hungary

Supporting websites:

- http://stallfreepropellers.com/
- https://www.facebook.com/Stallfree-Propellers-100452335016157

Disclaimer

1. This eBook is a transcript of the PPT presentation of the same title. Minor alterations and omissions have been made.
2. Neither advertising nor criticism of any kind is meant for the companies whose names are mentioned in the text. The names have solely been used to identify an authentic technical state of the art for fans and propellers.

Foreword

I love sailing. It happened around 2000, when thinking about aerodynamics of the main sail of a yacht, that I made an invention which seemed to apply well to aviation rotors and propellers. First, to make sure the idea had any real value, some investigation had to be done.

Reading books and relying heavily on the Internet, step by step it was made clear today’s propellers had limitations, which on the one hand were quite painful for the whole (yes!) of aviation and, on the other, could be handled by this invention nicely.

Using only the options available for an amateur, facts were collected to support both the necessity and feasibility of the concept. Most importantly a mathematical case was built to prove this concept could deliver the not so modest claims concerning propeller efficiency and working speed range.

Also, silent propeller-operation was expected to happen as a byproduct.

Due documentation for the patenting process was prepared and submitted. (Most of it is part of the present eBook.) The process is under way. Positive reflections were received from the authorities, including the PCT. Unfortunately, no prototype could be built or tested. A feasible design has been prepared and charted as per the normal requirement of patenting.

The eBook partly covers the findings of the initial investigation; fully contains the drawings of the patent application and exclusively contains the mathematical description and proof of operation. It was my intention to provide information in the eBook that was sufficient to support a possible prototyping effort by the reader.

Laszlo KRUPPA

Contents

Objective of the proposed invention

Main purpose of the proposed invention is to improve efficiency of the propeller by means of partial change of construction - using an altered way the blades are built and operated;

- Ease of replacement is achieved by use of parts and methods interchangeable with those of the widespread variable pitch propellers.
  - E.g. the servo unit used for blade operation can be quite like that of the present variable pitch propellers: both are feasible based on a single hydraulic cylinder per propeller hub;
- Cyclic blade control (Swashplate Control) is possible (Eccentric hub only) but is mostly neither necessary nor desirable.

Claims & Statements

In contrast to the monolithic blades of recent propellers the newly proposed Torsional Blades,

the TB –s are

- complex mechanisms assembled of several moving parts.

Main parts of the TB -s:

1. a skeleton of internal fanning rods („the Fan”),
2. a modular structured skin („Skin of Scales”).

Mathematical equations describing variation of angles of both

- the chord lines of blade sections

  and

- the resulting velocity (*)

are approximately identical (containing the same function)

- in a wide range of axial velocity,
- along the whole radius.

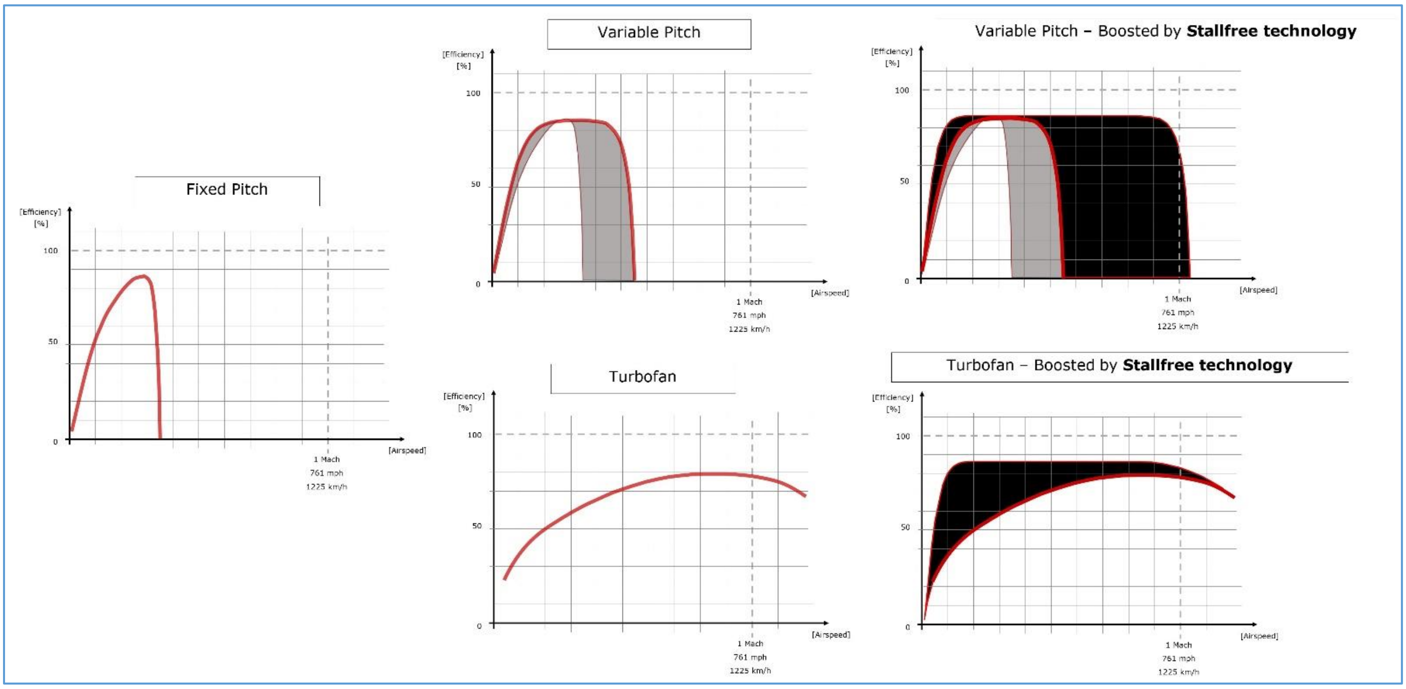
TB–s can primarily be manufactured with a straight leading edge and zero sweep.

(*) Description according to the simple blade element theory.

Efficiency remains close to its maximum value in a wide range of speed or of the J, ADVANCE RATIO :

- even at relatively low RPM;
- blade tip speed can be kept well below extreme values, that is
- no need to come close to, or exceed the speed of sound; consequently
- both efficiency and safety of operation is improved.

Estimated improvement of efficiency in case of different propeller applications:



(Expected improvement shown as blacked area.)

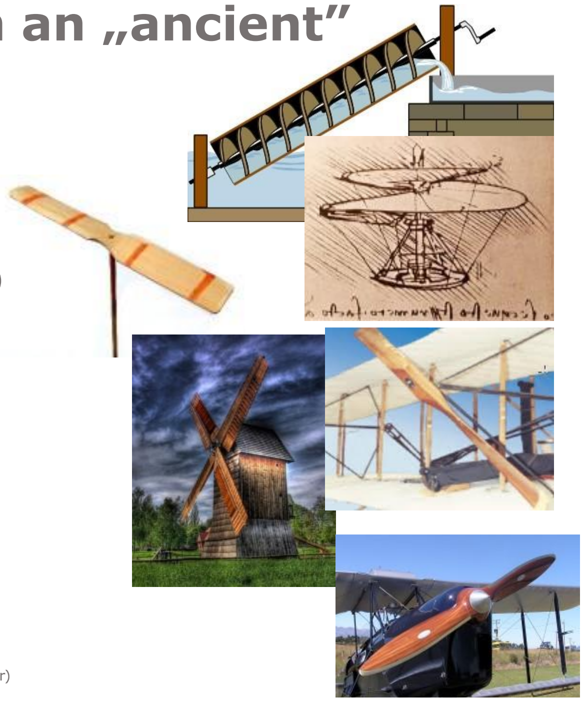
Positioning

Is there any business potential in development of props? Such an „ancient" technology...

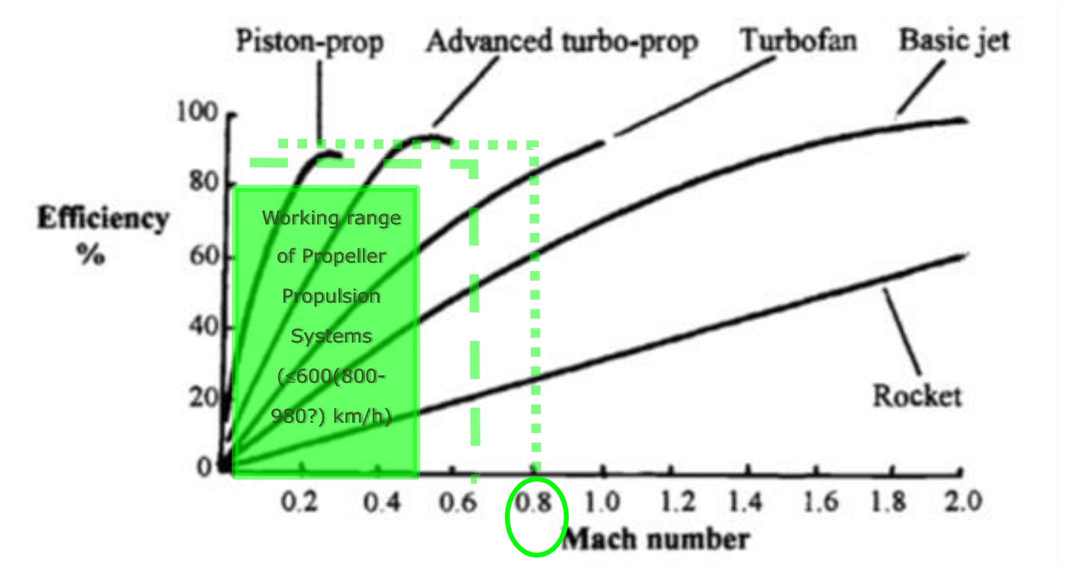
Propellers have been around for ages:

- About 400 B.C. – China (a toy)
- III. century B.C. - Archimedes' screw (non-aerial~)
- From XII. century in Europe - windmills
- XV. century – Leonardo's helicopter (only design)
- XVIII -XIX. century – several applications with straight (untwisted) blades – plans, toys, (ship and) airship propulsion
- Early XX. Century – Wright brothers, prop with twisted blades – first actually working airplane

(https://en.wikipedia.org/wiki/Propeller)



... Working **speed range different** from that of other propulsion systems



Aircraft propulsion systems – their efficiency as a function of airspeed

http://164.100.133.129:81/econtent/Uploads/ACD2501_Day%204_Aircraft_Propulsion.pdf

Business potential

*"The **subsonic transport market**, which is by far the largest, the most certain, and the most competitive..."*

(National Research Council (gov.), US, 1992)

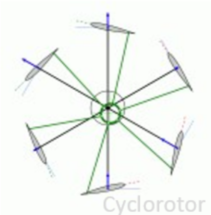
Subsonic transport
- Huge market,
- Potentially dominated by propeller driven aircrafts. (See previous chart.)

➢ Propeller propulsion is to stay for long

➢ Finding investors is likely

Options for Development of Propellers

New objectives: energy saving & noise reduction



Regular goals:

- Weight reduction
- Cost reduction (manufacture + operation)
- Extending lifespan
- New materials

Efficiency improving marginally but continuously

Non-trivial goals:

- Changing the aerodynamic concept
- Basic structural modification
- Other significant modification

Sharp change of efficiency possible

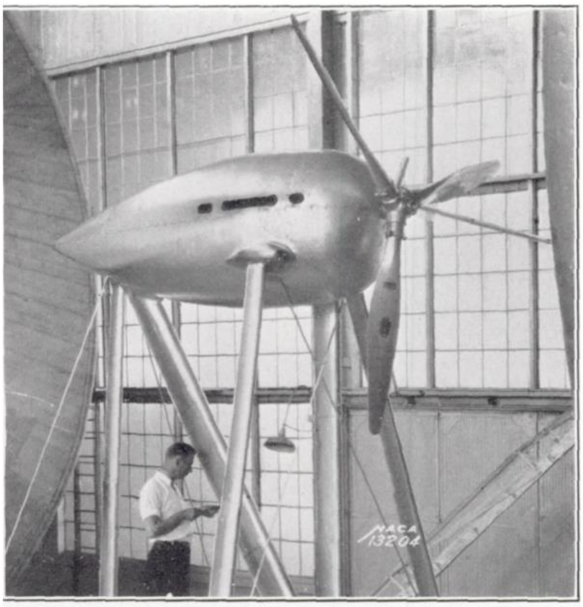


FIGURE 3.—The liquid-cooled engine nacelle with round nose.

Efficiency of Propellers

- **Efficiency:**

  Ratio of the useful (output) power to the used (input) power;

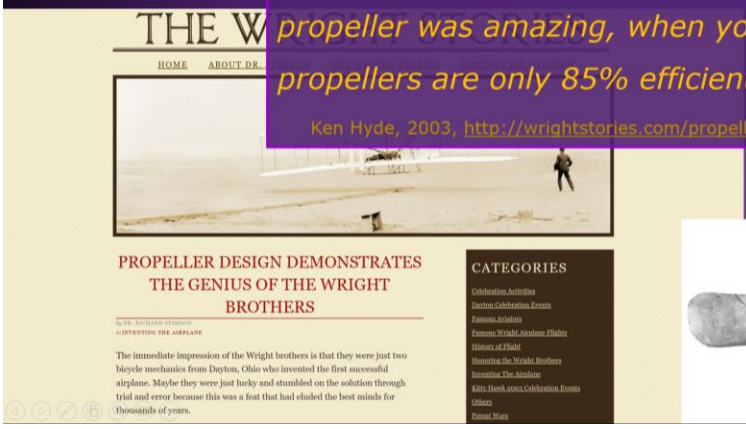
- General characteristics and functions are used, taken „as it is” from technical books.

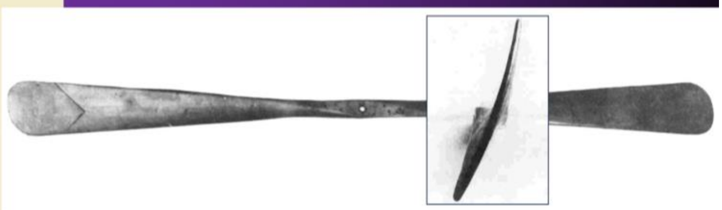
(No new derivations are performed.)

Ken Hyde had one of …(Wrights' 1911) propellers … tested at the Langley Full Scale Wind Tunnel. (In 2003.) It achieved an efficiency of 77% operating at a flying speed of 40 mph.

Hyde commented, "The performance of our remanufactured Wright propeller was amazing, when you consider that today's wood propellers are only 85% efficient."

Ken Hyde, 2003, http://wrightstories.com/propeller-design-demonstrates-the-genius-of-the-wright-brothers/





Is it possible to make some significant increase of propeller efficiency our days?

(For the last 100 years of human flight just a few %-s of improvement have been achieved.)

Yes, it is!

Very much, as we have brand new materials :

Teflon
Kevlar
Carbon fiber

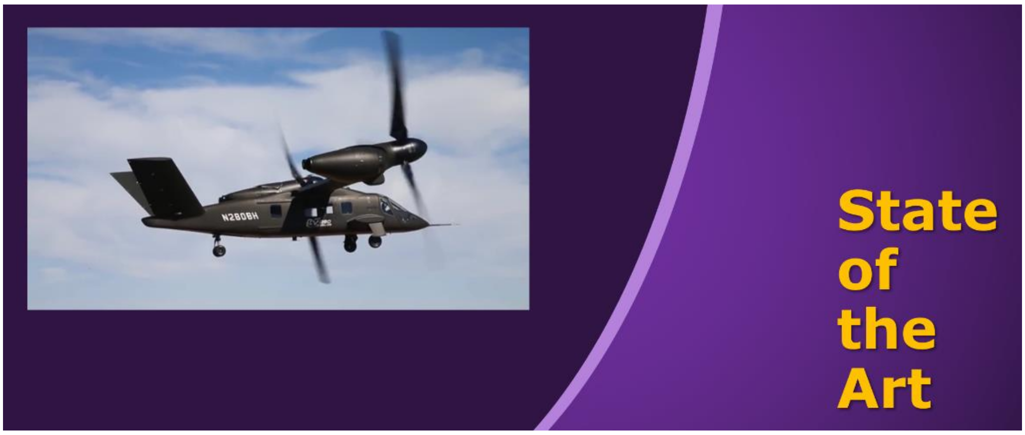
} Key elements of the proposed invention

But – not in the field of maximum values! (*) Significant increase is possible in the extension of the working range. (Speed range.)

(*) Some improvements even of the maximum values are still possible. Recently happens that the possible η_{max} values are intentionally made less (i.e., worse) in order to get a wider working range for the prop. This practice will obviously be stopped as unnecessary. Actual measurements will decide.

First it was only a hunch the speed range of the propellers was their sore point. It seemed very narrow. Some confirmation for this idea was needed. I searched the net. The task was:

define state of the art for the propellers.



Internet Search for Data on the State of the Art

- As we are concerned with improving efficiency, state of the art shall be defined as efficiency data from the known top-level solutions.
- Actual characteristics would be needed.
- The brand new (?) tilt-rotor technology can be expected to represent also cutting-edge propeller technology.
- The search was based on the above ideas.

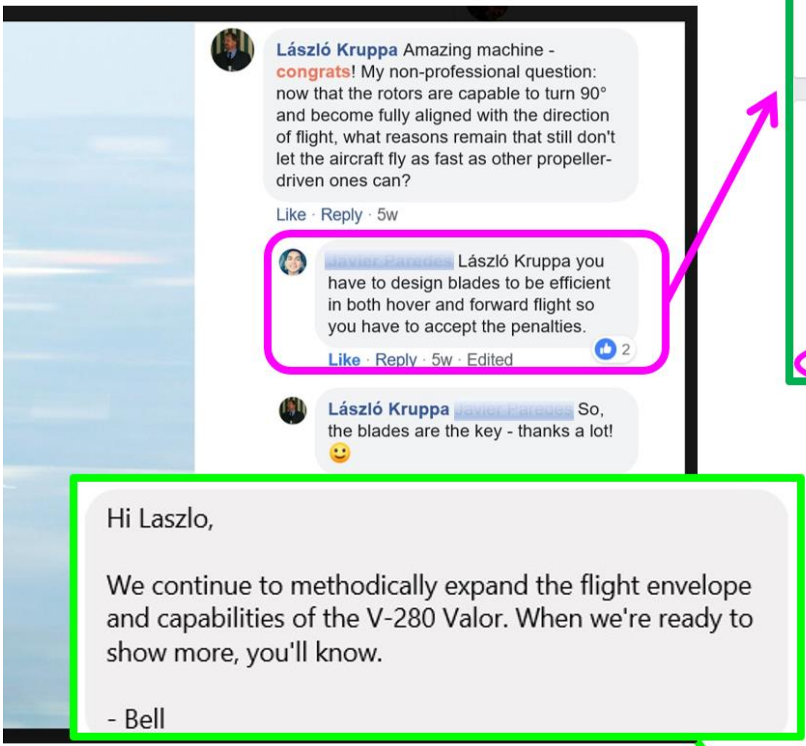
Early 2019 it was posted on the FB that the

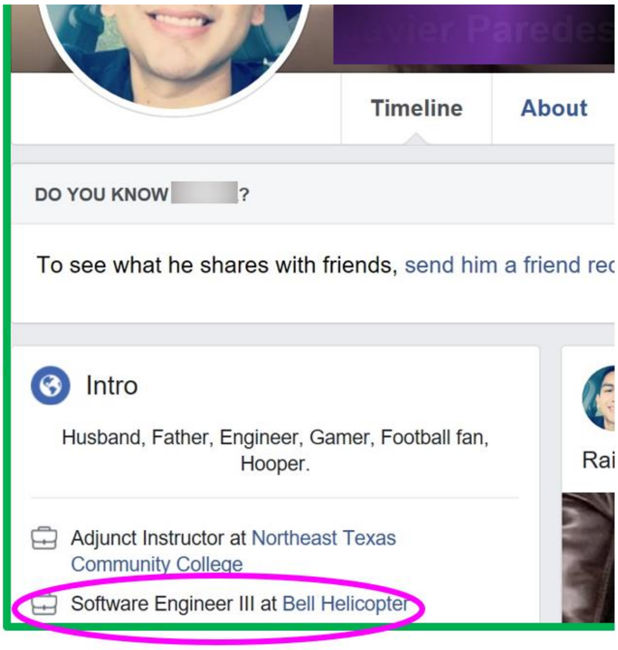
Bell V-280 Valor

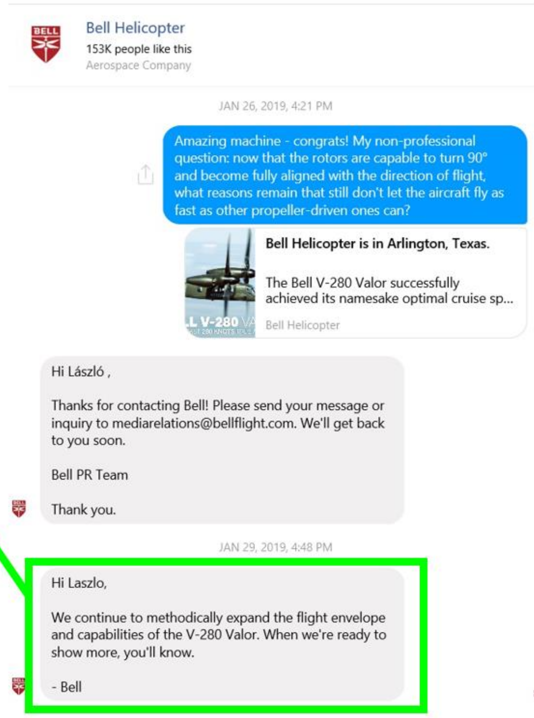
tiltrotor aircraft had been successfully tested for the 280 knots (520km/h) top design speed.

- I tried to use the festive mood of celebration to get some technical information on the props.
- I have managed but not the way expected...

State of the art?







Almost everything is confidential.

The first, very general technical answer slipped out accidentally. It was corrected immediately.

Can be taken for granted that propellers, especially blades are a tender spot – there must be problems below the surface.

The dialog that took place, of course, was far from providing a basis to ask for propeller characteristics. Still my conviction got stronger about the presence of unsolved problems with propeller efficiency, working range and the blades;

I started to investigate...

Finally, after some systematic search, I found some interesting data. Out of all keywords „Tilt-rotor" was the winner.

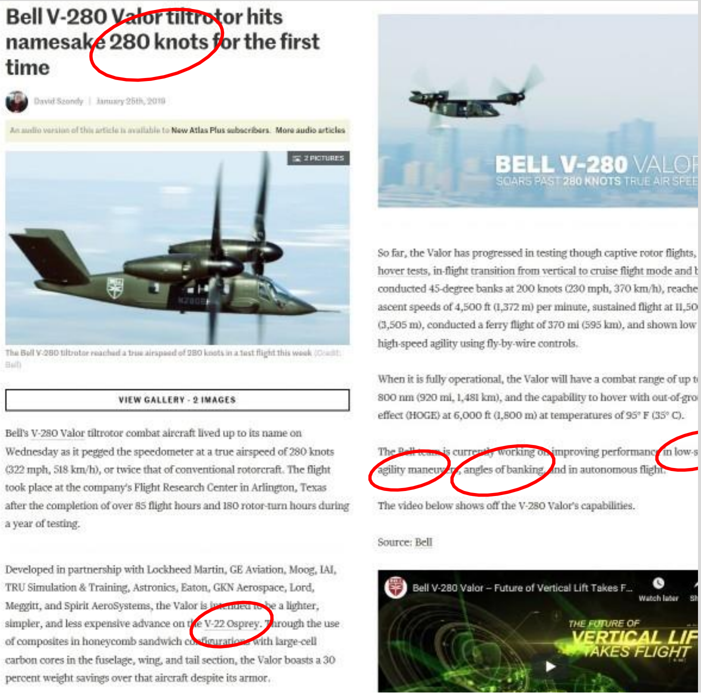
Detective work on the net

a) The newly achieved cruising speed record is

280 knots = 518,56 km/h.

In principle this could be much more! For other, non-helicopter, propeller driven aircrafts this figure could reach 8-900 km/h. Insufficient blade twist may cause the trouble?...

b) More trouble with maneuvers performed in hover and banking is likely present too...



Bell V-280 Valor tiltrotor hits namesake 280 knots for the first time

David Szondy | January 25th, 2019

An audio version of this article is available to New Atlas Plus subscribers. More audio articles

The Bell V-280 tiltrotor reached a true airspeed of 280 knots in a test flight this week (Credit: Bell)

VIEW GALLERY - 2 IMAGES

Bell's V-280 Valor tiltrotor combat aircraft lived up to its name on Wednesday as it pegged the speedometer at a true airspeed of 280 knots (322 mph, 518 km/h), or twice that of conventional rotorcraft. The flight took place at the company's Flight Research Center in Arlington, Texas after the completion of over 85 flight hours and 180 rotor-turn hours during a year of testing.

Developed in partnership with Lockheed Martin, GE Aviation, Moog, IAI, TRU Simulation & Training, Astronics, Eaton, GKN Aerospace, Lord, Meggitt, and Spirit AeroSystems, the Valor is intended to be a lighter, simpler, and less expensive advance on the V-22 Osprey. Through the use of composites in honeycomb sandwich configurations with large-cell carbon cores in the fuselage, wing, and tail section, the Valor boasts a 30 percent weight savings over that aircraft despite its armor.

So far, the Valor has progressed in testing though captive rotor flights, hover tests, in-flight transition from vertical to cruise flight mode and b conducted 45-degree banks at 200 knots (230 mph, 370 km/h), reache ascent speeds of 4,500 ft (1,372 m) per minute, sustained flight at 11,50 (3,505 m), conducted a ferry flight of 370 mi (595 km), and shown low high-speed agility using fly-by-wire controls.

When it is fully operational, the Valor will have a combat range of up t 800 nm (920 mi, 1,481 km), and the capability to hover with out-of-gro effect (HOGE) at 6,000 ft (1,800 m) at temperatures of 95° F (35° C).

The Bell team is currently working on improving performance in low-s agility maneuvers, angles of banking, and in autonomous flight.

The video below shows off the V-280 Valor's capabilities.

Source: Bell

Lessons learned (1.)

Accepting that all tilt-rotor solutions are built on cutting edge propeller technology, it can clearly be stated that

limits of working speed-range of propellers in general, known from existing reference, still have not been exceeded. In this connection it was observed that

blade stall could not be prevented even in cases when exact flow parameters were known from calculations and measurements in advance.

All problems experienced relate strictly to subsonic flight conditions.

Lessons learned (2.)

Observations made during the study of the above tilt-rotor reports indicate that as state of the art for the working range of propellers, data available from

- existing textbooks and other
- open-source technical documentation

are fully acceptable and can be used (with the condition of due verification and control).

Note

Possibly, the above statements can partly be explained or made more easily accepted by this reference from the first chapter, on History of Propellers:

- *(for jet propulsion becoming popular) ... post-World War II. prop-development has practically halted;*
- After the oil price explosion in 1973, slowly it was restarted in the 80-ies, worldwide;

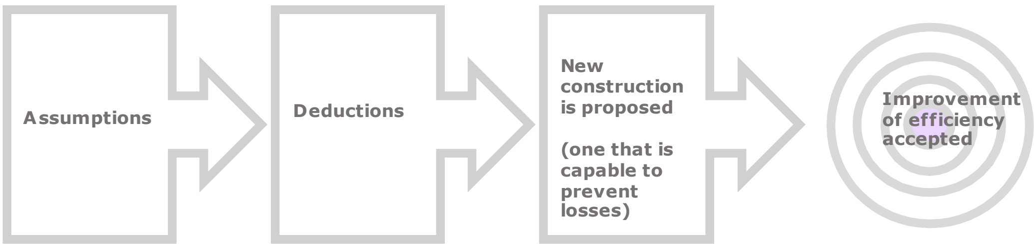
The approach

- The present invention is hoped to be able to significantly improve efficiency of the propellers;

- However (as no prototype has been made) there are no actual test results to confirm hopes;

- Therefore, for the sake of correctness, the following method of proving is adopted:

1. Assumptions - hypotheses will be made as to the reasons of deterioration of characteristics;
2. Deductions;
3. From deductions a proposal will be made that prevents most of deterioration;
4. Objective of the invention is achieved.



Sources used

- Hypotheses built on the basis of an arbitrary (but reliable) **textbook**:

  Gausz Tamás, LÉGCSAVAROK, BME, 2015 (university textbook)

- Basic method of propeller design, the simple **blade element theory** (see more below) is used.

Efficiency chart of a fixed pitch propeller

- Regimes by speed range:
  - **a) Below optimal**
  - **b) Optimal**
  - **c) Above optimal**

(Fine print and my comments in parentheses are shown in more detail on following pages.)

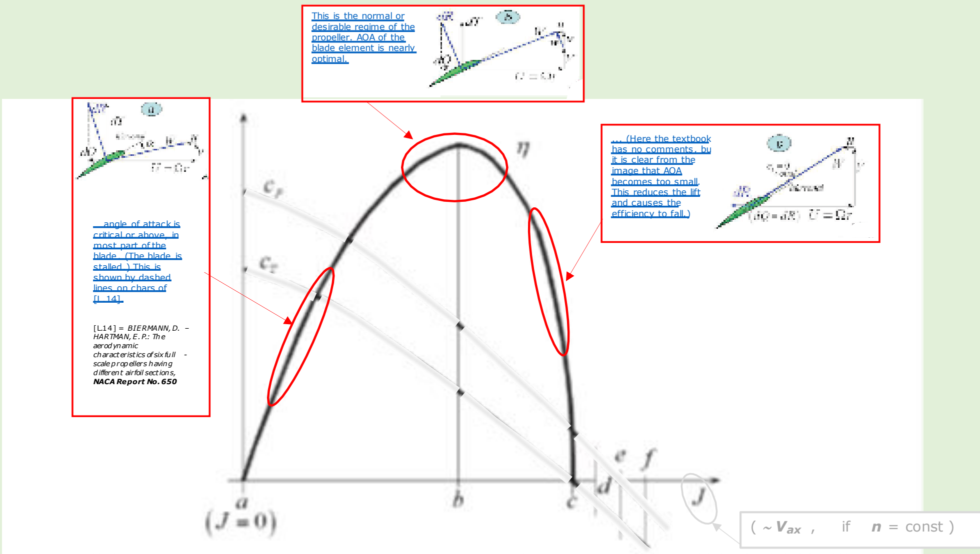
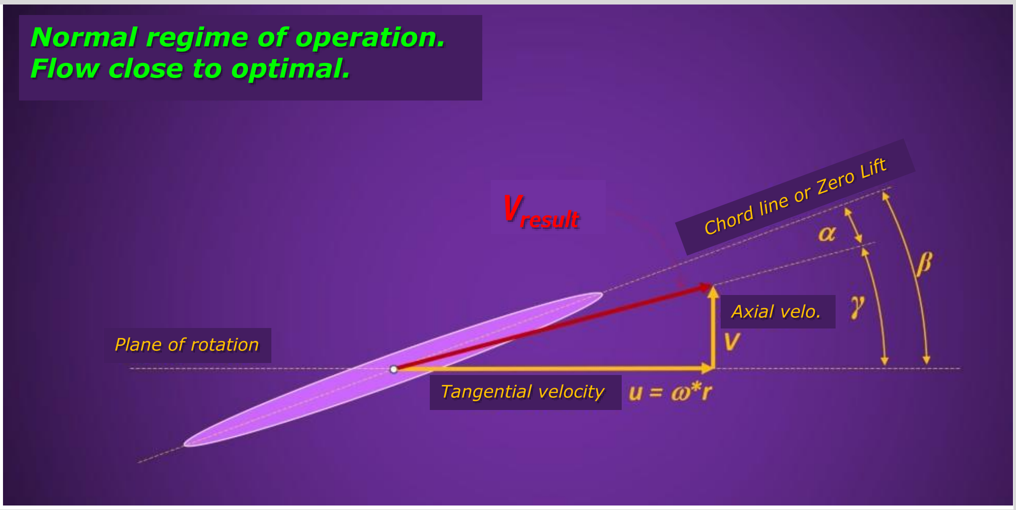


Fig. L&21 – ~~Thrust and power coefficients, and~~ efficiency as functi ns of advance ratio

Regime „b"

$J = J_{design}$

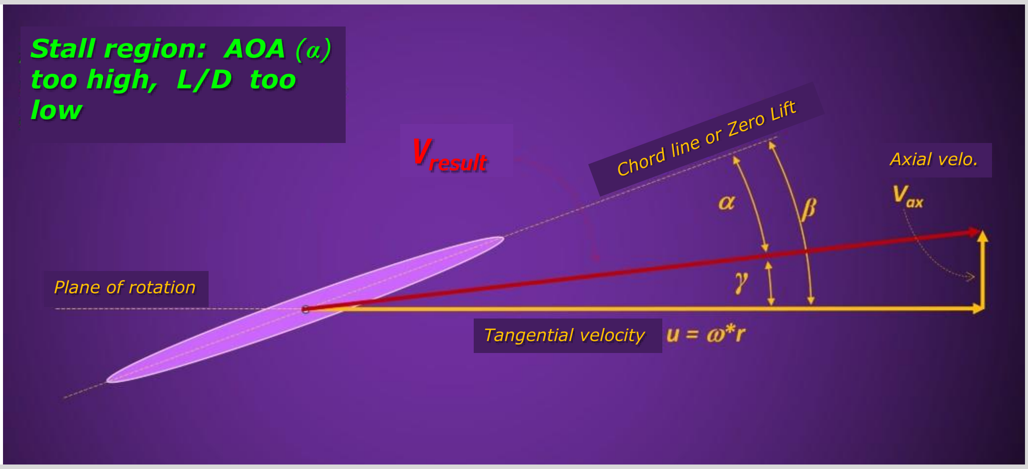
Position of the blade section compared to that of the resultant flow velocity (V_{result}) is close to optimal.



Regime „a"

Low value of J makes V_{ax} small too.

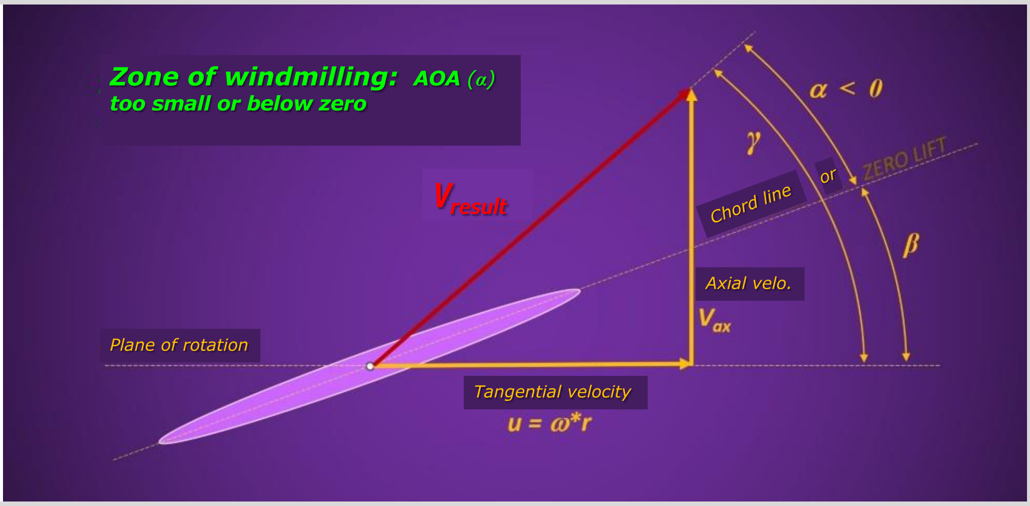
Position of the blade section compared to that of the resultant flow velocity gets distorted according to Fig.

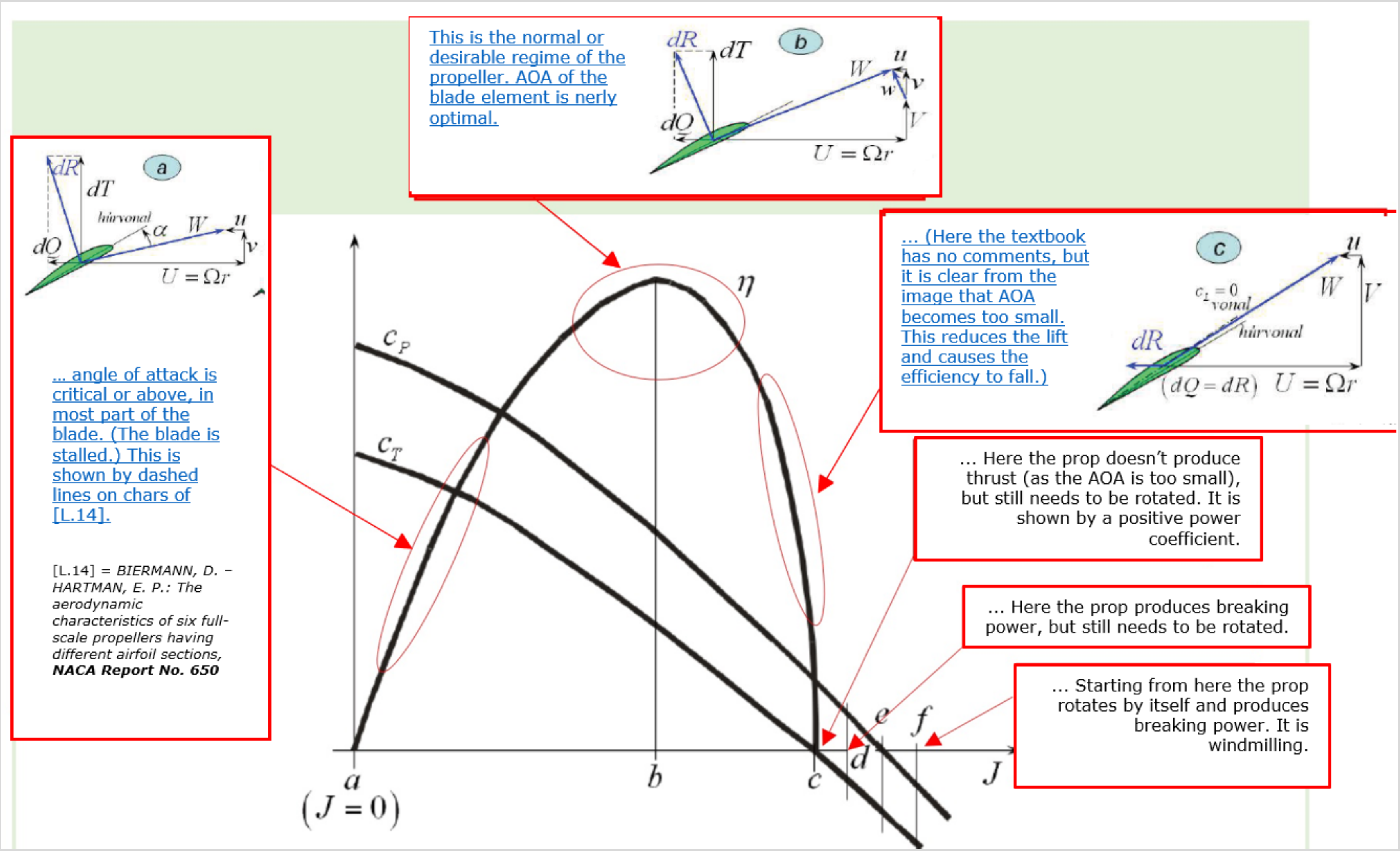


Regime „c"

High value of J causes V_{ax} too high.

Position of the blade section compared to that of the resultant flow velocity gets distorted as shown on Fig.





a
dR
dT
hirvonal
α
W
u
v
dQ
$U = \Omega r$
... angle of attack is critical or above, in most part of the blade. (The blade is stalled.) This is shown by dashed lines on chars of [L.14].
[L.14] = BIERMANN, D. – HARTMAN, E. P.: The aerodynamic characteristics of six full-scale propellers having different airfoil sections, **NACA Report No. 650**
This is the normal or desirable regime of the propeller. AOA of the blade element is nerly optimal.
b
dR
dT
W
u
v
w
V
dQ
$U = \Omega r$
... (Here the textbook has no comments, but it is clear from the image that AOA becomes too small. This reduces the lift and causes the efficiency to fall.)
c
u
$c_L = 0$
vonal
W
V
hirvonal
dR
$(dQ = dR)$
$U = \Omega r$
... Here the prop doesn't produce thrust (as the AOA is too small), but still needs to be rotated. It is shown by a positive power coefficient.
... Here the prop produces breaking power, but still needs to be rotated.
... Starting from here the prop rotates by itself and produces breaking power. It is windmilling.
η
c_P
c_T
a
$(J = 0)$
b
c
d
e
f
J

SHORTCOMINGS

This curve is

- very much humpback;
- it has only one single point of optimum (see below) ;
  - More criticism:
    - ➔ too small working range,
    - ➔ aircraft is no washing machine -
    - ➔ has to operate at more than just one speed,
    - ➔ needs smooth transition between „gears”

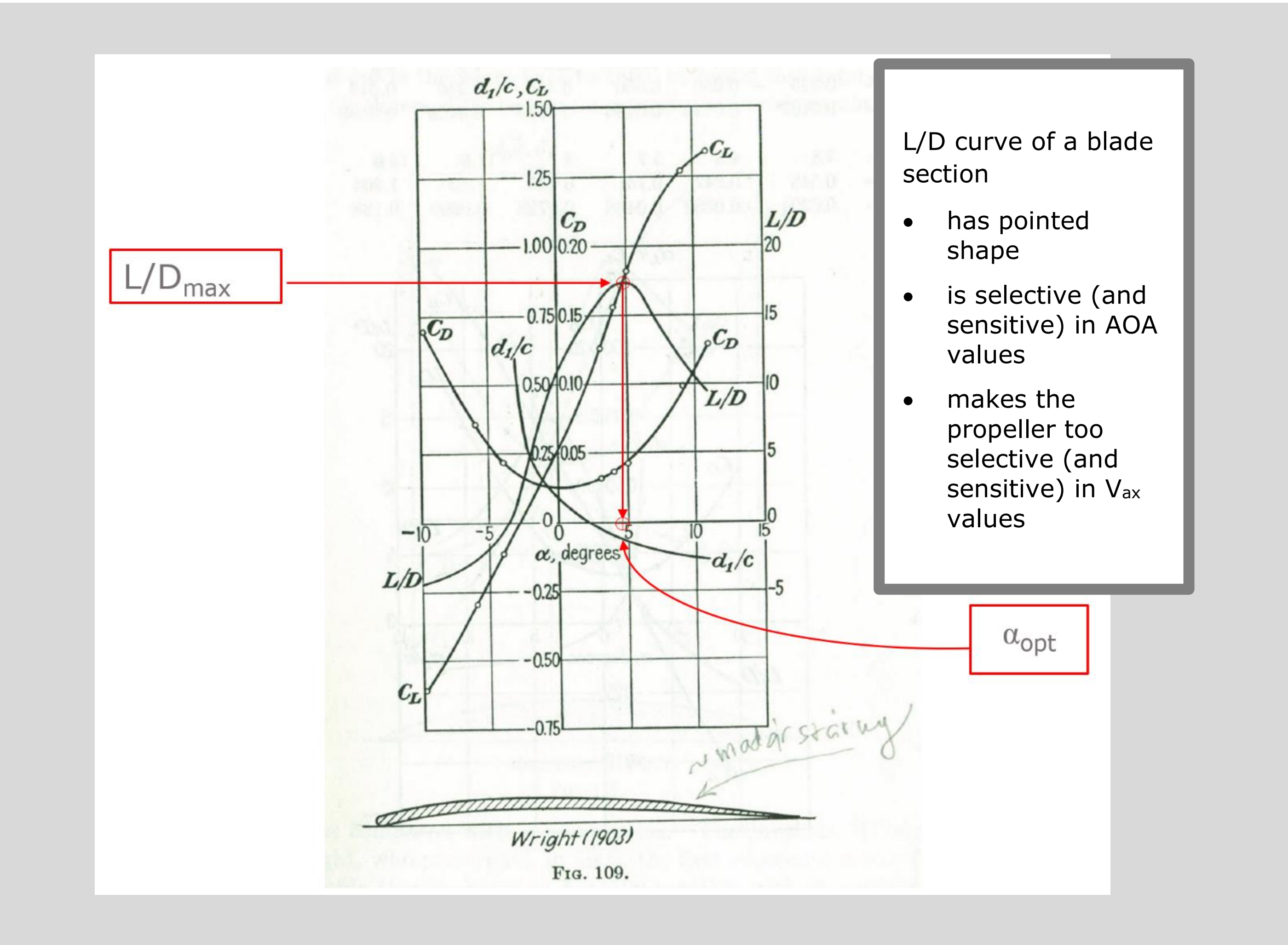
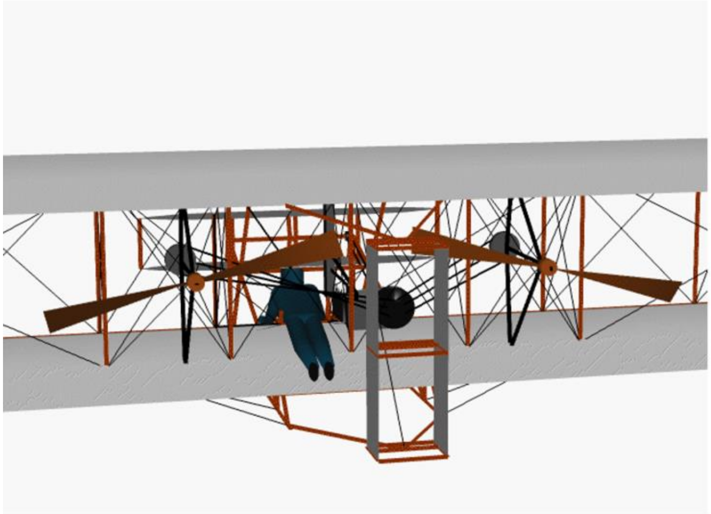


FIG. 109.

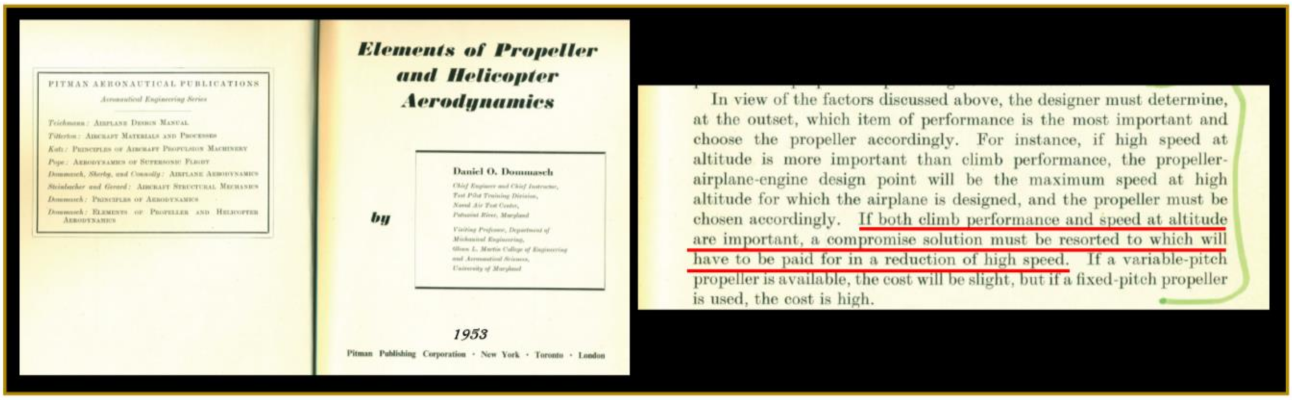


Working speed-range of propellers

Working speed-range of propellers

***Working range** of propellers is understood as a certain set of values either of the axial speed $\boldsymbol{V_{ax}}$ or the advance ratio **J**, at which the propeller produces a high or acceptable level of efficiency $\boldsymbol{\eta}$.*

The **narrowness** of the working range of propellers in technical literature is seen as a **given thing** and almost no such „complaints" can be found:



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Elements of Propeller and Helicopter Aerodynamics

by

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Visiting Professor, Department of Mechanical Engineering, Glenn L. Martin College of Engineering and Aeronautical Sciences, University of Maryland

1953

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In view of the factors discussed above, the designer must determine, at the outset, which item of performance is the most important and choose the propeller accordingly. For instance, if high speed at altitude is more important than climb performance, the propeller-airplane-engine design point will be the maximum speed at high altitude for which the airplane is designed, and the propeller must be chosen accordingly. If both climb performance and speed at altitude are important, a compromise solution must be resorted to which will have to be paid for in a reduction of high speed. If a variable-pitch propeller is available, the cost will be slight, but if a fixed-pitch propeller is used, the cost is high.

„... If both climb performance and speed at altitude are important, a compromise solution must be resorted to which will have to be paid for in a reduction of high speed ..."

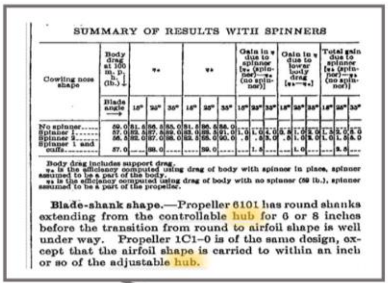
Chapter **3.2. Propeller Selection**

Reliable measurement/test data was needed for analysis

Efficiency characteristics of props taken from the Internet were checked. It was found that

- for making estimates and theoretical comparisons, and
- for evaluation of both the maximum efficiency values and the size of the working range
- NACA Reports 642 and 650, **1938-39**, USA, are sufficiently authentic and fully acceptable today.

- NACA Reports 642 and 650, **1938-39**, USA << **Data to be used. Correct figures – even today.**
- Reports contain exact size-data of props as well as descriptions of measuring procedures.



SUMMARY OF RESULTS WITH SPINNERS

Blade-shank shape.—Propeller 6101 has round shanks extending from the controllable hub for 6 or 8 inches before the transition from round to airfoil shape is well under way. Propeller 1C1-0 is of the same design, except that the airfoil shape is carried to within an inch or so of the adjustable hub.

https://digital.library.unt.edu/ark:/67531/metadc66302/m1/24/?q=hub

AERODYNAMIC CHARACTERISTICS OF PROPELLERS HAVING DIFFERENT AIRFOIL SECTIONS 11

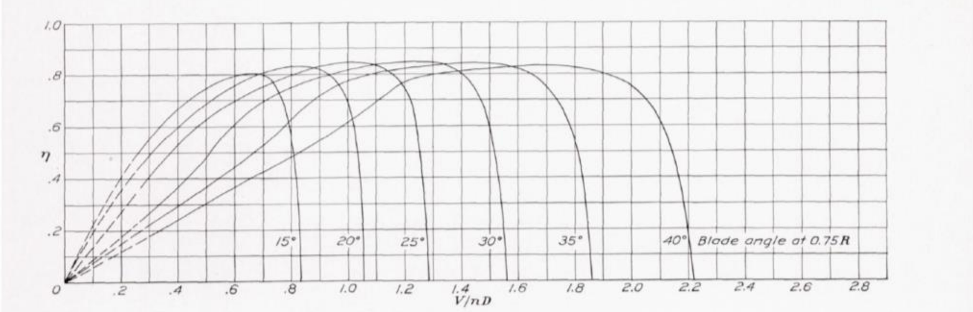
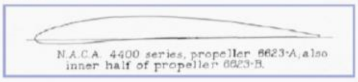


FIGURE 14.—Efficiency curves for propeller 6623-A (N. A. C. A. 4400 section).

propellers tested have three blades, are 10 feet in diameter, and are identical in shape except for blade sections. B = 3 D = 305 cm



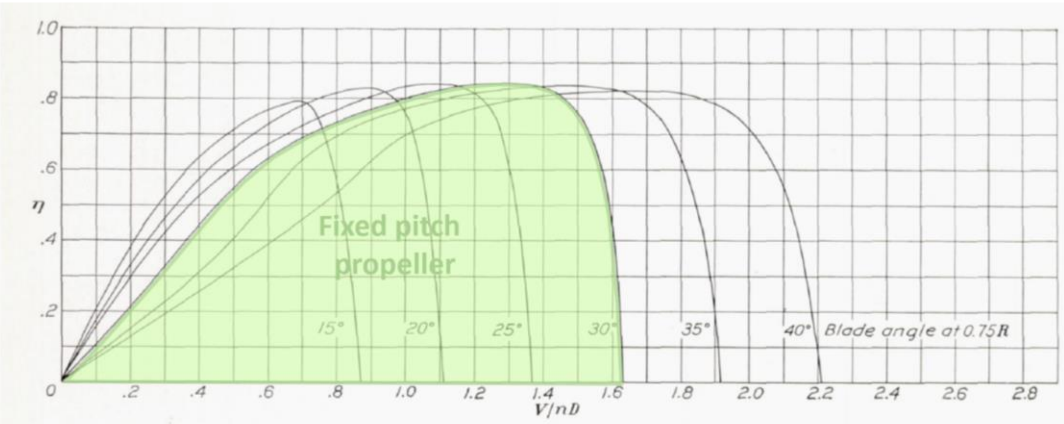


FIGURE 26.—Efficiency curves for propeller 6623-D (N. A. C. A. 6400 section).

Efficiency of propeller as function of nondimensional velocity.

(J = V / (n*D) = ADVANCE RATIO = nondimensional speed)

Today's variable pitch propellers have blades that rotate around their radius. Thus working speed-range is made wider.

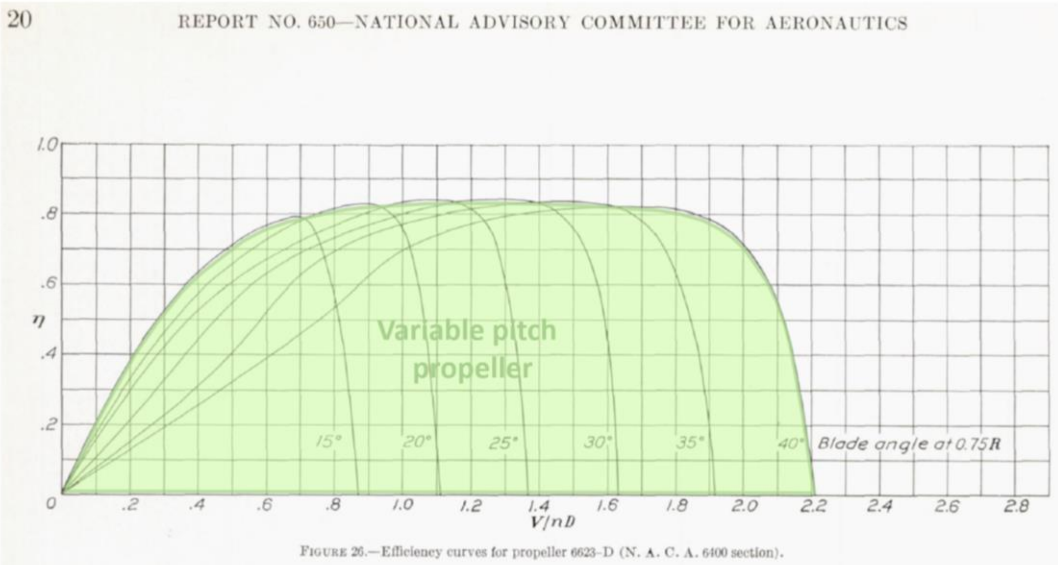


FIGURE 26.—Efficiency curves for propeller 6623-D (N. A. C. A. 6400 section).

Is this range really narrow? Exactly **how narrow?**

To get an estimate we will convert the axis of nondimensional velocity **J** = V / (n*D), to one of actual (that is dimensional) speed-values. The conversion requires exact parameters of the propeller. E.g. if

D = 3m, n = 20 sec^{-1}, J = 0,2 – 2,8 (then) **>>**

>> V = J*n*D ≈ (43 – 605) km/h

Is this range really narrow? Yes.

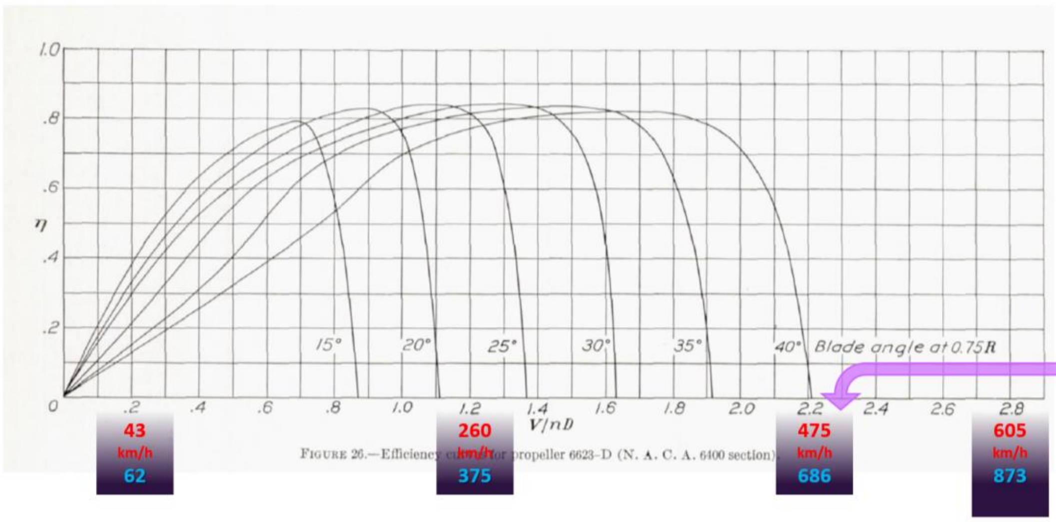


FIGURE 26.—Efficiency curves for propeller 6623-D (N. A. C. A. 6400 section).

Condition to calculate maximum speed of rotation:

- tangential velocity of blade tips equals 80% of speed of sound.

Ideally this could reach 8-900 km/h for propeller propulsion.

D = 3m, n = 20,00 sec^{-1} (RPM=1200), J = (0,2 – 2,8) range of measurement >> V = J*n*D ≈ (43 – 605) km/h

Another conversion for the maximum attainable speed:

D = 3m, n = 28,87 sec^{-1} (=n_{max}), (RPM=1732), J = (0,2 – 2,8) range of measurement >> V = J*n*D ≈ (62 – 873) km/h

Reasons of efficiency drop

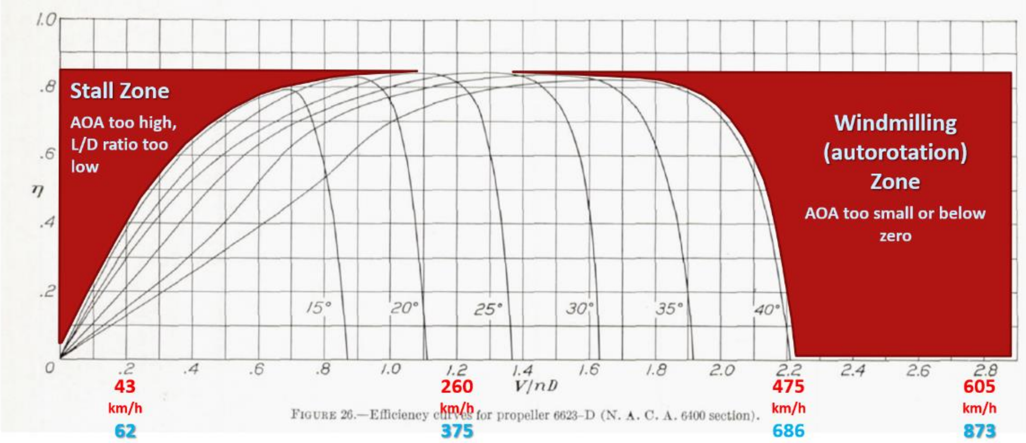
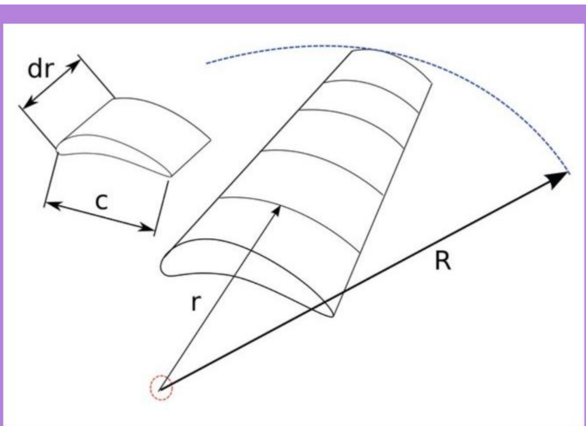


FIGURE 26.—Efficiency curves for propeller 6623-D (N. A. C. A. 6400 section).

In both cases trouble is brought about by the incorrect value of the Angle of Attack (AOA).

➔ How blade geometry effects efficiency – must be checked.



Link Between Blade Geometry and Propeller Efficiency

Within geometry the **blade twist** is looked at: how sections are positioned along the radius

> *„…the **pitch distribution** may be considered as the most important **geometric characteristic** of a propeller design…"*
>
> Mises, Richard von, Theory of Flight, 1959

„… **pitch distribution** (is) the most important … „

... meaning neither the blade PLANFORM, nor the section profile assignment is...

- Blade parameters' impact on efficiency (η) :
  - **a)** Shape of planform → n * 0,1 % ,
  - **b)** Section profile → n * 0,1 % ,
  - **c)** **Pitch distribution → n * 10 %** ,

Blade twist that is pitch distribution

- We must have the **equation** of the geometric twist of a blade in order to
- Consider the positions of blade sections in the airflow;
- A basic method of propeller design, called the **Blade Element Theory** is applied.

The Simple Blade Element Theory

Source: Mises, THEORY OF FLIGHT, 1959 - a real classic

Velocity and force components on a selected blade section:

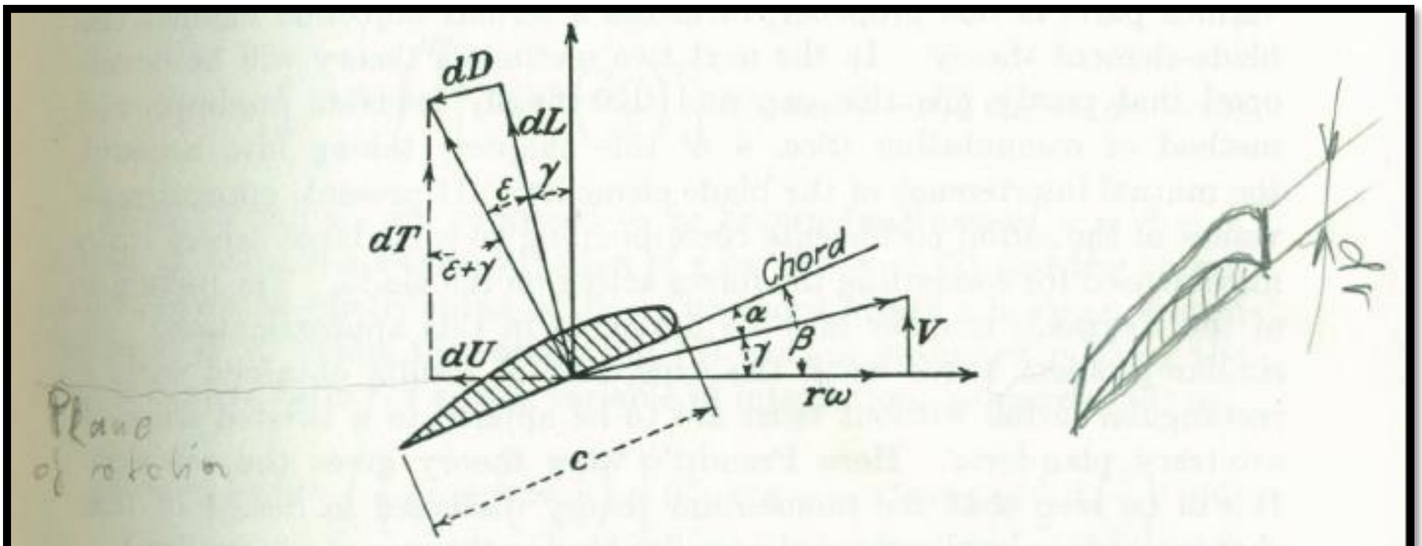


FIG. 238.—Resolution of forces acting on a propeller section.

Notes:

1. Equation of blade twist we want to use has the form:

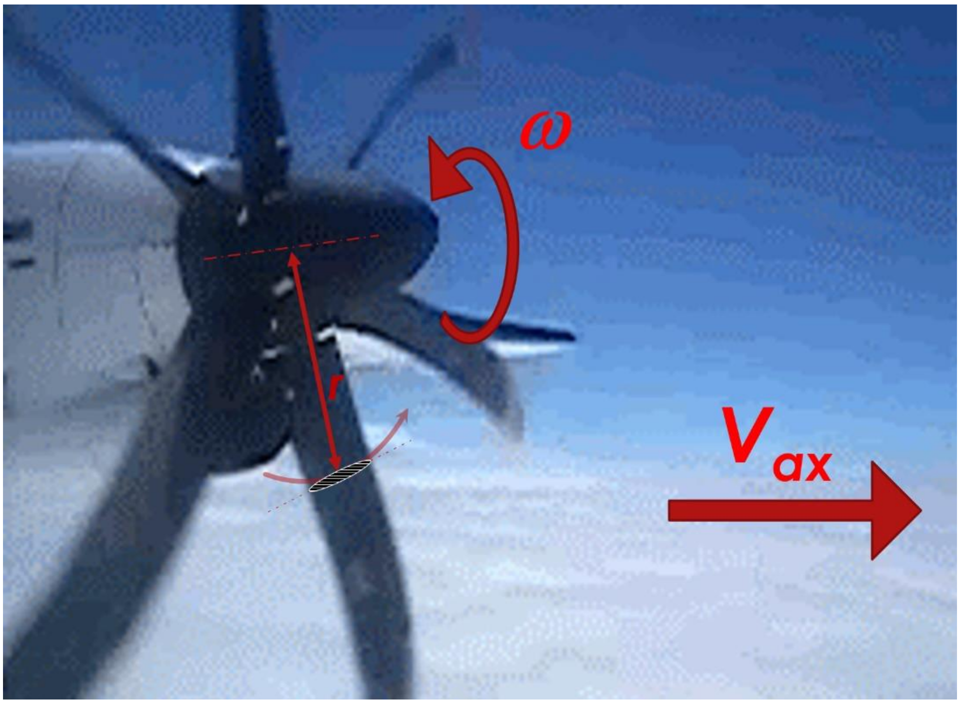
$$\beta = f(r)$$

2. Main goal of the analysis is to check behavior of the AOA (*α*) as the speed changes. Optimally

$$\alpha = const \neq f(V_{ax}, r)$$

3. Physical quantities required for the above task are all covered by the Blade Element method;
4. Other, more precise methods (involving e.g., the induced components of speed or blade aspect ratio) are omitted. However
5. Results received form the present approximations are readily applicable to and can be used by the more complex methods of calculations.

A section (i.e., blade element) for analysis is picked:



Triangle of vectors under the Blade Element Theory $(u + V_{ax} = V_{result})$

Assumptions :

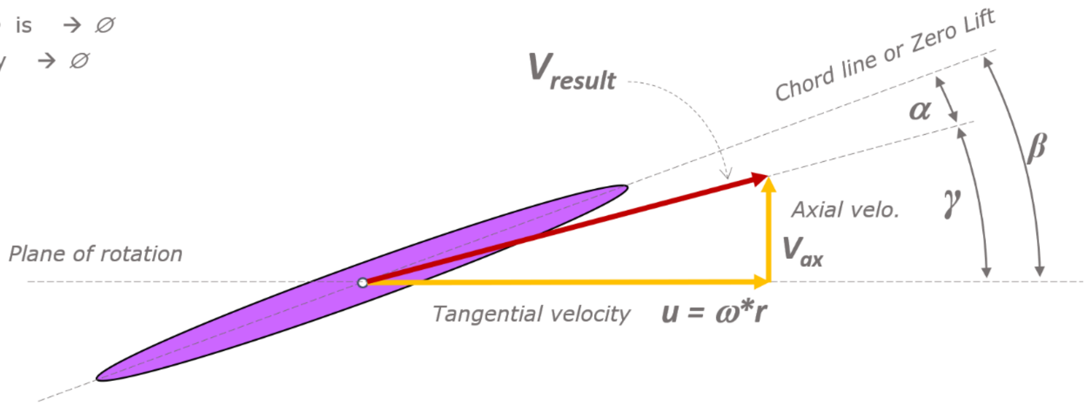
a) The selected blade element participates in a linear motion of velocity V_{ax} , and a rotation of angular velocity ω, simultaneously

b) Width of the blade element is dr

c) Aspect ratio of the blade element is $A/R \rightarrow \infty$

d) Effect of the Re is $\rightarrow \varnothing$

e) Induced velocity $\rightarrow \varnothing$



- As we are interested in the **geometry** of blade twist
- **speed components only are studied** (no need to look into forces)

Dominant angles associated with the propeller's **optimal regime** can be calculated as:

$$\alpha = \alpha_{opt} = const \neq f(r, V_{ax})$$

$$\gamma = arctg \frac{V_{ax}}{\omega * r}$$

$$\beta = arctg \frac{V_{ax}}{\omega * r} + \alpha$$

- It is known (and also seen in the above equation) that optimal distribution of the blade angle, $\beta(r)$, is a function of the axial velocity.
- Traditional propeller blades, as a rule, are made as stiff and monolithic bodies manufactured with some **fixed distribution** of the blade angle along radius.
- When $V_{ax} \neq V_{design}$, blades partly stall and/or start windmilling. Propeller efficiency drops.
- In practice it is possible to compensate for the changes of V_{ax} , by modifying the propeller RPM, but only in a rather limited range:
    a) Most of the engines used for driving propellers have **single optimums** of RPM;
    b) Another (upper) limitation comes from the blade tips: their speed must not exceed the speed of sound.
- **Variable pitch propellers have become widespread. Working range has grown. A little…**

An example

(We check behavior of the AOA (α) through example calculations.)

A **variable pitch propeller** is picked with a blade twist shaped according to the equation :

$$\beta = arctg \frac{V_{ax}}{\omega * r} + \alpha$$

(⟵ this is **standard** pitch distribution)

We specify some exact data : (⟵ input for the example-calculations)

$R = r_{max} = 1000$ mm

$r_{HUB} = 150$ mm (⟵ see next page)

$n = 2598\ min^{-1} = 43{,}3 s^{-1}$ (⟵ $n = n_{max}$, when the speed of blade tips reaches 0,8MACH)

$\omega = 2\pi * n = 272\ s^{-1} = const$

$\alpha_{opt} = 4^{\circ} = const$

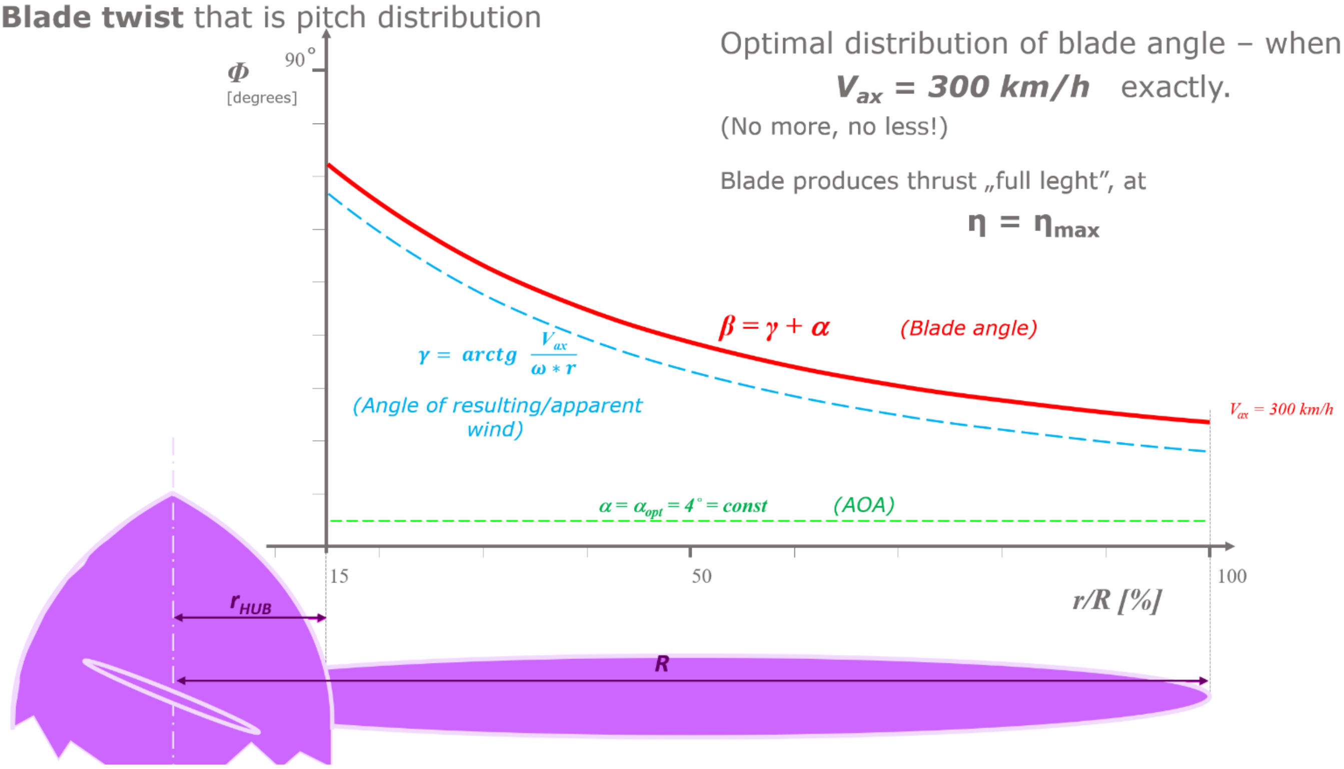
$V_{ax} = 300$ km/h

Having substituted data in the equation

$$\beta(r) = \gamma(r) + \alpha = arctg \frac{V_{ax}}{\omega * r} + \alpha$$

… graphs of the blade twist are computed:

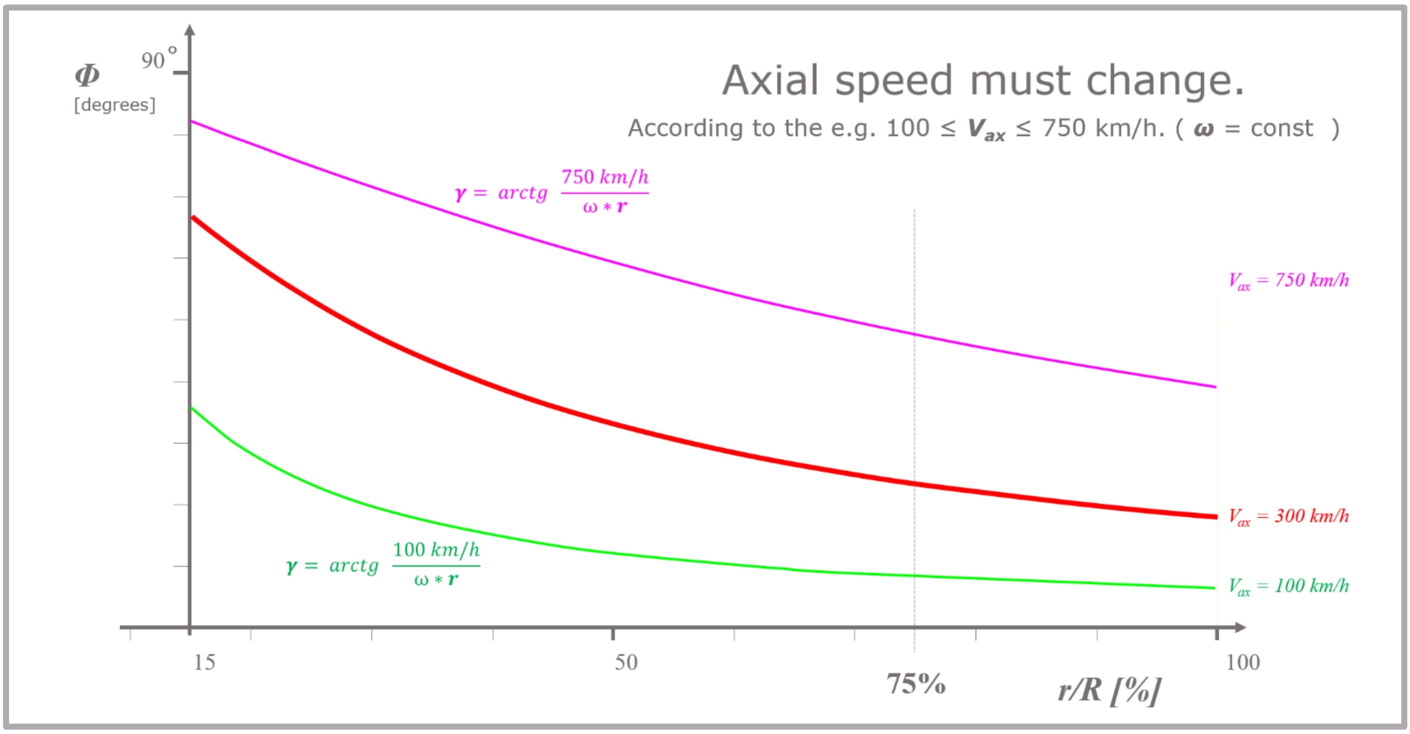
Blade twist that is pitch distribution



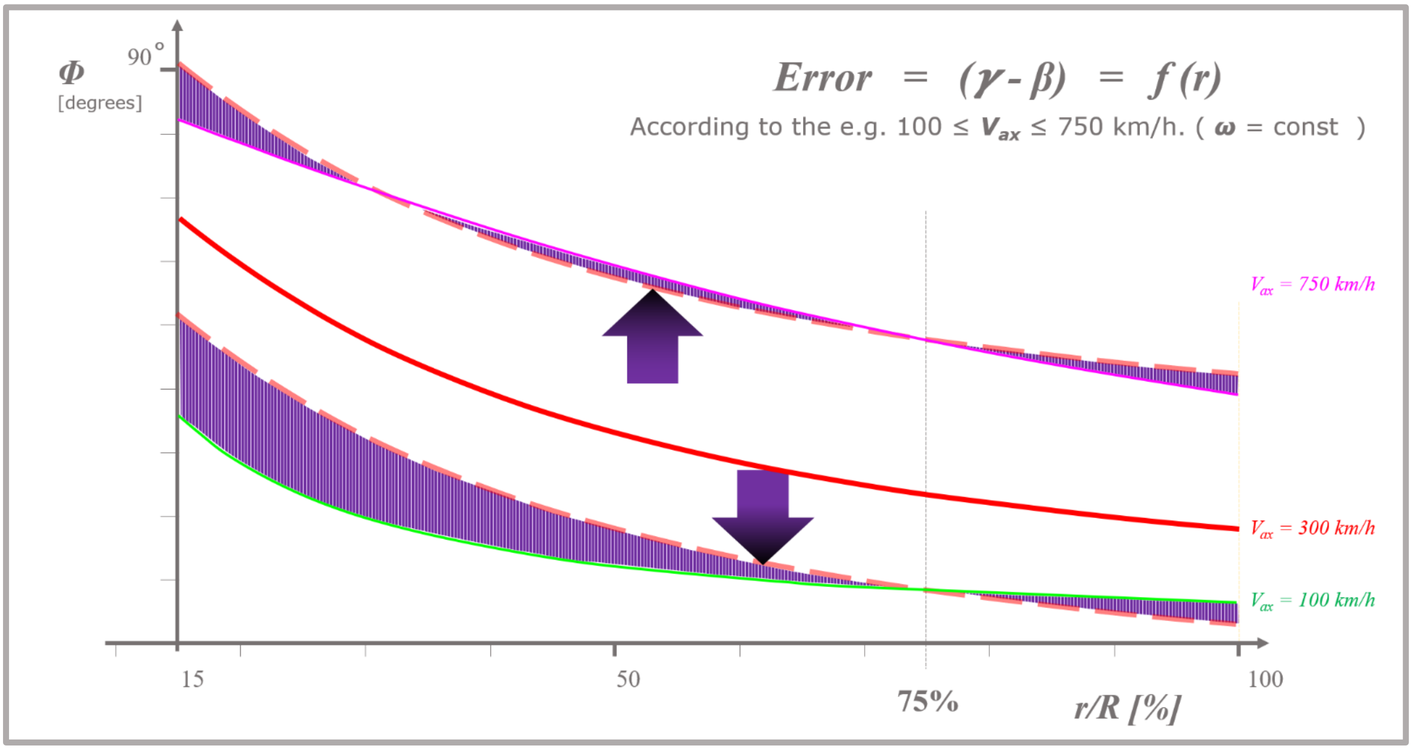
Variable pitch propeller

Design speed = 300km/h

- For a different V_{ax} there will be a different distribution of $\gamma(r)$
- By turning the blades around their radius, a limited compensation of the $(\gamma - \beta) = f(r)$ error can be achieved
- 0,75R = design point ➔ the error is measured here by agreement



We see large zones of errors (shown as shaded areas) are created between the actual and desirable distributions as the blades – stiff bodies – are turned around to follow the changing wind.



Summary

1. Axial speed (V_{ax}) will always change during the flight cycle

2. This causes the angle of the resulting wind (γ) change too, all the time

3. Charts of the resulting wind angle ($\gamma(r)$) can be used as guidance to find the optimal blade twist ($\beta\ (r)$). Thus, for equation of the **optimal** (theoretical) **blade geometry** we have

$$\beta\ (r) = \gamma(r) + \alpha$$

4. With the change of the axial speed (V_{ax}) graphs of the optimal blade geometry undergo such a nonlinear re-shaping that

5. it can only be followed with errors by the rotation of the fixed twist, stiff-body blades

6. The more the airflow velocity will differ from the design speed of the propeller (here V_{design} = 300km/h), the lower the efficiency will get

Below is a family of curves built for the angle of the resulting (or apparent) wind,

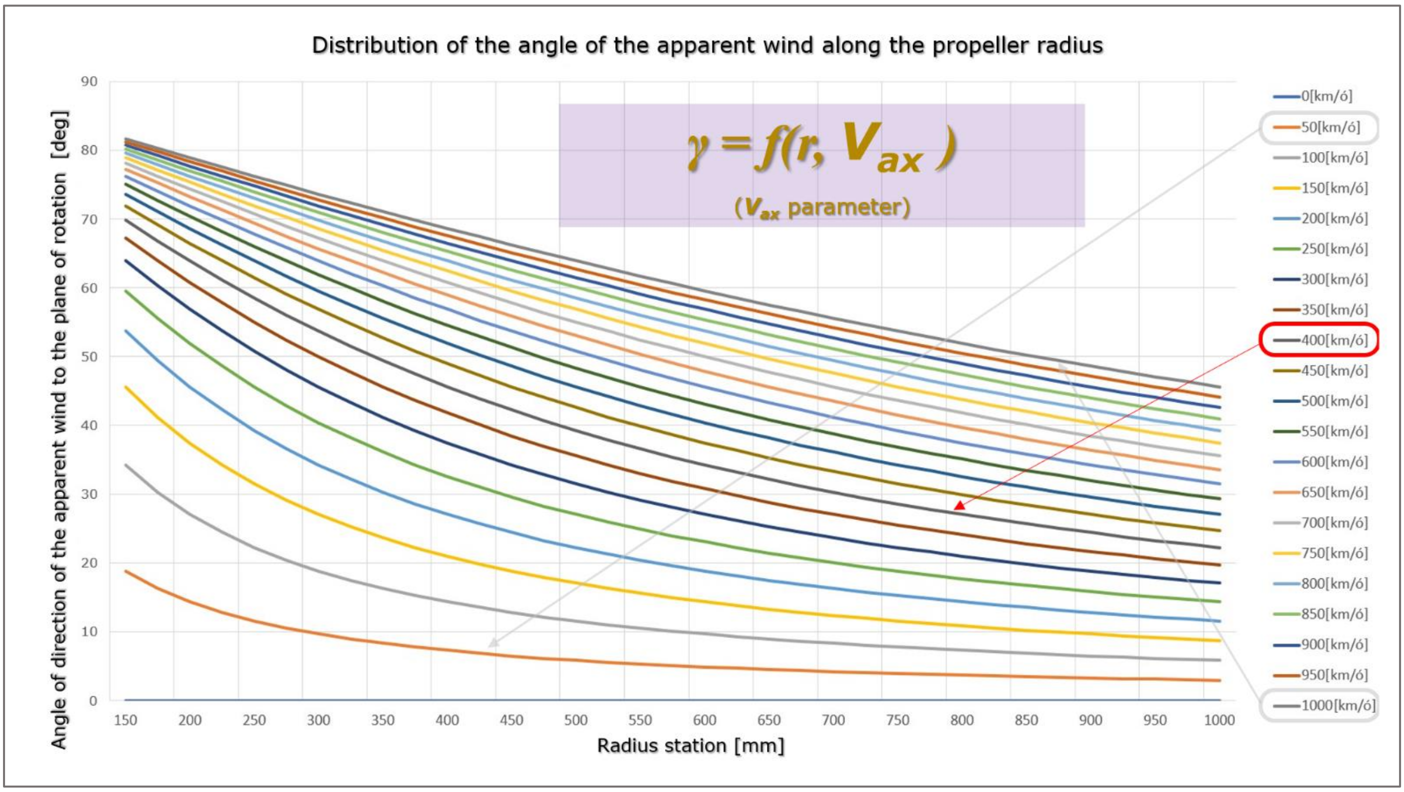
$$\gamma = f(r)$$

- with V_{ax} as the parameter.
- This is used as background for the graphical analysis of errors arising as
- fixed twist, stiff-body blades of the propeller are rotated around their radius
- in order to compensate for the changes of the axial velocity.
- We assign

$$V_{ax\_design} = 400 \text{ km/h} \quad ,$$

- and define upper speed limit as

$$V_{ax\_max} = 1000 \text{ km/h}$$

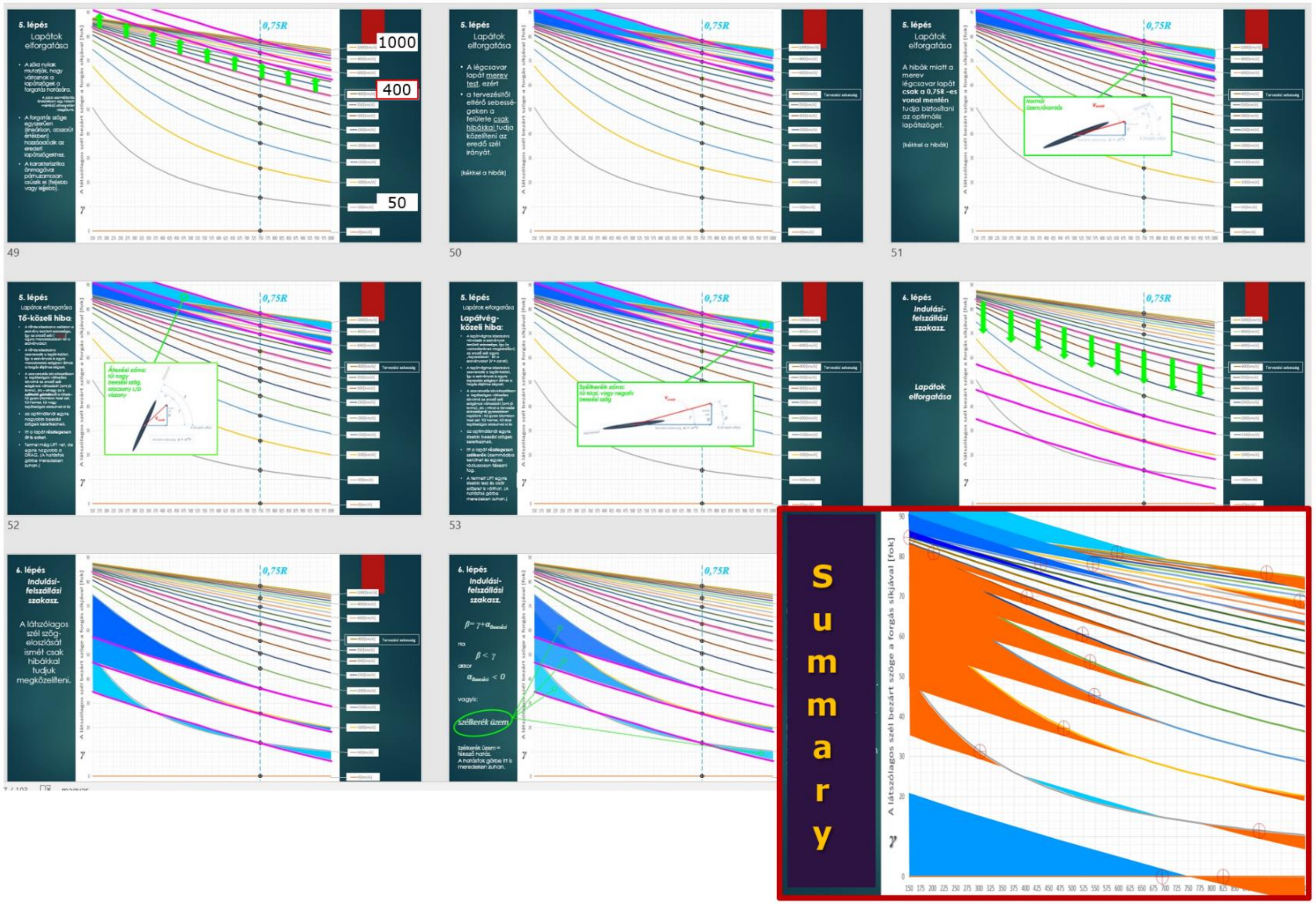


A series of charts showing several phases of rotation of a **fixed twist, stiff-body blade** of the propeller in an attempt to compensate for the changes of the axial velocity

- Blades of the propeller are rotated around their radius in order to alter the blade pitch.
- Such a rotation does not change the curve of the blade pitch – it (the curve) will only shift up or downwards on the diagram, parallel to itself.
- Segments on the charts, seen as shaded either blue or orange, represent differences between the optimal (desirable) and the actual pitch distribution. These are the segments of errors.
- The more errors are indicated the lower the efficiency of the blade drops.

Inaccuracies appearing when traditional, fixed twist blades are used to compensate for the changes of the axial velocity

Design speed equals 400km/h.
(Listed in square balloon among V_{ax} values.)



Summary graph

In the last **Summary** window, the following distinction is made between the two undesirable regimes of operation, using colors.

Inaccuracies cause the blades assume a state of

a) BLADE STALL

$$\alpha \gg \alpha_{opt} \quad (\beta \gg \gamma)$$

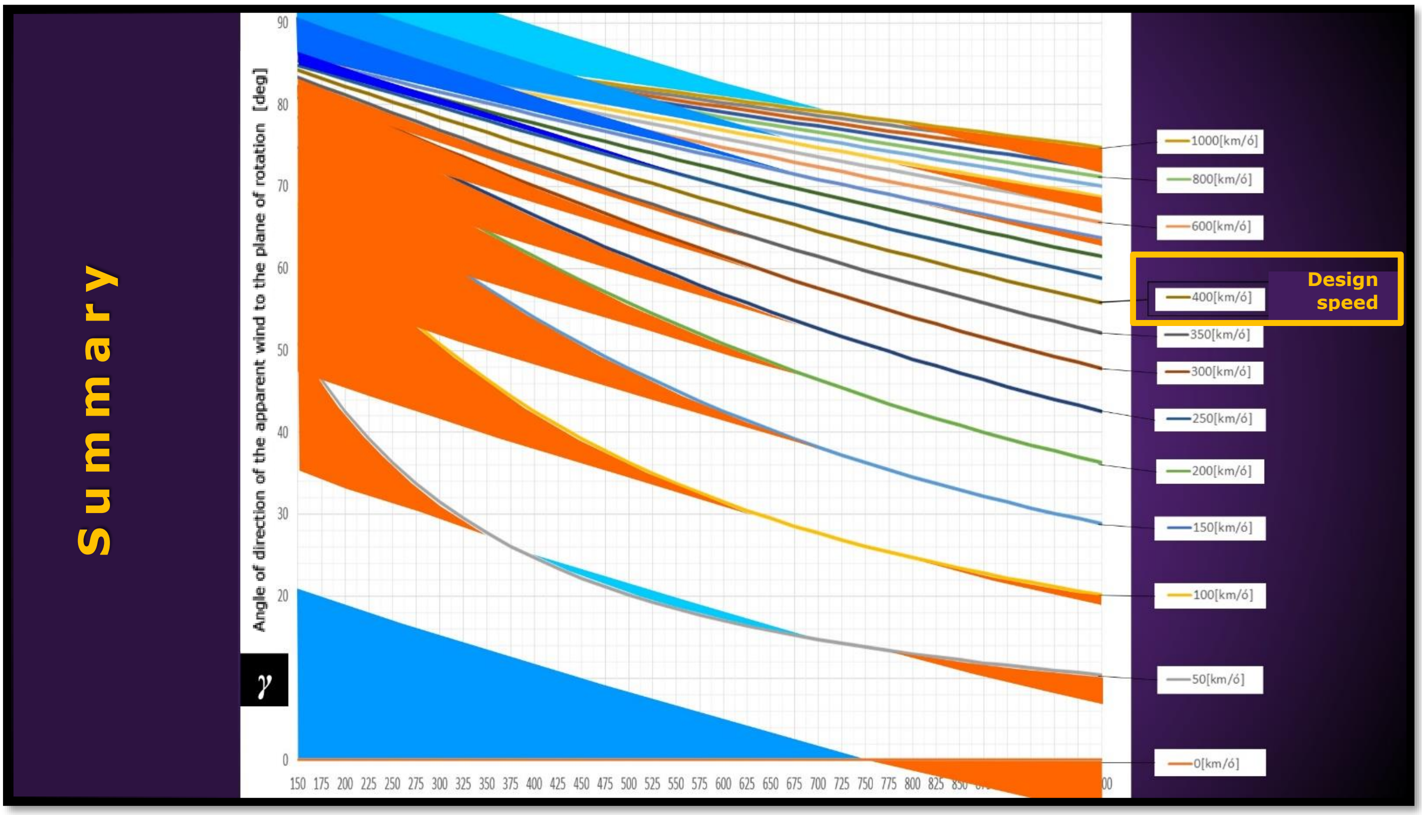
Still some thrust is being produced but drag is greatly increased.

b) WINDMILLING

$$\alpha < 0 \quad (\beta < \gamma)$$

Negative thrust that is a breaking force is produced.

It is remarkable that windmilling and stall regimes can be present even on the same blade, simultaneously.



Graphic analysis of functions

$Error = (\gamma - \beta) = f(V_{ax}, r)$ and $\beta = arctg\frac{V}{\omega * r} + \alpha$

have proven the following:

a) By rotating fixed twist, stiff-body blades it is impossible to reproduce theoretically optimal blade angles for a changing axial velocity;

b) The more the axial velocity differs from the design speed of the propeller the greater the errors become.

Assumption:

1. The above errors limit the efficiency curves from running higher and broader;
2. Limitations are present both in the lower and the higher speedrange.

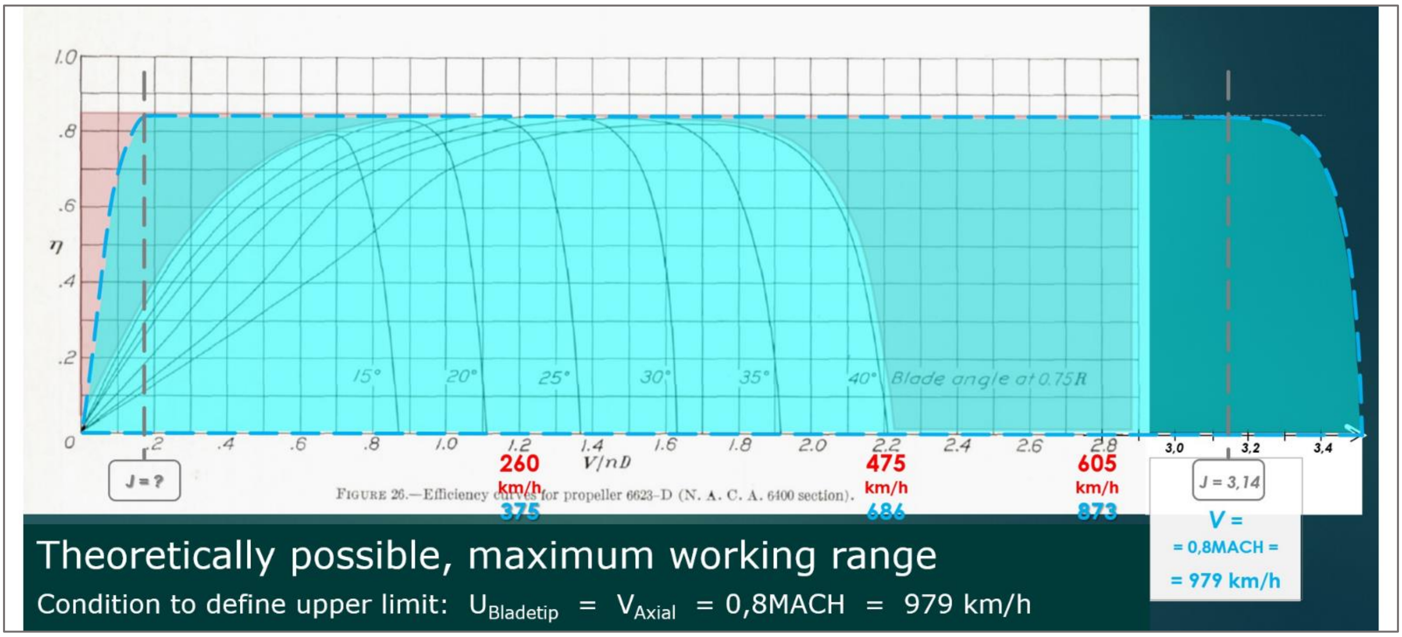
FIGURE 26.—Efficiency curves for propeller 6623-D (N. A. C. A. 6400 section).

Deduction :

1. If the right values of the blade angle could be retained in all phases of the rotation
2. the propeller's working range could become much wider.

Presently, with no test results on hand, degree of actual growth of the propeller's speed range can only be guessed.

- Upper limit **J=3,14** shown on the figure – although fully realistic - is just an arbitrarily chosen value.
- New limiting factors are likely to be considered. More calculations and testing will be necessary.



Assumption :

I. Limitations of the propellers' working range are a result of the inherent inaccuracy of the stiff body-blades, which have a fixed twist and are only capable to produce linear changes in the radial pitch-distribution. (When rotated around their radius.)

II. As the axial speed moves away from its design value, the angle of the resulting wind changes non-linearly along the propeller radius.

III. The more the axial speed will differ from its design value (either up or down) the bigger the inaccuracies will grow between the angles of the resulting wind and the blade (along the radius), causing the efficiency drop sharply.

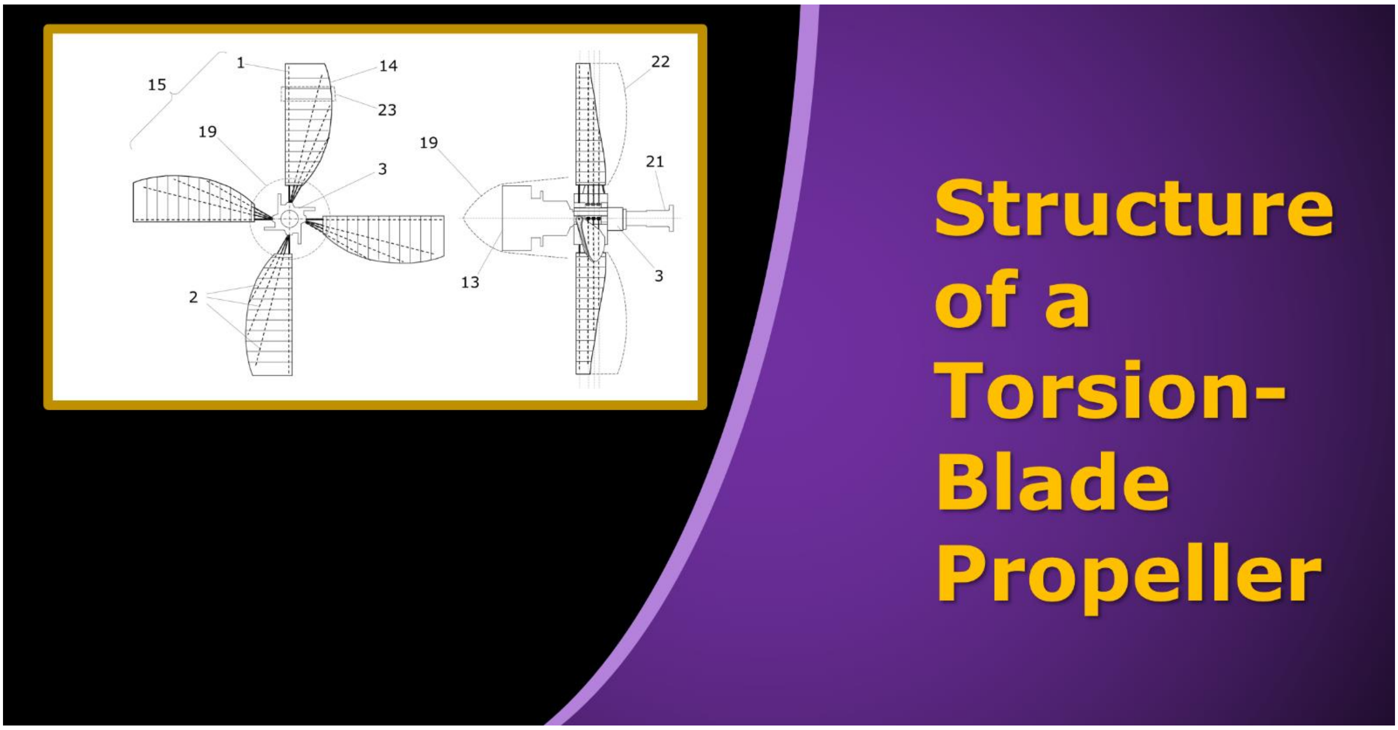
Deduction :

1. If the right values of the blade angle could be retained in all phases of the rotation (i.e., rotation of the blade around its radius)
2. the propeller's working speed range could become much wider.

Main idea of the proposed **invention** :

- When the **resulting wind** changes it is only possible to keep the blade angle distribution optimal (or close to it) if

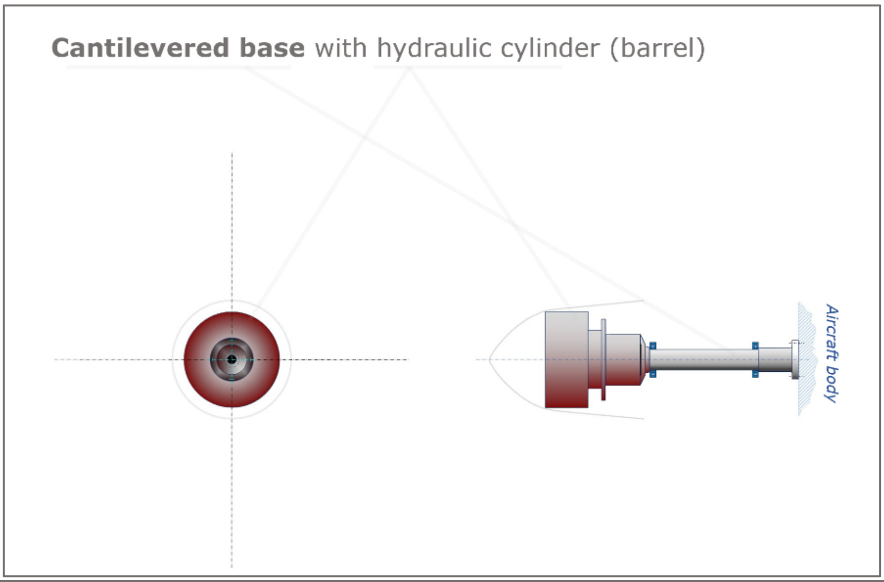
the **blade geometry** does **change too.**



Torsion-Blade Propeller

Structure and Operation

A four blade design



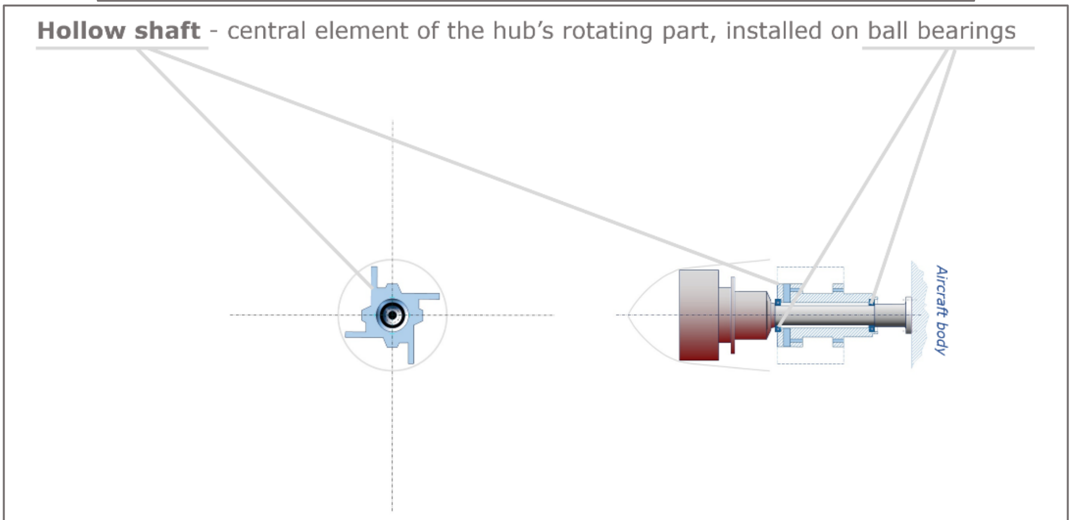
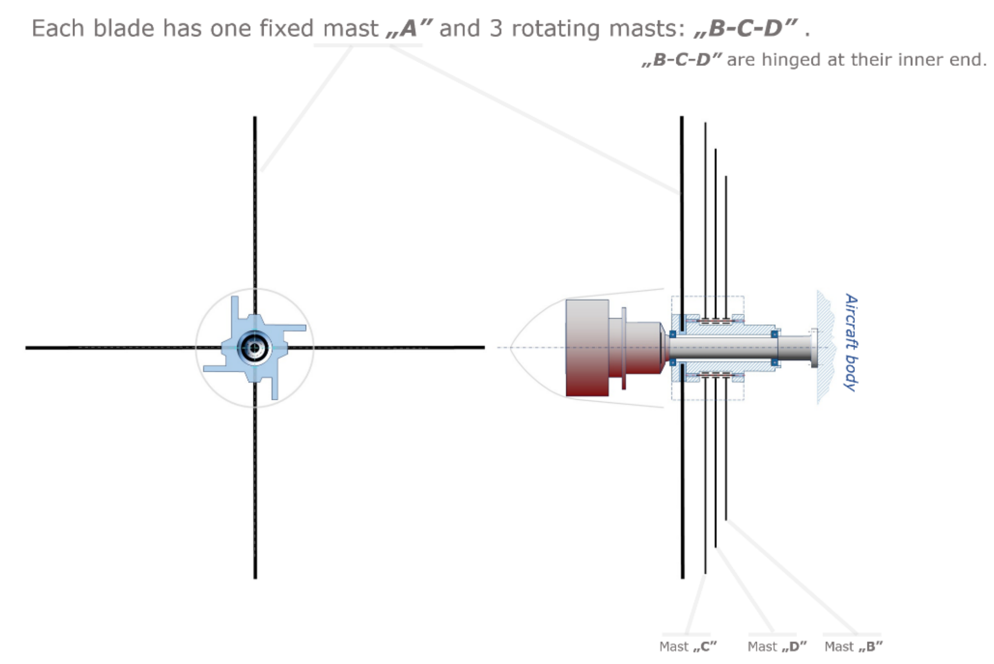


Image of the hydraulic cylinder not shown on the front view; material of the hollow shaft is cast aluminum.

Building the blades

Step 1 :

Masts are installed



The „fan” – inner skeleton of blades is based on the masts

Shape of the blades has 3D geometry, which is mainly defined by the masts :

- *„A” and „B” are the main masts. They are two, and two is the minimal number of masts a blade must have. Both can have their own drive. (*)*
- *„C” and „D” are secondary masts that never have their own drive.*
- Number of secondary masts can be different: 0-1-2-3-4 and even more.

(*) The propeller hub presented in this document has “A” masts that are rigidly fixed to the hollow shaft. Such a solution can be considered as quasi-drive as the mast moves absolutely together with the rotating shaft. Unlike masts “B” – which have not even a quasi-drive. Position of the masts “B” (and also that of all the other, secondary masts) is defined by the spaced battens (the TTM-s, see later), in particular by the reinforced TTM0.

Masts must be massive. They are

- cylindric or tapered *(recommended)* rods; **(*)**
- made of carbon fiber;
- having proper strength and stiffness, so
- the thrust „taken from the air”, is duly transmitted to the propeller hub.

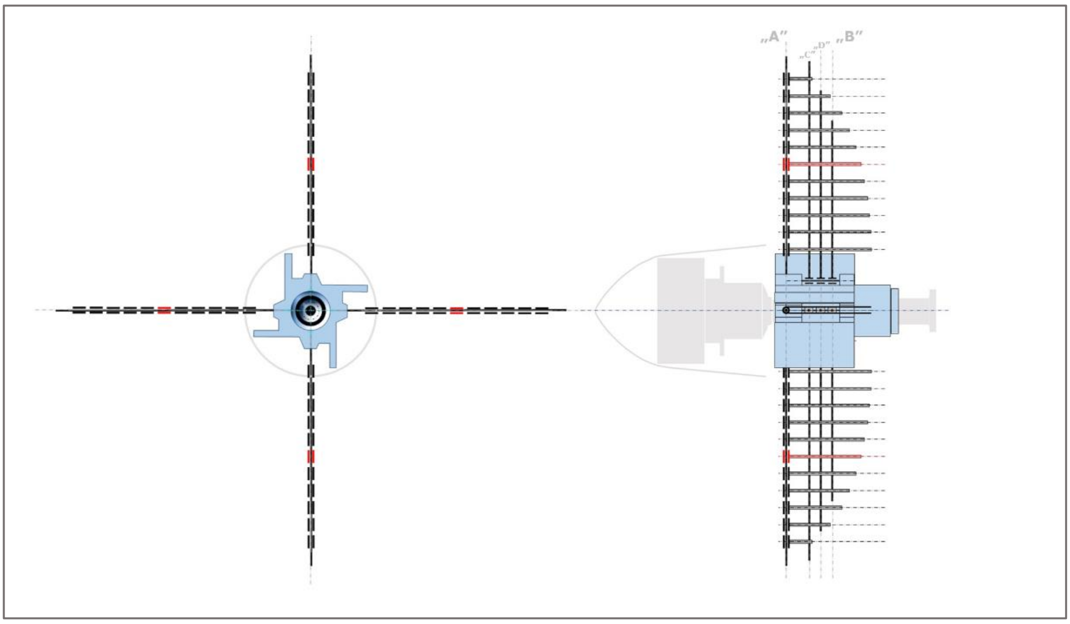
(*) For the sake of simplicity on the present chart all masts are cylindric. For practical implementation however application of tapered masts could be much better. In masts thick at the base and having a linearly decreasing diameter towards the tips, mechanical loads (tension) can be distributed more evenly, allowing weight reduction.

To the inner skeleton an outer **skin** is integrated

Spaced battens (TTM-s) support the skin. TTM-s are key elements

TTM-s are part of both the skeleton and the skin.

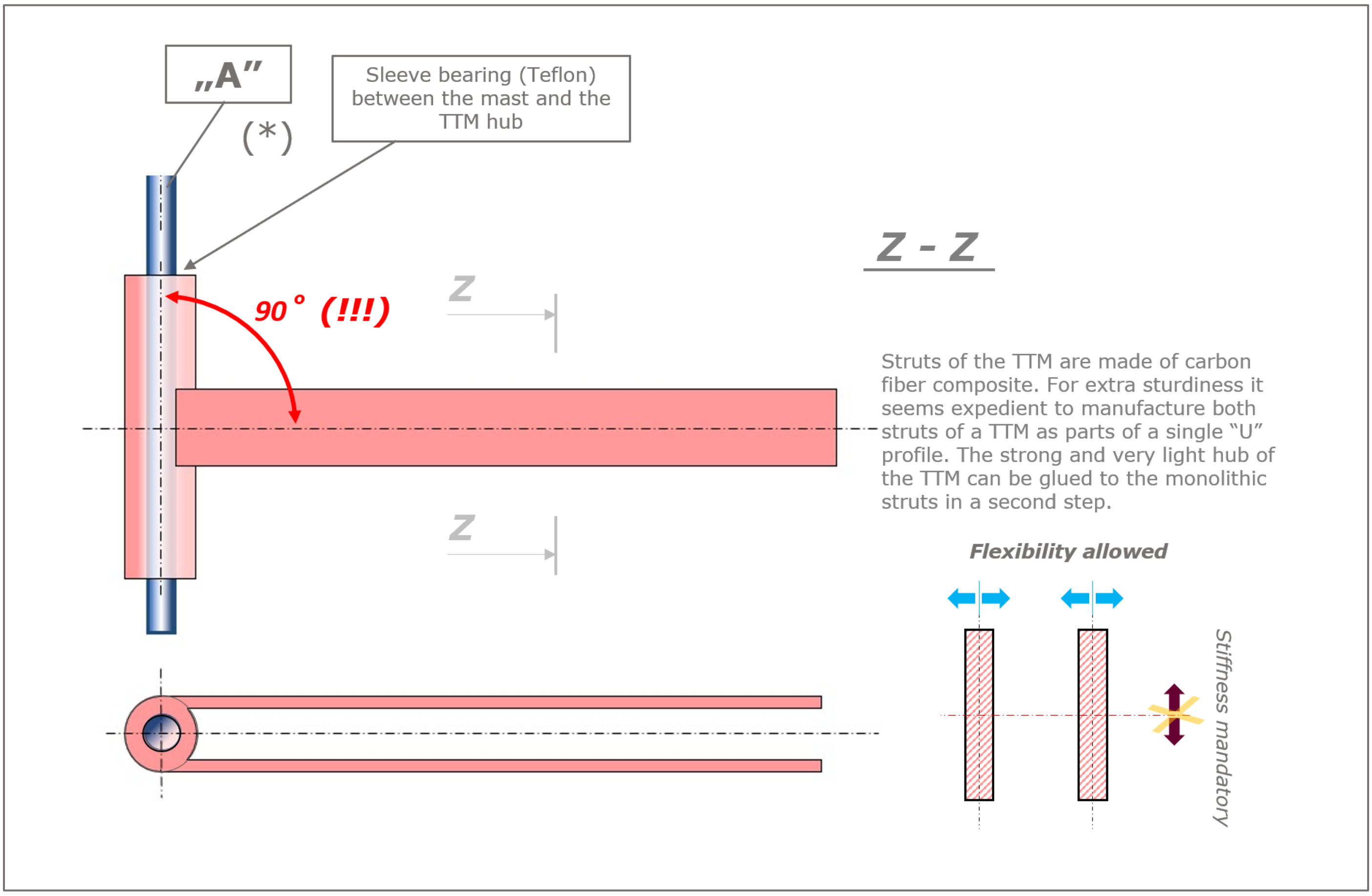
Point of integration between the skin and the skeleton are the TTM-s.



The TTM –s

- define profiles of the blade sections

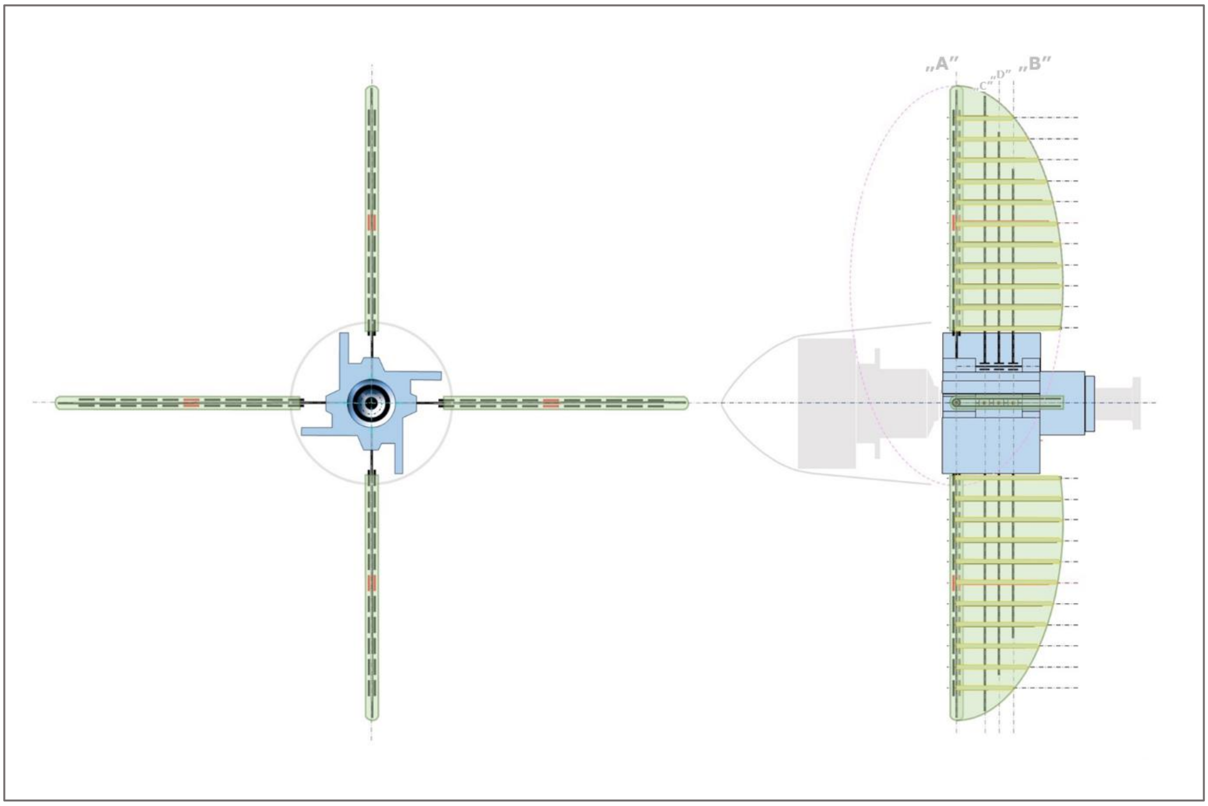
  Provide a basis to perform computations of the **BLADE ELEMENT THEORY**;
- define shape of the blade PLANFORM;
- mechanically guide the rotating masts;
- support modular elements of the skin.



(*) For the sake of simplicity on the present chart all masts are cylindric. For practical implementation however application of **tapered masts** could be much better.

In masts thick at the base and having a linearly decreasing diameter towards the tips, mechanical loads (tension) can be distributed more evenly, allowing **weight reduction**.

Installing the sails - modular elements of skin – to produce an elliptic planform (first attempt)



- The skin has a modular structure;
- Building blocks - or modules – are called **the sails**;

Material of the **sails**:

- supple, resilient **foil**;
- of high tensile strength, fatigue resistant (e.g. Kevlar reinforced matrix);
- abrasion resistant, low friction surface (e.g. Teflon coated);

Sail elements (together a whole rig constituting the blade surface) are arranged according to a special **ORIGAMI DESIGN** (see later) .

Installing the sails - optimizing the blade-planform

Suppose an amendment of the blade layout is required. E.g., an increase of the surface is necessary because

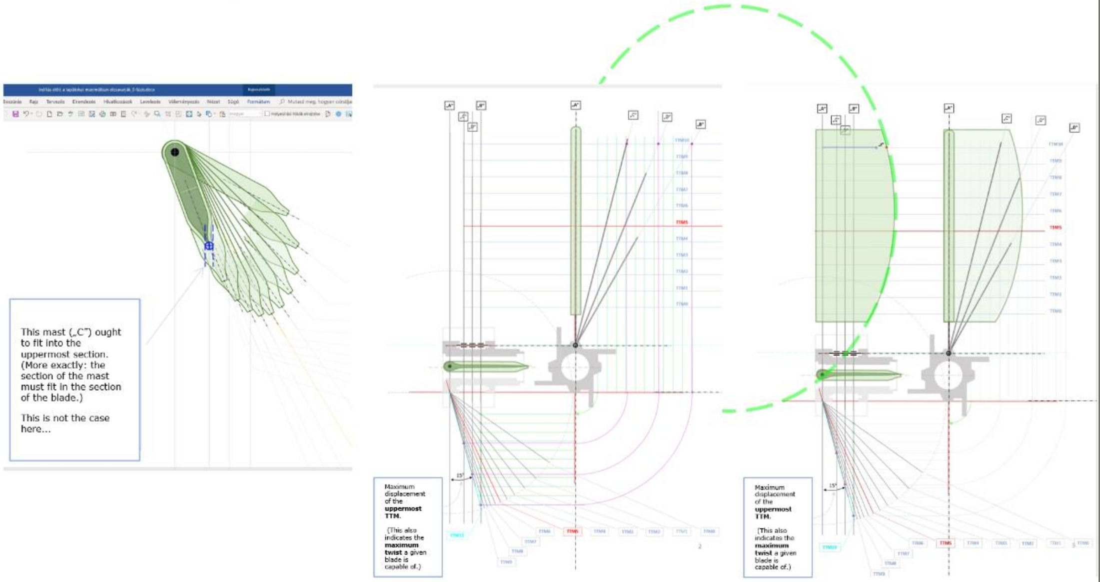
a) to absorb a given engine-power a greater blade surface is required; or
b) the maximal design twist carries the masts „too far" away from the „A" mast so the upper sections can't hold the appropriate tips (this was the case when I was working on the presentation);
c) or by any other reason.

Installing the sails - **re-designing** the blade-planform

In the process of a 2D design it is possible to define and/or calculate all the basic data of blade geometry:

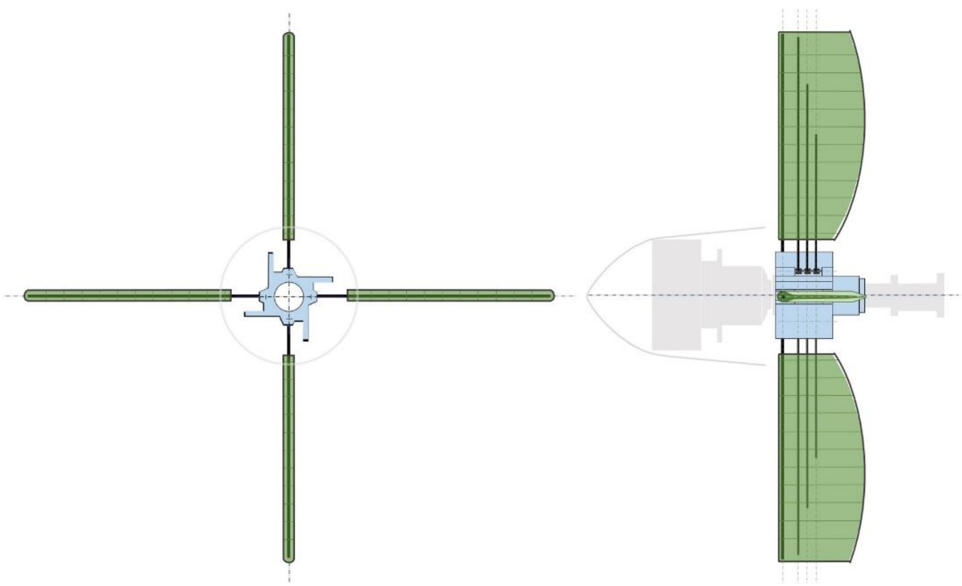
- most desirable planform;
- length of the masts;
- distances between the bases of the masts;
- maximum twist;
- lengths and number of TTM –s;
- design and size of the sails
- etc.

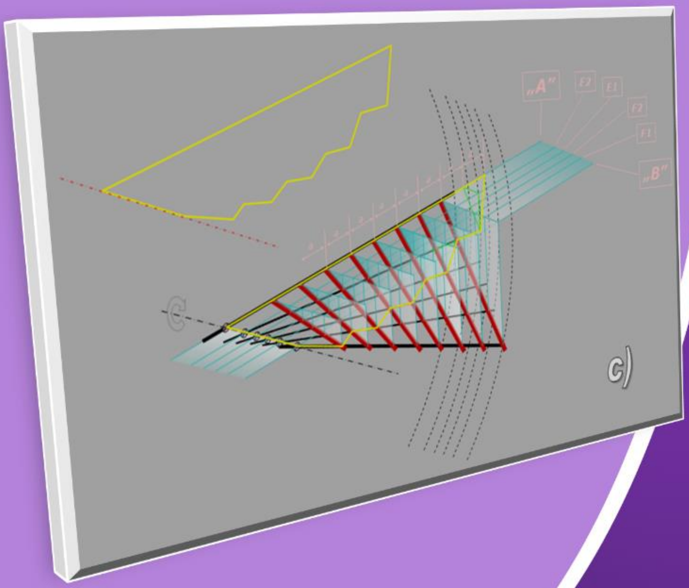
From the point of view of both **design and manufacturing / production** it is a great advantage that most works require **2D processing** only.



The problem → *Re-design on the basis of modified input data* → *Accepting the solution (another elliptic planform...)*

Blades with a modified planform





Operation of the Torsion-Blade Propeller

In the previous chapter a

four-blade propeller

design concept was completed. Now the operation concept follows.

In this chapter

- the full **morphing cycle** of the blades is introduced step by step
- of the main parts
    - the **skeleton**'s fanning rods are shown in operation, and
    - the skin's general role, location and movements are indicated. (More details of the skin description are given in the chapter **Origami Design**.)

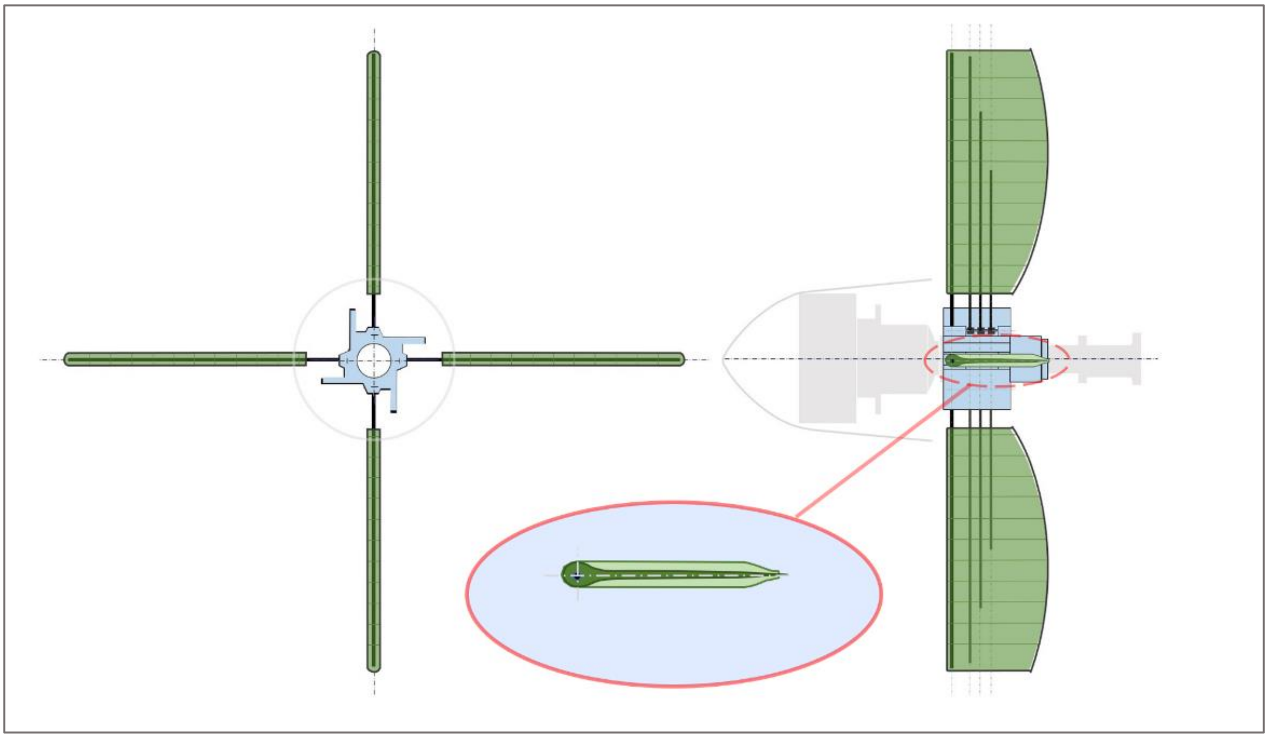
Main features:

- All detailed displacements of the parts constituting the blades' morphing process are performed during the **undisturbed rotation** of the propeller, in accordance with functional necessity and/or the pilot's will;
- Control of the blades' morphing process can also be automated.

Home position of the torsion blade propeller (TBL) is the **feathered** state

FEATHERING is the initial position of the blades.

FEATHERED STATE = the Fan is fully closed = blades in baseline position.



To aerodynamically optimize the blade sections, one has to modify the sail design.

In this figure the simplest case is shown. Sails are made of plane foil. This kind of flat profiles are baseline for the given blade design.

(More about the profiles' possible aerodynamic fine-tuning in the ORIGAMI DESIGN section.)

Blades in **maximum twist** position

Applicable (possibly) to starting or hovering regimes of flight.

Maximum twist means minimal blade angle.

(Blade angle, **β ,** equals the displacement between the plane of rotation of the propeller and the sections’ chord line.)

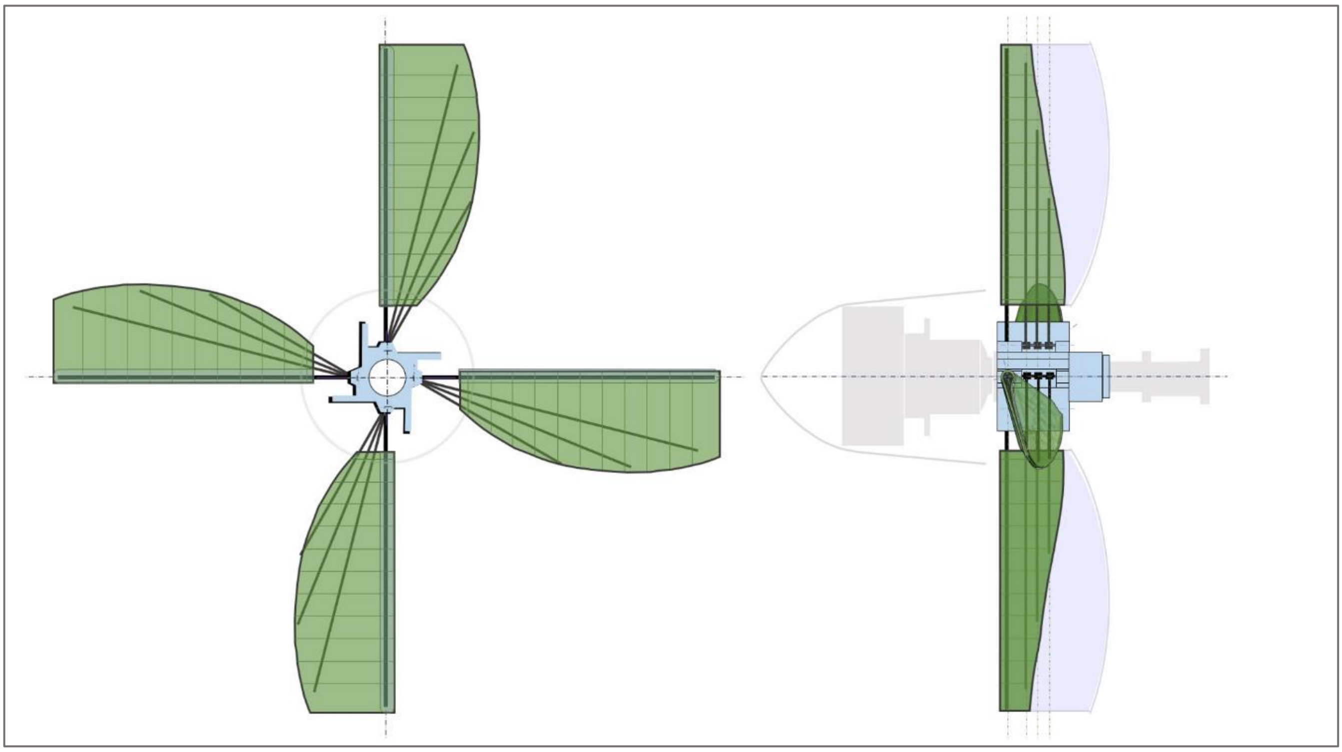
$$\beta = \min$$

(= 15° measured at the outermost TTM)

The twist angle (say $\boldsymbol{a}_{Twist}$)

$$\boldsymbol{a}_{Twist} =$$

$$= 90° - \beta = \max$$



Lowering twist, or (what is the same) **increasing blade angle**

For accelerating the aircraft etc.

Design of the blades guarantees the parity between radial distribution of angles of both the profiles' chord lines and that of the resulting wind, for any axial speed – if the right twist-control is in place. This parity means a mathematical identity (or quasi-identity) of functions governing both distributions**.**

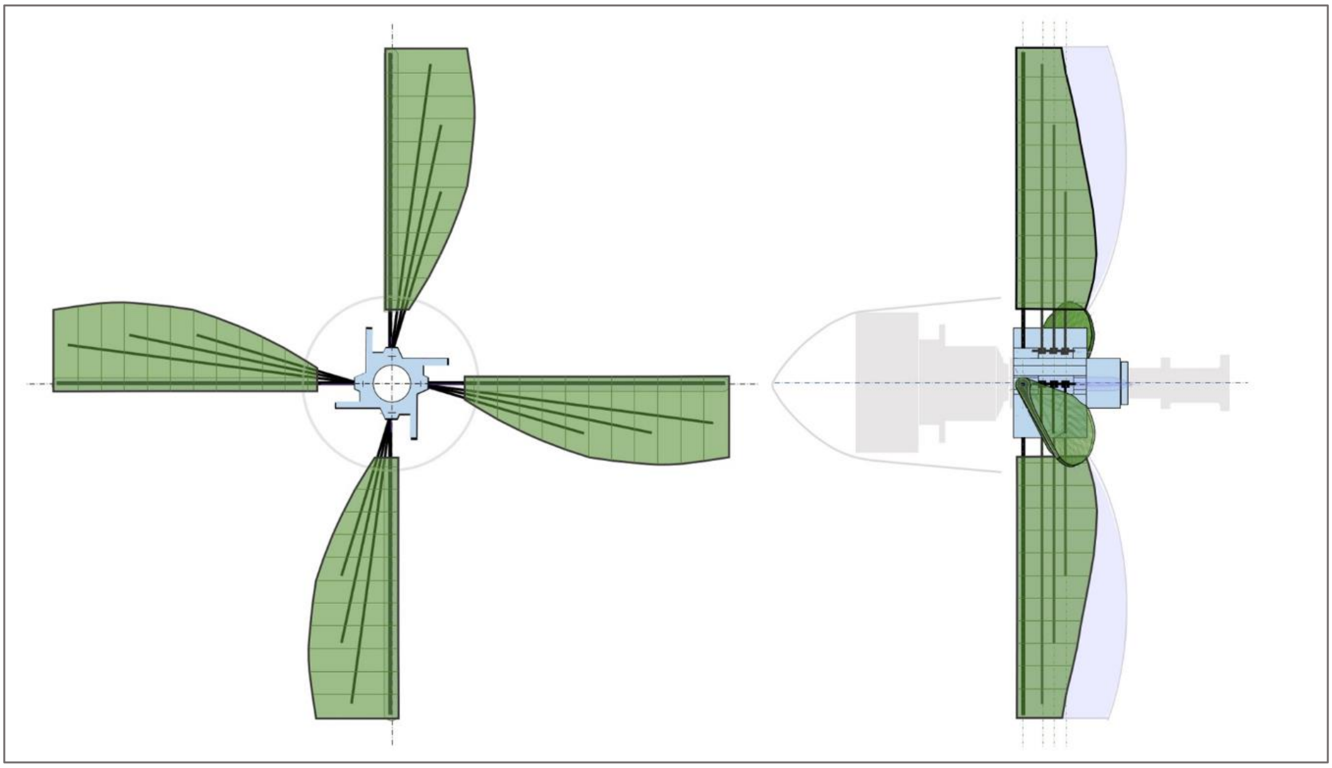
The error in parity

- is finite,
- can be expressed in equation,
- predictable and
- can be reduced to zero (see later).

β = 27°

(measured at the outermost TTM)

The twist angle α_{Twist} **= 90° - β = 63°**



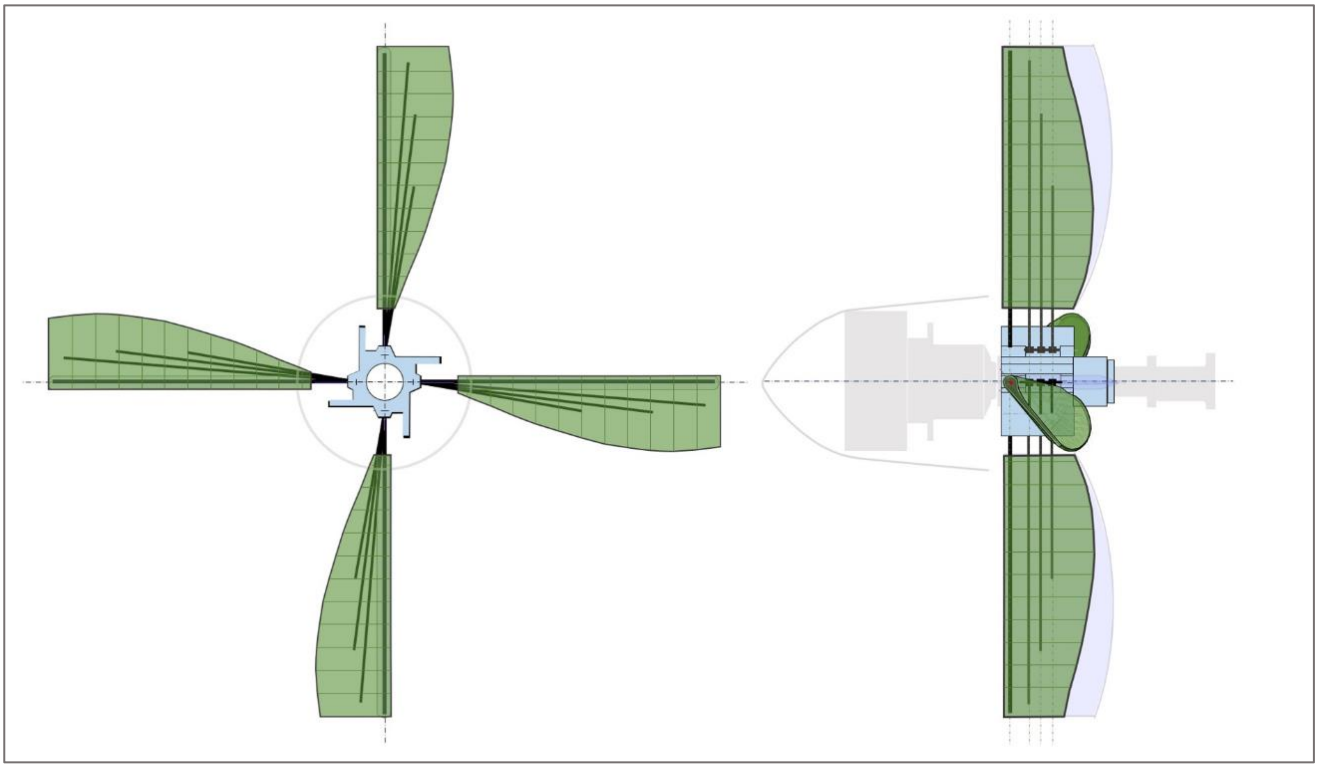
More lowering of the twist - further increasing blade angle

β = 40˚

(measured at the outermost TTM)

The twist angle α_{Twist} =

= 90° - β = 50˚



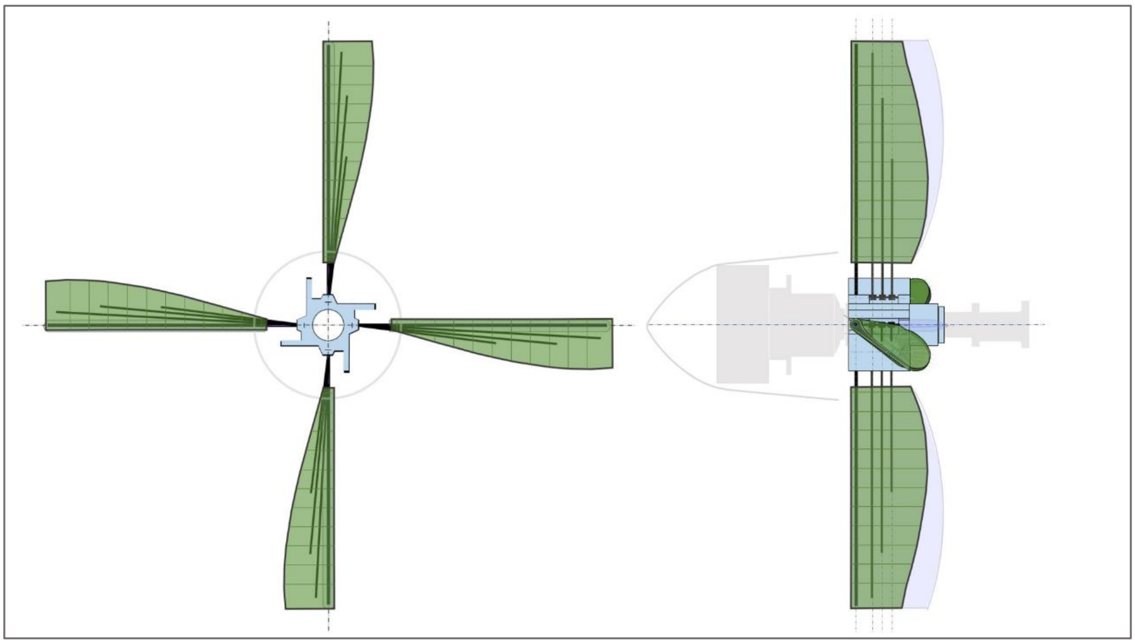
More lowering of the twist - further increasing blade angle

Travel speed goes further up.

β = 53,5°

(measured at the outermost TTM)

The twist angle α_{Twist} **= 90° - β = 36,5°**

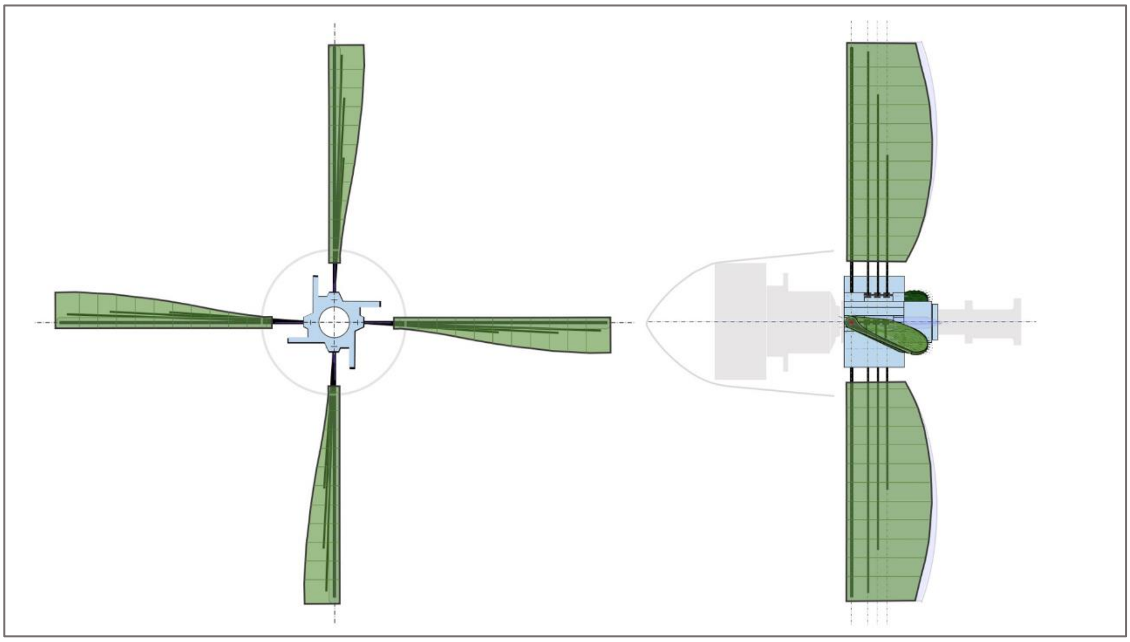


High speed:

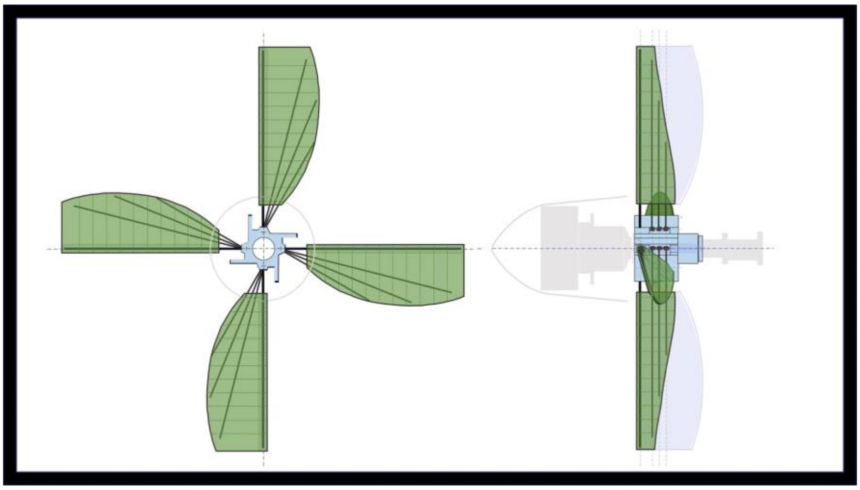
β = 65°

(measured at the outermost TTM)

The twist angle α_{Twist} **= 90° - β = 25°**

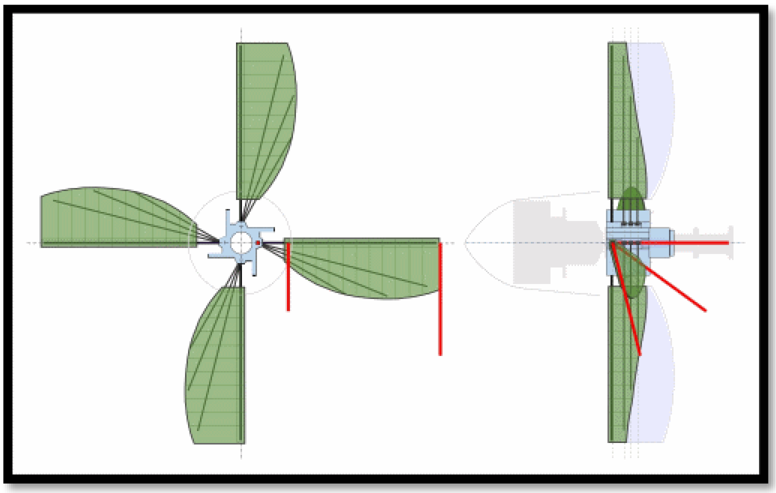


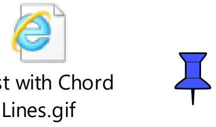
GIF of the full morphing cycle

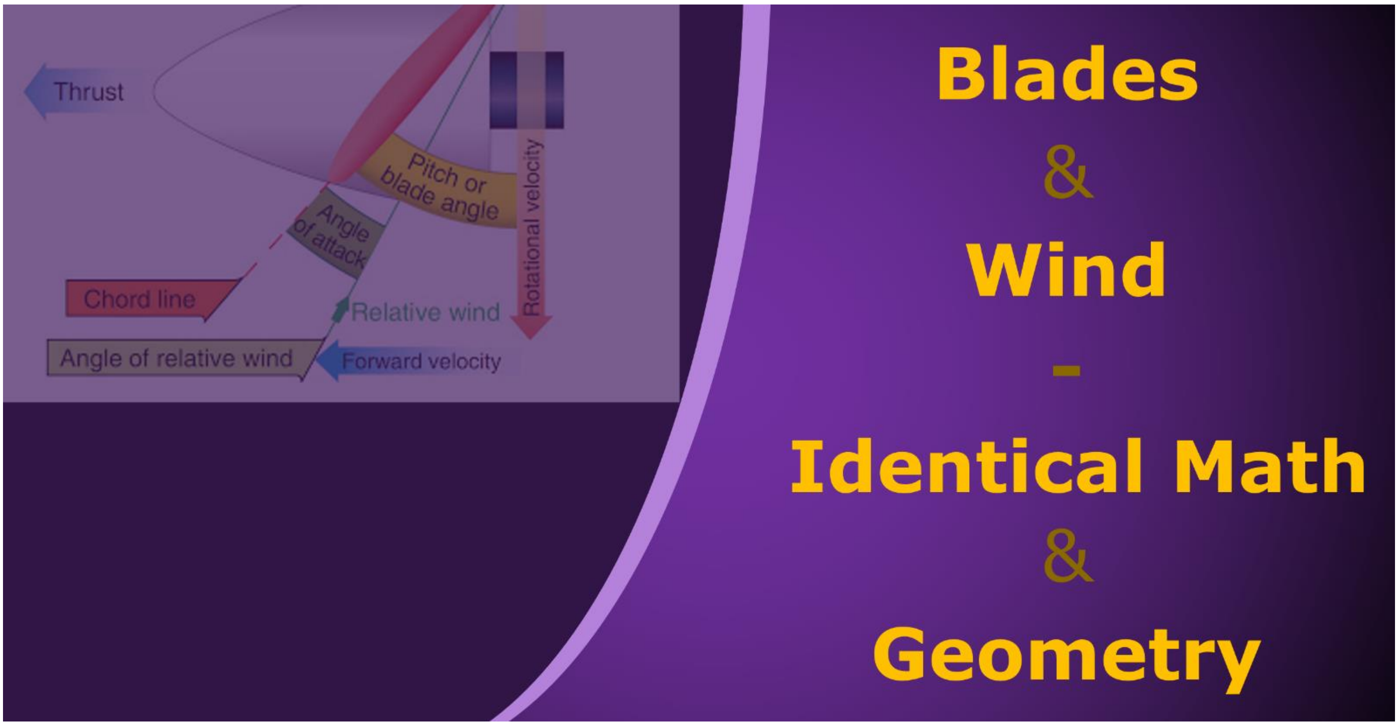


Blades are twisting – not rotating

- Chord lines of certain blade sections were selected and fitted with red sticks.
- Notice that angular displacements are changing – not only between the chord lines and the plane of rotation, but also between the chord lines themselves.
- This latter indicates twisting.







In the previous chapters a **four blade propeller** design concept was completed, then explanation of

the motion of skeletal rods

followed that enabled the blades to assume different 3D shapes – that is **morphing**.

In this chapter

1. using the knowledge of how the skeleton with an integrated skin moves
2. an attempt will be made to specify the function that

   governs the blades' 3D geometry

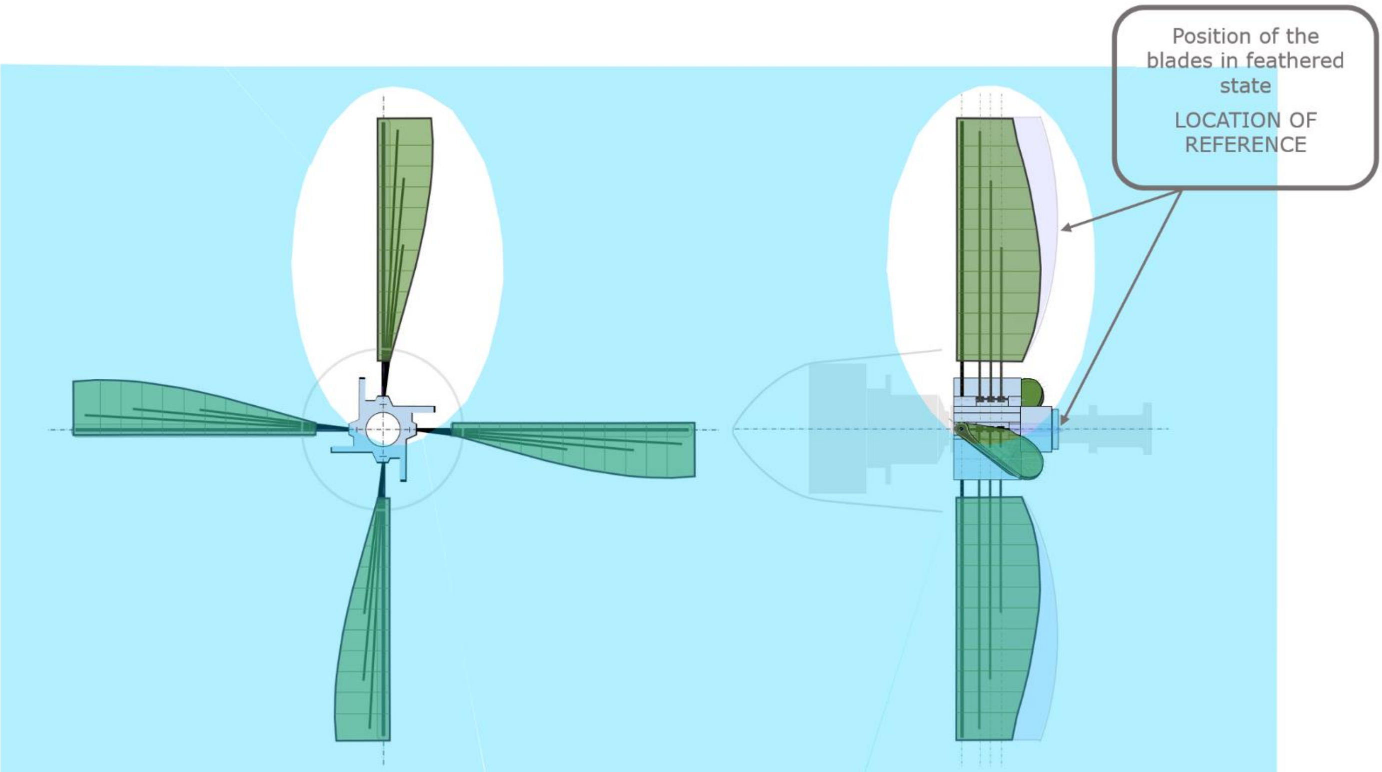
   during the morphing process;

3. having the function, it will be compared to the one received earlier, for the radial distribution of the **resulting wind's angles**.

Mathematical and geometrical conformity

Abstraction

- What we have: a concept design of the blade **mechanism**;
- What we need: a **geometric model** of the blade surface.



Above is a drawing to model the 3D surface of a blade. (We pick an intermediate stage of blade twist.) Plane of the feathered state is used as location of reference. Now – the geometric model has to be extracted.

3D model of blade geometry

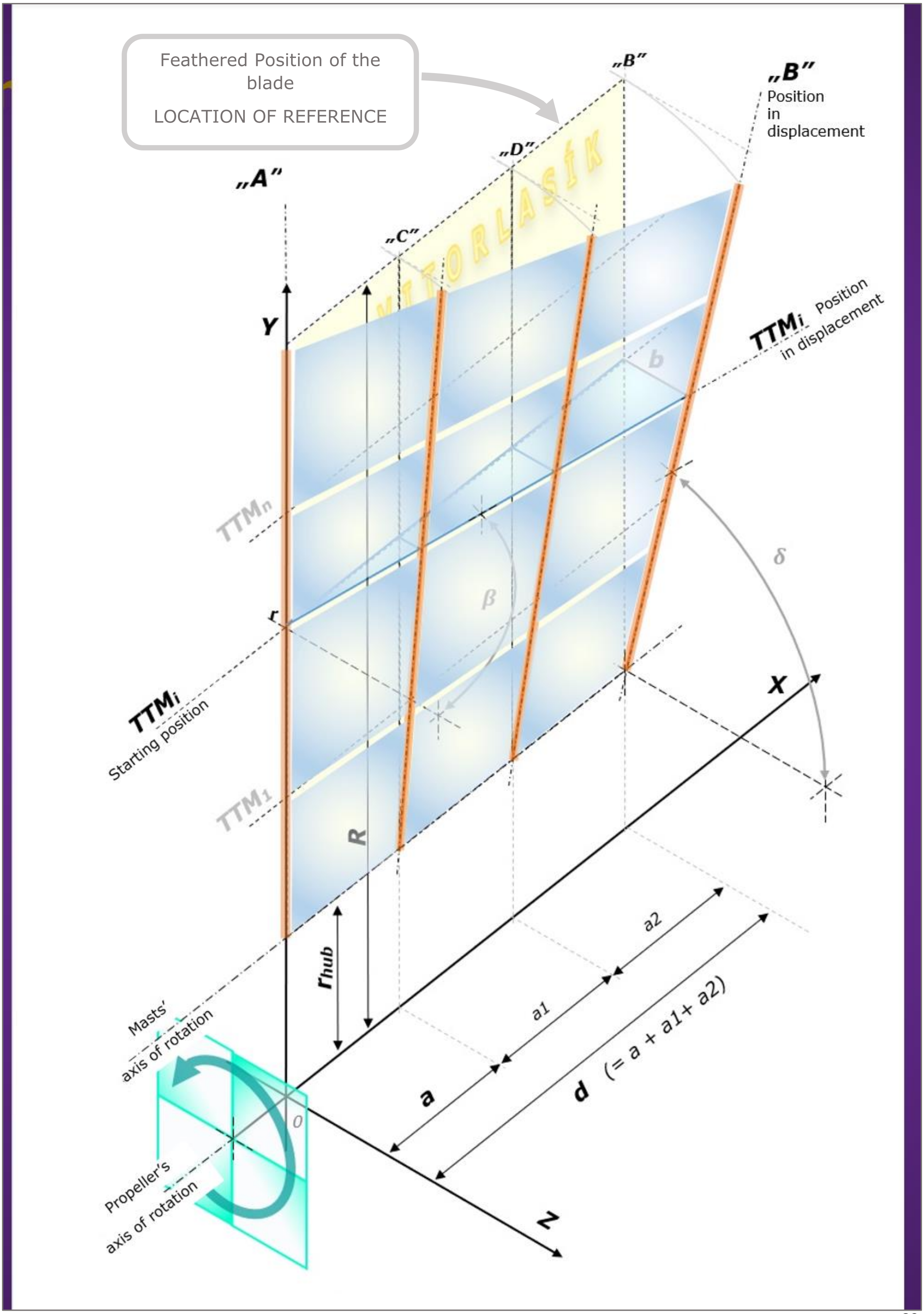
Identification of reference parts:

- Plane of feathered state (plane X-Y, shaded yellow) ;
- Propeller's plane of rotation (plane Y-Z) and axis of rotation (axis X);
- The masts („A-B-C-D") with their axis of rotation;

  Important detail:

  The propeller's axis of rotation is different from that of the masts**!**

- The **TTM** –s, or more exactly their **medians** (TTM1-i-n);
- The sails (elements of skin).


Feathered Position of the blade
LOCATION OF REFERENCE
„B"
„B"
Position in displacement
„D"
„A"
„C"
VITORLASÍK
Y
TTMi
Position in displacement
b
TTMn
β
δ
r
TTMi
Starting position
X
TTM1
R
a2
rhub
a1
d (= a + a1+ a2)
a
Masts' axis of rotation
0
Propeller's axis of rotation
Z

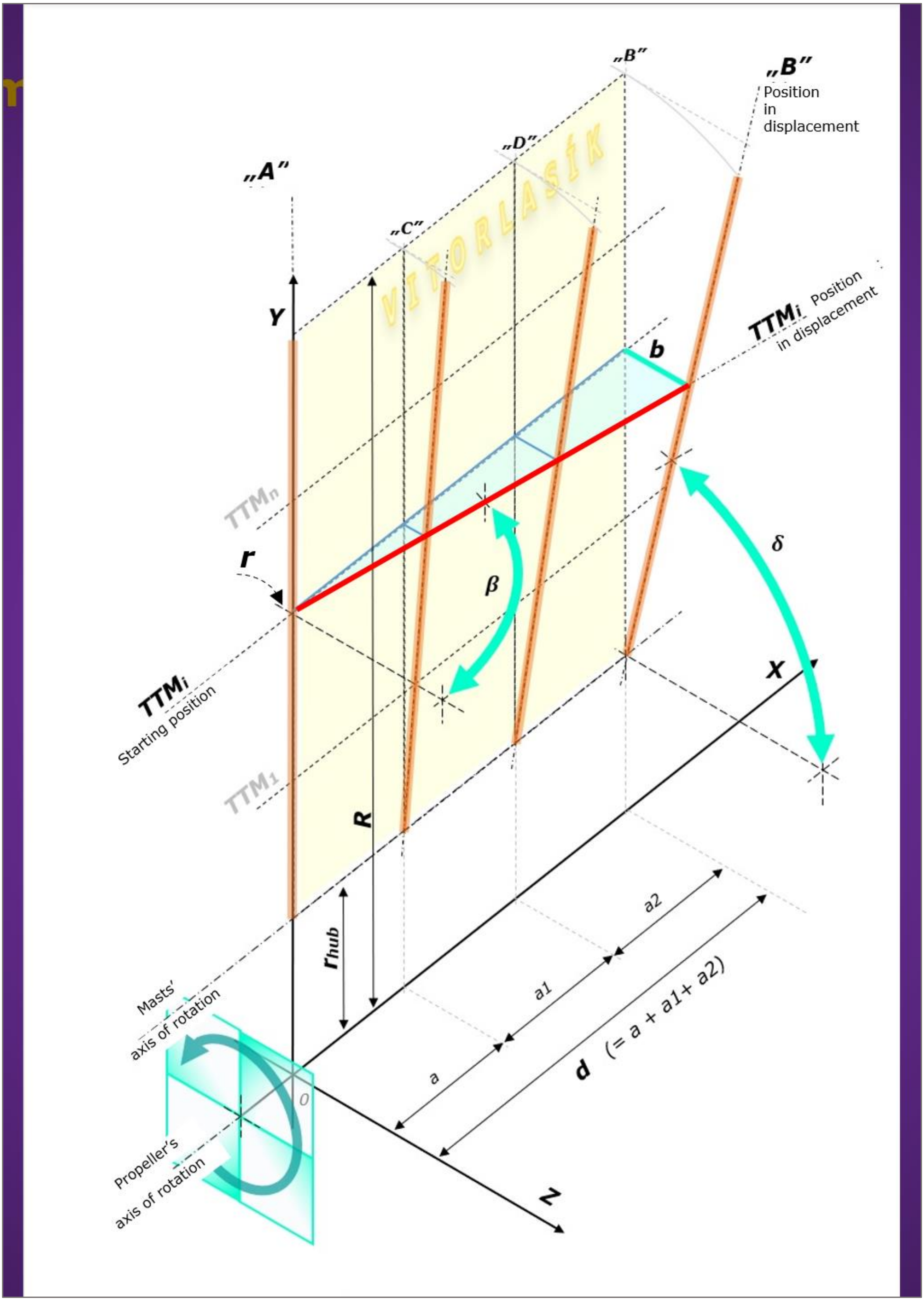
Sails removed. (Skeleton alone is left.)

- A general position (intermediate) TTM is picked
- Be it $\boldsymbol{TTM_i}$
- Centerline of the section belonging to $\boldsymbol{TTM_i}$ is called **typical generator** of the (model-) blade surface
- Two special triangles having one side in common
- Let us write the equation of spatial position of the blade surface using the typical generator ...
- ... in the form of this function:

$$\boldsymbol{\beta = f(r)}$$

Careful :

Typical generator – straight line constituent of a bent surface – not so trivial!


„B"
„B"
Position
in
displacement
„D"
„A"
„C"
VITORLASÍK
Y
TTMi Position
in displacement
b
TTMn
r
β
δ
TTMi
Starting position
X
TTM1
R
a2
rhub
a1
d (= a + a1+ a2)
Masts'
axis of rotation
a
0
Propeller's
axis of rotation
Z

Blade angle β

Expression for blade angle ***β*** as function of the radius:

$$b = \frac{d}{tg\,\beta} \quad ; \quad b = \frac{r - rHUB}{tg\,\delta}$$

$$\boldsymbol{tg\,\beta = \frac{d * tg\,\delta}{r - rHUB}}$$

Equation is reshaped to become comparable with that of the resulting wind.

It is known that

d, tg δ ≠ f(r) ,

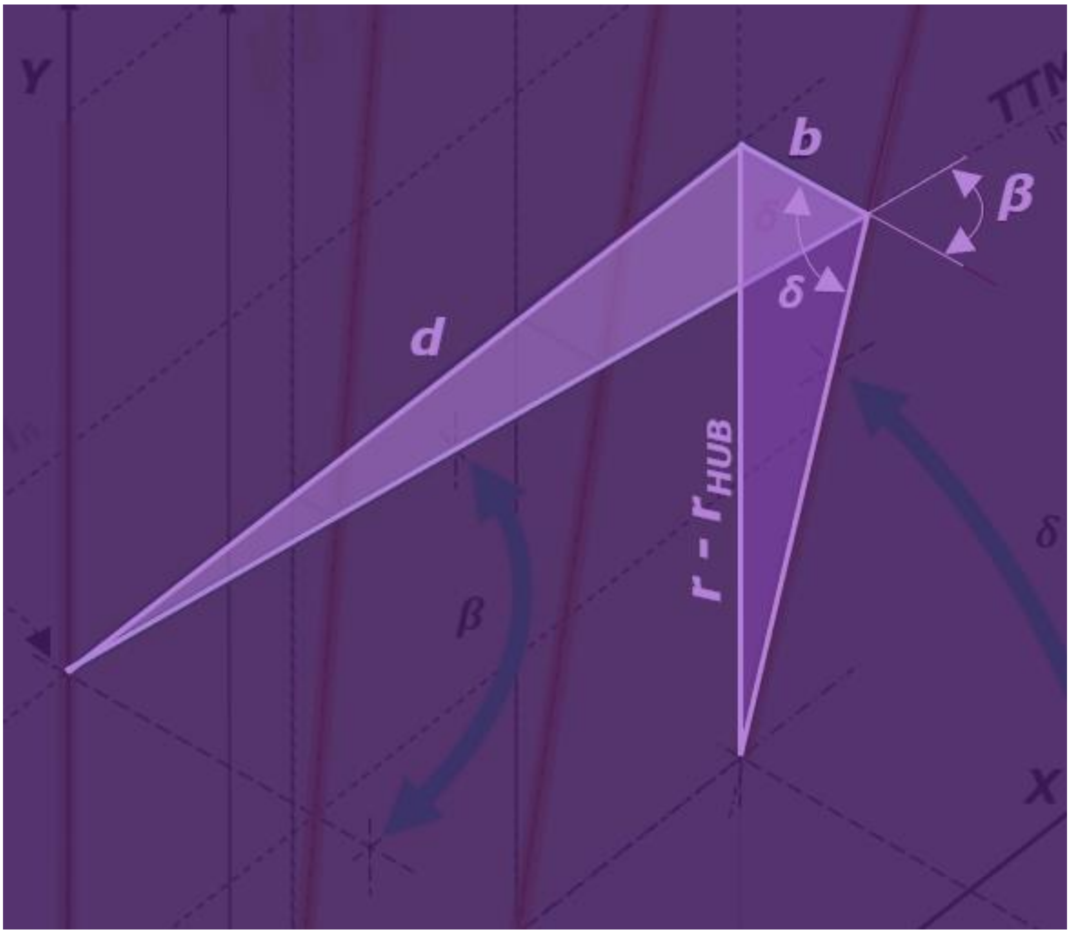
Therefore, let's have

d * tg δ = C1

Now blade angle as function of the radius :

$$\boldsymbol{tg\,\beta = \frac{C1}{r - rHUB}}$$

$$\boldsymbol{\beta = arctg\frac{C1}{r - rHUB}}$$


Y
b
β
δ
d
$r - r_{HUB}$
β
δ
X

Angle of resulting wind

Equation we had earlier, for the resulting wind angle :

$$tg\,\gamma = \frac{V_{ax}}{\omega * r}$$

Here too, we transform to prepare for the comparison. It is known that

$$V_{ax}\,,\ \omega \neq f(r)\ ,$$

Therefore, let us have

$$V_{ax} / \omega = C2$$

Then

$$tg\,\gamma = \frac{C2}{r}$$

That is

$$\gamma = arctg\,\frac{C2}{r}$$

Blade angle, β	***Angle of resulting wind, γ***
$\beta = arctg \frac{C1}{r - rHUB}$	$\gamma = arctg \; \frac{C2}{r}$

When looking for conformity it is good news the angles of both the blades and the resulting wind are governed by the **same type** of function along the radius :

$$y \sim arctg \; \frac{1}{x}$$

Conformity however is only partial :

$$\beta = arctg \frac{C1}{r - rHUB} \qquad \neq \qquad \gamma = arctg \; \frac{C2}{r}$$

Further it will be shown that the difference (or ***error***)

a) is predictable;
b) can be expressed in equation and
c) can be reduced very small – even to zero.

Size of the difference between the two functions indicates how close the blade surface comes to the optimal configuration defined by the direction of the resulting wind.

- For another **example** we will use main data from the previous example, but will consider that the propeller is replaced by a new one of the **torsion blade**-design;
- It is assumed that at **r = 0,75R** we will have 100% conformity :
-

$$\beta(0{,}75R) = \gamma(0{,}75R)$$

- For visual analysis of the error a graph can be built :

$$\Delta = \gamma - \beta = arctg \; \frac{C2}{r} \; - \; arctg \; \frac{C1}{r - rHUB}$$

Plan of visual analysis

1) Charts of functions

$$\boldsymbol{\beta = arctg\,\frac{d * tg\,\delta}{r - rHUB}}$$

and

$$\boldsymbol{\gamma = arctg\ \frac{V_{ax}}{\omega * r}}$$

will be calculated and drawn;

2) Range of calculations:
   $r_{HUB} \leq r \leq R$ **(R=1000mm)**

   $0 \leq V_{ax} \leq 1000km/h$

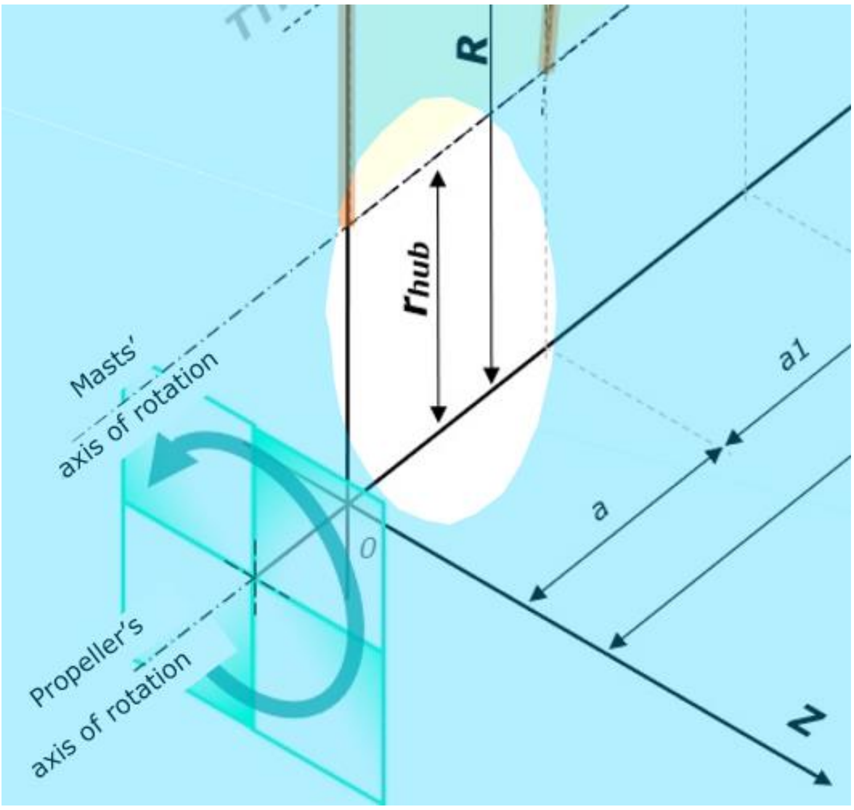
   $n = 2598\ min^{-1} = 43{,}3\ sec^{-1}$

   $\omega = 2\pi * n = 272\ s^{-1} = \omega_{max} = const$

   Note

   When calculating charts of the blade angle-function it is made sure they always intersect the resulting wind-charts in the 0,75R points;

3) Degree of conformity of the two charts is manipulated by varying the r_{HUB} value.

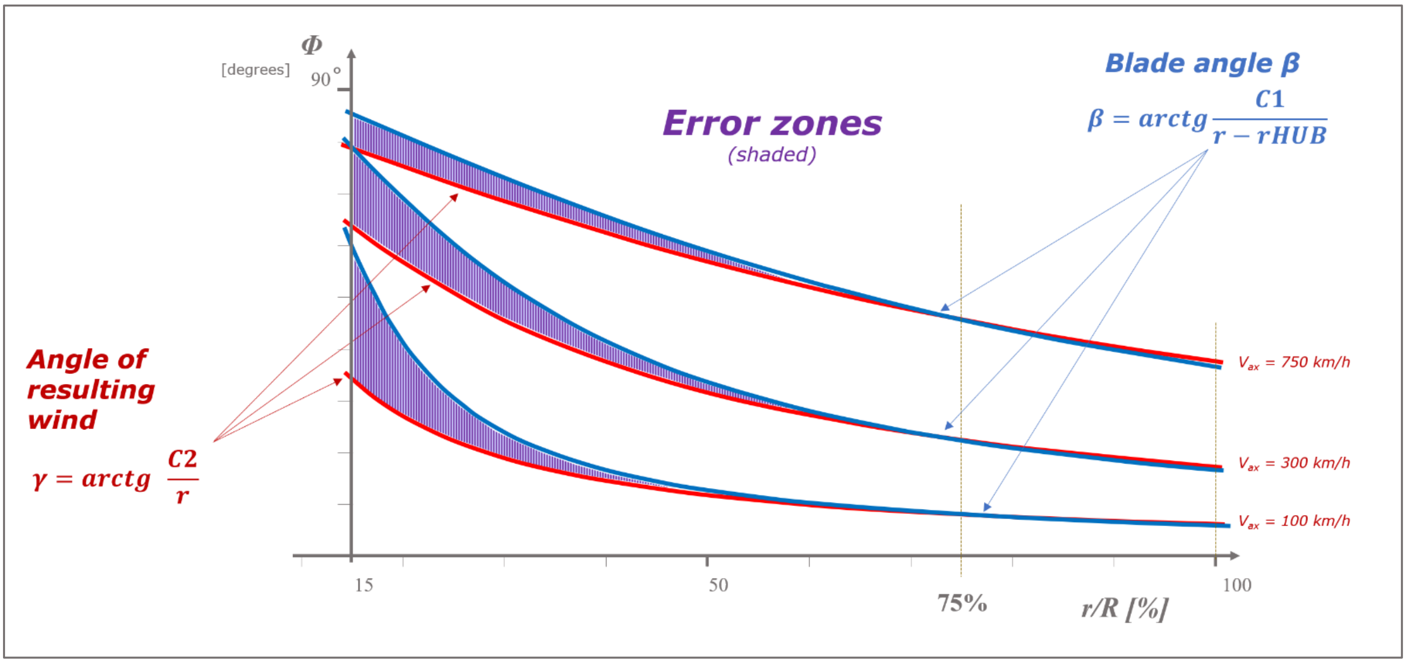

R
rhub
Masts'
axis of rotation
0
a
a1
Propeller's
axis of rotation
N

r_{HUB}

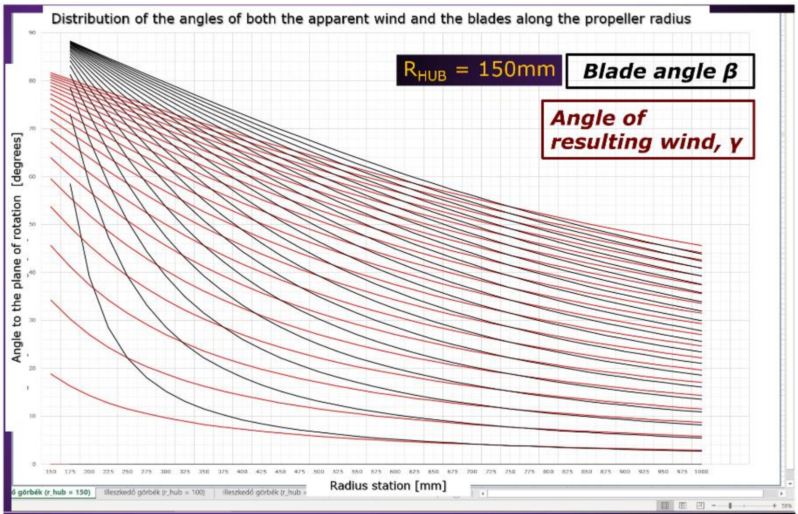
- One of the critical parameters of blade construction is r_{HUB} that
- heavily effects twist of the blade surface. By this
- ***r_{HUB} is main factor in making difference between radial distributions of angles of both the blade and resulting wind.***
- The smaller is r_{HUB} , the fuller is conformity between ditributions of angles.
- In case of the CONCENTRIC HUB design r_{HUB} = 0. This makes the error to be zero too.
- So far the ECCENTRIC HUB design has been used to make analysis of the blades' morphing process easier.
- The CONCENTRIC HUB design is introduced in the chapter of DRAWINGS.

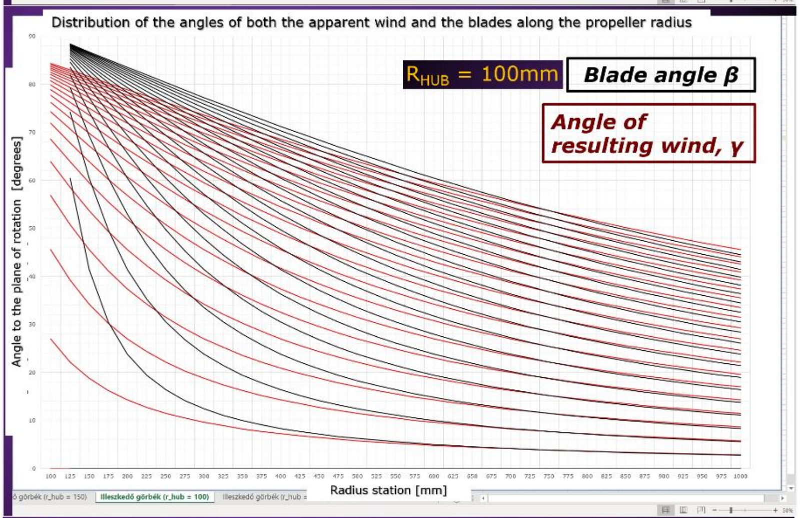
Error zones

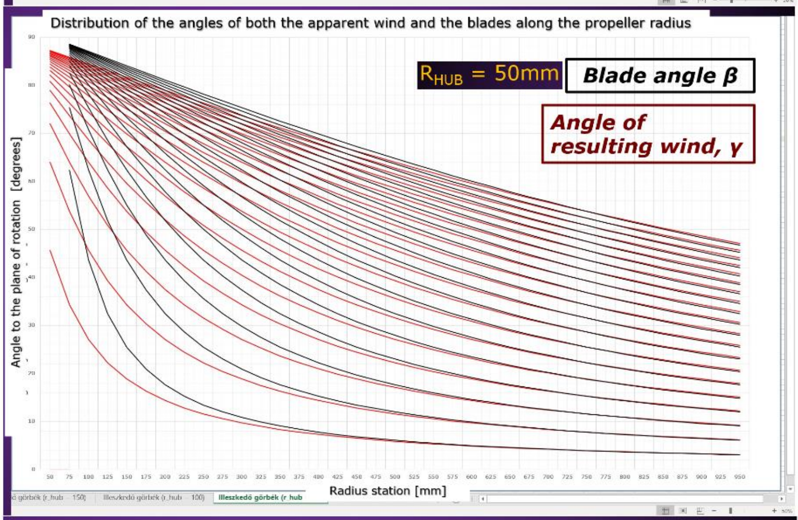
- Smaller than before;
- By reducing „r_{HUB}" the errors can be made even smaller;
- At the external third of blade radius (which produces most of the thrust) blade efficiency keeps its maximal value both at high and at low twist;

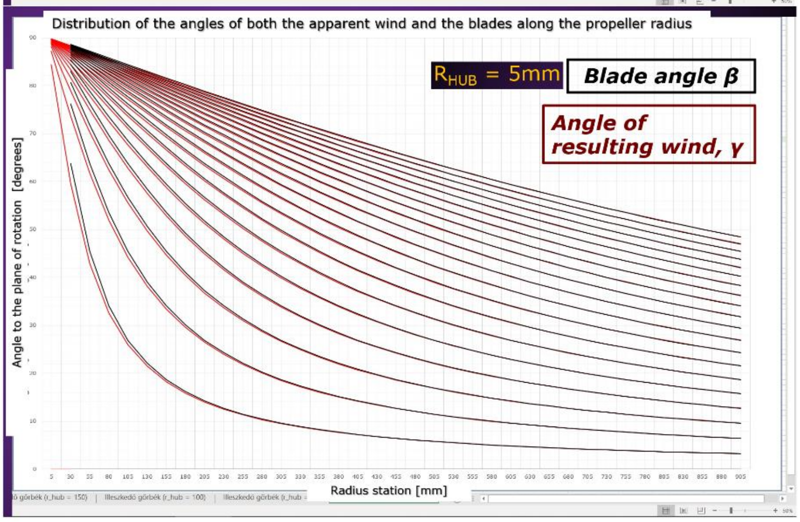


Conformity of functions of both the blades and the resulting wind can heavily be affected by the size of r_{HUB}



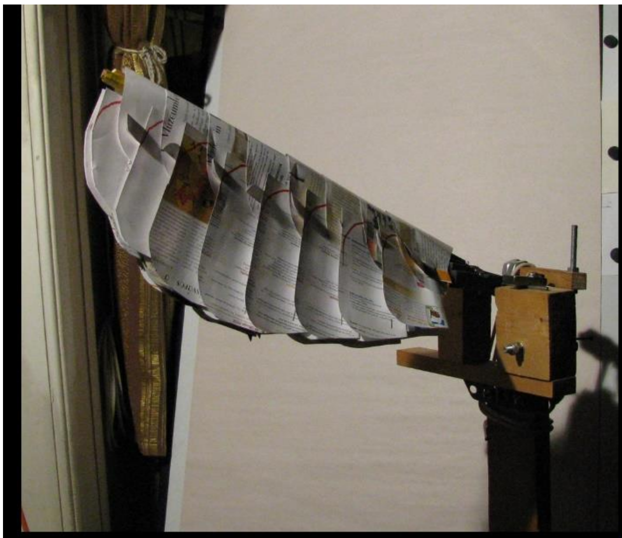






The charts show a steadily improving conformity with the step-by-step reduction of size $\boldsymbol{r}_{\boldsymbol{HUB}}$.

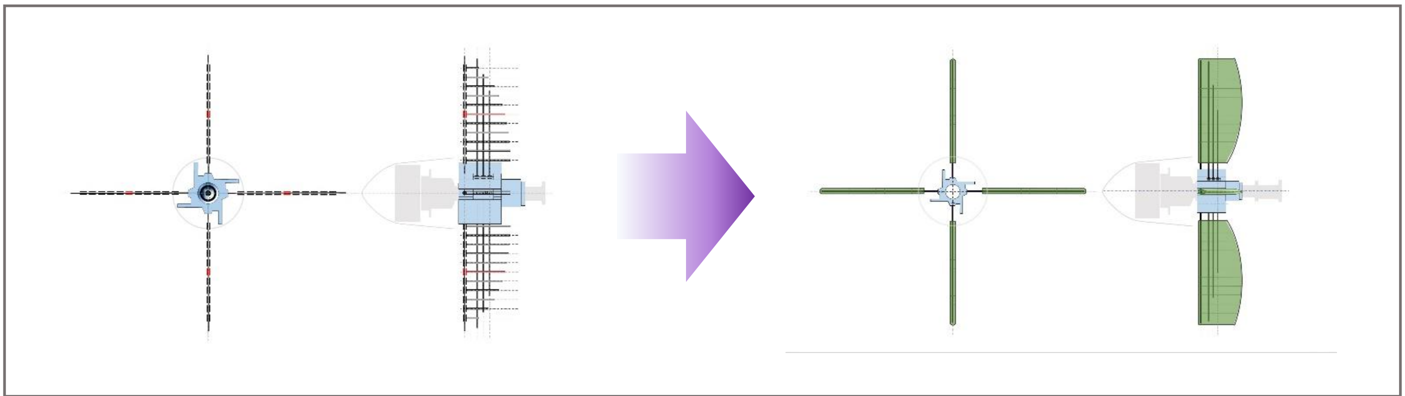
This makes the application of the **CONCENTRIC HUB** design (that allows $\boldsymbol{r}_{\boldsymbol{HUB}}$ = 0) most promising.



The Skin

Main task of the skin is

- to form an aerodynamically effective, smooth blade *outer* surface,
- incorporating every reference point of a changing configuration defined by a mobile system of *internal* masts and TTM-s,
- all the time leaving free motion of the masts and TTM-s unhindered.

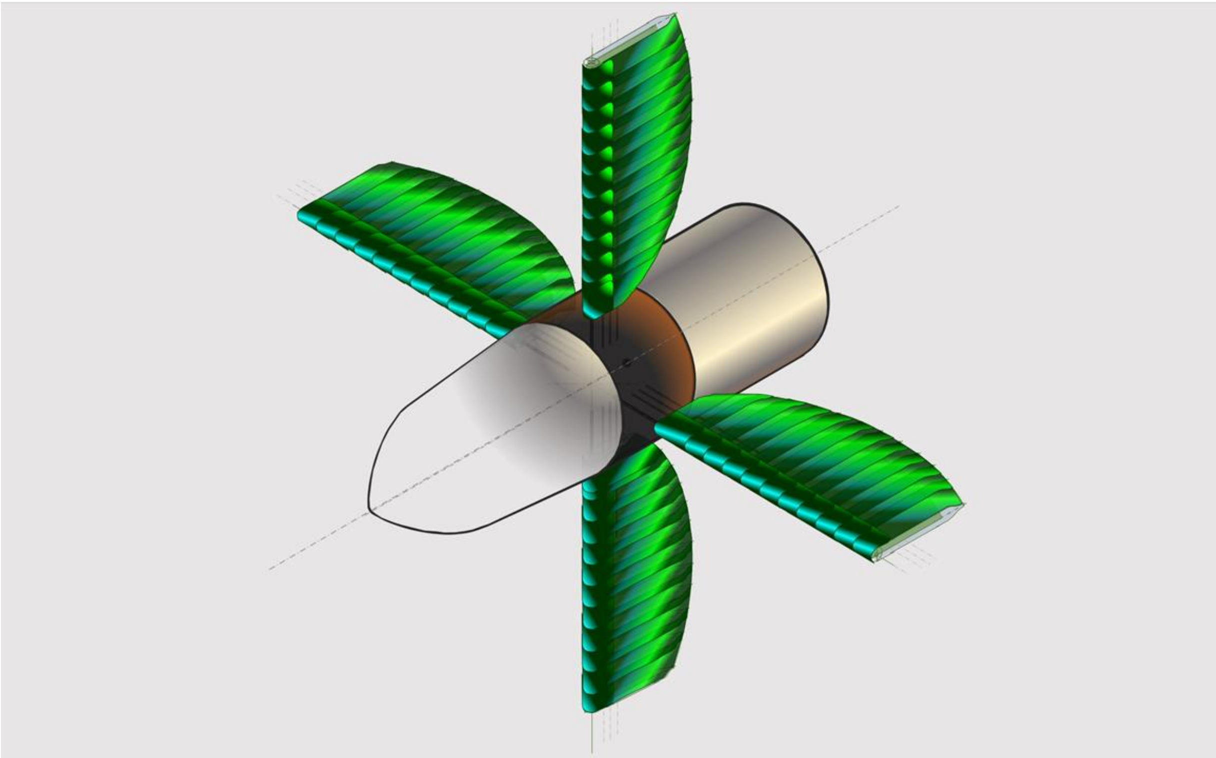


Implementation – what we have known about it:

- To the skeleton an outer skin is *integrated*.
- Spaced battens, the TTM-s are the skin's supporting parts. They are key elements.
- Skin is **modular** – built of sails ;
- material of the **sails** is foil ;
  - supple, resilient ;
  - of high tensile strength, fatigue resistant (e.g., Kevlar reinforced matrix) ;
  - abrasion resistant, **low friction** surface (e.g., Teflon coated) .

Propeller assembly (Without the blade tip pieces.)

All softness of the sails is fully compensated and unnoticeable for the airflow.



Torsional blades' **ability to morph** is based on a **modular rig** of sails covering the TBs' outer surface :

- For aerodynamic effectiveness it is mandatory the rig has a **bracing** that fully compensates for any softness of the elements under the load from the airflow ;
- Such a bracing can be composed using both appropriate supporting/skeletal elements and a special way the sails are rigged. This latter is described in the **ORIGAMI DESIGN** section.

The Origami Design

This is how the figures on next page are referenced:

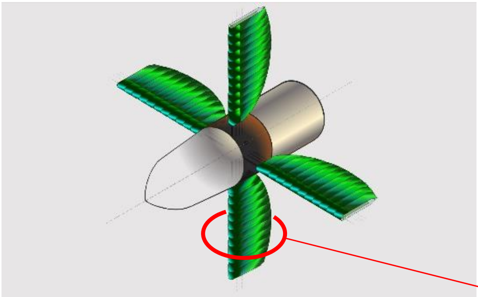
1.	2.
3.	4.
5.	6.

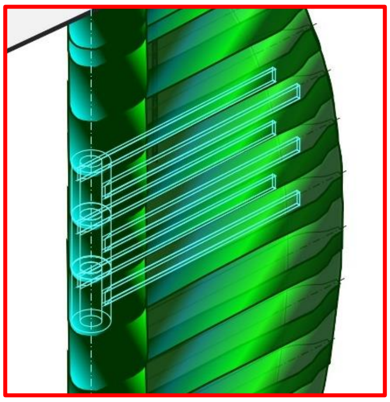
1 – 2. We zoom in on an arbitrary fraction of a blade.

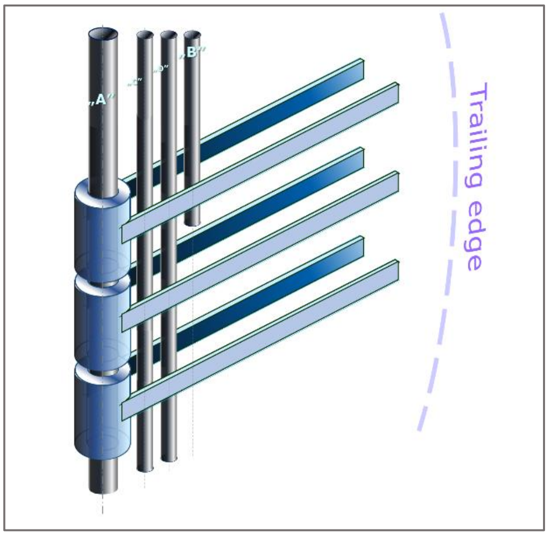
2. We look under the hood. Surface modules of the skin (the sails) are supported by the TTM-s.

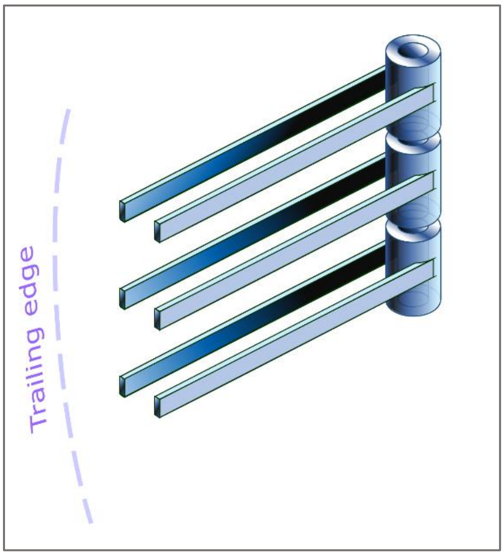
3 – 4. We Rotate view 180°, and also remove the masts.

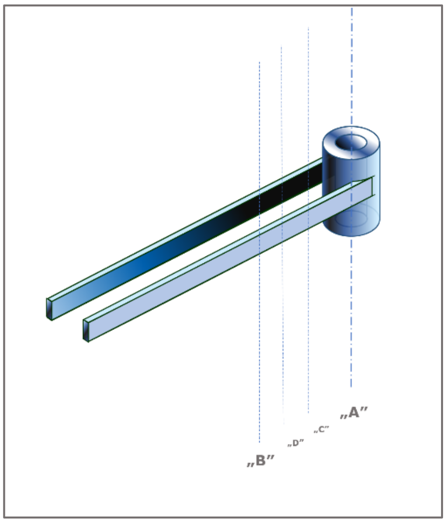
5 – 6. Modular skin is built unit by unit. Right and left cuffs are installed.

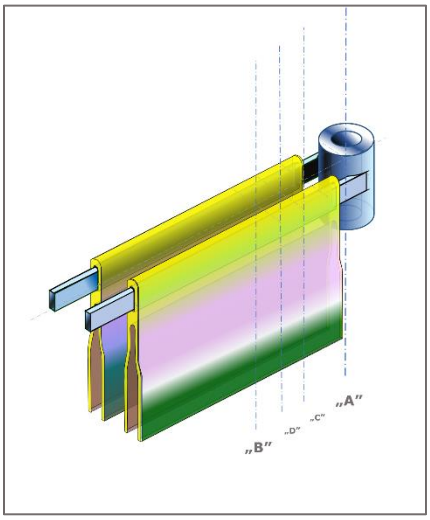





„A”
„B”
Trailing edge


Trailing edge


„A”
„C”
„D”
„B”


„A”
„C”
„D”
„B”

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7.	8.
9.	10.
11.	12.

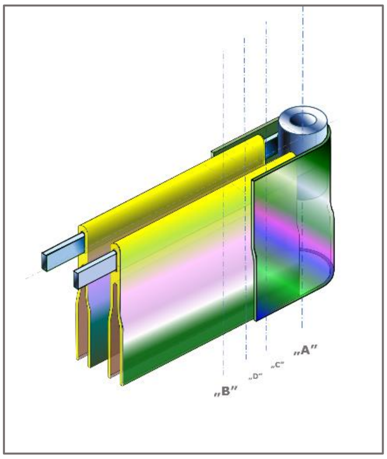
7. Third element of the skin-module, the collar is installed.

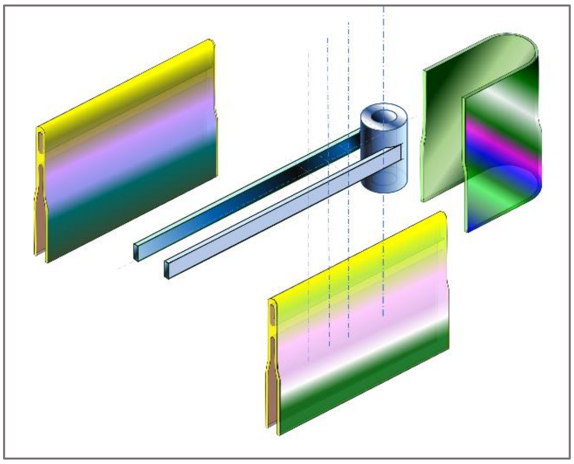
8. Exploded view of the skin-module.

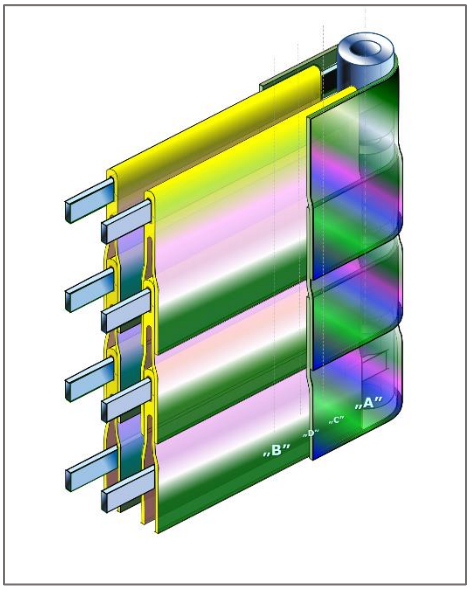
9. This is how modular skin of the blades is built.

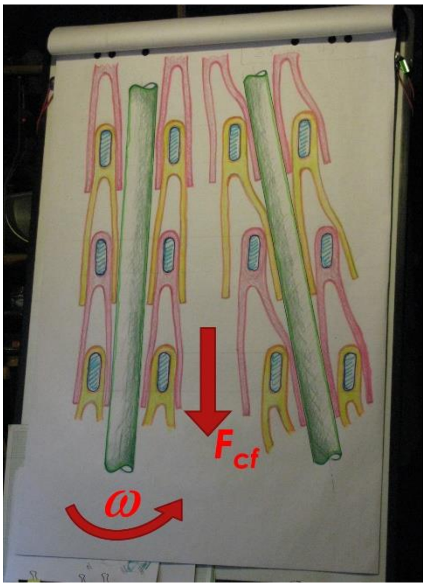
10. When the propeller is in operation displacement of the masts cause normal deformation of the skin. Smoothness of blade surface is maintained by the centrifugal force ($\mathbf{F_{cf}}$) due to the rotation (ω). Own stiffness of sails, and application of elastically preloaded profiles (instead of plain foil) can help improving quality of airfoil shape.

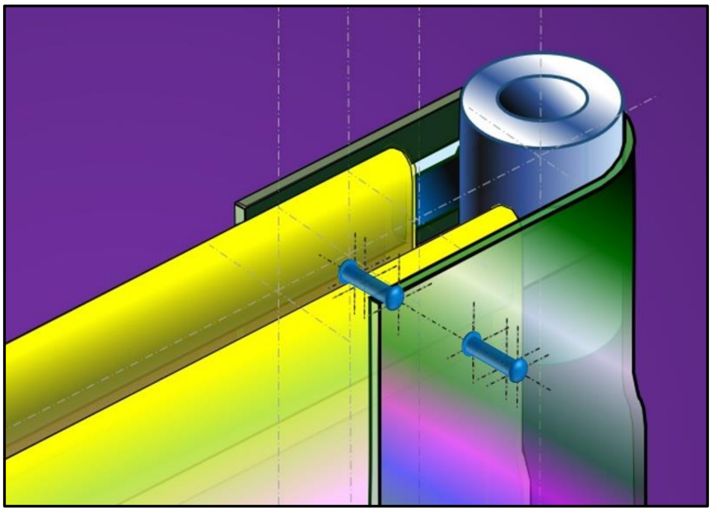
11-12. The cuffs have single point attachments to the collar. This solution provides for securing both the collar on the blade, and the cuffs on the struts of the TTMs, while also lets the parts have a minimal free motion – just enough to facilitate the blade's morphing process.

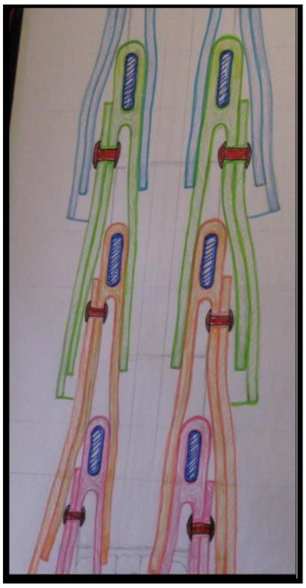

„B"
„D"
„C"
„A"

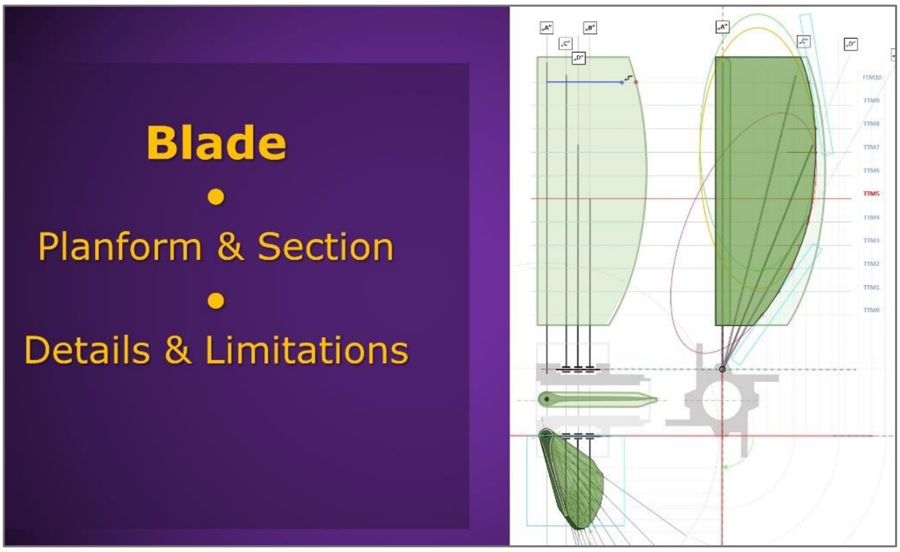



„B"
„D"
„C"
„A"


F_{cf}
ω







Blade Planform & Sections

Torsional propeller blades cannot have quite any shape of their planforms and blade sections. Limitations come from two main sources :

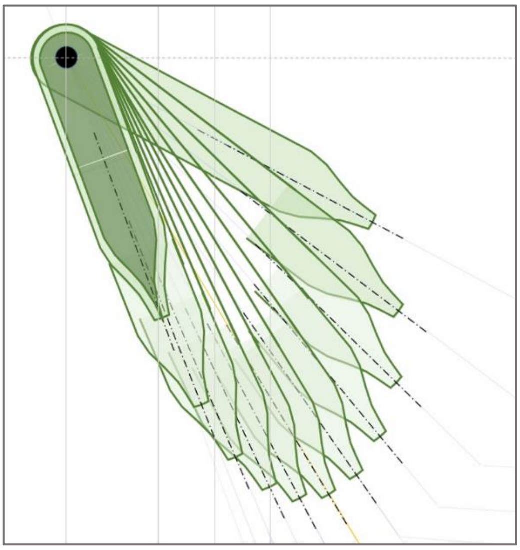
i. Skeletal rods (masts and TTM-s) moving inside the body of the blade require certain minimum-space; and

ii. Skin modules must be kept overlapped in the whole range of their deformations.

Important limitations apply to the blades' leading edge: no sweepback and no curved shapes are allowed.

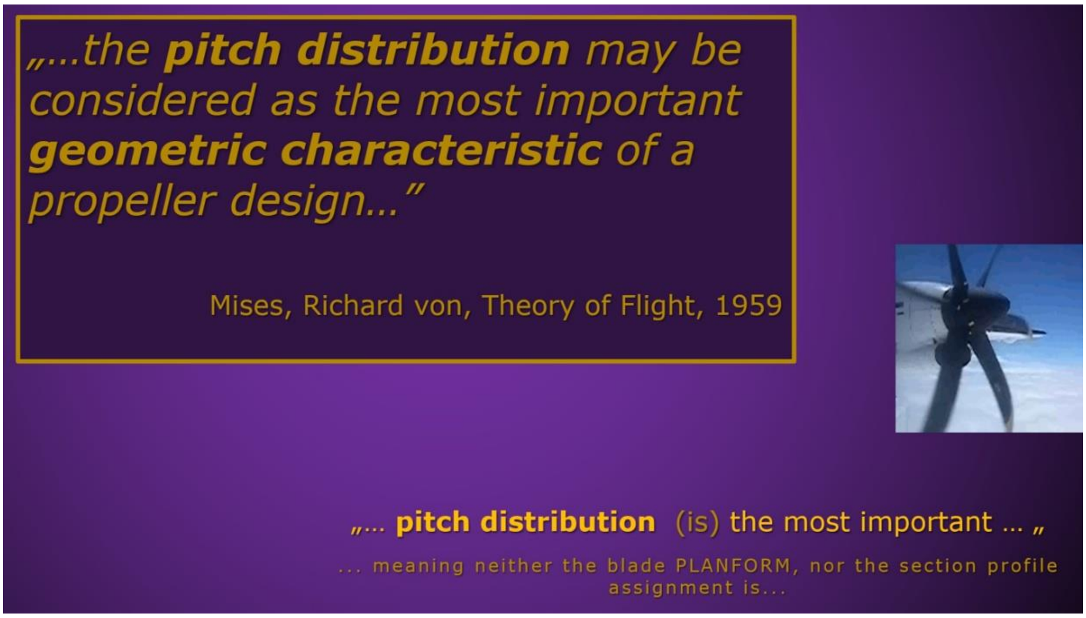
i. Torsional blades (TB-s) have a straight leading edge, perpendicular to the propeller's axis of rotation - always.

ii. Aerodynamic fine-tuning of section-profiles is limited as well. Mainly because of skin's active role in morphing.



Preliminary assessment of limitations

A citation to remember from Chapter 3.:



Blade parameters' impact on efficiency (η) :

a)	Shape of planform	~	n * 0,1 %
b)	Section profile	~	n * 0,1 %
c)	Pitch distribution	~	n * 10 %

Summary:

- A correct pitch is more important than shape of the planform or section profile;
- Torsion Blade Propellers (TBP-s) are expected to outperform existing propellers e.g., by
  1. having no need for blade tips to come close or exceed speed of sound in order to increase travel speed. Thus, transonic losses are avoided;
  2. Pitch distribution remains correct in whole range of speed regulation. (Radius-wide.) Thus, both blade stall and windmilling losses are avoided.

Blade sections – aerodynamic fine tuning

Conditions to manage

Limitations come from two main sources :

i. Skeletal rods (masts and TTM-s) moving inside the body of the blade require certain minimum-space; and

ii. Skin modules must be kept overlapped in the whole range of their deformations.

Important limitations apply to the blades' leading edge: no sweepback and no curved shapes are allowed.

TB-s have a straight leading edge, perpendicular to the propeller's axis of rotation - always.

Aerodynamic fine-tuning of section-profiles is limited as well,

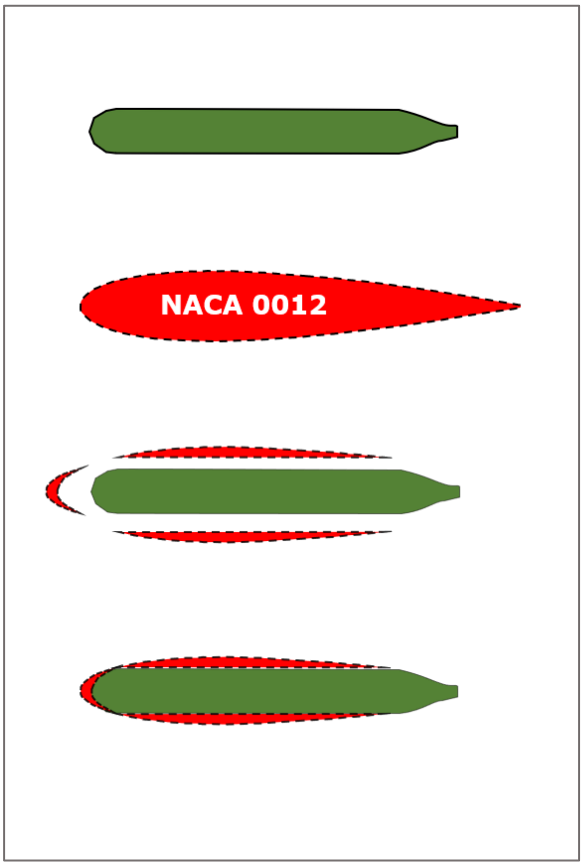
mainly because of skin's active role in morphing.

In this document symmetric section profiles with a straight camber line are studied only.

Drastic profile shaping is excluded in the case of torsional blades. E.g., implementation of very thin and/or strongly cambered airfoils is mostly impossible.

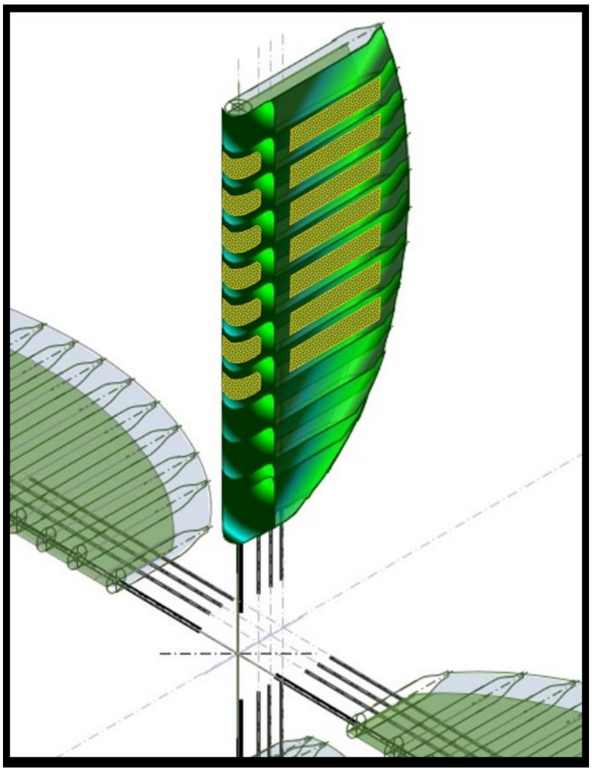
Origami design of the skin presented earlier allows for a limited free-shaping of the blade section profile. Correcting elements, arranged in zones running in line with the leading edge, can be fixed on skin modules for the purpose.

The NACA 0012 airfoil shown here is a random example picked for illustration only.



Said restrictions can be partially eased by the application of conical masts thicker at the foot and thinning towards the head. Then blade profiles also can become thinner in the region of the blade tips.

In the figure possible locations are indicated, where pieces of profile correction can be fixed. (The „gluing spots” are shown.)

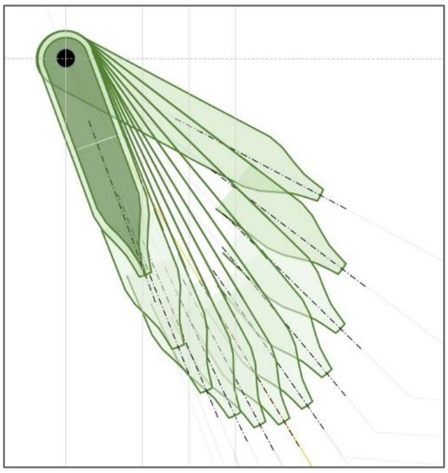


The trailing edge of the blades

Former explanations and drawings also covered the structure of a basic profile of a typical torsional blade section. They did not, however, elaborate on how the trailing edge was made.

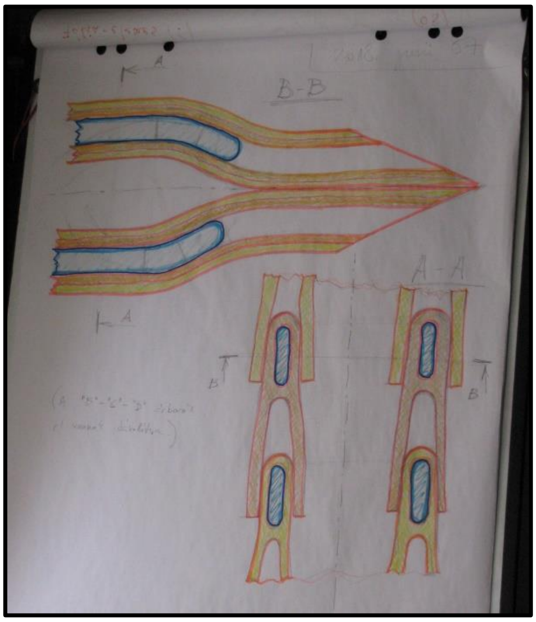
Some tips of shaping the trailing edge of a torsional blade:

Blade sections as sketched in the structural part of description:



Shapes, shown where the blade's trailing edge is running, are a consequence of the way the foil of the skin modules is cut.

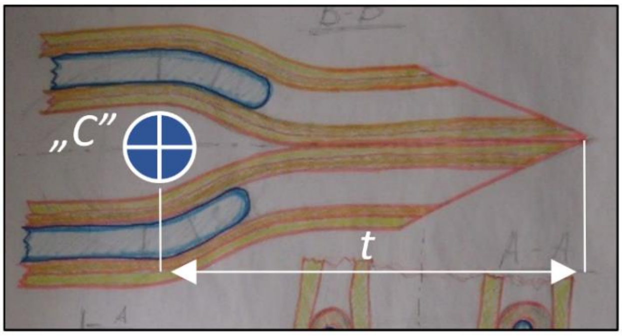
What is the best way to trim free-hanging parts of the skin modules („cuffs") to get an optimally shaped trailing edge?



Tips of the TTM struts are bent;

Foil of the cuff-elements has its own limited stiffness;

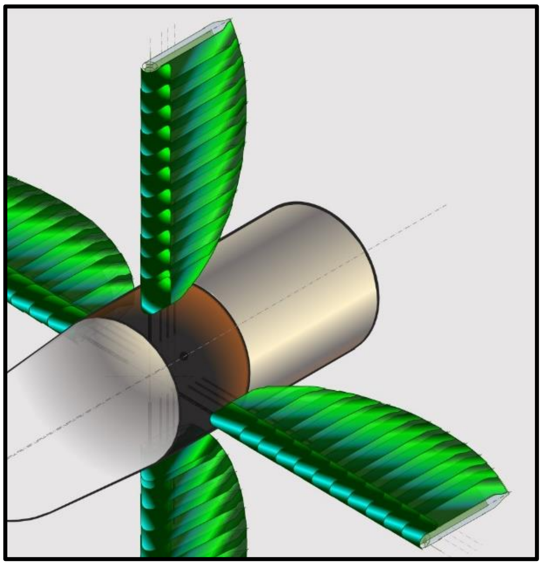
The two above combined with the appropriate cutting of the cuffs' loose ends produce a near optimal shape of the section in the region of the trailing edge.

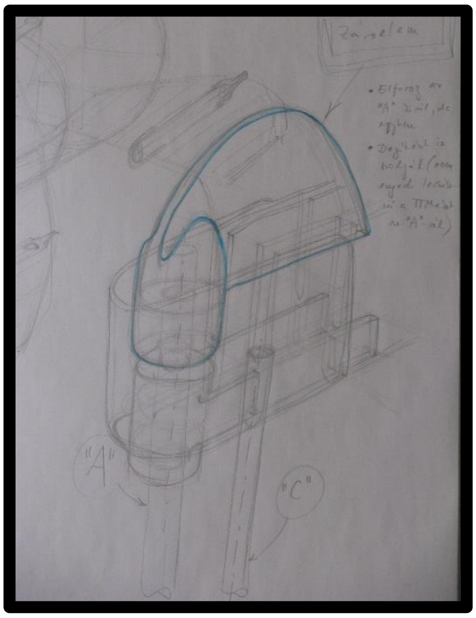


When defining a new planform for a torsional blade proper clearance for the masts moving inside must be secured. „t" is the minimal distance to be kept between trailing edge and the outermost mast (in its maximally tipped-out position);

„t" depends (also) on the materials actually used to build the blade. It is a structural constant.

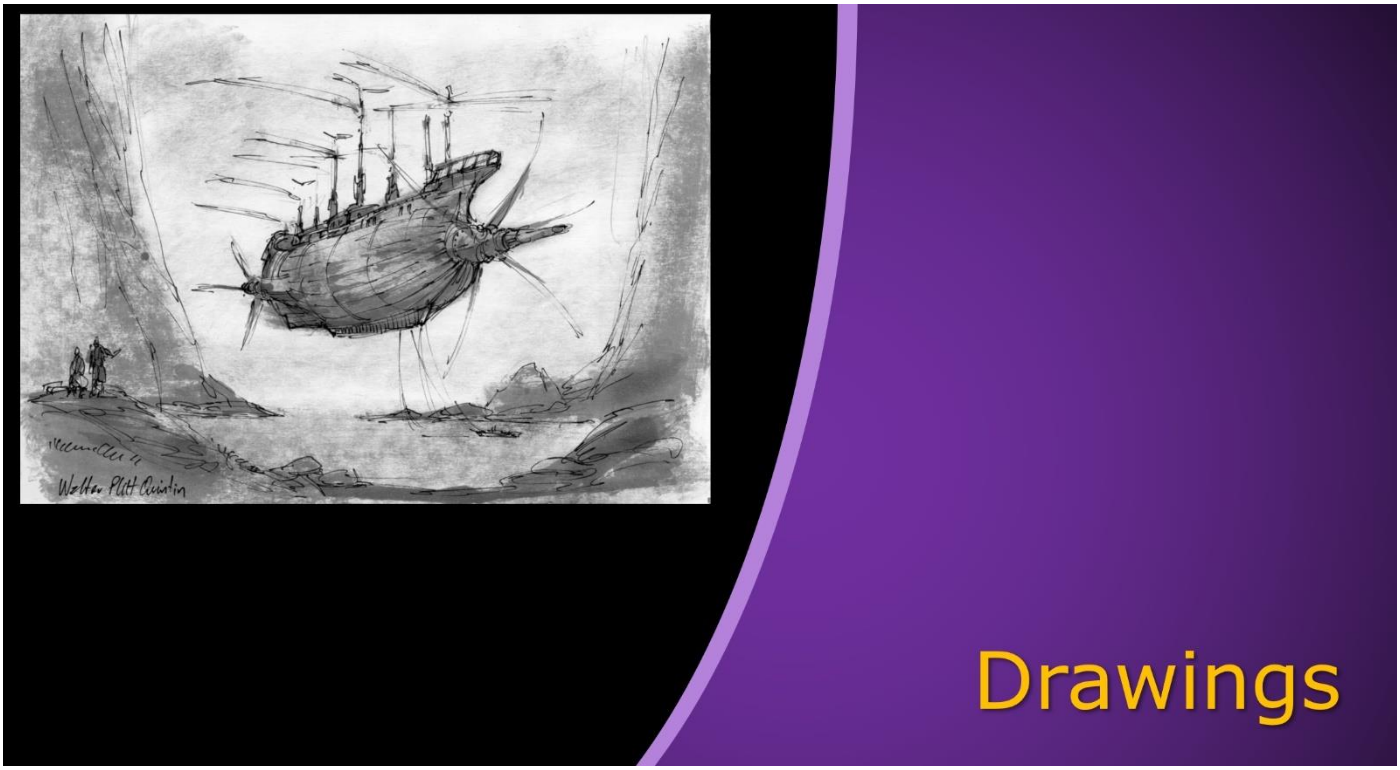
Blade tips play an important role in shaping the flow and, also, influence propeller efficiency.





Without getting deep into details we sketch up a list of requirements. Blade tip elements

1. Their motion is controlled by the radially outermost TTM, the TTMn;
2. They work as winglets and play a role in shaping vortices at the circumference of the propeller disk;
3. They can reduce losses born at the blade tips;
4. Properties of tip-elements deemed useful, preliminarily: they are
   a. made of elastic material,
   b. partially self-adjusting.
5. The optimal shape of a blade tip that produces minimum losses, is to be defined experimentally.



Drawings

In previous chapters we have familiarized :

1. a structure-concept of the torsional blades (TB-s);
2. radial alignment of distributions of both blade angles and angles of the resulting wind.
3. We learned that achieving a 100% alignment requires presence of special hub.
4. Degree of desirable alignment between radial angle-distributions is strongly influenced by technical implementation of the hub.

Degree of desirable alignment between radial angle-distributions is strongly influenced by technical implementation of the hub.

Two main implementations of the hub:

a) EXCENTRIC and

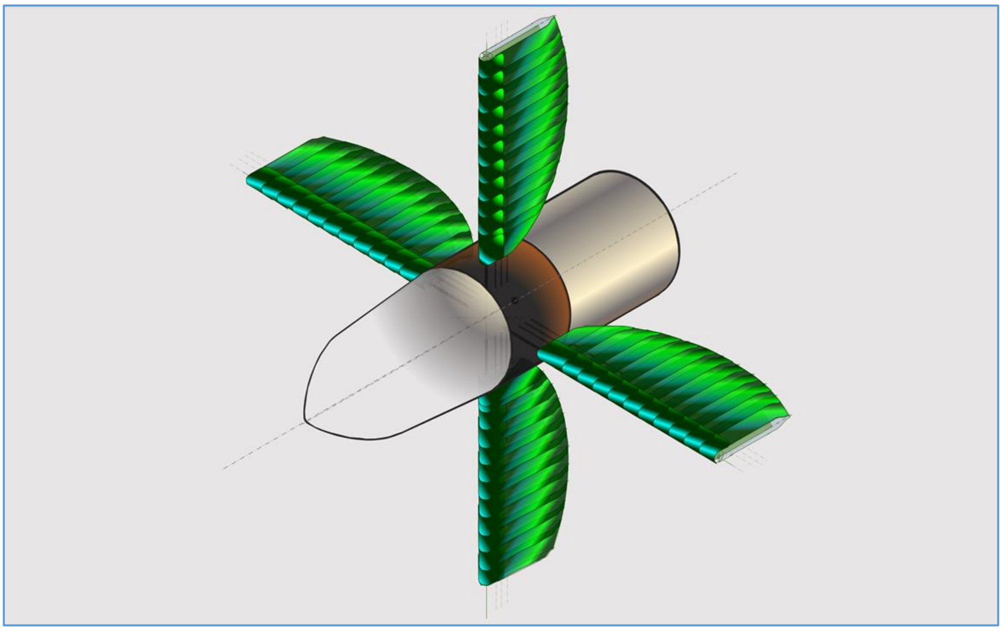
b) CONCENTRIC

Another implementation of the concentric hub may become necessary when and if the torsional blades find their way to the TURBOFAN ENGINES.

See the concept in the following chapter FAN Blade Regulation Concept.

Eccentric Hub Design

Outer view of the propeller:



Inner structure of the hub is looked at in this chapter.

This is how figures of the next collection are referenced:

13.	14.
15.	16.
17.	
18.	

19.
20.

13. Concept structure as starting point – blades in feathered position.
14. Central, non-rotating base of propeller. Through this cantilevered base both lateral bending and axial pushing/pulling loads are passed to the aircraft body. Twisting moment is transferred separately by the driving shaft unit. (See 17.)
15. Propeller cantilevered base with hydraulic cylinder (barrel, in section view)
16. Hydraulic cylinder removed. Hollow shaft is mounted on ball bearings. Cutaway sideview is shown. Also, Bases of the 4 „A" masts are secured in their respective boreholes on the hollow shaft;

    Suggested material of hollow shaft is cast aluminum;

    The 4 TTM∅-s (innermost TTM-s) are shown partially: lower geared parts are visible; tops are broken off;

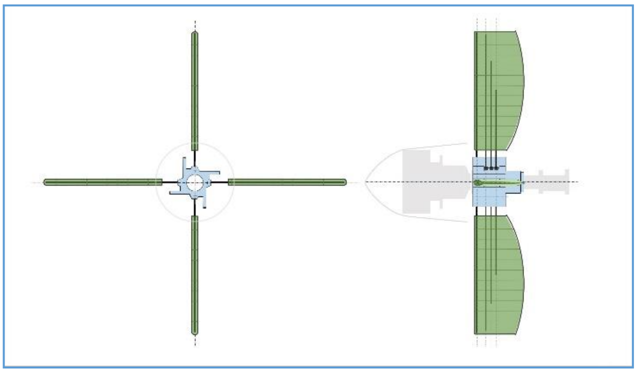
    TTM∅-s (with gears at their bases) rotate freely around the feet of the „A" masts as axes;

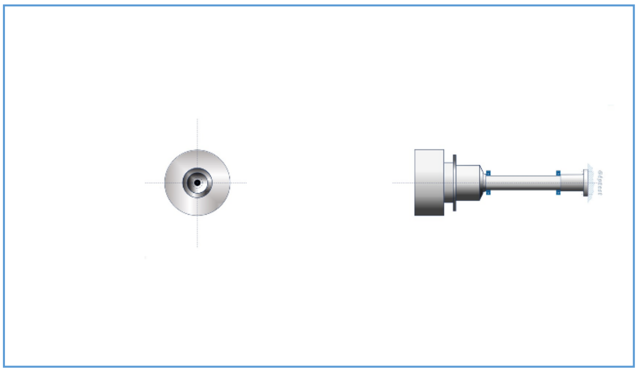
    4 pieces of sliding plates (made of steel), with racks fixed on them, are installed in slots of the hollow shaft;

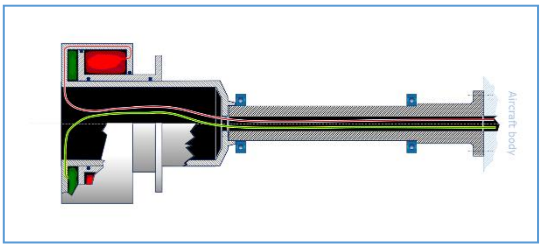
    Racks mate with the gears that are parts of the TTM∅-s;

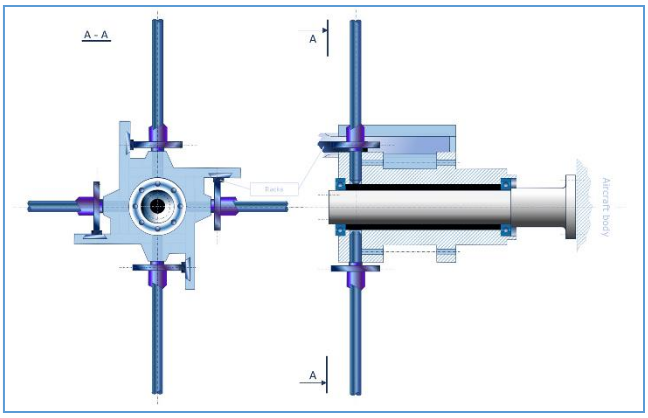
    Sliding plates are shown partially and in cutaway views;
17. Eccentric hub – masts „B-C-D" in place. Typical low-moment & high RPM driving shaft solution (e.g., for electric drive) …
18. All masts and the TTM∅ spacers are shown, armature removed.

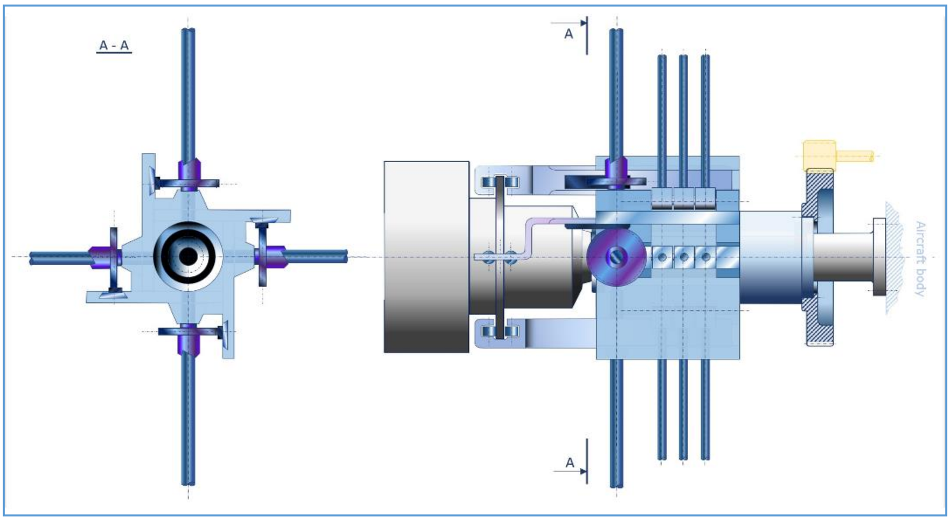
    TTM∅-s carry no skin modules on their struts. TTM∅s' main purpose is to guide and tip masts „B-C-D" – exactly as instructed, either by the pilot or the control system. TTM∅ spacers are of sturdy build. They have almost zero flexibility. Stiffness is necessary as in the region close to the mast-bases relative high forces are acting against the TTM struts.

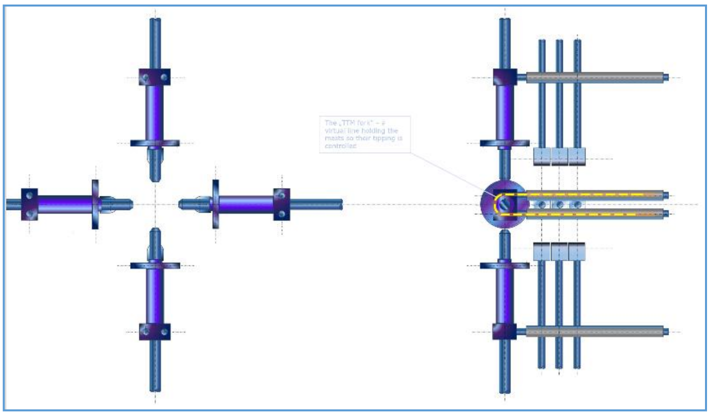


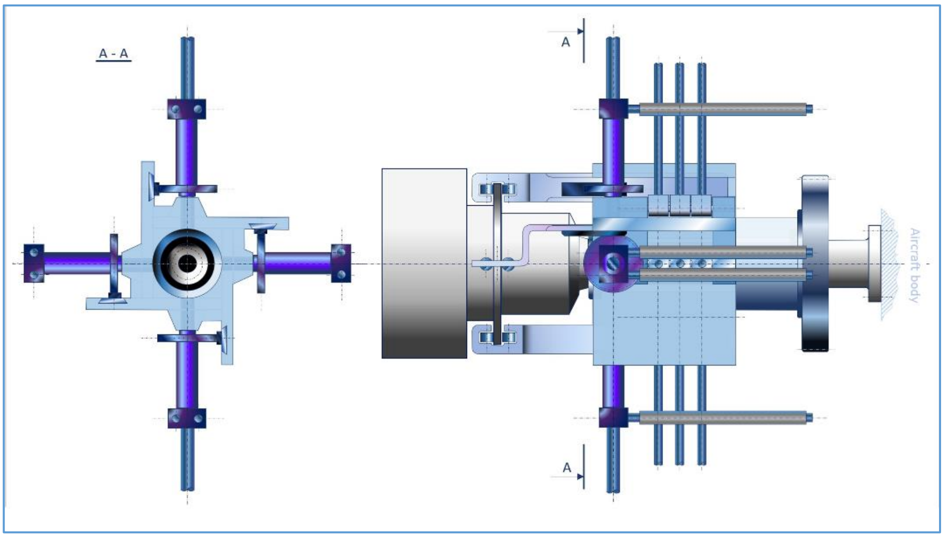


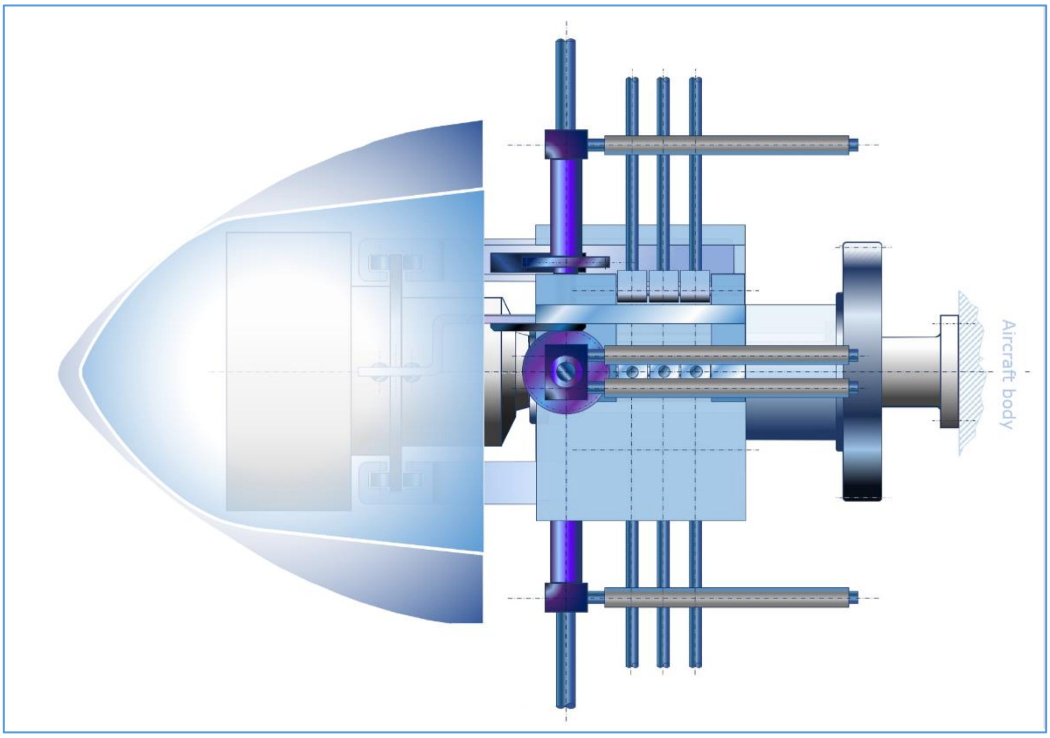

Aircraft body


A - A
A
A
Aircraft body


A - A
A
A
Aircraft body

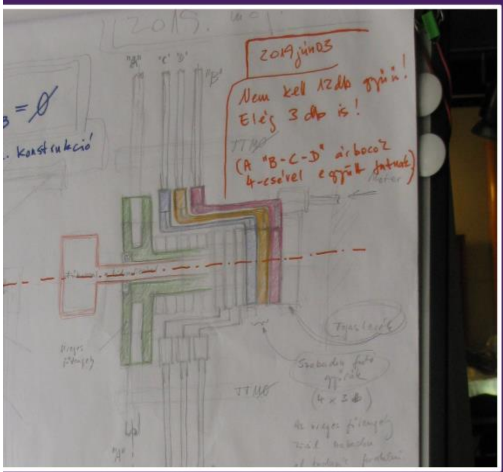






19. Hub complete with the full view of TTM∅ spacers. As the hydraulic cylinder is a non-rotating part it can serve as a suitable base for mounting and fixing the propeller cone to it.

20. Variants of the propeller cone mounted.



CONCENTRIC HUB design

Concentric Hub Design

Definition:

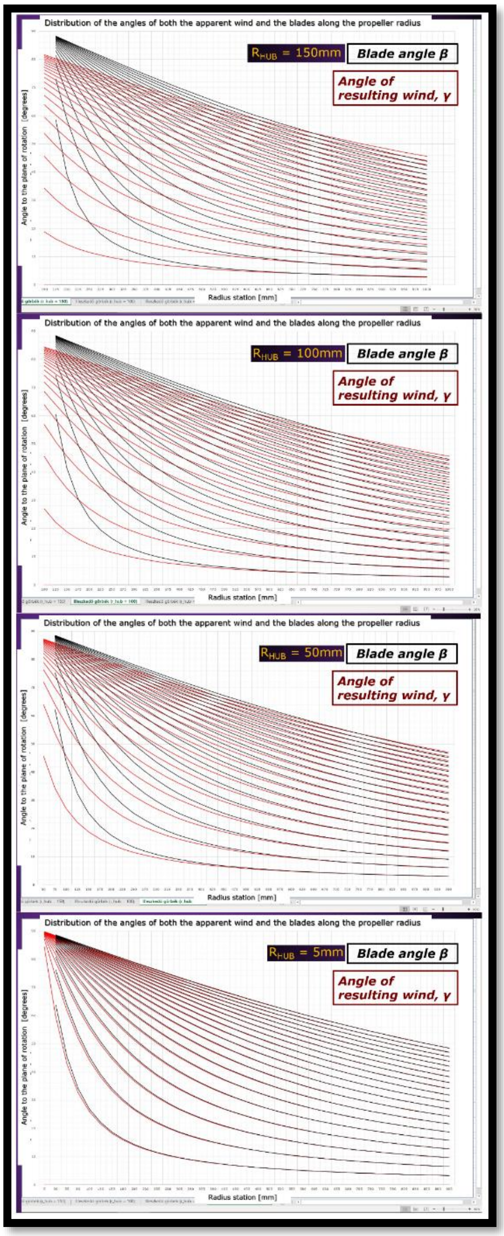
The hub of a torsion blade propeller is concentric when the axes of rotation of all the masts coincide both

a) with each-other, and
b) with the propeller's axis of rotation;

Purpose of the concentric hub design is to facilitate maximum alignment of

a) the blade angles
b) with the angles of the resulting wind,
c) along the whole working radius of the propeller.

Maximum alignment means also maximum improvement of propeller efficiency. That is why concentric hub allows generally higher efficiency than eccentric hub design.



In chapter 6 we had a math-analysis of two functions of angle-distributions along the propeller's working radius. It was shown the difference between the functions of the blade angle and the angle of the resulting wind can be heavily influenced by the value of the physical parameter **R_{HUB}** .

(R_{HUB} is the distance between the axes of rotation of the masts, and that of the propeller.)

In the case of the Concentric Hub Design

$$R_{HUB} = ø$$

We use some transformations to get the mechanical solution of the new type hub. Essence of the transformation is :

- by allowing minor modifications of the hollow shaft familiar from the first eccentric hub, mechanical solution of the new concentric hub can be reached;
- Most elements of the eccentric hub remain unchanged during the transformation.

This is how figures of the next collections are referenced:

21.	22.

<table>
<tr><td>23.</td><td>24.</td></tr>
<tr><td colspan="2">25.</td></tr>
</table>

26.
27.
28.

21. Initial state – eccentric hub with partially twisted blades.

As next steps

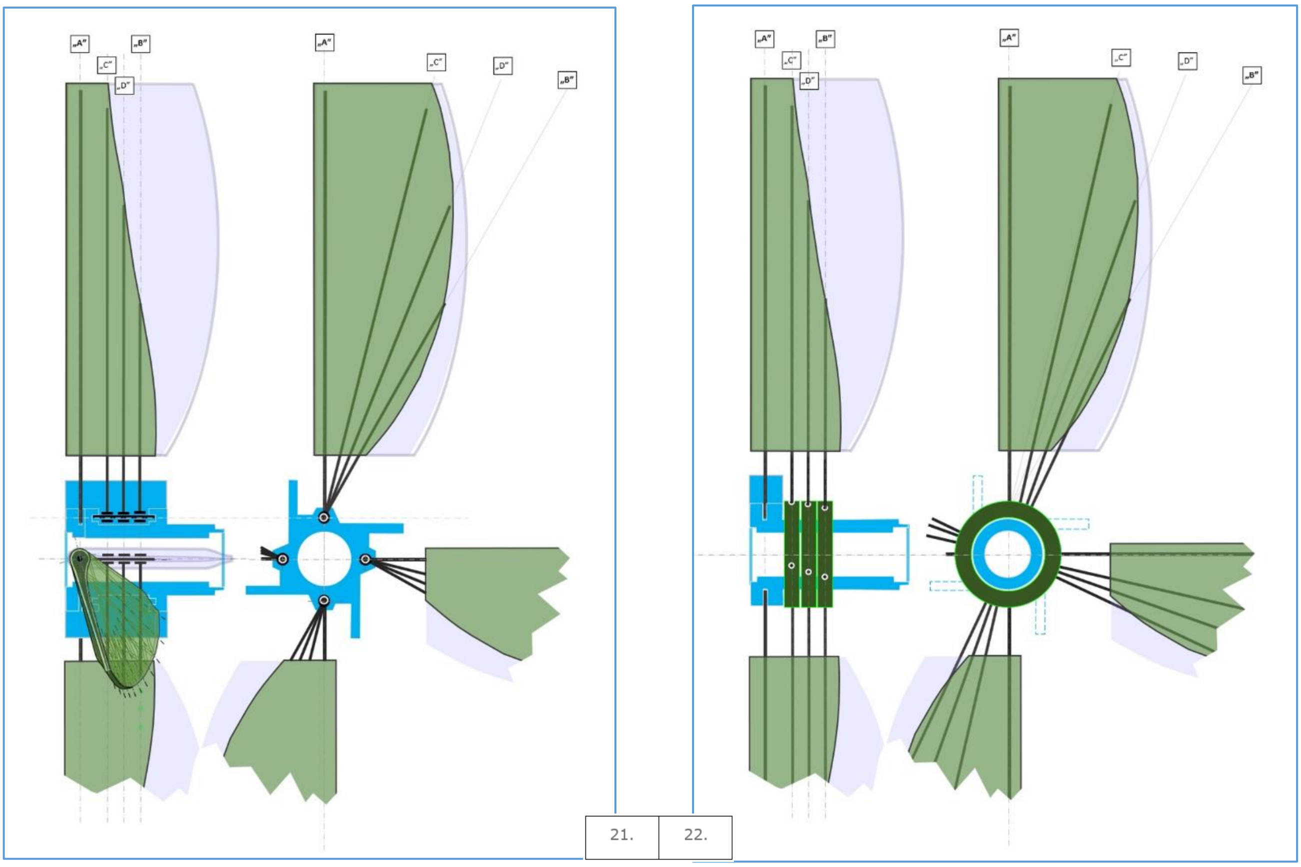
- Axis of rotation of the masts, with all the bearings are removed;
- Length of the cylindric part of the hollow shaft increased. (This step makes the length of the slots for the sliding plates shorter. A safe minimal length shall be retained.);
- Masts „A" remain mounted as they were before.

22. In following steps, in the planes of rotation of each of the secondary masts (masts „B-C-D") a ring is slipped on the new cylindric part of the hollow shaft;

Material of the rings is polyamide (suggested). Independently each ring can rotate freely around their common (cylindric) shaft;

Bases of masts „B-C-D" are fixed on the perimeters of the rings so that one ring will carry only „B" or „C" or „D" masts;

It is quite noticeable how the positions of masts „B-C-D" change as a result of the transformation. This change actually is a correction – errors of the eccentric hub are being corrected this way. In case of the concentric hub directions of longitudinal axes of all masts are radial. In case of the eccentric hub only masts „A" are radial always. „B-C-D" masts become radial only in feathered position of the blade.



21. 22.

23. Hollow shaft of the eccentric hub with the masts, in feathered state - this is the reference state to initiate transformation. Masts „B-C-D” are lifted off their places, while positions relative to each-other and to the propeller axis of rotation remain unchanged;

24. Length of the cylindric part of the hollow shaft increased. (This step makes the length of the slots for the sliding plates shorter. A safe minimal length shall be retained.).

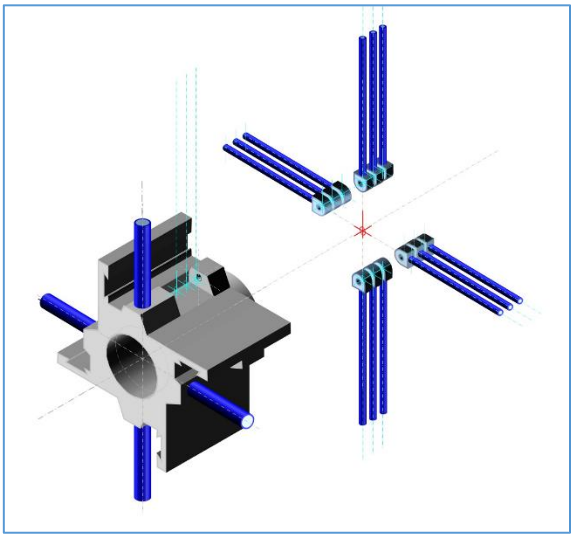
Masts „A” remain mounted as they were before.

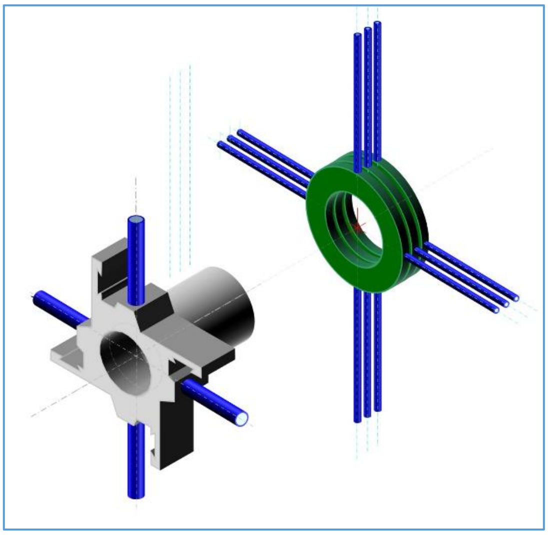
Axis of rotation of the masts, with all the bearings are removed.

In the planes of rotation of each of the secondary masts (masts „B-C-D”) a ring is installed concentrically with the propeller. Material of the rings is polyamide (suggested).

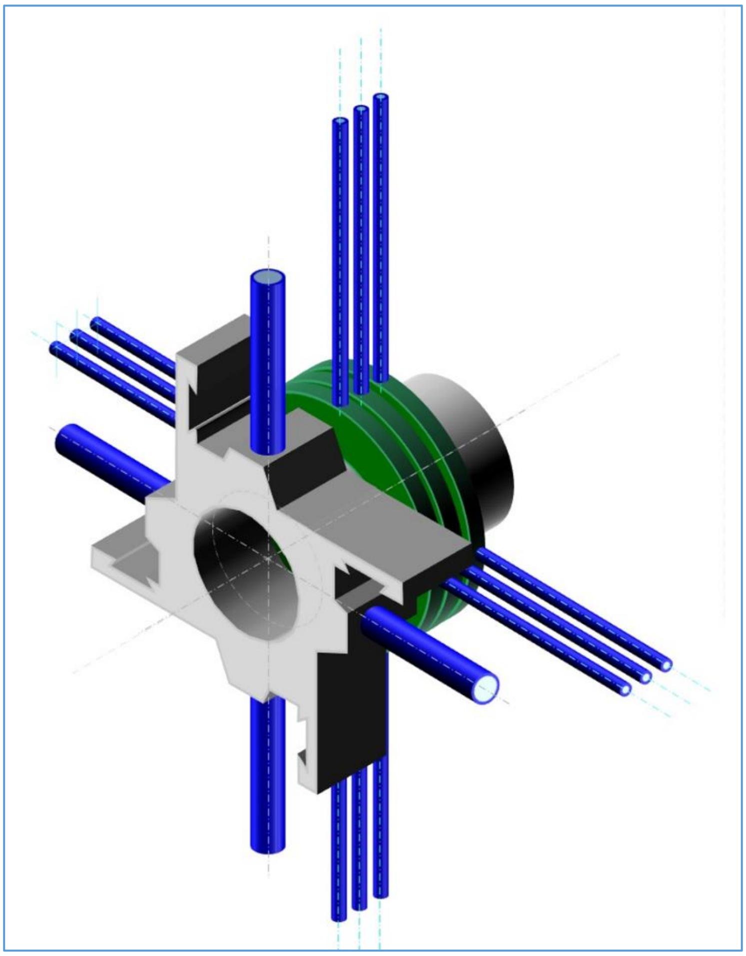
25. The rings, with the masts attached to them, are slipped on the cylindric part of the hollow shaft. Independently, each ring can rotate freely around their common (cylindric) shaft.

Positions of the masts „B-C-D”, relative to each-other, have been kept, but as now they are based on concentrically rotating rings, they retain radial position not only in feathered state, but also in their tipped out states.





23.	24.
25.	



More refined drawings of the new design

Mechanical implementation

26. We use the already known structure of the eccentric hub as a starting point. Here we see the eccentric hub complete with the TTM∅ spacers

    Cutaway view is moved near masts „B-C-D”.

27. We remove axis of rotation and bearings of masts „B-C-D”, break off spacers etc. Cylindric part of the hollow shaft is made longer.

    In the planes of rotation of each of the secondary masts (masts „B-C-D”) a ring is installed concentrically with the propeller.

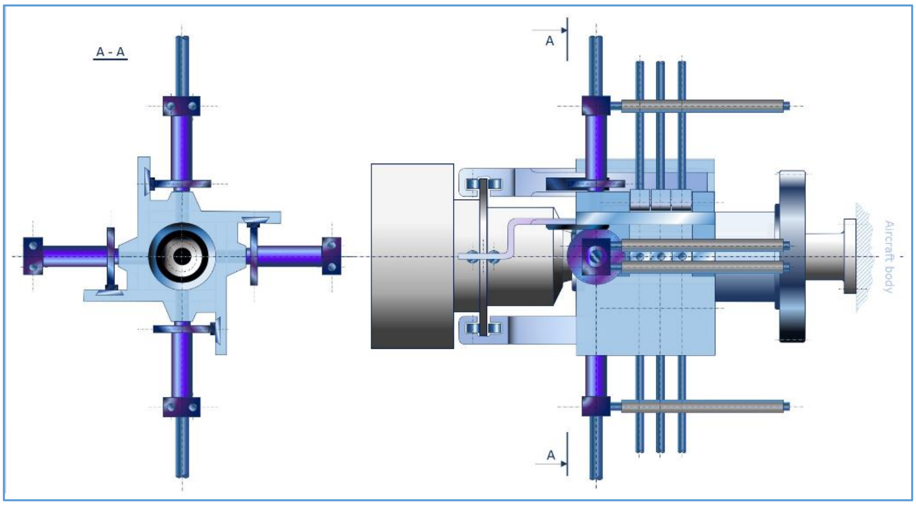
    Bases of masts „B-C-D” are fixed on the perimeters of the rings so that one ring will carry only „B” or „C” or „D” masts.

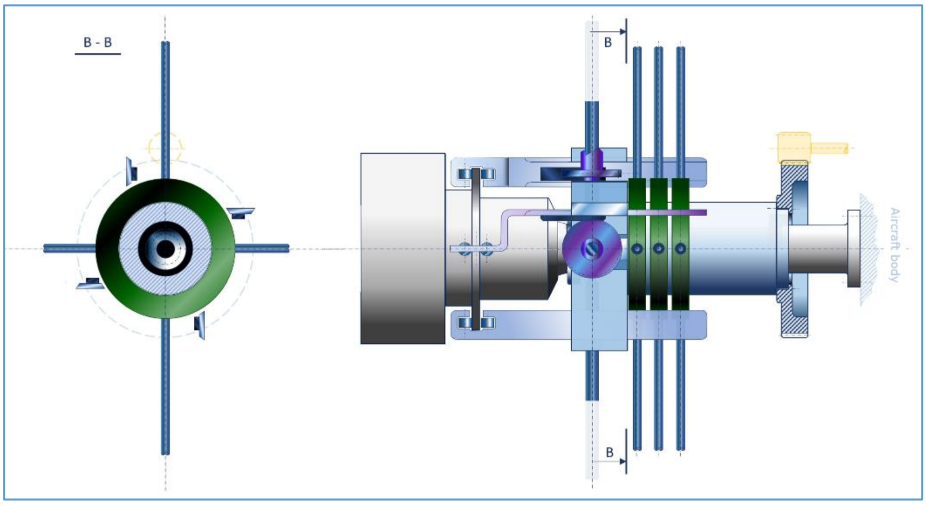
    Material of the rings is polyamide (suggested). Independently, each ring can rotate freely around the hollow shaft.

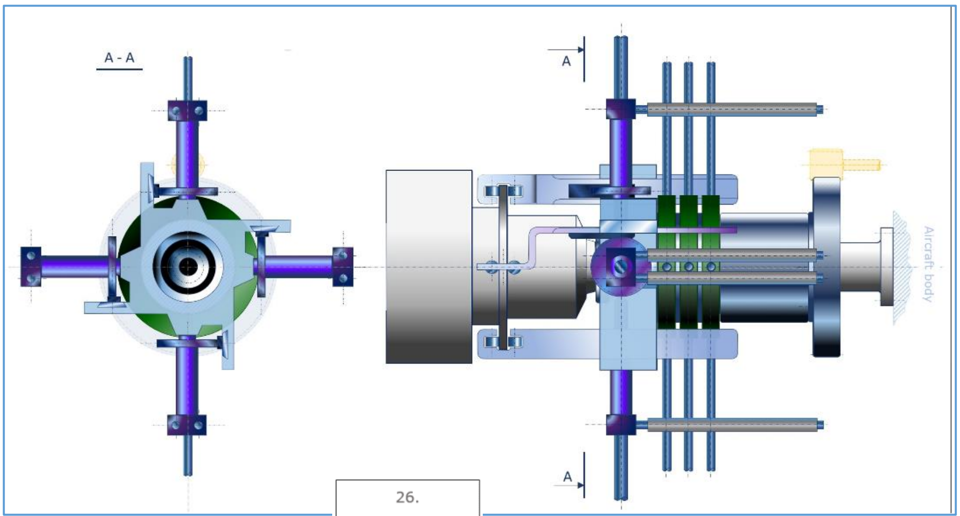
28. Broken views are restored; cutaways are moved back to initial positions.

    Secondary spacer rings are installed on the hollow shaft to secure both correct positions and free rotation of the mast-bases.

    Hub transformation completed.







26.
27.
28.

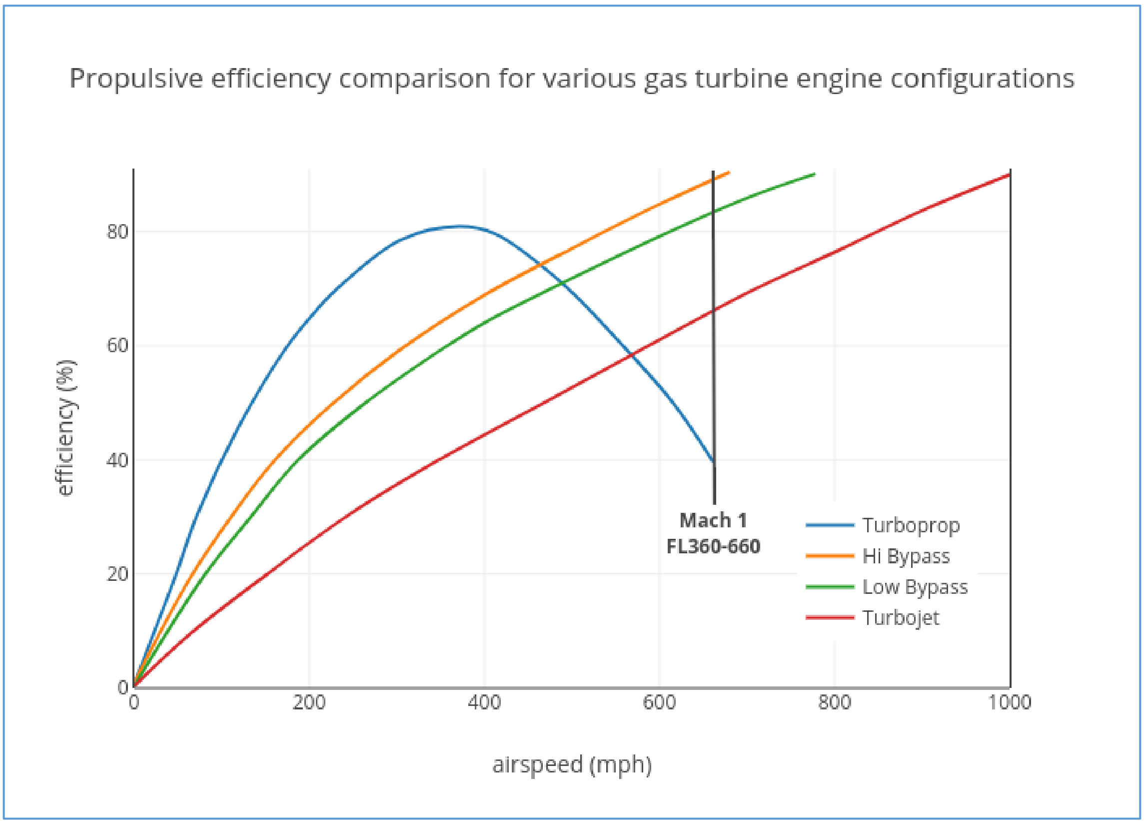
FAN Blade Regulation Concept

Turbofans – a huge market

“All commercial aircraft designed in the last 40 years (other than aircraft with fewer than a dozen passengers) are powered by gas turbine engines, either turbofan or turboprop.”

National Academies of Sciences, Engineering, and Medicine. 2016.

Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions. Washington, DC: The National Academies Press. doi:10.17226/23490.



https://upload.wikimedia.org/wikipedia/commons/0/01/Gas_turbine_efficiency.png

Excellent speed range: high subsonic to not so high supersonic TAS.

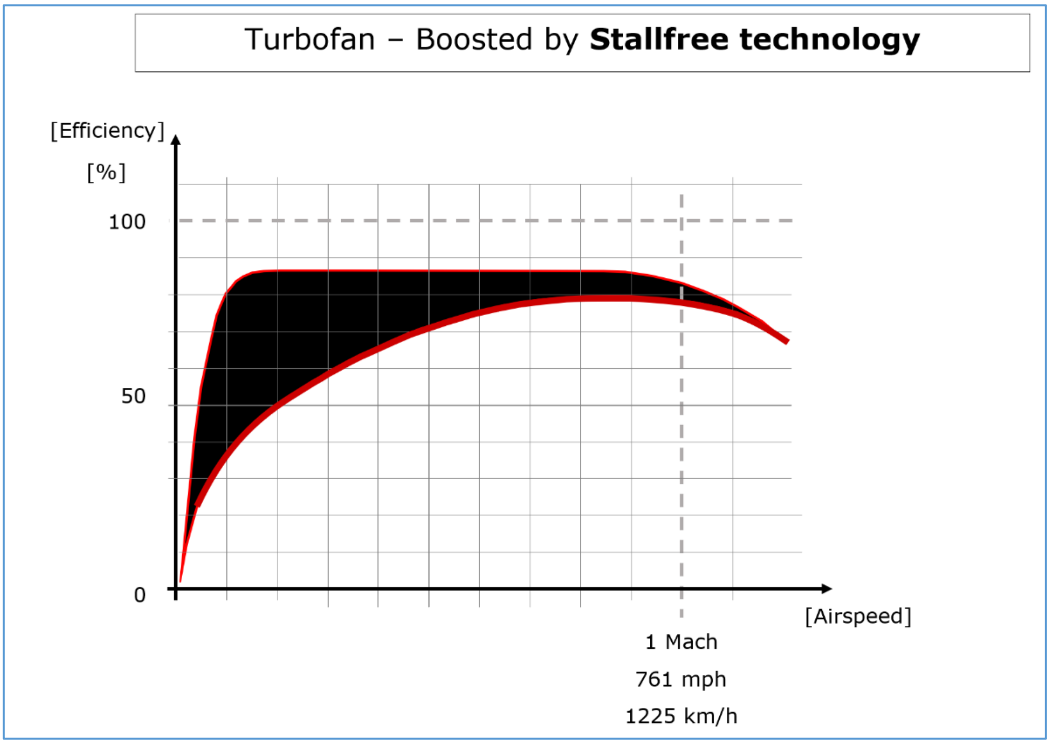
Nearly all (even the newest – see on title page) of today’s turbofan engines are made with unregulated fans.

Regulated fans could improve both takeoff and top cruising speed (lower-subsonic) efficiency. Plus reduce noise levels.

Concentric Hub Design of the Stallfree propeller offers a concept for compact structure and wide range regulation of fan blades.

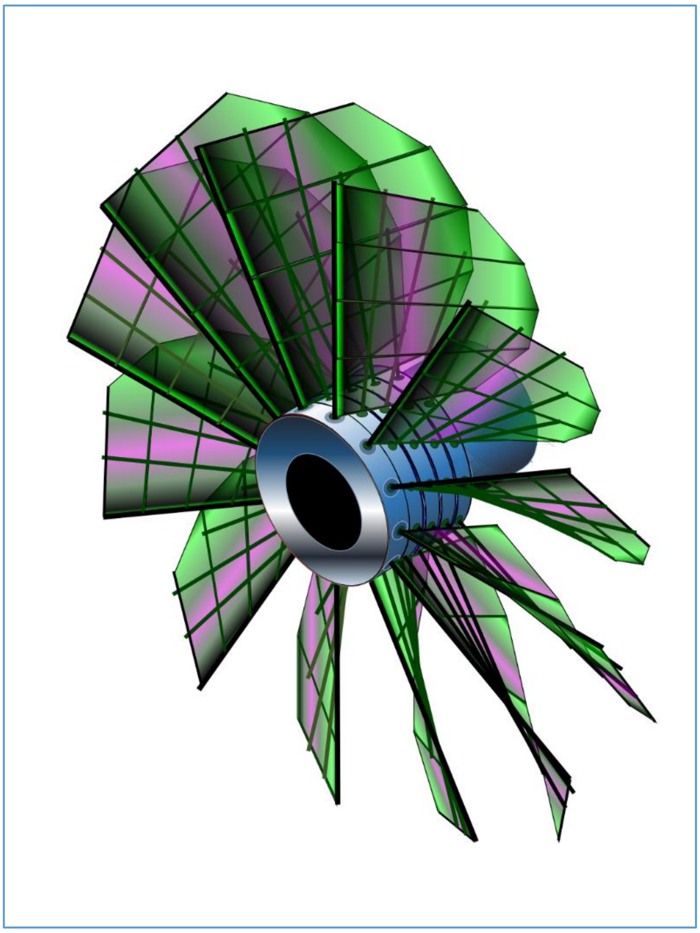
Possible rewards:

1. Turbofan RPM can be reduced so the blade tips remain subsonic to about 0.8Mach of TAS;
2. Takeoff characteristics improve – shorter runway and less fuel consumed;
3. Quieter and more efficient operation at subsonic speeds.

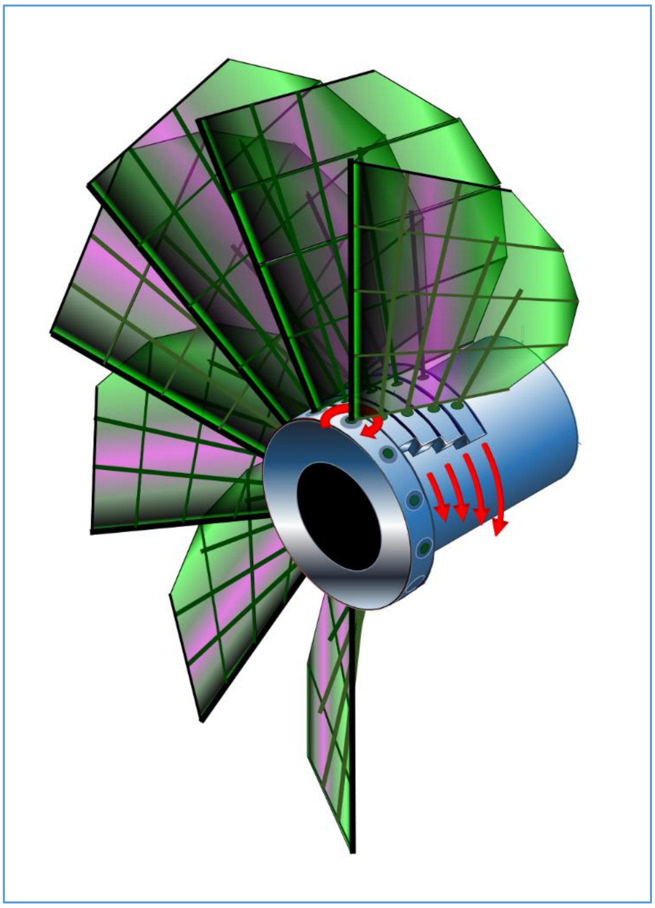


(Estimated improvement shown as shaded area.)

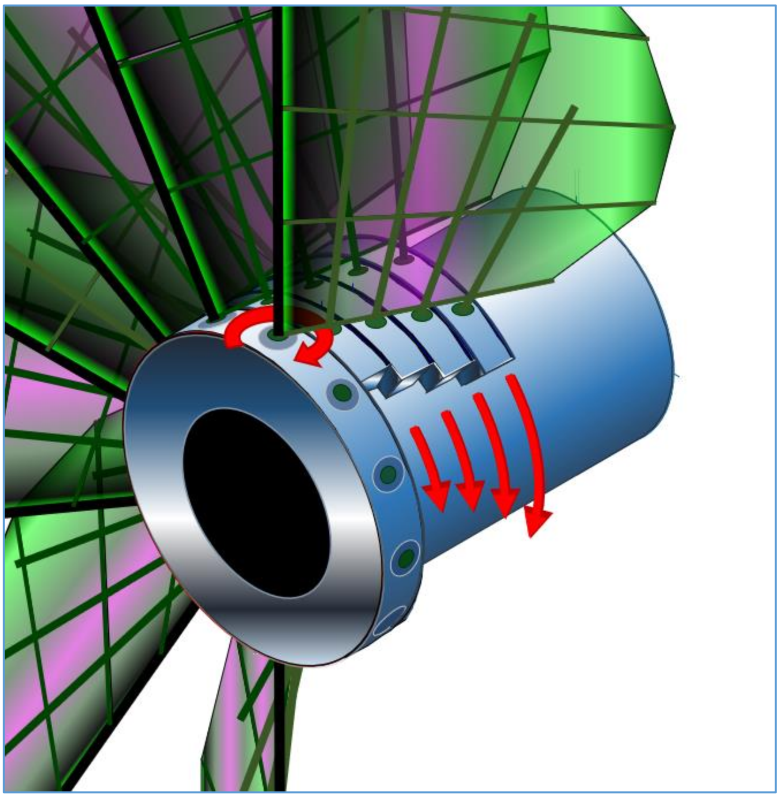
Sketch of a fan with regulated blades:



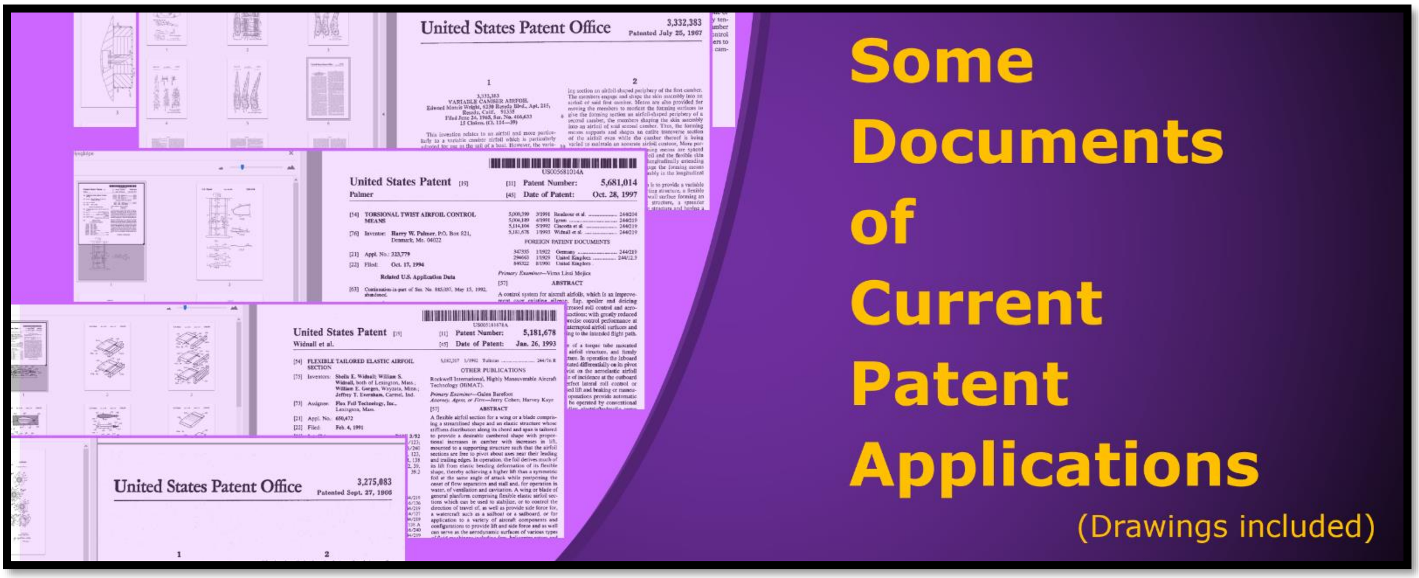
Here is a cutaway image to show how the rings carrying secondary masts move:



Notice how the TTM-s turn around masts „A” as all the „B-C-D” masts tip:



(Masts „A” are not turning. They serve as axes of rotation for the TTM-s.)



Some Documents of the Current Patent Applications

Currently (April 2021) both domestic and international patenting processes are in progress.

SZELLEMI TULAJDON NEMZETI HIVATALA
1081 Budapest, II. János Pál pápa tér 7. • 1438 Budapest, Pf. 415.
Telefon: 312 4400 • Telefax: 474 5534
Adószám: 15311746242 SZJ 15 Közigazgatás

Ügyiratszám:
P2000013 /5
Ügyintéző:
Mézes Sylvia

PINTZ ÉS TÁRSAI Szabadalmi, Védjegy és Jogi Iroda Kft.

Budapest
Pf. 245.
1444

A fenti címen Pintz és Társai Kft. részére.

Tárgy: Írásos vélemény

ÍRÁSOS VÉLEMÉNY

Az újdonságkutatás a Szellemi Tulajdon Nemzeti Hivatalahoz benyújtott 849/20 iktatószámú szabadalmi leírás és iktatószámú igénypont és 849/20 iktatószámú rajz alapján készült.

A Szellemi Tulajdon Nemzeti Hivatala az alábbi előzetes megállapítást teszi arról, hogy az újdonságkutatási jelentésben megjelölt iratokra és adatokra figyelemmel a találmány kielégítheti-e az újdonság, a feltalálói tevékenység és az ipari alkalmazhatóság követelményeit:

Újdonság
Igen 1-10 igénypont(ok)
Nem -- igénypont(ok)

Feltalálói tevékenység
Igen 1-10 igénypont(ok)
Nem -- igénypont(ok)

Ipari alkalmazhatóság
Igen 1-10 igénypont(ok)
Nem -- igénypont(ok)

INDOKOLÁS

A bejelentés tárgya: javított tulajdonságú légcsavar légi járművekhez, amely agyra szerelt lapátszerkezetet, erőátviteli egységet, fő tartószerkezetet tartalmaz.
A lapátszerkezet az agyhoz hozzáerősített és a lapátszerkezet belépőélének gerincét alkotó árbocrudat és az árbocrúd mellé sorolt legalább egy darab segédárbocot tartalmaz. Az árbocrúdra merevítő szárral bíró, elfordítható távtartó-merevítő idomok vannak felhúzva, a merevítő szárak moduláris elemekkel vannak burkolva. Az egymáshoz átlapolással illesztett, hajlékony moduláris elemek héjazatot alkotnak.

2. Az írásos vélemény a következő iratokra hivatkozik:

D1: US 3227221 A
D2: EP 3406522 A1

A D1 irat helikopter rotorlapát kialakítására vonatkozik, amely agyra szerelt lapátszerkezetet, erőátviteli

13127191 JPU0013D.77X 20.02.18:02:32 P2000013/5 Mech. O./Mézes Sy. 1 / 2

egységet, fő tartószerkezetet tartalmaz (ld.1. és 2. ábra).
A lapátszerkezet az agyhoz hozzáerősített árbocrudakat (13) és azokra szerelt különálló aerodinamikai szárnyszelvénnyel ellátott lapátrészekből (11) álló lapátokat (3) tartalmaz.
Lapátonként a lapátrészeket (11) egy az árbócrúd mellé sorolt torziós rúd (23) kapcsolja össze, amely a kereszttartókra (27) elforgathatóan rögzített hüvelyekben (25) van vezetve.
Az árbocrúd elforgatásával árbocrúdhoz rögzített lapát-szakaszok beesési szöge változtatható.

A D2 irat légijárművek rotorjára vonatkozik (ld. 5A. ábra), ahol a rotorszerelvénynek (200) egy repülőgéphez kapcsolt agya (204) van, melyből oldalirányban rotorlapátok (212) nyúlnak ki.
A rotorlapátok (212), mindegyikének van egy belső és külső vége, és legalább egy lapáttő működtető (252) szerkezete, amely a rotorlapátok közül legalább az egyiket a többi rotorlapáttól függetlenül tudja állítani.
Legalább egy vezérlő csatlakoztatható a lapáttő-működtetőhöz (252), amely úgy van kialakítva, hogy jelet küldjön a lapáttő-működtetőhöz (252), ezáltal lehetővé téve a forgórészlapok legalább egyikének beállítását (ld. leírás [0057] bekezdés, és 5F-5G. ábrák.).
Egy másik kiviteli alak szerint legalább egy a rotorlapáthoz (212) kapcsolt fékszárnyat (352) működtetnek a rotorlapát (212) alakjának beállításához (ld. 6A-6C. ábrák).

3. Újdonság
A feltárt iratok egyike sem tartalmazza a találmány összes jellemzőjét, a találmánytól lényeges elemeiben eltérő megoldást ismertetnek. Ezért az 1-10. igénypontban feltárt találmány megfelel az újdonság követelményének.

4. Feltalálói tevékenység

A technika állásából nem olvasható ki utalás olyan légcsavarra, amelynek lapátszerkezete az agyhoz hozzáerősített árbocot és mellé sorolt legalább egy segédárbocot tartalmaz, és ahol az árbocrúdon merevítő szárral bíró, elfordítható távtartó-merevítő idomok vannak, amelyek egymáshoz átlapolással illesztett hajlékony moduláris elemekkel burkolva héjazatot képeznek.
Az így kialakított alakváltó légcsavar lapátok speciális belső rudazatának mozgatása révén biztosítható a lapát menti légáramlások eredőjéhez alkalmazkodó lapátforma, amely folyamatosan biztosítja a lapátszelvények pontos hozzáigazítását az adott helyzetben optimális beállítási szöghöz.

A fentiek értelmében ezért az 1-10. igénypontban szereplő légcsavar megalkotása feltalálói tevékenységet igényelt.

5. Ipari alkalmazhatóság
A bejelentésbe foglalt találmány iparilag alkalmazható.

6. Egyéb

A szabadalmi bejelentés érdemi vizsgálata során a releváns iratok, illetve adatok köre változhat, ezért ezen írásos vélemény megállapításai nem tekinthetők véglegesnek a találmány szabadalmazhatósága szempontjából.

Budapest, 2020. február 18.

Mézes Sylvia
szabadalmi elbíráló

13127191 JPU0013D.77X 20.02.18:02:32 P2000013/5 Mech. O./Mézes Sy. 2 / 2

Primary / domestic patent research document stating the invention is real, has no conflicting patents and is suitable for industrial application.

International process of patenting started 08 September 2020:

WIPO PCT
The International Patent System
WORLD **INTELLECTUAL PROPERTY** ORGANIZATION

Receipt of Electronic Submission

The Receiving Office (RO/IB) acknowledges the receipt of a PCT International Application filed using ePCT-Filing. An Application Number and Date of Receipt have been automatically assigned (Administrative Instructions, Part 7).

Submission Number:	058337	
Application Number:	PCT/IB2020/058337	
Date of Receipt:	08 September 2020	
Receiving Office:	International Bureau of the World Intellectual Property Organization	
Your Reference:	KRUPPA-propeller	
Applicant:	KRUPPA, László	
Number of Applicants:	1	
Title:	IMPROVED EFFICIENCY PROPELLER FOR AIRCRAFT	
Documents Submitted:	KRUPPApropeller-appb-000005.pdf (Description-Claims-Abstract-Drawings EN.pdf)	1723239
	KRUPPApropeller-appb.xml	999
	KRUPPApropeller-fees.xml	2237
	KRUPPApropeller-poat-000001.pdf (POA - Laszlo KRUPPA.pdf)	623992
	KRUPPApropeller-requ.xml	3842
	KRUPPApropeller-vlog.xml	1068
Submitted by:	György PINTZ (Customer ID: user_HU_PINTZ_GYORGY_7389)	
Timestamp of Receipt:	08 September 2020 17:12 UTC+2 (CEST)	
Official Digest of Submission:	C7:11:52:5C:85:8D:50:07:B7:5D:90:C1:A3:48:6A:00:37:B4:C4:A5	

/Geneva, RO/IB/

A positive opinion of the PCT search authority was received early December 2020:

PATENT COOPERATION TREATY

From the
INTERNATIONAL SEARCHING AUTHORITY

To: see form PCT/ISA/220	PCT WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY (PCT Rule 43*bis*.1)
	Date of mailing *(day/month/year)* see form PCT/ISA/210 (second sheet)
Applicant's or agent's file reference see form PCT/ISA/220	**FOR FURTHER ACTION** See paragraph 2 below

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/IB2020/058337	08.09.2020	10.01.2020

International Patent Classification (IPC) or both national classification and IPC
INV. B64C11/00 B64C27/54

Applicant
KRUPPA, LASZLO

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/IB2020/058337

Box No. V Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-10
	No:	Claims	
Inventive step (IS)	Yes:	Claims	2, 3, 5, 7-10
	No:	Claims	1, 4, 6
Industrial applicability (IA)	Yes:	Claims	1-10
	No:	Claims	

2. Citations and explanations

see separate sheet

Item list of the patent applications for the interpretation of drawings:

1	main mast (or mast "A")
2	secondary mast
3	propeller hub (excentric)
4	axis of rotation (of secondary masts)
5	spacer with struts
6	lateral piece of skin module (gauntlet cuff)
7	parallel line
8	mast base
9	axis of rotation (of the propeller)
10	leading edge
11	blade structure
12	
13	servo unit
14	strut socket
15	skin
16	strut (or batten)
17	secondary mast base piece
18	frontal piece of skin module (collar)
19	propeller cone
20	blade tip element
21	cantilevered base (outline)
22	feathered position of blade

23	modular unit of skin
24	hydraulic cylinder (barrel)
25	piston
26	cantilevered base (with sectional image)
27	bearing
28	excentric propeller hub (with sectional image)
29	hub of spaced batten
30	gear fixed to the hub of spaced batten
31	slider plate
32	rack
33	roller
34	driving gear
35	gear
36	propeller hub (concentric)
37	spacer
38	secondary mast base ring
39	blade section untrimmed
40	airfoil shape (any standard)
41	element of aerodynamic profile trimming
42	aerodynamically trimmed blade section
43	(allowable/designated) locations to fix aerodynamic trimming pieces
44	aircraft body

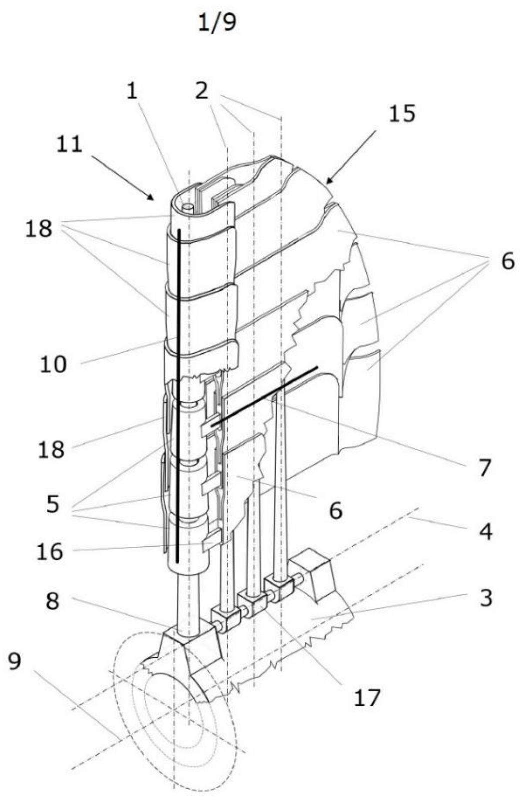


Fig. 1

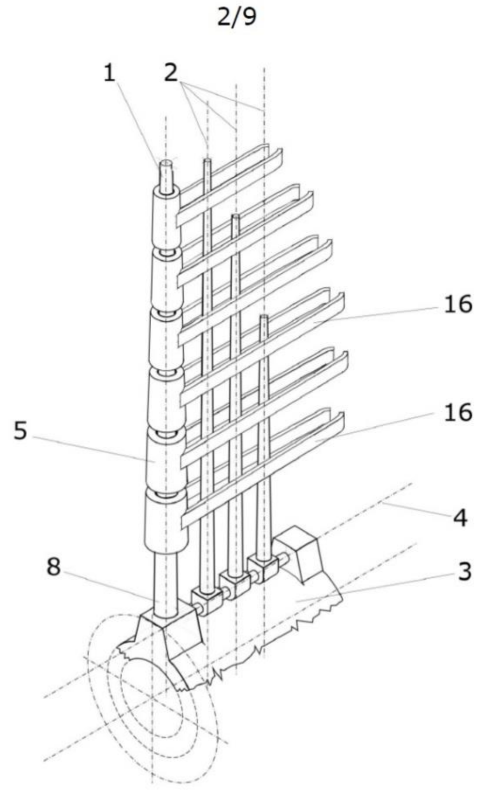


Fig. 2

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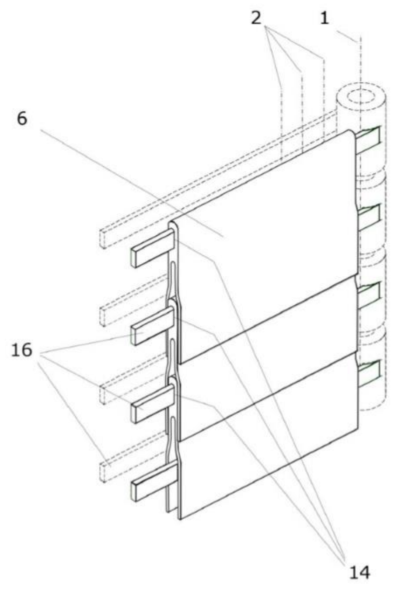
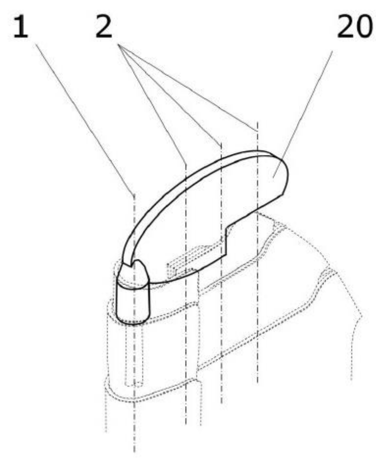


Fig. 3



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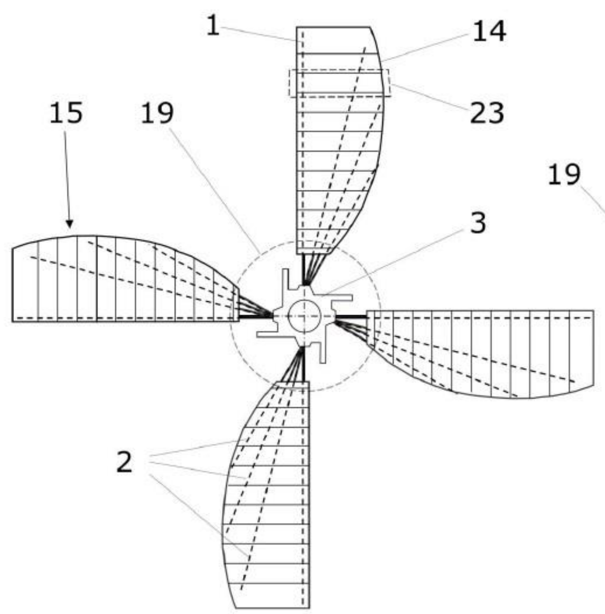

Fig. 4

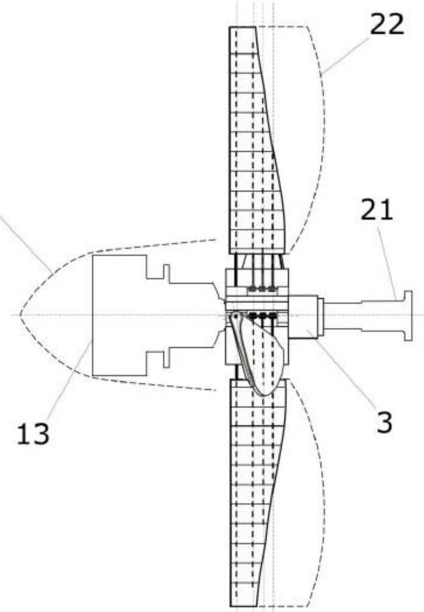

Fig. 5

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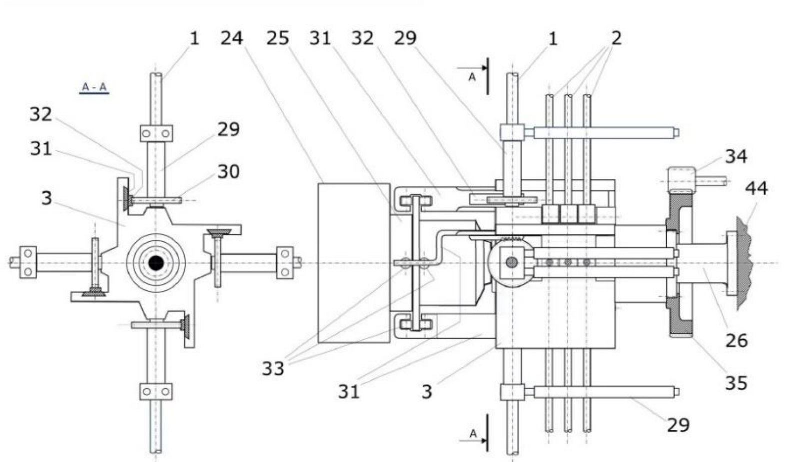

Fig. 6

Fig. 7

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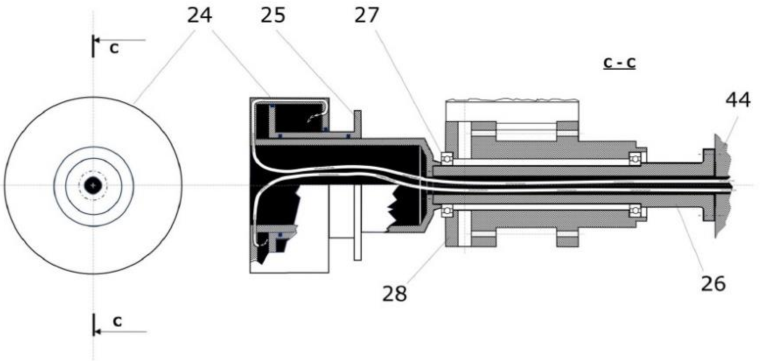

Fig. 8

Fig. 9

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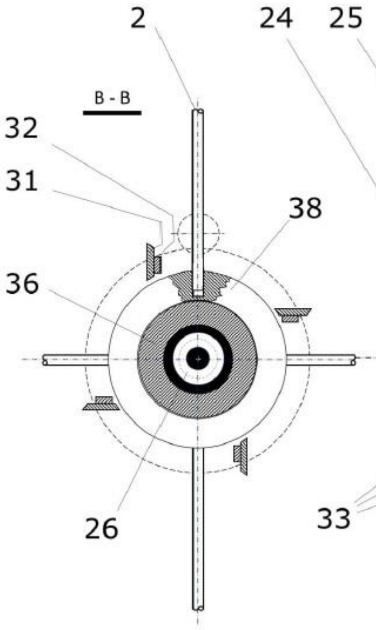

Fig. 10

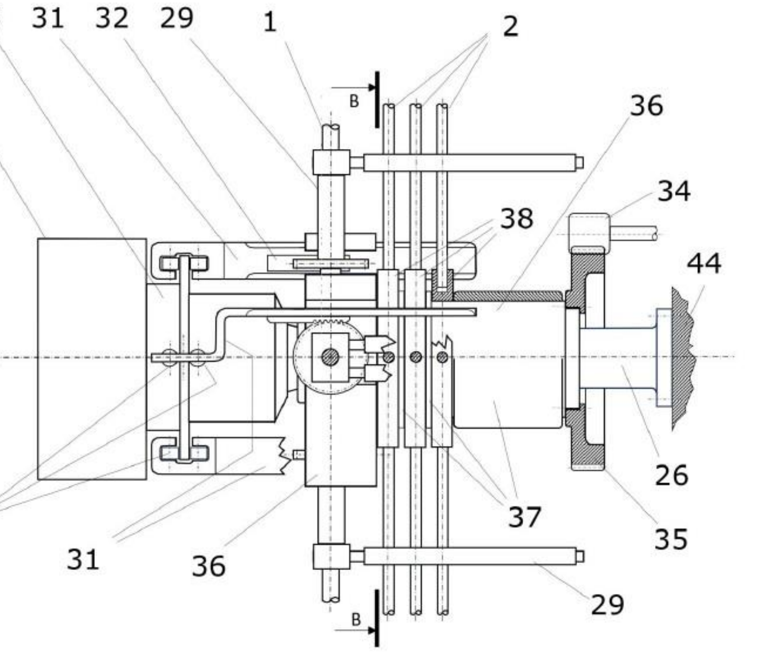

Fig. 11

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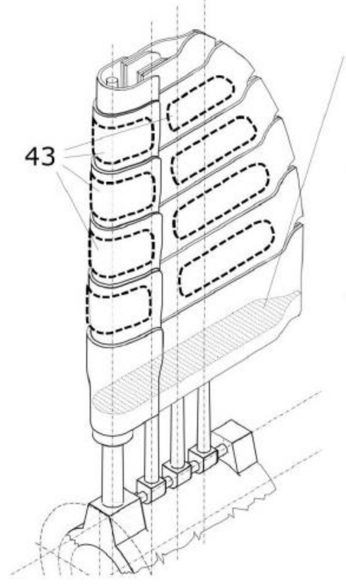

Fig. 13

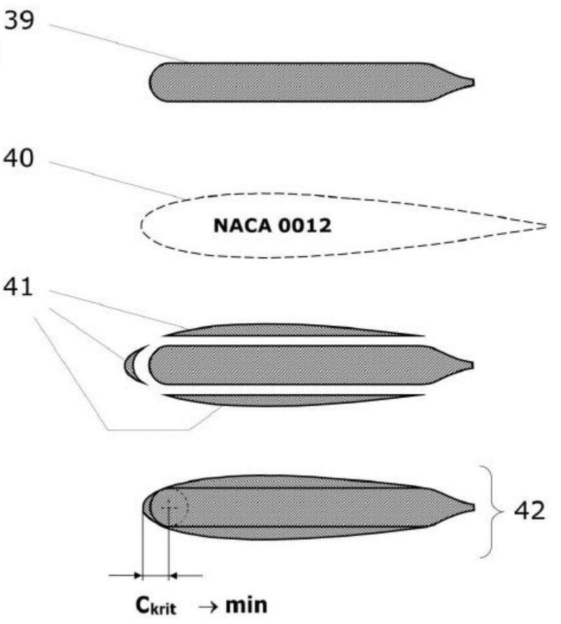

Fig. 14

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Propulsion Issues of Today's **eVTOL Development** are

a) EFFICIENCY

Flight duration & range - critical

b) SPEED RANGE

Vertical lifting performance versus top cruising speed

c) NOISE

Bad for urban environment – critical for air taxis & UAM

All 3 are basically

PROPELLER RELATED.

More than that. They all are related to the same problem of

BLADE GEOMETRY

Explanation and solution in the

eBook

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