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APPLICATION OF METHODS AND TOOLS FOR COMPUTER-AIDED DESIGN IN INVESTIGATION OF PROSPECTS FOR CIVIL AIRCRAFT PROGRESS

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Abstract

A brief description of a dialog system developed at TsAGI for preliminary design of passenger aircraft is presented in the paper. Given are some examples of the system application for solving the following set of problems, connected with the investigation of prospects for civil aircraft improvement:

- selection of rational aircraft parameters;
- analysis of different design concepts;
- selection of rational requirements for the airplanes being designed;
- selection of the requirements with due regard for the unification of engines for two airplane types.

The combination of human creative abilities and computer speed possible due to a dialog mode of interaction allows to solve effectively the problems emerging during optimization of the requirements for an advanced passenger transport fleet.

Structure of the Preliminary Design System

At present computer-aided engineering systems are widely used during aircraft design. Such a system of preliminary passenger airplane design was developed at TsAGI and has been extensively used since 1975 during solving different design and research problems. Similar to the majority of such systems[1,2] it is constructed according to modular principle (Fig.1).

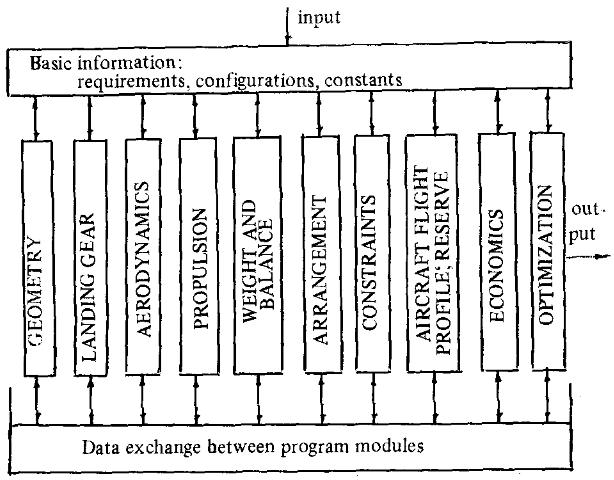

Fig.1. Modular structure of the preliminary design programm.

A set of modules enables to calculate basic characteristics of the aircraft project, which are necessary at a preliminary design stage.

The following data should be specified as the system input.

Requirements to the aircraft:

- passenger number,
- design range;

Constraints:

- take-off and landing distances,
- approach speed,
- climb gradient at engine failure for various take-off trajectory legs,
- capability to accelerate up to a specified cruise speed.
- wing fuel tank volume.

Usually the following parameters are considered as varied ones:

- wing area,
- engine thrust,
- aspect ratio,
- wing sweep,
- cruise mach number.

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Also for complete presentation of the aircraft layout it is necessary to describe it by specifying definite features with respect to components (Fig.2), e.g. the type of fuselage cross section and the number of seats and aisles, the airfoil type, the type of high-lift devices for leading and trailing edges, the arrangement and the type of horizontal and vertical tails, the number of main undercarriage legs and wheels of the bogie, the number of engines under the wing and on the fuselage.

The combination of possible component features generates a sufficiently large number of layouts. For instance, on the basis of features, shown in Fig.2, it is possible to obtain $5 \cdot 10^7$ configurations. If the time spent for optimizing parameters of one aircraft configuration is about 1 min, the optimization process for all possible layouts will require the computer time of 100 years.

Obviously, this approach is not real, and the remedy is supposed to combine the designer's creative abilities and computer speed.

The designer might input a required configuration data in a dialog mode, calculate it and then select some other arrangements and compare them. Thus, we would obtain all the data necessary to make a decision. Certainly, all possible configurations would not be considered, but the experience and intuition must prompt a proper choice in this situation.

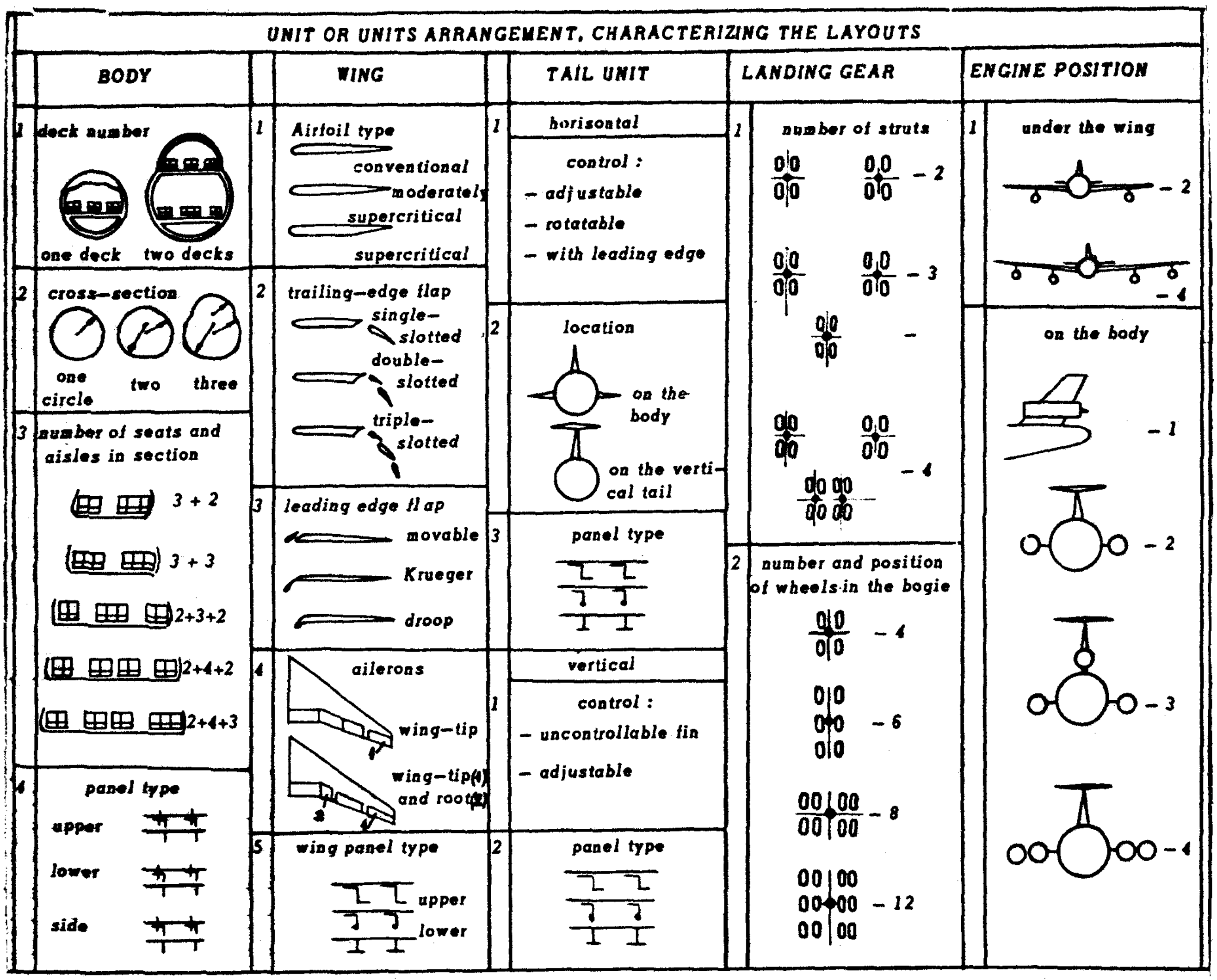


Fig.2. Information about Configuration Features in the Module "Preliminary Configuration Definition"

The optimization of varied parameters at specified constraints is carried out either by a gradient method or by using approximation of the objective function in the vicinity of extremum with quadratic function.

In solving the problems concerning the choice of the requirements for the aircraft being designed the following characteristics are used as the objective function:

- fuel consumption per passenger-kilometer,
- direct operating costs,
- total annual fuel consumption or direct operating costs for a network of airlines.

Some Examples of the System Application

General arrangement drawing

In the computer-aided mode drawn is a general arrangement of the aircraft with specified layout features (Fig.2), specified passenger capacity and design range, as well as with selected rational parameters (wing area, engine thrust, aspect ratio, sweep, etc.) (Fig.3).

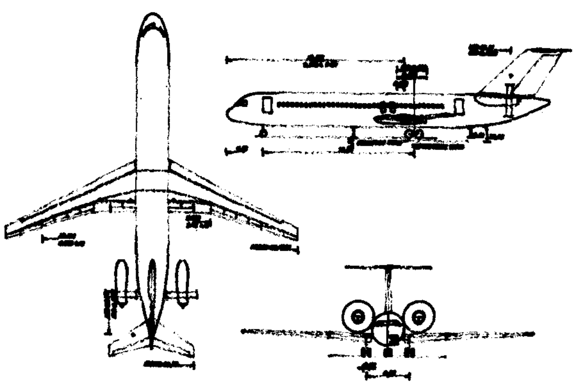


Fig.3. General Arrangement Generated by Computer Application

Parameter optimization

As an example of the parameter optimization results the selection of the wing sweep and cruise Mach number for an advanced aircraft with propfan engines designed to replace the Yak-42 (Fig.4) is given. It is shown, that the cruise Mach number and the wing sweep providing a minimum fuel consumption per passenger-kilometer are significantly lower (X=23°, M=0.74) than the parameters assuring minimum operating costs (X=35°, M=0.82). As the fuel cost increases these parameters approach those for minimum fuel consumption per passenger-kilometer.

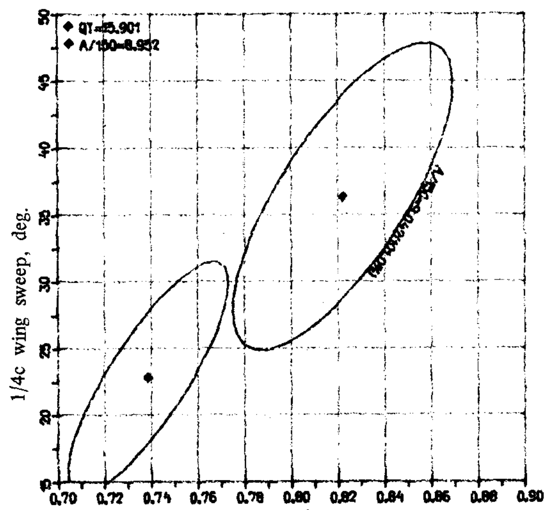
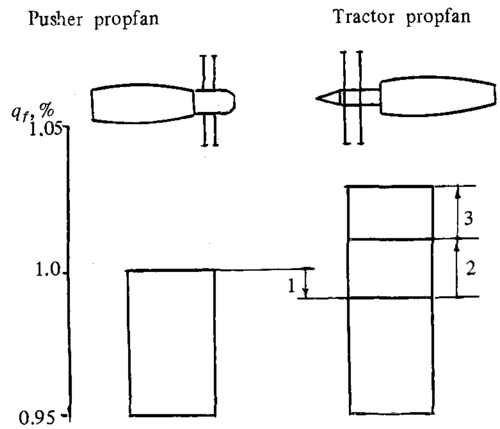


Fig.4. Parameter optimization

Selection of design concepts

As an example of selecting design concepts shown is the comparison of a propfan geared engine, positioned on the aft fuselage of a short-medium haul airplane with pusher and tractor propfans (Fig.5).

While the specified fuel consumption of the engine with tractor propfan is somewhat lower, than that of the pusher propfan (absence of airbleeding to cool the gearbox and root propfan elements), cruise lift to drag ratio is dropped due



Variations in fuel consumption q_f are caused by:

1. Difference in C_R
2. Difference in K_{max}
3. Difference in weight of sound suppression system

Fig.5. Selection of Design Concepts

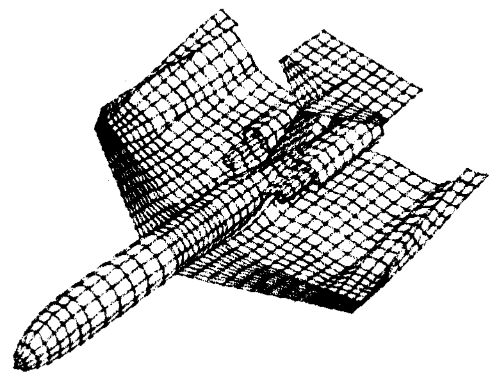


Fig.6 Vortex Sheet behind Wing

to blowing over the nacelle and the pylon by the propfan airstream and more close location of the propfan plane to the passenger cabin necessitates increasing the weight of sound insulation. Because of all these reasons the fuel consumption of the concept with a pusher propfan is by about 3% lower than that for the concept with a tractor propfan. When the engines are on the rear fuselage, an important factor is the location of the wing vortex sheet relative to the propfan plane and speed field in its plane. These data are obtained through calculations on the basis of the linear theory (Fig.6).

Selection of requirements for new airplanes of the fleet

At solving similar problems with the computer-aided design system a set of airplane versions, differed by requirements (e.g. passenger capacity) is calculated, then at simulating the operation of these airplanes on the network of airlines according to an integral criterion (total fuel consumption on the network or total operating costs) the rational requirements for new airplanes are determined. Variation of the passenger capacities for airplanes designed on the basis of the same technology level (engine, aerodynamic and weight efficiency) results in the following influence on the fuel efficiency at the same load factor (Fig.7)

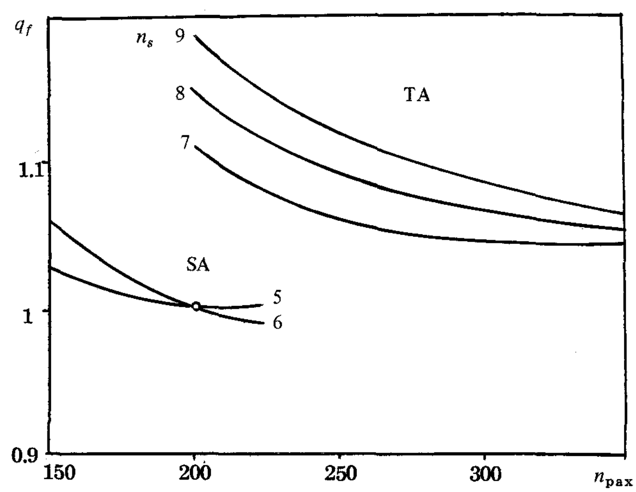


Fig.7. Influence of Passenger Capacity on Fuel Efficiency

Airplanes with one aisle cabine have maximum fuel efficiency at the passenger capacity ultimate for the aircraft of this type (200-220 passengers).

Airplanes with two aisle cabine and 7-9 seats abreast have minimum fuel consumption per passenger-kilometer at passenger capacity from 300 (7 seats abreast) to 350 passengers (9 seats abreast). The value of fuel consumption per passenger-kilometer for wide-body aircraft is higher by 4-6% than that for narrow-body ones. It is due to increase of the fuselage and its cross section because of two longitudinal aisles.

Let us consider an example of passenger capacity selection for two types of aircraft operating on short- and medium haul airlines. Among these airlines there are routes of low utilization (daily passenger traffic is less than 100 passengers) (Fig.8). So the utilization of an aircraft with capacity above 100 passengers on these airlines while retaining the flight rate of more than one trip a day would lead to incomplete aircraft loading.

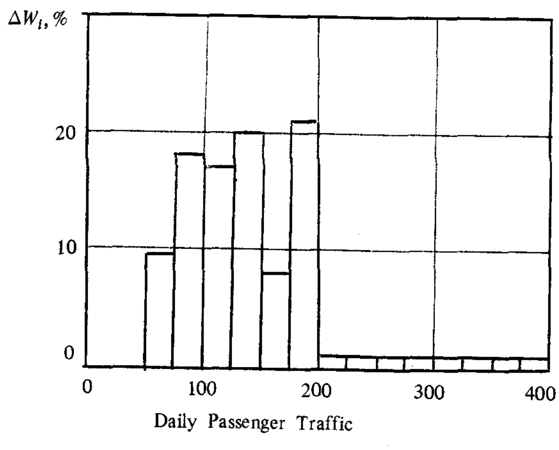


Fig.8. Distribution of Air Traffic Among Short Range Airlines

In relation to minimum total fuel consumption for the air route network considered it is reasonable to use two types of airplanes with 100 and 160 passengers (Fig.9). If these two types of airplanes are to be designed on the basis of a common engine, the optimum shifts towards increasing the passenger capacity for the

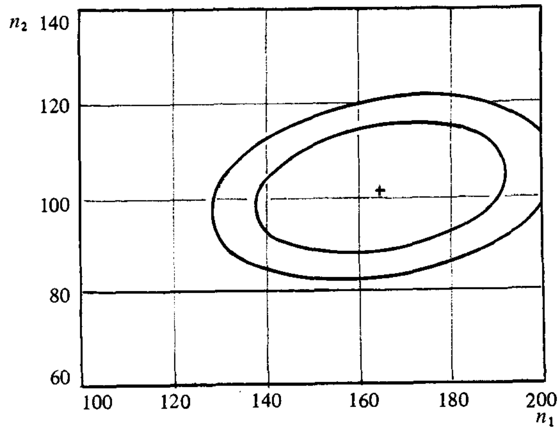


Fig.9. Selection of Passenger Capacity (two types of airplanes)

aircraft of the first type (n_1=140) and reducing the seating capacity for the aircraft of the second type (n_2=105, Fig.10). This can be explained by less increase in fuel consumption of the airplane with less seating capacity, which uses the engine designed for an aircraft with more passengers, when their seating capacities become closer.

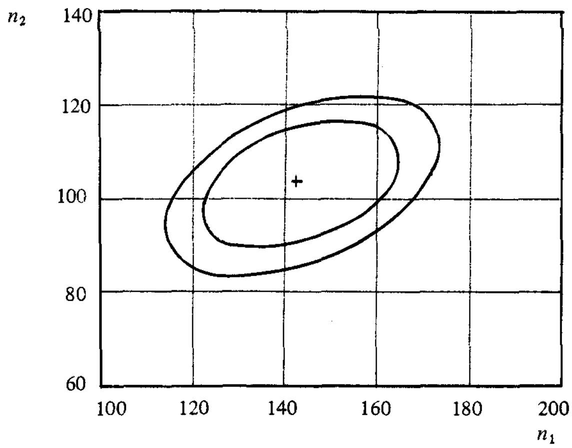


Fig.10. Selection of Passenger Capacity (two airplane types, similar engines)

Technology Progress and Rational Number of Aircraft Types

In the process of aircraft development each next airplane generation differs from the preceding one by improved characteristics of some or other components (engine, aerodynamics, structural materials), that results in improvement of fuel and cost efficiencies of a new airplane.

Let us consider one effect of increasing the aircraft efficiency level. The aircraft with more efficient aerodynamics, improved engine and weight characteristics can have larger range at less increase of the take-off weight, while the airplane with a given take-off weight can efficiently operate in a wider range of flight distances (Fig.11).

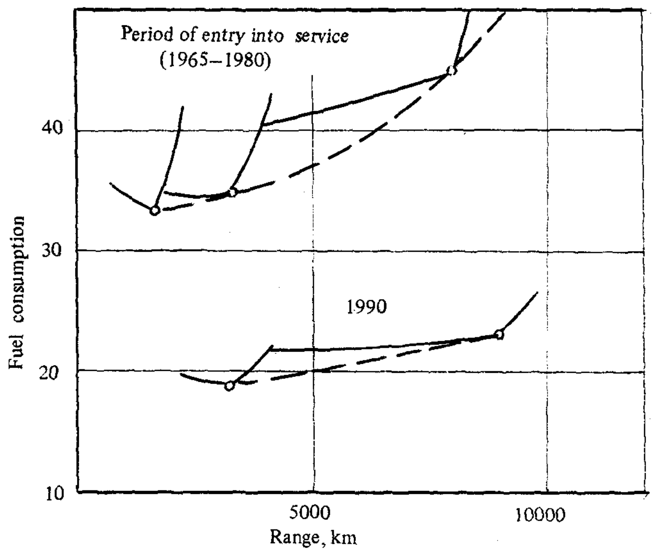


Fig.11. Reduction of Range Effect Due to Technology Progress

Thus, for example, the transition from 3 types of aircraft intended for the whole range of flight distances to 2 types at efficiency level typical of the second generation aircraft now being exploited by Aeroflot would result in the total fuel consumption increase by 6% for all the airlines (Fig.12). The same reduction of aircraft types from 3 to 2 at the efficiency level typical of the third generation aircraft at present under certification would lead to the total fuel consumption

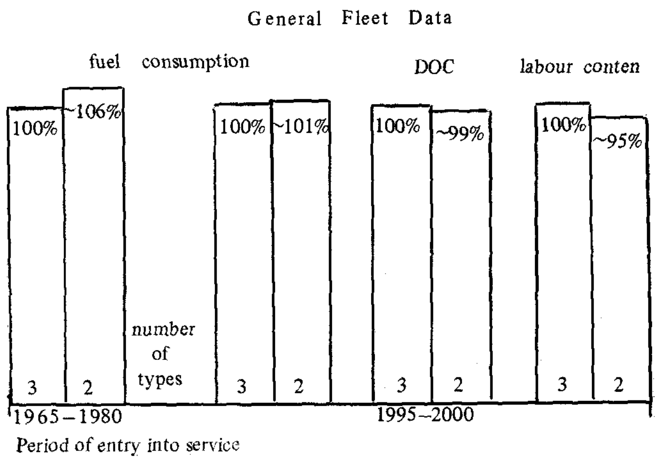


Fig.12. Possibility of Reducing the Number of Airplane Types for All Airlines

increase by 1%, while the cost of development, annual operating costs and labour hours for the production of aircraft in a required quantity would be reduced. Hence, technology progress could lead to decrease in a rational number of aircraft types.

Conclusion

Experience in application of the dialog system developed at TsAGI for preliminary design of passenger aircraft has shown that it is a fairly efficient tool for solving the whole set of design and research problems at initial design stage, particularly when optimizing the aircraft requirements.

References

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2. Denisov V.E., Shkadov L.M. Basic Principles of Constructing the System for Computer-Aided Aircraft Design. Trudy TsAGI, No.2021, 1979.