The Ministry of Education and Science of the Russian Federation
Samara State Aerospace University
(National Research University)

CONCEPTUAL AIRCRAFT DESIGN

Term Project Guideline

SAMARA
2011

УДК 629. 7. 001 (075)

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Conceptual Aircraft Design = Концептуальное проектирование самолетов [Electronic resource]: Term Project Guideline / The Ministry of Education and Science of the Russian Federation, Samara State Aerospace University; Compiler D.M. Kozlov. - Electronic text (58 kb). - Samara, 2011. - 1 CD-ROM.

Goals, tasks, contents and stages of the term project execution, requirements for the term project of the discipline "Conceptual aircraft design" are considered for students of the specialty 160100 “Airplane construction” and for the Masters programme «Designing, construction and CALS-technologies in Aeronautical Engineering» for education direction 160100.68 «Aeronautical Engineering». . It is also useful for students of the specialty 160100 “Airplane construction”, 160900 “Technical maintenance of aircrafts and engines”, 160201 “Airplane and helicopter construction”.

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CONTENTS

1 THE GOALS AND TASKS OF THE TERM PROJECT. THE PROJECT CONTENT, VOLUME AND SUBJECTS

The term project "Conceptual airplane design" is carried out according to curriculum for MSc of the specialty 160100 "Aircraft construction" and Msc program "The airframe design and CALS-technologies" developed and implemented in SSAU. The term project complements the theoretical course (module) of the same name and is carried out in parallel with studying this course in the third semester of the MSc educational program.

The MSc curriculum and content of the module "Conceptual airplane design" are developed for students who have already finished their study at Bachelor basic educational program of the specialty 160100 or related programs. The discipline (module) is a part of the professional MSc curriculum, and it is obligatory for all students of this MSc program. Students who have their own individual curriculum can be exceptions. The discipline (module), "Conceptual airplane design " along with the discipline "Airframe design" takes a key place in the MSc program. On the one hand, it completes the basic engineering training of a Master; on the other hand, it provides the basis of goal-setting in the study of subjects chosen by students.

The main goals of the term project are:

- consolidate, expand and deepen the knowledge of conceptual airplane design theoretical foundations and gain a better understanding of the relationships between the main aircraft parameters and characteristics;
- develop the skills of complex (system) approach for solving design problems;
- Develop the skills of processing and analyzing large volumes of diverse information, and creating the technical documentation using the up-to-date information technologies.

During the execution and defense of the term project students obtain the task-oriented training in solving the following design problems, which are defined by GES and are relevant to the specialty:

- preparation of requirements for design;
- conceptual design of complex aeronautical systems;
- development of draft, technical and final projects of the aircraft using information technologies and CAD/CAE systems, state-of-the-art experience of development of competitive products;
- development of methodology and governing documents, technical documentation, implementation proposals and activities for the developed projects and programs;
- description of operational principles and arrangement of the designed aircraft with justification of decisions.

The task of the term project is to develop an airplane draft project according to the design task. The airplane should meet its purpose and have the characteristics that would ensure higher efficiency then of the existing and developing airplanes.

The term project plays an important role in preparing masters for carrying out their graduate qualification works. It may have a research focus and be an integral part of the scientific and research master's work.

The project content includes executing operations that realize the main stages of developing the technical offer (pilot project) and some operations of developing the draft project according to the task requirements in terms of the educational process. The term project topics include civil and military aircrafts of various applications: passenger, cargo (military transport), training (military or civil), light multipurpose (general aviation), administrative, fighter-interceptor, fighter-bombers, attack aircraft and etc.

The term project contains the explanatory note and the graphical part.

The explanatory note is made using word processor and is printed out on paper. It includes all necessary justifications, calculations and graphical illustrations (diagrams, sketches and etc.).

The project graphical part consists of following drawings:

1) a three-projection drawing of an airplane general view that is made on standard-sized paper and contains a list of the main airplane technical characteristics;

2) the airplane layout drawing;

3) the airplane balance drawing.

The project graphical part is carried out by using CAD systems, for example, «Компас».

All term project materials should be prepared according to the requirements of the Unified system for design documentation (USDD) and requirements of the SSAU Organization Standard (OST) "Requirements for the text document preparation".

The overall complexity of the term project is 84 hours (2.33 credits), including 27 hours of classes (including the project presentation) and 57 hours of the student non-scheduled work. The term project presentation lasts one day and supposes the presentations of all students. The term project presentation date is set up by the department under the agreement of the faculty dean. Students should know the date no later than two weeks before the presentation.

The students receive the initial data for the term project from the individual tasks for the development of the airplane project. The task includes the aircraft type and purpose and its main performance data.

Conceptual airplane design supposes searching, analyzing and processing large volume of diverse information and making a number of the design decisions. Most of them play an important role and to the utmost (comparing with the decisions made at the subsequent stages of airplane design and life cycle) determine the future aircraft efficiency and the success of the whole project.

2 THE ORDER OF EXECUTING OF THE TERM PROJECT

The term project complements the student training, started by the theoretical course, the general content of which is included in the textbook [1] and in the manual [2]. The term project is carried out with using state-of-the-art technologies of conceptual airplane design, which are described in the books [3, 4, 5], and takes into account the current state of the aviation and its impact on scientific and technical progress in aviation and related areas [6, 7, 8].

The term project execution order consists of the interconnected and subsequent stages that are listed in the Table 1.

The Table 1 – The stages and terms of executing the term project

№ stage	The stage content	Hours		The term of execution (week)
		Class work	Non-scheduled work	
1	Analyzing the task. Developing the airplane design concept.	4	8	1,2,3
2	Developing the performance requirements	2	4	4
3	Choosing the airplane scheme	4	8	5,6,7
4	Defining the required start thrust-to-weight ratio of the airplane	2	4	7,8
5	Defining the airplane take-off mass	2	4	9,10
6	Defining the main parameters of the airplane	2	4	10,11
7	The airplane weight calculation	2	4	11-12
8	The airplane layout	4	13	13,14,15,1

				6
9	The airplane balance (COG location)	2	4	17
10	Developing the general view drawing and the technical description of the airplane	2	4	18
11	The term project presentation	1		18
		27	57	
	Total	84		

2.1 Analyzing the task. Developing the airplane design concept

Designing a new airplane begins with developing the concept - the general idea of airplane creation [2]. In the referenced manual the tasks, content and technology of developing the future aircraft concept are considered in details. Students should thoroughly study Section 1 and follow the given order while executing the term project.

The first stage of developing the airplane concept in the term design project is gaining the statistics of the aircrafts that have similar operational and technical characteristics to yours. Such airplanes are usually called as prototype airplane. The information about the prototype airplanes is used to analyze and forecast changes in external parameters and characteristics of the aircraft with time. The table of prototype airplanes data is made up according to the form given in the Appendix A of the textbook [2]. Along with forecasting parameter values using the trend functions, the analysis of the project situation is carried out according to the subsection 1.2 of the textbook [2] using the references recommended in the manual and aviation sites, and also the monographs [3, 4, 6, 7]. The table should include at least 5-6 prototypes. The last column is for the designed airplane data. It will be filled in as you execute the term project. The table of statistics includes the most

up-to-date and successful aircrafts. The statistics allow you to get the idea about the existing technical level of the considered type of airplanes.

Forecast of changes for two or three main characteristics of the design airplane is made in the term project. According to [2] for this task the special table is made up that consists of only the values of forecasted parameters for the large number of aircraft, including the aircraft created in different periods of time (different generations). The list of the forecasted parameters and the form of the data table is agreed with the project supervisor. Dynamic and/or static diagrams (according to recommendations of the supervisor) for retro series of prototype parameter are plotted; their trend functions and forecasted values. In the manual [2] the table of statistics is presented in general terms and applied to the airplanes of different types. The unnecessary and unimportant parameters should be excluded from this table (for example, weapons for civil airplanes).

Analysis of the current technological level and the results of forecast of the main characteristic values allow us to formulate the concept (the general idea) of the design airplane. The more detailed and formalized description of this concept will be presented in the list of the airplane performance requirements. The explanatory note provides a brief description of the concept according to the subsection 1.2 of the textbook [2].

2.2 Developing the performance requirements for the design airplane

The performance requirements (PR) of the design airplane define the main purposes of its creation and the tasks of the airplane and set up the required (expected) values of its main parameters and characteristics, the conditions for its production and maintenance. The initial data of developing PR is the contents of design task, results of the design situation analysis and the design airplane concept.

The set of PR is developed according to Section 2 of the manual [2]. First, the list of the qualitative requirements is made up; with the help of project supervisor the most important of them are selected for ranking (usually no more

than 10 requirements), then ranking is done by the method of paired comparisons. The chosen main requirements and their quantitative characteristics should be well justified. The final list of the main requirements and their quantitative characteristics is placed in the end of the section.

Developing the set of PR is the important stage of the airplane design, as it determines the future aircraft efficiency. Therefore, it is important to develop the PR set as thoroughly as possible and with the accurate justifications. All decisions made in the following project stages will be aimed at satisfying the PR set.

2.3 Choosing the airplane scheme

The airplane scheme defines the number, shape and relative position of its main units - wing, empennage, fuselage, landing gear, engines (and their air intakes). The main problem solved while choosing the aircraft scheme is that the chosen scheme should satisfy the PR set in the best way, provide the minimum take-off and airframe weights, high aerodynamic efficiency and maximum effectiveness of the aircraft.

The work content and the general principles of decision-making for justification of the scheme parameters are given in Section 3 of the manual [2]. Under the agreement with project supervisor the justification for two or three of the most important scheme parameters is made using the trend functions. Other scheme parameters are selected according to the method described in the subsection 3.2 of the manual [2]. The initial parameters of the aircraft and power plant are defined (the subsection 3.3 of the manual [2]).

The three-view general drawing made with CAD system and the list of the main aircraft and engine parameters are given in the end of the project subsection (see the subsection 3.3 of the manual [2]).

2.4 Defining the required start thrust-to-weight ratio of the airplane

The start thrust-to-weight ratio is the dimensionless value calculated as the ratio of the total static thrust P_0 to the take-off weight of the aircraft. The thrust-to-weight ratio determines the main aircraft performance characteristics that depend on the power plant performance. In the textbook [1] the start thrust-to-weight ratio $\bar{P}_0$ along with the specific wing load p_0 (daN/m^2) are called "the aircraft starting parameters", because these two parameters together influence on the aircraft performance characteristics: ranges of altitudes and flight velocities, maneuverability, take-off and landing characteristics and etc. In Section 4 of the manual [2] you can find the lists of flight mode conditions that are essential for selecting the required start thrust-to-weight ratio. The value of this ratio should be chosen as to fulfill the requirements defined in the PR. Also there are formulas for determining the required start thrust-to-weight ratio for the main flight modes of the aircraft with gas turbo-jet engines.

For aircraft with turbo-prop engines and piston engines or similar engine types (turbo-fan engines, rotary engines and etc.) the start power-to-weight ratio $\bar{N}_0=10N_0/m_0g$ (kW/daN) is defined instead of the start thrust-to-weight ratio $\bar{P}_0$. N_0 is the total engine power at start. For clarity, it should be noted that the value N_{e0} (the effective starting power) is usually given for turbo-prop engines. It consists of the propeller shaft power and the exhaust jet power. This jet creates the significant "aid" to the propeller thrust, and its influence should be considered in calculating the airplane performance characteristics. In Section 4 of the manual [2] the formulas for determining the required start power-to-weight ratio of the airplanes with turbo-prop and piston engines are given.

In the term project you should choose 3-4 main flight solutions for the design airplane taking into account the ranked PR, and calculate the required values for $\bar{P}_0$ or $\bar{N}_0$ according to the method described in Section 4 of the manual [2].

2.5 Defining the airplane take-off mass

This task is the most important in the airplane design. Its idea is to fulfill the full set of PR with the minimum take-off mass m_0, because the unnecessary overweight always reduces the airplane efficiency and competitiveness. In the design practice the aircraft take-off mass is determined iteratively with gradual increase of the accuracy for its value as the project develops. In this term project the take-off mass of the design airplane is also determined in several iterations. The airplane existence equation is used for defining the airplane take-off mass [9]. The process of determining the airplane take-off mass is described in the manual [2] (Section 5). The value of the design aircraft take-off mass is determined in the following order:

1) Defining the payload and crew weights according to the subsections 5.2 and 5.3;

2) Finding a probable value of the airplane take-off mass (it is also called the zeroth approximation take-off mass) m'_0 according to the subsection 5.1; according to the recommendations from the manual the relative masses for different components (airframe, power plant, fuel system, equipment and control systems) are chosen using the statistics given in the textbook [1], p.130, the table 6.1.

3) According to the subsections 5.4 - 5.7 the relative masses of airframe, power plant, fuel system, equipment and control system are determined.

4) According to the subsection 5.8 the first approximation of take-off mass is calculated.

2.6 Defining the main airplane parameters

The calculated value of the airplane take-off mass together with the relative parameters of the airplane scheme, the specific wing load, the start thrust-to-weight ratio and the values of the relative masses of the components allow to obtain the

main airplane geometric, mass and other parameters. The content of the work and the order of defining the absolute airplane parameters are considered in detail in Section 6 of the manual [2]. The term project works are executed according to this manual.

According to the calculated absolute aircraft dimensions a preliminary three-view general drawing of the airplane is made, with the list of all of its main dimensions. The drawing is made with CAD systems and printed out on A3 or A2 paper. The three views should be the left side view; the plan view (view from above) below it; the front view to the right of it. The plan view and the front view can show only the part of the starboard side. The final dimensions and the general drawing of the aircraft will be revisited in the subsequent stages of the project while defining the aircraft layout and balance.

2.7 The airplane weight estimate

The absolute geometric dimensions and specified parameters and characteristics allow defining more exactly the airplane take-off mass by calculating the values of the main units and systems masses. In fact, at this stage three interconnected problems are solved: specifying the aircraft take-off mass – defining its second approximation; minimizing the take-off mass; making the weight summary. The content and procedure for calculating the airplane weight are considered in Section 7 of the manual [2]. The statistical formulas contained in references from [2] are used. Taking into account the method of multiple calculations [2] it is recommended to use at least three different formulas for each unit and not to exclude the extreme results while determining the unit weight.

The weight estimate is carried out by using the statistical formulas and gives rather accurate results while designing the aircraft that similar to the prototypes in scheme, operating conditions, construction materials, production technology, equipment and etc. i.e. the design airplane belongs to the same generation as the prototypes. While designing the aircraft that differs significantly from the

prototypes (by the external shapes (scheme) and/or the take-off mass) it is advisable to use a novel approach to estimating the weights of the units and the whole aircraft. It is based on the subsequent high-precision finite-element simulation of the airframe starting from the early design stages [10, 11]. This approach for calculating the airplane weight can be the basis for transforming the term project into the research project.

This term project section is finished by making the aircraft weight summary using the form of the Table 7.1 from the manual [2] and calculating values of the weight efficiency coefficients. These values are put in the table of statistics (along with the corresponding values for the prototype airplanes).

2.8 The airplane layout

The airplane layout is the most difficult and longest stage of the term project (see the Table 1). It consists of three interconnected types of work executed almost in parallel: space and weight layout, aerodynamic layout (specifying the airplane aerodynamic scheme); structural and load-carrying layout (developing the structural and load-carrying scheme).

The content of each layout is considered in Section 8 of the manual [2]. There are also references recommended: primarily the basic textbook [1] and the useful book [12]. The useful additional information for developing the airplane layouts can be found in [3, 4, 5, 6, 7, 8], as well as in descriptions of the certain airplanes selected from prototypes - and other airplanes that are similar to yours.

The result of developing the layout is the layout drawing. The main requirements for its content are given in the subsection 8.4 of the textbook [2]. The specific content of the layout drawing concerning quality and location of fuselage cross sections is agreed with the project supervisor. At least 5-6 cross sections of the fuselage are plotted at the drawing. You should pay attention to the rather detailed development of the aircraft load-carrying scheme, particularly in the areas

of unit joints and application of large concentrated forces (armament hardpoints, cargo strapping points and etc.), strengthening of the large cut-outs.

The layout drawing is made using CAD systems and printed out on paper of A1 size (or larger). The layout drawing may be changed later due to the results of calculation of aircraft balance. Therefore, the final layout drawing should be printed after balancing the aircraft.

2.9 The airplane balance

The aircraft balance is the process of defining the airplane center of gravity (COG) position relative to the wing mean aerodynamic chord (MAC) and providing the acceptable COG position for various airplane configurations. This acceptable range is expressed in terms of balance range. Section 9 of the textbook [2] provides recommendations for choosing the acceptable balance range for different aircraft and the initial (starting) balance values according to wing scheme parameters.

The airplane balance drawing and the list of balance values are made for calculating the airplane balance. The balance drawing requirements and the balance list form are given in the manual [2]. The list of required variants of calculating the balance values, methods for correcting the balance values, and guidelines for making the balance diagram are also given in this manual. In the term project the simplified balance diagram is plotted according to the method described in [1] (see the subsection 9.5 of [2]). It shows the change of COG position for the fully loaded aircraft during the flight for the design range. The initial point has balance coordinates m_0 and $\bar{X}_{m0}$ for extended landing gear and take-off mass. Then the balance changes due to landing gear retraction, in-flight fuel consumption, landing gear extension before landing (for the landing mass).

According to the results of the balance calculations the final versions of aerodynamic scheme, layout and dimensions of the airplane are specified.

The balance drawing is printed out on A2 or A3 paper. The balance diagram is plotted on the balance drawing with the corresponding title.

2.10 Developing the general drawing and technical specification of the airplane

The three-view general drawing of the airplane is made in full compliance with the current standards in the electronic form. The requirements for the drawing content and execution are given in Section 10 of the manual [2]. The project explanatory note contains the technical specification for the airplane. The brief technical specification of the aircraft is given in the subsection 10.2 of the textbook [2]. Good examples of technical specifications are provided in the books [13, 14]. For the term project the technical specification of the aircraft that includes the table of the main technical characteristics, consists of 3-4 pages.

3 THE TERM PROJECT PRESENTATION

The term project presentation is carried out according to the special schedule for each academic group of students. At the designated time all students make the presentation. The term project should contain the explanatory notes prepared according to the university's requirements, and the drawings: the general view of the airplane (1,5-2 A1 size paper sheets), the layout drawing (1.5-2 A1-size paper sheets), the balance position drawing with the balance diagram (one A2 or A3 size paper sheet). The explanatory notes and drawings should be signed by the project supervisor. The presentation is given for the committee that consists of at least two professors. The committee must include the term project supervisor. The students, executing the same project can attend the term project presentation of others. At the beginning of the presentation a student makes a brief (within 5-7 minutes) report about the contents of the executed project and then answers to questions from members of the committee. In addition to the student's drawings the project presentation may be complemented by computer presentations. The presentations may include only material contained in the explanatory notes. By permission of the committee other students can also ask questions. The committee assesses the term project results, the student's work during the semester, report and answers at the presentation. Marks for the term project will be declared after presentations of all students.

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