

CONCEPTS FOR A SAFETY DEVICE IN CONVENTIONAL TRACK-LINKAGE KINEMATICS TO PREVENT SKEW IN A SINGLE FLAP SYSTEM

M. Lerch, F. Thielecke
Hamburg University of Technology, Institute of Aircraft Systems Engineering
Nesspriel 5, 21129 Hamburg, Germany

Abstract

Conventional high-lift systems are used for lift augmentation during start and landing operations of the majority of modern transport aircraft. Besides this, they have limited functionality during the rest of a flight mission. A possibility to provide more functionality is the use of single flap systems, that enables differential flap setting. For the implementation different technical realization can be used. In addition to dropped-hinge kinematic and fail-safe actuators, this paper presents various concepts for a novel safety device, which is integrated into the track linkage kinematic. For the so called flap track brake (FTB) an integration into the carriage is conceivable. The main task of the FTB is the prevention of flap skew in failure cases. Therefore different concepts are presented and discussed. For carriage integrated concepts a VDI 2225 like evaluation is conducted. The use of the FTB requires an adjusted drive system, which actuates every single flap with an independent and redundant electrical power unit. For investigations of the FTB and drive system in early development stage a co-simulation can be used to gain early results. Therefore the drive system can be modeled in MATLAB/Simulink and the flap kinematics are emulated in MSC/Adams.

1 INTRODUCTION

Today's civil transport aircraft provide lift augmentation systems for low airspeed operations. This is achieved by extending high-lift systems installed at the leading (slats) and trailing edge (flaps) of the wing. Research activities of the INSTITUTE OF AIRCRAFT SYSTEMS ENGINEERING from the HAMBURG UNIVERSITY OF TECHNOLOGY (TUHH) enter the question how to provide more functionality to flap high-lift systems. The *Airbus A350* was a first industrial step in this direction, where differential flap setting was enabled [1]. Proceeding single-flap systems, where every flap is an independent sub-system, consequently have no mechanical coupling due to the transmission and other connecting elements between the flaps. New system architectures and devices will be needed to prevent flap skew and provide a safe and reliable airplane operation. This paper will present possible concepts and system architectures to achieve this goals.

Therefore the first part of the paper gives an overview about conventional trailing edge high-lift systems to clarify the difference to single flap systems. Moreover possible failure cases and their state of the art detection are described.

The next part points out the advantage and gain in functionality of high-lift systems with enhanced

functionality. Therefore three options for a possible technical realization of a single-flap system are presented. One option, next to dropped hinge kinematics and fail-safe actuators, is a novel safety device, integrated into track linkage kinematics components, called flap-track brake (FTB).

General boundary conditions for this FTB and the possible actuation system will be introduced in the subsequent section. Furthermore potential failure cases are outlined, a kinematic analysis and the use of multi-body simulations for preliminary investigations are described.

Concepts for carriage integrated FTBs are presented in the following section. These concepts are evaluated according to VDI 2225.

2 CONVENTIONAL HIGH LIFT SYSTEM

To clarify the difference between a conventional and a single flap system, this section provides a brief overview of the state of the art trailing edge high-lift systems.

Today the majority of airplanes have two pairs of flaps, named after their position, the inboard and outboard flaps. Flaps of airplanes like the Airbus A320 or Boeing 737 realize a so called fowler motion. This motion pro-

okes an extension of the wing area and increases the wing camber, which can increase the lift for a single-slotted system up to 93% [2] in comparison to a cruise configuration. The beginning of the flap extension is characterized by a nearly translational movement which changes into a rotational movement at the end of flap extension.

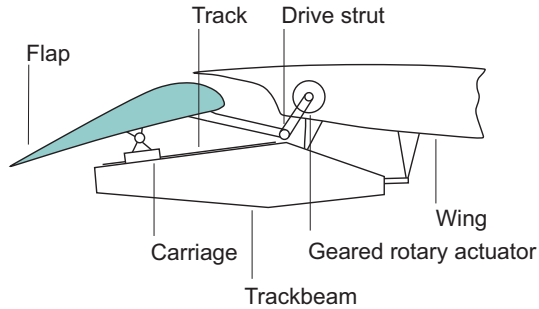


FIG. 1: Schematic representation of track kinematics

A large variation of kinematic mechanisms, which ensure these motion characteristics can be found in the different airplane types. One widely used kinematic is the track linkage kinematic (see figure 1 for schematic representation), that can be found in most Airbus (A330/340, A320) and Boeing (737, 777) airplanes. Except the most inner station a flap is mounted on two or three of those guiding mechanisms. The carriage can move translational along the trackbeam and withstands the main load. The trackbeam itself is mounted to the wing structure.

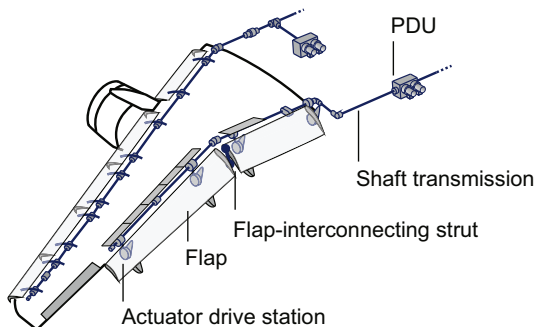


FIG. 2: Schematic representation of a drive system using the example of Airbus A320 [3]

A drive system is needed to move each flap to the commanded discrete position. The central element of the drive system is a power drive unit (PDU), located inside the fuselage of the aircraft, which provides the required energy to a shaft transmission. The shaft transmission is guided by different line gearboxes, right angle gearboxes, bevel gearboxes and bearings through the two wings and transfers the energy to the various actuator drive stations. At these stations geared rotary actuators (GRA) move the flap via drive struts. Figure 2

shows a schematic representation of an Airbus A320 like high-lift system.

2.1 Failure Cases and Detection

For the control and monitoring functionality sensors are available at the PDU output shaft and the respective end of each shaft transmission. The sensor located at the PDU, called Feedback Position Pick-off Unit (FPPU), is a redundant resolver that measures the angular position of the shaft. The FPPU is used for control and monitoring functions [4]. The Asymmetric Position Pick-off Unit (APPU) is equivalent to the FPPU and located at the tip of the shaft transmission. In contrast to the FPPU, the APPU is used for monitoring functions only. Furthermore the flap interconnecting strut (FIS), the mechanical connection between inboard and outboard flap, is equipped with contact sensors. This sensor sends a discrete signal to the control computer when the inboard and outboard flap move relatively to each other.

Two redundant and dissimilar slat and flap control computer (SFCC) perform the control and monitoring function of the high-lift system. The fault monitoring is based on the evaluation of the APPU and FPPU sensor values respectively the calculated rate of revolutions. Thus the following failure cases can be detected [4]:

- *Asymmetry* - Characterized by an angle difference between the left and right APPU. A possible cause is a break in the transmission.
- *System Jam* - A significant low rotational speed caused by jamming gears is detected by the FPPUs.
- *Runaway* - The angle difference between FPPU and APPU is above a limit.
- *Overspeed* - The rotational speed detected by the FPPU is too high. This could be caused by a failure in the hydraulic control units in combination with high aiding loads.
- *Uncommanded Movement* - The rotational angle difference in halt between the commanded position and the measured FPPU position is too large.

A break of one drive strut or the transmission shaft can cause a freewheeling drive station. This leads to a kinematically indeterminate system state of the affected flap. The released degree of freedom (DoF) will be compensated by the FIS. The FIS is integrated into the load path only in failure cases.

In the event of one of the above mentioned failures or the activation of the FIS sensors the whole flap system will be deactivated.

3 HIGH-LIFT SYSTEMS WITH ENHANCED FUNCTIONALITY

During normal operations high-lift systems are only extended during take-off and landing phases to generate a sufficient lift at low speed. At the main part of a flight mission, the cruise flight, the system is inoperable. Current research activities focus on the question how to provide more functionalities to the high-lift system and improve the overall efficiency. One possibility is the use of single flap systems. The basic idea behind this concept is an independent movement of each single flap, the so called differential flap setting. This can be accomplished by using no mechanical coupling between inboard and outboard flap. Considering the above described conventional high-lift system the continuous shaft transmission and the FIS must be rejected. Figure 3 shows the concept of autonomous in- and outboard flaps with distributed PDUs.

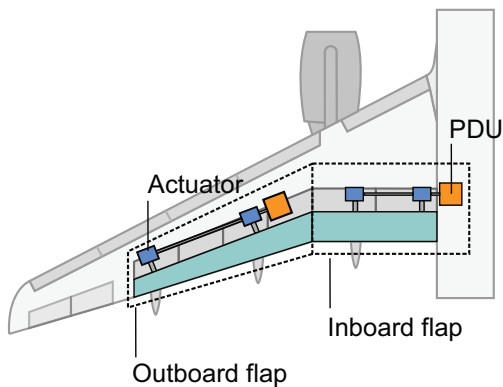


FIG. 3: Schematic representation of autonomous inboard and outboard flaps

3.1 Aerodynamic Enhancements

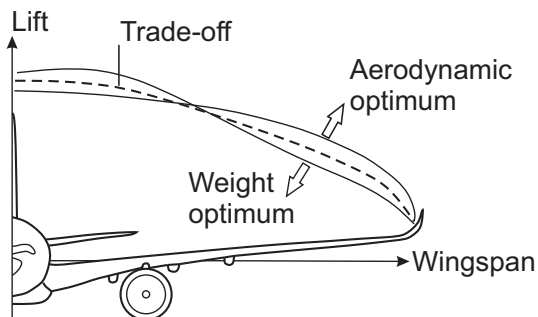


FIG. 4: Trade-off between aerodynamic and weight optimized lift distribution [1]

An elliptical span-wise lift distribution corresponds most closely to the aerodynamic optimum. However this distribution leads to a high bending moment of the wing structure caused by airloads. For reducing

the bending moment the center of lift (CoL) is moved closer to the wing root during the wing design phase (see figure 4), along with a loss of aerodynamic performance.

With differential flap setting, the CoL can be varied in spanwise direction to depend on the current flight phase, which can be seen in figure 5. Therefore, the structural wing design can be optimized, which results in weight reduction.

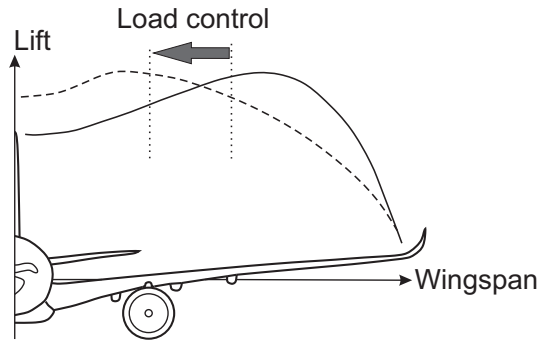


FIG. 5: Load control during flight maneuvers [1]

3.2 Additional Enhancements

Availability

A malfunction of one single flap leads to a deactivation of the corresponding flap at the opposite wing, for symmetrical reasons. The remaining flaps could stay active and ensure a safer aircraft operation. A single failure in the conventional flap system can cause the shutdown of the whole system. The missing flap system performance can lead to a reduced aerodynamic performance and higher landing speeds.

Assembly and Maintenance

Depending on the system architecture highly modularized options allow the complete pre-assembly of the entire single flap system before installing the module on the wing. The complex installation of the transmission drive system with multiple gears and mounts is not anymore necessary. In case of a system malfunction, the entire flap module could be replaced rapidly, which could reduce the aircraft on ground time. Because of the simplified system configuration the number of maintenance actions can be decreased. Furthermore electrical rigging can be used for compensating lateral imbalance of the aircraft caused by manufacturing deviations. All of this can lead to a cost reduction during installation and maintenance of the high-lift system.

3.3 Possibilities for Technical Realization

For the technical realization of a single flap system different approaches can be taken into consideration. One main challenge is to provide sufficient safety level in failure cases. As mentioned in section 2.1 the released DoF caused by a freewheeling drive station

shall not result in a critical situation. In the following, three different approaches for the technical realization of single flap systems are described.

Dropped Hinge Kinematics

The *Airbus A350XWB* is the first step towards a single flap system, where the inboard and outboard flap can be deployed differentially. As a result no FIS-like coupling between inboard and outboard flap is installed. Each flap is supported by a simpler hinge kinematic consisting of a fixed support and a lever. Fixed support and lever are connected by a spherical bearing, which represents the hinge point (see figure 6). Due to the dropped hinge, the flap kinematic will be transferred into a kinematic determinate state, in the case of a freewheeling drive station.

As a matter of principle the Fowler motion of the dropped hinge kinematik is considerably less pronounced compared to the track linkage kinematic [1]. Therefore the aerodynamic performance is reduced. For controlling the gap between flap and wing, an additional spoiler droop function is needed. This necessity increases the system complexity caused by the control and monitoring of the spoiler, which must avoid a collision with the flap by all means. In case of a jamming spoiler in drooped position a retraction of the flap is not longer possible. This failure case must also be detectable by a qualified monitoring system.

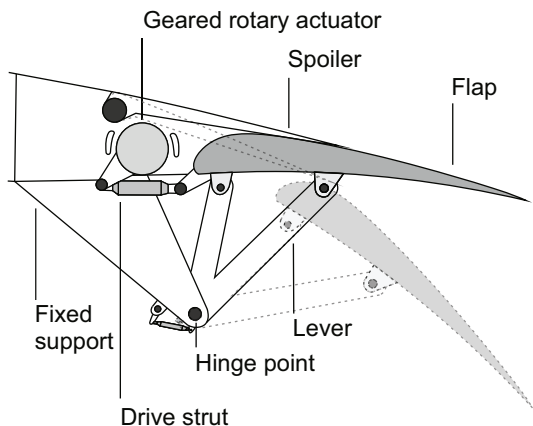


FIG. 6: Dropped hinge kinematics [1]

Fail-Safe Construction

The idea behind the fail-safe concept is, that in the event of a failure a component reverses to states know to be safe. Thereafter the component may operate in a highly restricted mode, which includes the complete loss of functionality, reverting to backup or redundant features [5].

In case of the described flap system this means that if a failure occurs which normally results in a free-wheeling drive station, a redundant load path must be available. Assuming a track linkage kinematic at least

the drive struts and the GRAs must be constructed with dual load paths. However, the redundant design will increase components weight and directly influences the direct-operation costs (DOC). In figure 7 a possible concept for dual loadpath GRA is presented. More information can be found in [6]

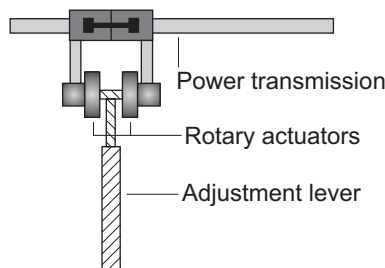


FIG. 7: Schematic representation of a fail safe actuator [6]

New Safety Device

The previously presented realization possibilities show some disadvantages. A third possibility is the use of a novel safety device. In failure cases the safety device must be able to attach the released DoF at each drive station of a track linkage kinematic supported flap. Therefore the motile carriage must be fixed (see figure 8). Because of the braking function and the integration into the track linkage kinematic it is called **Flap-Track Brake (FTB)**.

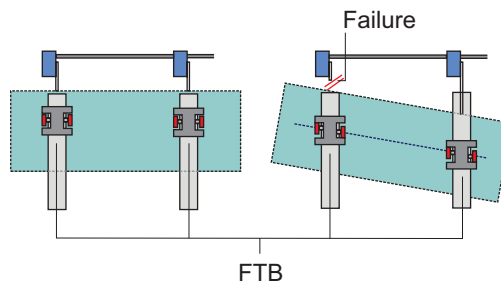


FIG. 8: Schematic representation of the fundamental functionality of a Flap-Track Brake

In addition to the safety device itself, a new system architecture and control and monitoring concept for the flap system must be taken considered. In the following, concepts and possible system configurations, in which the FTB can be integrated, will be introduced.

4 FLAP-TRACK BRAKE - OVERVIEW

The FTB needs an adjusted high-lift system architecture. However, performance and safety characteristics must be at least at the same level compared to conventional systems like shown in figure 2. This section gives an overview about regulations, a possible actuation system, an analysis of kinematics and a concept

of multi-body simulation use during the design phase.

4.1 Regulations

A new safety device must fulfill the mandatory regulations of the aviation authorities for high-lift systems. In the following, a brief insight of the principal regulations is given. The regulations of FAR-/CS-25 [7] are subdivided into individual sections, which are addressed to the different components (e.g. engine, structure, equipment). Additionally they pay attention to implementation guidelines, which are important for designing high-lift systems.

The loss of a high-lift system causes, due to the diversity of aircraft types, different effects. Thus the regulations do not state a specific value for maximum failure rates. Some typical values (given in *probability per flight hour (FH)*) for a medium-haul aircraft, according to [4], are shown below:

- Slats and/or flaps operating at reduced rate: $\leq 10^{-3}$
- Slats *or* flaps cannot longer be moved: $\leq 10^{-5}$
- Slats *and* flaps cannot longer be moved: $\leq 10^{-6}$
- Slats or flaps cannot longer be moved without warning or configuration indication: $\leq 10^{-9}$
- Runaway of flaps (driven by motor): $\leq 10^{-9}$
- Runaway of flaps (driven by airloads): $\leq 10^{-9}$
- Asymmetric flap movement: $\leq 10^{-9}$

§25.701 demands a synchronization of the left and right winged flaps:

*"Unless the airplane has safe flight characteristics with the flaps or slats retracted on one side and extended on the other, the motion of flaps or slats on opposite sides of the plane of symmetry must be **synchronized by a mechanical interconnection or approved equivalent means**"*

Control and safety systems of new single flap systems without mechanical coupling between flaps must prove the ability to replace the FIS and power transmission by robust and reliable monitoring functions. Besides the detection of failures, it is necessary to implement systems like the FTB, that are able to respond to failures, transfer the system into a safe state and give an indication to the pilot.

4.2 Possible Actuation System Architecture

The concept with a flap-track brake is targeted at single flap systems. Therefore a different drive system, compared to the conventional system (see 2) is needed. In the following a presumed target drive system will be introduced. The assumed actuation architecture refers to the actuation concept presented in [8].

The single flap panel is actuated by two drive stations, which must ensure, in combination with safety devices, that failures do not lead to catastrophic events. A redundant electrical PDU drives a shaft transmission, which connects the drive stations. Brakes are integrated into the PDU, to hold the system in normal mode and failure cases. The transmission between the drive stations is called cross-shaft. In figure 9 the cross-shaft is shown as a straight connection, which is a simplified representation. It is assumed, that the target wing requires the use of further components to guide the transmission trough the assembly space. These components are for example a line gear box or steady bearings. At each drive station an actuator is installed, that transforms the rotational movement of the transmission into the translational movement of the carriage.

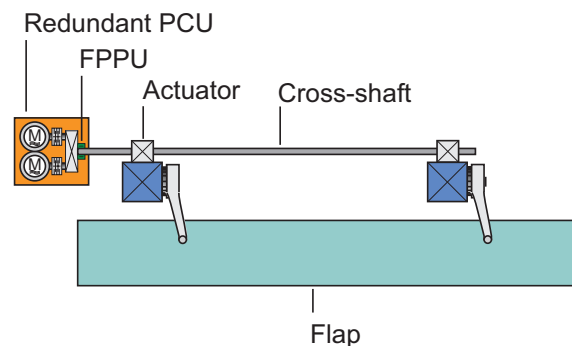


FIG. 9: Schematic representation of the target drive system referring to [8]

4.2.1 Failure Cases

In the introduced actuation system, several failure cases can occur. The resulting failure characteristics can be described as asymmetry and flap skew. The ability to react on a skewing flap and transfer the system to a safe state is the main task of the FTB. Depending on the final realization of the FTB, it may be possible to prevent asymmetry additionally.

Asymmetry

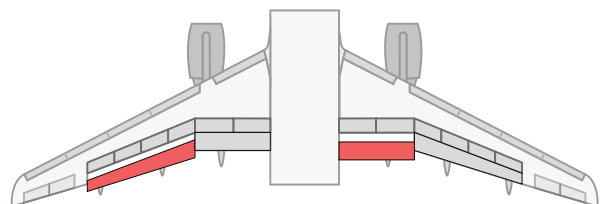


FIG. 10: Schematic representation of an exemplary asymmetric flap position

Figure 10 shows a situation with asymmetric flap extension. For single flap systems a distinction between

intended an unintended asymmetry must be made. An intended asymmetry is part of the extended functionality of the single flap systems. A roll moment provoked by aircraft unbalances can be compensated by a commanded asymmetry.

A unintended asymmetry can cause a roll moment, which can not be compensated by other control surfaces, which leads to a potentially catastrophic situation. Possible causes for a unintended asymmetry are:

- *Powered runaway*: A failure in the PDU control commands, a flap extension at too high or low speed, in the wrong direction or at the incorrect time.
- *Unpowered runaway*: The system can move freely caused by a loss of the mechanical coupling between PDU and drive transmission. Along with the aerodynamic loads the flap can be displaced.

Flap Skew

A flap skew can occur by losing the torque transmission between shaft transmission and flap. Figure 11 shows the scenario of a skewing flap.

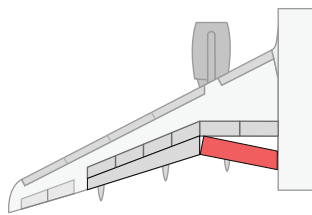


FIG. 11: Schematic representation of flap skew

Possible causes of this failure are:

- A drive strut break and
- Actuator failure, which leads to a freewheeling drive station.

A failure combined with maximum airloads can damage the whole structural integrity of the flap system. In the worst case a flap panel can be lost and may end in a catastrophic event. To avoid these consequences a FTB with suitable kinematics is needed, which are described in the following section.

4.3 Kinematics of Exemplary Single Flap Systems

In figure 12 a schematic illustration of the target system kinematics are shown. The represented outboard flap kinematics are closely related to the Airbus A320 outboard flap support. One drive station represents the so called master track, the other side the slave track. In contrast to the master track the slave track allows a translational motion in spanwise direction. A possible safety device should not affect the faultless flap system, but must ensure the attachment of a freewheeling system after a drive strut burst.

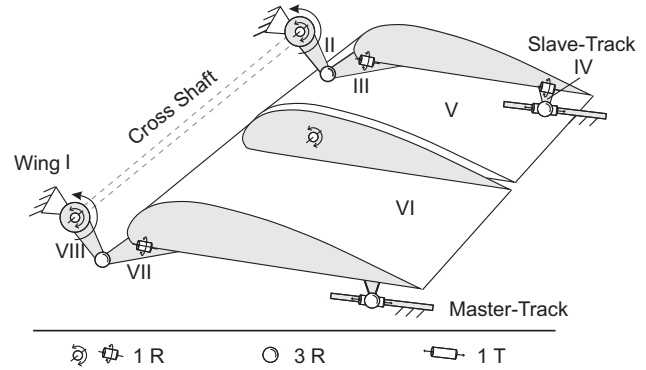


FIG. 12: Schematic illustration of the kinematics of the target system following [9]

According to [10] the degrees of freedom (DoF) can be calculated with equation 1. With the drive system, shown in figure 9, no direct kinematic coupling between the drive stations due to backlash in the shaft transmission exists, in normal operation.

$$\begin{aligned}
 (1) \quad F &= 6 \cdot (n - 1) - 6 \cdot g + \sum_1^g f \\
 (2) &= 6 \cdot (8 - 1) - 6 \cdot 10 + 20 = 2
 \end{aligned}$$

- n – Number of gear elements
- g – Number of joints
- f – Degrees of freedom of the joint

The result of equation 1 shows a DoF of two for the target system by assuming rigid bodies and ideal joints. That means that the revolute joints at the actuators can be moved independently from one other. It is recalled that the flap is divided into two parts, connected by a revolute joint.

A breaking drive strut leads, with equation 1, to a $DoF = 3$. By fixing the free moving carriage and the intact drive station via the shaft transmission, the DoF is reduced to one. The remaining DoF must be constrained by the torsion stiffness of the flap panel. Consequently, the flap panel must be designed, so that the torsion displacement will be kept in acceptable limits.

4.4 Preliminary Investigation with Co-Simulation

This section gives an introduction about a co-simulation concept that will be used for preliminary investigations of the FTB. Multi-body simulation (MBS) reproduce real systems with rigid bodies and ideal joints. MBS can be used for example to analyze loads, velocities and accelerations acting on the FTB. For receiving conclusive results, the following characteristics are significant:

- *Representative modelling of the geometry* - Only with representative geometrical dimensions the load and lever ratios are meaningful and the load can be analyzed expediently.

- *Representative modelling of the kinematic behavior* - The correct implementation of DoF and joints ensures a correct movement behavior compared to the real system.
- *Use of representative airloads* - The different positions of the flap deployment cause different airloads. The acting airloads are divided into normal and tangential components. Figure 13 shows the changing airloads depending on the flap angle. The extension of the spoiler has also an influence on the applied airload. Figure 14 shows the load distribution along spanwise flap direction for different flap angles. Including the dependency of flap angle and spanwise load distribution gives a more precise representation of the real load situation and the failure cases get special characteristics depending on the flap extension angle.
- *Representative characteristics of the flap panel* - To analyze the impact of the flap panel flexibility effects on failure characteristic, the panel must represent the panel properties. A main task of the panel in failure cases, as described in section 4.3, is to constrain a DoF due to the torsion stiffness. Modelling a panel with false torsion stiffness would affect the simulation results negatively.

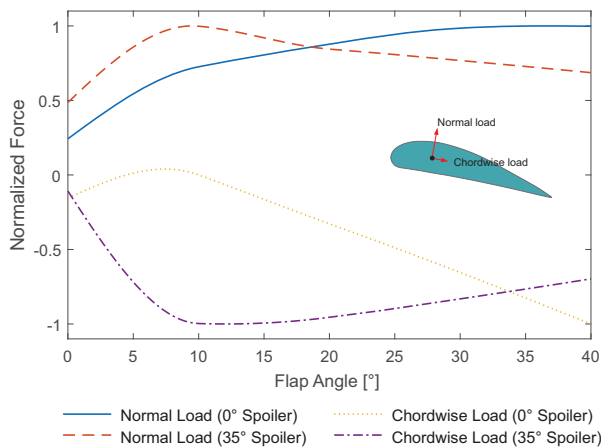


FIG. 13: Total airloads depending on the flap angle and spoiler deployment

As a MSB modeling environment the tool MSC.ADAMS can be used. To get more detailed investigation results, the model of the drive transmission created in MATLAB/SIMULINK and the MBS model can be coupled via co-simulation. Figure 15 presents the principle of the concept. This way it is possible to investigate the influence of the actuation system on the FTB. In [9] a detailed presentation of the co-simulation possibilities is given.

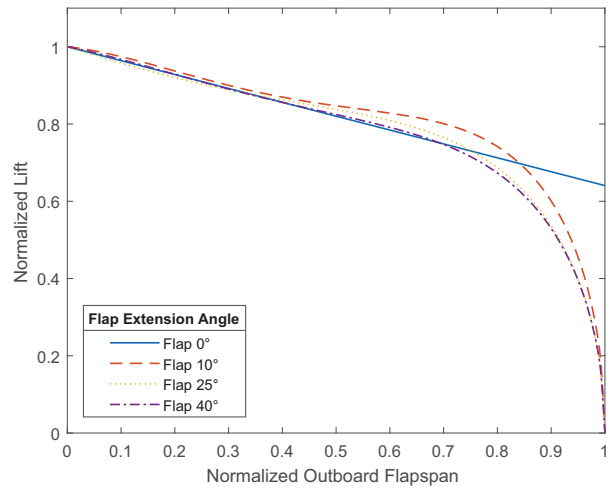


FIG. 14: Spanwise loads distribution of the outboard flap

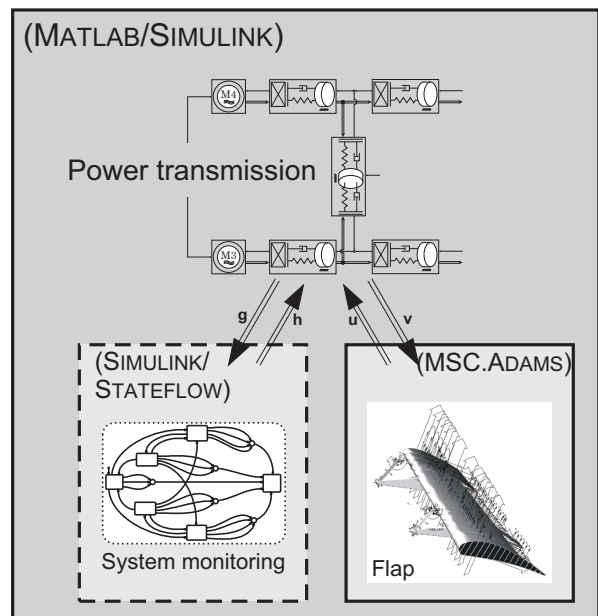


FIG. 15: Principle of co-simulation of ADAMS and SIMULINK/STATEFLOW after [9]

A step further is the additional integration of a monitoring system modeled in MATLAB/STATEFLOW. This allows to investigate the influence and accuracy of the different monitoring functions.

With an enhanced knowledge of the final FTB design the MBS co-simulation can be sharpened and results with more validity are available.

5 CONCEPTS FOR A FLAP-TRACK BRAKE

For the realization of the FTB some general constraints have to be established. In the following, principle requirements will be presented.

- The reliability and mean time between failure

(MTBF) must be at least equal to comparable Airbus A320 airplanes

- The maximum flap skew must not exceed $\alpha = 4,55^\circ$ (see figure 16).
- The FTB should not exceed the installation space actual Airbus A320 like airplanes provide.
- The FTB must be easy to maintain and durable.
- The activated FTB must be easy to identify. This can be realized by sensors or a mechanical indicator. The pilot must be informed about malfunctions of the flap system.

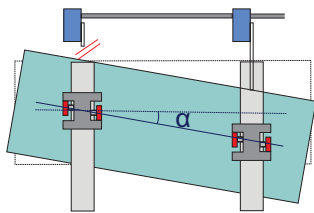


FIG. 16: Flap skew angle

The active braking part of the FTB can be installed either into the carriage or into the trackbeam assembly. The following part will present some general considerations how a FTB could be implemented.

5.1 Concepts with Carriage Integration

The basic idea is to implement the active braking mechanism into the carriage. The exterior shape and the leading rolls arrangement of the carriage should resemble the original carriage. Because of the movement of the carriage along the trackbeam no robust interfaces for power supply or sensor cables can be used. Therefore the FTB must be released mechanically via relative motions between flap panel and support kinematics. The necessary braking energy must be stored in the carriage. Spring assemblies can be used to move the locking mechanism or to provide the braking force directly. It should be pointed out, that the release mechanism is not part of this paper.

5.1.1 Concept 1 - Form-Locking Via Gear Wheels

This concept is based on the form closure principle and is shown in figure 17. The track is adapted with two parallel and continuous gear racks. The leading gears are permanently meshed with the gear rack and freewheeling during normal operation. Therefore they do not transmit any torque. The gears are lifetime-lubricated and pivoted at the guide axles of the carriage.

In the locking-case, the freewheeling gears are fixed by slide-in gears (marked blue in figure 18). These slide-in gears are actuated via pre-loaded springs (green springs).

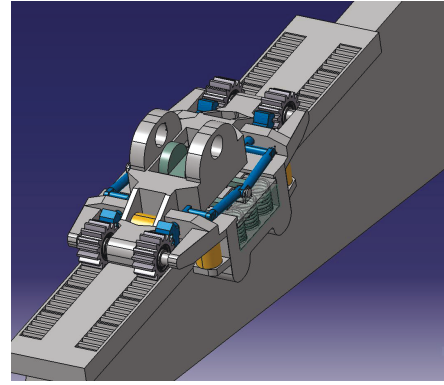


FIG. 17: Concept 1: Form-Locking with gear wheels

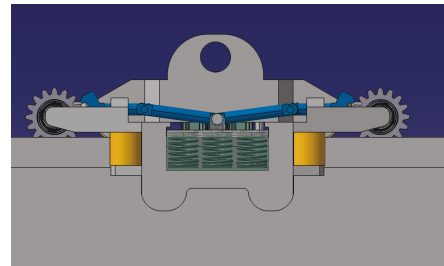


FIG. 18: Side view of concept 1

The carriage is locked and can no longer be moved. To release the brake the springs have to be compressed manually, which pulls back the slide-in gears.

5.1.2 Concept 2 - Force Fit

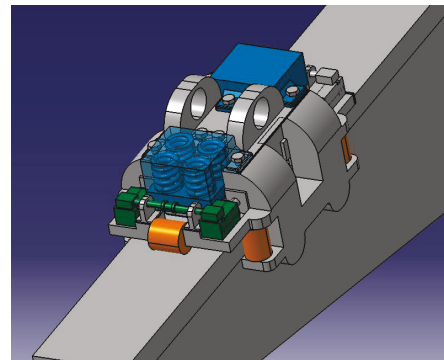


FIG. 19: Concept 2: Force Fit with two friction linings

Two friction linings, positioned at the front and back of the carriage (see figure 19), are pressed on the track by pre-loaded springs. The carriage is locked by the friction forces. In this approach the track doesn't need large adjustment compared to conventional tracks.

Two springs at each friction lining apply the necessary force (see figure 20). The main challenge of this concept is to provide the necessary friction force at all environmental conditions. Especially friction reducing conditions like ice, oil or water on the track have to be considered into the spring dimensioning.

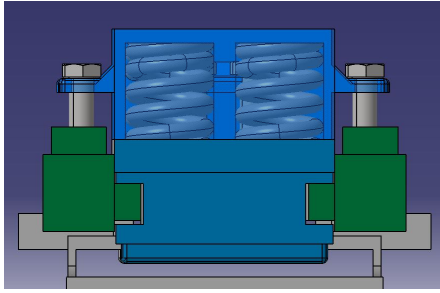


FIG. 20: Front view of the friction lining with springs

5.1.3 Concept 3 - Form Closure Via Blocking

Figure 21 shows the principle behind concept 3. In the front and rear of the carriage, bricks are installed, which were hold up in normal operation. The track is equipped with protruding blocking teeth. In case of failure the bricks are released and pushed down by integrated springs. The movement will be stopped by the bricks jamming on the blocking teeth.

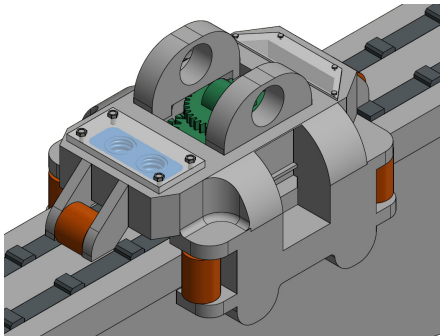


FIG. 21: Concept 3: Form Closure with blocking bricks

5.1.4 Evaluation

The various concepts for the carriage integrated FTB were assessed according to the guideline VDI 2225 [11]. For calculation only the braking mechanism is considered. The release mechanism was not taken into account. In order to assess the different concepts different criteria were rated from unsatisfactory (0) to very good (4). Because of the early degree of maturity a low level of information and concreteness is available. Therefore the rating range is kept small, like the VDI 2225 propose. The established criteria are:

1. - Possible failure of the braking mechanism
2. - Complexity of the braking mechanism
3. - Expected manufacturing costs
4. - Needed assembly space
5. - Effort of disassembling the released FTB
6. - Possible system damage in case of activation

Each criteria is weighted by a factor, which allows a differentiation between the importance of each criteria. The results of this rating are shown in table 1.

The final assessment values of all concepts are very small. Referring to [11] a rating under 0.6 is dissatisfying. This indicates that a realization of a track integrated brake seems to be difficult.

The highest rated concept is concept 1, followed by concept 3. Nevertheless **concept 1** has some issues, which need to be investigated in more detail. For example the question if dirt, ice or other foreign objects at the gear rack can cause a jam in normal operation. A jam can lead to an aircraft on ground and has to be avoided in any case. Furthermore, analyses of the locking shock, the huge resulting loads and the following effects at the whole flap system must be executed. Moreover the customization of the track will lead to an increase in manufacturing costs.

Providing the needed brake force in **concept 2** is very challenging and results in the worst rated concept. Generating the force via springs is not practicable. The high pre-loaded springs lead to strengthening of the carriage, that increases the weight of the carriage unacceptably. Especially for situations where the coefficient of friction is reduced (ice, oil pollution), high friction forces are necessary. An optimization of the design may reduces the needed forces, but they still remain high.

Concept 3 needs also an adaption of the track, which causes costs and makes the track more vulnerable to environmental influences (ice, dirt, etc.). In case of braking events the resulting damage can require a change of the whole track because of irreparable damage due to shocks. Like concept 1 possible effects of locking shocks are difficult to predict.

Therefore, all three concepts can not been seen as acceptable solutions. For solving the challenges new designs, system architectures and innovative manufacturing solutions (e.g. 3D-print) must be taken into consideration.

6 SUMMARY AND OUTLOOK

In the present paper a system architecture, a possible investigation method and different concepts for safety devices integrated into track linkage kinematics for single flap systems with enhanced functionality were presented. Single flap system enable an in-flight adjustment of the wing load. Among other advantages single flap systems retain in failure cases a higher functionality compared to conventional high-lift systems. Different failure cases, including flap skew, were described, which desire a new safety device. The general idea of this safety device, called flap track brake (FTB), was explained on the basis of exemplary actuation and kinematic configurations. In principle the possibilities to integrate the FTB into the carriage were

TAB. 1: Concept assessment according to [11]

Criteria	Weight	Con. 1	Con. 2	Con. 3
1. Possible failure of the braking mechanism	2	2	1	2
2. Complexity of the braking mechanism	2	2	1	2
3. Manufacturing costs	2	3	1	2
4. Needed assembly space	1	1	2	1
5. Effort of disassembling the released FTB	1	3	1	2
6. Possible damage in case of activation	1	3	3	2
Number of points		21	12	17
Maximum number of points		40	40	40
Rating		0.53	0.3	0.43

identified. Therefore various concepts were presented and discussed. For the carriage integrated solution an evaluation according to the guideline VDI 2225 was conducted. As a result of this evaluation it turned out, that carriage integrated FTB concepts do not fulfill the needed demands.

Further work had to drive new FTB concepts forward. Therefore, to solve the appeared problems, innovative technologies and designs must be taken into consideration. Furthermore, simulation models, like the here presented possibility of co-simulated multi-body simulations, can be used to investigate the loads and accelerations. Investigations on a real FTB demonstrator can be used to validate the simulation models and analyze the real behavior of the safety device in different system states.

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