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Reverse Engineering with LsDyna and Nastran SOL 400 for an unexpected structural event during a Test Flight campaign for Parachutist drop tests

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Abstract

Nowadays, one of the most important problems faced by the industry is how to support old designs when some modifications (or some unexpected problems) arise. Here is shown how modern F.E. technics alongside step by step approaches help to understand the behaviour of those structures when loaded and to mitigate the possible risks of further in flight failures

1. Introduction

A military transport aircraft from the sixties was designed, analysed and qualified for paratrooper, which are jumping out of the aircraft over both doors outside of the fuselage. Nowadays, the mass of the paratrooper increases, mainly due to the increase of equipment. Somehow, it reaches point where a new qualification of the system is required. The initial analysis (hand based calculations) indicated no obvious problem. But based on the nonlinear nature of the problem, and all the acquired knowledge since the original design was put in place, it was advisable to carry out several test campaigns. And during those test campaigns, some troubles arose. And there were unexpected events that leaded to a redesign of the system. The step by step approach to substantiate the redesign as well as to mitigate further risk for future flight test campaign is presented in this article. The main goal is to show that modern techniques of Virtual Testing are fully applicable and can contribute to the support of in-service issues for ageing fleets.

2. Presentation of the problem

The main goal of a qualification campaign is to show compliance with the requirements. It is necessary to repeat this qualification each time the requirements changes. Paratrooper launching is one of those requirements. And to show the capability to launch and recover (if necessary) those troops is a compulsory performance of any military transport aircraft. In the following figure, some of the means to allow this capability is shown. It could consist in external means (presented in Figure 1) or internal features (presented in Figure 2)

Figure 1: External Means for Paratroopers launching

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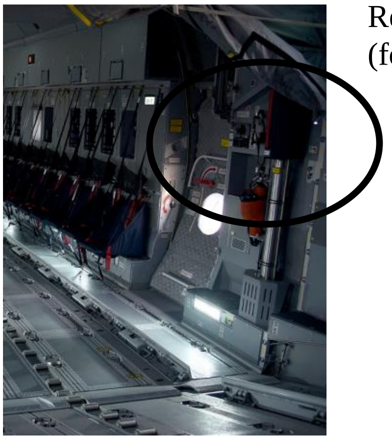

Figure 2: Internal Means for Paratroopers launching

Sometimes, when problems arise during the qualification campaign, a detailed investigation has to be carried out to understand the reason of the failure and to redesign the part in such a way that it can cope with the new requirements. This was the situation now. A modification in the requirements, involving an increase in the launched weight, was set down. When it was tested, the system broke down.

The main focus of the test is a test dummy (simulating the paratrooper), which is dropped out the aircraft. The dummy is connected with a rope. The function of this rope is the pull out of the parachute. All paratroopers are connected to this rope. During one of test campaigns with the biggest dummy mass, a part of a rope guide structure was broken. It changes the guidance of the rope and as a consequence the test was not fulfilled

An investigation was carried out to find the main root cause of this event. The German Airforce expects a low cost modification for an ageing aircraft and the German Certification Authorities expect a structural statement of the event for the upcoming new flight test campaign.

To do so, virtual testing techniques has been used, developing a non-linear model to account for all the effects. The first step is to tune up the model so the failure is properly reproduced and then, to use the model to modify the design and to give confidence that the new design is able to cope with the requirements when flight tested.

It is very important to empathise the point that reverse engineering is being done. To do so, in-deep knowledge of the failure is required. Understanding the structure is the key point to be successful in this task.

3. Brief description of the analysis procedure

At first a FE-Model for Nastran SOL 400 was created due to high non-linear displacement and locally non-linear material behaviour. The engineering assumption was compared to the real facts in the video of the structural event moment. The main focus of the video was to document the test procedures and not the structural behaviour as there is any other graphic records of the test.

Based on that model and the initial analysis, the most critical areas where identified. And then, a cheap redesign was proposed (just the modification of some fasteners). With the new configuration, the analysis was run again and the new configuration shown the capability to withstand the requirements. The main aim was to give confidence about the success of the new test campaign.

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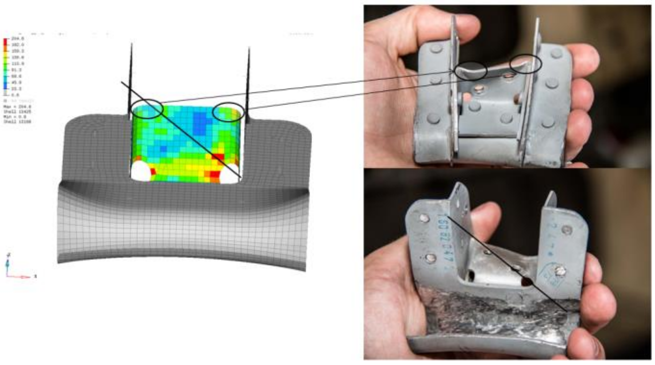

Figure 3: Pictures from NASTRAN model, compared to the real situation.

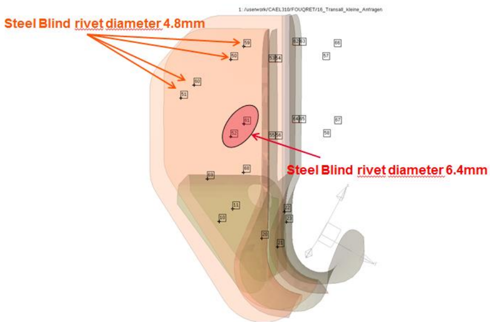

Figure 4: Brief description of the modification

Unfortunately, some mismatch with the applied load was discovered. When this new loads were considered, the NASTRAN model was not able to reproduce the failure. So it was deemed to replace this model with another one using LsDyna (to better reproduce the behaviour). So the highly non-linear behaviour of the process could be properly reproduced. The first step is, again, to reproduce properly the event (and be representative enough at structural level).

One of the main aims is to confirm that the critical areas obtained in the previous model remains. This is very important, as the modification was already in place. Once this is confirmed, it is necessary to check whether the modification is enough or not. Otherwise, some additional modifications should be implemented.

Nevertheless, LsDyna model is much more complex than the previous one, and some sub modelling needed to be done. One for the cable and another for the spot weld analysis. The aim of this sub models is to be able to modify the Young Modulus for one of the components of the model and to check the failure criterion of the spot weld elements. Basically, additional work has been done in the modellisation of the rope and the failure of the part of the rope guide structure. Furthermore, the new model could be modified for the new upcoming test flights with different load introduction.

The spot weld sub model has to be built to simulate the behaviour of rivets including failure criterion according HSB 20210-01 curve D. The spot weld was modified to suppress the rotation of the nodes shown the figures 5 to 7. The main driver of modification is number for Yield Strength. The objective of the element is to simulate forces running thru the element, like a physical rivet and broke over a certain force level. Several different types of sub models are created to check this behaviour (see figures 8 and 9). [1][2]

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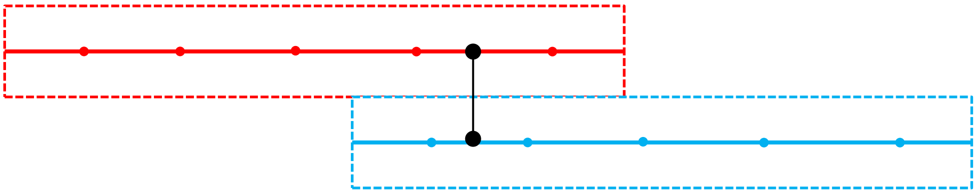

Figure 5: Unrealistic Yield Strength value produces linear spot weld behaviour

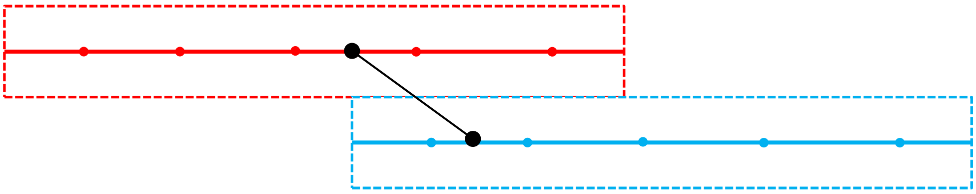

Figure 6: Beyond Yield Strength value ideal plastic hinge behaviour occur

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*MAT_SPOTWELD_DAMAGE-FAILURE
$#     mid        ro         e        pr      sigy        eh        dt     tfail
         202.80000E-9   72000.0      0.33    5000.0    1000.0       0.0       0.0
$$ Failure Parameter          0.0
$#   efail       nrr       nrs       nrt       mrr       mss       mtt        nf
       0.0       0.0       0.0       0.0       0.0       0.0       0.0       3.0
$#      rs       opt      fval    true_t      asff      beta              dmgopt
       0.0       0.0     100.0       0.0         0       0.0         0         0

*DEFINE_FUNCTION
$#     fid                                                             heading
       100
$#                                                                    function
g(nrr,nrs,nrt)=sqrt((nrs*nrs)+(nrt*nrt))/3350.+(nrr/3350.)
```

Figure 7: LsDyna Submodel Spotweld card including failure criterion

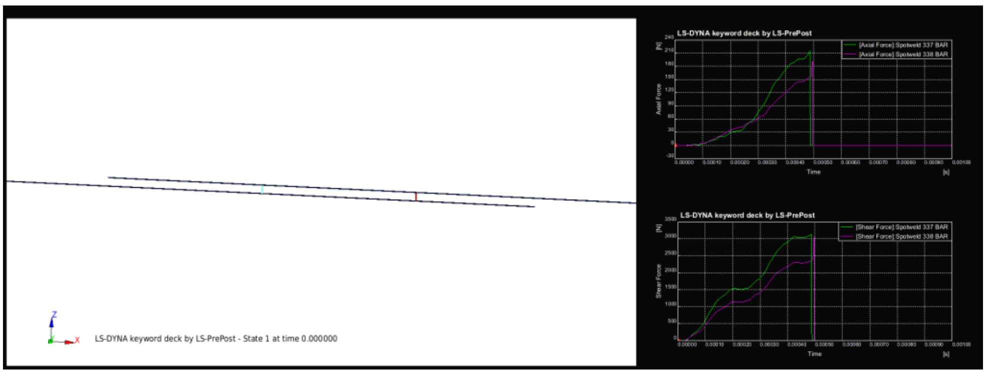

Figure 8: Pictures from LsDyna Submodel 1

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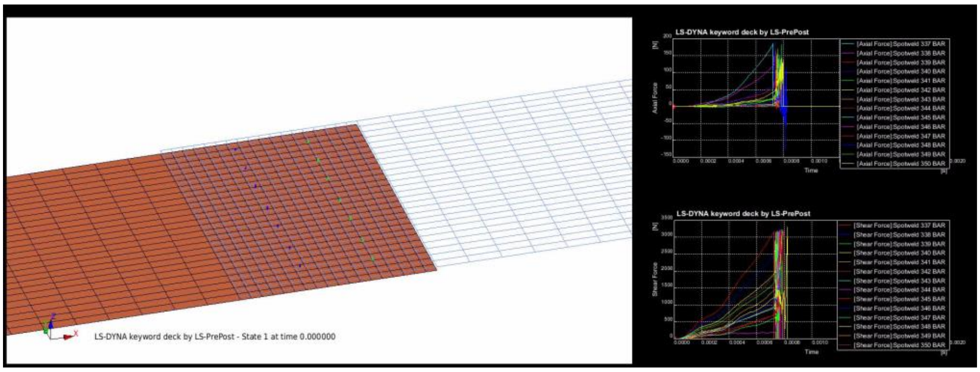

Figure 9: Pictures from LsDyna Submodel 1

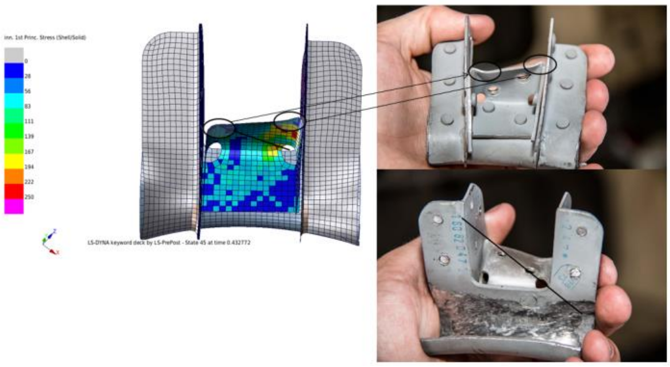

Figure 10: Pictures from LsDyna model, compared to the real situation

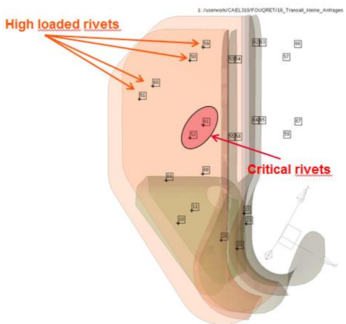

Figure 11: Situation with LsDyna

The results obtained using LsDyna confirmed the initial assessment of the part and gives a good feedback about the modification implemented to overcome the problem. The critical areas remain and a better understanding of the physic involved is achieved. Using the model with different load cases is a way of reducing the risks in the flight test campaign aimed to qualify this item.

4. Conclusions

F.E Modelling can be used to as a cheap and efficient tool to reproduce the failures and it is good way to validate the design of aged aircrafts that requires certain modifications to extend their useful life. A sort of virtual testing can be done to foresee the results in different configurations and to analyse/predict failures of the structure that were not checked at the moment of the original design. Moreover, it allows implementing the most suitable configuration for the new/modified design. And provide confidence that the design, once tested, is suitable and can be qualified with new requirement. This means a certain level of reverse engineering using sophisticated F.E.M., being sure that the reverse Engineering FE-Model must represent truly the real physics (with all the implications lying behind in the sense of a complete knowledge of the way the structure is working).

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This procedure helps, as well, in the case a flight test campaign has to be conducted, giving confidence that no unexpected events will happen. Offering the possibility, as well, once properly tuned, to run virtual testing to validate the structure.

References

[1] Livermore Software Technology Corporation. Ls-Dyna Keyword user’s Manual, Volume II Material Models. 31.05.2017 revision 8410

[2] Livermore Software Technology Corporation. Ls-Dyna Theory Manual. 20.02.2019 revision 1085. Pages 22-194 to 22-196.