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MISSILE FIN PLANFORM GEOMETRY OPTIMIZATION FOR HINGE MOMENT BY MINIMIZATION OF CENTER OF PRESSURE VARIATION

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ABSTRACT

All movable missile control fins are rotated to generate loads in horizontal and vertical planes that are used to control direction of the missile according to the required maneuver. Fins that have different planform geometries have a variety of center of pressure characteristics. Based on the fin planform center of pressure variation over different flight conditions, hinge moment loads which are used in design of control actuating systems can be large or small with respect to the hinge axis. It is important to minimize these loads since the minimization of hinge moment loads reduce the control actuator performance requirements in terms of power, space and weight. In this paper, a minimization study for center of pressure variation is performed while keeping the normal force coefficient constant with the help of rescaling the wing planform to adjust to the required value. The geometrical parameters defining the wing planform defined by three sections are changed by an optimization study to get a suitable wing planform.

INTRODUCTION

The standard missile fin planform shape is trapezoidal and most of the fins are all movable control surfaces with the ability to utilize all the panel area for generating control loads. The planform shape is important for normal force which in turn produces stabilizing moments. Panel deflections increase the normal forces generated so that higher moments for maneuver control are produced. However increasing the normal force has a cost. Having low aspect ratio, possibly at a large flight Mach number range, and panel deflections for control, missile fins have high variations in center of pressure compared to high aspect ratio wings on other platforms. However, the fin planform geometry can be modified to have three sections, or the planform geometry may be defined by a number of points to minimize center of pressure travel. Such a study was performed before. In the past study, the fin planform optimization was performed for hinge moment. Example wing planform geometries with a

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favorable center of pressure travel are shown in this study which were taken from the literature are shown in Figure 1 [Lesieutre, D., Dillenius, M., Lesieutre, T., 1998]. A number of factors are also known to affect fin axial center of pressure locations such as section profiles, fin-fin and body-fin interactions, gaps, body and canard vortices, shock waves at the trailing edges and boundary layer interactions. Also the thickness ratio and distribution can also have significant effect on the axial center of pressure [Nielsen, J.N., Goodwin, F. K., 1982]. Some might argue that for thin fins large deformations change the planform shape such as in the case of air to air missiles, the aero elastic deformations should also be taken into account [Lee, S. J., Park, J. Y., 2016]. The baseline and optimized fin shape of the study by Lee and Park are given in Figure 2. The flow speed is also very important for center of pressure location. These factors make the center of pressure very difficult to estimate by engineering level methods especially at high angles of attack. Therefore, wind tunnel or CFD solutions are better suited for the fin center of pressure and hinge moment calculations compared to the engineering level prediction methods. In the wing platform optimization study, engineering methods are used as pre-selection tool and then CFD analyses are performed during optimization routine for minimizing center of pressure travel.

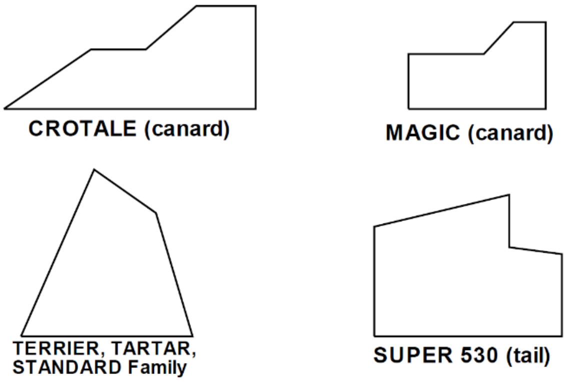

Figure 1 Optimized Fin Planform Geometries for Limited Center of Pressure Travel in a Past Study [Lacau, R.G., 1988]

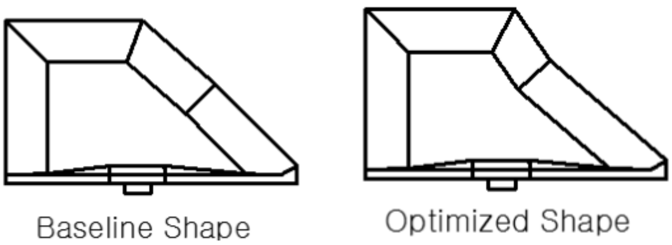

Figure 2 Baseline and Optimized Fin Planform Geometries for Limited Center of Pressure Travel [Lee, S. J., Park, J. Y., 2016].

WING PLANFORM OPTIMIZATION

A parameter study was established for wing planform optimization by using HEEDS MDO program. The parameters of the optimization depend on the geometric variable ratios as shown in Figure 3 with the chord taken unity as shown in Table 2. After a unique wing planform is defined by optimization, it is rescaled in the inside routines. The reference values are given in Table 1.

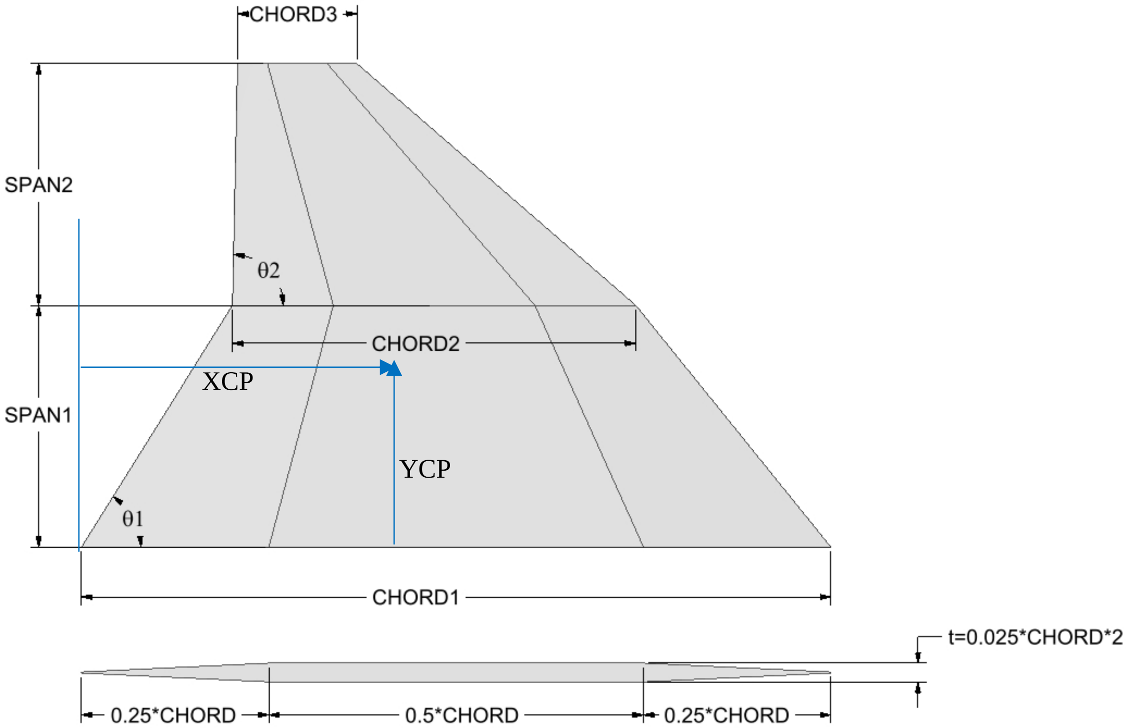

Figure 3 Three Section Fin Planform Geometry Description Parameters, Axial (XCP) and Longitudinal (YCP) Center of Pressure Location Definitions

Table 1 The reference values for the coefficients

Reference length	30.0 cm
Reference area	706.8578 cm^2

Table 2 The minimum, maximum and baseline parameters for the wing optimization problem

	min	baseline	max
CHORD1	-	1	-
CHORD1/SPAN1	0.5	1.69	7
CHORD2/CHORD1	0.3	0.5	1
θ1	0	20	40
SPAN2/SPAN1	0.1	0.318	1
CHORD3/CHORD2	0.2	0.5	1
θ2	0	20	40

It must be noted that the parameters in the table are only used to define unique wing planform. After the unique planform definition, the unit wing is rescaled by DATCOM to obtain the required panel normal force. The limits were imposed on the two parameters:

CHORD1 < 35.1 cm
SPAN1+SPAN2<28.1 cm

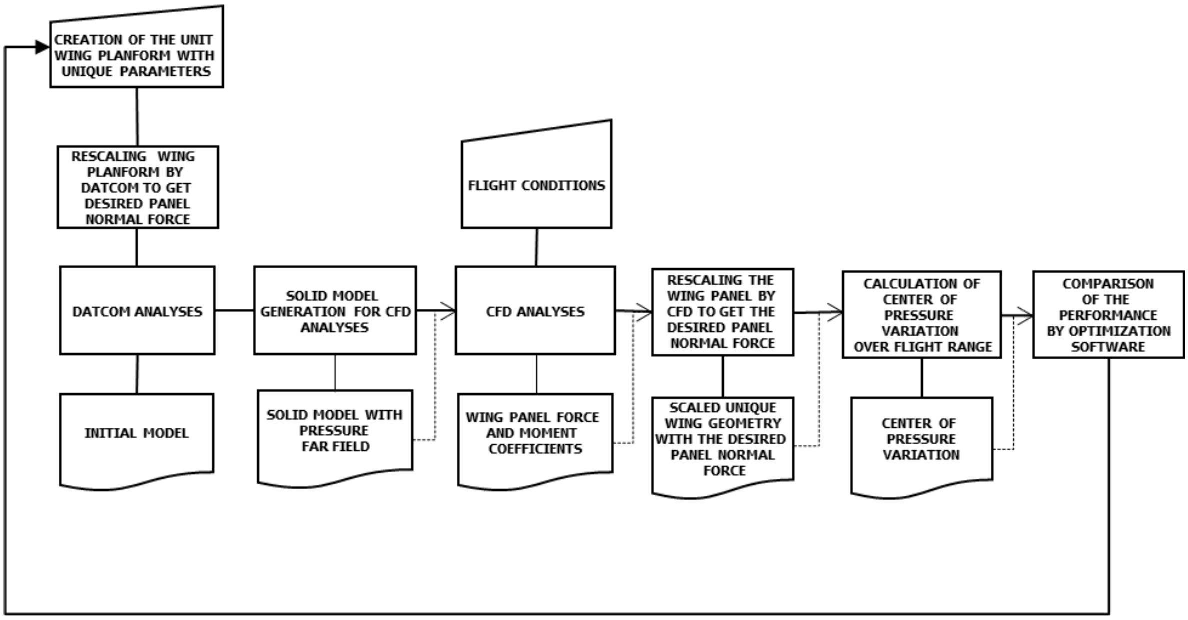

Figure 4 The flowchart for the optimization problem

The optimization problem steps are given in the Figure 4. Generated unit wing planforms are scaled by DATCOM to obtain 0.45 average panel normal force coefficient over the flight conditions given in the Table 3. If the evaluated wing planform has average panel normal force coefficient lower than 0.3 the CFD analyses are not performed. Thus the optimization process do not lose time by the small wings. If the DATCOM step is passed successfully CFD analyses are performed. After CFD analyses are finished, average normal force coefficient will be different than 0.45, therefore a second time wing planform is rescaled to have exact normal force coefficient of 0.45 by the following formula, the variation of the panel center of pressure is also rescaled:

$$\boldsymbol{Shrinkage\ Ratio} = \left(\frac{\boldsymbol{CN_{required}}}{\boldsymbol{CN_{average}}}\right)^{\mathbf{0.5}}$$

In the problem setup, panel normal force is required to be constant and $CN_{required} = 0.45$. For comparing different unique wing panel planform geometries this scaling for the average normal force coefficient is important. By this operation the same maneuver performance from different unique wing planform geometries is ensured. If the specific wing platform exceed the limits imposed on the chord or span, it is not evaluated in the optimization process. The main aim is to minimize the chordwise center of pressure variation which is formulated as:

$$\Delta \boldsymbol{XCP} = (\mathbf{max}(\boldsymbol{XCP_{CFD}}) - \mathbf{min}(\boldsymbol{XCP_{CFD}})) \cdot \boldsymbol{Shrinkage\ Ratio}$$

Table 3 The flight conditions of the optimization problem

Index	Mach	Alpha
1	0.6	10
2	0.6	15
3	0.85	10
4	0.85	15
5	1.2	10
6	1.2	15
7	2.0	10
8	2.0	15

The CFD problem is set-up for the half domain by taking advantage of the symmetry. The solution domain is shown in Figure 5. The FLUENT CFD tool was used in this paper as the CFD solver. The solver options was selected density based solver with energy equation. The other details are not given since it is not the main interest of this study.

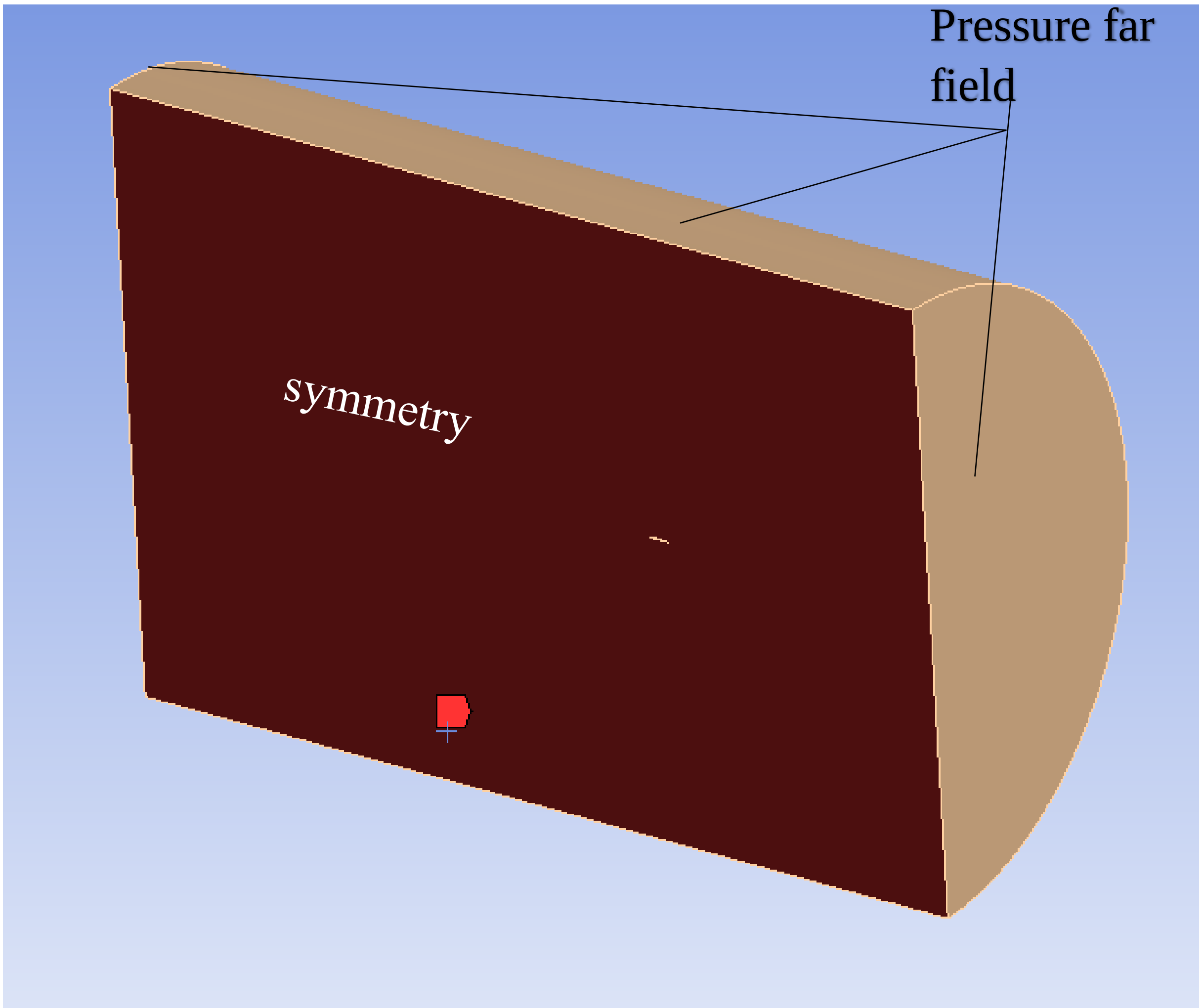

Figure 5 The CFD problem definition for the wing alone analyses

RESULTS

The optimization study to minimize the center of pressure variation of the defined three section wing planforms was performed with the given parameters in the previous section. During this optimization process the wing planforms were scaled by using shrinkage ratio so that all the panels had exact CN coefficient of 0.45. The history of center of pressure variation during iterations satisfying the geometrical constraints is given in Figure 6. From color and size of the markers in the figure change of the total chord and span during the iterations can be observed.

For the evaluated geometries, the correlation matrix of the geometrical parameters with center of pressure variation is given in Figure 7. According to this figure, the most influential factor is chord to span ratio.

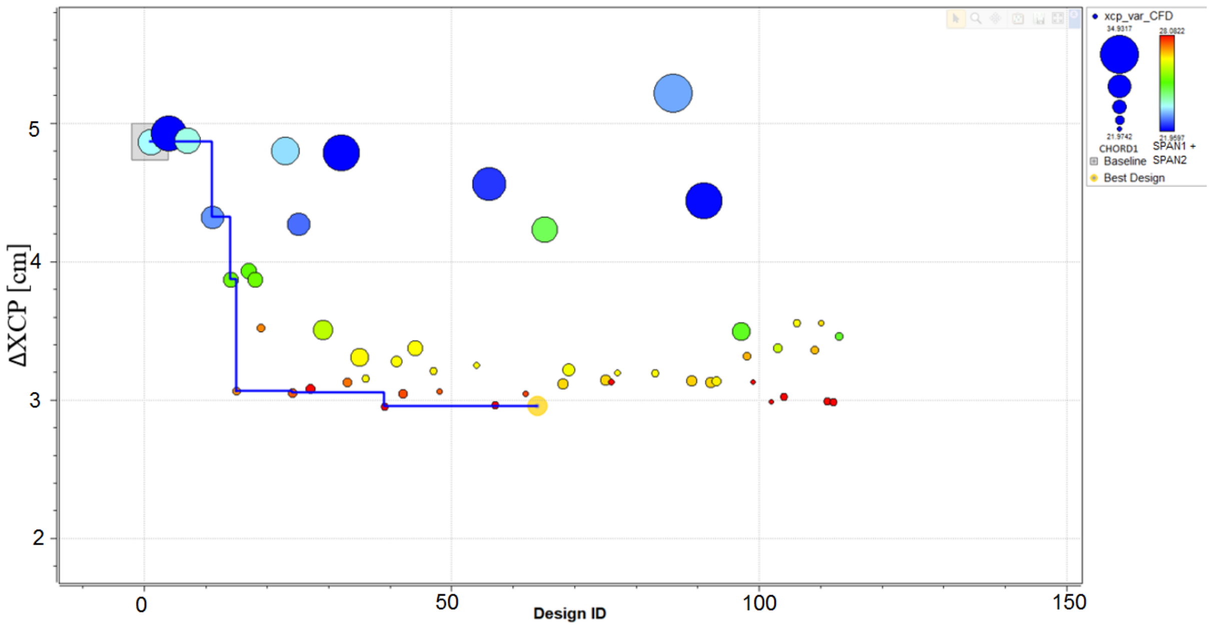

Figure 6 The change of the center of pressure variations [cm] during optimization

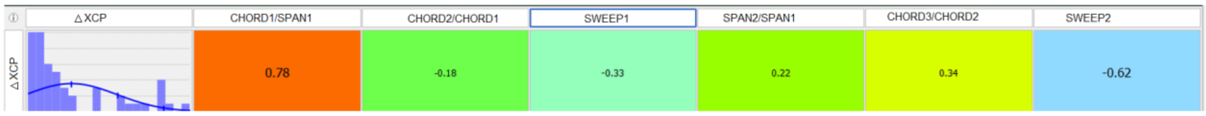

Figure 7 The correlation of geometrical parameters with center of pressure variation

To observe the individual effects of the chord and span, the center of pressure variation was plotted with these geometrical parameters in Figure 8.

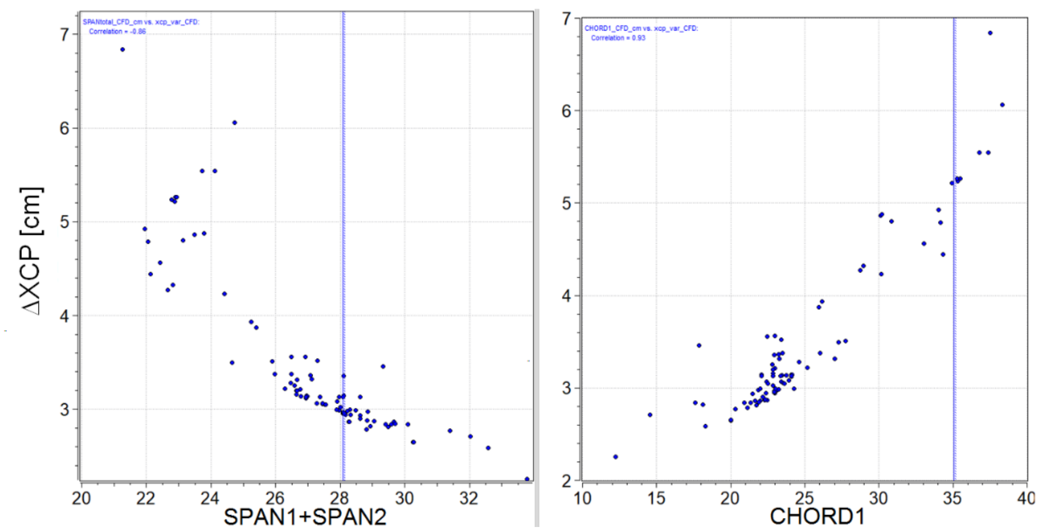

Figure 8 The center of pressure variation in units of cm with scaled root chord (CHORD1) and total span (SPAN1 + SPAN2)

The results in Figure 8 indicate that in general, as the chord increases the center of pressure variation becomes larger, on the contrary as the span increases variation decreases.

Therefore a long span, short chord configuration is expected for the hinge moment optimized results.

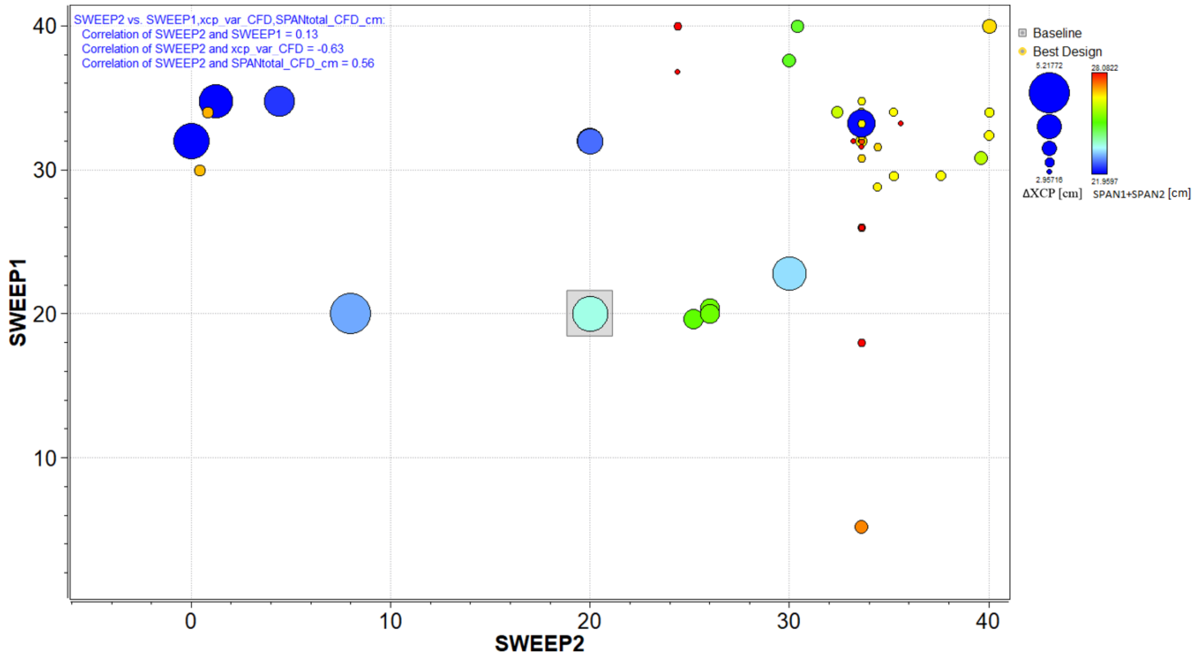

Figure 9 The center of pressure variation with respect to SWEEP1($\theta 1$ º), SWEEP2($\theta 2$ º) and SPAN1+SPAN2

The effect of sweep parameters is shown in Figure 9 together with the total span. The bubble size in the figure shows the center of pressure variation. The best geometries within the constraints are accumulated in the top right region $\theta 2$ is greater than 30 in that region and $\theta 1$ is mostly greater than 20 º. The big blue bubble in that region have short span length. The best ones with the lowest bubble size have red color meaning that they have high span. The good ones in the top left region also have high span values.

The best planform geometries found by the optimization study for the problem defined are listed in Figure 10 with the limits imposed on span and chord lengths shown by blue lines. The total wing span reaches to the limit values, chord gets smaller compared to the baseline geometry as expected. The center of pressure variations are shown in Figure 11 with the indices showing the flight number sequence in Table 3.

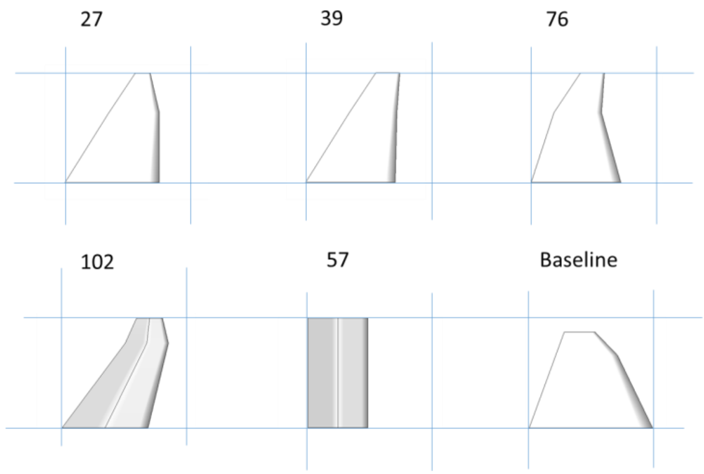

Figure 10 Wing panel planform geometries with the minimal center of pressure variation obtained by optimization study compared with baseline

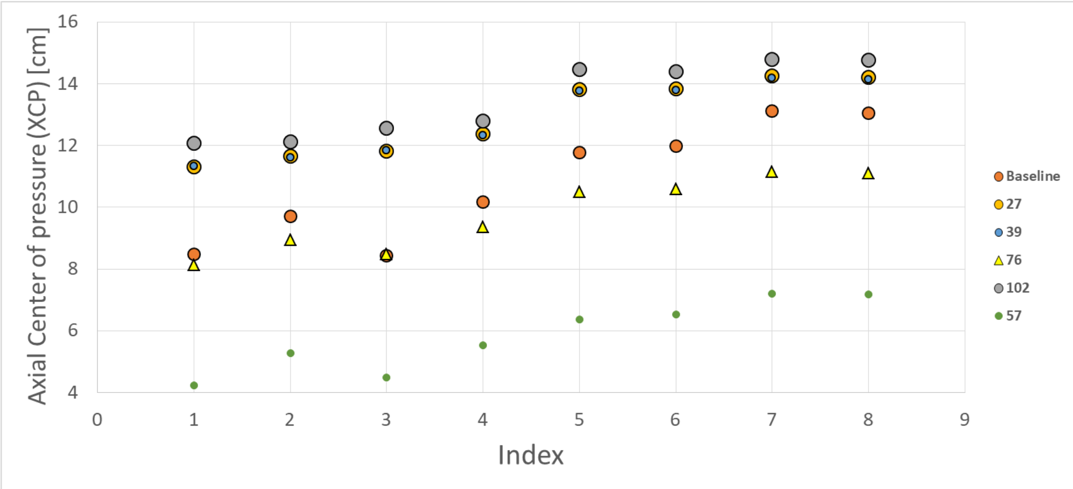

Figure 11 Axial center of pressures with respect to the leading edges of the optimal configurations compared to the baseline configuration

The worst planform geometries evaluated by the optimization study for the problem defined are listed in Figure 12 with the limits imposed on span and chord lengths shown by blue lines. The common property of these planforms is the long chord length and shorter span. In addition, planform 98 has a different shape with short root chord and long tip chord. The center of pressure variations are shown in Figure 13 with the indices showing the flight number sequence in Table 3.

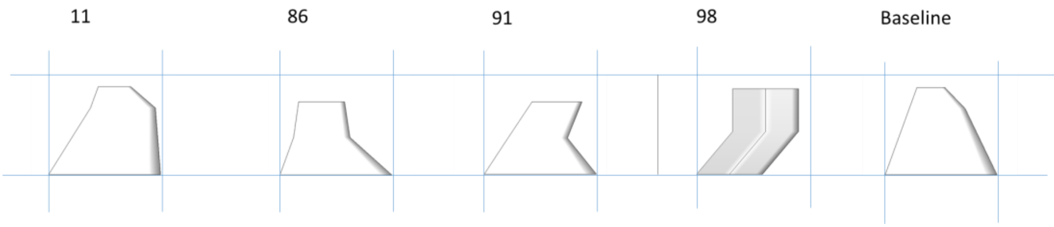

Figure 12 Wing panel planform geometries with high center of pressure variation evaluated by optimization study compared with baseline

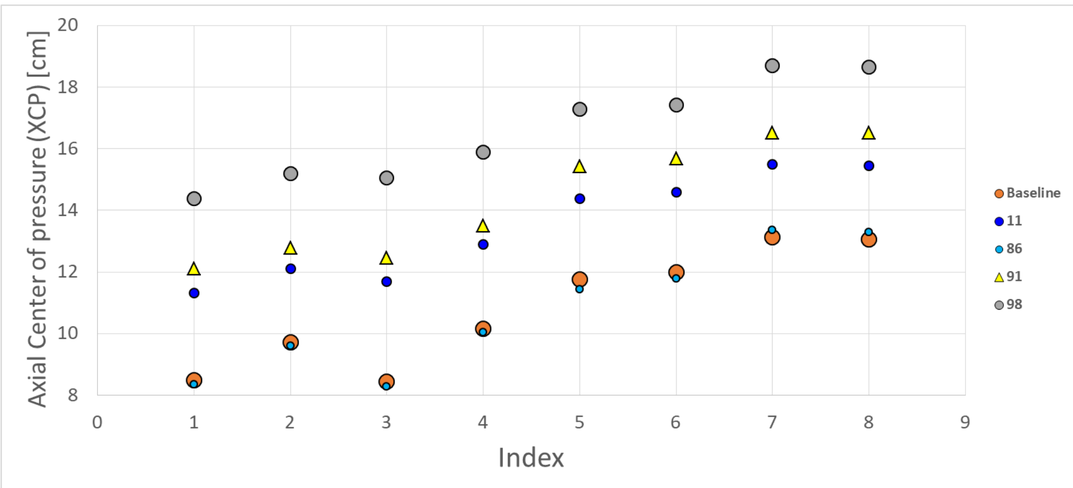

Figure 13 Axial center of pressures with respect to the leading edges of the worst configurations compared to the baseline configuration

Since the axial center of pressure location travel are similar for optimal configurations, the longitudinal center of pressure locations were compared in Figure 14. According to this figure, Panel 57 has the furthest distance from the root chord. Since the panel normal forces are equal, keeping this distance minimum is good for bending moment in general.

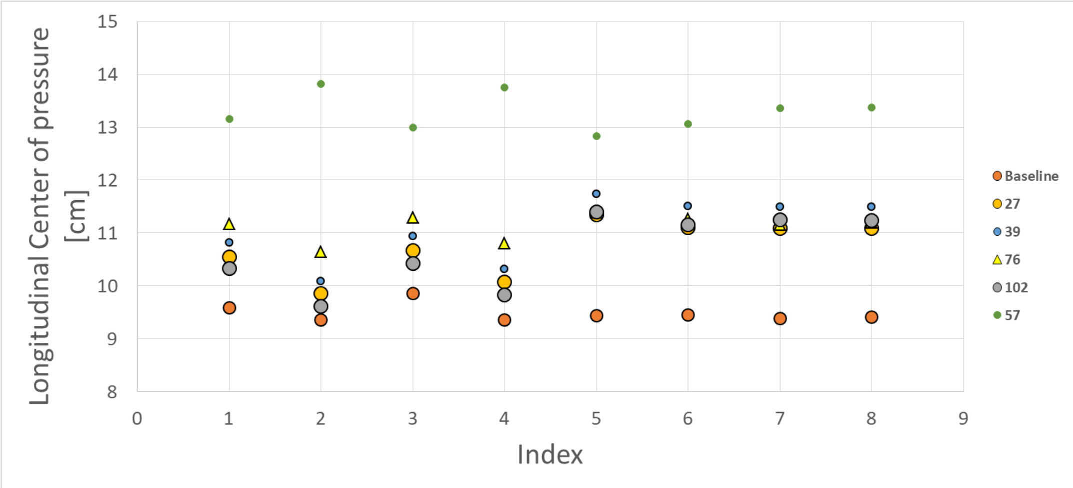

Figure 14 Longitudinal center of pressures with respect to the leading edges of the worst configurations compared to the baseline configuration

CONCLUSION

- Different panel planforms were investigated during optimization process by scaling the dimensions to make normal force coefficients equivalent. According to the results, long span planforms have low center of pressure variation.
- In general planform geometries with long chord have high center of pressure variation.
- According to the best results, to minimize center of pressure variation for the proposed flight conditions, a moderate sweep angle is required.
- The optimized wing planform geometries are found for the defined problem. If the flight conditions, or other requirements defining the optimization were changed or defined in other ways the optimized wing planforms might be different.
- The effect of thickness was not investigated, it can be studied for the optimized planform geometries.
- Other criteria such as bending moment can be used for further selection between optimized wing planforms.

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