Key Animations for Adding Twist Control to High Aspect Ratio Rotor Blades

(mechanical design clues)

Purpose

There are many good reasons to implement blade twist control for rotors and propellers. All these reasons have one common root, which is the improvement of the way these devices generate thrust. That is - an increased propulsive efficiency.

Electric aircraft traveling range could be increased approximately three times while keeping battery **capacity unchanged**. Or top cruising speed of propeller driven planes could reach 0.8 Mach – becoming a strong competition for jet propulsion in the subsonic transport. And more.

High efficiency also has the "side effect" of making propellers quite silent. When the volume of wasted engine power gets reduced drastically, noise generation is reduced accordingly.

Finally, tiltrotor aircraft should be mentioned too, which would greatly benefit from having the twist control option for their proprotors. For their flight in helicopter regime they could have the optimal low-twist rotor blades. That would make vertical takeoff and flight easy, safe and absolutely stable. At the same time, for cruising flight those tiltrotors could use the then-optimal, high twist rotor blades. And, as a consequence, potentially, also the 0.8 Mach top cruising speed could be reached.

(The 07-23-2024 post at the VFS Open Forum has an example for the increased propulsive efficiency diagram shown as the "Osprey++ curve".)

Refreshing memories: why must a propeller blade have the twist ?

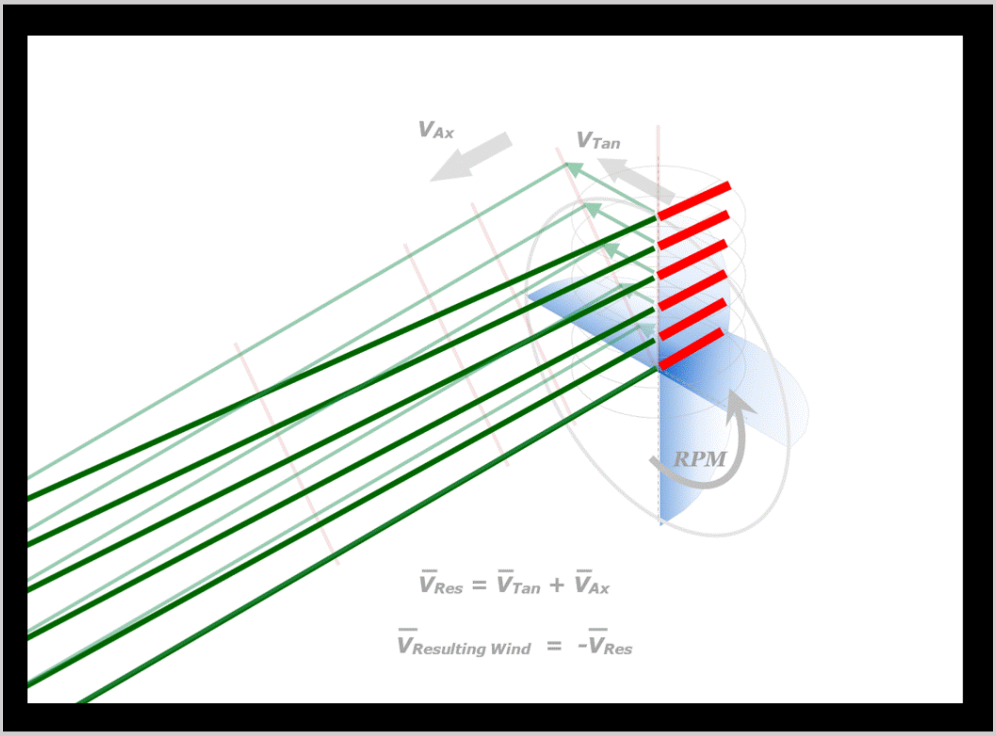
Relying on the Blade Element Theory (BET) of propeller design, a chart of the airflow (or rather speed vectors) belonging to **one blade**, was built for a general aviation (GA) propeller. Turbulence and losses were neglected for the analysis.

Three vectors of the BET are used to build a model of the airflow in 3D, around a rotor/propeller blade. Axial, tangential and the resulting speed together constitute the famous vector-triangle of the BET. When shown in 3D they provide a self-explanatory picture of the well-known propeller blade twist.

In normal operation sections of the propeller blades shall be in alignment with the direction of the resulting airspeed vector. Along the whole radius - in order to develop the best **LIFT(~THRUST)/DRAG**. Of course, this alignment is not precise: there must be a difference between the angle of the section chord, and that of the line of action of the resulting wind. The difference is called **Angle of Attack, the AOA**.

Optimal AOA is a small value of around 4 degrees. It is kept constant along the radius and - because of its relative smallness - is not shown on the model. Hence, the **propeller blade twist** (which is a 3D quantity) can be taken as **identical** with the geometrical **twist of the array of the resulting wind vectors**.

GIF_No1.



https://stallfreepropellers.com/wp-content/uploads/2024/11/Triangles_04_upload_.gif

(Click the link to play.)

How to look: *camera travels along with the top blade. Records vectors of the airspeed as they change.*

To be noticed: *lowest member of the array of the resulting speed vectors (the one closest to the propeller axis) retains its direction, which is the same as that of the axial speed* $\boldsymbol{V_{AX}}$ *. All the time. Thus position of the uppermost vector becomes an objective measure of the degree the blade is twisted.*

In aviation, mostly, the propeller ***RPM*** *(****ω****) is kept constant. That makes the tangential speed* $\boldsymbol{V_{TAN}}$ *remain constant too,* ***depending on the radius*** *only.*

(At first you may want to disregard the bright red shapes on the right side of the drawing. Text below contains reference/explanation of them.)

The model is straightforward enough to be applied in propeller design. Really, it has been popular for a long time. Problems start however, when the axial speed starts changing. Details of this latter topic were addressed in a former post at the VFS Forum.

Present animation is modelling a case when the axial speed is changing cyclically in a wide range. Actually, in real life this cyclic process doesn't happen. Here, the only purpose of using it is to show more of the nature of the resulting wind "twisting" around the propeller blades.

The **array of the vectors of the resulting wind** can be seen as an extension of the **surface of the propeller blade**. We see this surface is bending – i.e. changing twist. (Something a stiff blade will never be capable of!) Bright red shapes symbolize how sections of an ideal morphing blade shall be arranged in order to keep their alignment with the corresponding vectors of the resulting airspeed, all the time.

Diversion

It is assumed also helicopters built with the traditional arrangement of the main rotor, may profit from the introduction of blade twist control. But potentially the main beneficiaries are going to be the tiltrotors - and (outside of the VTOL industry) wind turbines.

These latter are famous about their rotor blades, which are biggest in the world, and always cause public sensation when transported from the places of their manufacture, to the places of their operation. As a rule, montage of these blades goes spectacularly too, frequently with the presence of media and even film makers.

It is known, transportation and montage/replacement of wind turbine blades are high cost operations. Although (fortunately!) this happens quite seldom, failure and destruction of these blades too does involve high costs and public attention. For the times of extreme storms and hurricanes wind turbines stop production of electricity, and feather their blades. Monolithic and stiff blades however can't be feathered perfectly. Because of their constant twist, parts of these blades will always generate lift and thrust, and also have very high drag. And - get damaged.

For wind turbines, therefore, blade twist control is important not just because of efficiency, but also for

a) the option of easier transportation (Present monolithic outer hull is replaced by the system of the proposed skeleton and modular skin. Thus delivery of the disassembled blade piece-by-piece, and montage on the spot of the final operation becomes possible.); and

b) the option of the perfect feather.

VTOL industry requires high aspect ratio rotor blades

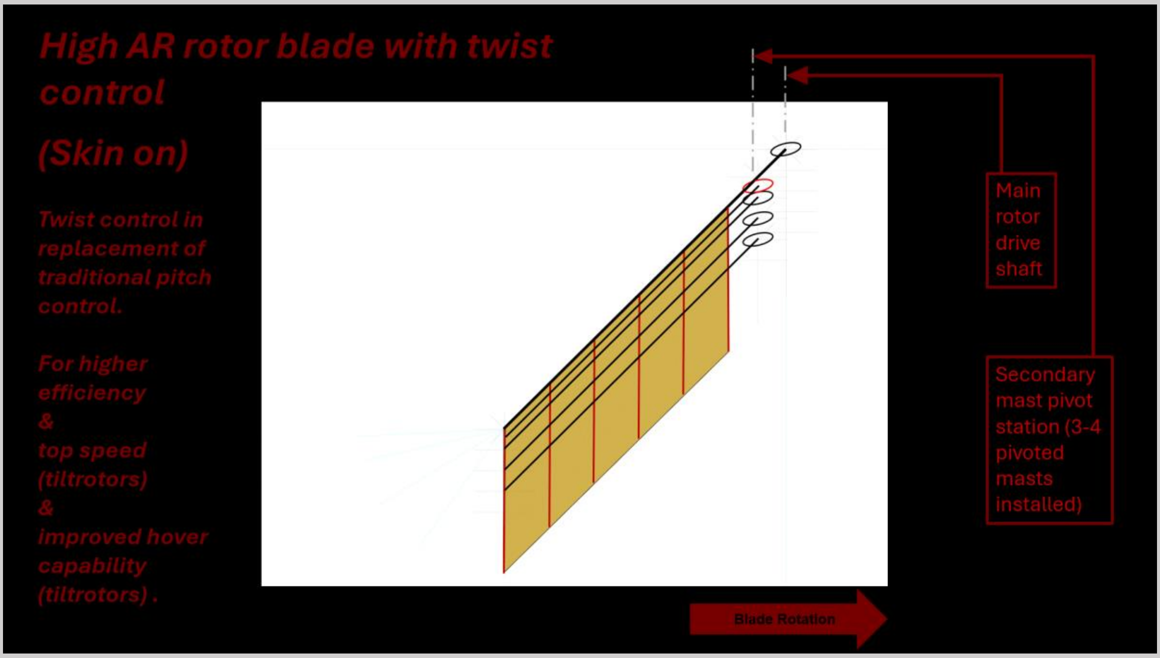
The propeller covered by the patent description has a relative low AR of the blades, characteristic mostly for GA propellers. VTOL and tiltrotor aircraft however require blades with very high AR for their rotors. For a good mechanical engineer such an adaptation (i.e. transforming the GA blade solution to one for high AR blades) isn't really a hard task. By offering a possible own solution, still, this post aims to help getting a deeper understanding of the concept.

Images in the GIFs of this post are intended to hold features of both the new morphing structure, and the well-known helicopter blades. GIF_No4. in particular, with the modified version of the pitch horn assembly, also has a special importance. GIF_No4. is key to fully understand meaning of the phrase (used also in earlier posts) that "adding twist control" to a usual blade is in fact an "upgrade" operation. It is a hint that, possibly, **present blades of a VTOL can** plainly **be replaced with** new, **twist-enabled ones**, and let the VTOL fly on right away, happily.

It is absolutely imperative though that the high-AR versions of the blades to be worked out, keep exactly the way the original (i.e. the ones described in the patent) blades twist. The mathematics describing the distribution of blade angles along the radius (i.e. the twist itself) must not change, just as the mathematics (or rather vector-geometry) of the airflow through the propeller disk will not change either. The solution suggested here does meet this requirement.

One last note on the mathematics: it uses simple, high school level trigonometry. Details can be found in the eBook.

GIF_No2.



https://stallfreepropellers.com/wp-content/uploads/2024/10/Feliratos_nyujtott_02_Tiltrotor.gif

(Click the link to play.)

How to look: *camera travels along with the blade. Stays near the tip, and is facing towards the center.*

Main eye-catcher of the drawing is the presence of a perfect feather. Morphing blades are capable of it, which is a valuable feature to provide an option for making the range of regulation wider.

Smooth transition from feather to high-twist, then to low-twist, and to very low twist statuses demonstrated. Shall be remembered too that changes of the blade surface follow the mathematical function that governs changes of the resulting speed of the airflow around the blade. All the time.

That means the **pilot will always find** one particular position/value of the blade twist, which corresponds to a **perfect alignment** with the twist of the speed vectors of the **actual** resulting wind.

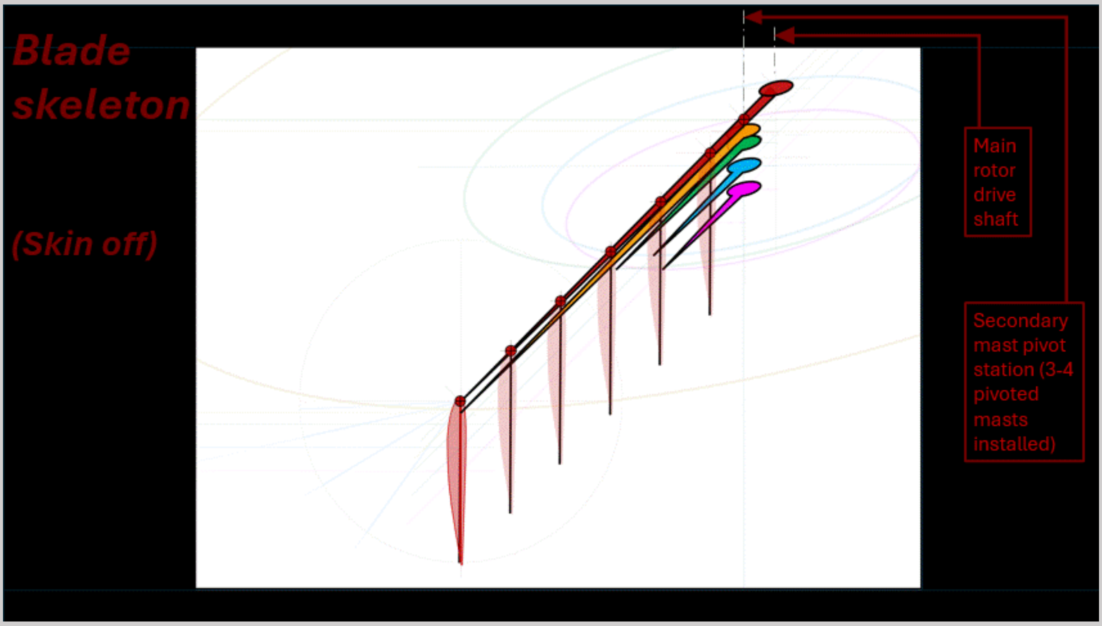
Skeleton defines how the morphing happens, and skin creates the aerodynamic surface of the blade. The two (skeleton and skin) must work together in harmony.

Skin is a special modular structure consisting of a set of skin units. These units are called scales for their resemblance to the scales of fish. They are small pieces of elastic foil with Kevlar reinforcement, and a Teflon coating for near zero friction and wear. There is no difference between skins suggested for either propellers or those for high AR rotor blades. (See more details in the eBook.)

Design secret – **Secondary Mast Pivot Station (SMPS)**:

- the need for cyclic control makes it inevitable to have an SMPS set at a nonzero distance from the main rotor axis;
- technically, SMPS's axis must be as close to the main rotor axis as possible. As the distance between the two axes is growing, so is the error in the precision of the twist (i.e. distribution of the blade angle along the radius);
- the error remains negligible until the distance is not more than about 10% of the main rotor radius (See calculated charts in the eBook.);
- for rotors and propellers without cyclic pitch control, secondary masts too are pivoted on the main rotor shaft. I.e. they have no separate SMPS.

GIF_No3.



https://stallfreepropellers.com/wp-content/uploads/2024/11/Blade-skeleton-skin-off_02_big.gif

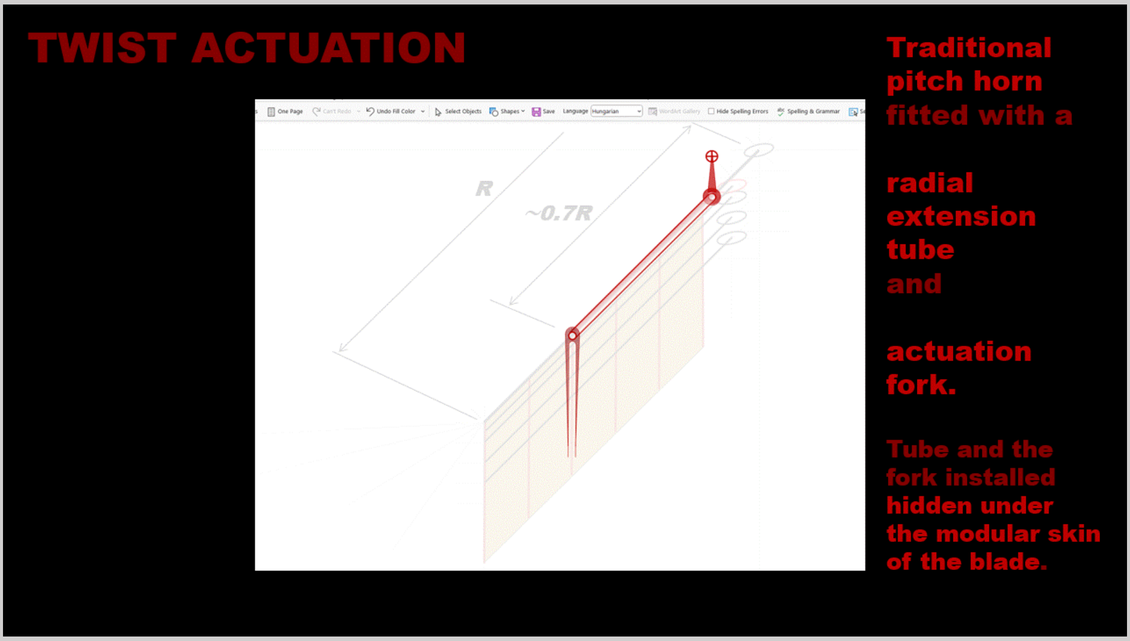
(Click the link to play.)

Showing the **blade skeleton** serves several purposes. Supporting mechanical design is one of them. Also, it is useful to know that the morphing blade consists of very simple, **non-morphing** (i.e. stiff) parts. Most parts are rods and hinges made of carbon fiber.

Hinges are depicted in exaggeration to help following the concept of motion of the parts. A very natural motion also enabling a nice, **even distribution of loads** along the blade surface.

Airfoil like shapes show locations of the hinged braces (see parts "TTM" in the eBook). Very important parts. They essentially are **forks hinged on the main mast**, and are both guiding and being guided by the secondary masts. Greatly responsible for operational integrity of the morphing blade. Their density shall be chosen in correspondence with the **number and spacing of the masts** (or rather that of the mast bases). The resulting grid shall be adjusted appropriately so the bracing of the blade surface becomes near optimal.

GIF_No4.



https://stallfreepropellers.com/wp-content/uploads/2024/11/Pitch-Horn_04_Upload_.gif

(Click the link to play.)

This GIF is intended also to be a statement or message: twist control is the same as pitch control. Just - is much better!

Important requirement: twisting moment (or torque) shall be applied to the blade surface at one single point only, of the radius R. In other words, the actuation fork of the pitch horn assembly shall be connected **to just one section** of the rotor blade. Purpose of this requirement is to save the freedom of the blade skeleton to assume a shape dictated by its own system of masts and hinged braces alone. The root purpose is, of course, keeping all the blade sections in full alignment with the direction of the resulting airspeed.

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27 October 2024, Budapest, Hungary