USING THE H-AIRFRAME PARADIGM FOR CONSTRUCTING SEPTA-ROTOR UNMANNED HELICOPTERS

Petar Getsov

Svetoslav Zabunov

Garo Mardirossian

Abstract

Using multi-rotor unmanned helicopters for various purposes becomes a practice in the recent years, due to the increased efficiency of electrical motors and batteries and at the same time their lowering cost. Multi-rotors are applicable in a number of situations, from pollution monitoring and disaster management to scientific research.

Starting from tri-copters and quad-copters users are more and more demanding multi-rotors with larger number of propellers aiming at lower risk, higher efficiency, larger payloads, etc. Among those helicopters are machines with five, six, seven, eight or even a larger number of propellers.

The current paper presents a comparison between the standard sever-rotor unmanned helicopter in "star"-configuration and a new design again with sever rotors, but using the H-airframe paradigm. The proposed design has a number of benefits that are disclosed in this publication.

Keywords: Unmanned multi-rotor helicopter, Multi-rotor helicopter airframe, Quad-rotor helicopter, Septa-rotor helicopter

Introduction

Recently, users of unmanned helicopters have a growing demand of carrying a larger payload onboard such as scientific equipment, cinematographic cameras, etc. A solution is to increasing the number of rotors. Another way of raising payload capabilities is to use larger propellers, but thus the risk of injury increases dramatically. Hence, in the last few years users are looking for platforms with larger number of propellers than the wide spread helicopters with three and four motors.

Wide spread are hex-rotors and octo-rotors and to a lesser extend quint-rotors and septa-rotors. All these are found mostly in “star”-configuration (see Fig. 1).

The current article presents a novel design of a septa-rotor unmanned helicopter and compares its qualities with the well-known “star”-configuration seven-rotor helicopter.

Septa-rotor helicopter based on the H-airframe

Septa-rotor helicopters are most wide-spread using “star”-airframe (see Fig. 1). This airframe shows a number of drawbacks that need a solution. These are:

1. Non-uniform propeller thrust causing non-uniform power distribution among motors.
2. Inefficient yaw turning manoeuvre (see Fig. 2).
3. Heavy airframe, due to long beams and only one connection point at the centre of the star configuration.
4. Limited room on the airframe for mounting modules.

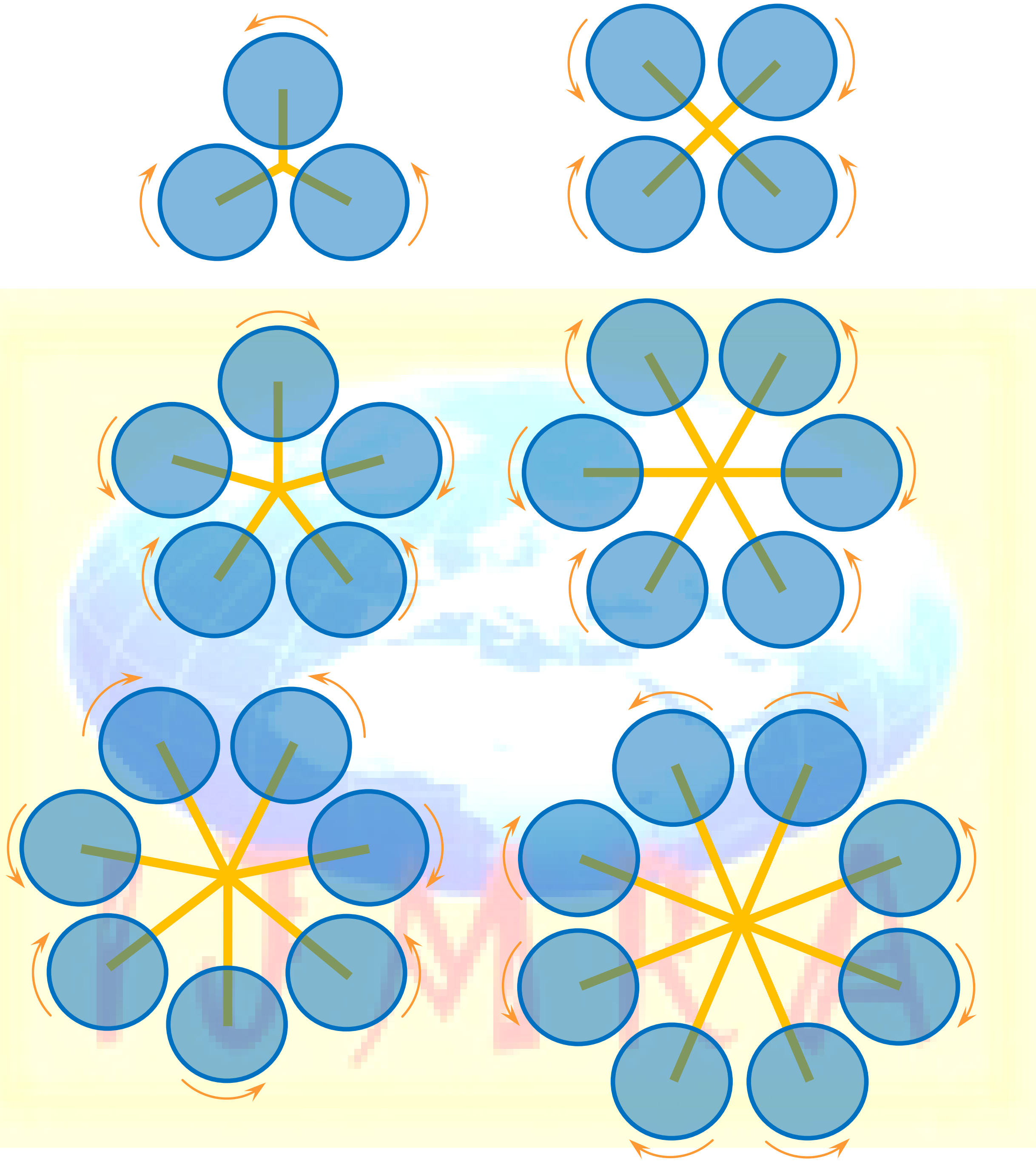

Fig. 2. Classic "star"-airframe based multi-rotor helicopters with three to eight rotors

5. Camera view is obscured by propellers.

6. Large airframe in the horizontal plane with plenty of propeller-free surface at the middle of the helicopter.

The non-uniformity of propellers thrust leads to unbalanced stresses to the airframe, using motors with different power ratings and weight, inefficiency of propeller usage and heavier beams for holding the heavier motors.

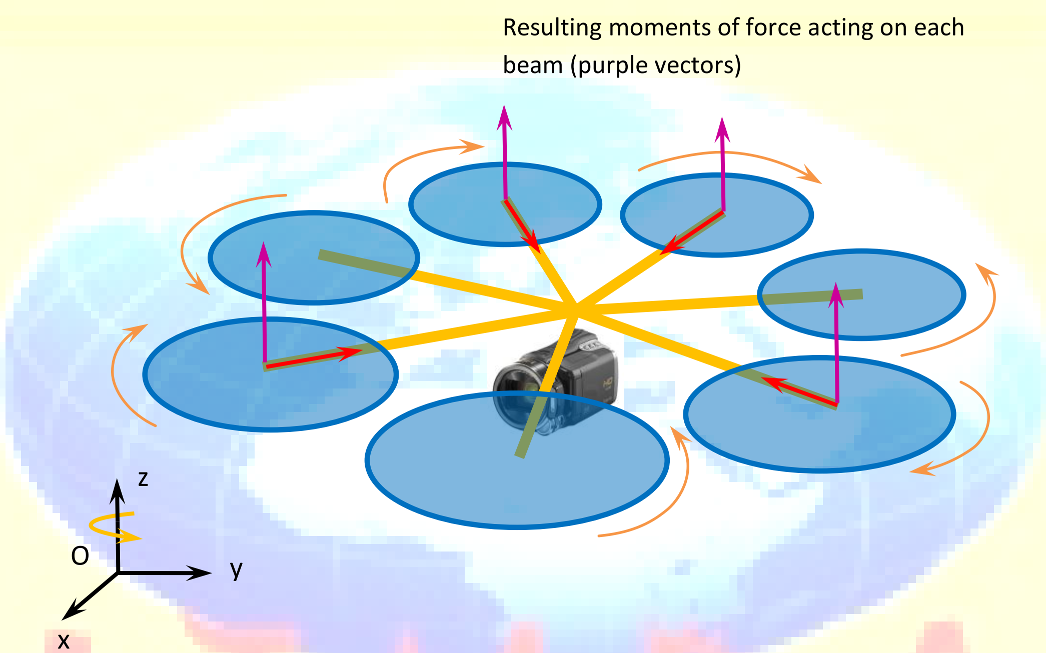

Figure. 2. Left yaw turn of a classical "star"-airframe septa-rotor helicopter

Further, the inefficient yaw orientation change manoeuvre is due to having the turning propellers create horizontal force vector components $\mathbf{Q}_i$ against the airframe centre (see red vectors on Fig. 2 and Fig. 3). These forces almost cancel out and their action wastes power. On Fig. 3 is presented one of the four propellers used to perform the yaw manoeuvre.

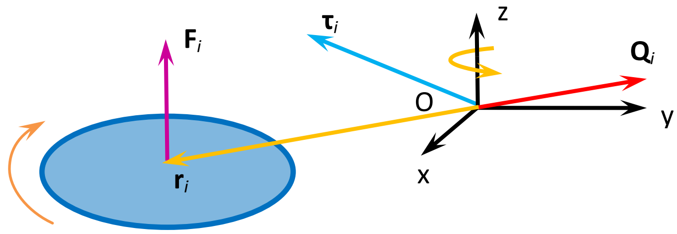

Figure. 3. One beam holding one rotor

To generalize the situation propeller is index with the variable *i*. The thrust force vector of the propeller with index *i* is almost vertical and is denoted with $\mathbf{F}_i$. Torque vector $\boldsymbol{\tau}_i$ that this propeller created against the star-centre equals:

$$(1.)\ \boldsymbol{\tau}_i = \mathbf{r}_i \mathbf{F}_i^*$$

In order to perform the yaw turn the helicopter need not to incline and thus the resulting torque generated by the turning propellers should be zero:

$$(2.)\ \sum_{i=1}^{m} \boldsymbol{\tau}_i = \sum_{i=1}^{m} \mathbf{r}_i \mathbf{F}_i^* = 0, m = 4$$

We need to remind that all beams have equal length:

$$(3.)\ |\mathbf{r}_i| = r_i = r$$

The thrust force normal is almost vertical:

$$(4.)\ \frac{\mathbf{F}_i^*}{F_i} = \mathbf{n}_i \approx \mathbf{z}$$

But not fully vertical hence it creates a horizontal component that depends of the thrust force with the approximate equation:

$$(5.)\ \mathbf{Q}_i \approx \frac{\mathbf{r}_i kF_i}{r} \Rightarrow \mathbf{r}_i \approx \frac{\mathbf{Q}_i r}{kF_i}$$

We me write that the sum of all horizontal components is almost zero:

$$(6.)\ \sum_{i=1}^{4} \boldsymbol{\tau}_i = \sum_{i=1}^{4} \mathbf{r}_i \mathbf{F}_i^* \approx \sum_{i=1}^{4} \frac{\mathbf{Q}_i r}{kF_i} \mathbf{F}_i^* = \frac{r}{k} \sum_{i=1}^{m} \mathbf{Q}_i \frac{\mathbf{F}_i^*}{F_i} = \frac{r}{k} \left(\sum_{i=1}^{m} \mathbf{Q}_i \right) \mathbf{z}^*$$

$$\frac{r}{k} \left(\sum_{i=1}^{m} \mathbf{Q}_i \right) \mathbf{z}^* \approx 0 \Rightarrow \sum_{i=1}^{m} \mathbf{Q}_i \approx 0$$

Although not completely zero, the horizontal force creates no torque because all $\mathbf{Q}_i$ vectors are parallel to the radius vectors. These horizontal forces have no beneficial impact to the yaw manoeuvre but do waste power.

The next drawback is due to propellers being too far from the centre thus forming a large airframe that needs rigid heavy beams. The large airframe wastes room between the propellers.

Just like all "star"-airframe helicopters, the septa-rotor "star"-helicopter has concentrated payload batteries and electronics in its centre and mounting all this stuff at the centre of the airframe is very uncomfortable and inflexible. If the septa-rotor is to carry a camera, then camera view is shadowed by the propellers.

The solution of these problems may be offered by the H-airframe paradigm, used in a number of designs created by the authors. The initial design, using H-airframe is shown on Fig. 4.

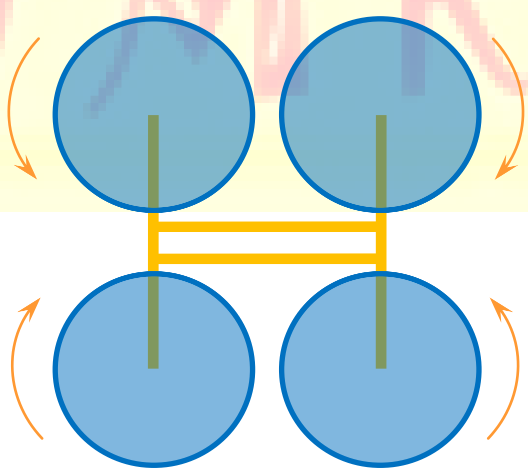

Figure.4. General view of an H-airframe quad-rotor helicopter (model XZ-1)

When this approach is applied to septa-rotor design a model with very interesting features is constructed and most importantly all the listed drawbacks inherent to the "star"0-airframe septa-rotor are eradicated. The novel design is shown on Fig. 5. It consists of six propellers mounted on three beams by counter rotating tandems and the beams are them mounted in a fuselage. A seventh larger motor is mounted in the centre of the airframe having a propeller under the airframe with diameter roughly square root of two times larger than the other propellers. Let's discuss how this construction removes the drawbacks that were found in the "star"-airframe septa-rotor helicopter.

Non-uniform propeller thrust is not present anymore – the construction is symmetric by thrust.

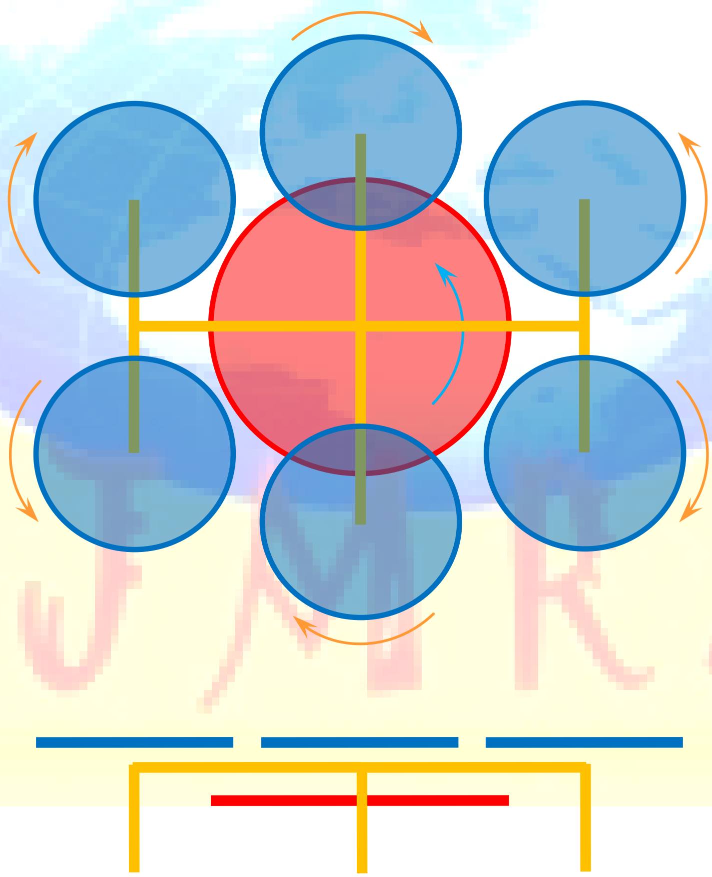

Figure. 5. General view of an H-airframe septa-rotor helicopter (model XZ-5A)

The yaw manoeuvre is much more efficient (see Fig. 6). Now the formed horizontal vectors (red vectors on Fig. 6) do create a torque and do not cancel out. This torque is in the direction of the desired yaw turn, thus making the yaw turn faster and performed with less power.

The airframe is lighter and more rigid, while the propellers are closer to each other efficiently using the surface of the airframe. This fact makes the airframe and the helicopter with narrower width capable of entering smaller openings. The larger propeller is between the smaller ones and thus is kept away from the outer line of the airframe making the helicopter lesser likely to cause injuries and damage to people or objects.

The fuselage enables the user to mount modules with comfort and the camera now is mounted at one end of the helicopter, not in the middle, thus leaving its objective view not obscured by the propellers as shown on Fig. 7.

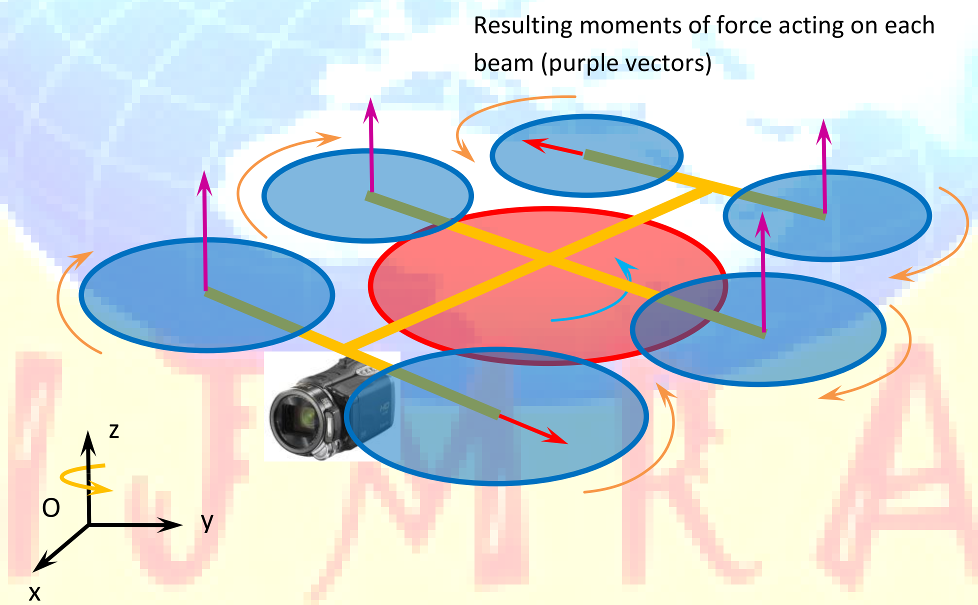

Figure. 6. Left yaw turn of XZ-5A

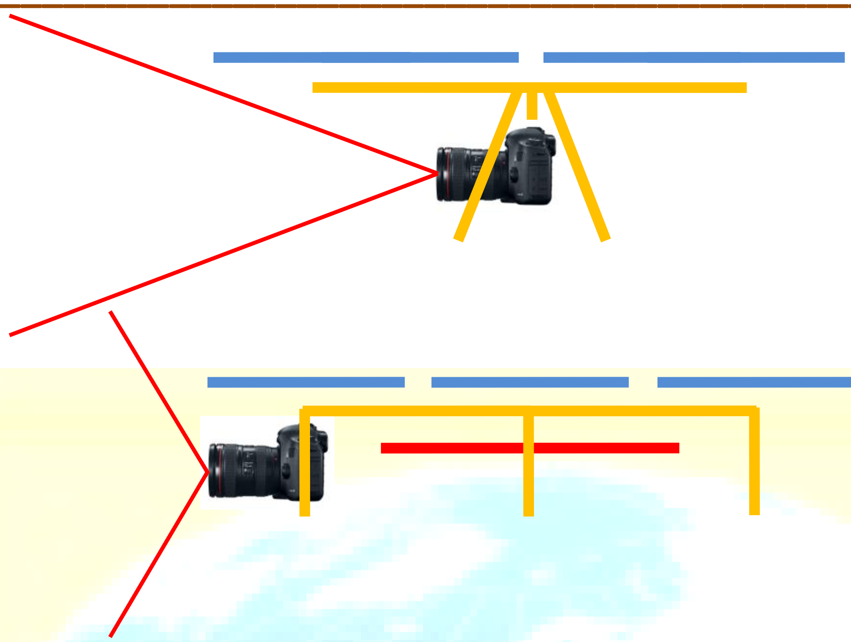

Figure. 7. Side view of "star"-airframe hex-rotor (top) and XZ-5A (bottom). The better camera position of XZ-5A is well pronounced.

Conclusion

As consumers and researchers are demanding more capable of payload lifting helicopter with better efficiency and lower accident probability the multi-rotor unmanned helicopters with more than four rotors are gaining prominence. Septa-rotor unmanned helicopters using the wide-spread "star"-airframe structure are plagued with problems and the novel design disclosed in the current paper solves these issues while offering benefits unattained by other "star"-airframe multi-rotors with six, seven or even eight rotors.

Authors are continuing their work on multi-rotor helicopter designs based on the H-paradigm in order to improve existing constructions and offer novel models encompassing features not achieved by the existing constructions.

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