INSECT SHIELDING KRÜGER – STRUCTURAL DESIGN FOR A LAMINAR FLOW WING

B. Schlipf,
Airbus Operations GmbH, Airbus-Allee 1, 28199 Bremen, Germany

Summary

For concepts of transport-aircrafts with laminar flow on the upper side of a wing, a Krüger-Flap is a common choice for the Leading-Edge-Device. For two important reasons: This device can shield the Wing-Leading-Edge (LE) from insects within the lower airspace and it avoids the flow-disturbing step of a slat's trailing edge.

Aiming at laminarity results in a design-challenge of contradicting requirements: High settings and no disturbance behind the stagnation point are standing against a thin profile with limited possibilities of modification. Going for a conventional design ends in an impasse of a lack of space, since typical high-lift-kinematics are working in a layer. This layer turns out to be too small, to house a mechanism which shall be capable to achieve the long travel and the large rotation angle of a laminar wing's Krüger.

A spatial-kinematics that solves this challenge is the pyramidal kinematics. The focus here is on its adaption to the application to a Laminar-Wing's Krüger-Flap. Its principle function is explained as well as its limitations. Furthermore a damage-tolerant design and a suitable actuation are described.

1. MOTIVATION

For a modern large transport aircraft a LE-Device is essential. Without its enhancement of high lift performance a wing would get too big for a competitive aircraft. When additional a laminar flow shall be achieved, the step of a slats trailing edge is inacceptable. A Krüger-Flap, which is stowed on the lower side, allows having an undisturbed surface at least on the upper surface of the wing.

Another difficulty for laminar flow is the boundary-layer-disturbance by particles, especially insects on the wing's leading edge. For this the Krüger offers a solution too: By adjusting the setting of the extended position such, that the Krüger shields the wing-LE from insect-impacts, it can be kept clean. Therefore the Krüger must be in extended position, while the aircraft passes airspaces containing insects. Since this is in the lower airspace, there is an overlap with flight phases when the Krüger-Flaps' high-lift-performance is needed anyway.

2. REQUIREMENTS

Up to now two different types of Krüger-Flaps are used. One stays near to the wing and is mostly sealed to it. The other one moves more forward and to a higher setting thus a gap is created between the Flap's trailing-edge and the wing.

To achieve the bug-shielding effect a higher setting is required than usually necessary.

The other hard constraint is given by the profile. Laminar wings are comparatively thin in the forward region of their cross-section. According to NIU [1], Krüger-Flaps should be used rather for thick wings.

To a certain extend also the lower side has to fulfil laminar surface requirements. Thus also the position of the stowed Krüger is constrained.

3. KINEMATICS – STATE OF THE ART

3.1. Pivotal Hinge Kinematics

A cheap, light and simple solution for the kinematics is preferred generally. Obviously a pivotal hinge kinematics is the least complicated solution of all. There are numerous examples for its application, especially on sealed Krüger-Flaps.

To minimize the cut-outs in the leading-edge the so-called swan-neck-design is chosen often. Since almost any local disturbance in the wing's leading edge area would cause a turbulent wedge, cut-outs are allowed on the lower wing surface only to a certain extent.

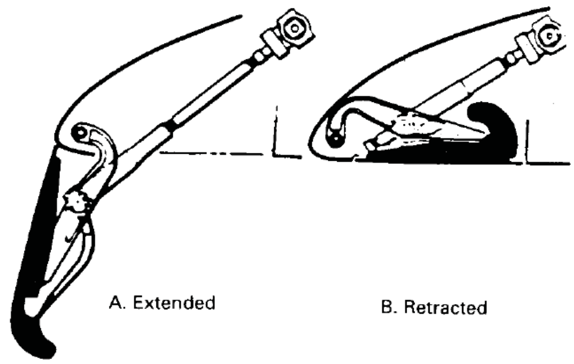

Figure 1. Krüger-Flap with Swan-Neck-Pivot Kinematics [1]

Figure 1 shows a sealed-gap-Krüger-flap where the pivot lays low and within the wing-shape. Thus the swan-neck-concept works very well.

Figure 2 depicts a comparatively high setting of the Krüger-flaps trailing edge in its deployed position, which is required for shielding of heavy particles.

Since only one extended setting is required, a pivotal motion of the Krüger is sufficient. For a given stowed and extended position a pivot-axis can be derived. On a cross-section, perpendicular to the hingeline all points move on concentric circles around it. Thus the two-dimensional determination of the pivot can be done by a standard geometrical approach. It can be determined, by finding the intersection of perpendicular bisectors on the connection-lines of the retracted and extended position, of two arbitrary chosen points on the Krüger. Choosing the trailing-edge and the leading-edge points improves accuracy.

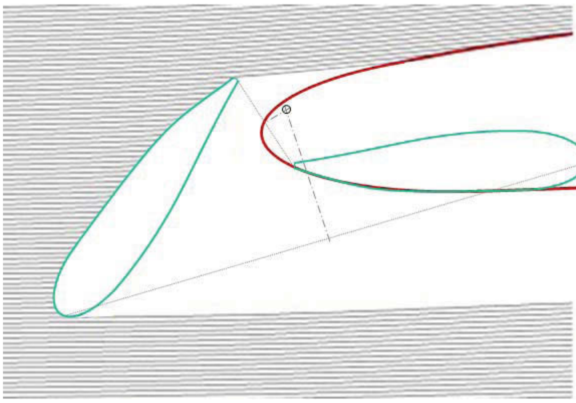

Figure 2. Sketch of Krüger-Flap-Setting and Pivot-Derivation for Shielding Requirement

The pivot is close to the wing-skin. Especially in the wing's outboard area, pivots based on that requirement clearly lead to design-clashes, since there is not enough space for the pivot's bearing available.

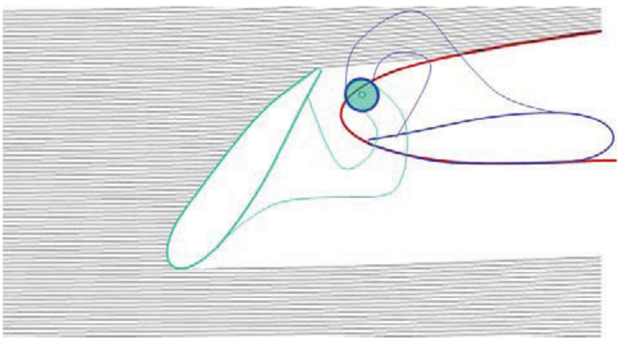

Figure 3. Sketch of Krüger-Flap with clash due to Shielding Requirement

Figure 3 shows another problem that appears, due to the requirement, of not having cut outs in the wing's leading-edge: a swan-neck-design of the kinematics, which could be deployed through the Krüger-cavity, exceeds the wing-shape.

Re-designing the wing-profile would compromise the laminar flow design and modifications of the setting would result in a performance drawback, due to turbulences caused by contamination of the upper wing-skin.

3.2. Linkage Kinematics

Since the simple solution reveals as not feasible, a more complex solution for the kinematics is necessary. In further investigations also linkage-kinematics, such as the four-bar-linkage or the scissor-linkage failed to fit in the very limited space of the outer wing-cross-section.

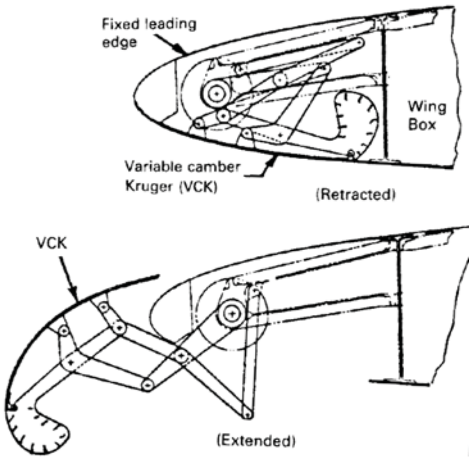

Figure 4. Krüger-Flap with Scissor-Kinematics [1]

Even though most of the linkages work in several layers, each link-element stays in a layer perpendicular to the pivot-line of the deployment motion.

Mainly the size of the bearings in combination with the previous mentioned requirements leads to clashes with the wing skin. Especially for the outer wing area of the laminar wing the lack of space is an unsolved problem for design of the linkage-type-kinematics.

3.3. Spatial Kinematics – State of the art

The long deployment-distance from the Krüger's stowed to its deployed position stands versus a quite thin Leading-Edge-Profile. Looking at a laminar-wing's cross-section it seems difficult to find a kinematics that can achieve the comparatively long deployment-distances and fold into this very limited available space.

Since more space is available in span-wise direction, it is obviously beneficial to use the space beneath the kinematics layer. There are several patents about Leading-Edge-Element-kinematics that are using this idea already:

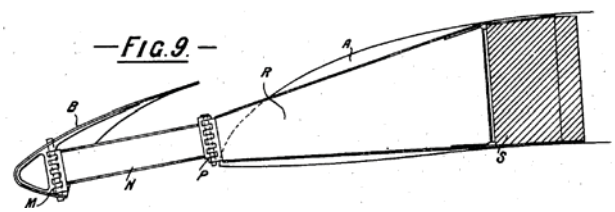

Figure 5. F. H. Page Patent US 1,780,838 [2]

F.H. Page patented in 1928 a mechanism that folds in span-wise direction [2], like shown in Figure 5. Here the both axes of one link are parallel, thus the Slat-motion is solely translational.

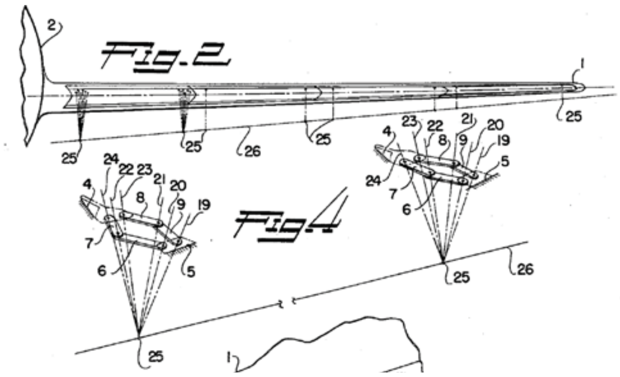

Figure 6. R. F. Wiele, Lockheed-Patent, US 2,973,925, [3]

The Figure 6 and Figure 7 are taken from a patent filed in 1958 by Lockheed. It is titled “automatic airfoil slat mechanism” and shows also a span-wise folding mechanism which is designed symmetrical [3].

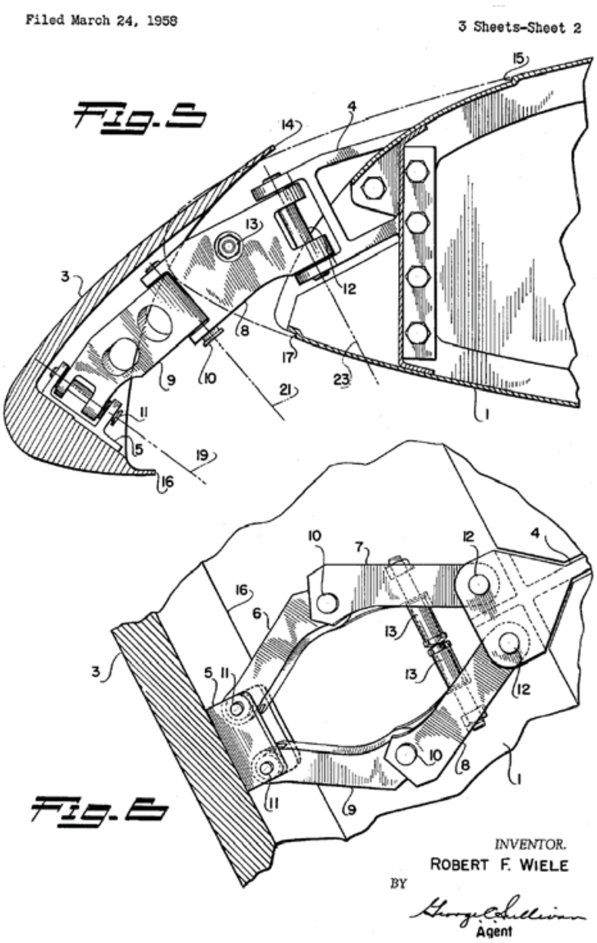

Figure 7. R. F. Wiele, Lockheed-Patent, US 2,973,925, [3]

Beside the symmetry, this patent adds two more important features to the idea of F.H. Page:

- In one kinematic chain between the slat and the wing-box are two linkage elements. This enables a motion approximately perpendicular to the spar.
- The three axes (No. 19, 21 & 23 in the figures) defining the kinematics of one kinematic chain have a common intersection (in point No. 25), which lays on the devices pivot-axis.

By putting those features together a kinematics can be designed which moves a device on a certain layer perpendicular to the hinge-line, without the necessity to have any structural element coincident with the hinge-line itself.

Because of these properties the pyramidal kinematics is an interesting solution for a laminar wing’s Krüger-Flap.

4. PYRAMIDAL KINEMATICS FOR KRÜGER-FLAP-APPLICATION

4.1. Axes Definition

As shown in Figure 8, the Krüger-fixed-axis is defined by two Krüger-Flap-Kinematics-Attachment-Points P1 and P2. It turns around the pivot P0. It is a major characteristic of the pyramidal kinematics, that every axis always is coincident with the pivot. No structural element is needed in P0 and between P0 and P2.

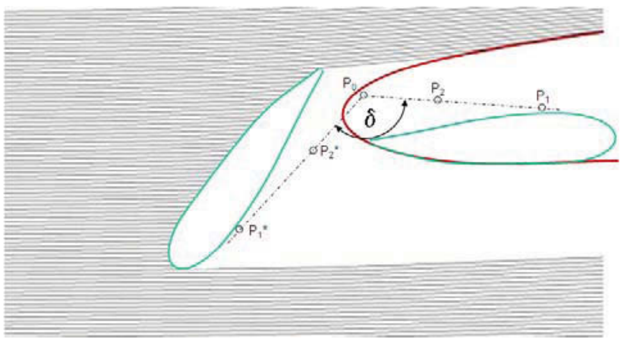

Figure 8. Sketch of Krüger-Device-fixed-axis in retracted and extended Setting.

For adaption of the kinematics from a slat- to a Krüger-Flap-application, the focus is on the main differences: The most significant is the extension angle δ. The rotational motion, which a Krüger has to fulfil during its deployment, is roughly about three times the one of a slat. So the angles between the axes have to be increased significantly.

The P1-P2-axis should be positioned as close as possible to the Krüger-Flap, because it has to share the rare space of the kinematics layer with the wing-fixed-axis.

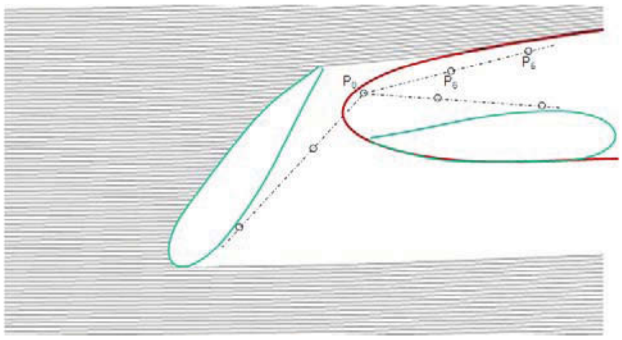

Figure 9. Wing-fixed-axis definition

The wing-fixed-axis should be, like shown in Figure 9, positioned as close as possible to the wing skin. P5 and P6 indicate the location of the wing-attachment-bearings, which define the axis.

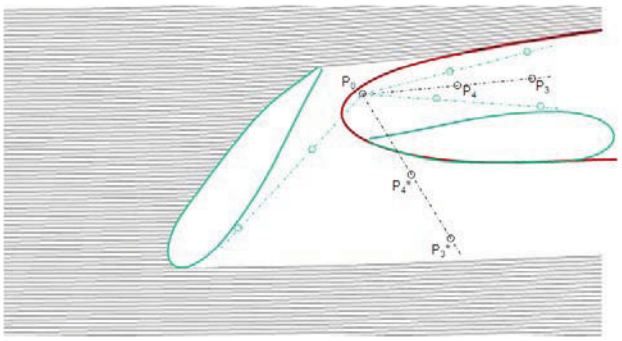

Figure 10. Middle-axis definition

Figure 10 shows the middle-axis definition. It is defined by the points P3 and P4, where the two link-elements are connected to each other. This axis is not in the same layer than the other two. For the definition of the fully extended kinematics position is important to have an angle smaller than 180° between the two links. As long as the actuation is not embedded within the kinematics a residual “kink” between those links must be considered. Otherwise the links might not fold up, if the Krüger-Flap is retracted.

As long as the wing-fixed- and Krüger-fixed-axes are designed in one plane, the middle-axis appears to bisect the angle in between. This is consequently also valid for its projection on this plane (see Figure 10 & Figure 11).

A symmetrical layout, as described in Wiele’s Patent [3] is not essential for the principle function. For the laminar wing-application, due to the space restrictions, an one-sided asymmetrical layout is preferable. Side-loads still can be taken. The side-load-stiffness is higher for the Krüger-application. This is caused by high deployment angle which results in a larger angle of the middle-axis to the kinematics layer.

4.2. Geometric Characterisations

The geometric characterisations is described direction-vector-based in the following.

The co-ordinate system’s origin is defined by the intersection of the Krüger-Flap-pivot with the Kinematics plane. The x-axis is coincident with the Krüger-Flap-pivot. The y-axis is defined by the Point P1 respective P2.

The vectors are defined as follows:

$$\vec{A} = \frac{\overrightarrow{P_0P_5}}{\left|\overrightarrow{P_0P_5}\right|} \quad (1)$$

$$\vec{B} = \frac{\overrightarrow{P_0P_3}}{\left|\overrightarrow{P_0P_3}\right|} \quad (2)$$

$$\vec{C} = \frac{\overrightarrow{P_0P_1}}{\left|\overrightarrow{P_0P_1}\right|} \quad (3)$$

$\vec{B}'$ is the projection of vector $\vec{B}$ on the y-z-Plane.

δ is the deployment angle.

$\vec{B}*$ is the location of $\vec{B}$ in a deployed setting.

$\vec{C}*$ is the location of $\vec{C}$ in a deployed setting.

α describes the angle between $\vec{A}$ and $\vec{C}$ in the retracted position.

The angles between $\vec{A}$ and $\vec{B}$ resp. $\vec{B}$ and $\vec{C}$ are equal and are named γ. This angle given per design of the link and is not changing during extension.

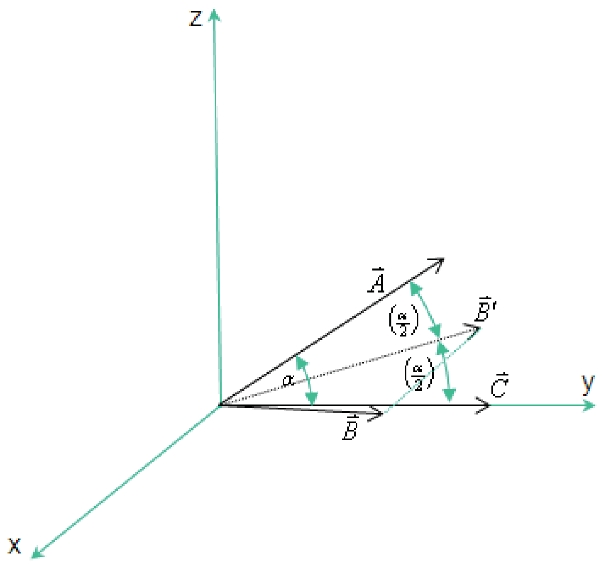

Figure 11. Axes in retracted position

The angle α between $\vec{A}$ and $\vec{C}$ can be chosen by design. The smaller it is, the higher are the bearing loads for the retracted position. The major limitation for α is given by the available space within the kinematics layer.

During extension of the Krüger the vector $\vec{C}*$ stays within the kinematics layer, due to 3D-constraints (see Chapter 4.3).

While the vector $\vec{B}*$ rotates around $\vec{A}$ the both kinematics links, here described by the constant angle γ, are unfolding. Since the axis $\vec{B}*$ is out of the kinematics-layer, and moving towards it, it can be seen, that the angle between $\vec{A}$ and $\vec{B}*'$ is $\left(\frac{\alpha+\delta}{2}\right)$. Finally $\vec{C}$ turns around the x-axis.

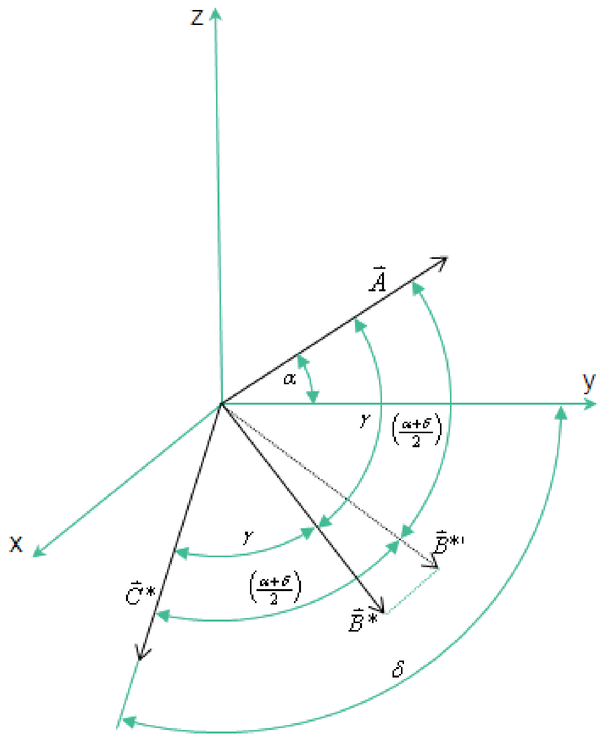

Figure 12. Axes in extended position

As described above the kinematics has its limitations: As long as the actuation is attached to the Krüger-Flap or the $\vec{C}*$-axis (see 4.5), the $\vec{B}$-axis must not move into the kinematics layer. If this happens, there would be no moment folding up the two links, since the moment's lever would be zero. Then the flap cannot be retracted. This would cause a clamping-effect, which has to be prevented. Otherwise the retraction of the Krüger-flap would be blocked. Thus

$$\gamma < \left(\frac{\alpha+\delta}{2}\right) \qquad (4)$$

In case the axes $\vec{A}$ and $\vec{C}$ are co-linear, they create a common rotation-axis for the link-elements. Then the vector $\vec{B}$ is not definite anymore. Thus another limitation is:

$$(\alpha+\delta) < 180° \qquad (5)$$

Since α is defined by space-allocation-issues, this constraint limits the maximum deployment angle δ.

4.3. 3D-Constraints

The explanation above assumes the vector $\vec{C}*$ stays within the kinematics layer.

This can be achieved by having a Krüger-Flap with a non-zero bending- and torsion-stiffness, plus a second kinematics station. The second station prevents the rotation of the vectors $\vec{B}*$ and $\vec{C}*$ around $\vec{A}$, by supporting a translational Degree of Freedom (DOF) around the x-axis.

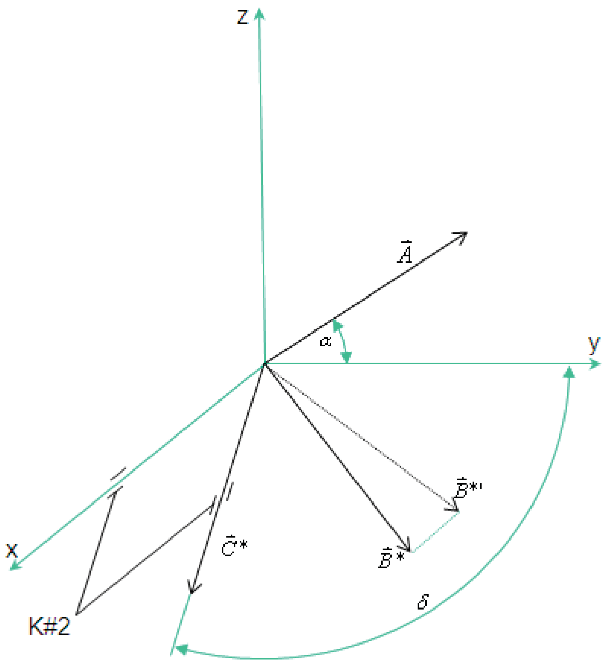

Figure 13. 3D-Kinematics-Principle

In Figure 13 the 2nd Kinematics station, named K#2, is idealized as a pivotal DOF around the x-axis.

A translational free DOF is required at the second kinematics station in x-direction, to support the Krüger-flap isostatic in the translational x-direction. This can be realized by a swing-link, for example.

Such a set of two kinematics-stations, one of them with a swing-link, and a Krüger-flap provides one free DOF pivotal to the x-axis. This remaining free DOF, enables he pivotal flap motion. It is defined by the drive-system.

4.4. Design

Like described above the angle γ is kept constant by two link-elements per kinematics station. They are connected by piano-hinge-type bearings. A damage-tolerant design can be realized by a minimum number of three lugs per axis. An example of such a design is depicted in Figure 14.

Like described in Chapter 4.2, the middle-axis must stay out of the kinematics layer. To ensure this, despite deformations or drive-system-malfunctions, the unfolding angle between the two link-elements has to be limited to a certain value smaller 180°. This can be done by designing stopper-elements, attached to one of the link elements. For realisation of the principle they might be located at any of the axis, as long as they limit one of the link's rotational motions. To ensure an optimum function, also of a deformed structure, the middle-axis is the preferred location.

As soon as a stopper limits the kinematics' extension, additionally, the pivotal DOF is supported by the kinematics. In consequence the Krüger-Flap is hyperstatic supported in the extended setting. This effect can be used to improve the Flap's bending-behaviour.

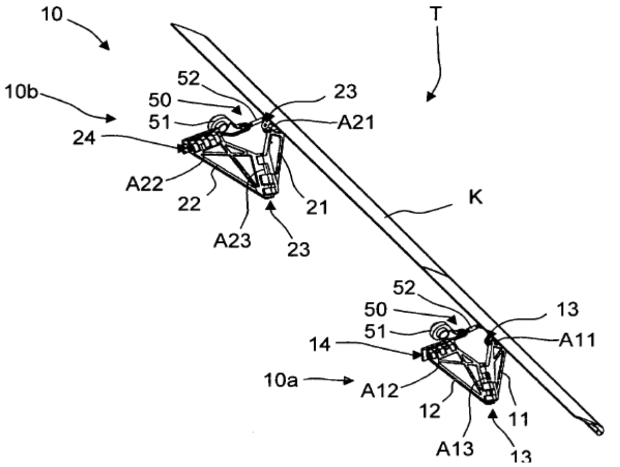

Figure 14. Krüger-Kinematics Design from Patent [4]

4.5. Actuation

Numerous possibilities exist to attach an actuation on the mechanism.

E.g., in the patent of Perez-Sanchez [5] the different radii of the P3 to the P4 Point are used to implement a linear actuation. This might be beneficial in terms of space-allocation on a slat-pyramid-kinematics. For the Krüger-flap-application this concept is not suitable.

Krüger-Flaps are deployed in the same direction, in which significant airloads are acting as well. In consequence these mainly load the actuators. Thus attaching the actuation directly to the kinematics, leads to high bearing loads within the kinematics.

The preferable solution for pyramidal Krüger Kinematics is designing a second, separate layer for the drive-system.

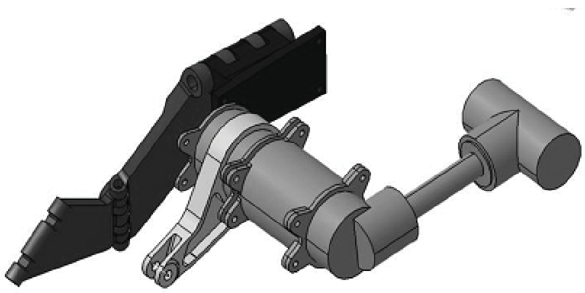

Figure 15. Actuation-Design with Rotary-Gear

The Figure 15 shows a solution that has a rotary-gear-driven lever. Figure 14 depicts a drive-strut (52) connecting the lever with the Krüger-Flap. The flap is statically determinate with one intact drive station. For damage-tolerance two drive stations are beneficial.

5. CONCLUSION

The pyramidal shielding Krüger-flap kinematics fits in the limited space of a laminar wing's outboard leading edge, where a non-spatial kinematics does not fit in.

It is feasible to adapt the pyramidal kinematics from a slat- to a shielding-Krüger-flap-application. The characteristic of a Krüger-flap requires a significant increase of the deployment-angle, which is close to the limit of the kinematics' principle.

A separated drive mechanism ensures a low level of bearing loads. Three lugs per axis and a stopper guarantee a damage-tolerant functionality.

6. ABBREVIATIONS

DOF Degree of Freedom

LE Leading Edge

7. REFERENCES

[1] Niu, Michael Chun-Yung; Airframe Structural Design; Conlimit Press LTD.; 8th Printing Jan. 1995

[2] F. H. Page, Patent US 1,780,838: "Means for controlling aeroplanes", assignor to Handley Page Limited, of London, England; Patented Nov. 4, 1930

[3] R. F. Wiele, Patent US 2,973,925: "Aerodynamically Automatic Airfoil Slat Mechanism", assignor to Lockheed Aircraft Cooperation, Burbank, Calif. ; Patented Mar. 7, 1961

[4] B. Schlipf, Patent WO 2010/108698 A1; "Aerofoil Compromising a High Lift Flap", assignor to Airbus Operations GmbH, Hamburg, filed 29th March 2010

[5] J. Perez-Sanchez, DE 10 2005 044 549 B4, „Flugzeugflügel mit ausfahrbarer Nasenklappe", assignor to EADS Deutschland GmbH, Ottobrunn, Patented 17.04.2008