Modern Trends in Airframe Structural Design

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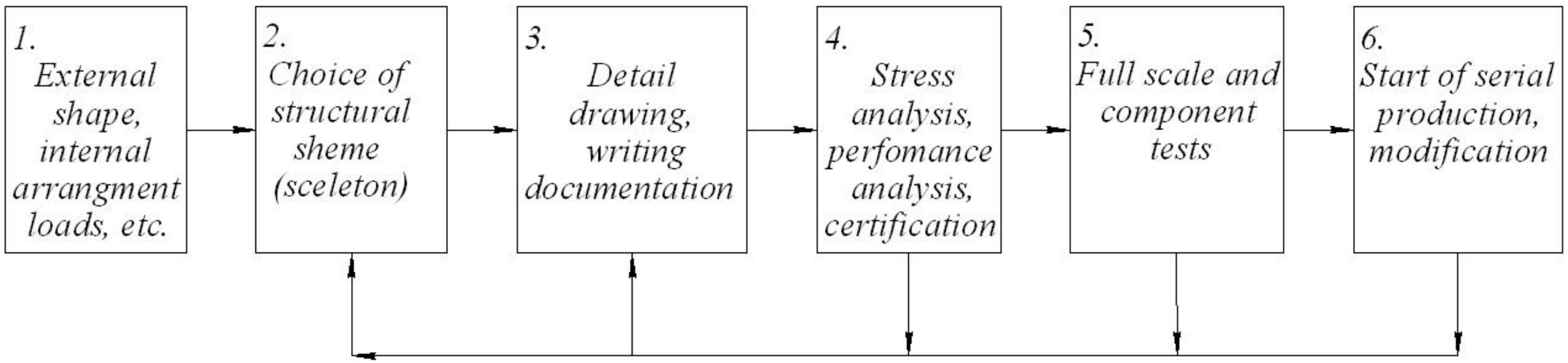
Plan of the presentation

1. General view on the modern structural design problems.
2. New ideas for improving design process.
3. The example of using a new ideas for research aerodynamic and weight efficiency of morphing wing.

Airframe design process

Sequental design paradigm

Preliminary design **Detail design** **Production follow-on development**



change decisions **deviation and errors**

final adjustments / development feedbacks

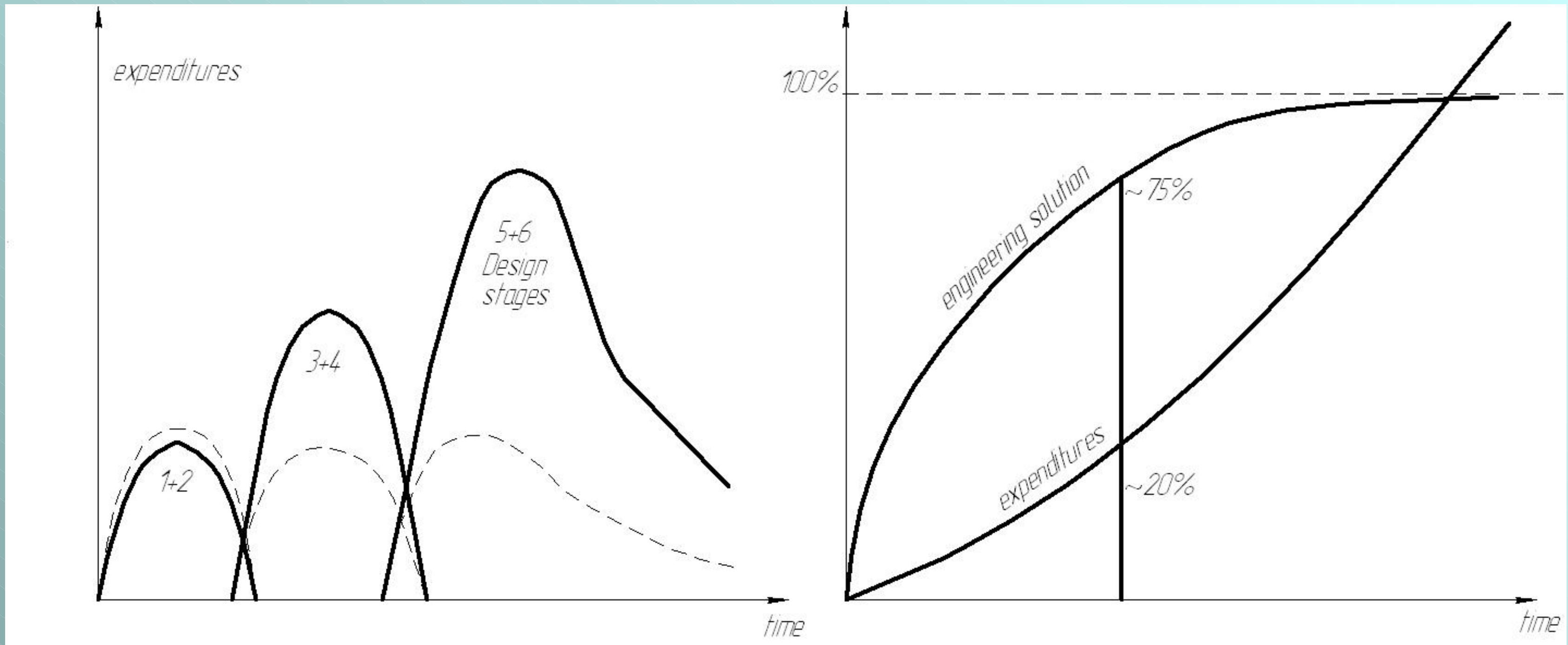
Small gpoup of specialists with broad experience. Main decisions based on experience and intuition.

Large gpoup of designers. Main decisions based on simplest mathematical models.

Highly qualified gpoup of analysts. Preparation for certification. Adequate mathematical modeling.

Hard and long work. Sometimes useless work!

Time and resource expediture

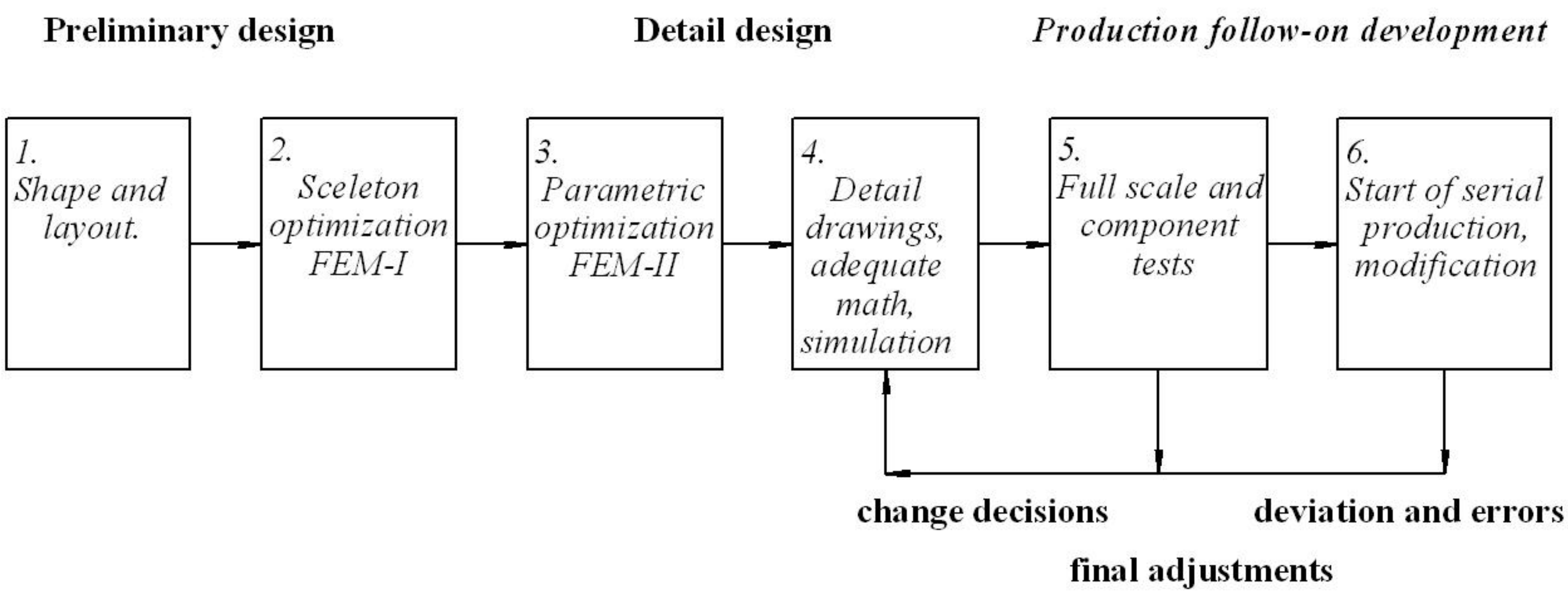


The main reason of greater charges of time and resources in sequential design paradigme is use very simple, (insufficiently exact) mathematical models on early stage of design.

For reduction of designing time it is suitable use of highly accuracy mathematical models on early stage design.

New paradigm for Airframe Structure Design

Concurrent design paradigm



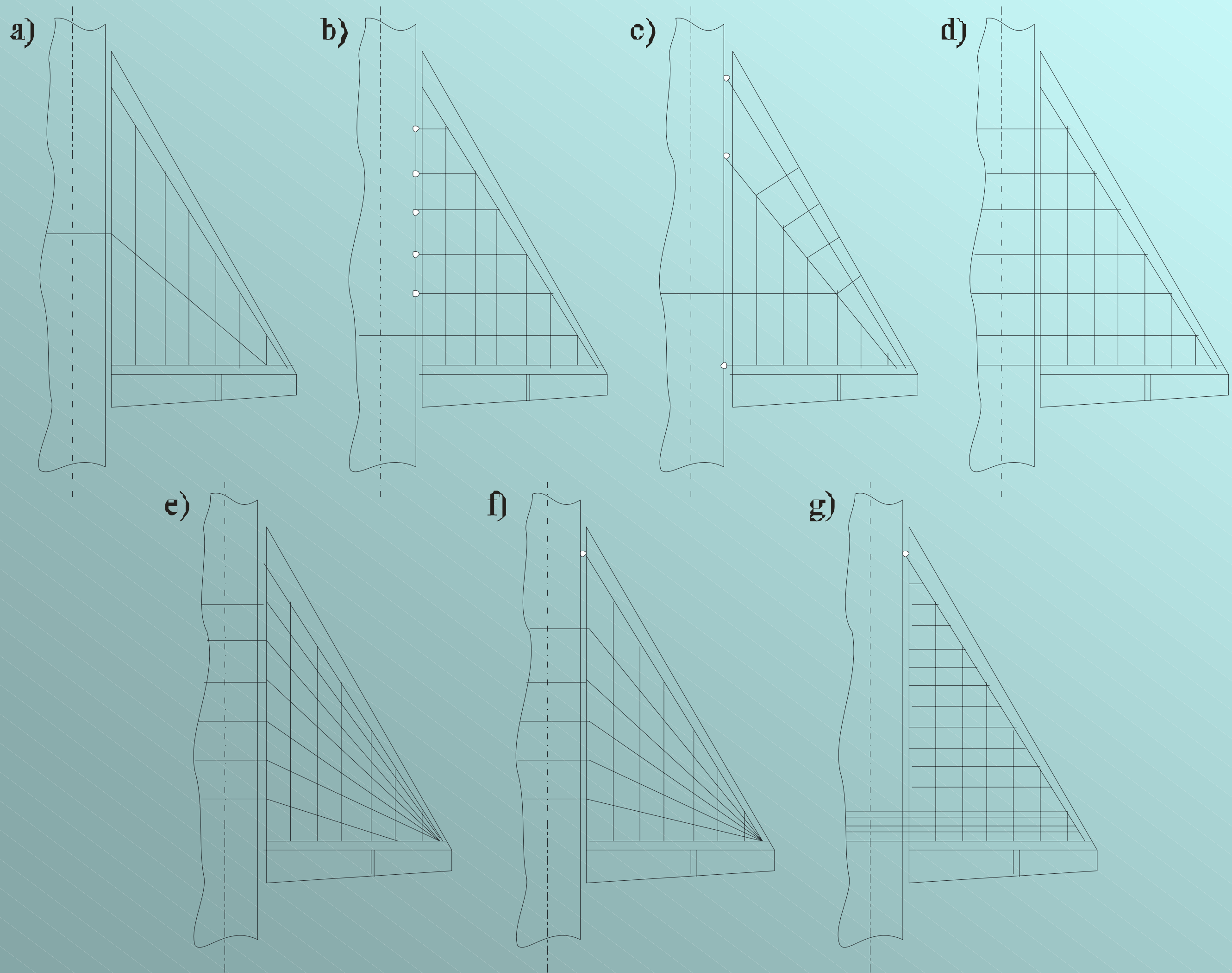
Small gpoup of specialists and spesialized software.

Analysts and designers work together.
Amount of mistaken less.
Time of change decisions in short because we have had mathematical models for adequate analysis of any problems.

The problem of weight estimation in structural design

1. Choice of structure topology (skeleton design).
2. Estimation of structural mass fraction.
3. Weight estimation of the wing, fuselage, etc.
4. Weight check.

Choice of structure topology



Estimation of structural mass fraction

Definition of flight vehicles takeoff gross weight via “equation of existence”

$$m_o = \frac{m_{pl}}{1 - \overline{m}_{st} - \overline{m}_{sys} - \overline{m}_f - \overline{m}_{pp}}$$

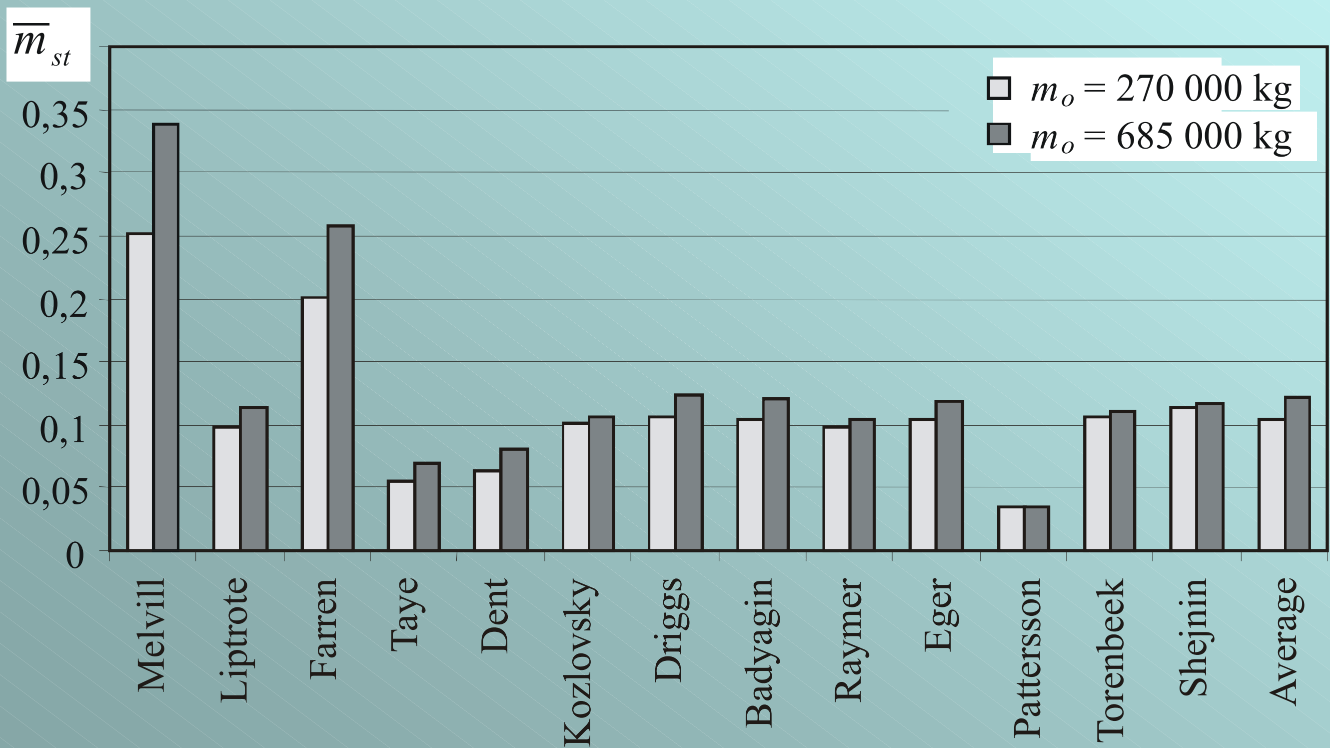
where

$$\overline{m}_{st} = \frac{m_{st}}{m_o}$$

Example of calculation a wing mass fraction via "weight equation"

Typical weight equation (Eger)

$$\overline{m}_{st} = \frac{7k_1 n_p \varphi \lambda \sqrt{m_0}}{10^4 p_0 \left(\overline{c}_0\right)^{0,75} \cos^{1,5} \chi} * \frac{\eta + 4}{\eta + 1} * \left(1 - \frac{\mu - 1}{\eta + 3}\right) + \frac{4,5 k_2 k_3}{p_0} + 0,015$$

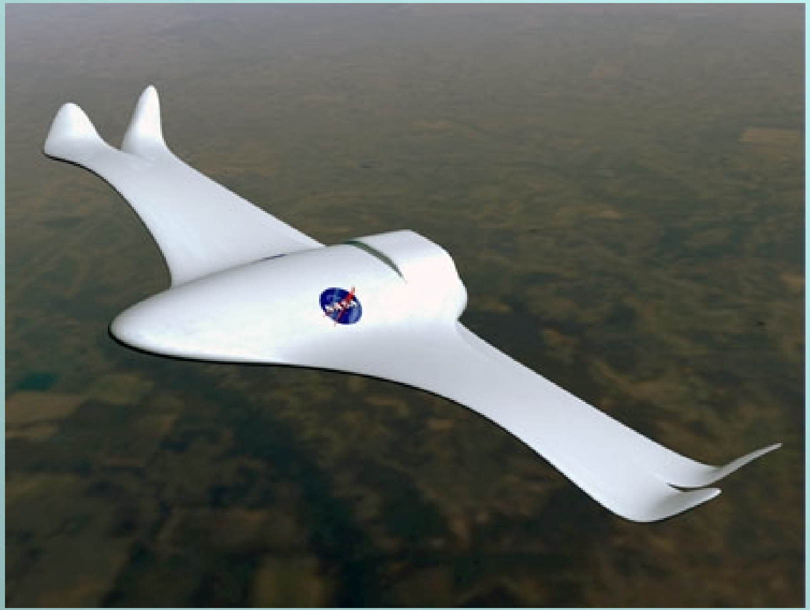


Weight Check

1. Definition of the weight limits for different part of structure before design.
2. Analyses of weight penalty after design (if necessary). Looking for decrease of structural mass.

Unconventional flight vehicles

Morphing Wing from TUDelft



(http://www.lr.tudelft.nl/live/pagina.jsp?id=fd5540a7-0cfe-44e5-b1bc-c806fa0410b8&lang=en)

$$m_{st} = ? \qquad \overline{m}_{st} = ??$$

New ideas for improving design process

1st idea. Load-carrying factor

Frame $$G = \sum_{i=1}^{n} |N_i| \cdot l_i$$

Thin-wall structure $$G = \sum_{i=1}^{n} R_i \cdot S_i$$

3D-structure $$G = \int_V \sigma^{eqv} dV$$

Definition of structural mass via "load-carrying factor"

Theoretical structural material volume

$$V_T = \sum_{i=1}^{n} \frac{|N_i|}{[\sigma]} \cdot l_i = \sum_{i=1}^{n} F_i \cdot l_i$$

Real mass of structure

$$m_{st} = \varphi \cdot \rho \cdot V_T = \varphi \cdot \rho \cdot \frac{G}{[\sigma]}$$ or $$m_{st} = \varphi \frac{G}{\overline{\sigma}}$$

G – take into account topology, geometry and external loads

$\overline{\sigma}$ – specific durability of material

φ – coefficient of full-mass structure, (it depends on design and technology perfect)

G-criteria allows to calculate absolutely mass of unconventional structure with high accuracy

2nd idea. Size less criteria of load carrying perfection of structure

Load-carrying factor is proportional to the linear sizes (coordinates of nodals) of structure and value of nodal forces (at retaining of the law of distribution of external loading) – ***dimensional quantity***

Sizeless criteria– coefficient of load carrying factor

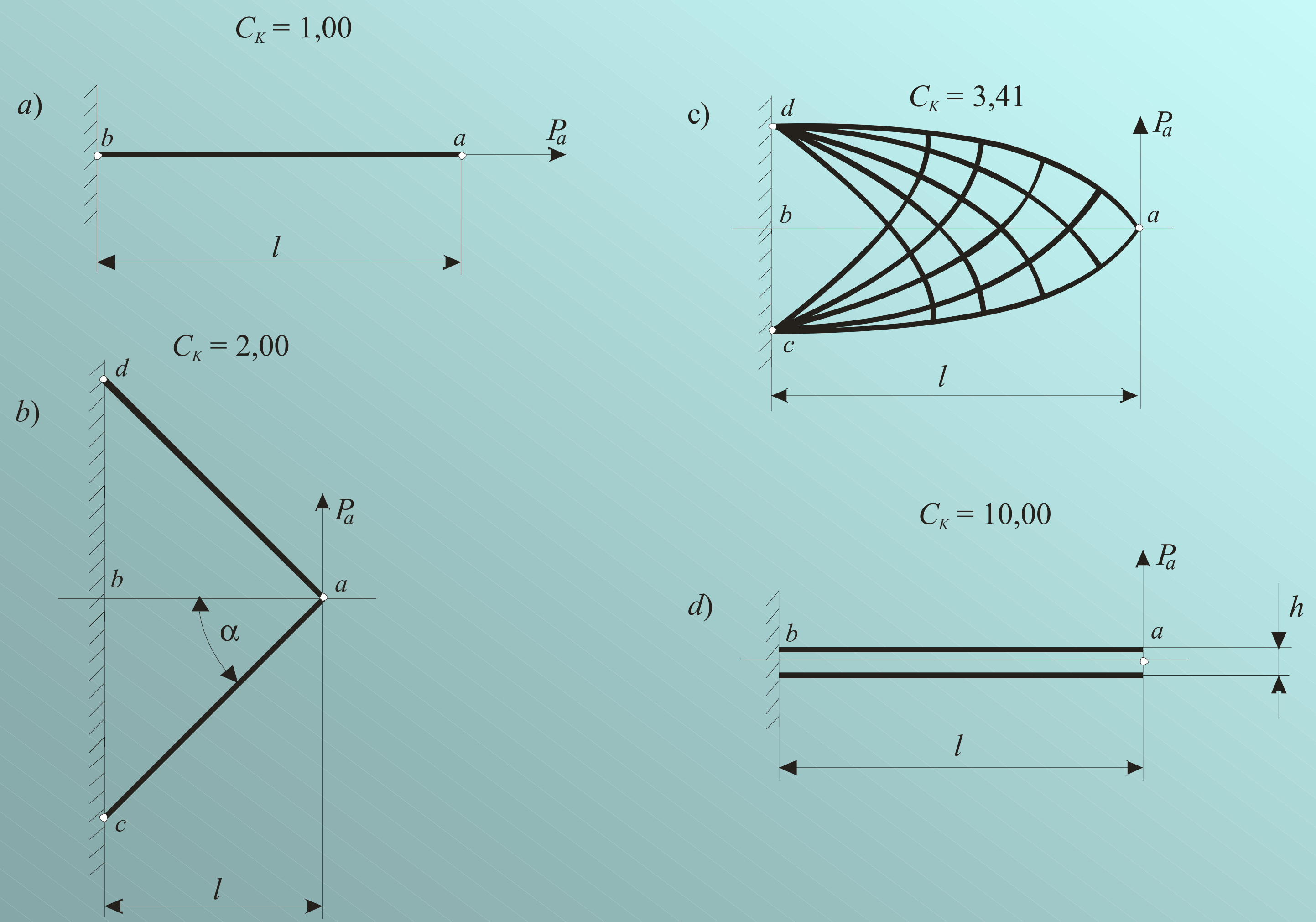
$$C_K = \frac{G}{P \cdot L}$$

where P- specific load

L- specific size

whence $G = C_K PL$ (aerodynamic analogy : $Y = C_y qS$)

Example of simple structures



New weight equation for definition of full wing mass and wing mass fraction

Specific size – square of wing in degree ½ - $\sqrt{S}$

Specific load – lift $Y = n \cdot m_0 \cdot g$

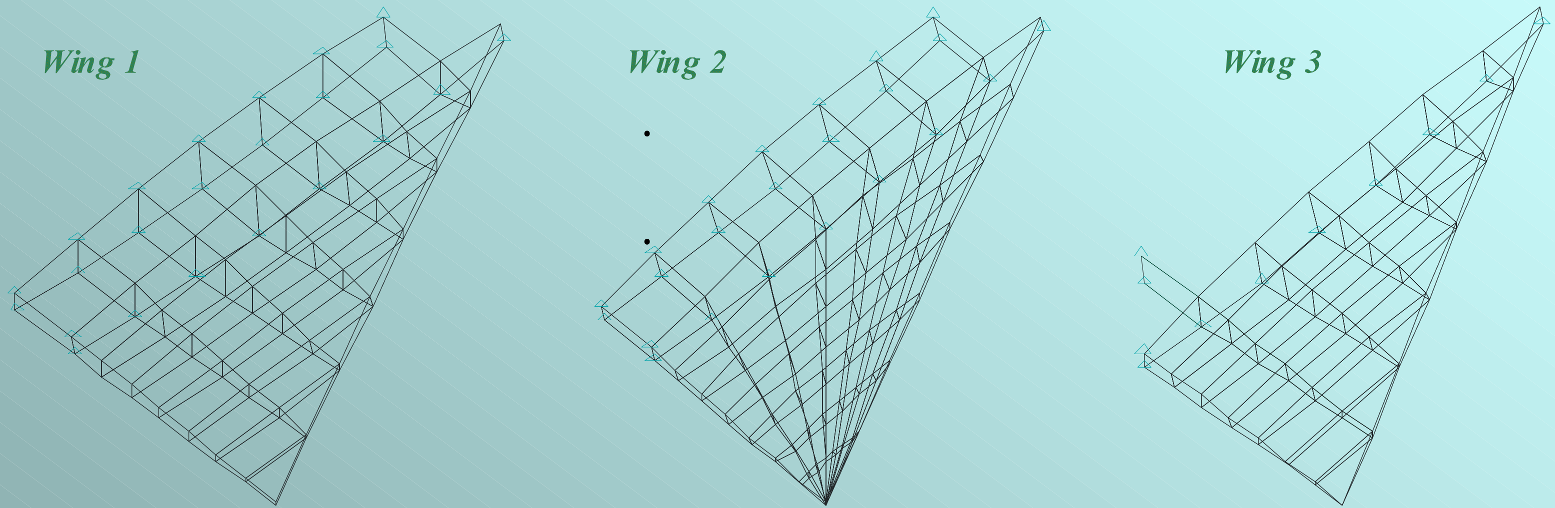
$$G = C_K \cdot n \cdot m_o \cdot g \cdot \sqrt{S}$$

whence $$C_K = \frac{G^*}{n^* \cdot m_o^* \cdot g \cdot \sqrt{S^*}}$$

Weight equation :

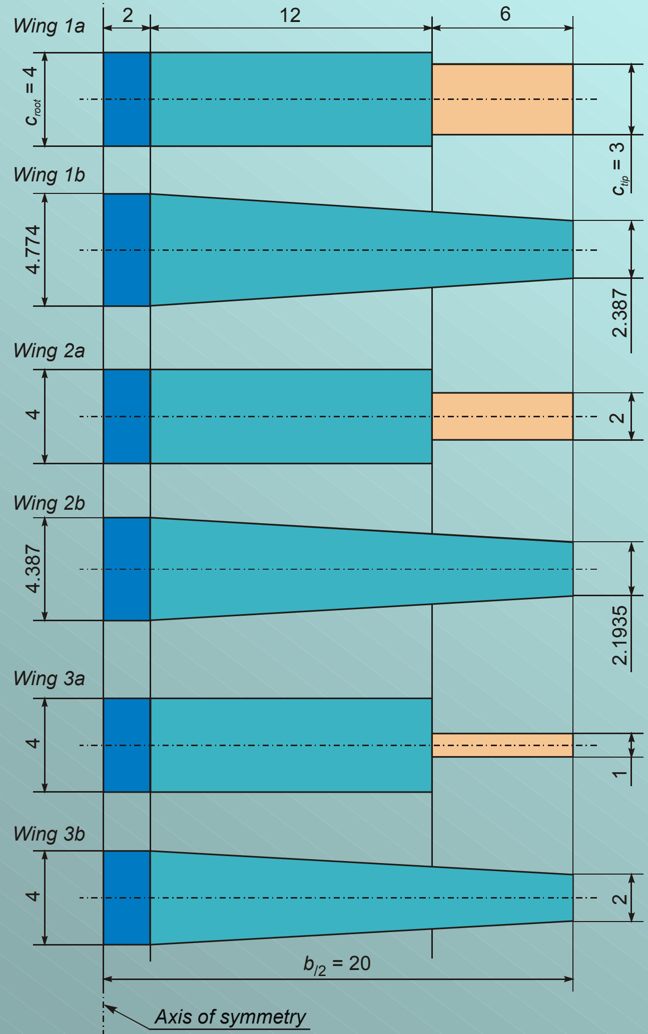
$$\overline{m}_{wing} = \frac{\varphi}{\overline{\sigma}} C_K \cdot n \cdot g \cdot \sqrt{S} \qquad m_{wing} = \frac{\varphi}{\overline{\sigma}} C_K \cdot n \cdot m_o \cdot g \cdot \sqrt{S}$$

Example of structural topology choice



Wing	Membrane structures	Panel structures					
		Strategy I			Strategy II		
		$\bar{\delta} = 0,6$	$\bar{\delta} = 0,5$	$\bar{\delta} = 0,4$	$\bar{\delta} = 0,6$	$\bar{\delta} = 0,5$	$\bar{\delta} = 0,4$
1	1,62	1,68	1,70	1,71	1,84	1,94	2,07
2	1,68	1,76	1,78	1,81	1,83	1,89	1,98
3	2,55	2,69	2,75	2,83	2,68	3,03	3,56

Example of morphing wing aerodynamic and weight efficiency research



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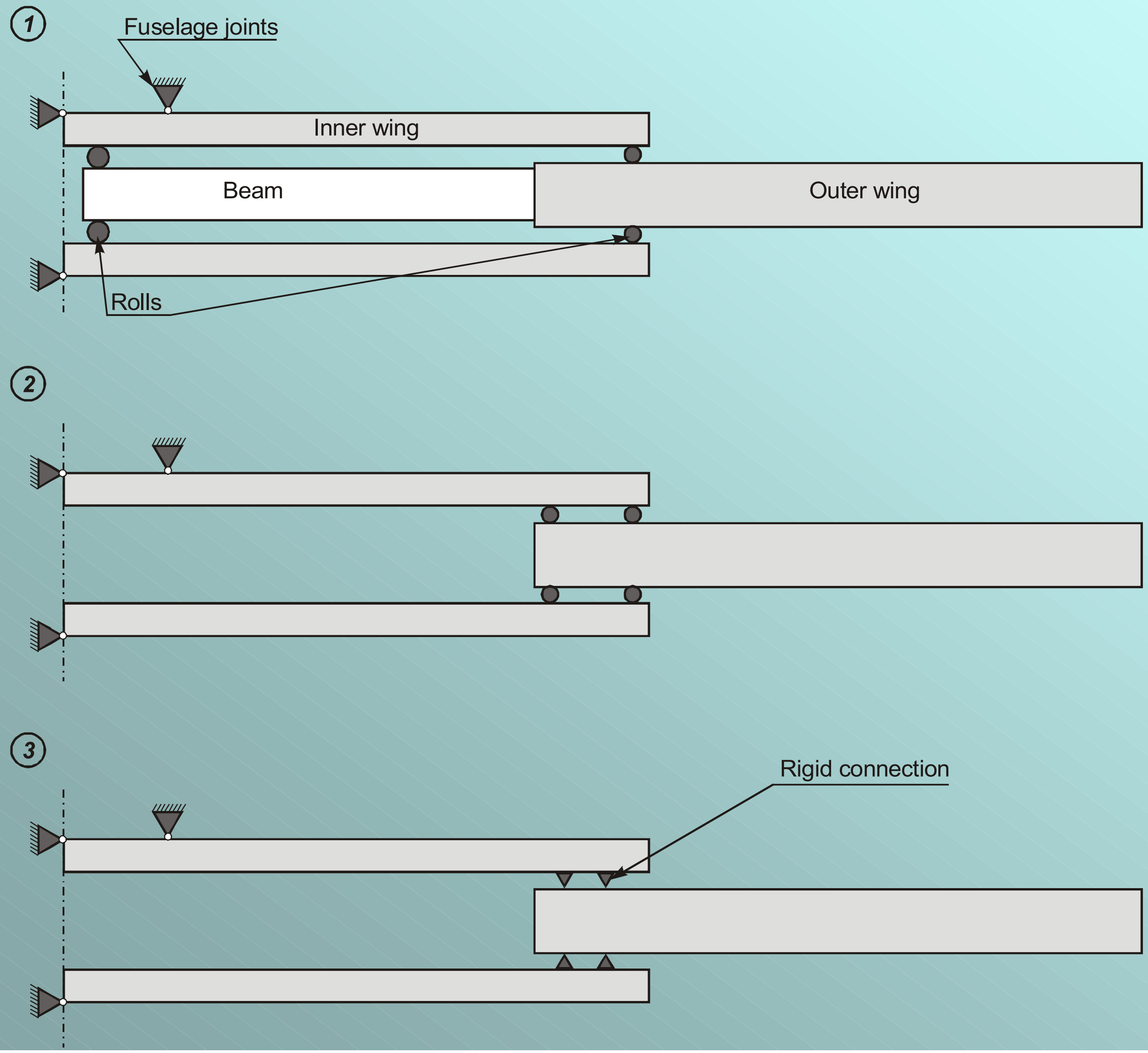
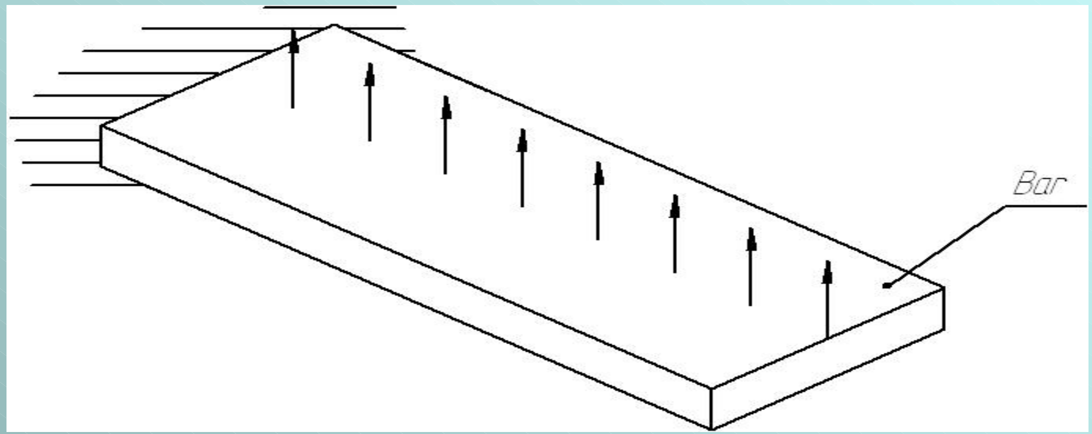
Scheme of wing parts joints

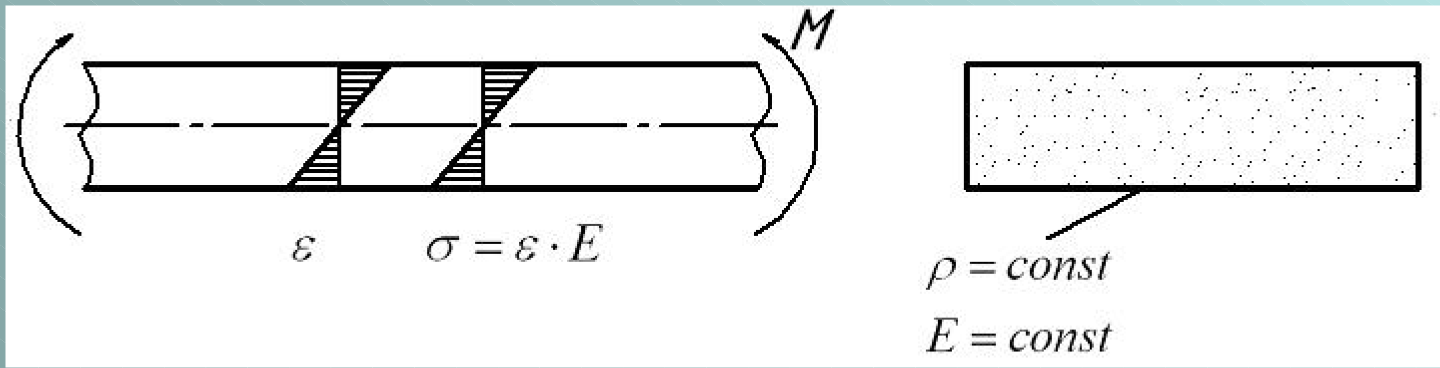


3rd idea. Using 3D-model with variable density

Model



Traditional material



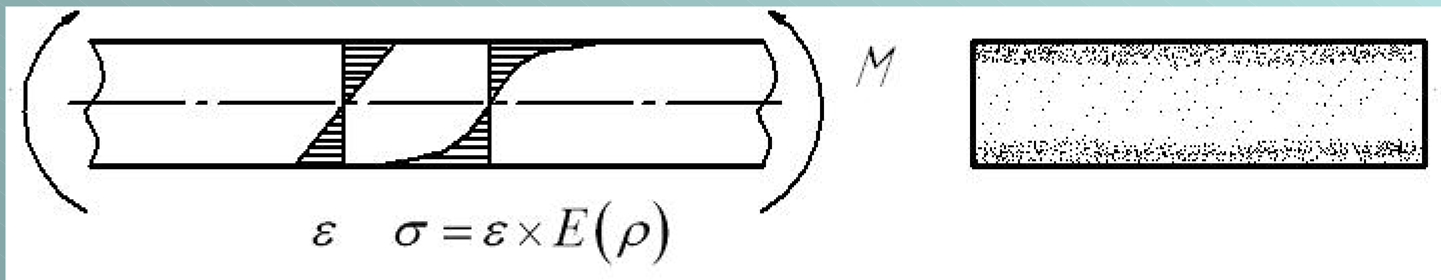
Hypothetic material with variable density

$$[\sigma] = \rho \cdot [\bar{\sigma}]$$

$$E = \rho \cdot \bar{E}$$

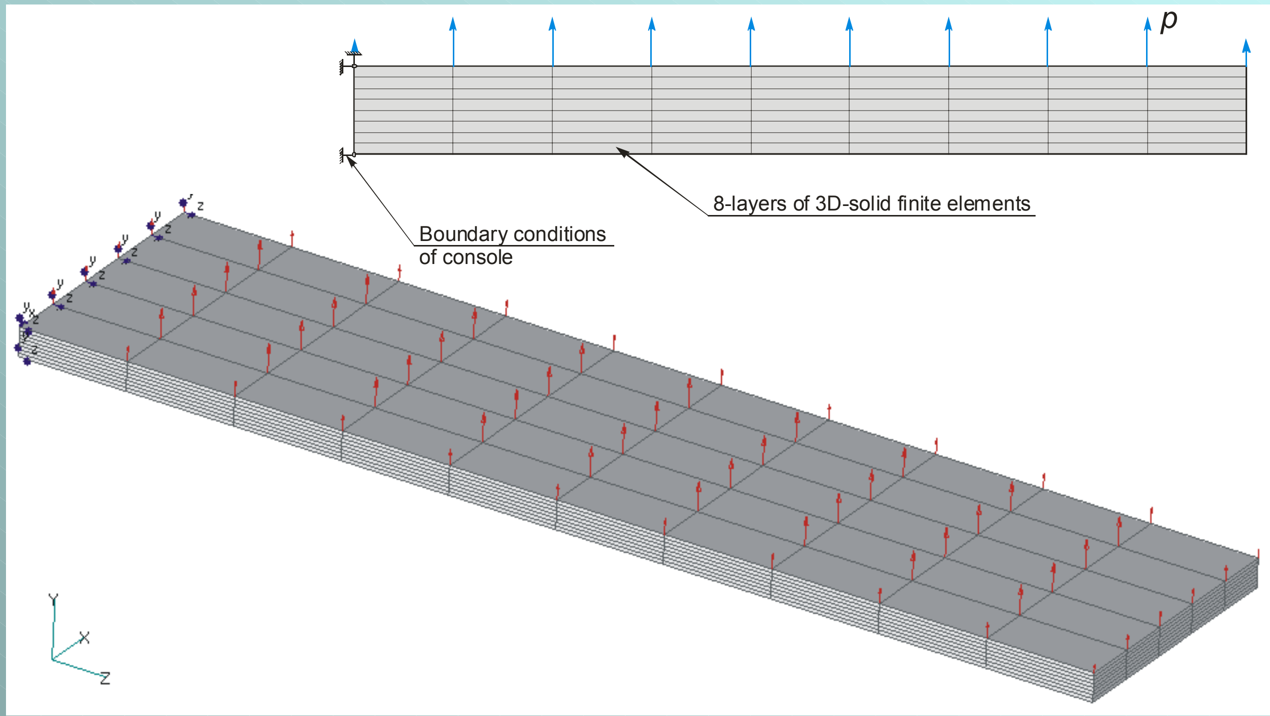
Algorithm of density distribution optimization

1. $\rho_{0i} = const$
2. σ_i
3. $\rho_{1i} = \sigma_{0i}^{eqv} / [\bar{\sigma}]$

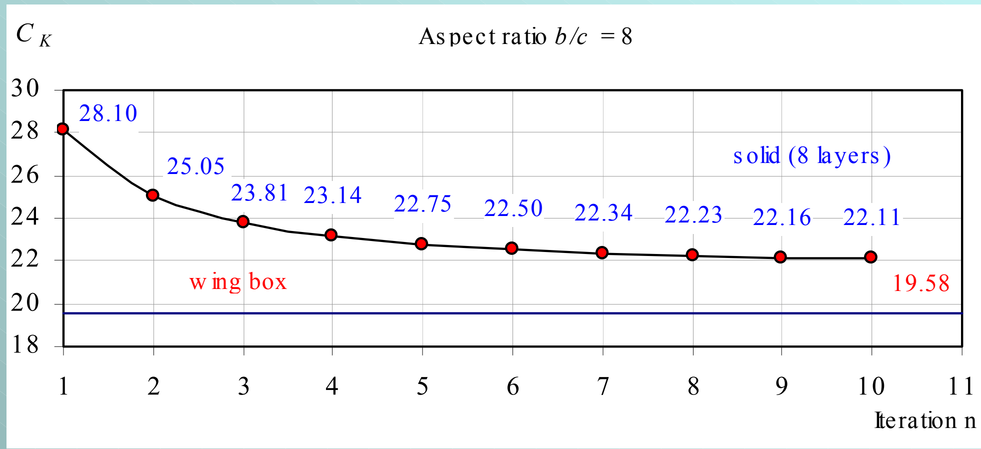


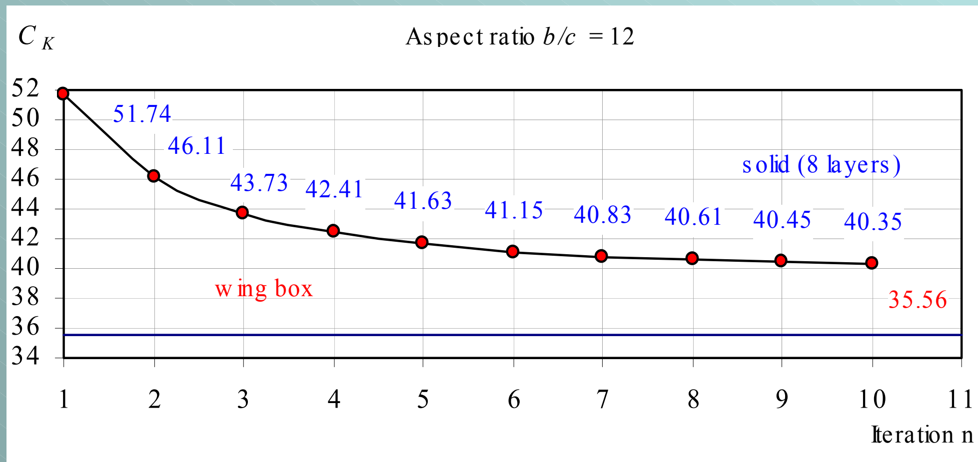
Test

3D-model of the wing structure

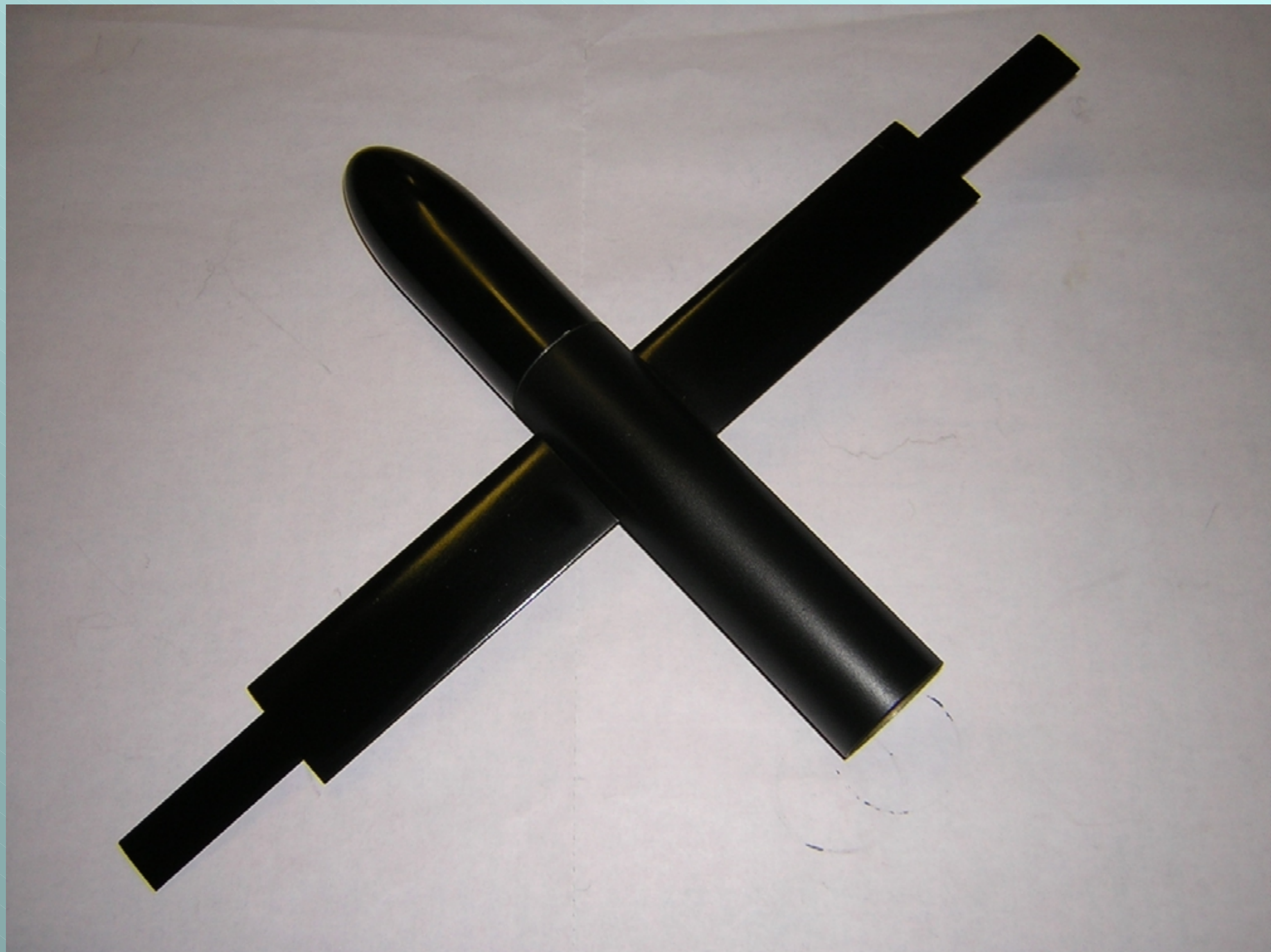


Comparison of load-carrying factor coefficient calculations for thin-wall structure and 3D-solid model with variable density

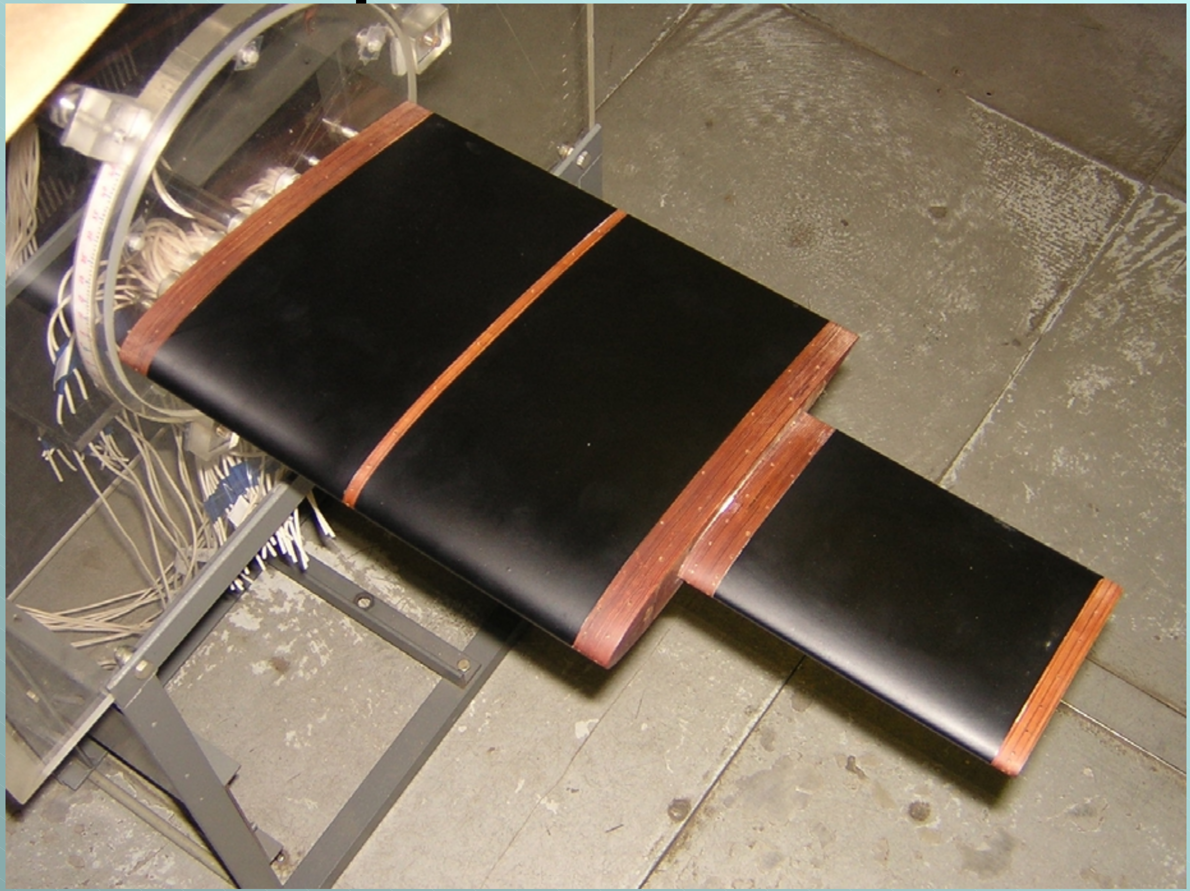




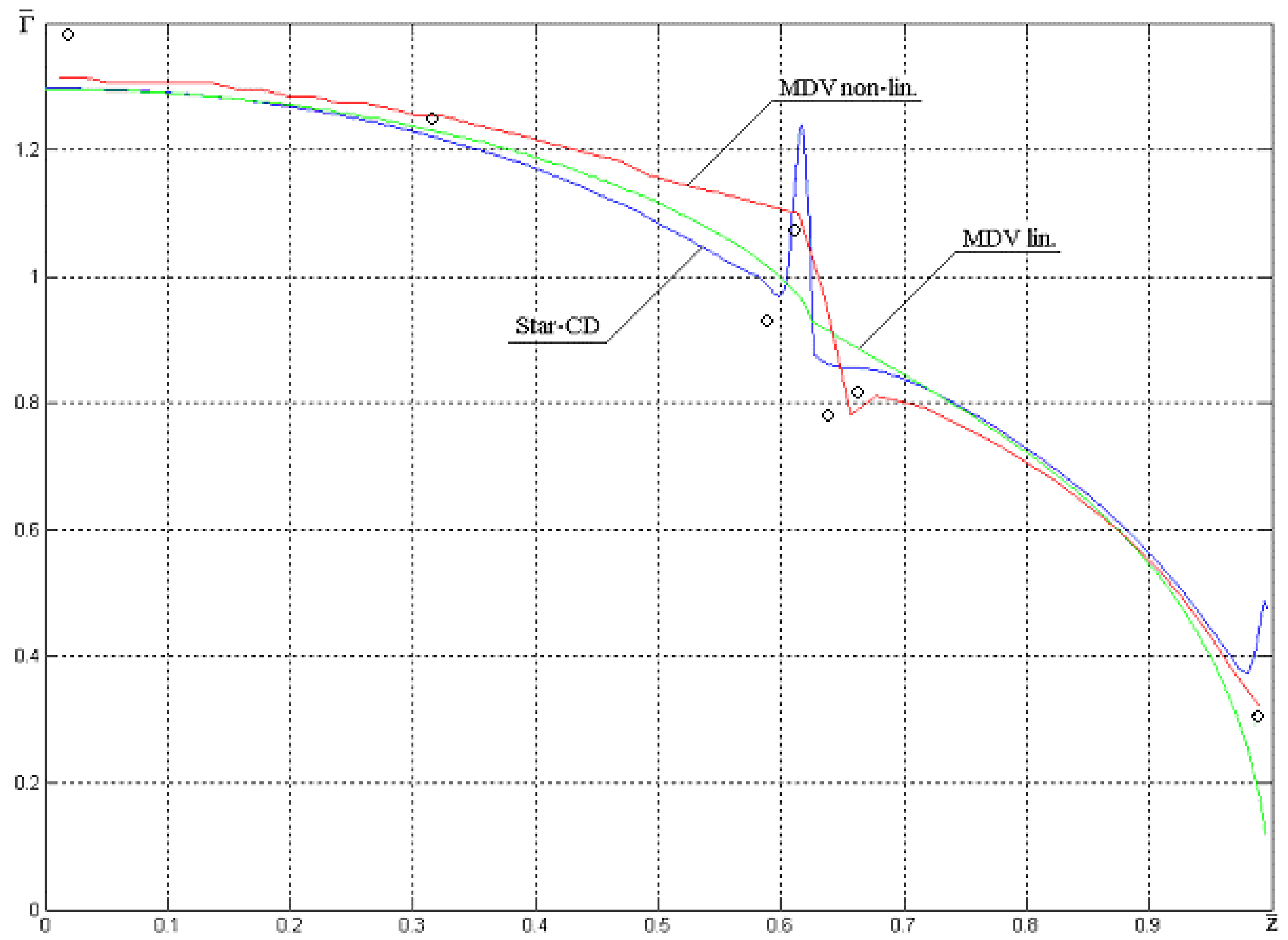
Wind tunnel model 1



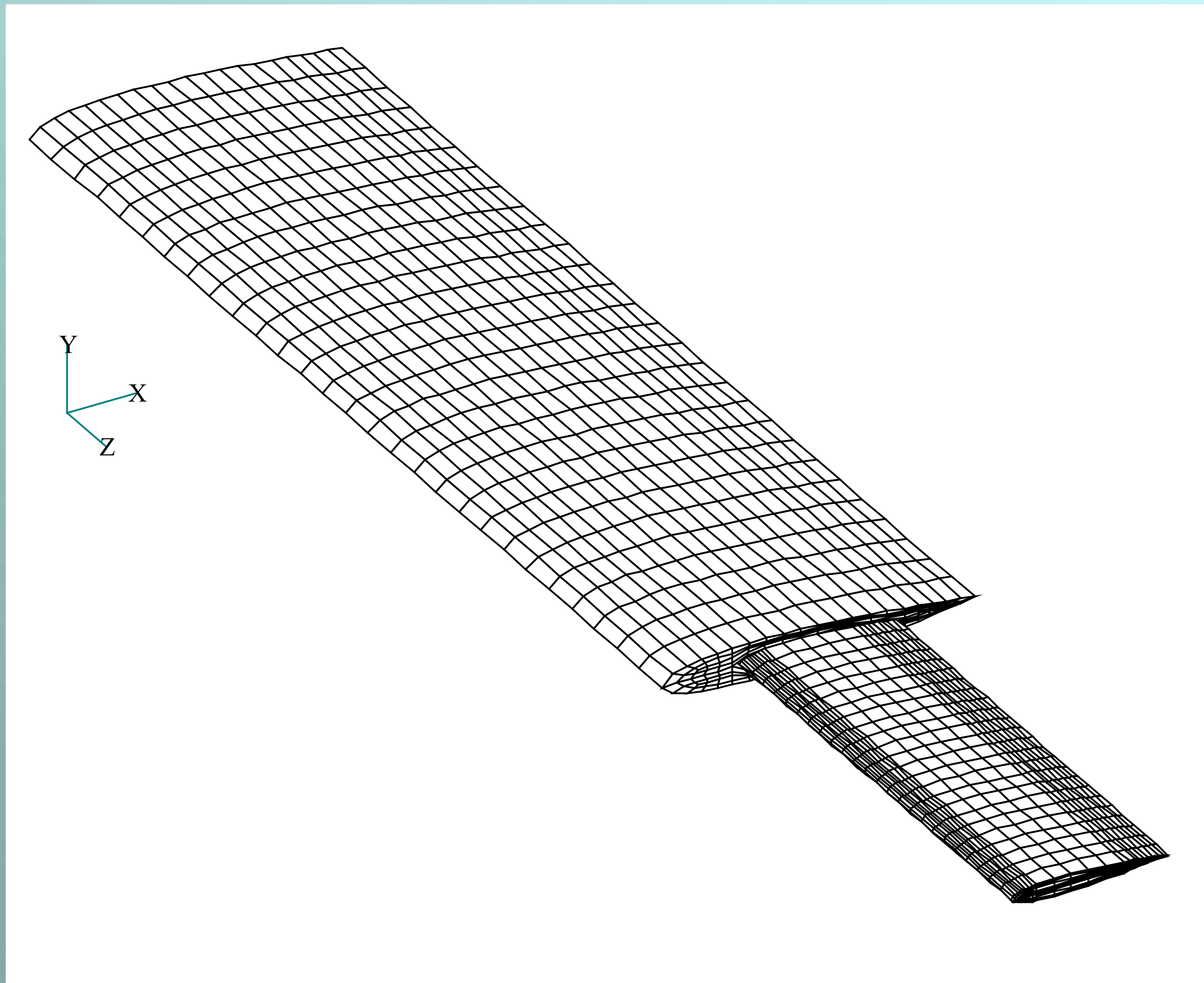
Wind tunnel model 2
with pressure of orifices



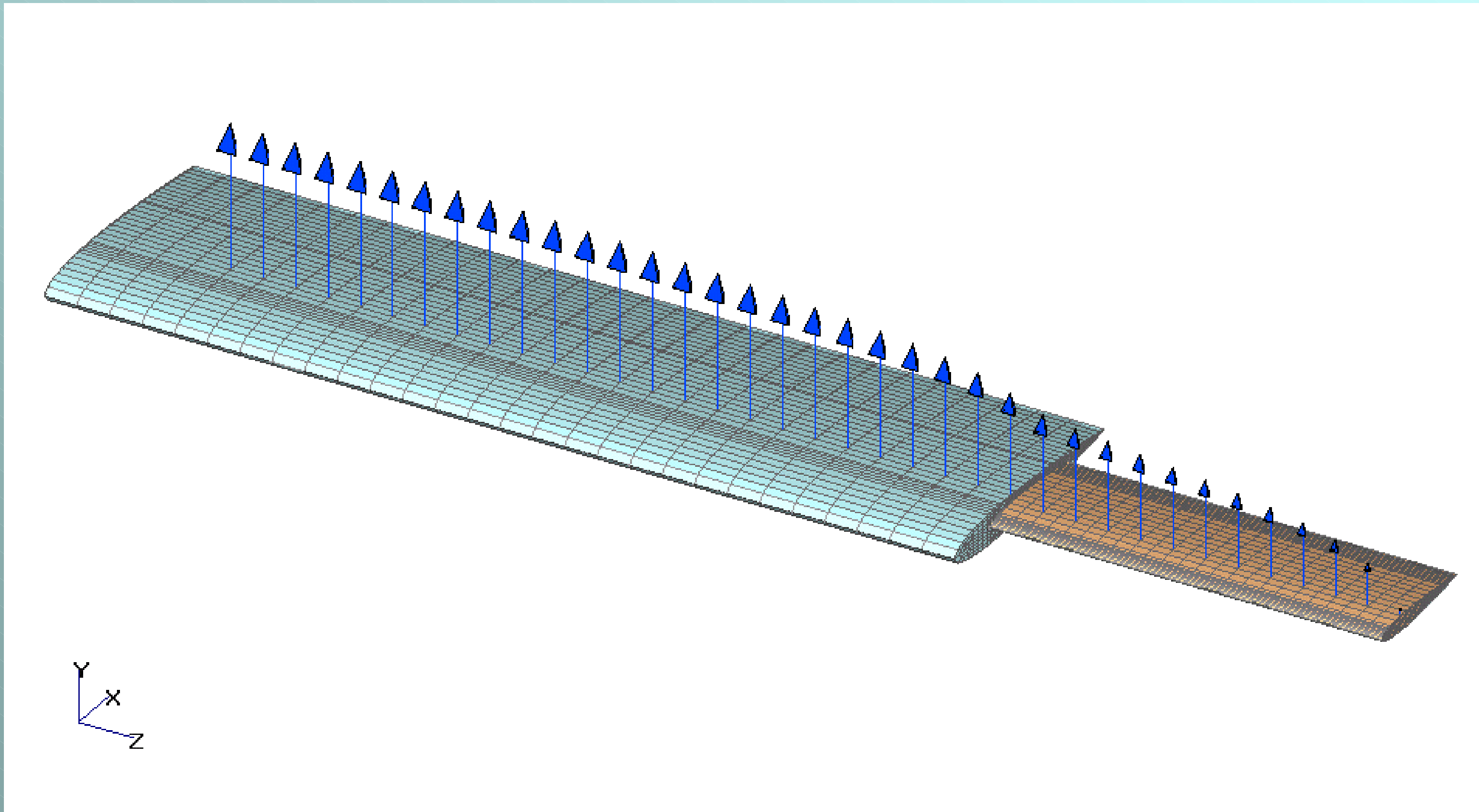
Spanwise load distributions



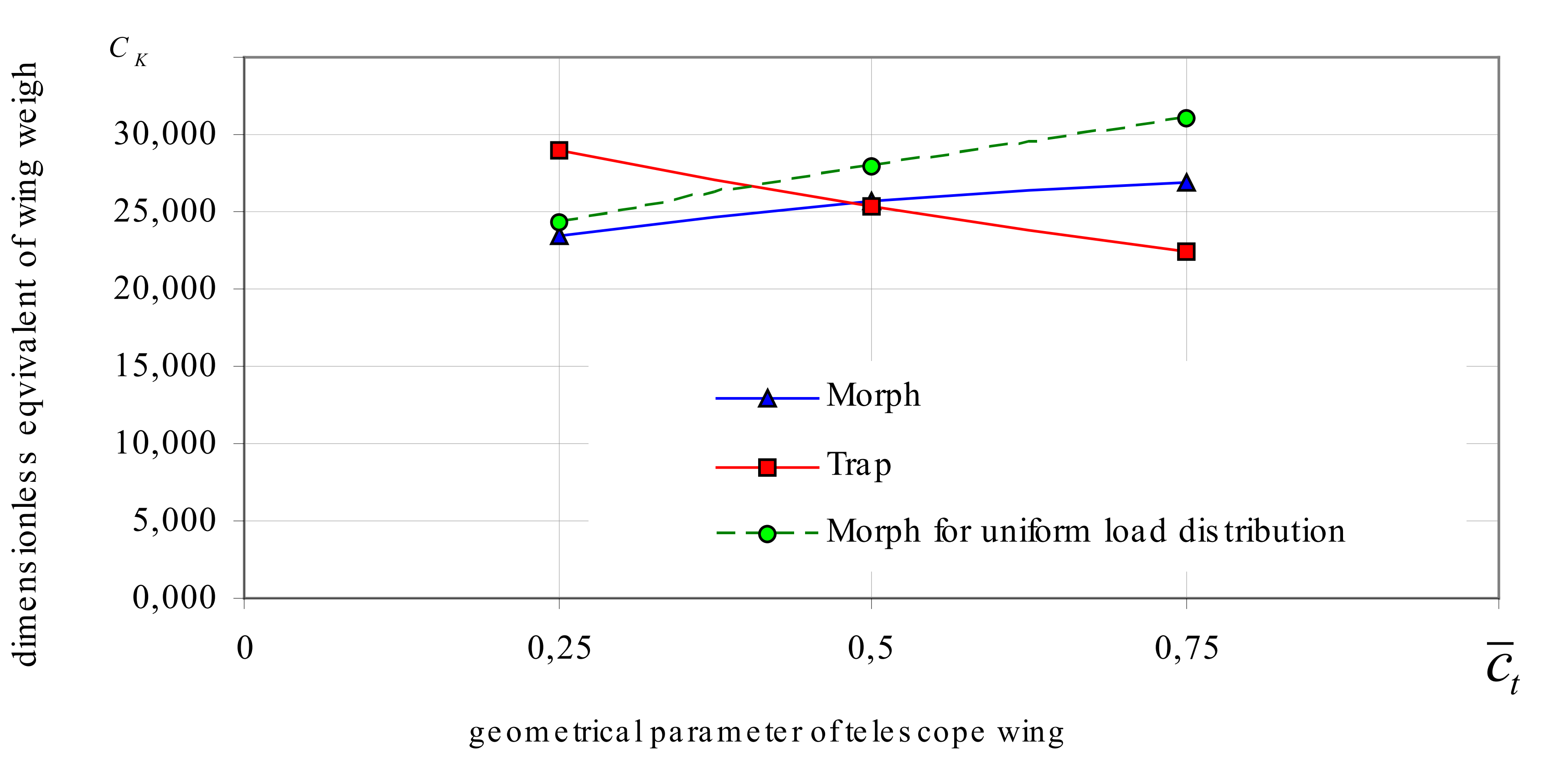
3D-model with variable density of material



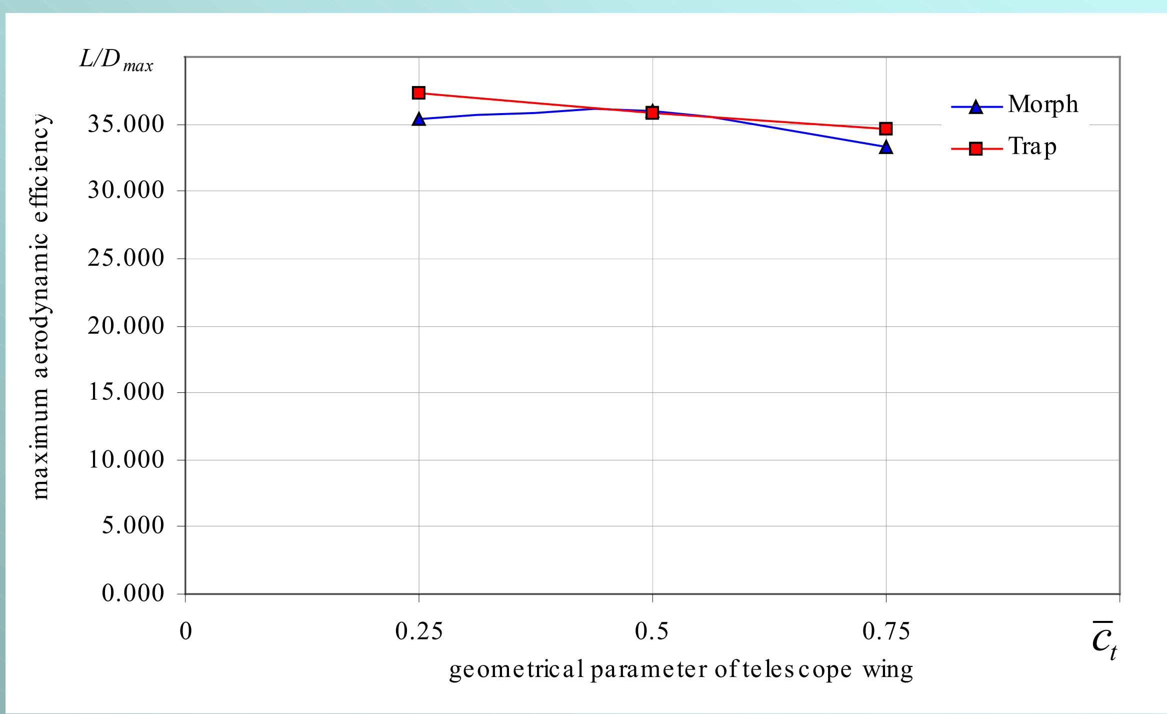
External loads



Comparison of weight perfection



Comparison maximum aerodynamic efficiency



Pressurized cabin, pressure vessel

Specific volume – volume - V

Specific load– pressure – P

$$C_K = \frac{G}{P \cdot V}$$

Some results for reservoirs:

Spherical – $C_K = 3/2$

Cylindrical – $C_K = \sqrt{3}$

Spherical from CM – $C_K = 3$

Cylindrical from CM – $C_K = 3$

Conclusion

Load-carrying factor C_K *allows*:

1. To put in according to load-carrying scheme (topology of structure) the certain dimensionless value which defines weight perfection of a design.
2. To build "weight" formulas for any designs.
3. To accumulate the knowledge in convenient form (dimensionless!) for analysis of existing and perspective designs.

There are 3 new ideas in the lecture, which can be useful to increase efficiency of early stage design.