MORPHING WING WITH SKIN DISCONTINUITY, KINEMATIC CONCEPT.

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Abstract. This paper describes novel discontinuous morphing flying wing concept, which despite its relatively simple design, has not been previously used. Potentially it can combine advantages of wing morphing without challenges of structure elastic deformation. Proposed wing structure has modular construction formed by rigid, separate segments, pivoted around swept spar. This paper presents preliminary investigation of wing kinematics on conceptual design level. Project assumptions, next steps and expected results are briefly presented.

Keywords: discontinuous morphing, nonlinear wing twist, flying wing.

1 Introduction

The idea of morphing aircraft structures is not new and had already been implemented (from very beginning of powered flight) by Wright brothers, to twist the wings for roll control. It was presumably based on the bird' wings observations which are still the most advanced example of morphing wings [1] to date. The main drive to use morphing is to improve the flight performance during off-design conditions [2]. For the same reason special aerodynamic devices (such as flaps and slats) are added to wings structures. Although these devices are already extremely effective in their function they are only locally applied (part of wingspan or chord), therefore cannot replace fully morphing wing. But in literature it is not well-defined how to clearly distinguish these devices from fully morphing concept. There are many overlapping definitions of morphing aircraft, with common factor of using technologies that enable significant geometry modifications for:

- Possibility to alter flying characteristics to improve performance and controllability,
- Real-time multipoint performance optimization (by NATO RTO Technical Team).
- Multi-role platform with possibility of substantial state change, with innovative design integrating advanced materials, actuators and flow controllers (by DARPA).
- Possibility to optimally adapt to each flight condition to achieve maximum efficiency and full controllability [3].

There is however a different approach presented by M. Ajaj et al. [4] which suggest a more generic categorization based on the functionality, operational envelope and application. It is proposed to define two types of morphing: discrete and continuous. First would include well established technologies such as landing gear, flaps, slats etc. Second is defined as “a single system that can provide multiple functions, in a continuous fashion along a mission, and is capable of carrying the various flight loads that the airframe is exposed to” [4]. The author will present his approach to morphing concept and its definition in section 1.2.

1.1 Stat of The Art

From 30's to early 80's researchers were studied extensively the possibility of additional wing adaptation possibilities by changing the basic wing parameters:

- Sweep - the most common of them and used in fighters: F111, F14, MiG23, Su24 and in bombers: Su71G, Tu160, B1;
- Span - the MAK-10 or glider FS29;
- Inclination angle in carrier-based air superiority jet aircraft F8;
- Cord in the experimental IS1.

All of these solutions were achieved using a heavy and complex mechanisms, it didn’t require elastic deformation of the wing structure. This first flexible solution appeared in the 80s when suitable flexible materials appeared together with the first electronic flight control systems, capable of automatic control of wing geometry change (morphing). The first example was funded by NASA, program called Mission Adaptive Wing [5], where the wing airfoil was able to changed its camber, while maintaining the continuity of wing skin (due to flexible skin material) Figure 1. The flight test data showed a drag reduction of around 7% at cruise to over 20% at an off-design condition.

Figure 1 (source: www.nasa.gov) a) MAW concept b) AAW concept

A decade later NASA founded another program called Active Aeroelastic Wing (AAW) to investigate proprieties of wing twisting, similar to the concept of the Wright brothers, to control roll angle on a modified F18 fighter plane. Less rigid wing construction allows for aeroelastic deformation, produced by aileron and leading-edge flap deflection. The aircraft successfully proved the viability of the concept in full scale during roll maneuver testing in 2004–2005.

The rapid progress in new technologies has resulted in the design of a new class of materials – called SMART, whose dimensions may be largely modified in a controlled fashion by external stimuli, such as electric current, (piezoelectric materials), temperature (shape memory alloys) and many others. New materials possibilities of elastic deformation, initiated a real explosion of studies on continuously morphing. These resulted in experimental morphing structures shown in Figure 2 such as: MFX 1 with variable sweep and span [6], Gull Wing with variable dihedral angle [7], variable twist in small UAV constructed in University of Florida [8], variable sweep in RoboSwift made by Delft University, and many other structures, which investigated morphing of almost all wing design parameters

However, it should be noted that for 142 continuously morphing aircrafts collected by S.Barbarino [9], only 8 (6%) used morphing mechanism for integration of some flight control functions with flight performance optimization, and none combines full control and flight optimization. It is very important difference, since separation of control functions from flight performance optimization, requires additional mechanisms and therefore bigger weight penalties.

Lack of suitable solutions is caused by conflicting demands on material properties, which should simultaneously be capable of withstanding the aerodynamic loads, and also able to change radically its shape. For this reason, current research in morphing technology focuses primarily on the development of high-energy actuators and elastic wing structure and flexible skin to resolve these problems.

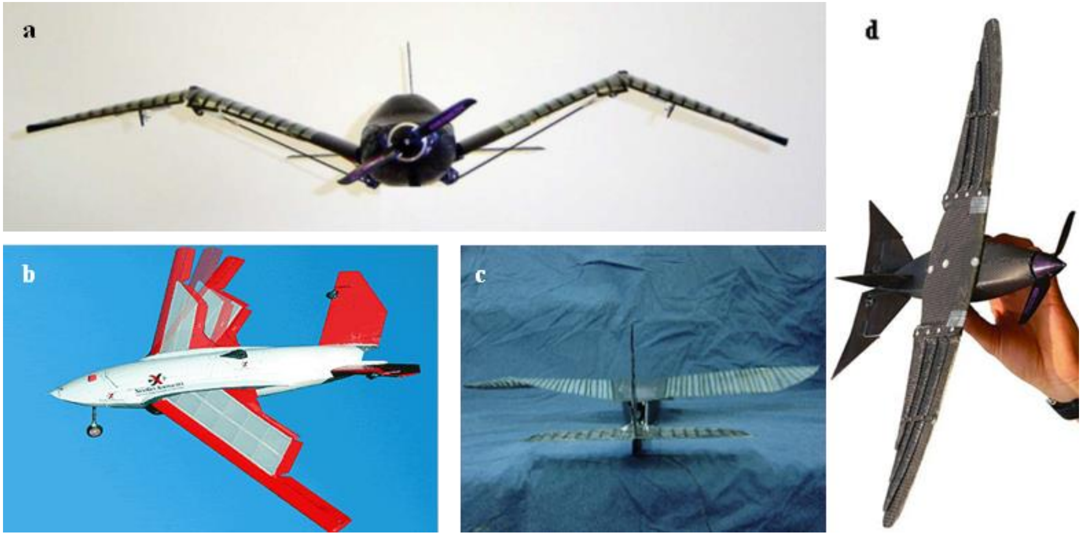

Figure 2 Examples of experimental morphing wings:

a) Gull Wing [7] b) MFX1 [6] c) University of Florida [8] d) RoboSwift (www.robosiwft.nl)

1.2 Discontinuous Morphing

The proposed novel construction of the discontinuous morphing flying wing, despite relatively simple design, has not been previously used as wing structure in such configuration. It is formed by individual, rigid segments without shared or continuous skin (Figure 3). During flight, segments are rotated against each other, effectively changing nonlinear wing twist. It would be the only mechanism used to create desired spanwise lift and drag distribution for control and performance optimization. It is estimated that each semi span-wing will contain from 10 to 15 segments (Figure 4).

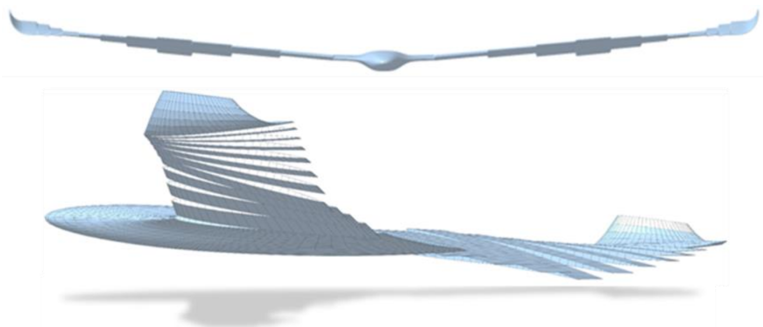

Figure 3 Morphing tailless aircraft

This wing structure may escape some definitions of morphing (presented in section 1), due to its skin discontinuity. Indeed, its construction reassembles more multi flap control system than ambiguous morphing wing concept. However, based on functionality, such structure meets the criteria of so praised continuous morphing. In fact, it integrates all control function (pitch, roll and yaw) with performance optimization in continuous fashion only by changing multipoint wing twist distribution. Even though, to differentiate it from continuous and discrete morphing definitions, author will use term: ‘Discontinuous Morphing’.

Obviously, continuously changing aircraft skin without any discontinuities will generate less drag during flight than its discontinuous counterpart. But taking into account current state of material technology, advanced continuous morphing solutions are yet to come. It is worth noticing, that previously mentioned birds' wing, as an unmatched example of morphing, also lacks surface continuity. It is rather composed of dozens of flight feathers that are independent and quite rigid structures, which are only together forming wing surface. Although similar, presented solution doesn't work on the same principle as bird's wing, since it doesn't have to provide propulsion (and other living organism functions), but potentially can have desirable flight capabilities.

2 Multipoint distribution of the wing twist

The concept of changing flight parameters by adaptable wing twist is not new and has been used in many applications. But very few have used it as the only means of flight control and, at the same time, for performance optimization as revealed in "Review of Morphing Aircraft" [9]. There was one exception, however; in extensive study on morphing swept flying wing (see Figure 7) conducted by R. Guiler [10], it was proven that wing twist change was an effective mechanism for roll, yaw and pitch control. Additionally, it has shown the potential for significant improvements over its conventional tailless aircraft equipped with elevons, in terms of efficiency and improved lift over drag ratio. Unfortunately, exploited mechanism for twist distribution was very rudimentary (as explained in section 3.1) and it is not adequate for performance optimization.

Discontinuous morphing wing, however, lacking continuous skin will most likely, produce much more vortices than its continuous counterpart, making it very difficult to predict its lift over drag ratio. Double delta wing produces a leading edge (LEV) vortex pair that mutually interferes with each other, greatly increasing its lift and maneuverability [2]. It is expected that similarly to double delta, presented concept will generate even more LEVs, which potentially can improve its performance.

Wing with that many degrees of freedom has never been investigated before, according to the author's best knowledge, and can offer new capabilities especially when combined with modern automatic control system.

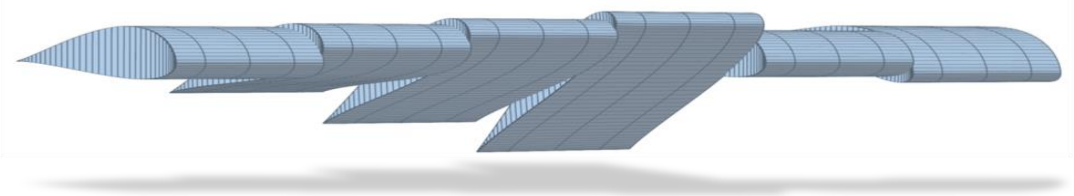

Figure 4 Wing front view, few segments deflected by 0°, 5°, 10°, 15°,0°, -5°.

Classical approach to flight control law depends on reduction of coupling between pitch, roll and yaw motion. It is based on classical aircraft concept, where control functions, required for sustained flight, were physically separated. Such approach greatly simplified control law and it was essential for first generation of flight computers. But modern automatic control systems due to their enormous computing power can easily use more complicate problem of coupled control surfaces, as in presented configuration, to enhance agility and operational performance of such an aircraft.

It is worth noticing (Figure 4) that present concept, although similar to multi flap solution, is in fact more like multi stabilator system e.g. all-moving tail. The difference is that flap occupies only small part of wing chord while stabilator entire one, rendering it much more efficient. Consequently, expected deflections of discontinuous morphing wing's segments, for flight control and performance optimization, are much smaller than conventional elevons and flaps.

The expected better flight stability over reverence aircraft (section 2.1) through active wing adaptation can eliminate vertical stabilizers, further reducing friction drag. Moreover, the energy level required for the morphing control, in comparison to the continuous morphing through elastic deformation, remain almost as low as in the case of non-morphing solutions.

2.1 Reference Aircraft

Stable flying platform is being developed currently at WUT, in the form of a conventional flying wing presented on Figure 5. It will be used as initial configuration and reference point for the discontinuous morphing wing. Initial conceptual analyses were performed and included: recognizing potential needs of the future user, propulsion type selection and sizing, estimation of the basic parameters of the aircraft. To improve the design numerical optimization was performed based but not limited to enhanced cruse duration.

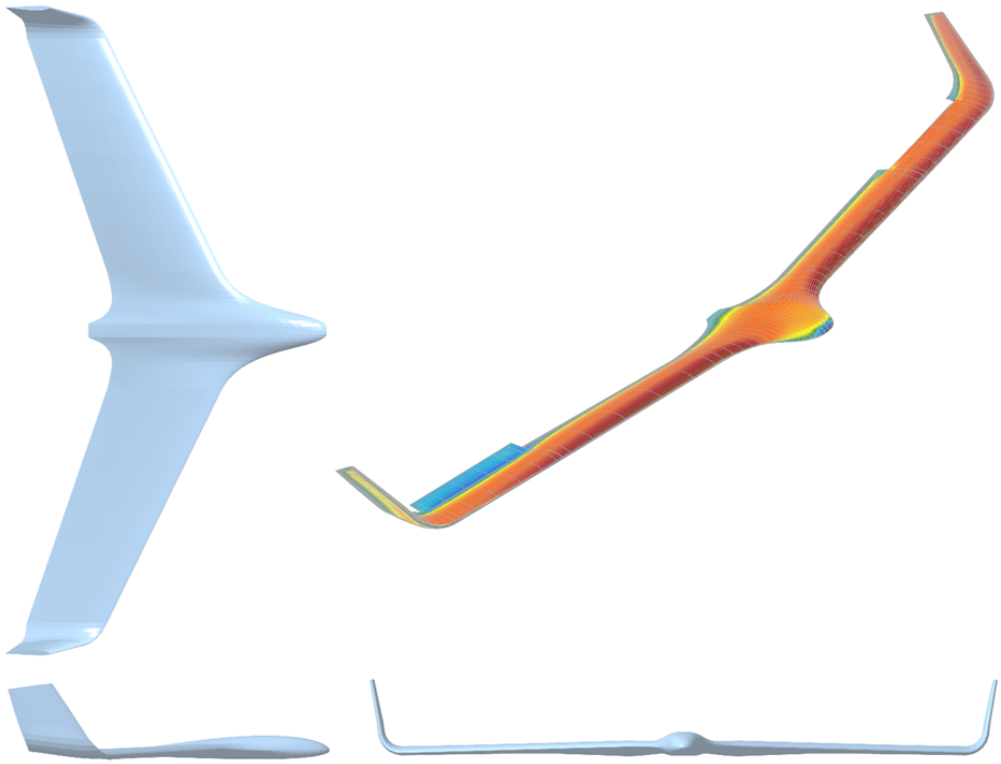

Figure 5 Reference tailless aircraft, wing span = 2.5 m, MTOW = 7kg.

3 Discontinuous Morphing Wing's Kinematics

It was decided that prior to numerical investigation, mechanical solution of such flying structure has to be firstly developed to test its kinematic and aerodynamical properties in the wind tunnel. Results will help to perform optimization, which will determine number and width of the wing segments together with other parameters of the moving parts forming the structure of the morphing wing.

To performed comparative analyses, presented morphing wing need to have the same geometric parameters i.e. aspect ratio, sweep, twist and dihedral as reference aircraft outlined in 2.1.It shows substantial sweep angle, almost 30°, which together with 10% thick airfoil, limits possible main spar position, its dimensions, and number of segments per semi wing.

3.1 Geometric Constrains

To provide each segment with variable angle of attack (AoA) or more precisely with variable incidence angle, it has to form a joint with wing's main spar. In this case it will be revolute joint with only one degree of freedom (DoF). To constrain this linkage (segment and spar) to rotational displacement only, it requires a line in the rotating segment to remain co-linear with a line in the main spar, and a plane perpendicular to this line in the rotating segment maintain contact with a similar perpendicular plane in the main spar. Mentioned line is the linkage rotation axis and the plane is the segment's rib (Figure 6).

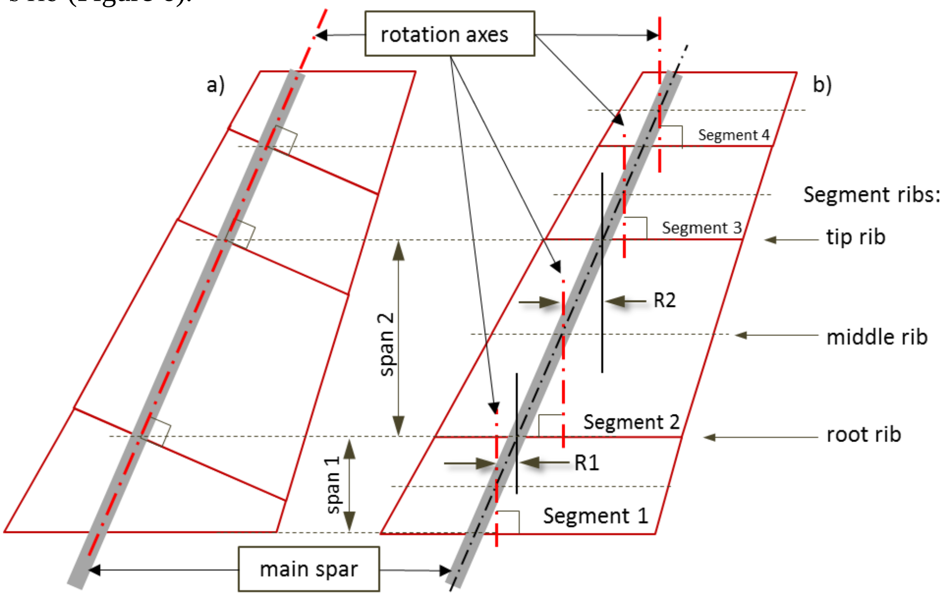

Figure 6 Wing segments' rotation axes: a) concentric b) parallel

The obvious solution is depicted in Figure 6a., where segment' rotation axes are collinear with main spar. Although it satisfies outlined revolute joint criteria, unfortunately, aerodynamically it does not make any sense, due to segment exposed at an angle to the air flow, when rotated. However, there is a workaround: covering wing segments by continuous elastic skin as depicted in Figure 7, [10]. In this solution segments are rotated by bent actuation rod (eccentuator) connected only to tip segment. Although full flight control has been provided by this solution, twist distribution control was limited to the pattern, provided by rotation of constant shape eccentuator [10].

Figure 7 R.Guiler morphing swept wing [10]

Second solution presented in Figure 6b requires that segment' rotation axes are not collinear with main spar. Contradictory to solution showed in Figure 6a, all segments are now streamlined with the flow, making it preferable solution, as it creates less drag. This linkage satisfies, as well, revolute joint criteria of having one DoF but not without some challenges.

When describing movement of two objects in relation to each other, it is important to define which frame of reference (FOR) is used. In this case there are two possible FORs: spar's FOR where segment is rotated around stationary spar (Figure 8b), and segment's FOR where spar is rotated around stationary segment (Figure 8a). Both FORs will be used to simplify description and save space.

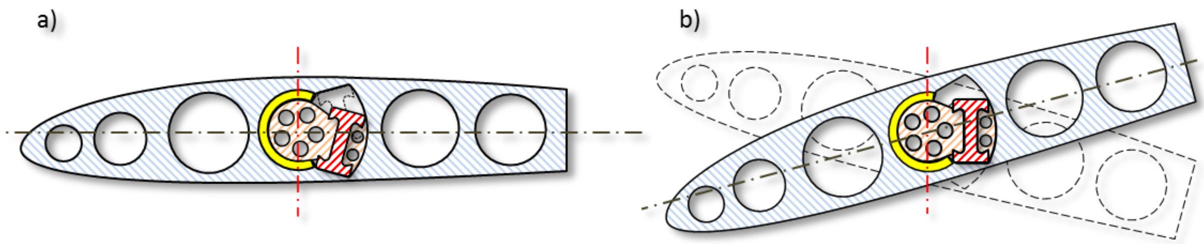

Figure 8 Reference frame: a) segment's FOR b) Spar's FOR

Since segment rotation axis is not collinear with spar center line, relative spar rotation (i.e. in segment's FOR) inside segment will require adequate space within segment itself. In other words, dimensions of the opening (Figure 9b and c) "cut out" by the spar in segment depends on spar cross section (Figure 9a), segment span (Figure 6b) and range of required angles of attack (Figure 9b, c).

As depicted in Figure 6b, the relationship between the segment's span and the radius of spar rotation (in segment's FOR) is directly proportional (R2> R1 for longer segment span). Consequently, the relationship between the radius of the spar rotation and the achievable range of the AoA, for a given thickness of the profile, will be inversely proportional; i.e. the greater the segment's span (less segments in the wing), the smaller the range of achievable of AoA.

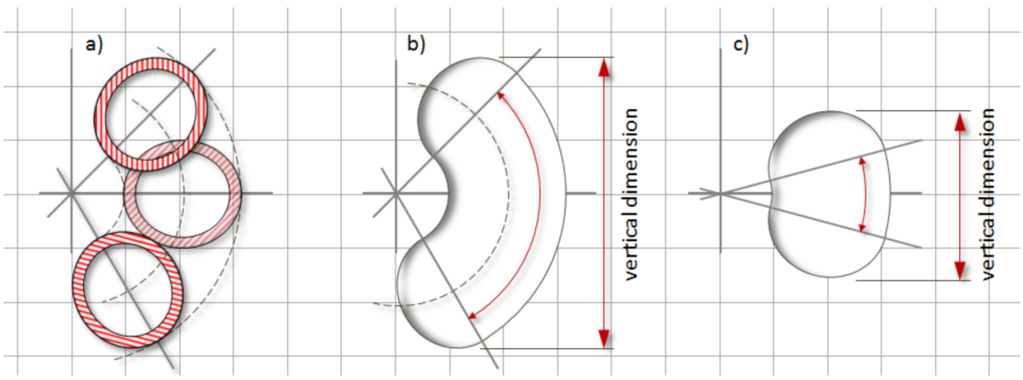

Figure 9 a) Tubular spar rotation in segment's FOR: b) from -45° to 60° c) from -15° to 15°

Figure 10a shows the position of main spar against segment root rib for rotation of 15°, 0° and -15°. It is worth noticing that due to eccentric type of main spar rotation, it rotates from upper wing skin for +15° to lower skin for -15° for root rib and opposite for tip rib.

Figure 10b shows cross section of wing segment at its root, middle and tip cross section at 15° AoA. Segment rotation axis is positioned after main spar for segment's root and before it for tip. Consequently, for the same AoA main spar is closer to wing upper skin for segment's tip section and closer to lower skin for root section. It is important observation, as neighboring segments, or rather their bordering ribs, during the same direction of rotation, will translate vertically in opposite directions. This will have impact on wing skin discontinuity.

Obviously, in order to achieve the maximum range of segment rotation, main spar should be positioned in segment's airfoil maximum thickness. For the morphing wing 10% thickness airfoil has been selected, as is for the reference aircraft. It is estimated that it will allow for segment rotation in the range of 30° (from -15° to +15°) when tubular main spar has 20 mm diameter and segment has 60 mm span. As it is depicted in Figure 10b, main spar is closer to segment leading edge for its root rib and further for tip rib, positioning spar at an offset to airfoil maximum thickness. Only in the middle cross section (middle rib) spar will be in the maximum rib thickness and coaxial with rotation axis.

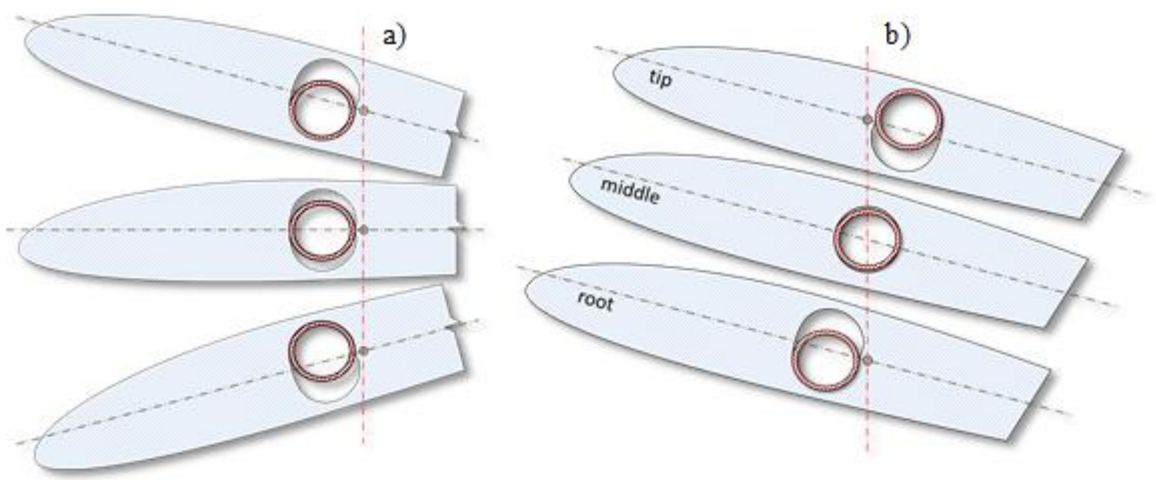

Figure 10 Segment x-section rotation vs main spar: a) only root b) all cross-sections at +15°of rotation

3.2 Pivot mechanism

As the investigated wing has relatively large swept angle (about 30°), there are two kinetically different locations within segment structure, where pivot support can be placed and fixed to the main spar: the middle rib and closing ribs (see Figure 6b). While kinetic connection is coaxial in the middle of the segment (where the rotation axis intersects main spar), it is eccentric at closing ribs. Both locations require a different kind of pivot mechanism to ensure segment rotation.

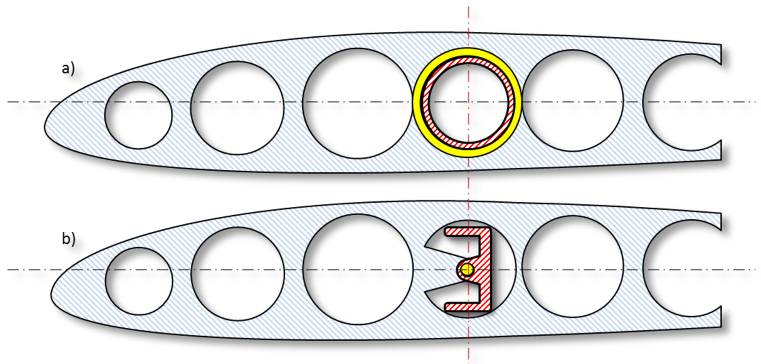

Figure 11 Concentric pivot mechanism: a) plain bearing joint b) pin joint

Figure 11 shows two basic variations of concentric revolute connections that can be used in the middle rib of wing’s segment: plain bearing and pin joints. Joint shown on Figure 11a is a simplification, because for tubular main spar, its cross section would be in a shape of ellipse, which would require more complicated solution (presented on Figure 13).

Concentric pin joint (Figure 11b) requires an access to center of rotation, limiting possible choices for spar cross section. C-beam cross section can be one of possible solutions. There is however, workaround, when there is no access to the center of rotation as it is depicted on Figure 12. It is based on the simplest type of 4-bar linkage or more specifically on parallelogram. One parallel pair of links is connected by pin joints with main spar through fixed ring, and second pair is connected to segment's rib through another set of pin joints.

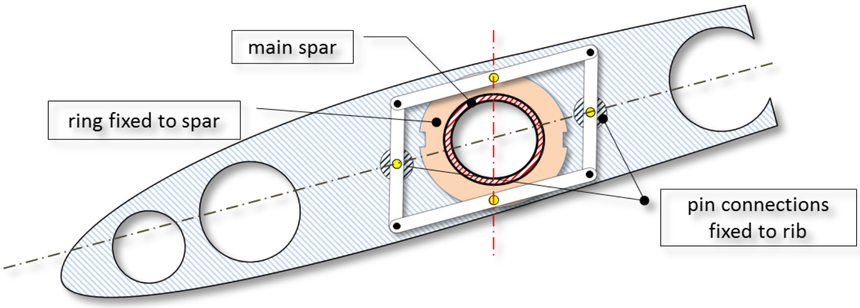

Figure 12 Parallelogram concentric linkage

Plain bearing joint is one of the possible solutions when main spar has closed cross section without access to its center of rotation. It requires matching sliding surfaces similar to plain bearing and it is depicted on Figure 13a. Ring A is permanently connected to main spar creating plain bearing with ring B, which is permanently fixed to segment's rib. Figure 13b shows that even for concentric connection where center of spar and rotation axis are crossed, main spar is at angle to plain bearing joint which seriously complicates solution.

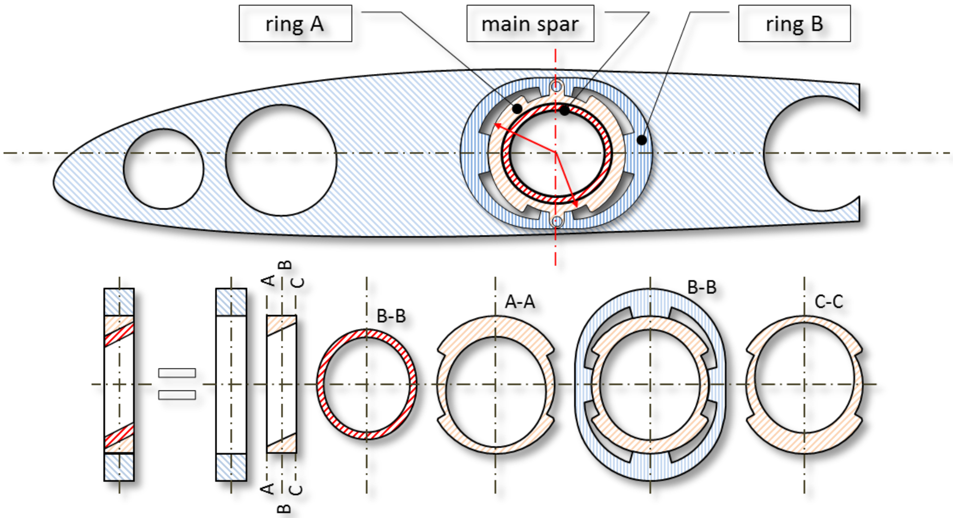

Figure 13 Concentric examples: a) plain b) plain joint cross section

Since there is only one concentric pivot mechanism possible for one segment, it is not good solution for segments with span larger than width of pivot mechanism. Segment unconstraint movement in roll can develop. Therefore two pivot mechanisms will be required, preferably next to segment's closing ribs, to prevent such wobbling. Additionally there will be not enough space for servo mechanism in short spanned segments with one pivot mechanism, which is important for factor for segment control system.

For closing ribs of wing's segment eccentric pivot mechanism has to be used, and few examples are depicted in Figure 14 and Figure 15. As it is for concentric mechanism there are basically the same variations of pivot mechanisms: plain bearing and pin joints.

Eccentric pin connection (Figure 14a) consists of two elements: pin link which is permanently connected to segment rib (yellow circle) and support link, permanently connected to H-beam cross section main spar.

Eccentric plain bearing connection has as well two elements creating in effect a plain bearing – yellow bearing surface is permanently connected to segment rib and support bearing surface permanently connected to main spar.

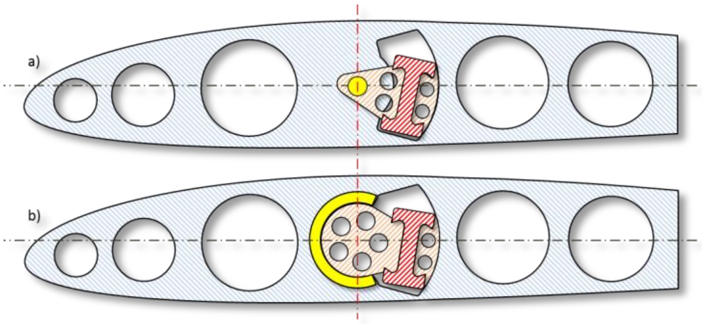

Figure 14 Eccentric pivot mechanism: a) pin joint b) plain bearing joint

The last presented solution is based on compliant mechanisms and is depicted on Figure 15a, where rotational displacement is provided by elastic element (Figure 15b) deformation connecting rib with main spar. Elastic element is permanently connected to main spar and rib simultaneously. In fact, it can be a part of rib itself. The motion is provided by deformation of elastic link between moving parts.

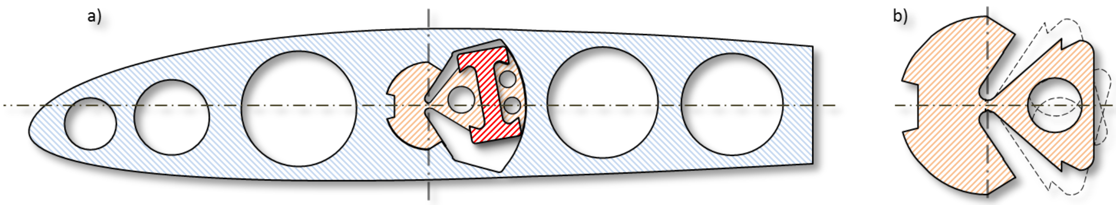

Figure 15 a) Eccentric pivot compliant mechanism b) Living hinge zoom

Compliant mechanisms have a lot advantages over theirs conventional counterparts, they lack friction or backlash, they are usually single-piece structures so no assembly is required, they are lighter, there are no joints and no lubrication needed [11]. But they are as well much more difficult to design. Four examples of compliant hinges are shown on Figure 15 and Figure 16, which can be used in wing segment pivot mechanism. They differ in construction, resistance through their deflection, range of pivot angle and value of parasitic center shift during rotation [11][12] [13].

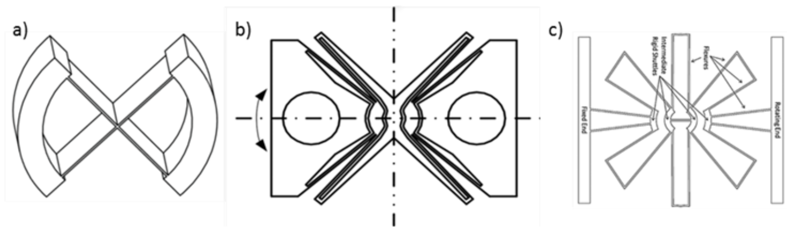

Figure 16 Compliant hinges: a) Cartwheel hinge b) Butterfly hinge c) Flex-16 hinge [13]

There are three configurations of pivot mechanisms possible for one segment: one concentric, two eccentric and combination of one concentric and one eccentric. One concentric pivot mechanism is suitable only for short span segments without servo mechanism. Two eccentric provides the most precise and robust solution, while combination of two different pivots, can be interesting solution in combination with C-beam type of the main spar.

Described pivot mechanisms can be divided due to their location within segment: middle or closing ribs, or because of their type. Advantages and disadvantages of each division have been gathered in Table 1 and Table 2 respectively.

Table 1 Pivot mechanism location

	Middle rib location **(collinear rotation)**	**Closing ribs location** **(eccentric rotation)**
Advantages	Only one mechanism per wing segment necessary. Less weight. Potentially easier installation on main spar.	Unlimited wing segment span within defined range of AoA. Guaranteed 1 DoF movement. More robust. Easier integration with segment and access to closing ribs.
Disadvantages	Segment unconstraint movement in roll axis (more than 1 DoF) if used separately. Lack of access to pivot point for main spar with symmetrical cross section. High precision elements required. Difficult installation inside wing segment and lack or difficult access. Limited space or unfeasibility for servo installation.	There are two mechanisms necessary to hinge one wing segment. More weight. Precision alignment necessary. Difficult access to segment's root rib after installation on main spar.
Application	Short span segments only. No servo segment. Best for C-beam type main spar or with open cross section.	Long span segments. Can be used in pair with one in middle location. Servo carrying segment.

Table 2 Pivot mechanism type

Pivot type	**Advantages**	**Disadvantages**
Pin Figure 11b Figure 12 Figure 14a	Simple construction and installation Small movement friction. Unrestricted range of rotation.	Wear after heavy use. More susceptible to foreign object damage (FOD)
Plain bearing Figure 11a Figure 13 Figure 14b	Unrestricted range of rotation. Bear more load – distributed on larger contact area, resist shocks, and tolerate misalignment.	Increased friction of rotation may result in high power consumption. High precision parts. More susceptible to (FOD)
Compliant Figure 15	No damage from (FOD) possible. No friction, no hysteresis. Simple construction – one piece of material. Wear reduction and no maintenance required.	Design and fabrication difficulty. Complicated fatigue analysis. Short range of rotation Parasitic center shift during rotation.

3.3 Main Spar

As outlined in section 3.1 there is enough space in wing segment for 20 mm high main spar to provide ±15° of rotation. There are three main spar cross sections under investigation: tubular, C-beam and H-beam. As aerodynamical loads distribution will be assessed during wind tunnel tests, main spar will be selected based on wind tunnel requirements and practicality of test model construction.

3.4 Segments Jamming

Due to the aerodynamic loads the main spar will undergo aeroelastic bending, which in turn can block or obscure rotation of adjacent segments (Figure 17), preventing accurate control of their deflection. Such segments jamming can be catastrophic and have to be eliminated in very early design phase. Amount of bending shown in Figure 17, is exaggerated and with preliminary plans for oversized spar, will not be as significant. However, even slight bending can hinder the relative displacement of segments.

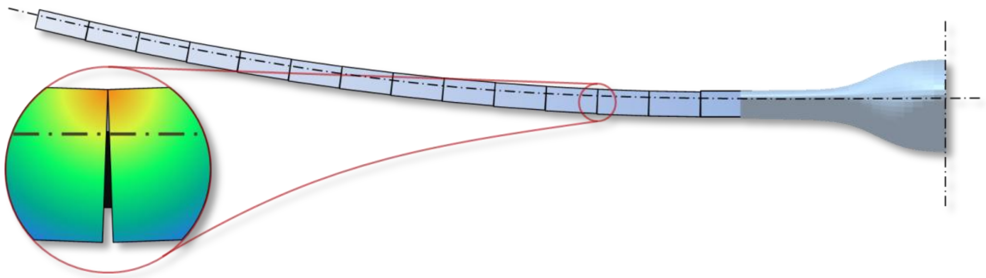

Figure 17 Main Spar bending

One of contemplated solutions to segments jamming is concept of span-wise free floating segments shown on Figure 18a. Thanks to suitable pivot supports, segments will be able to slide freely along the main spar, reducing friction stress when in contact. Problem with this solution is that sliding can occur only in one direction – outboard. As all segments (10 to 15 pcs) start to move, due to the main spar bending, the tip one will have considerable distance to travel, which in turn can deliver new complications.

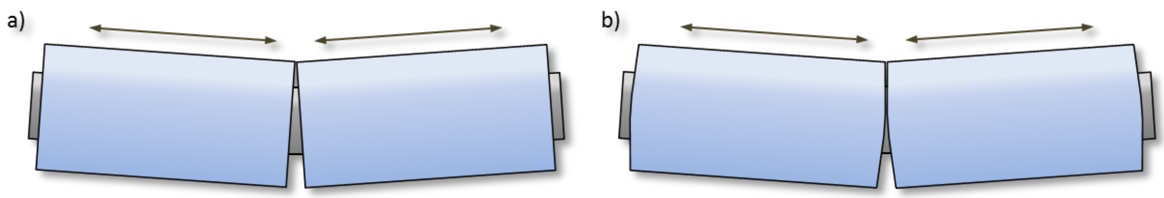

Figure 18 Segments anti-jamming solution: a) floating segments b) undercut segments

At initial stage of this project it is planned to use, as intermediate solution, undercut segments as shown on Figure 18b. This, unfortunately, will result in a small gap between segments, but can prevent jamming of segments during spar bending.

3.5 Segment Actuation System

As it was outlined in section 2, flight control is based on distributed wing twist realized by separate segments deflection. Actuation system is based on electrical micro servo actuators which provide the motive force necessary to rotate segment around the main spar and to control its incidence angle.

Servo mechanism is fixed to pivoting segment (Figure 19) for following reasons: geometric constrains described already in section 3.1 (limited space), challenging fitting to the main spar, counteracting with concept of free floating segments connection (section 3.4) and flatter suppression due to planned favorable forward position.

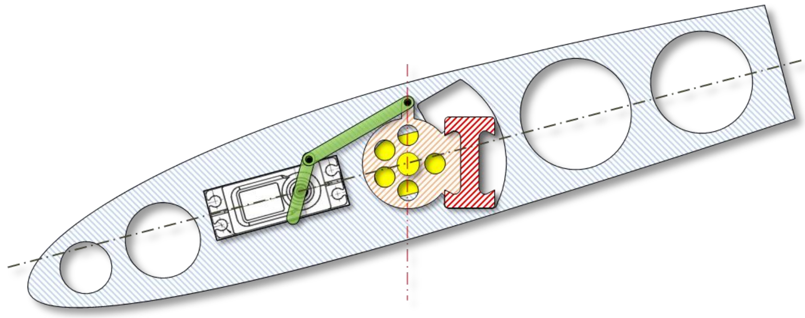

Figure 19 Segment actuation system

Due to its simplicity pin joint pivot mechanism (Figure 14a) is considered as first candidate for actuation system. Connection between servo mechanism and the main spar is realized in form of 4-bar linkage, well known from model airplanes as drive for control surfaces. There is however slight difference, while servo delivers motive force for rotation, it is as well subjected to it. Servo as a part of wing segment will rotate itself.

Technical details of the wing segment construction are still under development, but initial design is based on polystyrene foam laminated with glass-fiber composite skin and ribs made from sandwich-structured composite. Such setup is determined by its simplicity and ease of modification which is very important in such an early phase of the research. Wing segment airfoil shape will be provided by polystyrene foam core which will be cut by hot-wire cnc machine. Composite ribs and skin will be laminated to foam core after all necessary openings for the main spar and servo mechanism are cutout in the foam core.

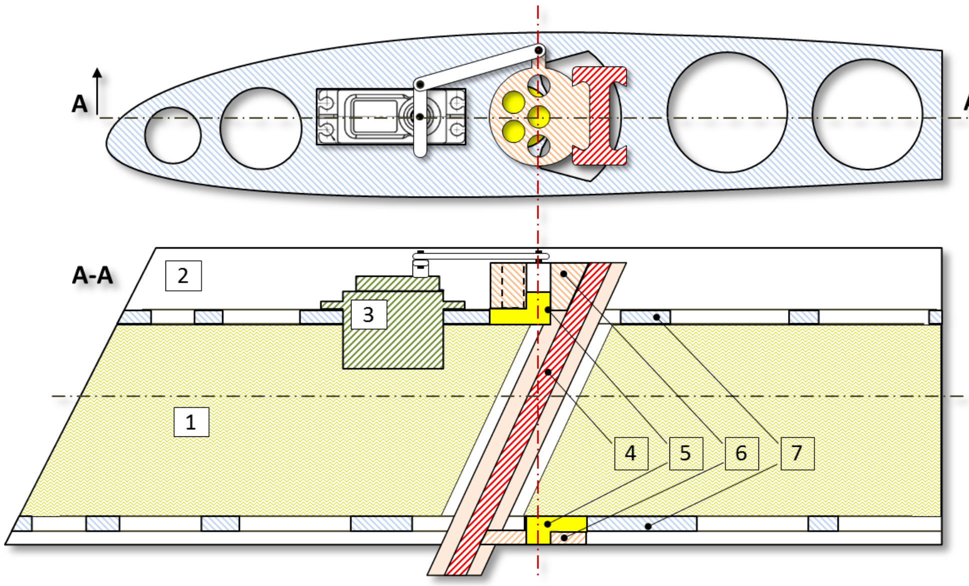

Figure 20 Cross section of segment

1. **Foam core**
2. **Segment surface**
3. **Servo mechanism**
4. **Main spar**
5. **Pin link (bonded to rib 7)**
6. **Support link (bonded to spar 4)**
7. **Segment tip rib (bonded to core 1 and surface 2)**

Sample solution of wing segment construction with its cross section is shown in Figure 20. Segment foam core (1) is bonded together with closing composite ribs (7). Next, this group is laminated with composite skin in a prepared rig. Followed by installation of pin links (5) into segment's ribs and then by servo motor, which is installed into tip rib for easy access. It is important arrangement as during sequential installation of wing segments there is access required to servo motor and its linkage. Then support links (6) are mounted on the main spar; first one is mounted root support link (6 down) then segment is pushed down the spar and suspended via pin link (5) on root support link (6), and finally second tip support link (6) is mounted to main spar and to tip pin link (5). Now, when segment is properly hinged, servo motor can be connected to tip support link(6).

Conclusion

The reason for this research is to create novel morphing wing solution which is not challenged by inevitable problems with elastic deformation of wing structure and can potentially provide better performance, stability and maneuverability in comparison to conventional tailless aircraft with elevons.

In this paper following concepts were presented and briefly discussed:

- Novel concept of discontinuous morphing
- Aircraft flight control using multipoint (all-moving segments) wing twist distribution
- Tailless reference aircraft
- Conceptual investigation of swept wing morphing kinematics

Following this investigation, wind tunnel (WT) model is planned to be fabricated and tested. Depending on results iterative process of optimization and further WT tests are expected. If successful, fabrication of two aircraft in the conventional and morphing configurations will follow. Then flight tests will be conducted to determine flight characteristics of both airplanes for comparative analysis.

Positive project results will allow for opening of new opportunities of scientific exploration, integrating laboratory research of morphing concepts with currently available materials technology. Wind tunnel testing of aerodynamic effects, produced by discontinued wing skin, will be an invaluable aid in the design of new morphing structures. In particular, they will expand the knowledge of the leading edge vortexes (LEV) generation and interaction together with drag fluctuation.

The results will allow for a completely new approach to morphing of aircraft structures, not limited by the challenges associated with elastic deformation. By breaking the paradigm of wing surface continuity, there is possibility of new approach to aircraft design based on 'Discontinuous Morphing'.

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