# The Method of Triads in the Aircraft Design

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**Abstract.** The article describes the features of the triad method application at the initial stages of aircraft design for the selection of fundamental decisions in aircraft design. The possibility of using the triad method to determine the initial appearance at the stage of conceptual design is analyzed. A brief overview and features of the conceptual design are given in this article. We are considering the general application algorithm and the basic concepts of the triad method. There are examples of the triad method used for the airfoil, aerodynamic design, and the selection of landing gear type. The formulated main postulates which allowed you to transfer this experience to the design of engineering products.

**Keywords:** Method of triads · Design · Minimal context method · Aviation technology · Conceptual design · Development of technical specifications · Airfoils · Aerodynamic configuration · Wing position · Landing gear

## 1 Introduction

**Formulation of the Problem.** In the entire lengthy process of creating an aviation technology, from the conception to the serial production start and operation start, design is worth highlighting. This is a complex process that requires huge amounts of computation. The new technical systems design is one of the most complex types of engineering creative activity.

The stage preceding the direct design of the requirements development for aviation technology, which carries out jointly by the customer and the development design office. This stage is called external or conceptual design.

A new aircraft design begins with the concept development – the general concept of its creation. The concept determines in what ways and means, what parameters will ensure the high efficiency and competitiveness of the designed aircraft, his superiority compared to aircraft in operation or development [1].

At this stage, based on parametric studies of promising aviation techniques, analysis of their interaction with the components of the complex in which they will operate, the required general characteristics of the future aircraft are forecasted.

At the same time, multi-variate calculations are carried out to determine and optimize the feasibility indicators of the operation of the proposed aircraft on the intended network of air routes. The necessary technical, economic and tactical, and technical characteristics of the aircraft are determined, allowing to formulate the requirements for its design, as a result of this work. It should be noted the reasonable task of requirements largely determines the success of the program of creating a new aircraft.


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**Analysis of Recent Research and Publications.** The main feature of the study an issue is the absence of publications directly related to the study subject, and the existing publications are out of date and indirectly related to the issue:

- publications related to conceptual design – focus on preliminary design, in fact [1, 2];
- publications on the method of triads focus on issues of its use in psychology and only consider [3] its use in design;

**The Aim of the Study.** The main feature of conceptual design is the need to make many decisions when it's insufficient or, conversely, excessive information. This publication outlines the way the triad method is used in the conceptual design of aviation equipment, which has not been used in this field before. Use will potentially help to shape the appearance of aircraft more in line with customer expectations.

## 2 Method of Triads

*The method of triads* is a design technique that allows you to identify the features of the research object based on comparison.

The method of triads is a powerful technique that effectively manifests itself in the initial stages of design, with which you can identify the concepts underlying the projected object.

George Kelly was the first to propose this technique. The basics of this method are described in his book "Theories of Personal Constructs". However, these and subsequent publications consider the use of the triad method in psychological studies, and only at later works are it considered the possibility of its application for engineering and design.

Initially, the method was considered within the framework of the method of repertory lattice.

The repertory grid technique was designed specifically to identify the individual categorical structure of the personality, to minimize the bias and any impact of the researcher on the respondent during the interview.

The minimal context method or triad method is most often used to identify constructs.

*The construct* is a speculative construction introduced hypothetically (theoretical) or created about observable events or objects (empirical) according to the rules of logic with well-defined boundaries and precisely expressed in a particular language [4].

According to George Kelly's Personal Constructs Theory, the people create subjective classifications – personal constructs to understand the world around us.

In general, the method of triads can be represented as an iterative sequence. (see Fig. 1).


**Fig. 1.** Three steps of the triad method.

**Step 1.** Items are presented in groups of three. This is the minimum number that allows us to determine the similarities and differences.

The groups are formed by some pre-selected list. With each of the elements, which the test subject should be familiar in advance.

**Step 2.** The test subject was imposed three elements from the entire list and proposed to name some important quality by the two of them are similar and therefore different from the third.

**Step 3.** The test subject is asked to name what exactly is the difference between the third element and the other two after the experimenter writes down the answer (if the test subject doesn't indicate which two elements have been assessed as similar to each other, he's asked to do so). The answer to this question is the opposite pole of the construct.

**Repetition.** The test subject is presented with as many triads of elements as the experimenter sees fit. There are no specific rules. It all depends on the size of the sample, which is the number of constructs to be investigated.

**An example.** There is a list of fruit names. "The apple-pear-orange" triad is taken. The respondent identifies two similar objects — "the apple and pear"; similarity quality — "the lack of an allergic reaction in the respondent", the difference between the third object is "allergic". So identified personality construct "allergy/lack thereof".

At the beginning of the triad study, a researcher or respondent selects six to ten specific related brands, products or services from a particular area. These examples of research incentives should be of a certain variety. Ideally, the respondents will be introduced to each of them before the session, because the purpose of the study is to identify what is important and meaningful to the respondent.

The researcher asks the respondent to select three examples (triad) for discussion, after identifying six to 10 examples/incentives from a particular area, and then invites him to explain how, according to his feelings; two of them differ from the third. This process can be repeated repeatedly, each time concentrating on a new triad to identify as many mental structures available to the respondent related to this area, if it's necessary

When many respondents participate in this study, we get a large amount of data in a specific area. As a rule, the constructs and their rating are different for different people.

The results of such a study are often surprising and noncorrelative and suggest that they may not have come to this study before the study.

At first glance, the triad study procedure may seem too simple, but it's actually about building an interview, which allows revealing deep-rooted opinions and perceptions, requires researchers to work very seriously and scrupulously.

The method of triads can be successfully used to analyze competitors and their products, as well as to compare different interface design options.

The method of triads, as a whole, is a powerful interviewing technique that helps researchers and designers understand how personal constructs relate to specific products and services.

## 3 Applying the Method of Triads in Conceptual Design

The object image or its constituent parts can create in a person's imagination as a result of the creative process in the early stages of design. A significant help in this action is the use of a method, an approach that could simplify, normalize and introduce into some framework the process of creative search.

In the conceptual design, process decisions are made that determine the subsequent appearance of the aircraft. There is no place for specific numbers – they will be obtained later, there is an operation with qualitative characteristics – better/more/stronger…

The aircraft design usually begins with the choice of an airfoil (Fig. 2).

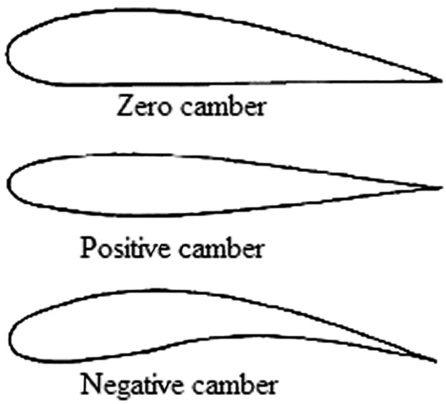


**Fig. 2.** Airfoils

Much depends on the profile shape; profiles have different maximum lift factor $C_{y\ max}$:

- for symmetrical (positive camber), the wing lift force coefficient is 1.2 to 1.4;
- ordinary asymmetrical with a convex lower surface (zero camber) – till 1.8;

– with a strong concavity of the lower surface (negative camber), it sometimes reaches 2.

However, need to remember that profiles with very high $C_{y\ max}$ usually have high $C_x$ и $m_z$ is pitching-moment coefficient. The aircraft with this profile, the tail plumage must develop greater strength to balance. As a result, its aerodynamic resistance is increasing, and the overall gain from the high-carrier profile is significantly reduced.

The following Table 1 gives a triad of an airfoil comparison. The arrow up shows the increase in the parameter, and down, respectively, a decrease.

**Table 1.** Triad of an airfoil comparison.

| | Symmetrical wing | Asymmetric profile with convex bottom surface | Asymmetric profile with strong concavity of the lower surface |
|---|---|---|---|
| $C_{y\ max}$ | ↓ | ↑ | ↑ |
| $C_x$ | ↓ | ↑ | ↑ |
| $m_z$ | ↓ | ↑ | ↑ |

In this table:

$C_{y\ max}$ – maximum lift force coefficient;
$C_x$ – drag coefficient;
$m_z$ – longitudinal moment or pitching moment.

Also undoubtedly important is the choice of the location of the tail (aerodynamic configuration):

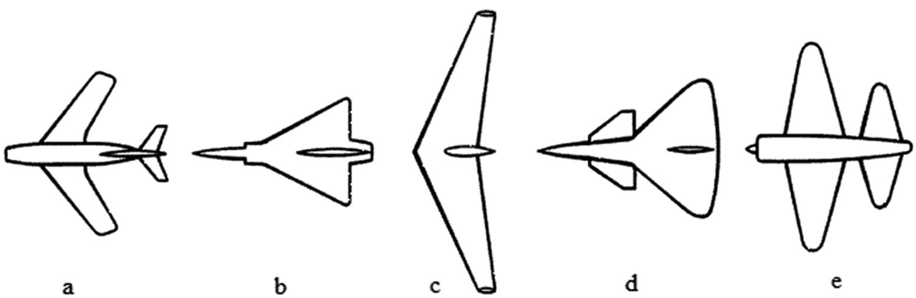


**Fig. 3.** Aerodynamic Configuration.

– Aft-Tail Configuration (Tail Plumage, see Fig. 3a);
– Tailless Aircraft (see Fig. 3b).
– Flying Wing (see Fig. 3c);
– «Canard» (Front Plumage, see Fig. 3d);
– Tandem-Seat Configuration (see Fig. 3e)

The normal aerodynamic scheme of the aircraft is characterized by the arrangement of horizontal plumage behind the wing. The wing is covered with an unperturbed stream. The plumage is in the worst conditions, but provides good longitudinal stability of the aircraft and control it.

In aircraft of the “Canard” type, the horizontal tail is located in front of the aircraft and is the bearing, which allows to reduce the wing area and weight of the aircraft (but makes horizontal tail more loaded). The front location of the horizontal tail increases its effectiveness (but worsens its road stability), which reduces the required angles of surface deviation and resistance when balancing an aircraft. The bearing horizontal tail radically changes the structural strength of the structure. In this case, the fuselage in flight “rests” on the wing and plumage; as a result of the loading and strength of it have the best performance.

The “Tailless” aircraft has a smaller mass and frontal resistance but requires measures to ensure the necessary in-flight stability of controllability.

As you can see, such a text isn’t very convenient for perception. The presentation of this information in the table according to the triad method will be much more visual. Let’s summarize the data on aerodynamic circuits for their comparison by the triad method in the Table 2.

**Table 2.** Comparison of aerodynamic circuits by method of triads.

| | Aft-tail configuration | Tailless aircraft | «Canard» |
|---|---|---|---|
| $S_{wing}$ | ↑ | ↑ | ↓ |
| $C_x$ | ↑ | ↓ | ↓ |
| m | ↑ | ↓ | ↓ |
| Pitching effectiveness | ↑ | ↓ | ↓ |

In this table:

$S_{wing}$ – wing area;
m – aircraft mass.

As much as important is the choice of the wing position.

Monoplanes are divided by wing height relative to the fuselage into the following types:

- Low-winged Aircraft;
- Mid-winged Aircraft;
- High-winged Aircraft;
- Parasol wing Aircraft (the wing is located above the fuselage).

The construction of the parasol wing aircraft isn’t widespread due to the low aerodynamic characteristics, therefore, we consider the first three according to the triad method (Fig. 4).

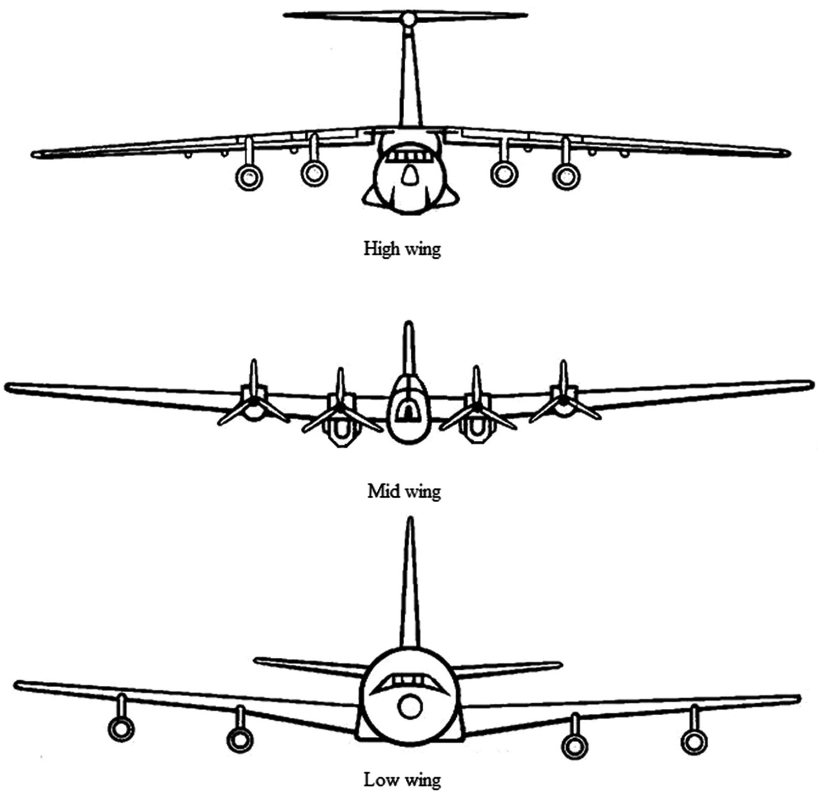


**Fig. 4.** Wing position

Let's considering their features by the triad method (Table 3).

**Table 3.** Comparison of wing position by method of triads.

| | Low wing | Mid wing | Shoulder wing |
|---|---|---|---|
| The speed and simplicity of a loading/unloading aircraft | ↓ | ↓ | ↑ |
| The runway requirements | ↑ | ↑ | ↓ |
| The simplicity access to engines and wing | ↑ | ↑ | ↓ |
| The fuselage protection | ↑ | ↓ | ↓ |
| The fuselage free space | ↑ | ↓ | ↑ |
| The simplicity of the wing/body intersection | ↓ | ↑ | ↓ |
| The wing-body interference | ↑ | ↓ | – |
| The dihedral (lateral stability) stability | ↓ | – | ↑- |
| The landing gear length | ↓ | – | ↑ |

We deliberately allowed deviations from the rules of the triad method in the last two compared qualities, whereby we will highlight only signs common for two of the three compared. This suggests that you need to allow such a departure or to discard characteristics, which don't fit this rule.

The chassis configuration extremely conveniently fits into consideration using the triad method.

The aircraft landing gear layouts divide into three main types depending on the main supports location and auxiliary supports location relative to the aircraft center of gravity (Fig. 5):

– Tailwheel-Type Landing Gear;
– Tricycle-Type Landing Gear;
– Bicycle Landing Gear.

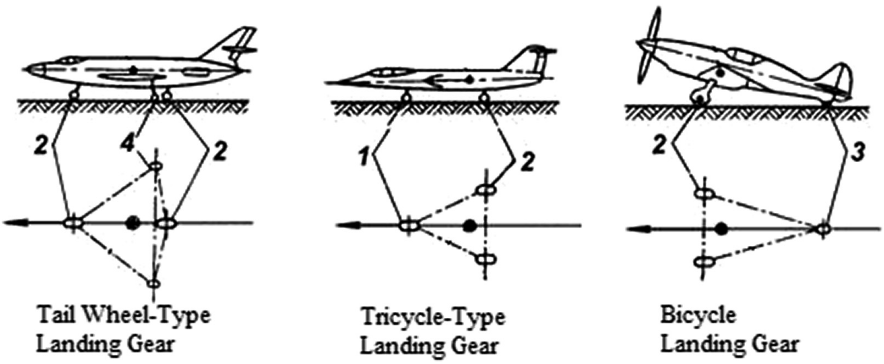


**Fig. 5.** Landing Gear: 1 – Nose Landing Gear; 2 – Main Landing Gear; 3 – Tail Landing Gear; 4 – Outrigger Undercarriage; Black Spot – Center of Gravity.

Let's summarize the data on Landing Gear for their comparison by the triad method in the Table 4.

**Table 4.** Comparison of Landing Gear by method of triads.

| | Tailwheel-type landing gear | Tricycle-type landing gear | Bicycle landing gear |
|---|---|---|---|
| The pilot skill requirements | ↑ | ↓ | ↑ |
| The chassis rack breakage risk | ↓ | ↑ | ↓ |
| The aerodynamic characteristics of aircraft | ↑ | ↓ | ↑ |
| The cockpit view | ↓ | ↑ | |

## 4 Level Detection of the Designer Competencies

The conceptual and sketch design processes are the most important stages of aircraft development, which at a maximum cost from 20% to 25% of the time of all work and as many as 5% to 10% of funds accept from 75% to 80% of the key project decisions (technical and organizational).

The fate of the project often depends on how correct decisions are made in the early stages, and not only because mistakes made in the early stages of project development lead to too much cost and time for its completion in the process of detailed design and construction, but and because the possibility of project implementation may even depend on them.

As seen, the conceptual design phase is one of the most important stages. Therefore, all decisions are so important at this stage.

Accordingly, there are increased requirements for the designer employed at this stage. He has to be an expert in his field. A team of experts should be used to reduce subjectivity.

There are different approaches to selecting the number of experts (m). The source [5] states that the number of experts should be no less than the number of alternatives (n), which are subject to ranking (m $\geq$ n). According to the sources [6, 7], the number of experts is recommended to be determined by the following formula:

$$m \geq 0,5\left(\frac{0,33}{b} + 5\right),$$

where $b$ – the level of the permissible error of the result of expert analysis, usually b from 0 to 0.1.

In general, there are recommendations to include from 6 to 15 (from 7 to 20 [8]) people in the expert group.

It's also important to determine their quality in addition to determining the number of experts. The following methods of the performance indices of experts are the highlights: a heuristic, a statistical, a test, a documentary and a combine. The heuristic evaluation methods are based on the idea that has developed about this expert in others (or himself), and correctly reflecting its true quality.

Many expert assessment methods now propose as an indicator of expert competence (C):

$$C_i = \frac{Cn_i + ar_i}{2},$$

where $Cn_i$ – the coefficient of the level of familiarity of the expert with the discussed problem; the expert himself assesses the level of his familiarity with the issue;

$Cn_i =$
- 0 – the expert isn't familiar with the question;
- 0.1..0.3 – the expert is new to the question, but the question falls within the scope of his interests;
- 0.4..0.6 – the expert is satisfactorily familiar with the issue, doesn't directly participate in the practical solution of the issue;
- 0.7..0.9 – the expert is well acquainted with the issue, participates in the practical solution of the issue;
- 1 – the question is within the expert's narrow specialization.

$ar_i$ – the argumentation coefficient, which takes into account the structure of the arguments that served as the basis for the expert for a certain assessment, is determined by Table 5 by summing up the values selected by the expert.

**Table 5.** The values of the argumentation coefficient

| Sources of argument | The influence quantity of the source of the argument on the expert opinion | | |
|---|---|---|---|
| | High | Medium | Lower |
| Theoretical analysis | 0.3 | 0.2 | 0.1 |
| Production experience | 0.5 | 0.4 | 0.2 |
| Generalizations of works by domestic authors | 0.05 | 0.05 | 0.05 |
| Generalizations of works by foreign authors | 0.05 | 0.05 | 0.05 |
| Personal acquaintance with the state of affairs abroad | 0.05 | 0.05 | 0.05 |

The coefficient of consistency or competency (CC) of the expert group is calculated according to the source [5] according to the following formula:

$$CC = \sum_{i=1}^{m} C_i,$$

where $C_i$ – the competency coefficient of the i-th expert.

The working group of experts formed is competent and able to correctly solve the tasks set before it, if the level of its competence meets the following condition [9]:

$$0,67 \leq CC \leq 1.$$

The issues of determining the number of experts and assessing their competence consider in more detail in the source [10]. A sufficient level of the competency coefficient allows us to confirm the reliability of decisions made by experts.

## 5 Conclusions

Certainly, the triad method isn't without drawbacks.

Firstly, it is the subjectivity of the results obtained - they are based on the experience of the designer and reflect only his point of view. The use of experience, relying on opinion, and not on accurate scientific results, leads to the fact that we can get incorrect results, distorted through the prism of perception of the designer.

Secondly, obviously, to achieve more accurate results, a corresponding extremely high degree of competence of the designer will be required. A deep understanding of all aspects of aircraft engineering design, a vision of the general concept, design experience supported by practice, and an understanding of the interconnectedness of various design decisions are needed.

Thirdly, the considered example of the application of the triad method in conceptual design doesn't take into account the mutual influence of one or another constructive solution on each other. But even a slight change in the appearance of the aircraft, for example, can radically change the flow pattern of an aircraft.

Fourth, the failure to use this method for the subsequent design stages is obvious due to its specificity.

However, despite these shortcomings, the triad method is quite applicable for the conceptual design of both aviation equipment and complex engineering products.

The subjectivity of the result can be reduced using the knowledge of several design experts. The final result can be obtained in several ways, for example, using the "Kemeny median".

The issues of the design competency definition, as well as a group of design experts, discusses in Sect. 4 of this article.

As for taking into account the mutual influence of constructive decisions on each other, at this development stage, this method doesn't take this into account and relies only on the designer experience and knowledge. However, it's quite possible to improve this method, using decision theory achievements in the field of solving multicriteria problems. The fundamental inapplicability of the stages method at other than conceptual design doesn't reduce the significance at the initial stage of design.

Moreover, in addition to the already described method of applying this method for the aircraft design, it's also possible to use the developments of this method in other development-related processes. This method can help to simplify (providing) the process of determining the main structural solutions for a customer who doesn't have sufficient knowledge in the aviation field. So, for example, in the design bureau engaged in the development of unmanned aerial vehicles, an order comes to create an original model with a look that must be approved by the customer. The application of the triad method, in this case, will allow you to quickly and effectively determine the preferences of the customer.

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