Memo

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To:
All participants who have filled in the
questionnaire on Added Values

OPerA –
Optimization in Preliminary Aircraft Design

Summary of Questionnaire Evaluation and Evaluation Results

Content

1 Background

For assisting the research on the project OPerA, that aims to apply formal optimization to aircraft preliminary design and preliminary aircraft cabin design, a questionnaire for Added Values (AV) in aircraft design was filled out independently by a group of people. The questionnaire (see Appendix) consisted of two pages: On **page 1** a **Hierarchical Table** with a hierarchical break-down of attributes, with percents summing up to 100 % for each break-down was used. On **page 2** a matrix, representing the base for an **Analytic Hierarchy Process (AHP)**, where degrees of importance for each Added Value are set.

2 Low and High Boundaries of Added Values

Even before setting the *weights*, for a proper Added Value assessment, low and high boundaries for each Added Value needed to be rationally set (for each type of aircraft – short, medium or long range). Depending on the Added Value parameter, a maximum of 10 *points* were attributed for minimal or maximal values. For example, DOC receive the maximum of 10 points for a minimal value, while 10 points are given for maximal cruise speed, which favors a short flying time, and a flight altitude for which gust sensitivity is small. The distribution of points between boundaries is linear, according to Figure 1. The resulting points are later multiplied with the weights and a *score* results, which goes into the objective function.

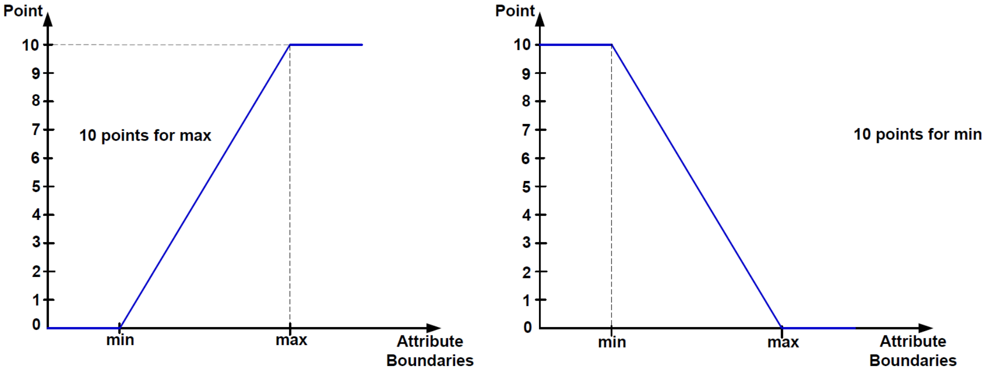


Figure 1 Conversion of optimization values into points

A few examples of Added Value limitations and the way points are assigned to the resulting optimization value are given in Table 1.

Table 1 Examples of Added Values boundaries

Example of Added Value	Low limit	High limit	Resulting point
Aisle height	Min = 1.75 m	Max = 2.10 m	$if\ Value < Min,\ then\ 0\ points$ $if\ Value > Max,\ then\ 10\ points$ $otherwise:\ Value = 10 \cdot \frac{Value - Min}{Max - Min}$
Take-off field length	Min = 1670 m	Max = 2700 m	$if\ Value < Min\ then\ 10\ points$ $if\ Value > Max,\ then\ 0\ points$ $otherwise:\ Value = 10 \cdot \left\lvert \frac{Value - Max}{Max - Min} \right\rvert$
Containerized cargo	Yes	No	$if\ Value = Yes,\ then\ 10\ points$ $if\ Value = No,\ then\ 0\ points$

Most of the Added Value boundaries are different depending if the aircraft is designed for short, medium or long range. For example, take-off field length boundaries in Table 1 are suitable for a medium range aircraft. For a short range aircraft, these boundaries should be smaller: they may be selected between 1200 m and 2200 m. A long range aircraft can have boundaries of 1600 m, respectively 3500 m. These limitations were set by looking at existing aircraft.

Boundaries of Direct Operating Costs are also different depending on the type of aircraft. The low boundary was set by calculating DOC for a maximum number of passengers and high cruise speed, while the high boundary was calculated for a minimum number of passengers and low cruise speed.

3 Questionnaires Evaluation

Each page of every questionnaire was evaluated, comparisons of assigned weights between the two pages were made and consistency checks were performed. Helpful literature sources were found to be [1], [2] and [3].

From the **Hierarchical Table** (page 1) the resulting absolute weights were calculated. This was done for each participant. Averages were calculated for experts, PhD students, students and averages for all participants.

The **AHP matrix** from page 2 was evaluated and compared the results from the Hierarchical Table from page 1. Existing scientific evaluation methods were applied. It was found that for square matrices larger than 9, it is rather difficult for the experts working on the questionnaire to handle the information (compare with [1] and [2]). A matrix for n parameters requires m individual evaluations to be done by the expert

$$m = (n^2 - n) / 2 \quad . \tag{1}$$

This function is plotted in Figure 2. A matrix for e. g. $n = 16$ parameters requires

$$m = (n^2 - n) / 2 = 120$$

evaluations, which is far too much work for an evaluator and not very practical.

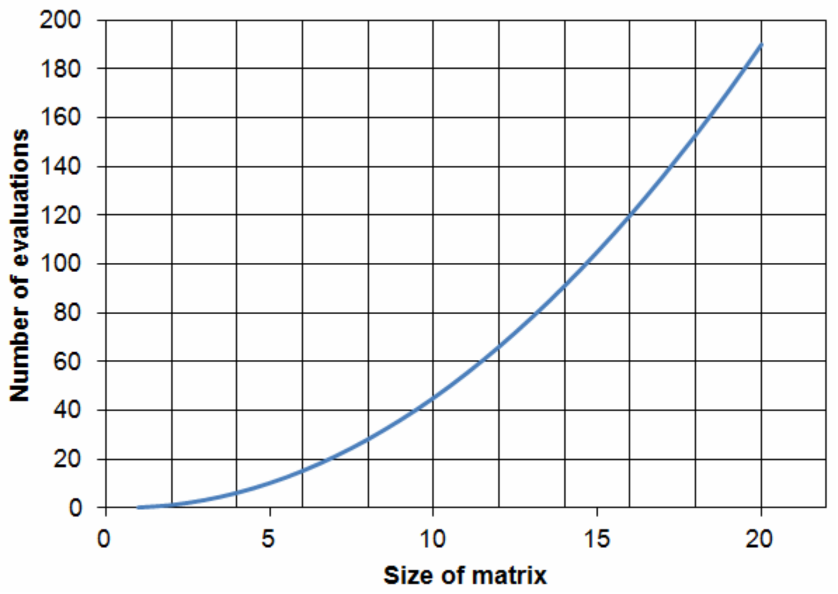


Figure 2 Required number of evaluations as a function of the size of the matrix

3.1 Consistency Check

User input from page 1 can not be checked on its own. However, a consistency check is possible and can be performed on the matrix of page 2. According to [1], a matrix consistency index can be defined as

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2}$$

where n is the size of the matrix and λ_{max} is the principal eigenvalue of the matrix from

$$Aw = \lambda_{max} w \tag{3}$$

with the weighting vector w.

In case of full consistency $\lambda_{max} = n$ and $CI = 0$. Otherwise $CI \geq 0$ because the principal eigenvalue $\lambda_{max} \geq n$ [1].

For **calculating the principal eigenvalue** for such a large matrix (of e. g. $n = 16$) a **simple approximate method** is applied. It is based on the *normalized reciprocal matrix* of the given matrix (see example in Figure 3). The reciprocal matrix is built by transposing the linear scale from 1 to 10 that the experts used to fill in the matrix, to a reciprocal scale from 1 to 9. This scale is indicated in Table 2.

Table 2 Linear scale and reciprocal scale example

linear scale up to 10	reciprocal scale
0	0.111
1	0.135
2	0.172
3	0.238
4	0.385
5	1.000
6	2.600
7	4.200
8	5.800
9	7.400
10	9.000

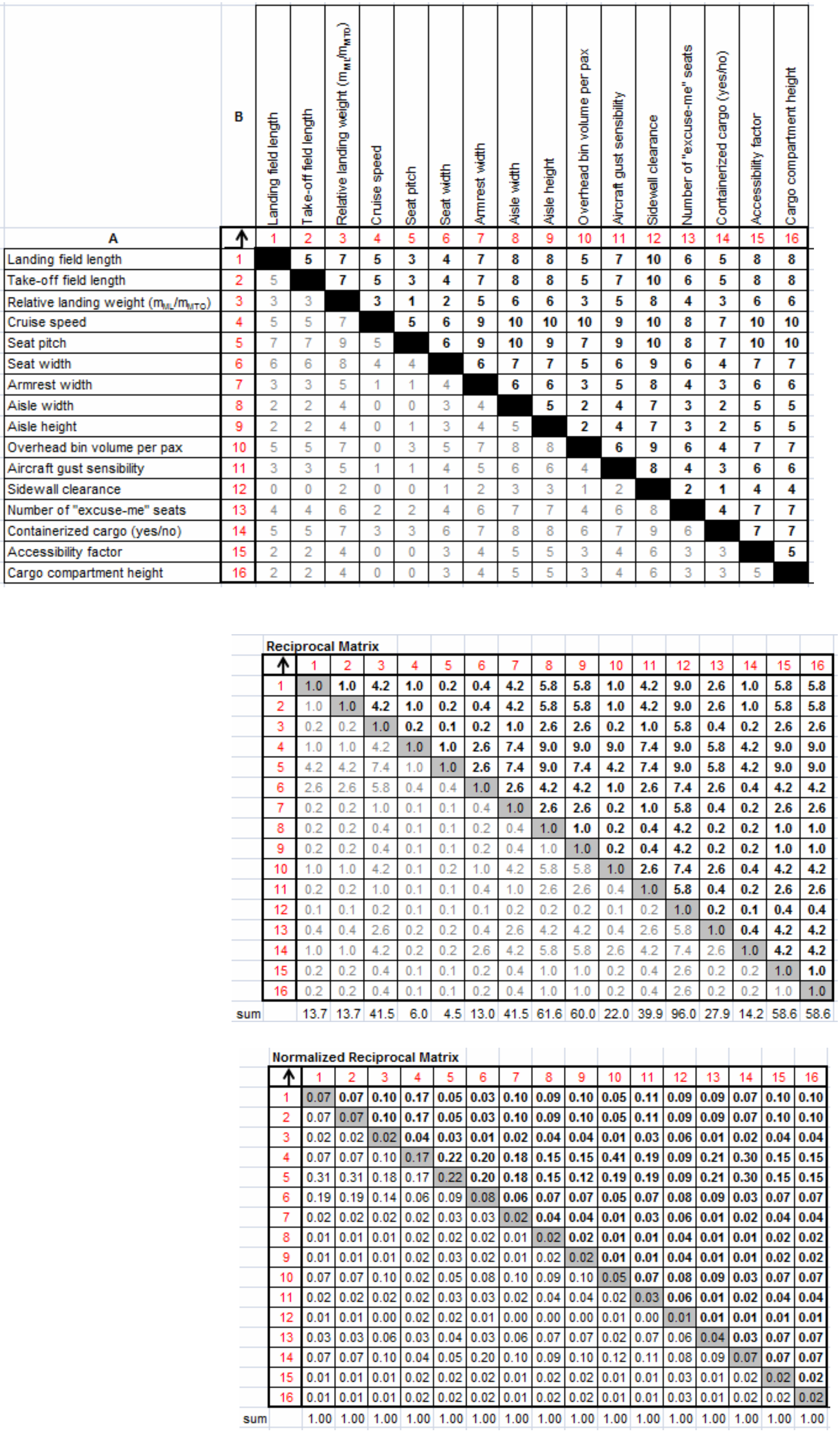
Table 3 Normalized eigenvector for the matrix in Figure 3

approximate method	exact method (MATLAB®)
8.7 %	8.6%
8.7 %	8.6%
2.9 %	2.7%
17.6 %	18.4%
19.4 %	20.0%
8.7 %	8.8%
2.9 %	2.7%
1.6 %	1.5%
1.6 %	1.5%
7.1 %	7.0%
3.0 %	2.8%
0.8 %	0.8%
4.8 %	4.5%
9.0 %	9.2%
1.5 %	1.5%
1.5 %	1.5%

In this simple approach the **eigenvector** is given by the averages of each line of the normalized reciprocal matrix. For example, the first element of the eigenvector is given by the average of the first line. The eigenvector for the matrix in Figure 3 is given in Table 3. The principal **eigenvalue** is calculated as the sum of the products between each element of the eigenvector and the sum of elements from the corresponding column in the reciprocal matrix. For the example in Figure 3, the principal eigenvalue has the value of 17.9 (see example calculation in equation 4).

$$\lambda_{max} = (13.7 \cdot 8.7\ \%) + (13.7 \cdot 8.7\ \%) + (41.5 \cdot 2.9\ \%) + (6 \cdot 17.6\ \%) + \ldots + (58.6 \cdot 1.5\ \%) = 17.9 \qquad (4)$$

The **exact calculation of the principle eigenvalue and eigenvector** requires much more steps in the calculation. A tool like MATLAB® allows an easy approach to such an exact calculation. For the same matrix, the method given by MATLAB® delivers a value of 17.29 for the principal eigenvalue. The eigenvector is given in Table 3. The small deviation, of only 2.9 % between the approximate and the exact calculation of the principle eigenvalue shows the suitability of the simpler method for the evaluation of the questionnaire. The advantage of the simpler method lies in the fact that it can easily be incorporated in a spreadsheet calculation.



	B	Landing field length	Take-off field length	Relative landing weight (m_{ML}/m_{MTO})	Cruise speed	Seat pitch	Seat width	Armrest width	Aisle width	Aisle height	Overhead bin volume per pax	Aircraft gust sensibility	Sidewall clearance	Number of "excuse-me" seats	Containerized cargo (yes/no)	Accessibility factor	Cargo compartment height
A	↑	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Landing field length	1		5	7	5	3	4	7	8	8	5	7	10	6	5	8	8
Take-off field length	2	5		7	5	3	4	7	8	8	5	7	10	6	5	8	8
Relative landing weight (m_{ML}/m_{MTO})	3	3	3		3	1	2	5	6	6	3	5	8	4	3	6	6
Cruise speed	4	5	5	7		5	6	9	10	10	10	9	10	8	7	10	10
Seat pitch	5	7	7	9	5		6	9	10	9	7	9	10	8	7	10	10
Seat width	6	6	6	8	4	4		6	7	7	5	6	9	6	4	7	7
Armrest width	7	3	3	5	1	1	4		6	6	3	5	8	4	3	6	6
Aisle width	8	2	2	4	0	0	3	4		5	2	4	7	3	2	5	5
Aisle height	9	2	2	4	0	1	3	4	5		2	4	7	3	2	5	5
Overhead bin volume per pax	10	5	5	7	0	3	5	7	8	8		6	9	6	4	7	7
Aircraft gust sensibility	11	3	3	5	1	1	4	5	6	6	4		8	4	3	6	6
Sidewall clearance	12	0	0	2	0	0	1	2	3	3	1	2		2	1	4	4
Number of "excuse-me" seats	13	4	4	6	2	2	4	6	7	7	4	6	8		4	7	7
Containerized cargo (yes/no)	14	5	5	7	3	3	6	7	8	8	6	7	9	6		7	7
Accessibility factor	15	2	2	4	0	0	3	4	5	5	3	4	6	3	3		5
Cargo compartment height	16	2	2	4	0	0	3	4	5	5	3	4	6	3	3	5	

Reciprocal Matrix

	↑	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	1	1.0	1.0	4.2	1.0	0.2	0.4	4.2	5.8	5.8	1.0	4.2	9.0	2.6	1.0	5.8	5.8
	2	1.0	1.0	4.2	1.0	0.2	0.4	4.2	5.8	5.8	1.0	4.2	9.0	2.6	1.0	5.8	5.8
	3	0.2	0.2	1.0	0.2	0.1	0.2	1.0	2.6	2.6	0.2	1.0	5.8	0.4	0.2	2.6	2.6
	4	1.0	1.0	4.2	1.0	1.0	2.6	7.4	9.0	9.0	9.0	7.4	9.0	5.8	4.2	9.0	9.0
	5	4.2	4.2	7.4	1.0	1.0	2.6	7.4	9.0	7.4	4.2	7.4	9.0	5.8	4.2	9.0	9.0
	6	2.6	2.6	5.8	0.4	0.4	1.0	2.6	4.2	4.2	1.0	2.6	7.4	2.6	0.4	4.2	4.2
	7	0.2	0.2	1.0	0.1	0.1	0.4	1.0	2.6	2.6	0.2	1.0	5.8	0.4	0.2	2.6	2.6
	8	0.2	0.2	0.4	0.1	0.1	0.2	0.4	1.0	1.0	0.2	0.4	4.2	0.2	0.2	1.0	1.0
	9	0.2	0.2	0.4	0.1	0.1	0.2	0.4	1.0	1.0	0.2	0.4	4.2	0.2	0.2	1.0	1.0
	10	1.0	1.0	4.2	0.1	0.2	1.0	4.2	5.8	5.8	1.0	2.6	7.4	2.6	0.4	4.2	4.2
	11	0.2	0.2	1.0	0.1	0.1	0.4	1.0	2.6	2.6	0.4	1.0	5.8	0.4	0.2	2.6	2.6
	12	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.2	1.0	0.2	0.1	0.4	0.4
	13	0.4	0.4	2.6	0.2	0.2	0.4	2.6	4.2	4.2	0.4	2.6	5.8	1.0	0.4	4.2	4.2
	14	1.0	1.0	4.2	0.2	0.2	2.6	4.2	5.8	5.8	2.6	4.2	7.4	2.6	1.0	4.2	4.2
	15	0.2	0.2	0.4	0.1	0.1	0.2	0.4	1.0	1.0	0.2	0.4	2.6	0.2	0.2	1.0	1.0
	16	0.2	0.2	0.4	0.1	0.1	0.2	0.4	1.0	1.0	0.2	0.4	2.6	0.2	0.2	1.0	1.0
sum		13.7	13.7	41.5	6.0	4.5	13.0	41.5	61.6	60.0	22.0	39.9	96.0	27.9	14.2	58.6	58.6

Normalized Reciprocal Matrix

	↑	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	1	0.07	0.07	0.10	0.17	0.05	0.03	0.10	0.09	0.10	0.05	0.11	0.09	0.09	0.07	0.10	0.10
	2	0.07	0.07	0.10	0.17	0.05	0.03	0.10	0.09	0.10	0.05	0.11	0.09	0.09	0.07	0.10	0.10
	3	0.02	0.02	0.02	0.04	0.03	0.01	0.02	0.04	0.04	0.01	0.03	0.06	0.01	0.02	0.04	0.04
	4	0.07	0.07	0.10	0.17	0.22	0.20	0.18	0.15	0.15	0.41	0.19	0.09	0.21	0.30	0.15	0.15
	5	0.31	0.31	0.18	0.17	0.22	0.20	0.18	0.15	0.12	0.19	0.19	0.09	0.21	0.30	0.15	0.15
	6	0.19	0.19	0.14	0.06	0.09	0.08	0.06	0.07	0.07	0.05	0.07	0.08	0.09	0.03	0.07	0.07
	7	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.04	0.04	0.01	0.03	0.06	0.01	0.02	0.04	0.04
	8	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.04	0.01	0.01	0.02	0.02
	9	0.01	0.01	0.01	0.02	0.03	0.02	0.01	0.02	0.02	0.01	0.01	0.04	0.01	0.01	0.02	0.02
	10	0.07	0.07	0.10	0.02	0.05	0.08	0.10	0.09	0.10	0.05	0.07	0.08	0.09	0.03	0.07	0.07
	11	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.04	0.04	0.02	0.03	0.06	0.01	0.02	0.04	0.04
	12	0.01	0.01	0.00	0.02	0.02	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01
	13	0.03	0.03	0.06	0.03	0.04	0.03	0.06	0.07	0.07	0.02	0.07	0.06	0.04	0.03	0.07	0.07
	14	0.07	0.07	0.10	0.04	0.05	0.20	0.10	0.09	0.10	0.12	0.11	0.08	0.09	0.07	0.07	0.07
	15	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.03	0.01	0.02	0.02	0.02
	16	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.03	0.01	0.02	0.02	0.02
sum		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Figure 3 Example of filled in matrix and the corresponding reciprocal and normalized reciprocal matrix

With the principal eigenvalue of 17.9 from Equation (2) a consistency index of 0.12 results. This result has, however, not much meaning yet. The important measure is a ratio called consistency ratio, CR. It is given by [1]:

$$CR = \frac{CI}{RI} \leq 10\ \% \tag{5}$$

RI is called random consistency index and has the meaning of a consistency index

$$RI = (\lambda_{max,av} - n)/(n-1)$$

$\lambda_{max,av}$ is the average of all principle eigenvalues obtained from evaluating very many matrices filled with random numbers. This means, if a matrix is filled for evaluation without giving any thought to, it will already have a certain consistency index $CI > 0$. Giving some thought to filling out the evaluation matrix should achieve a smaller *CI*. The consistency ratio, *CR* is hence the ratio of the *CI* of the evaluators matrix divided by the CI filled out randomly. If the consistency ratio, *CR* is sufficiently small (about 10 % or less) the evaluation is considered acceptable and the weights vector *w* can be trusted, otherwise consistency should be improved.

For $n = 16$, which is the size of the matrix in page 2 of the questionnaire, the random consistency index is $RI = 1.5978$. With consistency index *CI* of 0.12 (calculated from Figure 3) this results in this example to a $CR = 7.5\ \%$ which is acceptable because it is below 10% (Equation 5).

[3] presents an estimation method for $\lambda_{max,av} = f(n)$ and hence $RI = f(n)$ obtained from fitting a function to a very large number of principle eigenvectors from matrices with random numbers.

$$\begin{aligned} \lambda_{max,av} &= 2.7699 \cdot n - 4.3513 \\ RI &= (\lambda_{max,av} - n)/(n-1) \end{aligned} \tag{6}$$

$RI = f(n)$ is plotted in Figure 4.

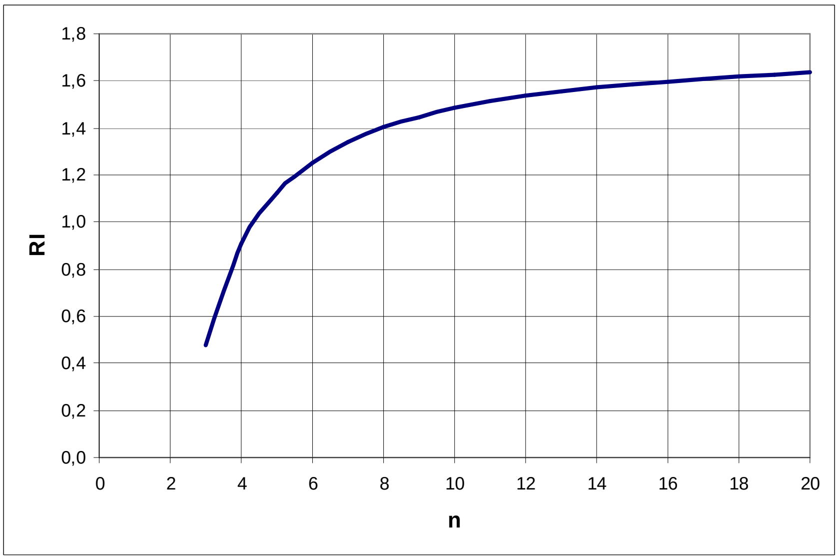
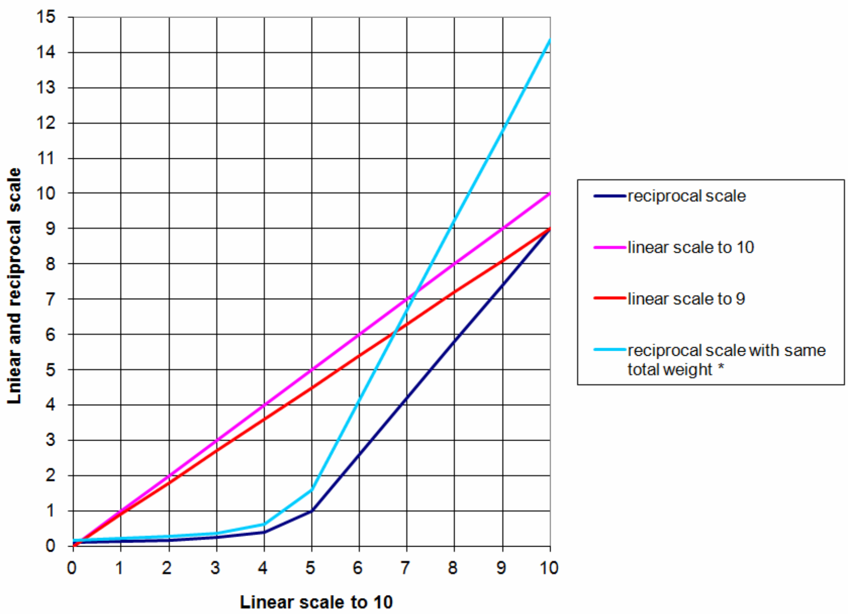


Figure 4 Random consistency index as a function of matrix size based on the estimation method for $\lambda_{max,av} = f(n)$

3.2 Comparison of Results

When **comparing the weights vector *w*** using the AHP matrix filled in by using the **linear scale** with the weights vector *w* using the same AHP matrix converted to the **reciprocal scale**, it is noticed that the resulting weights vector in the second case yields rather unrealistic values. In order to investigate this, Figure 5, based on Table 4, compares linear and reciprocal scales.



*as the linear scale to 9

Figure 5 Comparison of linear and reciprocal scales

The horizontal axis in the plot is the linear scale to 10. The dark blue line shows how points are attributed, when a reciprocal scale is used. The phenomenon becomes obvious when the "linear scale to 9" is compared with the "reciprocal scale to 9 with the same total weight as the linear scale to 9". Few points are given to low (bad) evaluation results and more points are given to high (good) results. As a consequence the reciprocal scale tends to polarize evaluations too much which may not be what is intended. This is the reason why **all the comparative and final results were interpreted using the linear scale**. The reciprocal scale was only used for calculation of the consistency ratio, *CR* which only works on reciprocal matrices.

Table 4 Linear and reciprocal scales

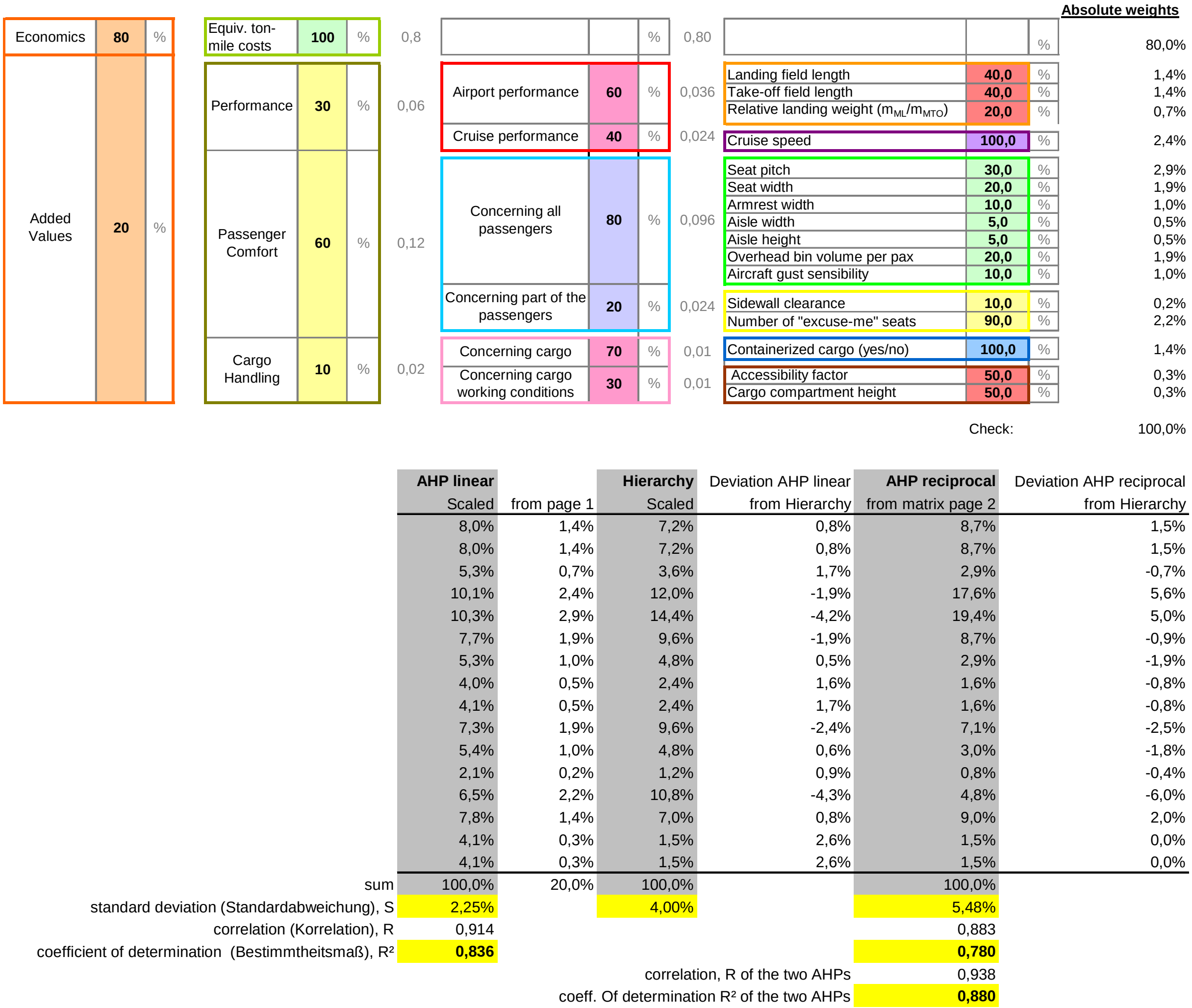
	Linear scale to 10	Reciprocal scale	Linear scale to 9	Reciprocal scale with the same total weight as the linear scale to 9
	0	0.111	0.0	0.177
	1	0.135	0.9	0.215
	2	0.172	1.8	0.275
	3	0.238	2.7	0.380
	4	0.385	3.6	0.613
	5	1.000	4.5	1.595
	6	2.600	5.4	4.146
	7	4.200	6.3	6.698
	8	5.800	7.2	9.249
	9	7.400	8.1	11.800
	10	9.000	9.0	14.352
Sum	55	31.041	49.5	49.500

Additional data examination was performed, namely a comparison of results between page 1 in questionnaire (Hierarchical Table) and page 2 in questionnaire (Analytic Hierarchy Process matrix). These assessments were performed via a correlation factor, *R* calculated based on standard deviation, as shown in equation (7). The comparison measure was R^2, called *coefficient of determination* (in German: Bestimmtheitsmaß). R^2 roughly indicates which percentage of the variation in the first variable can be explained with the variation in the second variable.

$$\begin{gathered} R(x,y) = \frac{\sum (x-\overline{x})(y-\overline{y})}{\sqrt{\sum (x-\overline{x})^2 \sum (y-\overline{y})^2}} \\ \overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \ ; \quad \overline{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \end{gathered} \tag{7}$$

Regarding the comparison of data from the two pages, the higher the R^2 the better the inputs in page 1 match the inputs in page 2. An example evaluation is shown in Table 5.

Table 5 Example results of one questionnaire and its evaluation



														Absolute weights
Economics	80	%	Equiv. ton-mile costs	100	%	0,8			%	0,80			%	80,0%
Added Values	20	%	Performance	30	%	0,06	Airport performance	60	%	0,036	Landing field length	40,0	%	1,4%
											Take-off field length	40,0	%	1,4%
											Relative landing weight (m_{ML}/m_{MTO})	20,0	%	0,7%
							Cruise performance	40	%	0,024	Cruise speed	100,0	%	2,4%
			Passenger Comfort	60	%	0,12	Concerning all passengers	80	%	0,096	Seat pitch	30,0	%	2,9%
											Seat width	20,0	%	1,9%
											Armrest width	10,0	%	1,0%
											Aisle width	5,0	%	0,5%
											Aisle height	5,0	%	0,5%
											Overhead bin volume per pax	20,0	%	1,9%
											Aircraft gust sensibility	10,0	%	1,0%
							Concerning part of the passengers	20	%	0,024	Sidewall clearance	10,0	%	0,2%
											Number of "excuse-me" seats	90,0	%	2,2%
			Cargo Handling	10	%	0,02	Concerning cargo	70	%	0,01	Containerized cargo (yes/no)	100,0	%	1,4%
							Concerning cargo working conditions	30	%	0,01	Accessibility factor	50,0	%	0,3%
											Cargo compartment height	50,0	%	0,3%
												Check:		100,0%

	AHP linear Scaled	from page 1	**Hierarchy** Scaled	Deviation AHP linear from Hierarchy	**AHP reciprocal** from matrix page 2	Deviation AHP reciprocal from Hierarchy
	8,0%	1,4%	7,2%	0,8%	8,7%	1,5%
	8,0%	1,4%	7,2%	0,8%	8,7%	1,5%
	5,3%	0,7%	3,6%	1,7%	2,9%	-0,7%
	10,1%	2,4%	12,0%	-1,9%	17,6%	5,6%
	10,3%	2,9%	14,4%	-4,2%	19,4%	5,0%
	7,7%	1,9%	9,6%	-1,9%	8,7%	-0,9%
	5,3%	1,0%	4,8%	0,5%	2,9%	-1,9%
	4,0%	0,5%	2,4%	1,6%	1,6%	-0,8%
	4,1%	0,5%	2,4%	1,7%	1,6%	-0,8%
	7,3%	1,9%	9,6%	-2,4%	7,1%	-2,5%
	5,4%	1,0%	4,8%	0,6%	3,0%	-1,8%
	2,1%	0,2%	1,2%	0,9%	0,8%	-0,4%
	6,5%	2,2%	10,8%	-4,3%	4,8%	-6,0%
	7,8%	1,4%	7,0%	0,8%	9,0%	2,0%
	4,1%	0,3%	1,5%	2,6%	1,5%	0,0%
	4,1%	0,3%	1,5%	2,6%	1,5%	0,0%
sum	100,0%	20,0%	100,0%		100,0%	
standard deviation (Standardabweichung), S	2,25%		4,00%		5,48%	
correlation (Korrelation), R	0,914				0,883	
coefficient of determination (Bestimmtheitsmaß), R²	**0,836**				**0,780**	
				correlation, R of the two AHPs	0,938	
				coeff. Of determination R² of the two AHPs	**0,880**	

Based on an example of one questionnaire as given in Figure 3 and Table 5, resulting values of the evaluation parameters are:

- Consistency ratio, CR = 7.5 % (this is less than 10% and hence this evaluation is acceptable)
- Coefficient of determination from comparison of HierarchicalTtable with AHP-Linear: $R_1^2 = 0.836$
- Coefficient of determination from comparison of Hierarchical Table with AHP-Reciprocal: $R_2^2 = 0.780$
- Coefficient of determination from comparison of AHP-Linear with AHP-Reciprocal: $R_3^2 = 0.880$

To summarize, the questionnaire assessment steps were:

- Calculation of resulting weights from the Hierarchical Table (page 1)
- Calculation of the normalized reciprocal matrix and the corresponding eigenvector of the AHP matrix
- Calculation of weights (scaled to 100%) from the AHP matrix in page 2 with linear evaluation scale
- Calculation of weights (scaled to 100%) from the AHP matrix in page 2 with reciprocal evaluation scale
- Calculation of the coefficient of determination for each comparative case (Hierarchical Table with AHP-Linear, Hierarchical Table with AHP-Reciprocal, AHP-Linear with AHP-Reciprocal)
- Calculation of the principal eigenvalue, consistency index, consistency ratio of the AHP matrix, consistency check

4 Results of Questionnaire Evaluation

Participants. 22 persons from the following categories filled in the questionnaires:

- Experts
    - Engineer from Aircraft Manufacturer: 3
    - Airline Captain: 1
    - Aircraft Design Professor: 1
- Aircraft Design PhD Students: 12
- Aircraft Design Students: 5

Separate additional comments from expert discussions were very helpful. Results are presented in Table 6, 7 and 8 in anonymous form.

Hierarchical Table versus AHP matrix. In general, the AHP matrices show poor consistencies. In all groups $CR > 10\%$ and hence the results demand improvement. The standard deviation for the Added Values in Table 8 highlights that the AHP matrices do not show meaningful (interesting) results. All Added Values come out with similar importance. This does not match reality and it also does not help the aircraft design process. It can be concluded that the much simpler evaluation of the Hierarchical Table is more suitable than the AHP matrix, for which CR yields large inconsistencies even for expert weightings.

Table 6 summarizes important averages of key evaluation parameters. Students show the highest consistency ratio for the AHP matrix on page 2. Experts have better coefficient of determination when comparing the Hierarchical Table with AHP-Linear and with AHP-Reciprocal.

Table 6 Averages of key evaluation parameters

Group	Parameter and average	Lowest value	Highest value	Comments
Experts	CR = 38.5 %	7.5 %	65.0 %	1 / 4 experts with acceptable CR
	R_1^2 = 48.4 %	17.5 %	83.6 %	comparison of Hierarchical Table with AHP-Linear
	R_2^2 = 53.1 %	26.2 %	78.0 %	comparison of Hierarchical Table with AHP-Reciprocal
	R_3^2 = 69.3 %	47.1 %	88.0 %	comparison of AHP-Linear with AHP-Reciprocal
Ph.D students	CR = 19.1 %	9.1 %	37.6 %	1 / 12 Ph.D students with acceptable CR
	R_1^2 = 34.8 %	16.8 %	48.7 %	comparison of Hierarchical Table with AHP-Linear
	R_2^2 = 41.8 %	15.9 %	52.3 %	comparison of Hierarchical Table with AHP-Reciprocal
	R_3^2 = 88.9 %	69.9 %	96.5 %	comparison of AHP-Linear with AHP-Reciprocal
Students	CR = 12.7 %	6.9 %	21.8 %	2 / 5 students with acceptable CR
	R_1^2 = 14.9 %	2.7 %	37.4 %	comparison of Hierarchical Table with AHP-Linear
	R_2^2 = 22.7 %	2.0 %	54.1 %	comparison of Hierarchical Table with AHP-Reciprocal
	R_3^2 = 86.7 %	74.9 %	95.7 %	comparison of AHP-Linear with AHP-Reciprocal
All	CR = 23.5 %	6.9 %	65.0 %	
	R_1^2 = 32.7 %	2.7 %	83.6 %	comparison of Hierarchical Table with AHP-Linear
	R_2^2 = 39.2 %	2.0 %	78.0 %	comparison of Hierarchical Table with AHP-Reciprocal
	R_3^2 = 81.6 %	47.1 %	96.5 %	comparison of AHP-Linear with AHP-Reciprocal

Added Values versus DOC. The results from Table 7 show there is a good agreement that DOCs are more important than the Added Values. If the ratio is 3 to 1 or if it is 2 to 1 can be debated. Experts also claim that the DOCs are everything and Added Values are nothing in practice. This extreme view is not helpful because it just states that the objective function for aircraft design should be DOC. In order to give a mixed DOC-Added-Value objective function some meaning DOC have been selected to account (only) for 75%.

Table 7 Group averages of Added Values main hierarchical breakdown

	From Hierarchical Table				
DOC respectively Added Value	Experts	Ph.D stud.	Students	All	Selected (see Chapter 5)
1 DOC	73.8%	67.3%	64.0%	67.8%	75.0%
2 Added Values	26.3%	32.7%	36.0%	32.3%	25.0%
2.1 Performance	36.7%	48.0%	41.0%	44.4%	35.0%
2.2 Passenger Comfort	43.3%	34.9%	36.0%	36.5%	55.0%
2.3 Cargo / Baggage Handling	20.0%	17.1%	23.0%	19.1%	10.0%
2.1.1 Airport Performance	50.0%	55.0%	43.0%	51.1%	50.0%
2.2.2 Cruise Performance	50.0%	45.0%	57.0%	48.9%	50.0%
2.2.1 Concerning all passengers	66.7%	66.5%	71.0%	67.7%	80.0%
2.2.2 Concerning part of the passengers	33.3%	33.5%	29.0%	32.3%	20.0%
2.3.1 Concerning Cargo	70.0%	64.5%	42.0%	59.5%	80.0%
2.3.2 Concerning Cargo Working Conditions	30.0%	35.5%	58.0%	40.5%	20.0%

Added Values weights from main hierarchical breakdown. Table 7 shows further that Performance (in addition to performance parameters influencing DOC directly) and Passenger Comfort are most importance among Added Values. The expert view stresses the importance of passenger related Added Values. Revenue from passenger aircraft, however, comes from passengers and only to a small part from cargo. For this reason passenger related Added Values should be valued more than twice as cargo related Added Values.

On the next level of detail, Airport Performance (take-off and landing distance) are weighted against Cruise Performance (cruise speed, taken as a measure of convenience). On average, experts and the over all evaluation take these two as equal important. Note that take-off distance and landing distance are not two independent parameters. An aircraft that lands at an airport also has to take-off from that airport. A better and more general view would be this: There is only on distance to be considered: the longer of the take-off distance and the landing distance. In general this is the take-off distance, so only this should be evaluated, the shorter one being ignored (and be given 0 %).

Added Values from which all passengers benefit should clearly be given more importance compared to Added Values from which only part of the passengers benefit. A ratio 3 to 1 is seen here on average. Looking at further details hidden in these categories, a ratio 4 to 1 may seem even more appropriate and was selected (see Chapter 5), because “2.2.1 Concerning all passengers” is further split into 7 Added Values, whereas “2.2.2 Concerning part of the passengers” is split only into 2 Added Values in the next level of the hierarchy. This fact may have been overlooked by some participants.

Added Values related to cargo handling can come from

a) the general way cargo is handled (containerized versus bulk) and
b) the details of cargo handling based on the aircraft parameters which are the accessibility of the cargo compartment (sill height) and the working conditions within the cargo compartment (cargo compartment height).

Experts clearly stress a), whereas students have opted for b) as being more important. It is important to understand that if cargo is containerized and the aircraft offers (semi-)automatic loading then acceptable cargo handling working conditions are automatically met. If all airlines want to work with containerized cargo in the first place is another (open) question.

Overall the Added Value receiving the highest weights are cruise speed, containerized cargo (yes / no) and take-off field length (see Table 8).

Table 8 Group averages of Added Values (scaled to 100 %) form Hierarchical table (page 1) and from AHP linear (page 2)

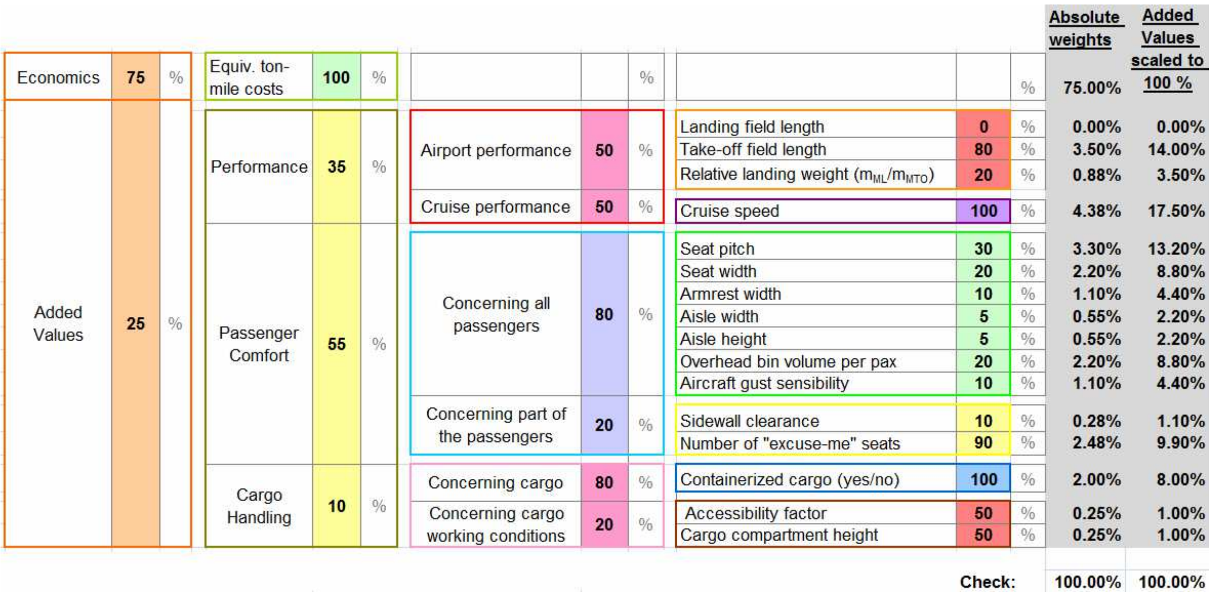
	From Hierarchical Table				From AHP linear			
Added Value	Experts	Ph.D stud.	Students	All	Experts	Ph.D stud.	Students	All
Landing field length	3.8 %	9.0 %	6.1 %	7.2 %	2.7 %	7.2 %	6.7 %	6.3 %
Take-off field length	8.6 %	11.1 %	6.1 %	9.4 %	9.6 %	8.4 %	6.8 %	8.2 %
Relative landing weight	2.8 %	4.8 %	4.4 %	4.3 %	2.3 %	6.3 %	7.6 %	6.0 %
Cruise speed	15.8 %	23.1 %	24.4 %	22.0 %	10.1 %	8.9 %	7.6 %	8.8 %
Seat pitch	6.2 %	4.4 %	5.5 %	5.0 %	5.2 %	7.2 %	7.1 %	6.9 %
Seat width	6.7 %	4.7 %	3.1 %	4.7 %	8.3 %	7.6 %	6.3 %	7.4 %
Armrest width	3.2 %	1.8 %	2.7 %	2.3 %	6.0 %	3.9 %	5.0 %	4.5 %
Aisle width	5.1 %	2.4 %	3.0 %	3.1 %	6.3 %	5.6 %	5.6 &	5.7 %
Aisle height	2.2 %	2.4 %	3.4 %	2.6 %	3.4 %	5.2 %	5.8 %	5.1 %
Overhead bin volume per pax	6.9 %	3.8 %	3.9 %	4.5 %	8.1 %	7.1 %	5.7 %	6.9 %
Aircraft gust sensitivity	3.0 %	2.9 %	3.8 %	3.2 %	5.0%	6.6 %	6.3 %	6.3 %
Sidewall clearance	6.8 %	4.6 %	4.5 %	5.0 %	4.6 %	4.2 %	4.2 %	4.3 %
Number of "excuse-me" seats	9.8 %	7.7 %	6.0 %	7.7 %	6.9 %	55.3 %	5.0 %	5.5 %
Containerized cargo (yes/no)	13.1 %	10.5 %	9.9 %	10.8 %	8.4 %	6.0 %	7.3 %	6.8 %
Accessibility factor	3.1 %	3.7 %	7.5 %	4.5 %	6.6 %	5.4 %	6.7 %	5.9 %
Cargo compartment height	2.6 %	3.0 %	5.6 %	3.6 %	6.6 %	5.0 %	6.3 %	5.6 %
			standard deviation	4.8 %			standard deviation	1.2 %

5 Selection of Final Weights

Results of the questionnaire evaluation (Chapter 4) show a diverse picture. The final weights for the Added Values should not be a "democratic average" but rather the best selected from overall knowledge gained from much insight into the topic and expert views challenged by views of students form the field. For these reasons it was decided to determine the final weights from the *best answer* (i.e. best consistency and high coefficients of determination) *corrected by technical insight, expert views and the average of all answers*. In its detail this method is not an algebraic one but rather a subjective trade-off. The resulting final weights are given in Table 9 and Table 10. The final weights in Table 9 may be compared with values in Table 7 and Table 8.

DOCs were selected to have a weight of 75 % – enough to account strongly for economic importance, yet leaving room for additional revenue generated by Added Values (namely 25 %). Passenger comfort was considered more important than performance: 55 % versus 35 %, while cargo working conditions received only 10 %. Cruise and airport performance were considered equally important.

Table 9 Attributed weights to the Added Values



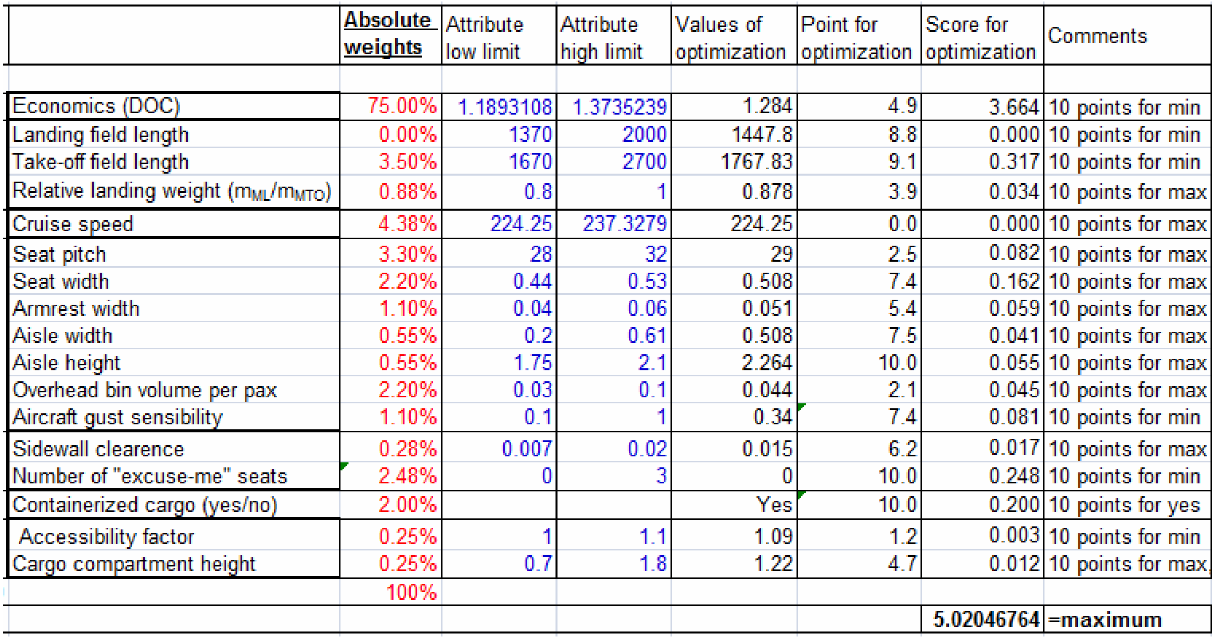
												Absolute weights	Added Values scaled to 100 %
Economics	75	%	Equiv. ton-mile costs	100	%			%			%	75.00%	
Added Values	25	%	Performance	35	%	Airport performance	50	%	Landing field length	0	%	0.00%	0.00%
									Take-off field length	80	%	3.50%	14.00%
									Relative landing weight (m_{ML}/m_{MTO})	20	%	0.88%	3.50%
						Cruise performance	50	%	Cruise speed	100	%	4.38%	17.50%
			Passenger Comfort	55	%	Concerning all passengers	80	%	Seat pitch	30	%	3.30%	13.20%
									Seat width	20	%	2.20%	8.80%
									Armrest width	10	%	1.10%	4.40%
									Aisle width	5	%	0.55%	2.20%
									Aisle height	5	%	0.55%	2.20%
									Overhead bin volume per pax	20	%	2.20%	8.80%
									Aircraft gust sensibility	10	%	1.10%	4.40%
						Concerning part of the passengers	20	%	Sidewall clearance	10	%	0.28%	1.10%
									Number of "excuse-me" seats	90	%	2.48%	9.90%
			Cargo Handling	10	%	Concerning cargo	80	%	Containerized cargo (yes/no)	100	%	2.00%	8.00%
						Concerning cargo working conditions	20	%	Accessibility factor	50	%	0.25%	1.00%
									Cargo compartment height	50	%	0.25%	1.00%
										Check:		100.00%	100.00%

Regarding comfort, the standards concerning all passengers received a higher weight (namely 80 %) than the standards concerning only part of the passengers (20 %). Among the parameters concerning the comfort of all passengers, seat pitch was seen to be the most important one, followed by seat width and overhead stowage volume. Even though seat pitch is defined by the airlines, the idea is here to optimally set important parameters for airlines (such as seat pitch), already during preliminary design. Seat pitch will define at this stage the cabin length and thus will have a major influence on the entire design. The next important parameters are armrest width, followed by gust sensitivity and aisle width and height. Aisle width is more critical for single aisle aircraft because a single aisle offers fewer possibilities for a passenger to bypass a trolley in the aisle during catering service.

It can be concluded that an efficient design is not a design that only reduces costs but also a design able to anticipate the later scenarios that an airline could consider necessary to implement. Without this design flexibility, the airline may decide not to buy the aircraft. Concerning the optimal comfort standards, that an aircraft manufacturer should consider, an interesting expert comment is: if too much cabin comfort is given (seat width and aisle width), airlines may end up squeezing more seats in a row than originally intended for the aircraft. The result of this is a cabin with no comfort at all. The BAe 146 is such an aircraft that was designed as a five abreast aircraft and was equipped in some cases also with 6 seats abreast.

Looking finally at the resulting absolute weights of the Added Values, cruise speed and take-off field length have the highest percentages of 4.38 % and 3.50 %, respectively. They are followed by seat pitch (3.30 %), number of “excuse-me” seats (2.48 %), seat width (2.20 %) and overhead stowage volume (2.20 %). These final weights make sense and stand a common sense check: It is first of all important to get us inexpensive from A to B within short time. During the flight we want to sit with some comfort in out seat, want to get out of our seat without too much hazel when necessary and we like to have much of our baggage with us in the cabin.

Table 10 Attributed weights to the Added Value and score calculation for the composed objective function



	Absolute weights	Attribute low limit	Attribute high limit	Values of optimization	Point for optimization	Score for optimization	Comments
Economics (DOC)	75.00%	1.1893108	1.3735239	1.284	4.9	3.664	10 points for min
Landing field length	0.00%	1370	2000	1447.8	8.8	0.000	10 points for min
Take-off field length	3.50%	1670	2700	1767.83	9.1	0.317	10 points for min
Relative landing weight (m_{ML}/m_{MTO})	0.88%	0.8	1	0.878	3.9	0.034	10 points for max
Cruise speed	4.38%	224.25	237.3279	224.25	0.0	0.000	10 points for max
Seat pitch	3.30%	28	32	29	2.5	0.082	10 points for max
Seat width	2.20%	0.44	0.53	0.508	7.4	0.162	10 points for max
Armrest width	1.10%	0.04	0.06	0.051	5.4	0.059	10 points for max
Aisle width	0.55%	0.2	0.61	0.508	7.5	0.041	10 points for max
Aisle height	0.55%	1.75	2.1	2.264	10.0	0.055	10 points for max
Overhead bin volume per pax	2.20%	0.03	0.1	0.044	2.1	0.045	10 points for max
Aircraft gust sensibility	1.10%	0.1	1	0.34	7.4	0.081	10 points for min
Sidewall clearence	0.28%	0.007	0.02	0.015	6.2	0.017	10 points for max
Number of "excuse-me" seats	2.48%	0	3	0	10.0	0.248	10 points for min
Containerized cargo (yes/no)	2.00%			Yes	10.0	0.200	10 points for yes
Accessibility factor	0.25%	1	1.1	1.09	1.2	0.003	10 points for min
Cargo compartment height	0.25%	0.7	1.8	1.22	4.7	0.012	10 points for max
	100%						
						5.02046764	**=maximum**

Besides absolute weights, Table 10 shows (for a medium range aircraft) the low and high limits, the resulting points and scores for a set of parameters, that in *OPerA* may result either from an optimization run, or are manually calculated.

6 Building the Objective Function

The score of each Added Value is calculated as a product between the weight and the resulting point, as explained in the first paragraph. The objective function is given by the sum of scores, which can reach a maximum of 10. Hence the objective is to maximize (up to 10) the composed DOC + AV function (AV = Added Value).

7 Summary

This memo aimed to deliver the general evaluation of the questionnaire filled in by a group of participants. More specific, the aim was to determine weights among Added Values. Added Value boundaries were discussed, the way points are attributed to aircraft parameters resulting from optimization runs is explained, and questionnaire evaluation methods are presented.

For the AHP matrix a consistency check was performed for every participant. Its calculation is based on the principal eigenvalue of the matrix for which a simple approximate evaluation method based on the normalized reciprocal matrix is available. Comparisons were performed via the coefficient of determination, R^2, between weights from the Hierarchical Table (page 1 of the questionnaire) and the AHP matrix (page 2 of the questionnaire) from a linear or a reciprocal evaluation scale. The reciprocal scale yielded unrealistic results. The only purpose of the matrix based on the reciprocal scale is hence the consistency check with the consistency ratio (which is not defined for a matrix based on a linear scale).

The Hierarchical Table was considered more suitable for defining the final weights. Final weights were determined from the best answer (i.e. best consistency and high coefficients of determination) corrected by technical insight, expert views and the average of all answers. Accordingly, Added Values have an importance of 25 % (75 % for DOCs). resulting absolute weights of the Added Values, cruise speed and take-off field length have the highest percentages of 4.38 % and 3.50 %, respectively. They are followed by seat pitch (3.30 %), number of “excuse-me” seats (2.48 %), seat width (2.20 %) and overhead stowage volume (2.20 %).

8 Conclusions and Lessons Learnt

Conclusions regarding questionnaires evaluation. The AHP matrix was rather difficult for the participants to fill in, due to its large size. It is interesting that a method exists that is checking the consistency of the information filled in. Satisfactory consistencies could have been obtained easier if the participants filling in the AHP matrix would have had already a knowledge of the weights resulting from the Hierarchical Table. Unfortunately the questionnaire did not provide this information because an independent start for the AHP matrix was intended. Showing the final weights resulting from the Hierarchical Table during the participant’s evaluation could also have had a beneficial influence on the Hierarchical Table itself.

Transforming the linear scale, that the participants used to fill in the matrix, into a reciprocal one, results in a quite polarized weights assignment. Also for simplicity reasons, a linear scale is more suitable and better understandable.

Conclusions regarding Added Values. It is not necessary to include landing field length as Added Value (take-off field length would have been enough). The selection of the rest of the Added Values seems to be a good choice. Arguments for this statement are the expert comments and also the results of the optimization runs (with the objective DOC + AV = maximum) performed with *OPerA*. To be reminded that the fundamental purpose was to optimize the preliminary design of a new aircraft.

Lessons learnt. We found that the Hierarchical Table is better suited than filling in a large matrix. For results obtained from the Hierarchical Table it would have been even better if we would have displayed the resulting weightings already in the questionnaire. In this way the participants would have had a better overview of the results of their selections. Instead of filling in a large matrix, splitting the Added Values into smaller selected matrices would have eased this task. For example only (all the) 9 cabin parameters or only the 7 "concerning all passengers" parameters could have been represented in a matrix (without the other parameters to be included in the AHP). This would have resulted in a better manageable number of evaluations $m = (n^2 - n) / 2$ (36 respectively 21 compared to 120 in the questionnaire).

9 Results from Optimization Runs

Besides their role in comparing aircraft of the same *existing* type as intended in [4] and [5], it was found that Added Values can play an important role in designing a *new* aircraft. The weights of the objective function DOC + AV increase the importance of higher speed, lower take-off field length (and implicitly landing field length), higher comfort standards and better ground handling.

Taking the A320 as a reference aircraft and varying basic aircraft parameters (landing mass ratio, maximum lift coefficients for landing and take-off configuration, sweep, taper ratio, aspect ratio, by-pass ratio, distance from engine to wing), basic cabin comfort parameters (seat pitch, aisle width and height, armrest width, sidewall clearance, number of seats abreast) and basic requirements (take-off and landing field length, cruise Mach number, span limitation increase), substantial improvement of DOC + AV function is obtained. This highly reflects on the rest of meaningful parameters: maximum take-off mass reduces by 11.2 %, fuel mass by 27.5 % and Direct Operating Costs, which represent 75 % of the DOC + AV function, are improved by 7.3 %. Yet, due to favoring of smaller landing and take-off field lengths, and increase in cabin comfort parameters, the design is less efficient than when optimizing for DOC alone.

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Appendix – Questionnaire

(presented on the following pages)

Aero

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

OPERA – Optimization in Preliminary Aircraft Design
Questionnaire for Added Values

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Background

The research project OPERA started at Hochschule für Angewandte Wissenschaften Hamburg in October 2010 in the frame of Aero (Aircraft Design and Research Group) led by Prof. Dr.-Ing. Dieter Scholz. I am a member of the team (http://Aero.ProfScholz.de). The aim is to apply formal optimization to aircraft preliminary design and preliminary aircraft cabin design. This topic represents the foundation of my doctoral studies conducted in cooperation with the Politehnica University of Bucharest.

DOC and Added Values

Formal optimization was applied on an Excel-based program called OPerA. You may want to have a look at the website of the project (http://OPerA.ProfScholz.de). The data gathered from the attached questionnaire will aid in building a new objective function, while considering both economics (DOC) and Added Values. In this way initial aircraft design parameters are optimized while accounting for aspects that bring an added value to the airlines. The idea is not new and based on papers from Chen [1] and Meller [2]. The selection of the Added Values was made in conjunction with Chen's and Meller's hints and plus my own thoughts. If you like, you can comment on my final selection of Added Values, however for this questionnaire I want to keep things simple. So let's consider the Added Values as given for now. Added values need to be weighted. This weighting is subjective. Many experts should be consulted to make the weighting of the Added Values less subjective. For this reason your help is very much appreciated.

Data Management

Data provided by the persons filling in the attached questionnaire will be kept confidential. Our interest lies in the average of the answer from all participants. Once I have evaluated all results, I will let everyone know about the outcome.

Hints for Questionnaire Completion

The questionnaire is written in MS-EXCEL 2007. Macros need to be activated (MS-EXCEL-Optionen → Vertrauensstellungscenter → Einstellungen für das Vetrauensstellungscenter → Einstellungen für Macros → Alle Macros aktivieren). The questionnaire contains two pages:

- Page 1: *Hierarchical break-down of attributes*, where the user fills in percents summing up 100 % for every break-down (differently colored). Here the user has the possibility to check whether he reached 100 % or not, by pressing a button.
- Page 2: *Analytic Hierarchy Process (AHP),* where the user sets degrees of importance in a matrix-based evaluation form. The lower diagonal is automatically filled-in. The scale is 0 to 10. An example point is set for illustration purposes only.

Please have in mind a *short / medium range aircraft* while filling in the two pages. We appreciate you taking the time to fill in this query. If your time does not allow for filling in Page 2, we are thankful if you fill in at least Page 1. Hint: Among all participants who make it through both pages we will draw five bottles of red wine – so keep your fingers crossed!

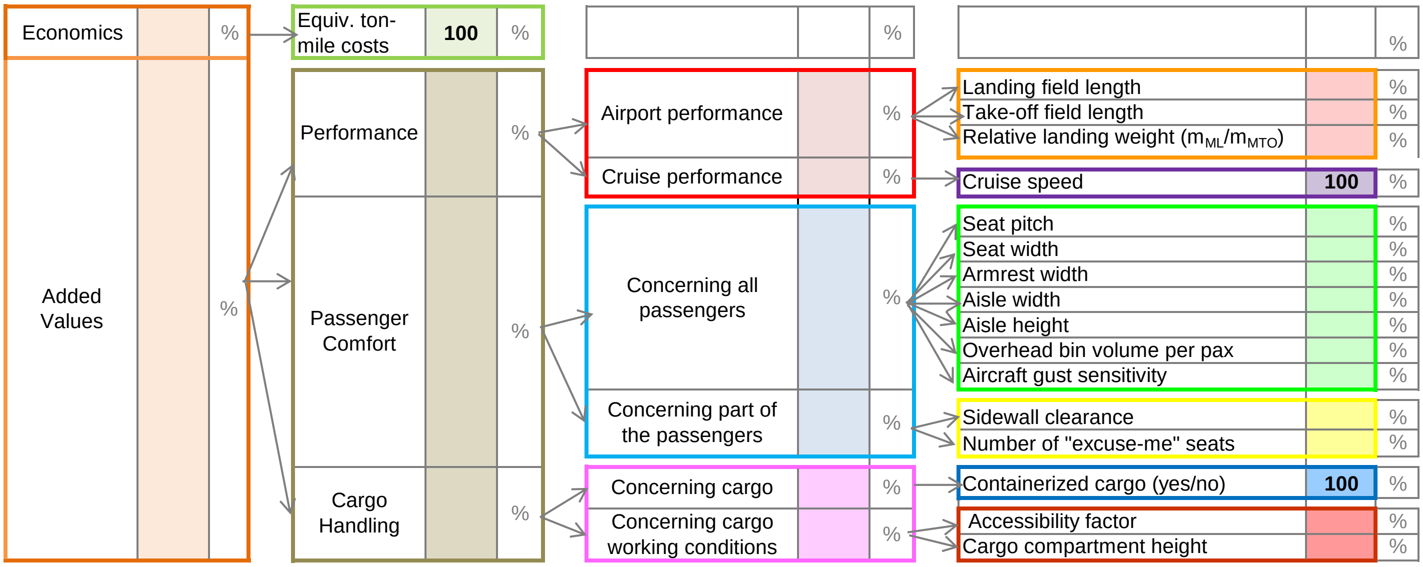
Literature

[1] Chen, G; Yingming, H; H.G. Nüßer; D. Wilken: A method of Evaluating Civil Aircraft Market Adequacy. In: DGLR Fachausschuß S2 Luftfahrtsysteme: Bewertung von Flugzeugen. Tagungsband zum Workshop. Garching, 26-27 October 1998. URL: http://www.fzt.haw-hamburg.de/pers/Scholz/dglr/bericht1098/Bericht1098.html und http://l2.dglr.de

[2] F. MELLER; P. JOST: Key Buying Factors and Added Value – a New Approach to Aircraft Evaluation. In: DGLR Fachausschuß S2 Luftfahrtsysteme: *Bewertung von Flugzeugen.* Tagungsband zum Workshop. Garching, 26-27 October 1998. URL: http://www.fzt.haw-hamburg.de/pers/Scholz/dglr/bericht1098/Bericht1098.html und http://l2.dglr.de

Hierarchical break-down of attributes and attribute weights

Every thick-line-box (differently colored) needs to have a total of 100 %



Economics		%
Added Values		%

Equiv. ton-mile costs	**100**	%
Performance		%
Passenger Comfort		%
Cargo Handling		%

		%
Airport performance		%
Cruise performance		%
Concerning all passengers		%
Concerning part of the passengers		%
Concerning cargo		%
Concerning cargo working conditions		%

		%
Landing field length		%
Take-off field length		%
Relative landing weight (m_{ML}/m_{MTO})		%
Cruise speed	**100**	%
Seat pitch		%
Seat width		%
Armrest width		%
Aisle width		%
Aisle height		%
Overhead bin volume per pax		%
Aircraft gust sensitivity		%
Sidewall clearance		%
Number of "excuse-me" seats		%
Containerized cargo (yes/no)	**100**	%
Accessibility factor		%
Cargo compartment height		%

Analytic Hierarchy Process - AHP

Please fill in the blanks above the diagonal with points from 0 to 10, depending on the degree of importance of each attribute.
Use the following table as reference.

6 to 10 points	The attribute is *more important* than the attribute to which it is compared to.
5 points	The attribute is *equally important* with the attribute to which is compared to.
0 to 4 points	The attribute is *less important* than the attribute to which is compared to.

For instance, in order to fill in line 5, the respective element in column A (seat pitch) is compared to all the elements in row B.

Example : comparisson of attribute 5 (seat pitch) to attribute 8 (aisle width)

Seat pitch is more important than aisle width and receives 7 out of 10 points.

Aisle width is less important than seat pitch, so it gets the remaining 3 points (automatically).

	B	Landing field length	Take-off field length	Relative landing weight (m_{ML}/m_{MTO}	Cruise speed	Seat pitch	Seat width	Armrest width	Aisle width	Aisle height	Overhead bin volume per pax	Aircraft gust sensibility	Sidewall clearance	Number of "excuse-me" seats	Containerized cargo (yes/no)	Accessibility factor	Cargo compartment height
A	↑	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Landing field length	1	■															
Take-off field length	2	10	■														
Relative landing weight (m_{ML}/m_{MTO})	3	10	10	■													
Cruise speed	4	10	10	10	■												
Seat pitch	5	10	10	10	10	■			**7**								
Seat width	6	10	10	10	10	10	■										
Armrest width	7	10	10	10	10	10	10	■									
Aisle width	8	10	10	10	10	3	10	10	■								
Aisle height	9	10	10	10	10	10	10	10	10	■							
Overhead bin volume per pax	10	10	10	10	10	10	10	10	10	10	■						
Aircraft gust sensibility	11	10	10	10	10	10	10	10	10	10	10	■					
Sidewall clearance	12	10	10	10	10	10	10	10	10	10	10	10	■				
Number of "excuse-me" seats	13	10	10	10	10	10	10	10	10	10	10	10	10	■			
Containerized cargo (yes/no)	14	10	10	10	10	10	10	10	10	10	10	10	10	10	■		
Accessibility factor	15	10	10	10	10	10	10	10	10	10	10	10	10	10	10	■	
Cargo compartment height	16	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	■