Towards a lightweight seat-pan. (Design Process)

TU DELFT, 2018

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Contents

Firstly a general list of requirements were made and followed throughout the project. This list of requirements was dynamic and incorporated changes as needed

General List of requirements

- The new seat pan must be designed for current European class economy seats for medium to long haul flights.
- The seat will be tested in pitch length will be 81cms according to standard economy class seats.

- Design priority will be given in following order
  - Compliance with FAA seat regulations
  - Comfortability
  - Weight

- The seat pan must is designed for CL3710 Recaro seats.
- The current seat pan in Recaro CL3710 seats will be taken as a comparison unit during testing.

General

- The designed seat pan must be similar or more comfortable in relation to current economy class seats.
- The designed seat pan should be lighter than current economy class seat pans.
- It must comply will FAA seat regulations
- The seat should be comfortable from p5 – p95 percentile of adult European passengers.
- The user should not feel the transition between spring foam and regular foam within seat.

Timeframe

- The seat design should be completed within next 6 months
- The seat could be implemented by end of 2019

Determining the Ideal Contour

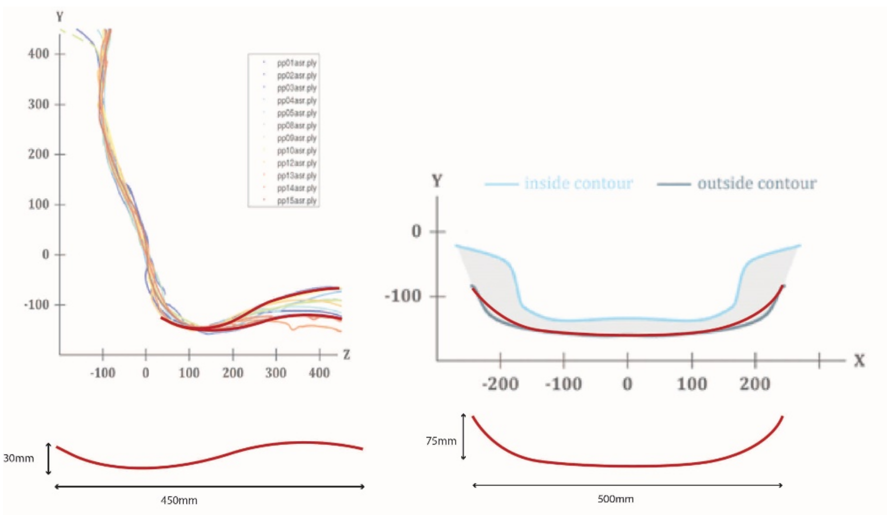
Firstly, It was checked whether it would be feasible to integrate spring-foam cushion to current seat pan since it would be easier for this to implement. However, after testing few iterations and testing it was concluded that the current seat pan is not ideal for spring-foam as it contained sharp ridges which could be felt during seating, masking of the ridges in seat pan would require additional foam which would significantly increase the weight of the seat cushion.

Therefore, first and foremost, a seat-pan needed to be produced that is optimized for Octaspring foams and can be tested.

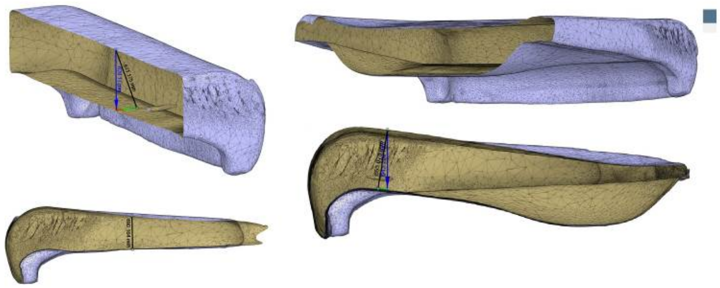
For the spring-foam seat-pan, Ideal contour for spring-foam was determined by combining profiles provided by (Hiemstra-van Mastrigt, 2015) and (Wang, 2018).

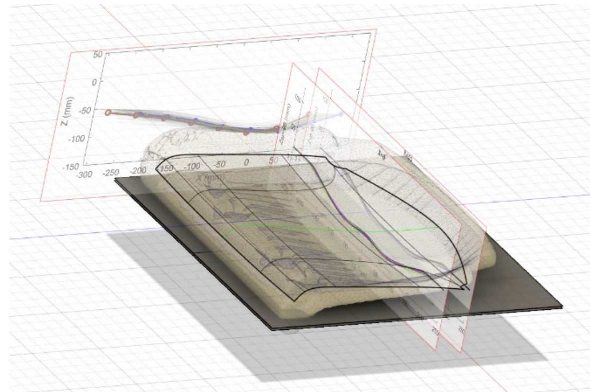
Process

1. Dimensions of curvature was extracted from the paper

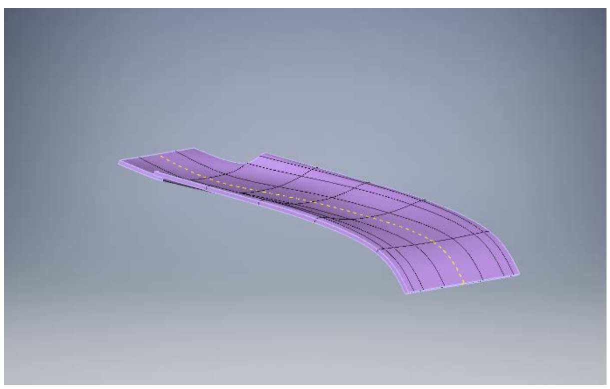


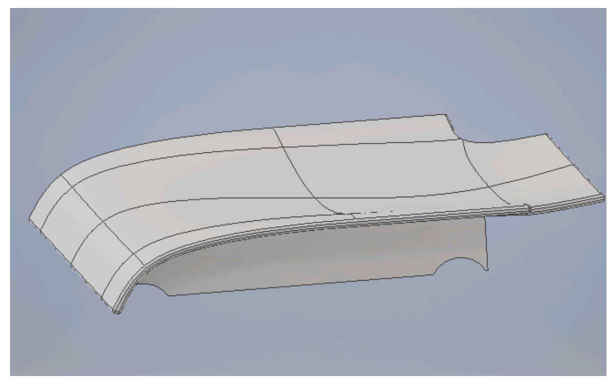
2. Current seat cushion was 3d scanned and overlaid along with the contour profile



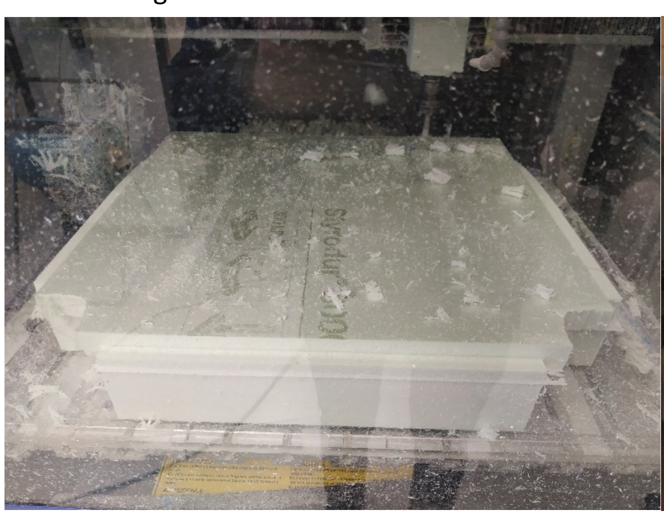


3. Contour was made accordingly and seat-pan was designed





4. The design was CNC'ed and the contour model was produced



Material analysis

Initial tests showed that properties and behaviour of spring-foam is different from regular foam, therefore literature and tests conducted on regular foam cannot be applied to Spring-foam. In addition, the data from these tests supplied as a baseline and initial guidance towards designing the seat and on estimating the ideal foam firmness and thickness required for desired application.

Test Objective

- Determination of Deflection value which “spring” mechanism starts to fail
- Determination of the Deflection value at which Octaspring bottoms up (determining support factor)
- Analyse different curve to determine a pattern (and a formula) to extrapolate the results towards other Firmness and heights.

Units Tested

The following Octaspring units were tested

Spring-foam height	**Spring-foam width**	**Spring-foam Type**			
45	65	19Kpa	16Kpa	10Kpa	8Kpa

Setup

Custom made wooden planks (300mmX300mm and 200mmX200mm) are clamped in Zwick Z010 testing machine (Figure ##).

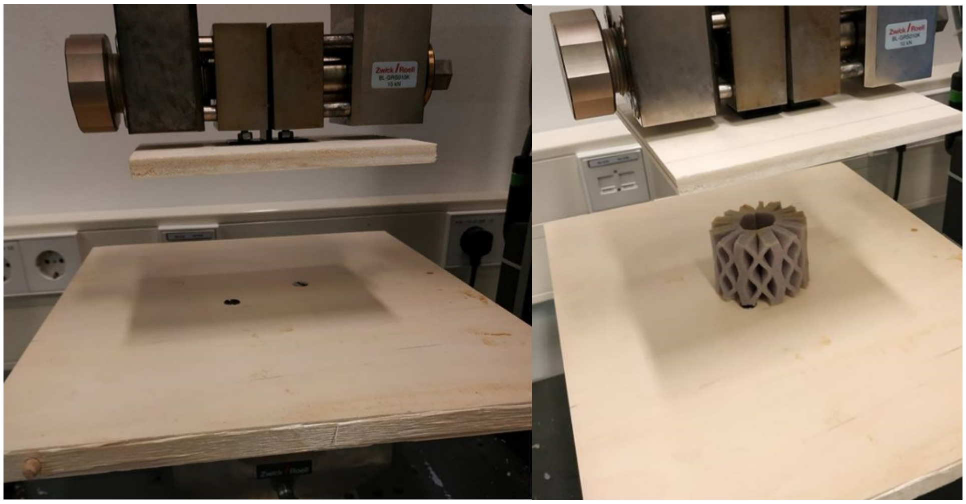


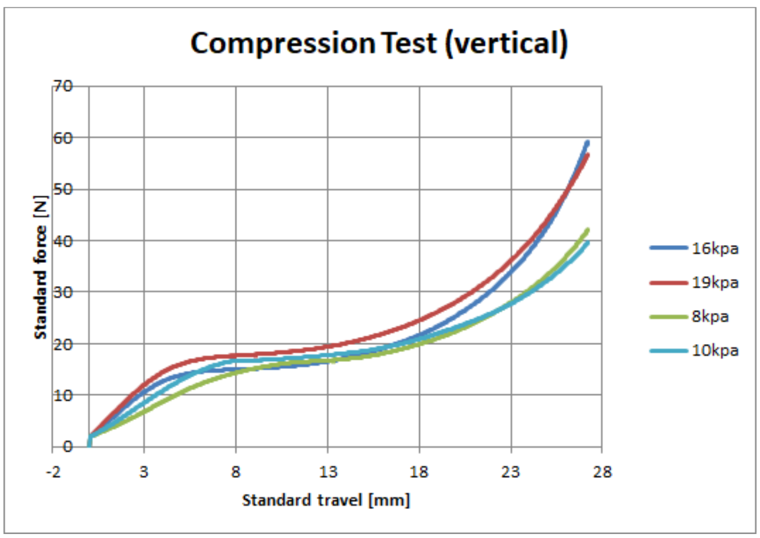
Figure X | Zwick Z010 material testing machine is initialized and calibrated using textXpert II software.

Procedure

Generally, foams are tested against ASTM standard (appendix I), however due to 'individual' nature of the spring-foam, this procedure is not fully relevant. Therefore, the following modified procedure is followed to test the spring-foam units.

1. Wooden plates (300mmX300mm and 200mmX200mm) are clamped in Zwick Z010 testing machine. The force value is reset to zero.
2. The spring-foam is placed in-between the plates and clamps contracted until the foam is compressed with 0.1N of force.
3. The test specimen is preflexed with 25% deflection for two times at 4mm/sec
4. The foam is then compressed at 0.83mm/sec until sharp increase in stress is noticed in the graph (bottoming).
5. The procedure 1-5 is repeated 5 times with different samples of same parameters
6. The data is recorded in testXpert II testing software
7. The process 1-6 is repeated until all the samples are tested.

Results & Discussion



The compression test showed that there is not much difference at around 13 mm of strain (4 newton difference between 8kpa and 19kpa). There is rapid increment in force from 0-8mm for all the samples but lower firmness spring is observed to have lower slope, this initial slope gives the softness "feel" to the spring foam (the softer the material the smaller the slope. The majority of difference lies at start (0-8)mm and at the end 23 mm.

It can be seen that there is another rapid increment in force past 23 mm (51%), this is assumed to be when spring-foam starts bottoming. So, For the seat-pan, to avoid bottoming, the compression has to kept within 51%. The Force value 51% compression gives the support capacity of the material. Soo at 51%the difference between 8kpa and 10Kpa is negligible, and there is approximately 10N difference between 8Kpa to 19KPa. So, for softness "feel" 8kpa spring foam should be used, whereas place where support is needed, 19 KPa is recommended.

Top foam layer determination

Before moving forward in next step of the design process, an ideal top foam layer for Octaspring was determined following the balance between the parameters provided below.

1. Light-weight.
2. Provides soft initial experience during sitting.
3. Is able to 'mask' individual spring foam units so that the user does not feel individual spring-foam during sitting.
4. Has good breathability

The degrees of freedom available in this topic and its influence is as follows.

Degree of freedom	Influence
Firmness	Lower Firmness would provide soft experience during stilling but is not able to 'mask' the individual spring-foam units completely
Thickness	Increasing the thickness increases the weight and provides lower breathability. However will be able to mask spring-foam

Method

Based on parameters provided, the following combinations were chosen for further analysis.

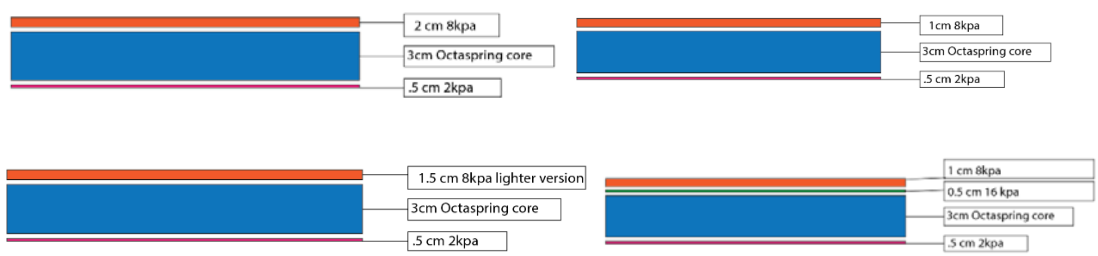


Figure 3

Among all the samples, only top layer was changed while keeping bottom layer and Octaspring core layer constant. All four samples were prepared with 450mm length and 480mm width. The samples were placed on Recaro cl3710 seat frame with modified seat-pan (figure ## 4).

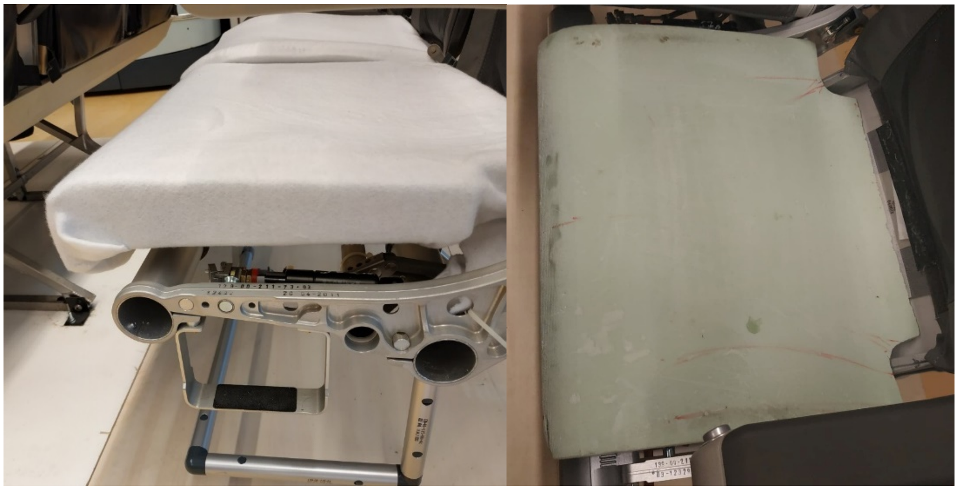


Figure 4

This was then tested using X-sensor LX100 with subject of weight 60 kg. The subject was allowed to sit in the sample for 5 minutes before pressure map was taken. Same sitting position was maintained throughout the study and estimated load on the seat-pan was kept at 150 N.

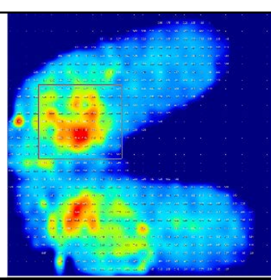
The following factors observed and compared through pressure map

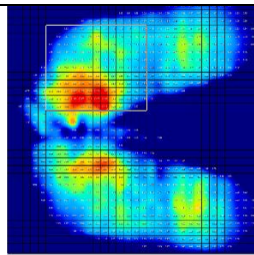
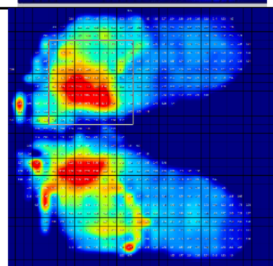
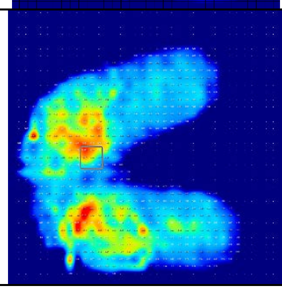
- Pressure gradient
- Peak pressure
- "Masking" of Octaspring cores

In addition, comfort and overall weight of the sample was also taken into account.

Results

The following results was obtained through this study

Top layer	Pressure Map	Pressure gradient rating	Weight reduction	Peak pressure	Masking ability	Comfort
1 cm 8Kpa		5	300g	11.7	3	5

2 cm 8Kpa		4	160g	12.5	5	4
1.5 cm 8 Kpa (lighter version)		3	250g	14	4	2.5
1 cm 8Kpa + .5 cm 16kpa		5	250g	10.97	4	5

Discussion

Using the result above commination of 1 cm 8Kpa with 1.5 cm 16Kpa was found to have good balance between weight reduction, comfort, pressure distribution and masking ability. Therefore, it is chosen as a top layer for spring-foam cushion.

Generative Design

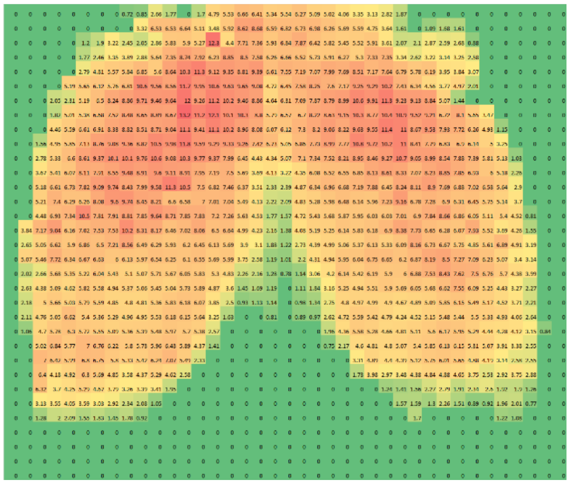
As a new seat-pan is needed to be made for spring-foam cushion, there is an opportunity to reduce weight of the seat pan using the emerging generative design technology. In generative design process, design parameters are fed to computer which simulates all the possible combinations matching the parameter, and provides an optimal design that is light-weight and yet strong.

The following process is followed for generative design of seat-pan

Firstly the following list of requirements are set guided by FAA regulations

- The

5 users over 60 kg was pressure mapped and their data was averaged out into single grid



This was tweaked and optimized to create a matrix that can be fed into the simulation.

0	0.8	3.4	5.7	6.9
0.24	5.17	8.42	10.7	7.68
1.76	7.72	9.4	9.4	5.91
3.4	7.8	8.7	7.4	3.4
3.4	5.9	5.9	5.7	1.84
3.01	5.8	5.5	3.8	0.25
2.54	4.9	3.7	0.65	0
0.2	0.4	0.2	0	0

Averaging out the matrix

0.5	1.3	3.4	5.7	6.9
0.74	5.17	8.42	10.7	7.68
1.76	7.72	9.4	9.4	5.91
3.4	7.8	8.7	7.4	3.4
3.4	5.9	5.9	5.7	1.84
3.01	5.8	5.5	3.8	0.75
2.54	4.9	3.7	3.7	0.5
0.7	0.9	0.7	0.5	0.5

Adjusted for threshold pressure and varation in postures

.5 Kpa added to each value less than .5

pressure repeated in front region

1.18	3.06	7.99	13.40	16.22
1.74	12.15	19.79	25.15	18.05
4.14	18.14	22.09	22.09	13.89
7.99	18.33	20.45	17.39	7.99
7.99	13.87	13.87	13.40	4.32
7.07	13.63	12.93	8.93	1.76
5.97	11.52	8.70	8.70	1.18
1.65	2.12	1.65	1.18	1.18

Converted into weight of 825N (as mapped)

1.6	4.1	10.7	17.9	21.6
2.3	16.2	26.4	33.5	24.1
5.5	24.2	29.5	29.5	18.5
10.7	24.4	27.3	23.2	10.7
10.7	18.5	18.5	17.9	5.8
9.4	18.2	17.2	11.9	2.4
8.0	15.4	11.6	11.6	1.6
2.2	2.8	2.2	1.6	1.6

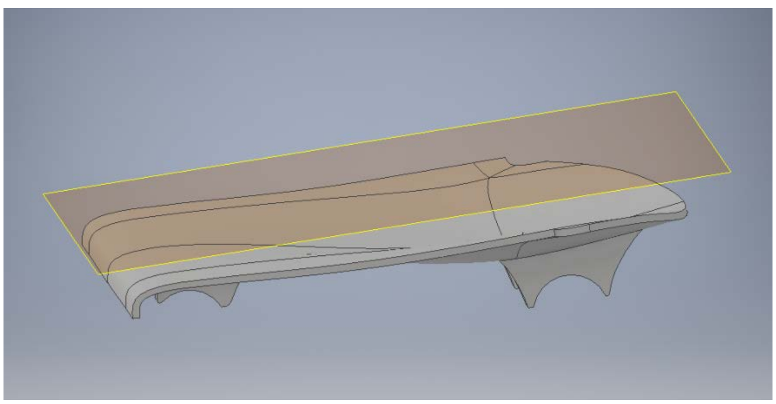
Converting to p 99 (110kg)

21.9	57.0	149.1	250.0	302.7
32.5	226.8	369.4	469.4	336.9
77.2	338.7	412.3	412.3	259.3
149.1	342.2	381.6	324.6	149.1
149.1	258.8	258.8	250.0	80.7
132.0	254.4	241.3	166.7	32.9
111.4	214.9	162.3	162.3	21.9
30.7	39.5	30.7	21.9	21.9

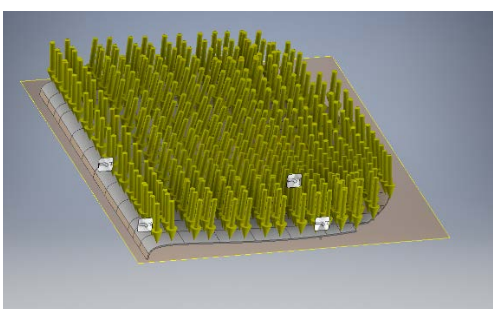
Force Exerted during 14g test

22	57	149	250	303	303	250	149	57	22
32	227	369	469	337	337	469	369	227	32
77	339	412	412	259	259	412	412	339	77
149	342	382	325	149	149	325	382	342	149
149	259	259	250	81	81	250	259	259	149
132	254	241	167	33	33	167	241	254	132
111	215	162	162	22	22	162	162	215	111
31	39	31	22	22	22	22	31	39	31
Final input value for simulation and generative design									
Each cell represents 25 cm2									

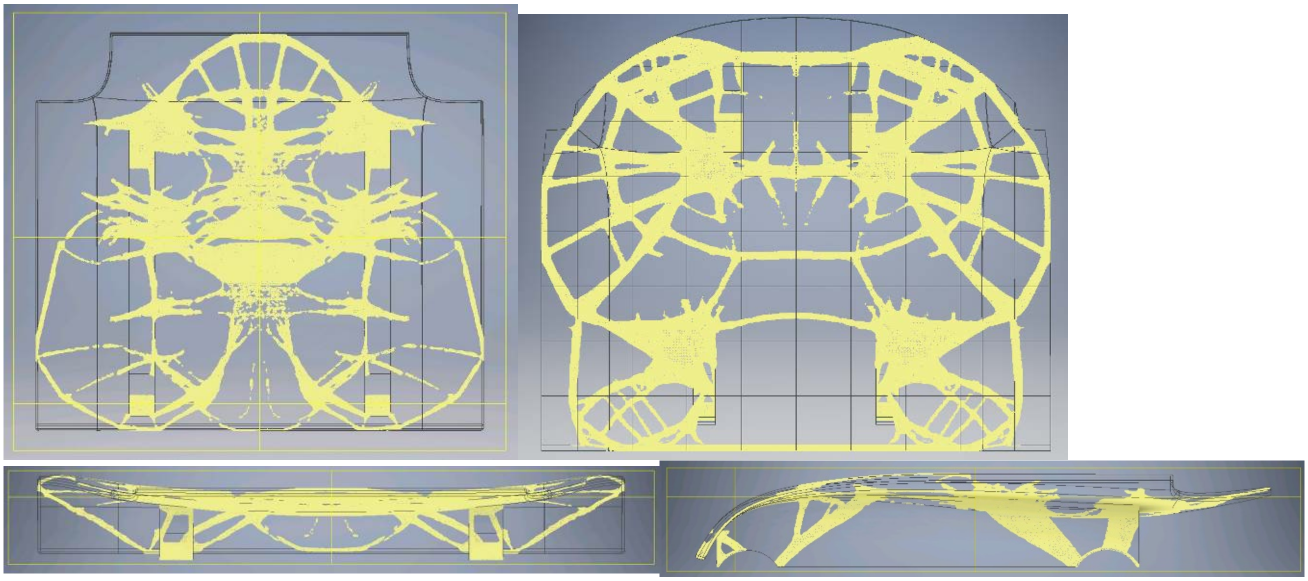
A “shell” model is made for design generation. (Here the 5 mm thickness is considered with sold bottom stands.



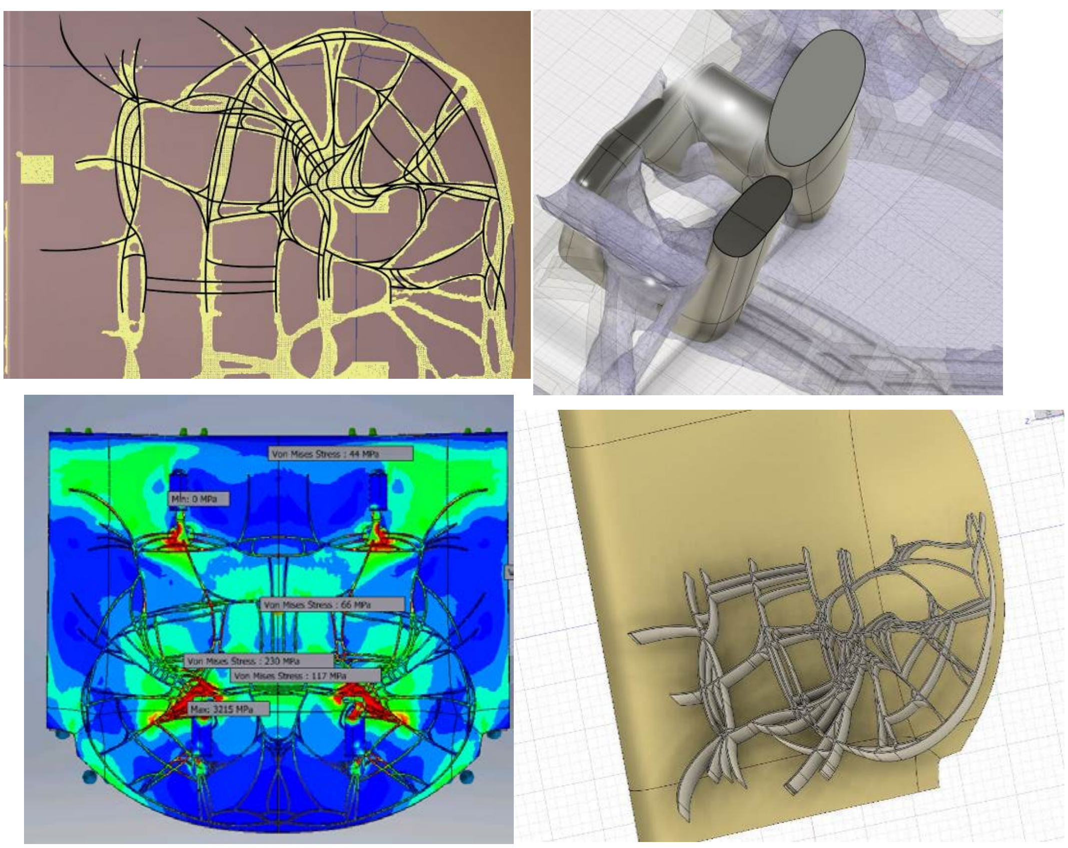
The calculated forces, material parameters and contact points is applied to the design



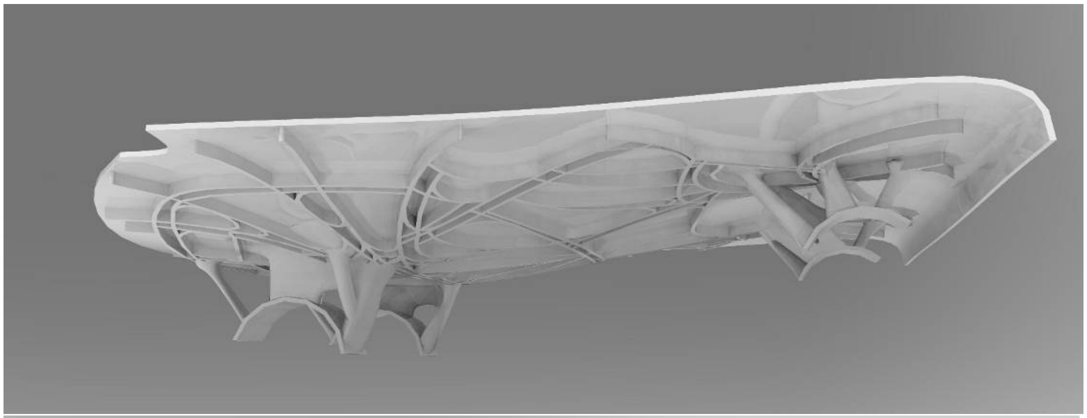
Several Iterations is made until optimal design that can be easily refined and post-processed was determined.

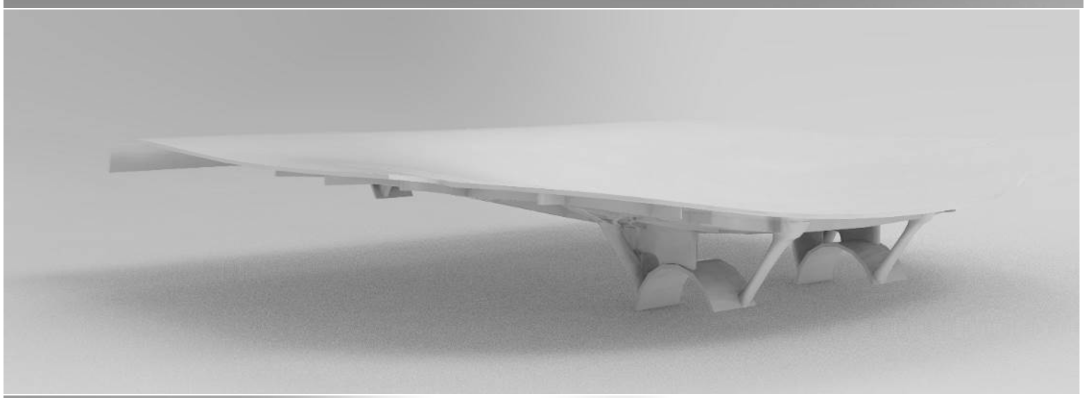


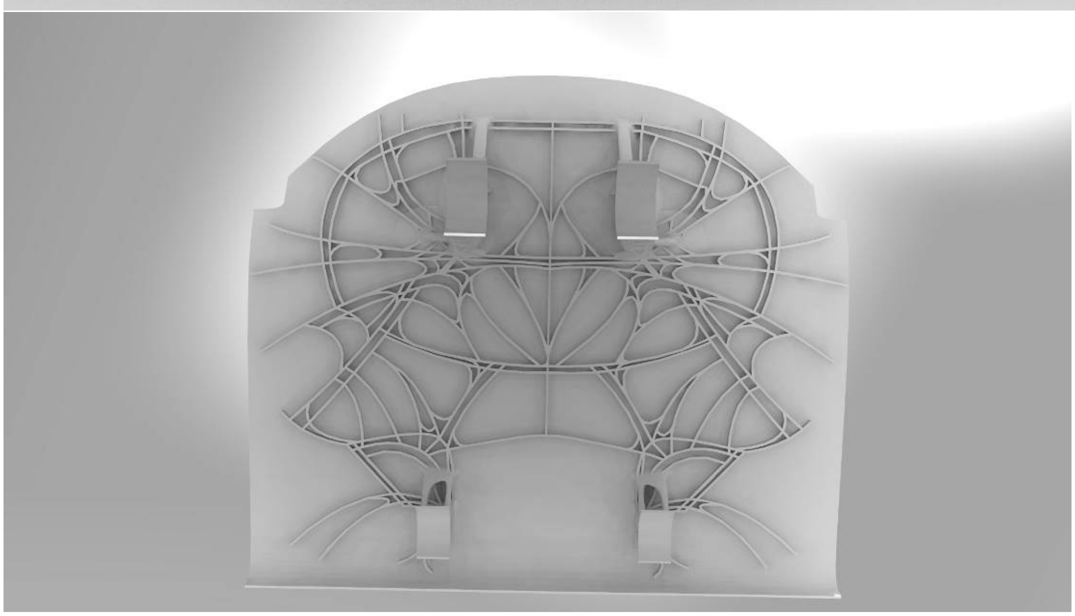
Post process: The generated design was taken as a reference to design a final seat pan bottom. Simultaneously, several stress simulations were conducted in order to check whether it is able to withstand 24g test. The design was iteratively improved following the results of the simulation.

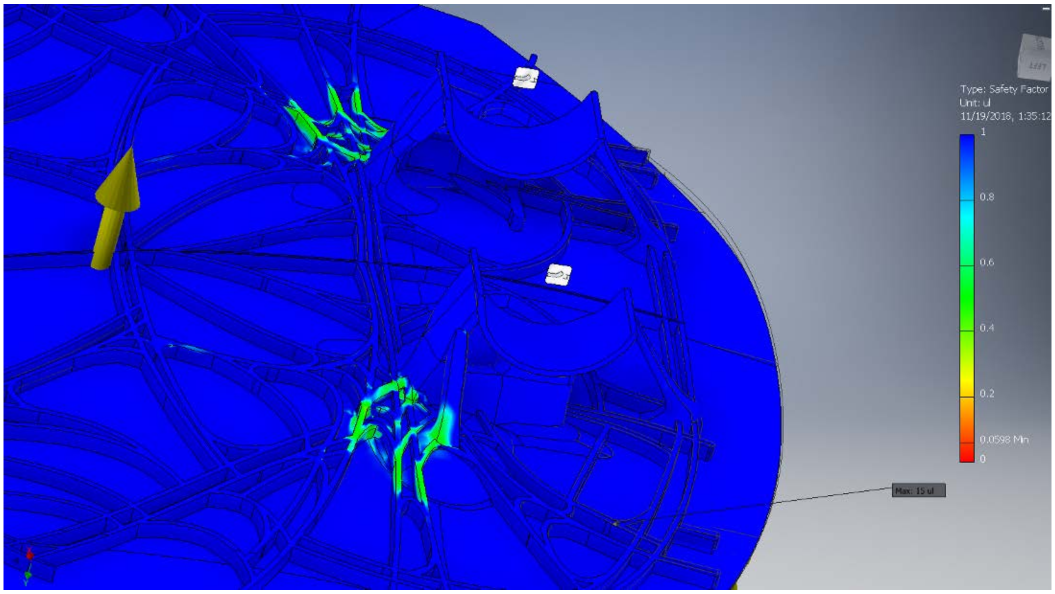


Final Design





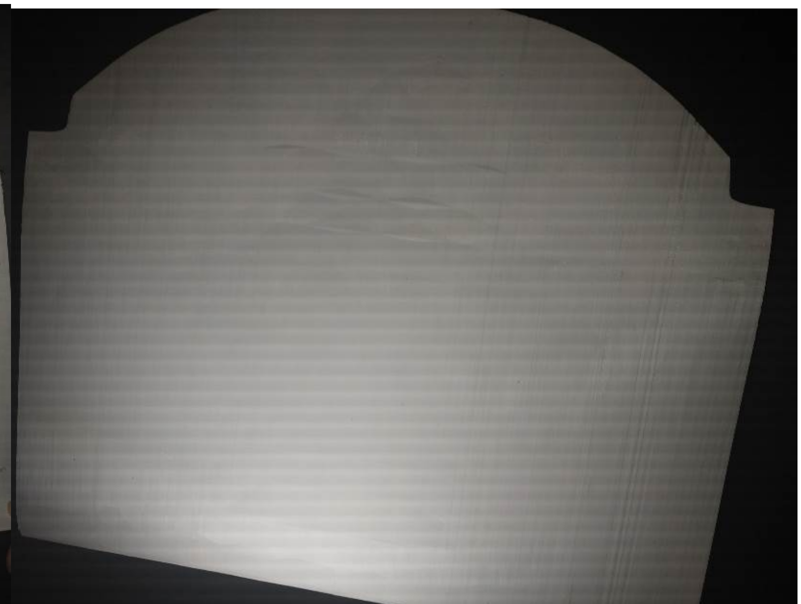
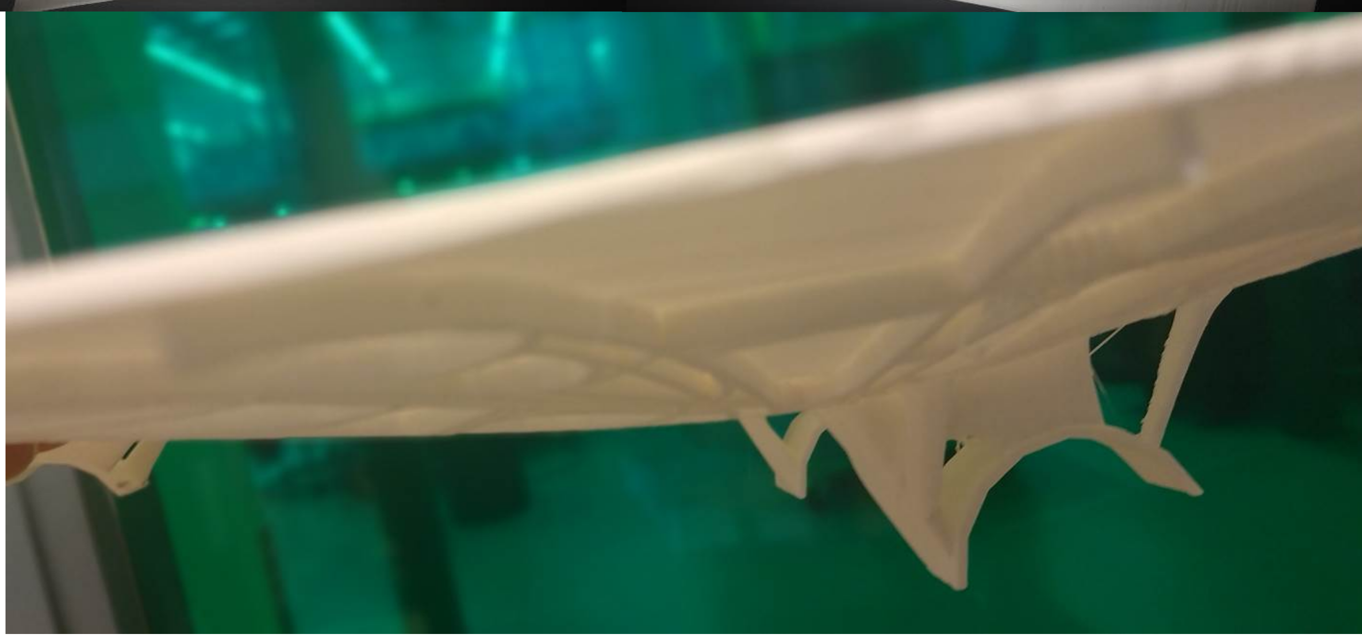




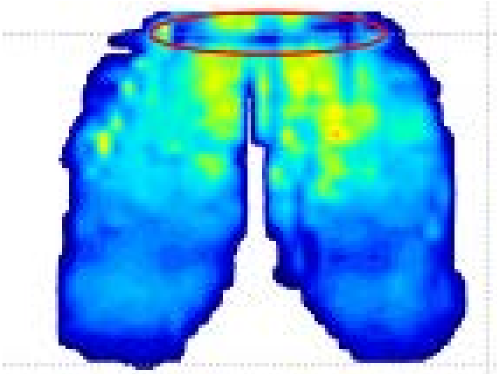
Currently this design is able to withstand 8-10g of force with a 110 Kg person at vertical (blue areas pass 14g test, green areas can only withstand 8-10g of force). Considering the 14g test is conducted at a 60* angle to the ground with p50 dummy, theoretically this design will pass the 14g test.

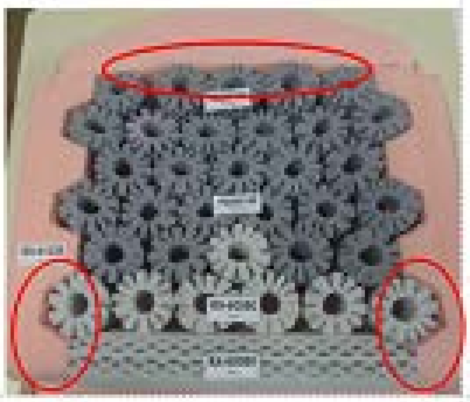
The mass of the seat-pan bottom is 320 g comparing this to 560 grams of current seat-pan bottom, this is a weight reduction of 240 grams, with further polishing and fine tuning of the design, the final mass of seat-pan is expected to be 350 grams with 210 grams of weight savings.

The design was 3D printed for a model representation.

Transition Area problem





According to the tests done by Recaro, During pressure mapping of previous designs of Octaspring, transition area from foam to Octaspring was shown in pressure map. Users testing the seat were able to feel this transition (Recaro personal interview, 2018).

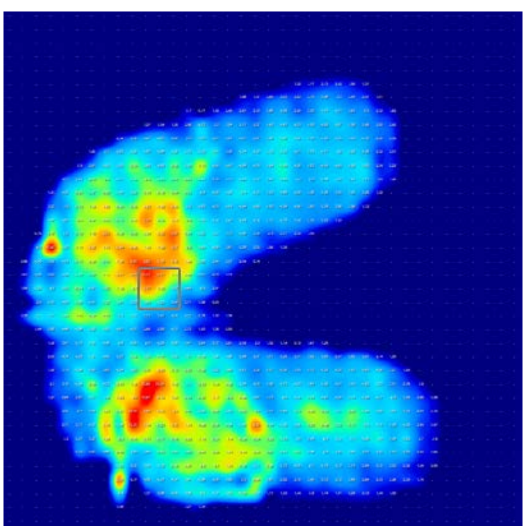
This needed to be resolved for a comfortable seat design. Therefore, through brainstorming and analysis of seats, reason for non-homogenous transitions were listed as shown in table below.

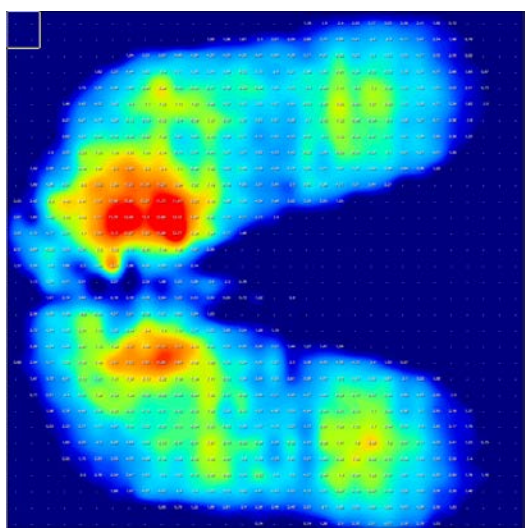
Reasons	**Possible Solutions**
- Thick outer boundary	- Make the boundary thinner by rearranging spring foams
Different material properties of foam to Octaspring	- Use modified Octaspring material to create boundary
Difference in hardness in inner diameter to outer diameter	- Use foam firmness similar to the edge of the springfoam diameter.
Insufficient, top foam layer.	Test the optimal foam layer

Follwing the table, two designs were created and tested with pressure map.

Both designs had their own pro and cons

Design 1	Design 2
o Uniform Material Properties o Sides can also change firmness o Able to create good packing o Reduced weight (+20 grams) o Increase in manufacturing cost and time o Chance of failing oil burn test	o Thinner outer lines o Firmness reduced form 8kpa to 6Kpa o Tapered edges o Less Chance of failing oil burn test o Easier to manufacture o Harder to change firmness depending on the area o Possibility of transition area still showing in pressure map



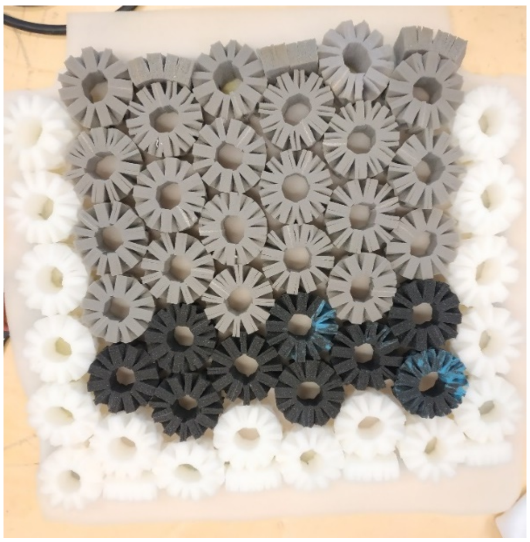


Upon testing both design showed no transition area. Therefore, considering the easiness of manufacture and less chance of failing oil burn test, design 2 was chosen to proceed further.

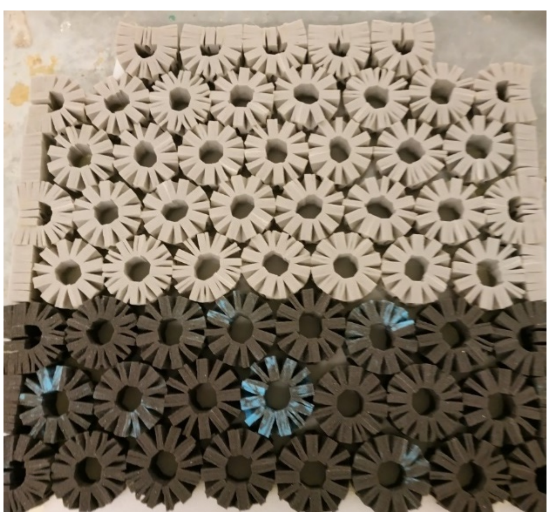
Octaspring setup user-test

As according to the material analysis conducted, in order to prevent bottoming at back with least height of Octaspring core, a 19Kpa core is determined to be required at buttock area. However, Ideal foam for the front sensitive part was still debatable. In addition, two different foam height, (4.5cm and 3.5 cm) could be used. Testing was needed to determine the optimum height and distribution in pressure.

Thus the following three cushions was tested



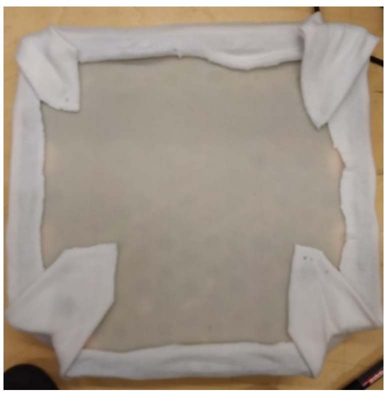
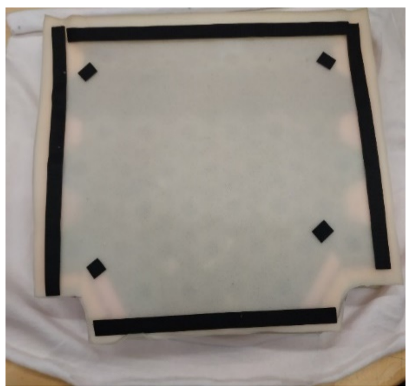
Cushion 1: 3cm (19 kpa (grey), 16 kpa (black) , 10 kpa (white). This firmness distribution derived from Smulders (2016) paper on firmness distribution.



Cushion 1: 3cm height (19 kpa (grey), 16 kpa (black).

Cushion 1: 5cm (19 kpa (grey), 16 kpa (black)

All of the cushion was upholstered in white cloth and was placed in standard Recaro 3x3 economy class seats as shown in image below.


Iterative Test Results.

Within the first two candidates, it became clear that 3.5 cm cushion was significantly more discomfortable than 4.5cm cushions. All the candidates felt bottoming after 20 minutes of seating of a 40 minutes seating user test. Therefore 3.5 cm cushions were excluded from further tests.

4.5 cm cushion was tested against standard Recaro cushions for next three participants. During a 40 minute test. 2 out of 3 participants did not find any significant difference in comfort or discomfort between 4.5cm Octaspring cushion and standard cushion. However, one participant (thin P50) felt bottoming even at 4.5 cm Octaspring cushion after 20minutes.

Further iterations were conducted to improve the comfortability of the cushion and reduce bottoming. The final two cushion specifications are as follows.

Cushion 1.

Firmness distribution

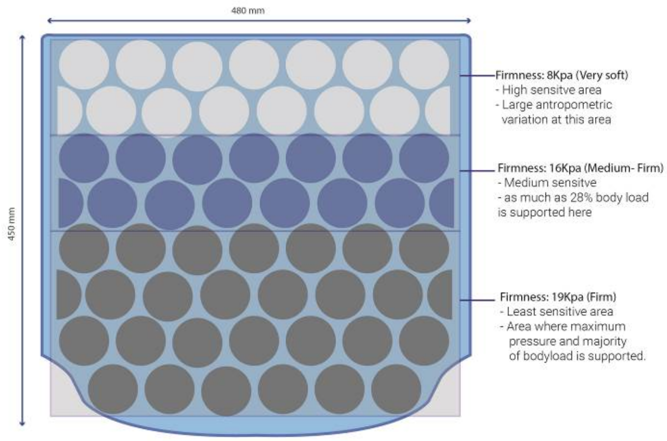


Figure 1: top view representing the firmness distribution of spring-foam.

Layer composition`

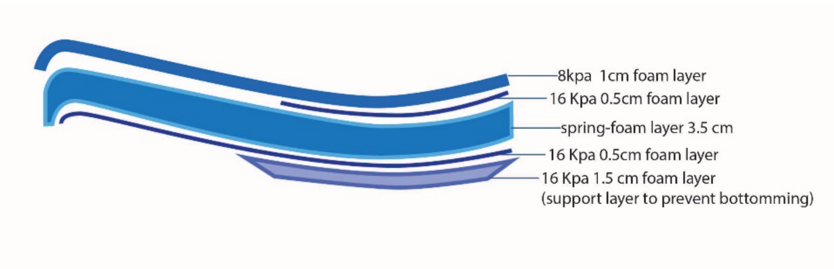


Figure 2: Side view of seat-foam showing layer composition

The total weight of the cushion was 500grams.

Seat-pan contour

Since 1.5 cm is added at the bottom of the cushion, the seat pan had to be adjusted to incorporate this change; therefore, a new seat-pan contour was determined to maintain the ideal contour profile.

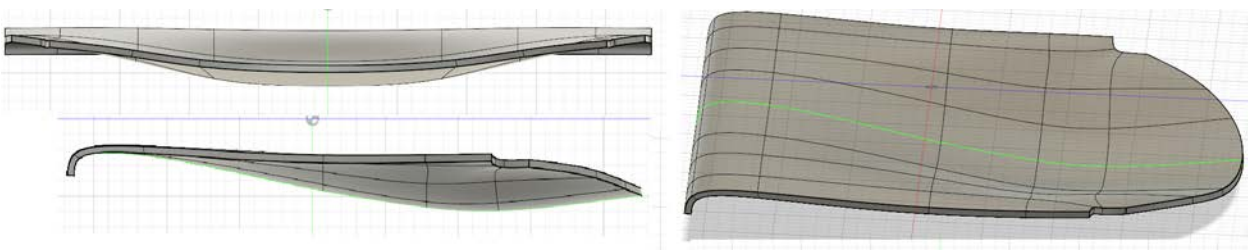
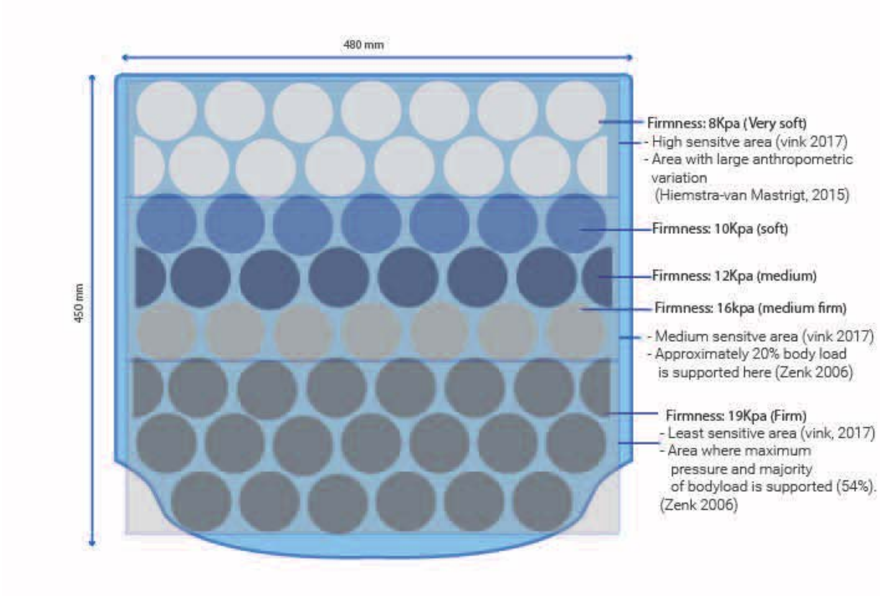


Figure 3. Seat pan contour, side view (bottom left), back view (top left), orthographic view (right).

Cushion 2



Layer composition`

The weight of cushion is 530 grams.

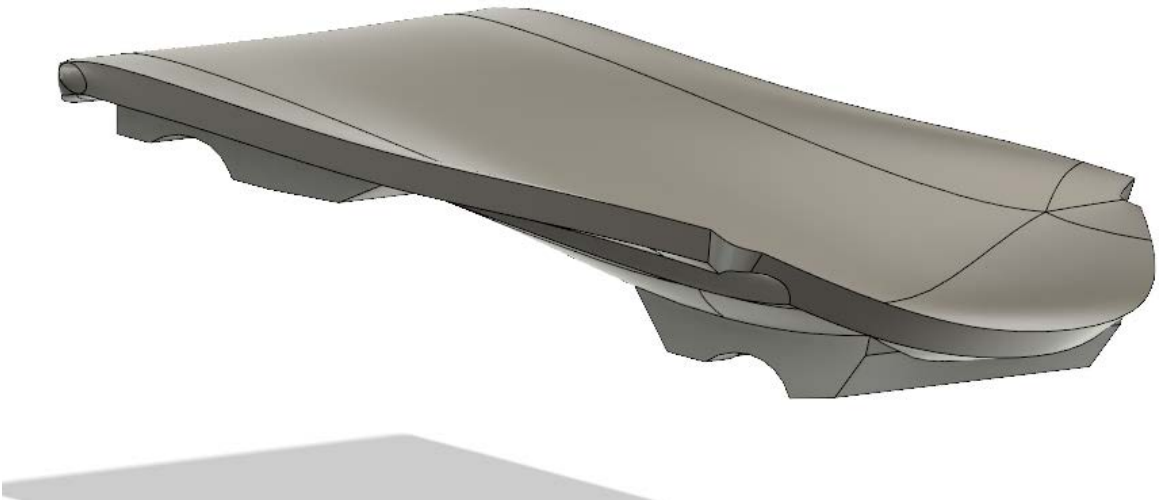
Final Determination

For choosing the final design and configuration, both of the designs were built and tested one week prior to the final user-test with 4 participants for 40 minutes. Three participants favoured cushion 2 while one participants favoured cushion 1. Although the second cushion was 30 grams higher, as comfortability a higher priority than weight, cushion1 was chosen.

User test cushion

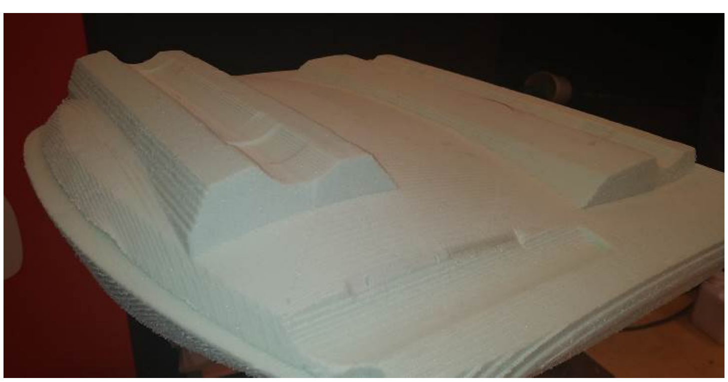
Final two cushions and seat pan bottom was built to fit in aircraft fuselage seat frame.

Final Seat pan bottom building process



Unlike the previous CNC'ed seat pan bottom, where only one side had contour, the new seat bottom had contour on both sides, therefore tradition method of two dimensional CNC could not be used. Therefore firstly a mould Designed and CNCed that had a negative contour of seat pan (see below),

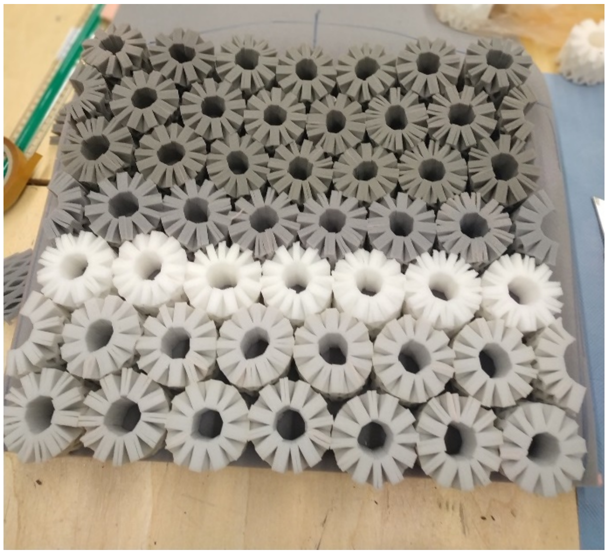
This mould was used to hold one side of seat-pan bottom in pale while other side is was CNC-d



Final CNC seat pan bottom.

Final Seat-pan cushion building process,

1. 5mm cushion sheet (19kpa 500*600mm) is attached to seat-pan bottom plate. The sheet was marked according to the dimensions of the cushion. Foam glue (Sababond 3802) was sprayed on the sheet and spring foam was placed and arranged accordingly as marked on the top. Octaspring away from marked lines were cut.



2. 15 mm (6kpa) sheet was cut and attached from the side creating boundary cushion to keep all the spring-foam in place and give smooth outer finish.

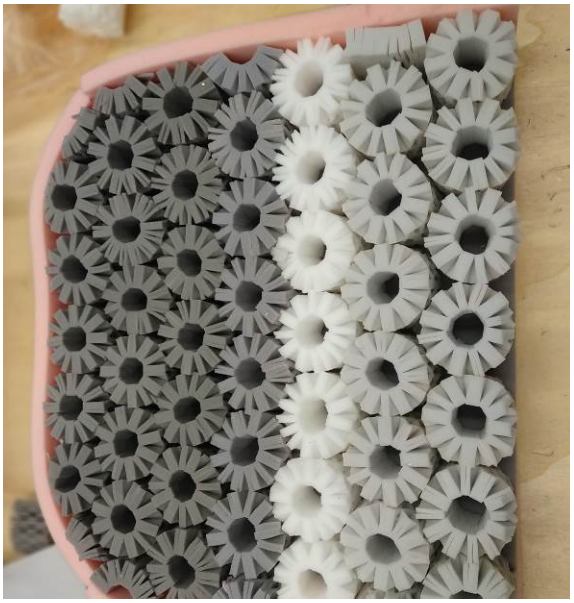
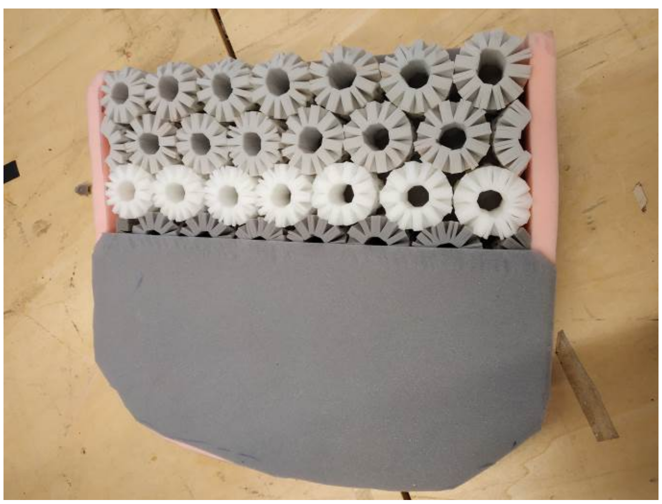
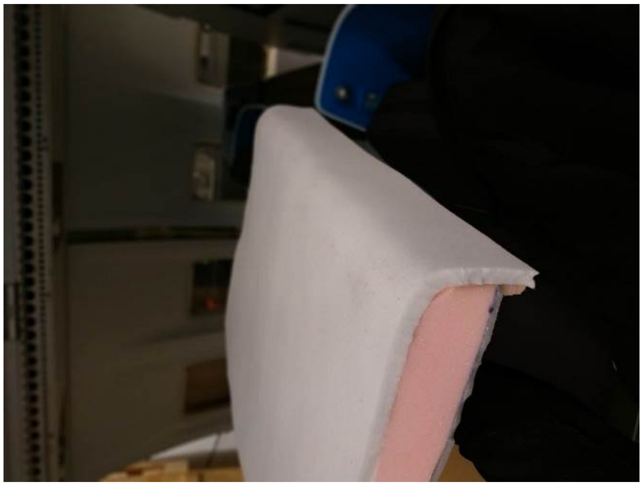



Figure 4: Gluing process

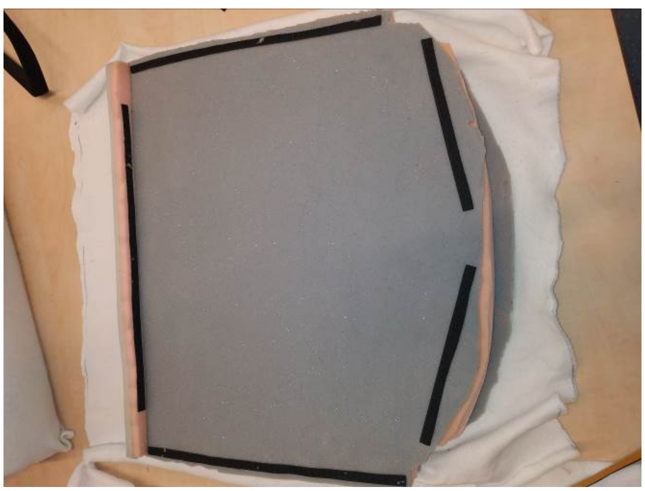
3. Additional 5mm foam layer (19kpa) over back part of seat was attached and front part was bevelled.



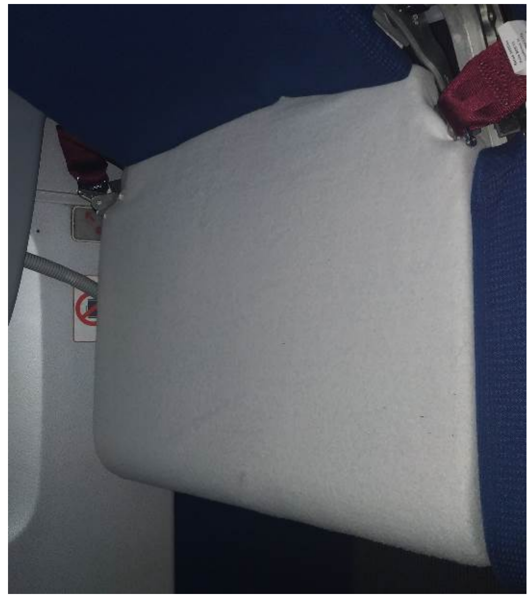

4. Final to cushion layer was added (10mm, 8kpa, 500*600) and trimmed. And the cushion was pressed frimly to set for 24 hours.




5. Velcro strips were attached to the bottom of cushion and white upholstery was placed.




Finally seat bottom plate was placed on seat fram and the cushion was placed on top, attached firmly by double sided tape.



Result

The user test was conducted successfully with following list of requirements achieved.

List Of Requirement	Achieved?	Remarks
- The designed seat pan must be similar or more comfortable in relation to current economy class seats.	**Yes .**	The user test result showed overall higher comfort than standard seat, with significantly higher initial comfort and at 30 and 60 minute mark than current economy class seat
- The designed seat pan should be lighter than current economy class seat pans.	**Yes.**	The seat cushion is 150 grams lighter and the seat pan bottom is 200 grams lighter, this gives a total of 350 grams in weight loss.
- It must comply will FAA seat regulations	**Partly.**	In simulation, whist bottom pan passes 14g test with P50 male. This was not tested physically. In addition, no oil-burn test was conducted. However, private tests in company showed spring foam seat is able to pass oil-burn test.
- The seat should be comfortable from p5 – p95 percentile of adult European passengers.	**Partly.**	P4 female to P 78 male found the seat comfortable in general. No person higher than 91 kg (P78 male) was found during the test. It can only be assumed that this result follows all the way till P95
- The user should not feel the transition between spring foam and regular foam within seat.	**Yes.**	No user complained regarding uneven pressure. Data from pressure mat shows no sharp pressure line suggesting a smooth transition from spring foam to regular foam within seat