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## Column



## Articles



## News & Information

# Structure Synthesis of Prospective Technical Systems

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## ABSTRACT

**For the creation of competitive products in aerospace, it is necessary to synthesize from 50 to 150 new engineering solutions. The method of structural synthesis of new systems to solve two problems is examined:**

- ***Direct problems.***
  **After the creation of the morphological array with the help of clusterization, a search of engineering solutions occurs.**
- ***Inverse problems.***
  **The effective search near existing solutions is carried out.**

**The operation of the method is given in three examples: Superlight Re-entry Vehicles, HAPs, and adaptive acoustic systems.**

## INTRODUCTION

For the creation of competitive products in aerospace, it is necessary to synthesize from 50 to 150 new engineering solutions. In [8], three levels of optimization are examined at the creation of new Engineering Solutions (ES). The first level is understood as a choice of managing technical ideas or a principle of action of a projected system. The second level of optimization is a search of rational structure and the third level is a definition of the best values of characteristics for the chosen structure.

The performance characteristics of the projected systems at the third level of optimization can be improved of the average of 10-15 %, and, in some cases, up to 30 %. Using the first and second levels, characteristics are improved of the average of 30-35 %, and occasionally, several times. The higher the level of optimization, the larger the effect of optimization. In engineering practice usually there is no way to allow simultaneously the choice of optimum engineering solutions based on conditions of the technical project.

It is possible to divide the process of designing (Figure 1) into two stages. After statement of problem at Stage 1 rational composition and the structure of the system (qualitative characteristics) are chosen, and at Stage 2 parametrical optimization with the fixed composition and structure (quantitative characteristics) are carried out. If necessary, the process is repeated. The problems of parametrical optimization are given in to formalization and are well investigated.

At the same time, problems of Stage 1 are difficult to formalize, and the solution is only small group of methods.

The problem is that the mistake in choice of ES cannot be further corrected. Therefore it is necessary to analyse, as far

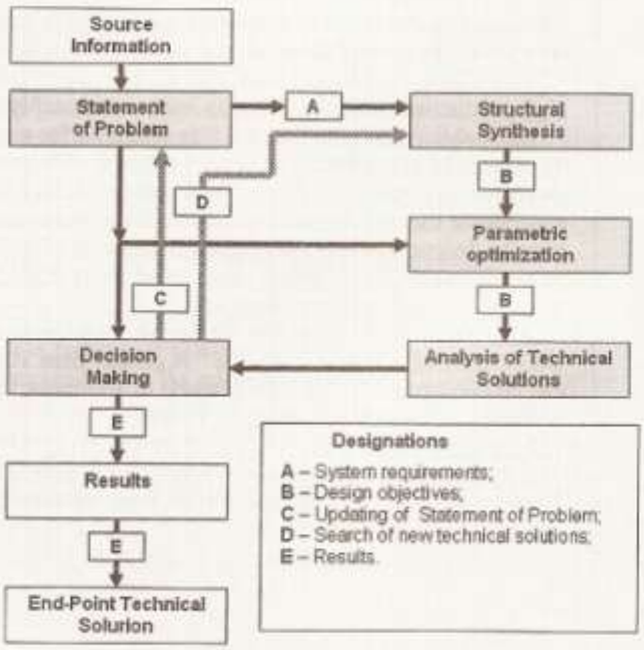


**Fig. 1. Design process diagram**

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as possible, all real variants whose number can run to several thousands. Accordingly, at the acceptance of the basic problem solutions; there is considerable excess of information volume on potential variants of choices in comparison with what the designer is able to process operatively [5].

## MORPHOLOGICAL METHODS

For structural synthesis the morphological method can be effectively used. It consists of the construction of the morphological table, filling it with possible alternative variants and in a choice from all array of the best solution combinations. The method was applied by Swiss astronomer, F. Zwicky, for the first time and henceforward was developed in a number of researches [1, 2, 3, 4, 6].

Morphological methods suppose computer realization. The search space is referred to as a morphological array; the process of this space definition – the morphological analysis, and a search of the decision – morphological synthesis. As a result of the analysis there is an array of variants or alternatives. The array contains all engineering solutions of an examined class devices, both real-life, and potentially possible.

The drawback of this method is the impossibility of the search and the analysis of all possible variants and the tendency of the morphological array (to run up to tens and hundreds thousand possible alternatives) can be enormous.

## STRUCTURAL SYNTHESIS OF TECHNICAL SYSTEMS

To reduce the dimensionality of the morphological array to a choice the method of the structural synthesis is developed. By means of the method it is possible to solve two groups of problems:

1. **Direct problems.**
   After the creation of the morphological array with the help of clusterization a search of engineering solutions occurs.

2. **Inverse problems.**
   The nearest vicinities in the searches of the more effective variants are examined according to the known ES.

The synthesis process provides the following stages.

1. **The creation of the morphological table.**
   The group of basic characteristics is singled out in the object. Depending on the type of problem the essential characteristics {P}, [i.e., able to affect the problem solution], are chosen from the array of characteristics $\{P_p\}$ thusly:
   $\{P\} \leq \{P_p\}$.

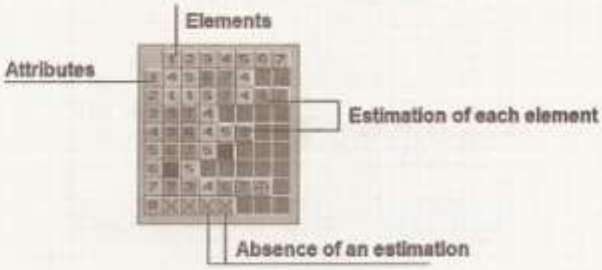


**Fig. 2. Morphological table**

The choice is the informal zonal moment. For example, the array of characteristics {P} can be revealed from the formulas of inventions.

For each characteristic the elements are chosen, i.e., the possible variants of its execution or realization. Arranging them among themselves, it is possible to get the array of various solutions (variants).

The total number of variants equals: N = A1 * A2 * . . . * Ai * . . . * An, where Ai (i = 1, n) is the number of values of 1, 2 . . . n the appropriate characteristic elements.

The morphological table (Figure 2) contains 100,800 potential variants.

The basic complexities on the way to choosing solutions are determined by two circumstances: the complexity of formalization of a problem and the great amount of various requirements, criteria and restrictions. The criterion is a similarity of purpose with its approximation model. At the transition from the purpose to criteria, the latter are considered as quantitative models of qualitative purposes. The definition of the criterion value for the given alternative is, in essence, the indirect identification of its appropriateness as a means for purpose achievement.

The next step in the comparison of each element of the morphological table is compared with the appropriate value of the criterion on which the estimation will be made. The weighting coefficients are given to criteria depending on the purpose [7].

2. At the second stage, **the generation of variants, their estimation and initial selection are carried out** and some array of rational variants {R} for the subsequent analysis is formed. Each newly-generated variant is compared with the previous one from the array {R}. If it is at the higher level it is registered in the array {R}, if at the worst level it is rejected.

3. Following the above, **the clusterization of variants using the entered measure of**

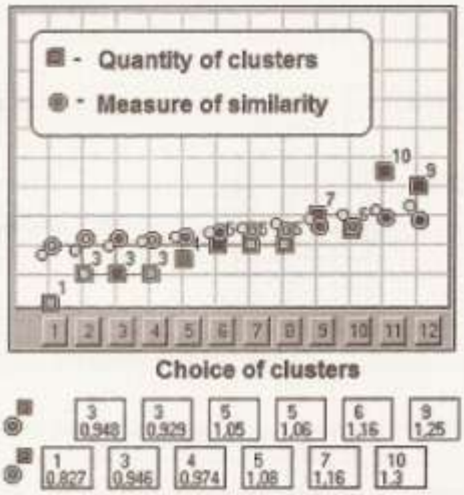


Fig 3. A choice of clusters quantity

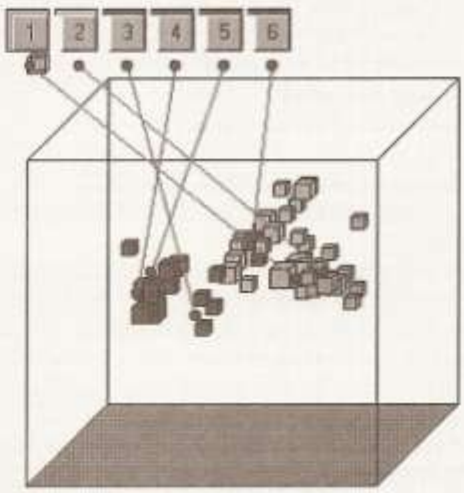

Fig 4. Grouping the variants in clusters (6 groups)

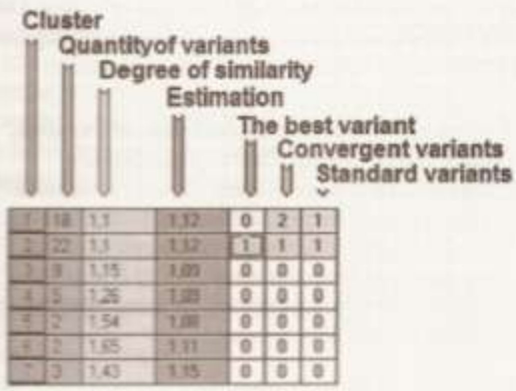


Fig 5. The analysis of clusters and variants

**similarity is carried out.** The process of clusterization is considered as the search of a "natural" grouping of objects. The designer can choose the necessary degree of allocation the initial array to clusters (Figure 3). The area of research is narrowed to several clusters (Figure 4) which are investigated further. Comparing variants, the best solutions which success is the most probable are being defined. The degree of novelty alternatives found (Figure 5) is introduced.

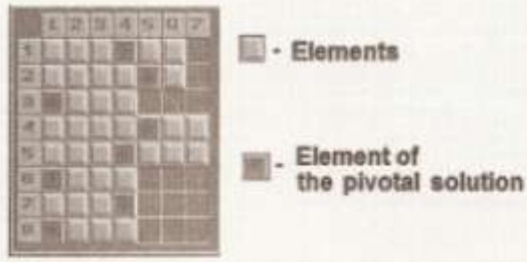


Fig 6. A morphological matrix with the pivotal solution

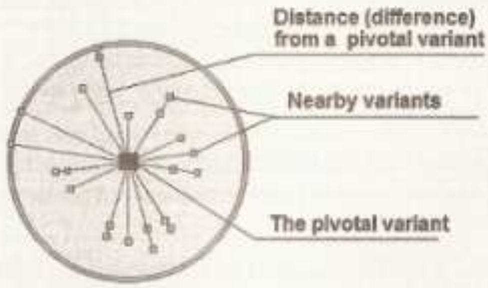


Fig 7. The process of research of the pivotal variant vicinities

4. And finally, **after choosing some number of variants** the parametrical optimization and the final choice are made.

**Inverse Problems**

The process of searching for a new engineering solutions is subjective. Designers have a psychological barrier; having found the first acceptable solution, the process of search stops and the work with the chosen variant takes place. It is intuitively obvious that the first acceptable solution will not be the best, and better alternatives are nearby. Psychologists have ascertained long ago, that in such situations people usually subconsciously single out some variants of ES, and *"forget"* about the others [5].

To eliminate this drawback, the method to solve the inverse problems of the structural synthesis [7, 8] is developed. The pivotal variant (idea) is registered in the morphological array (Figure 6).

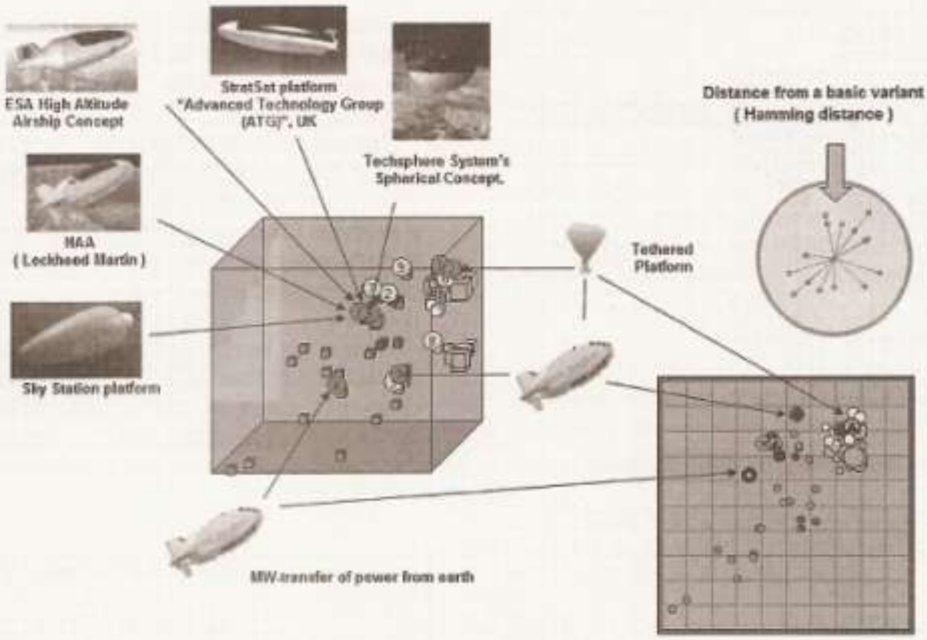


**Fig 8. A morphological field of the High Altitude Platforms**

Succeeding stages are the same as in the direct method. Variants which measure of similarity is close to the pivotal are included in clusters (Figure 7). The final matrix is composed of the best alternatives. In a matrix there is an array of acceptable solutions on which the choice of the most suitable variant is made.

Various technical systems from aerospace, power, ecological, and medical areas were investigated by means of the method. An example three engineering solutions: high-altitude stratospheric platforms, acoustic systems, and re-entry vehicles are given.

## STRUCTURAL SYNTHESIS OF AN ARRAY OF HIGH-ALTITUDE PLATFORMS (HIGH ALTITUDE PLATFORMS HAPs)

By means of the foregoing method the analysis and synthesis for stratospheric platforms for long-term basing are made. The total number of possible alternatives equaled 5180, and for the analysis 123 variants located in 7 clusters (Figure 8) were chosen. As a result some perspective systems were synthesized, among which was the universal [9,10].

Useful load is placed onboard the active tethered system (Figure 9). Power provision is carried out by the cable from the Earth. While cruising, the engines are constantly functioning, thereby advantages are inaccessible for prototypes are reached. By means of the shuttle system and the supply of a balloon bearing gas (helium or hydrogen), the delivery of the equipment and the measurement of the atmosphere characteristics, depending on the height, are possible. For studying the characteristics of the system

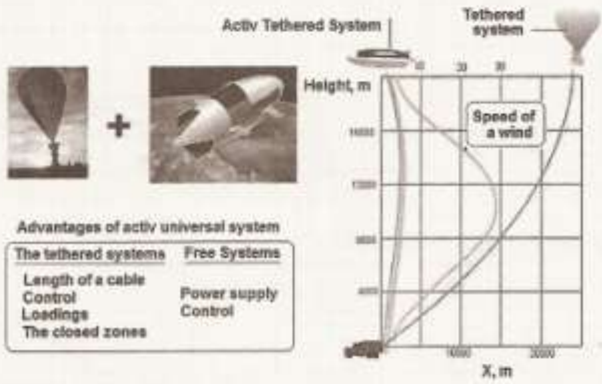


**Fig 9. Diagram of stratospheric system flight**

mathematical models were constructed and the ballistic and mass calculations [9,10] were made.

## STRUCTURAL SYNTHESIS OF THE PERSPECTIVE ACOUSTIC SYSTEMS

The method developed was applied to search the perspective acoustic systems [10]. The total number of engineering solutions equaled 17,200 variants. For the final analysis 60 generated variants, grouped in 8 clusters were chosen. Among the variants there were 2 pivotal variants and 7 convergent variants (Figure 10).

Two innovational solutions based on 4S effect were chosen as pivotal variants.

thermal insulation but not good for sound insulation. So it is better to add concrete or brick layers to the wall or floor to improve sound insulation."*

Other experts also adhere to this point of view.

Investigations have shown that it is possible to achieve an extraordinary reduction of noise level for thin-walled porous, cellular, and fibrous materials. In particular, for a technical foam panel of 30 mm thickness and with a specific area weight of less than 1 $kg/m^2$ the average of the sound reduction index can be up to 12 dB (Figure 11).

That effect has been achieved by the new so-called 4S-technology (Steerable Sound Suppression System). The creation of deformation zones on a surface and along the thickness of an insulating material, and also the interaction of that material with elastic membranes covering that material, are the underlying principles of the effect. Varying the degree of deformations and, hence, the density of a sound insulation material, enables a variation of the degree of sound suppression, and the frequency band, which allows the creation of active and adaptive systems for sound insulation, alongside the passive ones.

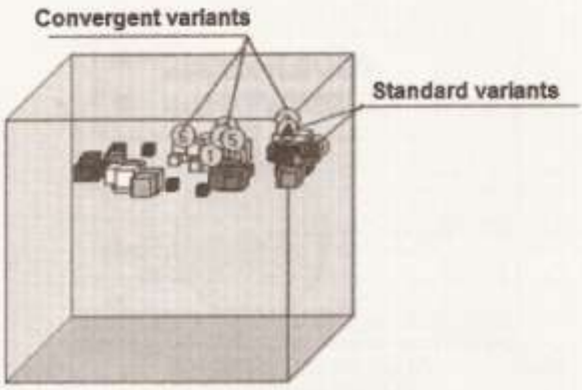


**Fig 10. The morphological space of solutions**

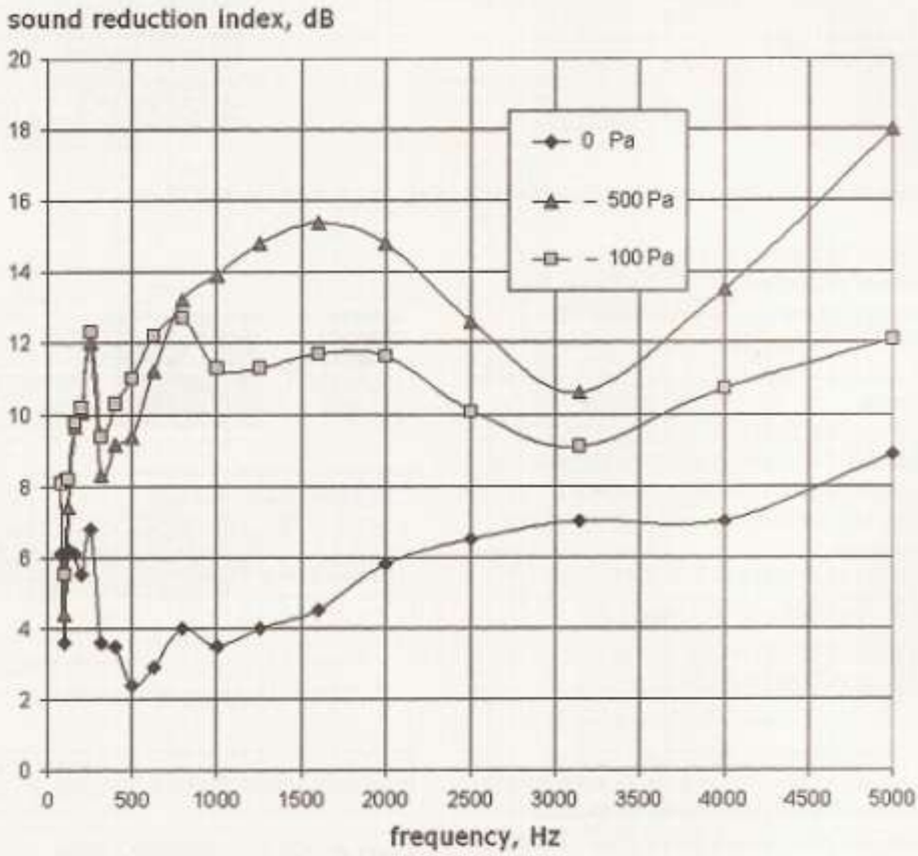


**Fig. 11. Sound reduction index of foamed polyurethane under low-pressure (30-mm rough porous foams: density 35 $kg/m^3$)**

It is traditionally considered, that it is basically impossible to get good soundproofing of air noise by thin porous materials. According to [11], "*. . . Foams are not good at insulation. The degree of insulation depends on the mass law. This law means the heavier the material the better it insulates. Thus the lightweight modern building, is good for*

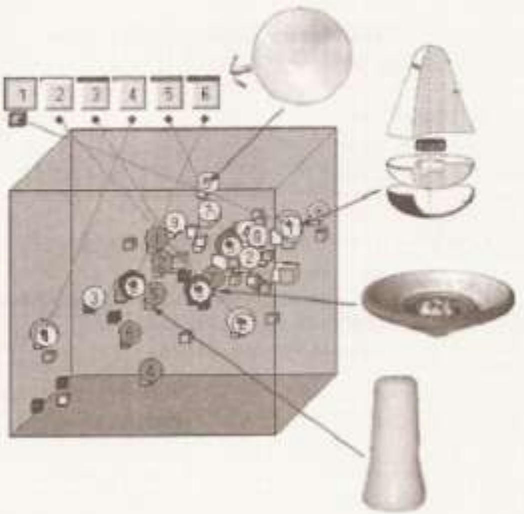

**Fig. 12. 3-dimensional classification field of RV**

## STRUCTURAL SYNTHESIS OF THE PROSPECTIVE SUPERLIGHT RE-ENTRY VEHICLES

The research method for re-entry vehicles (RV) is based on the theory of system, morphological, and cluster analysis, methods of mathematical simulation, and calculation experiments using the computer. The specifics of the structural synthesis analysis is the discrete character of variables and the presence of conditional and logical limits. The algorithm of design calculation for the sequence of calculation operations for finding the criterion is shown as the end function. This function does not satisfy the main requirements of theoretical optimization methods as it is discrete, it cannot always be calculated; it exists in the statement representation; it is *not* differentiable, *not* unimodal, *not* separable, and *not* additive. The other characteristic feature is that it is impossible to simulate analytically the hypersurface of the end functions and to prognosticate this change on each step of the variable increase. Instead of step-by-step movement in the attribute space, the method proposes zone examination with the help of clusters.

All of the variants are analyzed according to the degree of similarity. According to the results, a set of pre-optimal clusters is formed (Figure 12). For each cluster the level is calculated. The research fields included now becomes pre-optimal clusters (variants). The best variants are included in the final table where it is possible to evaluate the novelty of the synthesized variants. The evaluation is based upon the concept of the degree of similarity. At the end, the methodology involves a design of structural ES schemes ("white boxes"). They consist of element models and structural models. The procedure was used to solve the problem of searching for the new construction and arranging schemes of the RV. The modification of the focal object method and inverse approach were used to form the initial set of elements [12].

## CONCLUSIONS

Structural synthesis is a powerful means of research in various fields of knowledge. The offered procedure of the synthesis ES is a development of morphological methods and can be applied to solve the problems of Level 2 of optimization and partly to solve the problems of the first level. The method allows:

- Effective generation of the morphological array and, by means of a measure of similarity, to carry out the clusterization and to choose the best alternatives.
- Solutions of the inverse problems and to carry out the search of more effective engineering solutions by the given variant.

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