METHODOLOGY FOR THE DESIGN AND EVALUATION OF WING LEADING EDGE AND TRAILING EDGE DEVICES

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Abstract

This paper presents the development of a methodology for the design and evaluation of wing Leading Edge (LE) and Trailing Edge (TE) devices. This methodology covers the design of such devices, considering different aspects such as mass, reliability, structure and aerodynamic improvements. This paper will present the methodology but also show a case study of its use. The results of this case study will be then discussed and conclusions made.

1 General Introduction

The current technology development trend is to optimize the design and calculation processes using specific comparisons tools, though little has been done to actually look at new ways of designing wing moveable devices. Improving the design methodology would provide a quicker time to produce designs and ultimately finally improved designs.

The first part of this paper will present the methodology in details; and this will include a description of the method and tool used for the improvement of the overall design process. This methodology covers different aspects of the LE and TE design.

A description of the method used will be given to validate the methodology and each part of it.

This paper will describe the use of this methodology by a specific case study to show how the use of the developed methodology can be applied for research and development of new concepts, and in this case also looking at variable camber devices.

Following the case study, discussion of the results will provide a detailed explanation of the advantages and disadvantages of using the new methodology.

This discussion of the results is followed by conclusions which will give further information on how the methodology could be used and applied in today’s aerospace industry, and recommendations for future work.

2 Methodology

For many years, the design of the wing movables surfaces (LE and TE) has been late in the design process. That means that most of the wing configuration was defined and then the LE and TE would then be fitted, but there was little consideration on how to improve such devices at an early design stage .The overall aim of any design is to use as detailed a design methodology, as early as possible to improve accuracy.

It was therefore decided to develop a totally new methodology to design wing movable surfaces to take them it into account at an early design stage in the overall design process. Different parameters linked with the LE and TE devices can have massive implications in the Direct Operation Cost (DOC) of the aircraft. Parameters such as overall mass, final reliability of impact on the drag can affect the cost of running an aircraft. These different aspects of

the design process can be organized and new tools or method will be developed in order to improve the design, and also reduce the time to design.
The methodology developed for this research includes all these aspects in an organized and structured manner. It allows clear understanding of the design process, and shows where new tools are used. This methodology presents a common framework for the design of both the LE and TE devices; however it is important to see that there will be some tools used only for the design of one or the other device. For example, drag estimation is less likely to be required for the design of LE mechanisms, as they are normally included in the wing. Conversely, the TE devices will sometimes have mechanism fairings added, and so will create drag. The aim of this methodology is not only to have specific tools for both types of devices (LE & TE) but also to have a combined design methodology for the design of these devices.

Fig. 1 shows a schematic of the overall methodology. Subsequent paragraphs will describe individual blocks.

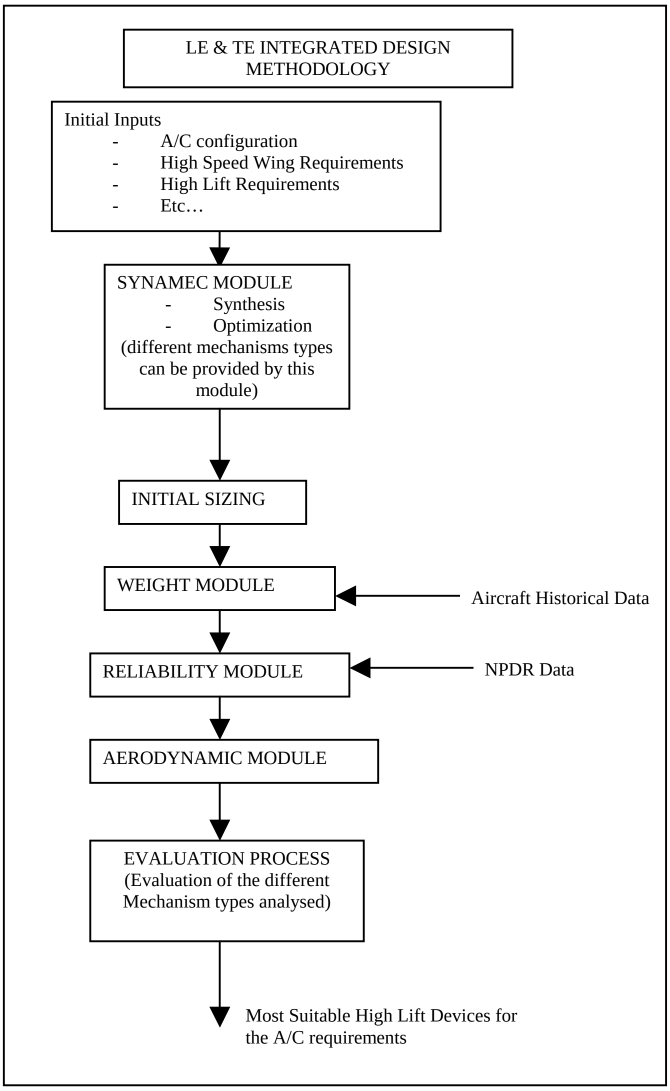


Fig. 1: Methodology graph

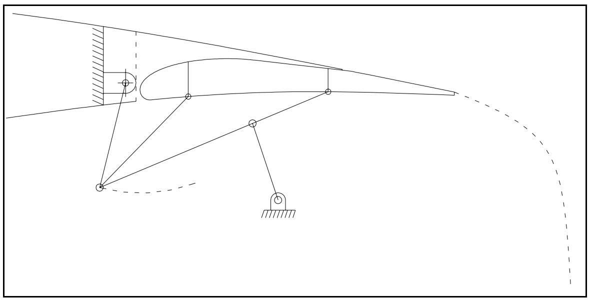


Fig. 2: Example of TE mechanism

3 Design Constraints

The design method is initially limited to single slotted TE devices and classical LE devices. This is similar to that shown in 2 for the TE.

The wing area, sweep angle, aspect ratio, twist and thickness are defined: lift, drag and pitching movements are predetermined during the aircraft conceptual design process.

Also, this methodology is limited to 2D analysis of mechanisms.

4 Details on the Different Tools

The overall principle of this design methodology has been explained above. However, it is necessary to describe each part of the methodology before describing a case study. The following paragraphs explain in more detail each module of the methodology for a clearer understanding on how they work and what kind of results are expected.

4.1 Mechanism Synthesis and Optimization

The synthesis of new mechanism is done using a new tool called SYNAMEC developed by a European consortium [1]. SYNAMEC is a recently concluded European Project, has provided very innovative work of research and development in the area of mechanism type synthesis and design. This work has brought a new approach to the early stages of the mechanism design process. The main objective of the project was to develop a computer-aided design and engineering software system for the synthesis of aeronautical mechanisms. The SYNAMEC System is capable of covering all the design stages of the mechanism design procedure, from mechanism type synthesis to preliminary and detailed design, and it is the main feature of the proposed methodology. Also the main advantage of this software is to generate automatically kinematics chains and joints with an already dimensioned mechanism which comply with the given support point and deployment trajectory.

The SYNAMEC SYSTEM design methodology is divided into 2 different stages: Type Synthesis and Dimensional Synthesis. These stages are all managed through 1 user interface that connects them, but can be used independently of each other.

At this point of the design process, the designer is required to provide the basic requirements for the mechanism. The mechanism type synthesis can be generated using these basic parameters. These requirements are usually in the form of known fixation points (usually a point randomly taken from a zone), a link member, hinge typical rotation angles or linear displacements, and 3 points of the objective trajectory, usually start, middle and end.
This information will allow the system to provide the designer with solutions for the problem that comply with the initial requirements (Fig 4).

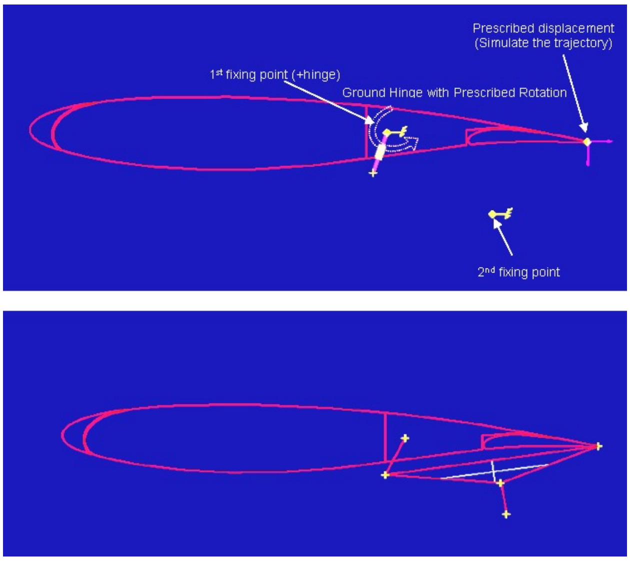


Fig. 3: Input data and solution from the type synthesis

The dimensional synthesis stage of the SYNAMEC Module is where the results of the type Synthesis are tuned for more accurate solutions. At this stage the designer can optimize parameters such as the gap, overlap, mechanism depth, etc...

It is important to point out that the solutions provided by the type synthesis stage are very basic, for example the mechanism solution provided passes through the 3 provided points of the objective trajectory, but might not pass through all the points of the same curve. The mechanism also passes through the required points for the initial deployment angle. Any changes to the value of the angle will change the deployment trajectory of the mechanism. However, using the optimization tool it is possible to further refine the final solution.

All these issues are taken into consideration at this stage and the end result is a more precise solution that complies with the high-lift design requirements.

4.2 Initial Sizing

A Visual Basic application was developed with the purpose of providing the new design methodology with information about the sizes of mechanism components. This application focuses on the definition of sizing methods for mechanism components by assuming generic mechanism configurations. The current application does sizing for components of 4 types of Mechanisms: Simple Hinge, 4 bar Linkage, Link Track and Hooked Track. Each of the previous mechanisms was decomposed and generic components defined, such as Pins, Links, Hinges and Fittings. To each of the previous elements, a specific sizing method can be created.

The VB application receives as inputs the mechanism coordinates and applied load, and using standard static calculations, determines the loads in each element and dimensions for each component.

The results of this module allow the designer to create a 3D model of the mechanism and will also provide information for the next stage of the methodology, the Weight Estimation.

4.3 Mass estimation

When designing a new aircraft mass is always a primary concern as it will influence the flying behaviour, but it will also largely affect the cost of running the aircraft and its economic viability. The less the mass of the aircraft, the more payload could be carried for an aircraft with the same lift characteristic. The cost of carrying extra mass when not part of the payload will decrease the possible profit as this extra mass will be an extra cost as the fuel burnt to fly the aircraft will increase. Doing an early mass estimation for the overall aircraft is therefore very important. Only the mass estimation for LE and TE devices has been performed as previous conceptual mass estimation tools were inadequate.

A new tool has been developed for the estimation of the mass of the different types of LE and TE devices mechanism, which depends on the number and size of the different panels on the wing. A totally new estimation method has been developed into an Excel spreadsheet to make the calculation process quicker and a lot easier. Users can easily compare the mass of the different types of devices, and also the effect of possible changes of configuration. These can includes changes of dimension, numbers of panel for inboard/central/outboard section of the wing.

The newly developed tool for the mass estimation uses a two layer structure, the primary layer being a more generic level (aircraft level), and the second level being a more precise level (mechanism type and component level). The first layer describes the overall dimension of the panels, the number of panels, the mass of the device for each section and the final overall mass for the LE and TE device.

The mass of the trailing edge flaps can be divided into four parts:

-Flap panels (Assumed that there is little variation between the different types of mechanisms)

-Actuation and Controls (depends on the type of actuation and it is not used in this work)

-Support and Linkages (volumes of each component are provided by the VB program and depending of the materials used the weights are calculated)

-Fairings (a typical value of weight per area is used to get the weights of these elements).

4.4 Reliability estimation

In any aircraft design it is important to consider the effect of the reliability of the different components of the different systems. The reliability of these components has a direct effect on the DOC by means of maintenance cost. It is interesting to consider the effect of reliability at an early design stage in order to optimize the overall cost when running the aircraft. This has even more implications for an airline as they normally run fleets of the same aircraft. The choice of one type of device compared to another one could mean thousands of pounds overspent compared to using another types of device. In order to estimate the reliability of the different type of devices at the TE and the LE it was decided to develop an entirely new tool. This will allow engineers and designers to quickly see the effect of using one type of device compared to other ones. Also the user can modify the given type of devices by adapting the number of components or the failure rate for each of them.

The part count theory was used for the overall development of this tool. The tool is based on the same structure as the mass estimation tool as it has two level, with the general or aircraft level describing the overall configuration of the aircraft as well as the reliability results. The second level or device level is more precise and in fact describes the reliability of the different components used in the different types of devices.

This second layer is connected directly to the first general layer as it gives the particular device reliability and the general level.

4.5 Aerodynamic Performance

Both LE and TE devices are analyzed in terms of aerodynamic performance.

The aerodynamic performance of each TE device is assessed in term of associated fairing drag and aerodynamic performance at the take off configuration, since every mechanism is optimized to guarantee the aerodynamic performance for landing.

After the mechanism optimization and Initial sizing, each TE device mechanism is assessed in terms of depth, width and length to determine the fairing areas required and, drag calculation performed. This calculation is based on the Hoerner equations [2] and the ESDU datasheet 79015 ("Undercarriage drag prediction methods”, 1987).

5 Evaluation Process

The evaluation process can be performed using the output of the different modules. Each part of the methodology gives one or more results, and it is possible to get several solutions. When merging all the results it is possible to get an optimum design for a chosen concept.

The evaluation is generally done using a results table with coefficients (or rankings) to see which solution is the best for each module and also for the overall methodology. By grouping (or adding) all these results it is easy to see which type of mechanism and which geometry will provide the best overall performance. The evaluation process can be based on different objective functions. It also has to be noticed that the final result is largely influenced by the original objectives. These can be very different, depending on what the final solution should be. It depends if it is expected to have a very reliable solution to be used in extreme conditions, or if it is to have the lightest option.

6 Case Studies and results

It was decided to use a case study to show how to use the methodology and also to see if the methodology could actually improve the overall design of LE and TE, with emphasis on variable camber flaps. For this case study it was decided to use a regional commercial aircraft design used for some research at Cranfield University. This aircraft is called the ATRA (Advanced Transport Regional Aircraft) and is similar to an Airbus A320 (Fig. 4).

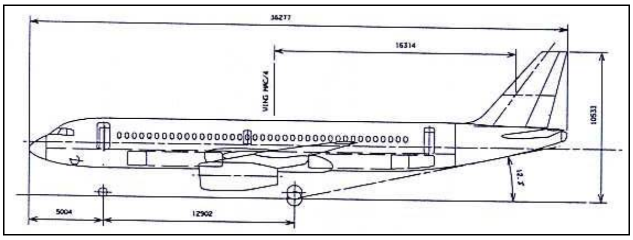


Fig. 4: Picture of the ATRA

The ATRA consist of a family of three derivative aircrafts designated ATRA 80, ATRA 100 and ATRA 130, where the numbers represent the passenger capacity. The ATRA family uses the same airfoil and wing planform,

and also feature Variable Camber Flaps (VCF) and HLFC technology.
For the case study it has been assumed that the planform and wing area are taken from the ATRA used and studied by Ammoo [3] and Edi [4]. Most of the focus will be on the improvement during the analysis stage due to the availability of the new analysis tools. Emphasis will also be made on investigating innovative solutions for the deployment of the LE device.

The ATRA wing planform is taken directly from data in Ammoo's research [3] which was selected after comparing data from existing aircraft.

The wing planform parameters are as described below:
-¼ chord sweep = 25 Deg.
-Taper ratio = 0.274
-Aspect Ratio (AR) = 9.5
-Wing area (S) =110.21 m^2
-Inbrd. section span (inbrd.=>kink)= 4273 mm
-Outbrd. section span (kink=>tip)= 10192 mm

6.1 Mechanism Synthesis and Optimization

Using the initial optimum high lift requirements established by Edi and Ammo for the ATRA, three different types of mechanism were optimized to achieve the required gap at landing configuration.
The optimization has 2 objective functions, minimize the gap and the TE point for the landing configuration, and 8 variables, the coordinates of all the rotation points of the mechanism.
Three different mechanisms were analysed and optimised:

- Simple hinge
- 4 Bar
- Link/ Track

Fig. 5 presents the optimization curves for the 4 bar mechanism.

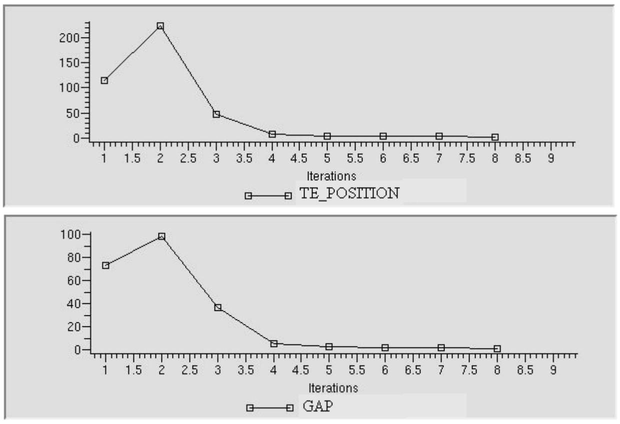
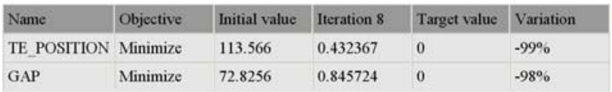


Fig. 5: Optimisation graph for TE mechanism study (4 Bar Mechanism)



Name	Objective	Initial value	Iteration 8	Target value	Variation
TE_POSITION	Minimize	113.566	0.432367	0	-99%
GAP	Minimize	72.8256	0.845724	0	-98%

Fig. 6: Optimisation graph for TE mechanism study (4 Bar Mechanism)

The optimisation run is quite as can be seen on fig 5. Though for more complex models like a Link/Track mechanism, that has more objective functions and variables it can take up to30 iterations

6.2 Initial Sizing

With the results from the previous module it is then possible for the designer to determine the initial size of the components for the different mechanisms using the Initial Sizing VB application.
Once the designer has gathered the results from the Sizing application he should be able to generate the preliminary CAD models for the different mechanisms, as seen in Fig. 7.

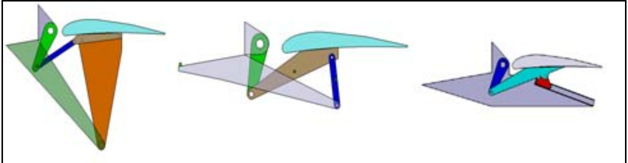
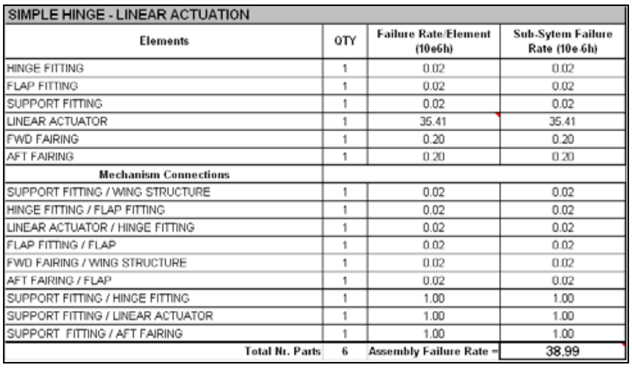
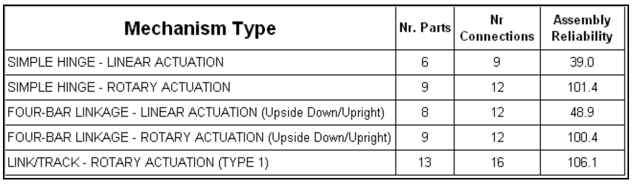


Fig. 7: CAD models of the TE mechanisms after initial sizing

With the CAD models available it is possible to determine a relative measure of the mechanisms reliability, by looking at the number of components and types of actuation available for each mechanism type, and compare them.



SIMPLE HINGE - LINEAR ACTUATION			
Elements	**QTY**	**Failure Rate/Element (10e6h)**	**Sub-Sytem Failure Rate (10e-6h)**
HINGE FITTING	1	0.02	0.02
FLAP FITTING	1	0.02	0.02
SUPPORT FITTING	1	0.02	0.02
LINEAR ACTUATOR	1	35.41	35.41
FWD FAIRING	1	0.20	0.20
AFT FAIRING	1	0.20	0.20
Mechanism Connections			
SUPPORT FITTING / WING STRUCTURE	1	0.02	0.02
HINGE FITTING / FLAP FITTING	1	0.02	0.02
LINEAR ACTUATOR / HINGE FITTING	1	0.02	0.02
FLAP FITTING / FLAP	1	0.02	0.02
FWD FAIRING / WING STRUCTURE	1	0.02	0.02
AFT FAIRING / FLAP	1	0.02	0.02
SUPPORT FITTING / HINGE FITTING	1	1.00	1.00
SUPPORT FITTING / LINEAR ACTUATOR	1	1.00	1.00
SUPPORT FITTING / AFT FAIRING	1	1.00	1.00
Total Nr. Parts	**6**	**Assembly Failure Rate =**	38.99



Mechanism Type	Nr. Parts	Nr Connections	Assembly Reliability
SIMPLE HINGE - LINEAR ACTUATION	6	9	39.0
SIMPLE HINGE - ROTARY ACTUATION	9	12	101.4
FOUR-BAR LINKAGE - LINEAR ACTUATION (Upside Down/Upright)	8	12	48.9
FOUR-BAR LINKAGE - ROTARY ACTUATION (Upside Down/Upright)	9	12	100.4
LINK/TRACK - ROTARY ACTUATION (TYPE 1)	13	16	106.1

Table 1: Mechanism description

The mechanism design and optimisation have shown great results for the TE, but for the following part the LE will be studied. The methodology works for both LE and TE.

For the weight and reliability estimation case study it has been decided to show the results using the LE.

6.3 Weight estimation

The weight estimation has been done using the program developed especially for this application. For this case study the authors have used the ATRA original wing planform and separated the LE in two sections (the inboard and the outboard section). Each of these two sections can then be subdivided in many panels, and use different type of mechanisms. By using the ATRA dimensions and also the weight estimation tool it is possible to analyse the overall effect of the potential LE mechanism on the overall aircraft mass.

Has in many other aircraft it has been decided to use 80% of the LE span with movable LE devices. The weight estimation tool provides a full set of results for the possible different configurations. It is then possible to display a full graph of the different weight. From there it is possible to extract what the optimum solution will be. The graph displaying the results is available at the end of this report (see Fig. 7 on page 10).

As expected the configuration using Krueger flap mechanisms (bull nose and variable camber) generally generate a higher weight due to the complexity of the mechanisms, however the fixed Krueger flap option is much lighter than the other types. This difference of mechanisms can have a huge impact on the aircraft mass, as there could be a maximum of 2000kg difference between the extreme configurations. However, this difference does not appear to be so important for the other types of mechanisms. The different configuration appears to be within a medium weight range and do not differ by more than 1000kg. Even if this represents quite a lot of weight and would ultimately have a cost, it is still not has bad as the extremes shown before.

Despite the mass the effect of the different concepts would give different performances and so will have a beneficial impact on the fuel consumption or on the landing and take off performances. This why the slat track mechanism comes as first choice, even if it is a solution which is on the top of the medium range of weights, the cost of manufacturing and designing this type of mechanism is generally lower. So for this case study, and in relation to the mass it is recommended to choose the option with 2 panels inboard and 4 panels outboard for a total weight of around 1726 kg for the wings LE systems (863kg for one side as shown on the graph).

6.4 Reliability estimation

The reliability estimation for this case study has been done following the same procedures as the weight estimation and using the same “input” set of data (type of devices, span, number of panels). The optimum reliability will correspond to the configuration having the lowest failure rate.

The reliability estimation for the same type of configurations is shown on Fig.8 in page 10, this figure shows clearly that there are tow groups of mechanisms appearing. These two groups are clearly separated and the slat track mechanism option appears to be one of the least reliable compare to the other options. This is due to the number of bearings and sliders which directly affect the time to failure of the overall mechanism. The other options which include fixed Krueger flap and bull nose concepts, these solutions are much more reliable due to the lower number of part with a low reliability or time to first failure.

6.5 Aerodynamic Performance

The results available from Initial Sizing and CAD modelling allow the designer to access the mechanism size and establish a fairing size, which can then be used to calculate the increment in drag for each mechanism.

Also each mechanism has a different deployment trajectory and it is possible to calculate which mechanism has the best landing performance by analysing the gap at the landing configuration.

MECHANISM TYPE	Increment in Drag	% of Total A/C Drag
SIMPLE HINGE	0.0000581	0.29
FOUR-BAR LINKAGE	0.0003562	1.78
LINK/TRACK	0.0003107	1.55

Table 2: Drag Fairing estimation

7 Discussion

The methodology presented in this paper clearly shows the possible improvements for the design of LE and TE at the early design stage; however it has also shown to be complete with the use of different innovative tools which will speed up the overall design process.

The advantage of this methodology is to reduce the time to design by helping aircraft designers to create (or investigate) different concepts and see quickly the effect of these concepts in term of mass, reliability or complexity.

Also the mechanism design side of the methodology provides the user with an efficient tool to investigate different design solutions to fit difficult deployment trajectories. It is important to point out that the solutions provided by the Type Synthesis stage are very simple, for example the mechanism solution provided passes through the 3 provided points of the objective trajectory, but might not pass through all the points of the same curve. However, using the optimisation tool is it possible to further refine the final solution.

The different estimation tools presented have shown to be particularly quick and simple to use and provide interesting sets of results.

For the estimation tools (mass and reliability) it is clear that they provide quick results for conceptual studies, and they also give a better understanding of the possible final effect on the overall aircraft depending on the different. However, at this stage of the research the tool do not provide an associated cost estimation to the effect of carrying more weight or having less reliable LE and TE systems. The results found in this research prove useful but are not quantified in financial terms.

8 Conclusion

The overall methodology described in this paper has been shown to cover many aspects of the TE and LE device design from conceptual to preliminary design. It has also been shown that this methodology if used correctly could give improved information in the design process. Each module of the methodology clearly improves the design process. The results obtained in the case study showed a relative improvement in the chosen design compared to the more traditional approach.

Using this methodology also gives the opportunity to investigate and generate more innovative designs. Another advantage of this methodology is to give a good evaluation for different aspects of the design at an early stage.

Following this research it could be possible to add a cost estimation module to be linked to the mass and reliability tools. Also it could be possible to link a manufacturing estimation tool to the mechanism design which will increase the complexity of the manufacturing process depending on the complexity of the given mechanism.

Also another area that could be investigated or developed further will be a small and quick aerodynamic estimation for the different types of LE and TE devices.

Acknowledgments

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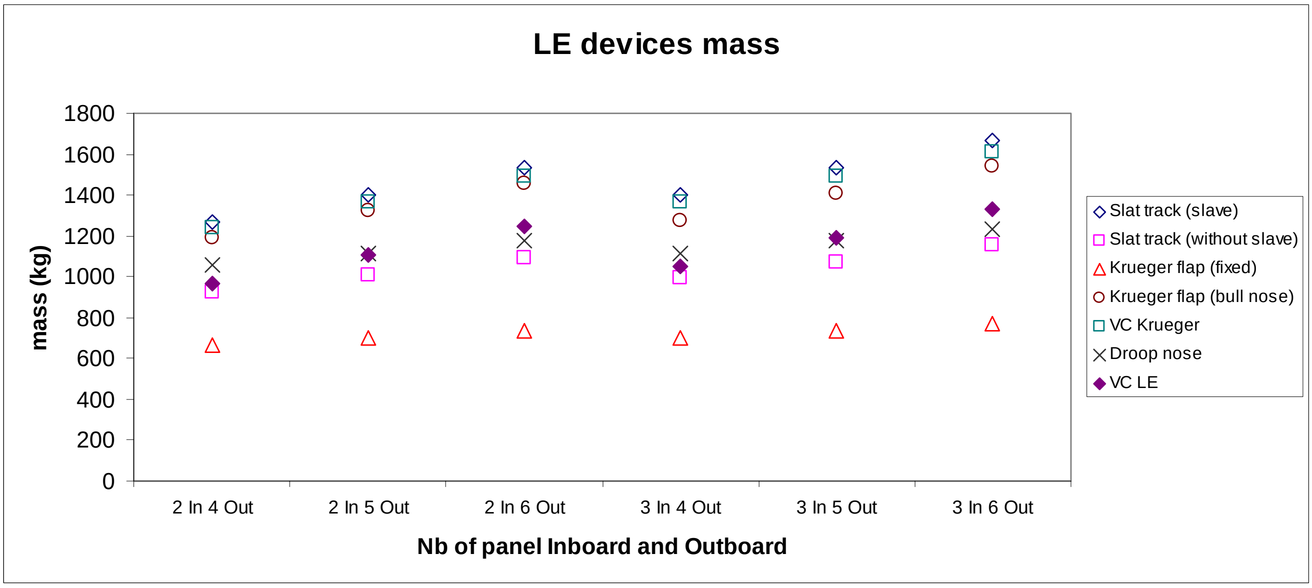

Fig. 7: Weight estimation results for LE (case study)

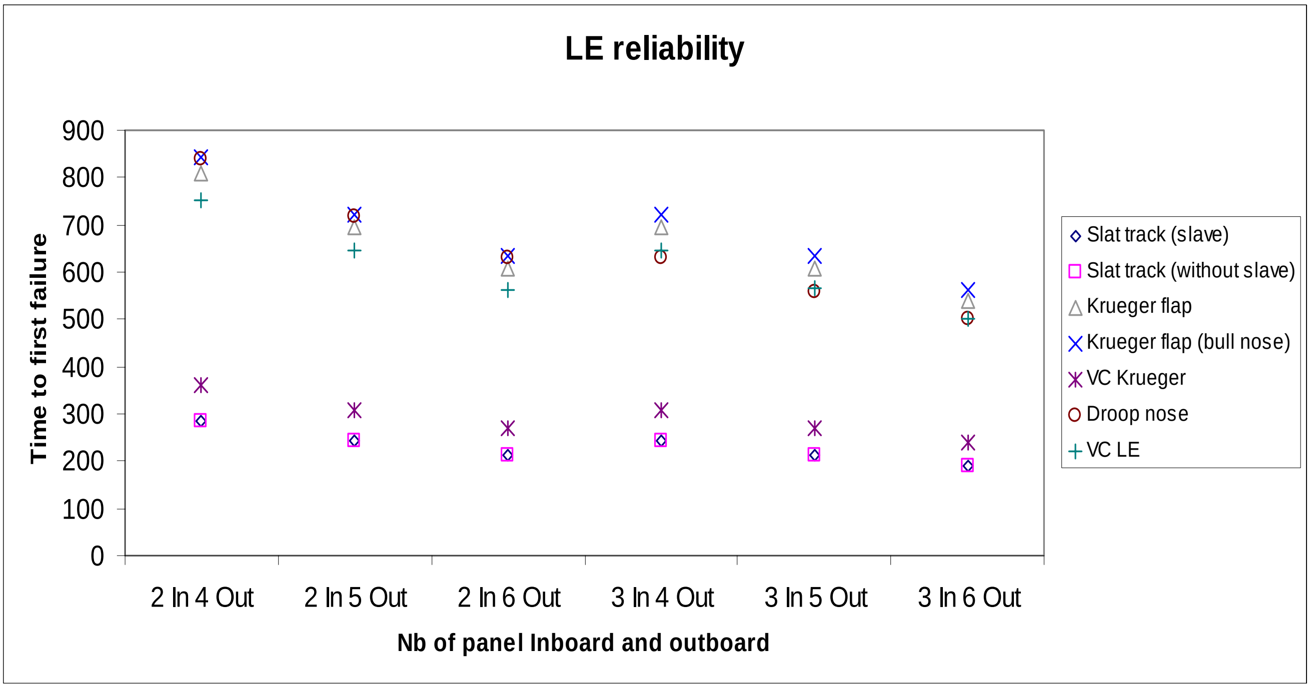

Fig.8: Reliability estimation results for LE (case study)