Influence of geometric constraints on aircraft design

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Abstract. The paper considers the requirements to helicopter operating conditions, forming geometrical constraints at the design stages and their influence on the geometrical appearance of the helicopter as a whole, structural design and layout of individual components and assemblies of helicopters. The methodology of forming the system of geometrical constraints is based on the generalised requirements to ensure the operational and technical characteristics of the helicopter: ensuring the basing and production of take-off and landing operations on marine vessels, ensuring transportability, ease of access to the cockpit, ease of access to the units during maintenance, reducing the labour intensity of individual helicopter maintenance operations. Key words: helicopter, aircraft development, design, geometric constraints, transportability, unit layout.

1 Introduction

The process of forming helicopter technical appearance in various design stages (GOST R 58849-2020 Civil aviation equipment. Creation procedure. Basic provisions) implies the analysis of a set of initial data: operating conditions, tasks to be performed, multifunctionality (including by changing the equipment of application variants), requirements of certain guidance documents, etc.

These factors have a significant impact on helicopter geometric shape, fuselage design, compartment sizes, door openings and hatches, as well as possible places for installation of removable (optional) equipment. The development of computer-aided design systems (CAD) allows to represent the influence of these factors in the form of limiting planes, the so-called system of geometric constraints (SGC). The formation of SGC at the early stages of design (preliminary and conceptual designs) allows considerably minimising the costs of reconfiguration of units and systems at the subsequent design stages [1].

2 Methodology for identifying geometric constraints

Geometric constraints can be divided into four categories: constant, parametric, conditionally variable, and borrowed. Let us consider each category of constraints in more detail.

a) Constant geometric constraints

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These constraints include required clearances between the helicopter structure and other structures, ergonomic requirements for required areas, volumes, etc., permissible transport dimensions (height of cargo on road and railway transport, dimensions of a certified sea container, etc.). Ergonomic requirements primarily affect the dimensions of the crew cabin, cargo (transport) cabin, dimensions of door and sash openings, etc. [2-4].

Allowable transport dimensions influence the fuselage design and systems layout, which allows at various stages of design to provide: reduction of labour intensity of dismantling/assembly of units when preparing the helicopter for transportation, to predict the necessity of application of technological devices and tare for dismantled units, etc. [5-6].

As an example, we will consider helicopter transportation by different types of transport. To ensure the required dimensions during transportation by different types of transport it is required to dismantle the rotor blades and gearbox with the rotor column. Some types of helicopter may also require the removal of the tail feather and/or tail beam. Determination at the early stages of design of the list of large units to be dismantled in the process of helicopter preparation for transport allows to reduce the preparation time due to installation of quick-release joints, and also to provide helicopter recovery after transporting "in the field" due to elimination of procedures requiring special technological conditions (for example, application of sealant) [7].

b) Parametric geometrical constraints

These restrictions include restrictions depending on the helicopter dimensional characteristics, for example - required dimensions of take-off and landing platforms (RWY) on offshore vessels and elevated platforms, depending on the helicopter length, in some cases - on the diameter of the rotor [8-9]. To a greater extent, this restriction concerns helicopters for the needs of state aviation, for which the required RWY dimensions depend on the diameter of the main rotor. It should be noted that in accordance with the current requirements, the required RWY dimensions for state aviation are smaller than for civil aviation. The increase in helicopter length while maintaining the diameter of the main rotor in the conditions of limited RWY areas in the conditions of rocking and wind significantly increase the requirements for simplicity and convenience of helicopter maintenance [10-11].

First of all, these constraints have a significant impact on the layout and design of doors and flaps of the helicopter transport (cargo) cabin when providing loading/unloading of cargoes of various types in conditions of limited space (GOST R ISO 15536-1-2010 Ergonomics. Computer mannequins and body models. Part 1. General requirements).

c) Conditionally variable geometrical restrictions

These constraints include constraints that depend on the characteristics of interrelated types of equipment and systems. For example, when ensuring the transportability of a helicopter by air transport it is required to take into account the dimensions of the cargo cabin and its aperture of a separate type of transport aircraft, ramp inclination angles, restrictions on the movement of loading telphers, dimensions and design features of towing means (including on sea vessels). At the same angles of cargo ramp inclination and different ranges of movement of electric telphers relative to the ramp, the type of transport aircraft with the smallest range of movement will be the most critical. Restrictions on the travel of the telphers require the location of the rear rigging units of the helicopter under the tail telpher, which in most cases requires lifting the nose of the transported helicopter and moving forward until the rear rigging unit is under the tail telpher. Then the tail part of the transported helicopter is lifted, the nose and tail telphers carry the transported helicopter into the cargo cabin of the transport aircraft. The peculiarities of loading the helicopter into the transport aircraft impose geometric restrictions on the nose tail part of the helicopter - ensuring the lifting and moving of the nose part of the helicopter in the vicinity of the aircraft ramp, as well as ensuring sufficient clearances between the ground and the tail part of the helicopter [12-13].

d) Borrowed geometric constraints

These restrictions include restrictions related to ensuring the operation of the helicopter under the conditions of serial helicopters operation - ensuring accommodation on take-off and landing sites, available hangars and on lifts of marine vessels of different designs, ensuring accommodation of transported cargoes or target equipment, as well as applied maintenance means (access means, lifting means, mounting and dismounting) similar to a helicopter of similar purpose. The borrowed geometrical limitations can also include the operating experience in terms of units and systems layout, frequency of inspection and maintenance works, as well as required sizes of hatches [14].

3 Results

Borrowed geometric constraints are in some way related to conditionally variable geometric constraints and have a cyclic character (see Fig. 1 "Relationship between borrowed and conditionally variable geometric constraints").

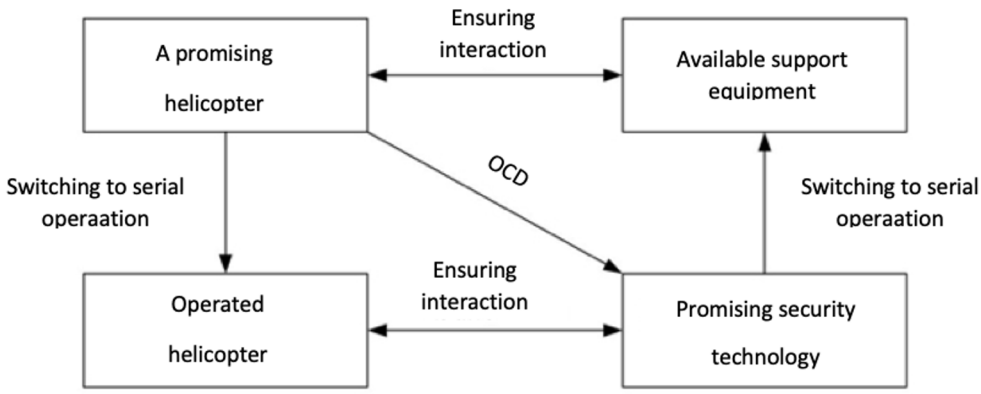

Fig. 1. Relationship between borrowed and conditionally variable geometric constraints

In this scheme, support equipment means equipment that provides maintenance (charging of systems with liquids and gases, power supply, ground diagnostics systems, etc.) and transport (in the cargo cabin of a transport aircraft, towing on the airfield, etc.) of the helicopter. In some cases, separate support equipment for a prospective helicopter may be developed within the framework of developmental work (R&D) for the helicopter or as a separate R&D project. Interaction in this scheme means the pairing of technical characteristics that ensure the fulfilment of specific tasks [15].

An example of coupling of borrowed and conditionally variable geometric constraints is observed in ensuring the placement of Ka helicopters in ship hangars. Depending on the ship design, hangar dimensions and their openings differ, but provide accommodation of helicopters in service. In the process of development of new types of helicopters, it is required to take into account the dimensions of hangars of ships and marine vessels in operation to ensure basing of newly developed helicopters.

The formed SGC taking into account the analysis of helicopter operating conditions, allows to form preliminary requirements to the maintenance system. In addition to the developing avionics, which provides for inbuilt control and diagnostics of electronic equipment systems, the SGC helps to identify helicopter zones requiring reduced frequency of maintenance work (including inspection work), introduction of systems for control and diagnostics of powerplant and control units and systems.

4 SGC formation result

SGC formation is multilevel in nature, requiring the analysis of various design solutions, reduced to the solution of direct and inverse problems. The main dimensional characteristics are determined by solving inverse problems - analyzing borrowed requirements, dimensions of take-off and landing sites, dimensions of transported cargo or number of transported passengers in the transport cabin), nomenclature and characteristics of optional equipment, etc. The obtained SGC requires further preliminary correction - establishment of required clearances taking into account ergonomic requirements, clearance changes (in the process of helicopter weight change from maximum take-off weight to empty weight due to fuel generation or by means of onboard pumping stations), specification of helicopter position on RWY, etc. The obtained results are refined taking into account the conditionally variable geometric constraints determined by the request for proposals of the helicopter [16].

SGC detailing and refinement is carried out at all stages of helicopter design, including the layout of systems and units. It is possible to use the "dummy" module (GOST R ISO 15536-1-2010 Ergonomics. Computer mannequins and body models. Part 1. General requirements), implemented in some CAD (NX, Catia, etc.) as one of the tools for forming detailed geometrical constraints. Application of the "dummy" module allows to optimize the size of hatches, to evaluate the convenience of access to compartments and serviced units at different positions of the human body at different stages of design.

The main disadvantage of using the "dummy" module (GOST R ISO 15536-1-2010 Ergonomics. Computer mannequins and body models. Part 1. General requirements) is the absence of:

- typical mannequin positions, adapted to the specifics of the aviation industry and typical operations on maintenance of aviation equipment units;
- natural restrictions on the rotation of body parts;
- the possibility of presenting the mannequin in winter or special uniforms;
- the possibility of using auxiliary equipment (e.g., headlamp).

These shortcomings of the module introduce significant errors in the process of design, modelling, ergonomic and operational evaluation on the electronic mock-up of aviation equipment [17-19].

The use of electronic dummy allows to develop the most rational technical solutions, which are further confirmed at the stage of prototyping and in the testing process [20].

5 Conclusions

Thus, SGC formation at early stages of helicopter development and its detailing at subsequent design stages contributes to significant improvement of helicopter performance and technical characteristics. This approach is also applicable to other types of equipment but requires an individual approach to the formation of criteria that define certain geometric constraints [21-43].

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