Comparison of Two Tiltrotor Crashes – Lessons and Guesses

Investigation documents of the 2022 eVTOL crash of Joby were published recently. The March 25, 2024 issue of the Vertical Magazine has the details. Precision of data included in the report – not so frequently found in the similar press - deserves appreciation and respect. They allow e.g. to make some analyses of your own. In hope to find out even more I am sharing thoughts for discussion.

1. Disclaimer

The below concept is built on the assumption that the crashes discussed happened as a result of rotor blade failure. But, because no official statement or other legally valid evidence in support are available on the Internet, please regard this story as just a fiction.

2. The Subjects

Grave events like accidents, as a rule hold a wealth of information to be explored in order to prevent repetition. To highlight a possible scenario of what technically has happened, a comparison is used. To compare with the Joby case (which happened during a remotely piloted, unmanned flight, with zero casualties) I picked one of the known Osprey crashes from 2017 (one with three casualties), which had both a video, and some features seemingly typical for that aircraft.

3. Tools used

Diagrams of efficiency and thrust of the rotors as functions of the axial speed are good tools to look into the actual behavior of propulsion during a flight case. Unfortunately, manufacturers of rotors and propellers have a habit of not making these charts public. Not the easy way. So, to start with, we simply have no rotor diagrams either for the Joby, or the Osprey VTOLs.

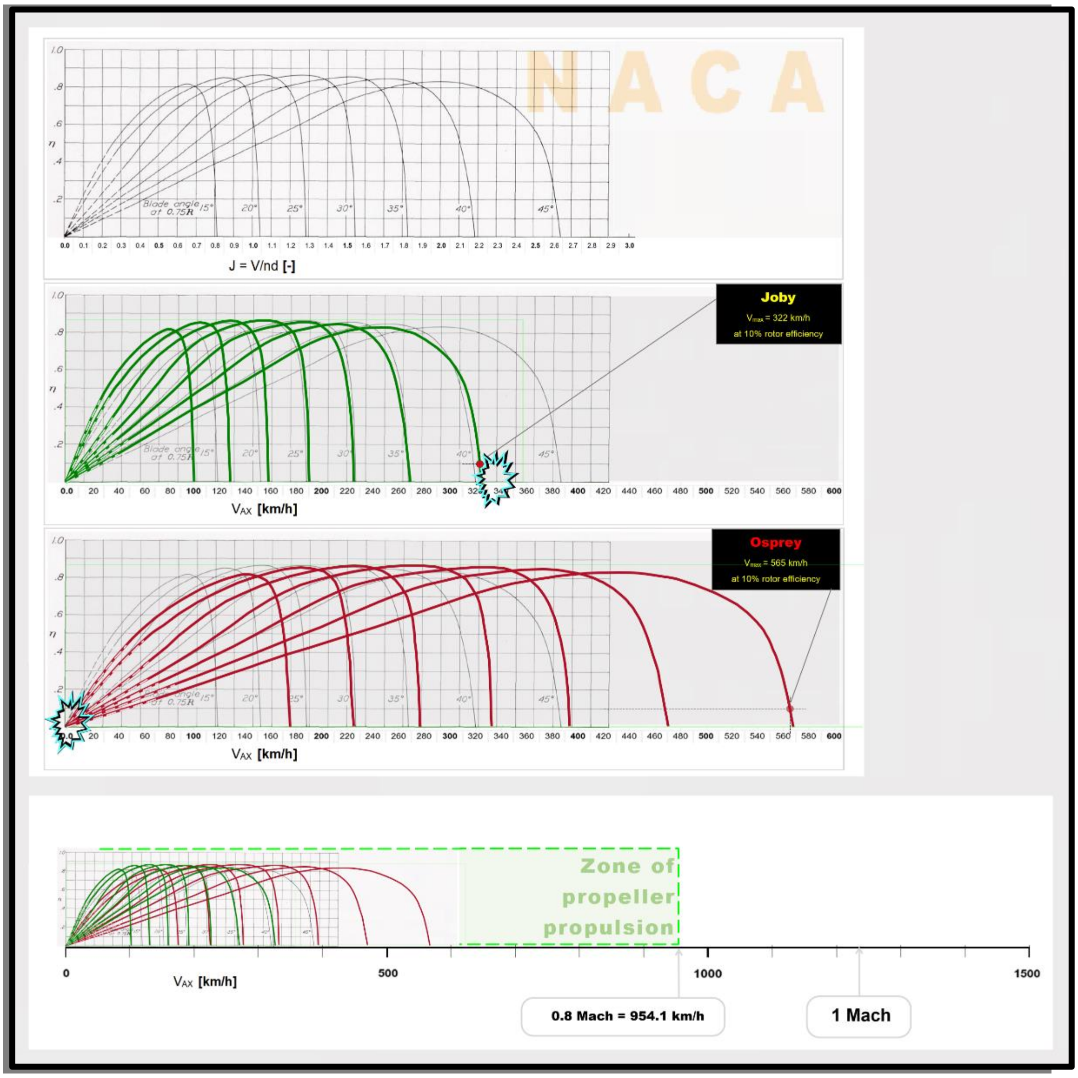
Luckily, the similarities of the curves known from the propeller theory, make it possible to have good quality approximations of these characteristics, requiring only a couple of real-life data. Degree of achievable precision will be sufficient to make some basic – but important - observations.

4. The Approximation

I have used the public NACA collections to find the best-matching efficiency and thrust-coefficient charts. The following input data were used both for the search and for the subsequent graphical approximation process:

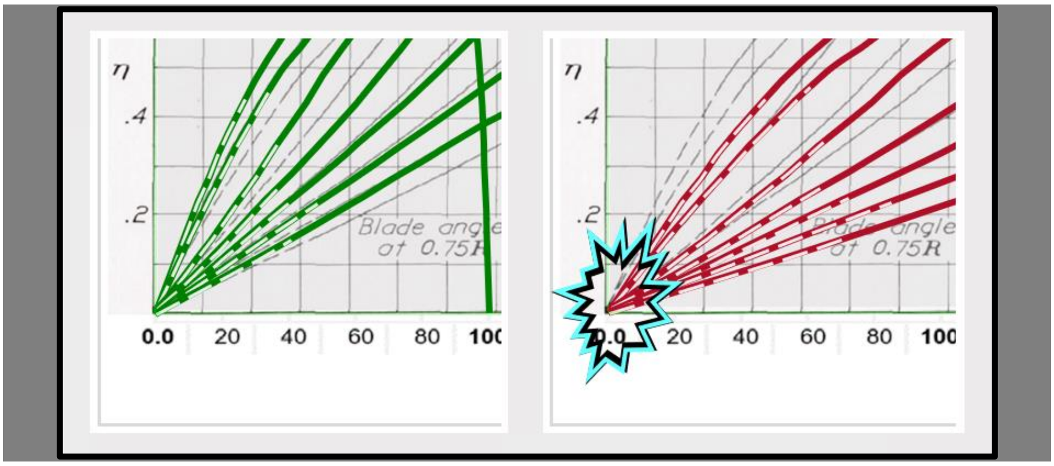
	Joby	Osprey
Rotor diameter **d [m]**	2,9	11,6
Rotor RPM at the time of the accident **n [RPM]**	744	412 (heli mode)
Rotor RPM at the maximum axial speed **n [RPM]**	744	333 (forward-flight mode)
Aircraft maximum axial speed **V [km/h]**	322	565
Aircraft axial speed at the time of the accident **V [km/h]**	335	00,00
Advance ratio at the maximal speed **J = V/nd [-]**	2,59	2,44

Finally, the selection was made. Actual test data of a 5868-9 (Clark Y section) type propeller, published in the 1939 NACA Report No 650, was used to prepare the below comparison chart.



To facilitate comparison the horizontal ADVANCE RATIO axis was converted to an AXIAL SPEED, **V_{AX}** axis, and was calibrated in **[km/h]** units.

In terms of the axial speed, spots of the crashes were indicated on the charts – respectively one for the Osprey, and one for the Joby. To see more of the low speed status of the propulsion another figure called CORNERS have been prepared too, with zoomed-in fractions of the main charts.



5. Observations: Suggested/Reconstructed Scenario of the Crashes

5.1. First about the **Joby case**.

According to the minutes referred to by the Vertical Magazine, the main cause of the accident was a series of "strong aerodynamic interactions" in connection with the "airspeeds beyond the expected operating conditions of the aircraft". The accident happened at a relatively high speed (181 KIAS = 208 mph = 334.7 km/h, axial for the rotors).

For a propeller capable to produce good thrust also at vertical lift (i.e. at zero axial speed) this must have been the upper limit of the speed range. Upper limit also means the **high-twist blades** work heavily **stalled**, with an increasing part of the outer radius getting into the regime of windmilling plus stall. (See a chart for defining blade stall status for different values of V_{AX} and blade pitch.)

The turbulence generated by a blade partly stalled (on the inner half of the radius), and partly windmilling plus stalled (on the outer part of the radius), can become quite hostile and lead to a flutter of high intensity. Chances are the initial moment of the recent accident (separation of one blade) has been a result of such flutter.

This theory is supported by the shape of the green (Joby) curves in the comparison chart. Near the crash speed the **curves go steeply down**. Meaning that only a minimal increase of speed of flight in this zone can lead to a full loss of rotor thrust. And – as propeller torque still remains nonzero here – starting from this point on, all engine power is used to generate turbulence.

Joby propulsion, however, also has a strong point in the low speed zone, quite obvious from the charts too. The CORNERS image shows the green (Joby) curves of efficiency running much higher than the etalon NACA lines run. Beside good safety, this high rotor efficiency partly explains the silent operation of the S4 eVTOL during takeoff, hover and landing. (As the main reason of silence, of course, remains the electric propulsion of the S4.)

5.2. The CORNERS image seems to be the right place to switch to the **Osprey case**.

In contrast to the Joby case, history of the V-22 has shown a rather good stability (and statistics too) at high cruising speeds (565 km/h – very high). The accident in discussion happened at low, practically at zero cruising speed. The "classic" VRS case has been analyzed and delt with many times also here, at the VFS Forum. It could be of interest still, how the transformed NACA diagram would support graphically what we knew from the reports.

Red graphs of the V-22 in the CORNERS image span much lower than the etalon NACA lines do. And – hardly half as high as the Joby lines, at the same speed. It is of interest too that the zone of the dashed parts of the graphs covers about double (up to 90 km/h) of the speed range the same does for the S4 graphs. NACA reports comment they used dashed lines in such places where direct measurement was impossible. If we check the blade stall status in the above chart, it can be understood why. A high bladetwist rotor (like that of the V-22) at zero, or near zero axial speed has all its blades partly stalled, and partly windmilling – at the same time. A very unstable status making aerodynamic testing difficult.

6. Conclusion

For Joby to remain safe it is enough to limit top speed. Is not too difficult a task to complete. Not very painful either - at least not at the first glance. (See more below!)

Unlike the Osprey. The only way to improve safety at low speeds is to **limit use** of almost **all VTOL capabilities**: no vertical takeoff and landing; no hover – especially not at low heights. Takeoff and landing shall be done in plane mode: by using runways always. Quite unhappy news.

Unfortunately, the S4 has some bad news too. Charts show it has a top speed (322 km/h) not really outstanding for a tiltrotor. Especially not if (as rumored in the press) some possible future military applications are targeted. The lower Mach-chart shows there is a lot of unutilized space for a rotor/propeller driven aircraft yet. BTW further increasing top speed can be attractive option for the V-22 too.

As stated in the introduction, all the problems discussed are connected to a rotor-blade issue. That issue (same for all problems mentioned!) can even be named as the "penalty of the stiff blade". Can be **cured by** a single-part **upgrade**, as described in the **"Business aspects…"** post at the stallfreepropellers.com website.

This latter is the good news.

Laszlo KRUPPA

2024 March

Better quality images for download here:

1. Input data table - https://stallfreepropellers.com/wp-content/uploads/2024/04/NACA-diagrams_scale-transformation_09_input-data-table.png

2. Comparison chart - https://stallfreepropellers.com/wp-content/uploads/2024/04/NACA-diagrams_scale-transformation_07_crash.png

3. Corners chart - https://stallfreepropellers.com/wp-content/uploads/2024/04/NACA-diagrams_scale-transformation_08_corners.png