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DEVELOPMENT OF AN AIRSHIP USING THE DESIGN PRINCIPLES OF BIONICS

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ABSTRACT

The design principles of bionics help design engineers to learn from nature as incitation for novel technological designs. This paper describes an example product design – the design of a model airship – which was carried out applying the design principles of bionics in combination with more conventional design methods. This application resulted in a novel design and gave rise to the hypothesis that the design principles of bionics can be a sensible addition to design methodology.

Keywords: Design Methods, Innovation, Creativity, Bionics, Airship, Ripcage

1 INTRODUCTION

In the Lake Constance region in the southern part of Germany the development of airships (e.g. Zeppelins) has a long tradition. Consequently, at the University Ravensburg-Weingarten a product development process of an experimental model airship was initiated. During this development it became clear that the use of bionics design principles was extremely fruitful. Additionally, it became clear that the procedures proposed in Bionics have to be used flexibly and have to be adapted to the given situation. In the project the top-down process of bionics (Nachtigall [2]) was integrated into a systematic design procedure according to Ehrlenspiel [1]. This resulted in a novel design, which provides considerable advantages in terms of weight compared with conventional airships. Besides the influence on the design result, the application of the design principles of bionics also altered the systematic design process. This paper describes the development of the model airship, the application of the design principles of bionics, and the findings resulting from a reflective analysis of the design process.

2 THE TASK

The basic idea of an airship can be described as follows: compensating or at least significantly reducing the gravitational force of the aircraft is the main principle of an airship. This is achieved by filling the airship with a lighter, that is to say less dense gas than the surrounding air. Because the gas volume changes according to temperature and pressure, a gas-proof and flexible hull is desirable. An airship can hover motionless in the air with no energy effort it is therefore a very efficient mode of air travel.

The basic challenge of the task to develop an experimental model airship was to design a model airship based on the following guidelines: the airship needed to carry at least a 2 kilogram load and the ship itself was allowed a maximum length of 6 meters.

2.1 Background: technical airship concepts of the past

After first weight estimations, all past design concepts would be too heavy and/or exceeded the maximum demanded length. So a new concept had to be discovered and developed for the successful fulfilment of this task. For a better understanding, the principles and differences of past airship concepts are described briefly in this section.

2.1.1 Rigid ships

Figure 1 LZ-127 "Graf Zeppelin" before the hangar [6]

Rigid ships are equipped with a firm skeleton. The outer skin and all other construction units are fastened to it (e.g. drive, control fin, gondola etc). The outer skin does not come in contact with the lifting-gas bag(s).
Inside the airship are special carrying gas bags, filled with so-called “lifting-gas” (hydrogen in the past, these days helium). These special carrying gas bags are not completely from the start filled. Thus the gas can expand or contract. Rigid airships do not depend on internal pressure to maintain their shape.

2.1.2 Blimps (non-rigid-airships)

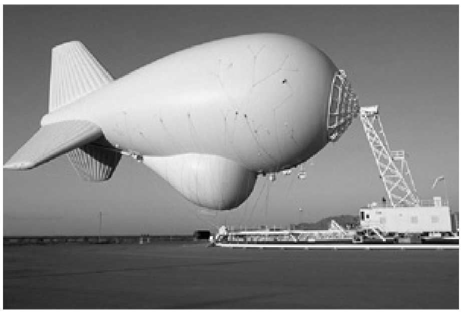

Figure 2 Blimp at the anchor mast [7]

The outer skin of blimps (non-rigid-airships) is the lifting-gas bag, and all elements are fastened directly to it. Blimps have an internal pressure ballonet so that they can retain their shape in different temperature and pressure conditions. Thus a rigid total structure is assured.

2.1.3 Hybrid ships (keel-ship)

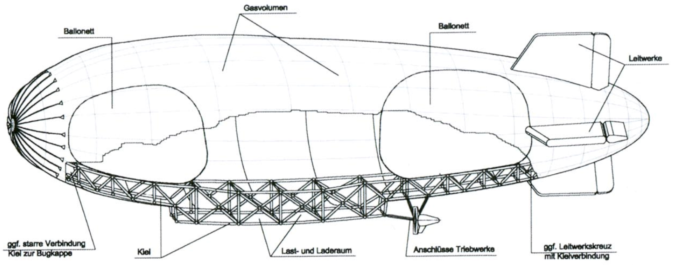

Figure 3 Principle representation keel-ship [4, S.32]

Hybrid ships are a combination of a blimp and rigid airship design. They have an aerodynamic keel, to which the gondola and all other loads are fastened. Here as well, changes in volume are counteracted with a ballonet.

3 DESIGN PRINCIPLES OF BIONICS

It is important to note that the term “bionics” is more broadly interpreted in Germany than in English speaking countries. It resembles more the English term "biomimetics" or "biomimicry". The word “bionics” was probably first used by the American air force major J.E. Steele in 1960 when he intended to learn from the “biological sonar” of bats. Nachtigall (2) defines bionics as “learning from nature as incitation for independent technological designs”. He presents 10 design principles of bionics which he also calls the 10 commandments of bionics:

1. integration instead of additive design
2. optimisation of the whole design instead of maximisation of single elements
3. multi-function instead of mono-function
4. fine adjustment to the environment
5. conservation of energy instead of waste of energy
6. direct and indirect usage of solar energy
7. limited life spans instead of unnecessary durability
8. complete recycling instead of accumulation of waste
9. networks instead of linear connections
10. development by means of trial and error

Nachtigall [2] points out that bionics cannot consist of only copying nature. Instead bionics is a process of learning from nature, of detaching phenomena from their circumstances and applying the learned components (ideas) to technological designs. In this project, many aspects of the natural ideal had to be changed, even turned into their opposite. The procedure in this section of the design process was oriented on the top-down process proposed by Nachtigall [2].
This top-down process consists of the four steps:

- defining the problem
- searching for analogies in nature
- analysing archetypes from nature
- searching for a solution for the problem by applying the observed characteristics

4. DESIGN OF THE AIRSHIP WITH A BIONIC APPROACH

In the first stages of the systematic design process one central problem of airships was identified. This problem can be stated as follows: “A system needs to become airborne through weight reduction by means of a gas lower in density than that of the surrounding air. This system should have a stable aerodynamical form without unnecessary additional elements that define the form.”

Desired characteristics:

- weight reduction (i.e. lifting-gas bag is the outer skin)
- The gas bag needs to be elastic and at the same time have a low diffusion rate.
- elements need to be lightweight and multifunctional
- It should adapt to changes in its own volume as to maintain its aerodynamic form.
- protected storage of the carrying gas

An interesting analogy could be found in nature: the lungs of mammals. The lungs and the ribcage achieve an expansion and a reduction in volume while breathing. This expansion of the volume is intentional. On the contrary, the volume expansion of the gas of an airship is caused by external influences. Still the “natural” design of a ribcage can be adopted for the technological design of the airship structure. By combining “ribs” made from wire with elastic tape, a design could be created that combines an expansion or reduction of the volume with an aerodynamic form. The natural design of the ribcage and the resulting design of the airship will be described in detail in this paper.

4.1 The Lung, the ribcage and the principle of respiration

The major task of the lung is breathing. It consists of two phases: Inspiration and expiration. During inhalation the pressure must be smaller in the lung than the air pressure of the environment (otherwise no air would flow into the lung). While breathing out, the opposite is the case. In order to manufacture these conditions, the lung volume must become larger during inhalation (inspiration), and become smaller while breathing out (expiration). This is done by the movement of the midriff (diaphragm), and with the assistance of breathing muscles, indirectly by means of ribcage (thorax) movement.
[6, S.78, 80]
This system allows a controlled change in volume. In an airship, the change in volume is an unwanted phenomenon due to changes in temperature and pressure. This is shown by equation (1) after the investigations of Boyle, Mariotte and Gay Lussac [9].

$$p \cdot v = R \cdot T \tag{1}$$

p pressure
v specific volume
R (specific) gas constant
T temperature

Therefore cause and effect are not the same. With the airship, it is reversed. Nevertheless, the desired characteristic "volume control" is obtained.

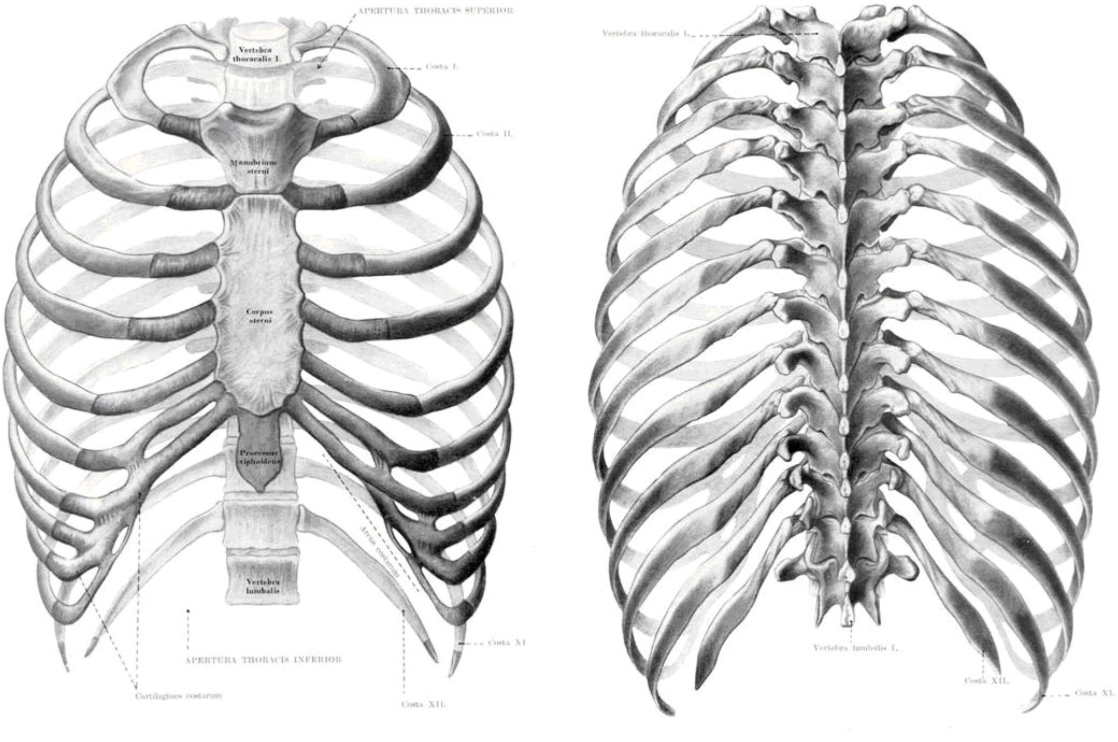

Figure 4 Thorax. Latus Ventrale [10, S.97]; Thorax. Latus Dorsale [10, S.98]

The backbone is the most important structure of the skeletal framework. The upper extremities as well as the ribcage are connected to it.
Downwards the first seven ribs are called "genuine ribs” (Costae verae). They are connected by their cartilage extension (with exception of the first pair) and by genuine joints with the Sternum (breastbone). The following five pairs of ribs are called "wrong ribs" (Costae spuriae).

Ribs VIII to X are indirectly connected by the cartilaginous rib elbow (Arcus costalis) with the breastbone. The two last pairs of ribs (ribs XI to XII) are called free ribs. These are not in contact with the breastbone.

The twelve pairs of ribs protect the chest entrails. They enclose these. Each rib (Costa) is articulated connected by Tuberculum costae and Caput costae with the transverse extensions and the eddy bodies (Articulatio costovertebralis). In Figure 5 the joint surfaces and the movement axle are drawn in.

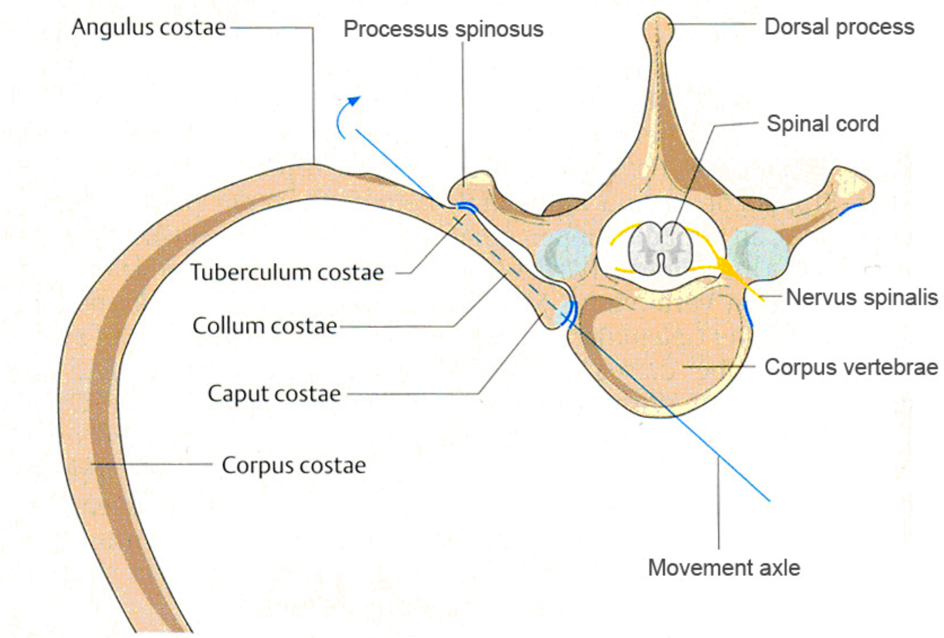

Figure 5 Thoracic vertebra and articulation with genuine rib [11, S. 90]

The described bone stand is a good example of a system which is protective and simultaneously flexible. It offers protection of the vital internal organs and permits by its mobility a volumetric expansion.

The reasons of this capability are the following mechanisms:

Inspiratorily effective:
- flattening (strain) of the diaphragm
- by strain of the Mm.scaleni and the Mm.intercostales externi an elevation (enlargement of the volume) of the thorax is achieved
- additional breath auxiliary muscles

Expiratorily effective:
- muscles of the abdominal wall (belly press) urge the diaphragm upward
- the reduction, by weight and self
- elasticity, of thorax and lung
- the strain of the Mm.intercostales interni

In each case two ribs lying one above the other and are interconnected by the Mm.intercostales externi and interni. As a result of the different lever lengths at the upper and lower rib the against-intimate effectiveness arises.
The gap between lung surface and chest wall is lined in each case by a smooth sheet, the lung skin (Pleura visceralis) and the chest skin (Pleura parietalis). This is called Cavitas pleuralis. Few cm³ of a clear liquid make a sliding possible of both sheets one on the other. Due to the developing negative

pressure by the inhalation, the lung follows the thorax and the diaphragm. The lung tries to become smaller by its self-elasticity in their natural situation. Lung and thoraxes are after a normal breathing out in the rest position. In this position the two forces waive themselves (the lung wants to become smaller and the thoraxes wants to extend). [6, S.80ff]

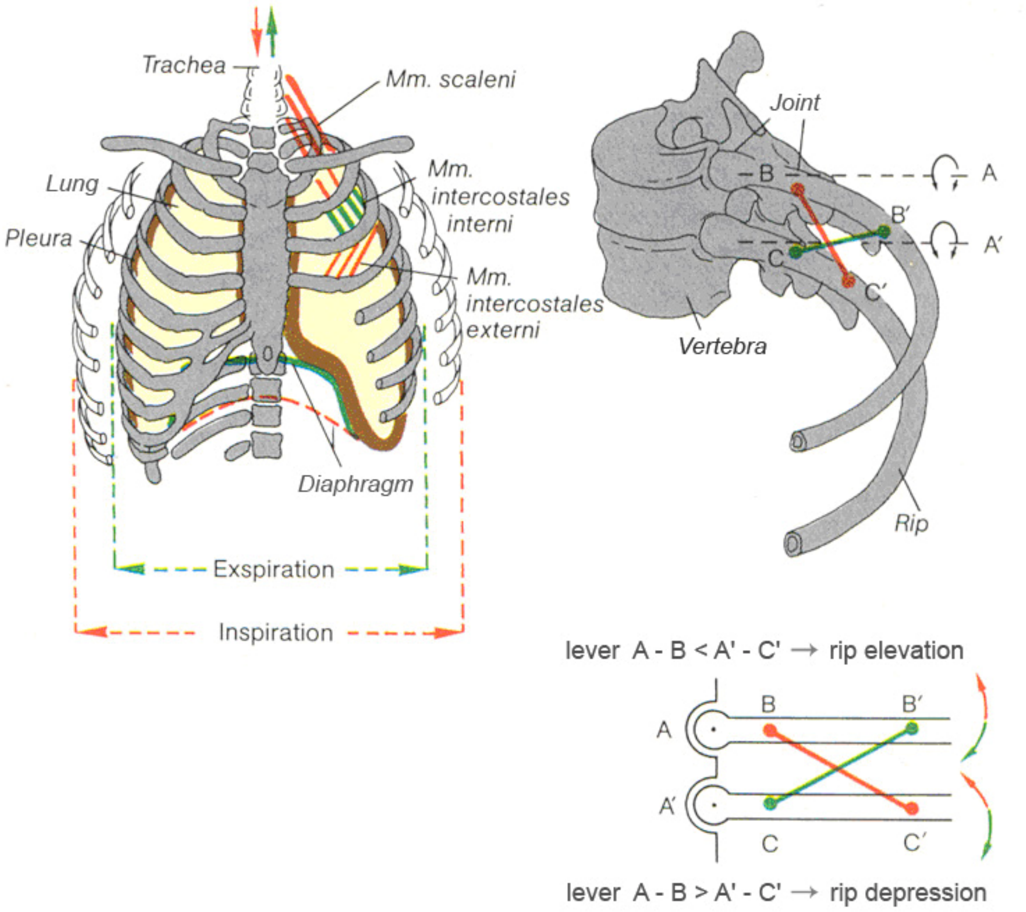

Figure 6 Respiratory muscles and effect principle [6, S. 81]

Resulting bionic starting points
After the analysis of the nature analogy thorax, the following bionic starting points can be won:

- breathing (variable) structure// body adapt to the gas expansion
- carrying gas foil = outer skin; an adapting system
- Exoskeleton - the outside skin can be seen as redundant protection
- Half-open supporting skeleton (like wrong ribs) to the reinforcement of the airship body. Additional protection from nicking or depressions of the lifting gas bag.
- weight reduction by not closed ribs
- strength allocation over all ribs; force flow by rib elbow and tapes
- Backbone as basic carriers and hinge point. (It serves the basic reinforcement; possible adaptation of load-bearing construction units; Auxiliary function nerve channel)

4.2 The resulting airship with bionic principles

The following working model is a technical model not true to scale. It was designed only to clarify the function according to the concept of a bionic breathing structure. It was also used for developing a better idea of the gas foil in combination with the exoskeleton.

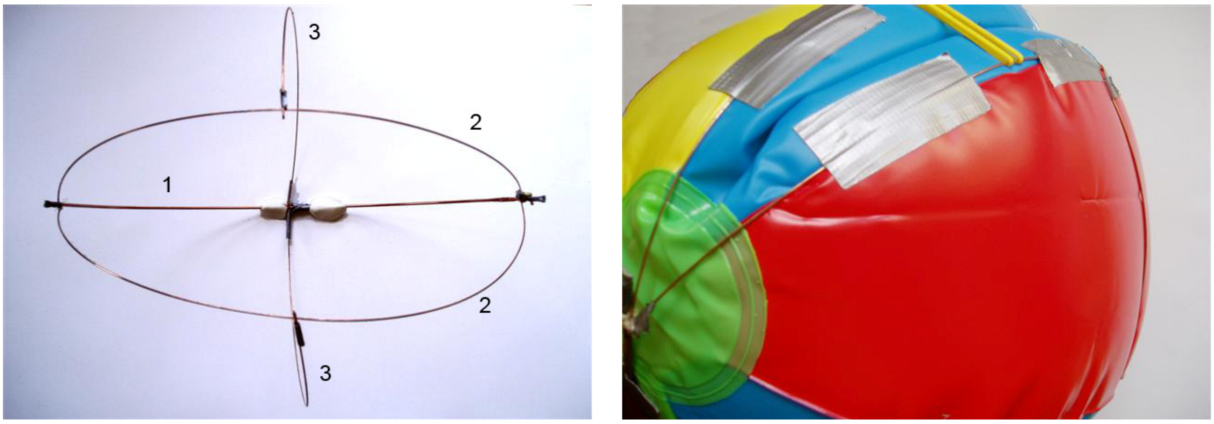

Figure 7 top view: skeleton structure; working model rib elbow [own figure; 2006]

1 backbone
2 rib elbow
3 rib

The Problem of finding a flexible and yet gas-tight foil was solved via the following regulatory system:
The airship geometry was designed for maximum expected volume V_{max}. This volume is not enclosed entirely by the ribs, which are flexibly attacked to the backbone.
The ribs are connected to the foil by means of through-way pockets. They also reduce the contact surface for the wind and serve additionally for the internal pressure for stabilizing the foil. The ribs end at the two rib elbows. They are flexible fastened to the backbone as well. The minimal Volume V_{min} is achieved when the rib elbows are closest to each other.

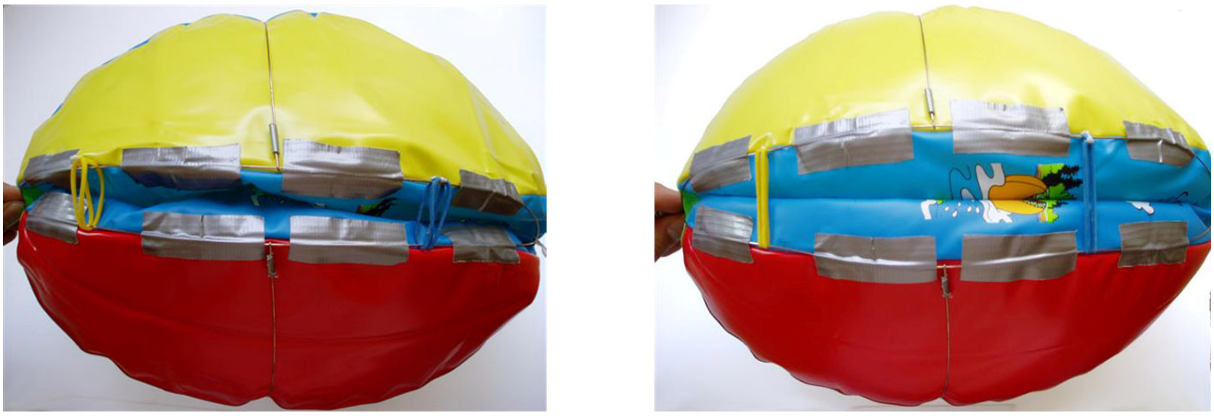

Figure 8 Reduced volume; Increased volume [own figure; 2006]

Rubber bands hold the rib elbows together. This results into a compression of the volume, which causes a smooth taut form. The "redundant" covering material is hidden in a fold. In the deepest point of this fold is a "moccasin -" welding seam where the material is allowed to crease.

Figure 9 sketch of a moccasin-welding seam

The rubber bands release appropriate covering material during a variation in volume. Otherwise this is kept in the fold. The punctually attacking load of the rubber bands is derived distributed over the rib elbows and the ribs.

Figure 10 front view; working model [own figure; 2006]

Partial parametric CAD model

For a better overview and increased flexibility, a partial parametric CAD model was composed in PRO/ENGINEER Wildfire 2. This models the necessary construction units depending on given length and aspect ratios. This concerns particularly the connecting and reinforcement elements as well as the cut-patterns for the hull foil.

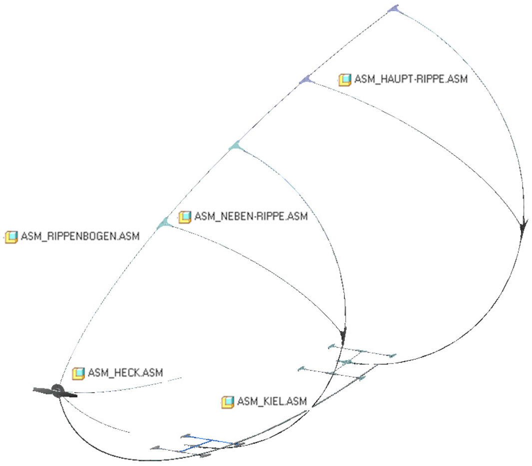

Figure 11 part-parametric CAD model with assembly file names [own figure; 2006]

Thus construction elements for different airship volumes can be designed easily, and due to the aicraft’s cylindrical design, a CAD model for only one quarter of the ship is sufficient.

5. METHODICAL DESIGN PROCESS

The basic structure of the applied design process can be described as shown in Figure 12.

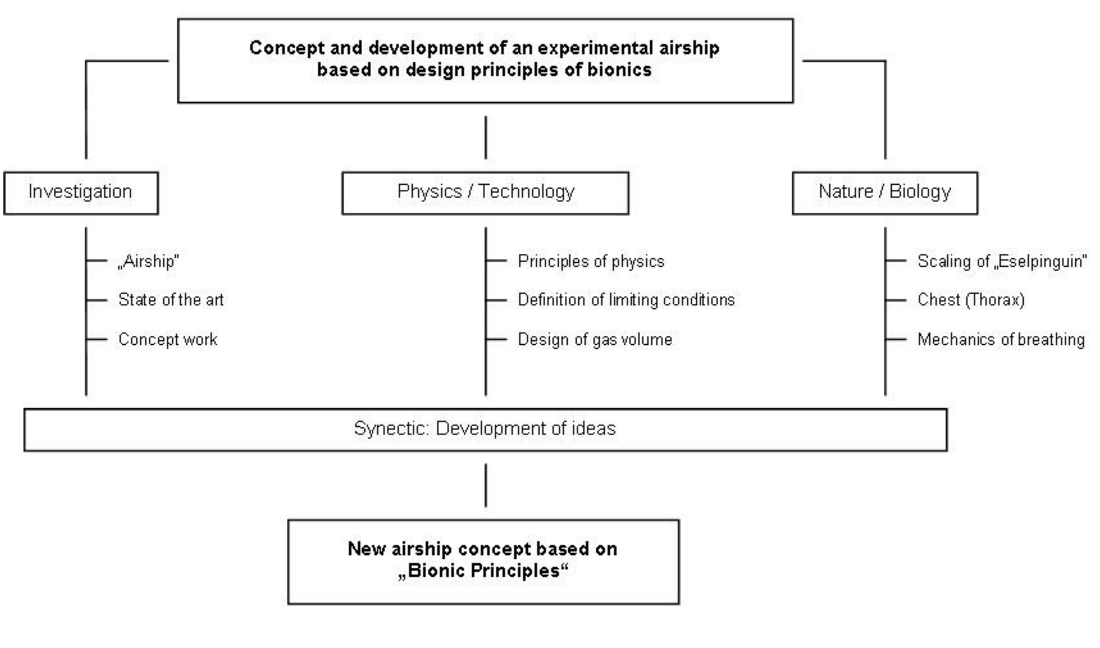

Figure 12: basic structure of the design process

The task is divided into three main points. These were dealt with in parallel. Each main point was divided into further sub-points and hence more detailed.
The merge of this compiled basic knowledge resulted in the development of ideas (synectics). From the idea development the new airship model developed according to a principle of the bionics.

The first two main points (investigation and physics/technology) and the idea development were worked dealt with according to Neid or Erlenspiel [1]:

- Create a function list
    - Which functions must be fulfilled?
    - Which priority is assigned to the functions?
- Define a list of requirements
    - Which requirement must be covered?
- Formation and evaluation of concept variants (morphologic box)
- Construction of a plastic working model
- Perform a failure mode and effects analysis (FMEA)

The specific point in this design process was the inclusion of the design principles of bionics. The third main point bionics (nature/biology) was added during the design process as the idea for the analogy suddenly appeared. It was intended from the beginning to look for such analogies however the right moment for the inclusion of the design principles was unclear. In the example project the general awareness of the design principles of bionics and a conscious application once the idea of an analogy had appeared resulted in the development of a novel solution.

Thus the experience in the example process gives rise to the hypothesis that a designer should be aware of the principles in all phases of a design process but should focus on them if an idea for an analogy appears. The most promising approach for applying the principles of bionics is most probably not a conscious application in a certain phase of the design project or in a certain situation but a constant awareness of the potential of these principles and open eyes.

6. SUMMARY

In the described project the top-down process of Nachtigall was combined to a systematic design procedure as prescribed e.g. by German design methodology. This process was carried out by an individual designer. It is important to note that the idea for the analogy did not result from an intentional process. The idea appeared suddenly during the probably unconscious mental occupation with the given problem. The top-down process of Nachtigall [2] was successfully applied afterwards for validation purposes if the analogy really could be used but not in the first instance, i.e. not in the generation of the first idea. This gives rise to the hypothesis that a main perquisite for an application of the design principles of bionics in rather small design processes of single designers is mainly fostered by an (unconscious) knowledge about the existence of these principles and by a broad knowledge about nature and its solutions.

The bionic method, as presented in this paper, yields few, possibly only one solution, but with the chance of it being very innovative. This is the difference to the TRITZ Methodology: here typically, existing solutions are modified, not radically invented. The TRITZ improvement technique generates an array of variations, in bionics however, the overtaken principles of interest are left as is. (de natura).

The findings and hypotheses concerning the integration of the design principles of bionics into systematic design processes are to be understood as preliminary as they are until now only based on one exemplary product development. However, the generation of additional examples might be difficult as the design principles of bionics are only applicable at certain problems.

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