Old Blades Are The Problem That Prevents Tiltrotors From Using Full Potential.

New Blades Guarantee Safety. And More. A Theory.

Latest incident

News about the latest V-22 incident are summed up in the below image (Fig. 1.). Normally, of course, an engineer would look for the root causes of the accidents. As none of those are given, one can save some time by not reading the clips.

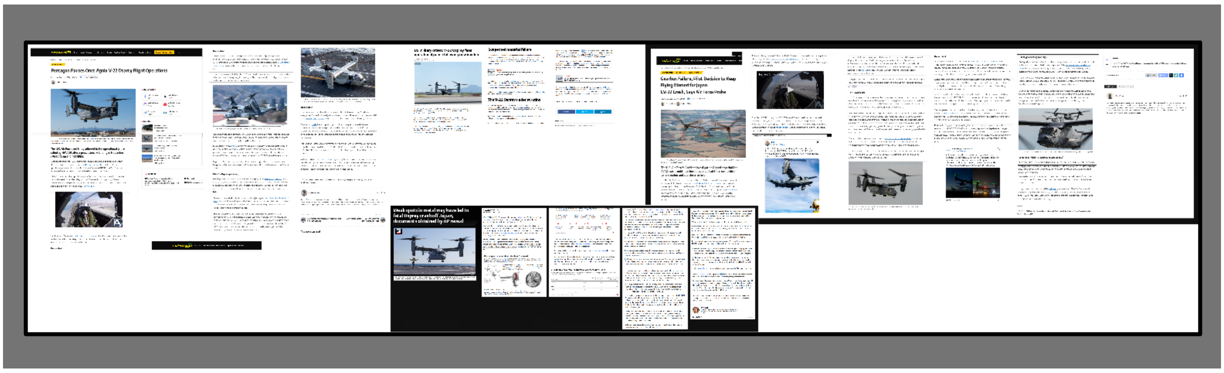

Fig. 1.

Public reports – incident press coverage.

Mystery part failures are given in detail – without conclusions. Or what is worse, with misconclusions! The “weak spots in metal” theory is promoted widely, which – considering actual production norms and quality assurance in the aviation industry – seems to be real nonsense. And even threatening innocent people getting penalized by mistake.

At the same time any notes of extreme vibrations and extremely high noise are totally missing from the press coverage. So is the VRS. As a person not having been present at the accidents, I can have only theories. There are some indeed.

VRS energy bubbles

As another reference to the above press coverage, it can safely be stated that extreme vibrations, VRS, and extremely high noise are probably present in the confidential reports, but outsiders must content themselves with the law of conservation of energy. (Which shall not be underestimated!)

Below are some clippings from a video made of a V-22 crash many years ago. (See Fig. 2.) When watching the full video, one can notice the rotors are repeatedly losing and regaining thrust. Main question is, of course, why the rotors lose thrust in the first place? Then, once regained it, why they would lose it again? Many know the answer: because of the extensive (up to and beyond 80% of the working radius!) rotor blade stall. Some more detailed explanations too are possible.

Fig. 2.

Basically, this is how parts break. But there are other options too. (1991, https://www.youtube.com/watch?v=VYeLishJ_Js)

Intensity of a VRS energy bubble is formidable. Shall be remembered that these bubbles are storing the unused part of the energy supplied by the **multi-megawatt engines**. There is of course dissipation, but the input is huge.

The bubbles store the energy in kinetic form, as chaotically whirling air. Forces applied to the rotor blades by this air mass from the outside, are chaotic too. Both in direction and in magnitude. Chances are some, otherwise normal parts in the transmission chain can break even before the blades hit the ground. Or – even when they don’t hit it at all! This latter is key, because:

a) destructive energy bubbles are created each time a VRS happens. Even in cases when there is an escape from it;

b) aerodynamic conditions within a VRS energy bubble are extreme and abnormal. Practically always;

c) Parts of the drive train – any of them - can break or get damaged in these abnormal circumstances.

Not all VRS occurrences end in a crash

Geometrical analyses of the rotor blades (see method in the eBook) indicate it is fully possible that a V-22 will meet a VRS occurrence **each time** it makes a vertical takeoff or landing. These occurrences – thanks to the strict operation rules and to the pilots' skills – are in most cases escaped "unnoticed" or at least happen without major damage to the aircraft. Still, it has been known for a long time - this is public data - that maintenance requirements of a V-22 Osprey are very high.

It is known too that using STOL capabilities of the V-22 instead of vertical flight, when possible, can be advisable for the sake of the aircraft's health.

VTOL operations always take their toll on the V-22's drive train. Therefore, referring back once more to the above news about the recent incident, **VRS always happens first**, and parts break only second. (Reports are trying to convince about the opposite. They say broken parts cause the accidents. Yes - if the VRS occurrences the aircraft escaped from during prior vertical takeoffs and/or landings, are ignored!) Seeing true sequence of the events is most important.

Engineers under high pressure - design dilemma of the stiff blades

We know, tiltrotors are supposed to fly both as helicopters and planes. They are expected to deliver the best of the two worlds: vertical takeoff and landing, hover on the one hand, and high speed cruising flight on the other. It is possible theoretically but, unfortunately, propellers of the Wright brothers have grown too old to meet the new requirements present day rotors and propellers must face.

Problems of the "old" propellers can be shown the easiest way by using their efficiency (and thrust) characteristics as functions of the axial speed.

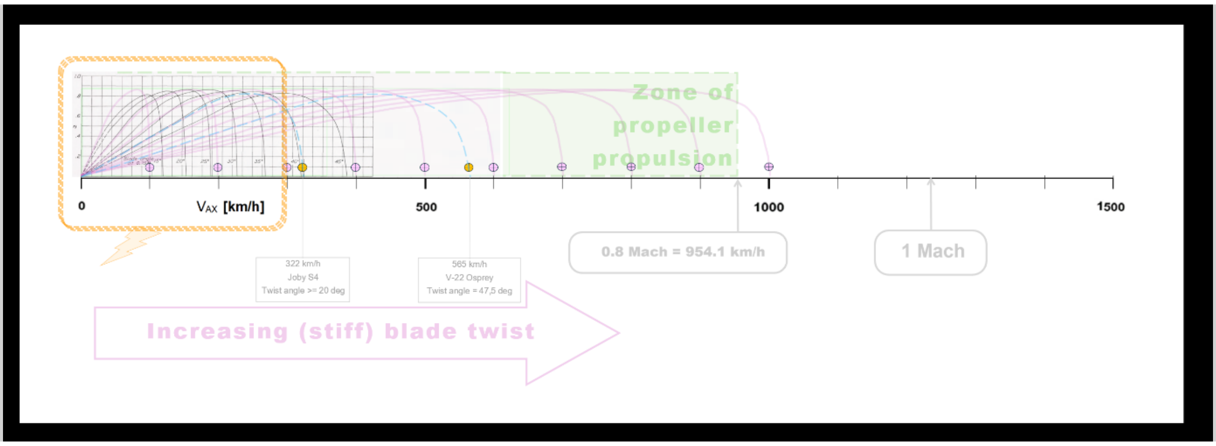

Fig. 3.

Original NACA diagrams and scale transformation (an approximation method introduced in the **2024April18 post**) were used to check rotor behavior. Precision provided by this method is sufficient to support a theoretical discussion.

Series of the pink curves is showing the options a designer has when picking top speed and design speed values for a new rotor/propeller. A 100 km/h increment of the top speed was used to build each next member of the series of the efficiency characteristics.

In traditional – stiff bladed - propeller design, when they want to increase (or lower) top speed of a new propeller, the general blade twist is increased (or lowered, respectively). Same goes for the design speed of that propeller.

See for example the propeller data of the two known tiltrotors given in the above chart, Fig. 3. Joby S4 with a 322 km/h top speed, has a blade twist a little above 20 degrees. At the same time the V-22 Osprey's rotor blades have a 47,5 degrees twist for a top speed of 565 km/h.

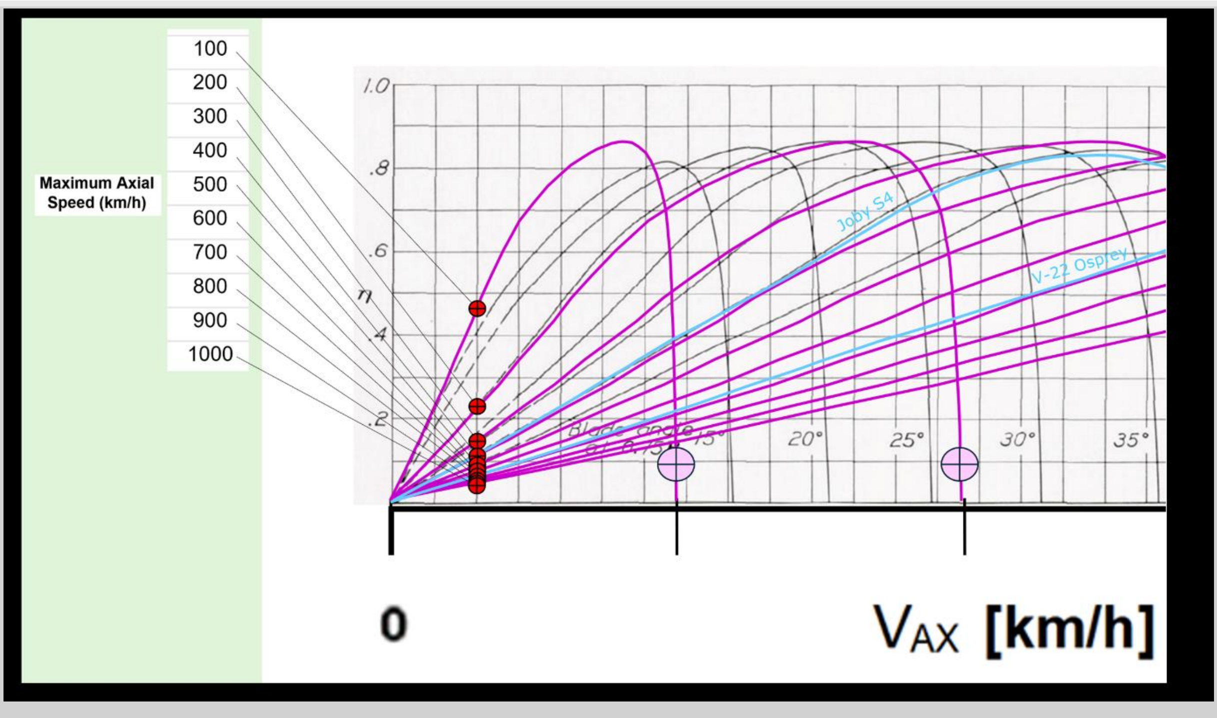

Fig. 4.

Curves clearly indicate a strong deterioration of efficiency in the zone of low speeds (vertical takeoff/landing, hover) as higher and higher top speeds are chosen for a given stiff blade. Because of stiffness these blades will have the same twist for the helicopter regime as they have for the high speed cruising flight. A tiltrotor designer's nightmare.

Once the value of the blade twist is decided, a multitude of additional geometric compensations can be applied to the final shape of the blades in order to improve quality of operation. However these improvements (efficiency level, speed range, noise etc.) as a rule, taken together can have only minor (<10%) effects. Nature of a stiff bladed rotor or propeller is decided basically by its general blade twist.

Note that at low speeds the rotors' thrust remains well above zero, quite high. This is not the reason for a crash. The problem is, because of the heavy stall, drag forces on the blades grow immensely out of proportion. They (drag forces) act in a plane perpendicular to the rotor axis. As the turbulence around rotors grow symmetry of the drag forces around the axis (left and right etc.) can be lost. When these forces are very big, their differences may become very big too. That is why in a VRS situation the rotor can unexpectedly be pushed to one side causing the aircraft tilt and lose normal position. Thus, crash becomes possible even with nonzero thrust of the rotors.

It has been shown in earlier posts (e.g. **here**) that rotor blades with variable blade twist – morphing blades – are capable to prevent dangerous blade stall both at low, and at high speeds. Exact mathematics describing nature of the morphing motion has been given too. In other words the solution for the V-22 problems exists – in theory. Prototyping and practical concept-proofing are missing, however. Considering the present crisis situation, it needs a miracle to make the actual "demand and supply" really to meet. Unless.

NASA, MIT, DARPA

When stakes are high the rule is to "send in the cavalry". Organizations like NASA, MIT and DARPA have not only high prestige but have also a documented expertise in development of morphing structures for aviation.

Additional motivation for these institutions can be the chance that a fundamentally new achievement in propeller technology will not remain limited to the VTOL industry. General aviation, and even naval transport too can become stakeholders.

Is the **product development task** fully defined? Yes. New rotor blades are needed, which shall be of the morphing type, and are capable to retain near optimal value of the AOA along the whole radius, at all speeds of the tiltrotor operation. This option was shown repeatedly in earlier posts as a real one. Such blades can guarantee both safety and efficiency.

And more than that: they (the new blades) can give a new **competitive edge** to the aircraft that will employ them first. Such as speed superiority in unprecedented VTOL situations. Not bad for the military.

Last but not least, the new blades shall be applicable to the existing aircraft as a rotor blade **upgrade**. That is mounting and removal shall be possible without requiring any major changes to the present design. Something like the one shown in the GIF of the Fig. 5.

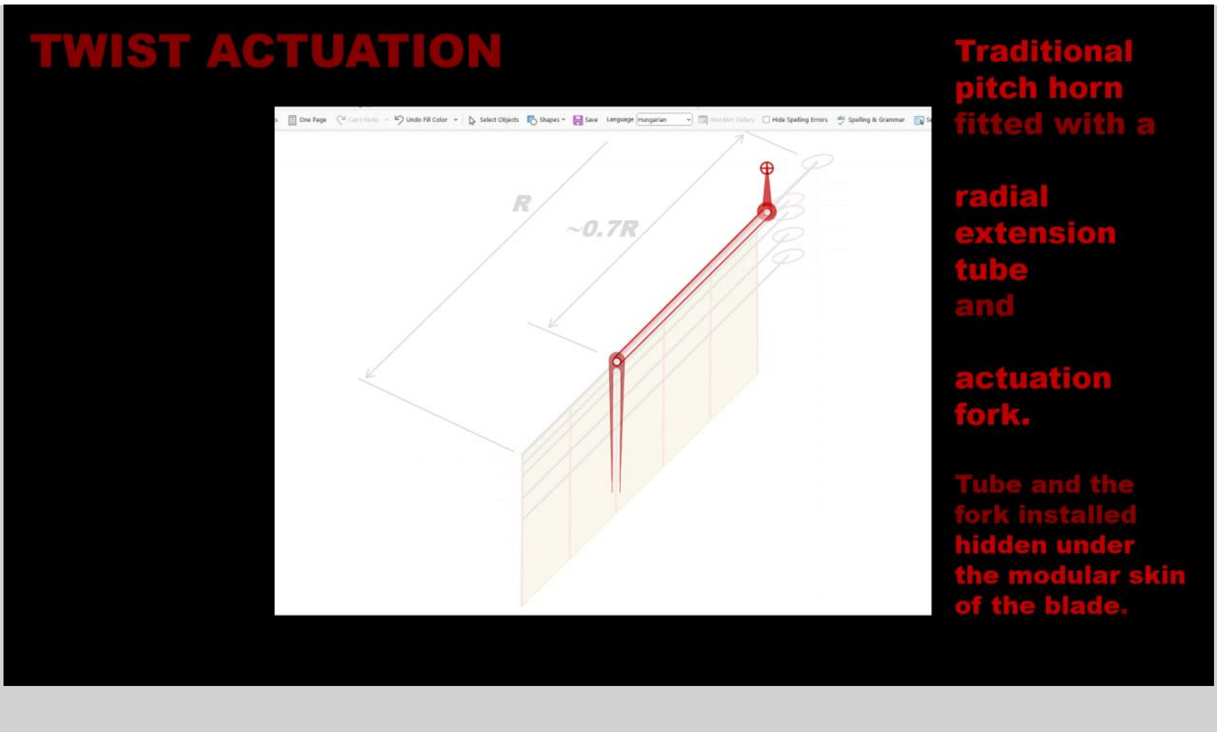

Fig. 5.

So, it is known NASA, MIT, and DARPA all have the expertise to develop suitable morphing structures in accordance with the special needs of aviation. Certainly too, they can be able to come up with the new and upgraded blades within some very attractive timeframe.

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