Study on a concept of a business jet with high passenger comfort

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Abstract

The paper deals with aerodynamic and configuration issues of a small business jet designed for 4-8 passengers. The novel layout provides considerable improvement of passenger comfort (maximum cabin height H=1.95m is the largest among business jets analogues) and achievement of maximum flight speed, corresponding to Mach number M=0.80 for the straight wing with thickness-to-chord ratio t/c=15-11% of the root and tip sections respectively. The use of the straight wing simplifies the structure and reduces its weight, makes it possible to obtain high lift characteristics without employing a slat and provides natural laminarization.

Introduction

At present more than 20000 business jets are being operated in the world. Business aircraft market is commensurable with that of fighters by volume of sales. In some countries of the former USSR, first of all in Russia, a constant growth of the business aviation market takes place owing to positive trends in economics.

Currently, the domestic fleet of business aviation consists of aircraft of western production and retrofitted home aircraft of Yak-40, Tu-134, Yak-42, An-74 type. However Yak-40 and Tu-134 aircraft, which are intensively operated, have high level of noise impeding their flights to foreign countries and must be retired in the nearest future.

The projects of Russian business jets are being elaborated in several design bureaus, however, the lack of new special features of a configuration, shortage of experience in designing the aircraft of this class and lag in technology make the realization of these projects hardly probable.

This paper deals with an original configuration of a small business jet designed for the transportation of 4-8 passengers to the range of 3500-4000km. Business aviation statistics has revealed that irrespective of maximum range and passenger capacity the number of passengers in flight averages to 3-4 persons and mean range is not more than 1500km (one daily round trip limitation). The flight range of 3500-4000km provides the connection between the head office and the most affiliated Russian companies, while with one intermediate landing it exceeds the range of all domestic airways. At last, the range indicated above, is sufficient for a direct link between Moscow and all cities of the Europe and the Near East.

The selected configuration of a new aircraft with a drop-shaped fuselage makes it possible to improve considerably passenger comfort (maximum height of the cabin is H≈1.9m-the largest among analogues) and, due to favorable aerodynamic interference, to get maximum flight speed corresponding to M=0.8 on the straight wing with thickness-to-chord ratio $\bar{c}$ =15-11% in root and tip sections, respectively. The use of the unswept wing simplifies the structure and makes it lighter. It also allows one to obtain high takeoff and landing characteristics without using a slat and provide natural laminar flow around the wing. A wide use of composite materials in the wing, fuselage and empennage structure will make it possible not only to increase the load ratio but also to accumulate required experience in design, production practice and utilization of composites for advanced domestic aircraft.

Implementation of above innovations will provide both qualitative technological superiority over aircraft of similar class and competitive advantages at the world market.

Peculiarities of aerodynamic configuration

One of the main criteria of business aircraft assessment made by a potential customer is a level of cabin comfort defined by its space and maximum height. Depending on maximum range (time) of flight all business aircraft are divided into four groups: short-range aircraft (L=3-3.5 thousand kilometers) with a standard cabin height H~1.5m, medium-range (L=3.5-6 thousand kilometers) with H~1.7-1.8m, long-range and super long-range aircraft with the possibility of moving along the passenger cabin standing up straight (H~1.85-1.9m).

Fig 1 : Premier 1A

Trying to increase cabin height, the designers, as a rule, arrange the wing underneath the fuselage contours which requires a large fairing (Fig.1). Such a configuration fully disagrees with the principles of a rational aerodynamic integration of aircraft components. In order to reduce unfavorable interference it is necessary to separate the areas of maximum disturbances. In this case, on the contrary, the addition of disturbedvelocities of the wing and fuselage takes place resulting in the strengthening of longitudinal pressure gradients and occurrence of earlier wave crisis phenomena.

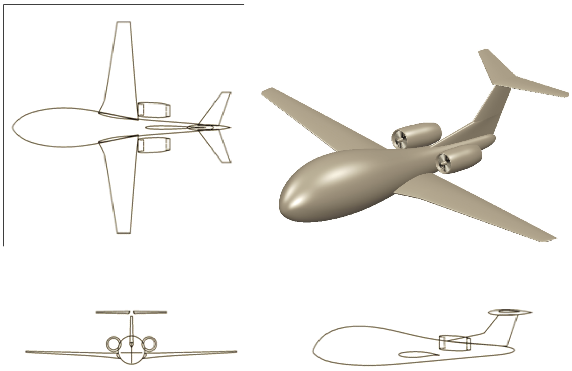

Fig. 2 : Rational configuration for aerodynamic interference

Taking into consideration aerodynamic interference, it is reasonable to install a wing into the region of a decelerated flow. In particular, a well-known area rule for transonic aircraft meets this principle.

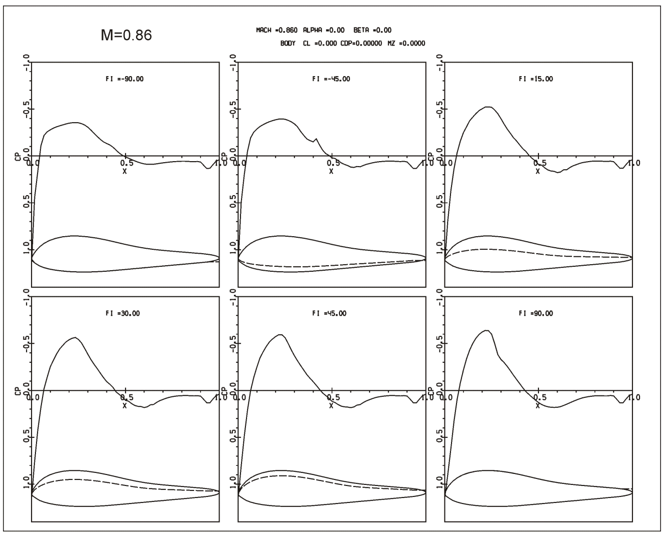

Fig. 3 : Pressure distribution over the fuselage

It is possible to achieve flow deceleration in the wing area due to fuselage waist and close arrangement of engines in the afterbody. Thus it may be a configuration similar to that presented in Fig.2.

The results of transonic flow computations around the configuration have proved a rationality of a selected scheme. It turned out that with a drop-shaped fuselage it is possible to increase thickness ratio to 20% without occurrence of shock waves up to M=0.86-0.87 (Fig.3). It means that maximum cabin height of 1.9m might be reached already with the fuselage length L~11m. A typical length of big business aircraft with such a cabin height exceeds 20m.

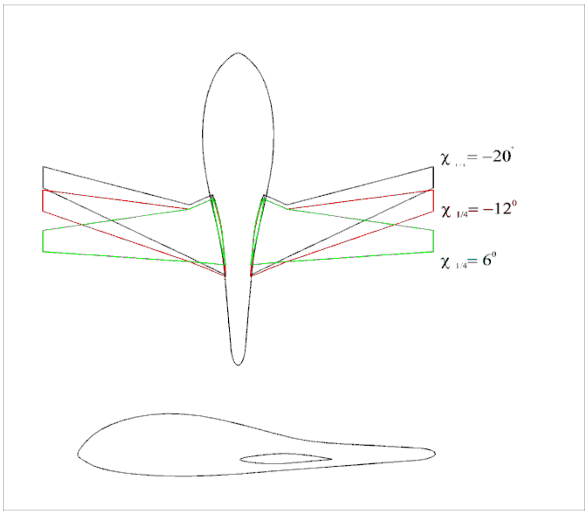

Fig. 4 : Wings with different sweeps of the outer panels

The wings with aspect ratio λ=8, taper ratio η=3 and different sweeps (Fig.4) have been considered for various flight speeds. The computations have revealed that with rational values of the wing thickness ratio it is possible to achieve M_{MAX}~0.85 at forward sweep χ~-20°, M_{MAX}~0.83 at χ~-10° and M_{MAX}~0.8 at χ~0°. There is no risk of leading edge contamination at all values of sweep, therefore extended natural laminar flow could be reached at maximum speed regimes.

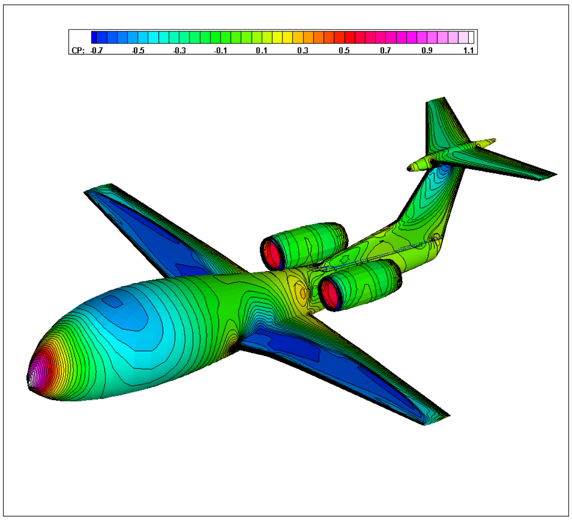

Fig. 5 : Pressure distribution over layout, M=0.8 Cl=0.35

The aerodynamic center position has been computed for a complete configuration (Fig.2) by using both the BLWF-56 program [1] (Fig.5) and the vortex lattice method. The values obtained appeared to be close although it will be necessary to carry out experimental studies to get more precise assessments. From standpoint of the layout, it is reasonable that the aircraft center-of-gravity position will depend weakly on fuel amount in the wing and overwing fuel tanks, i.e. it should be positioned in the vicinity of the front spar of the wing. Then, in this case, a required position of the aerodynamic center will be realized approximately at a zero wing sweep. With such sweep, the structure of the wing simplifies andlightens, takeoff and landing characteristics also improve making it possible to abandona slat.

The wing with zerorear spar sweep has been designed in more details with using traditional methods for aerodynamic design [2]. The wing has been specified by five basic sections which airfoils are given in Fig.6. The angle of wing setting is φ=1°. A small leading-edge extension is used both to increase structural depth of the wingbox and to eliminate probable separated flow ingestion into engine inlets at high angles of attack.

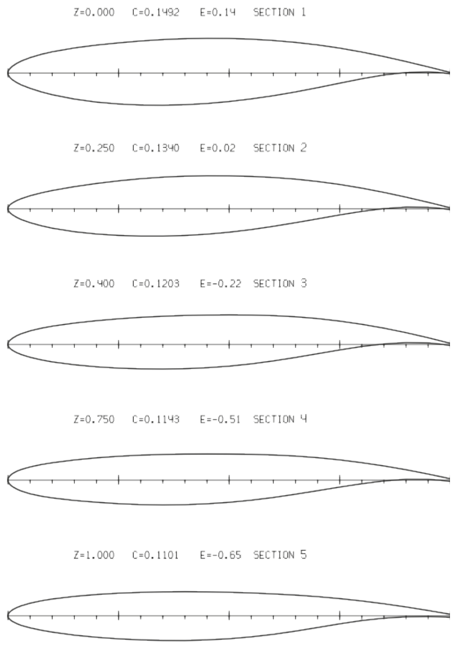

Fig. 6 : Airfoil sections

Aerodynamic design of business jet wing has its own peculiarities. For this class of aircraft the regime of maximum speed is perhaps more important than flight for long distances because fuel consumption is not a determining factor. Besides, according to statistics, mean range of flights makes up only 800-1000km for short-and medium-range business aircraft and 1400-1700km for long-range business jets. Because of the use of high-speed airfoils designed for Cl~0.3, strong nose shock waves appear at high angles of attack. Therefore the flight for maximum range (Cl~0.5) is realized at considerably lower Mach numbers as compared to high-speed cruising. For trunk aircraft the difference between flights for maximum range and maximum speed usually amounts to ΔM~0.03-0.04, while for business aircraft it is often equal to ΔM~0.06-0.08.

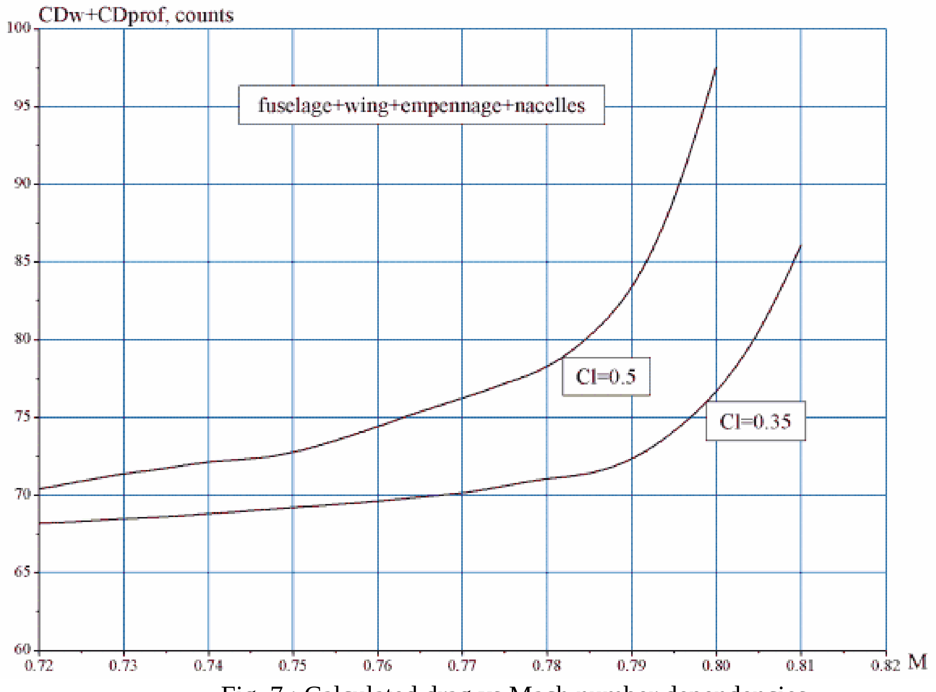

Fig. 7 : Calculated drag vs Mach number dependencies

Computed drag characteristics of complete configuration (fuselage-wing-empennage-nacelles) are presented in Fig.7. It is seen that unswept wingwithin conditions of favorable interference provides M_{MAX}=0.8 (850km/hour).

Flight for maximum range will be performed at $M_{MAX}\approx 0.76$ (810km/hour) (Fig.8). These speeds are typical for aircraft with swept wings ($\chi \sim 25^{\circ}$). Let us point out that there are no higher-speed models among current short-and medium-range business aircraft. Thus, for example, Embraer business jet Phenom-300 with a swept winghas $M_{CRUISE}=0.74$, $M_{MAX}=0.78$.

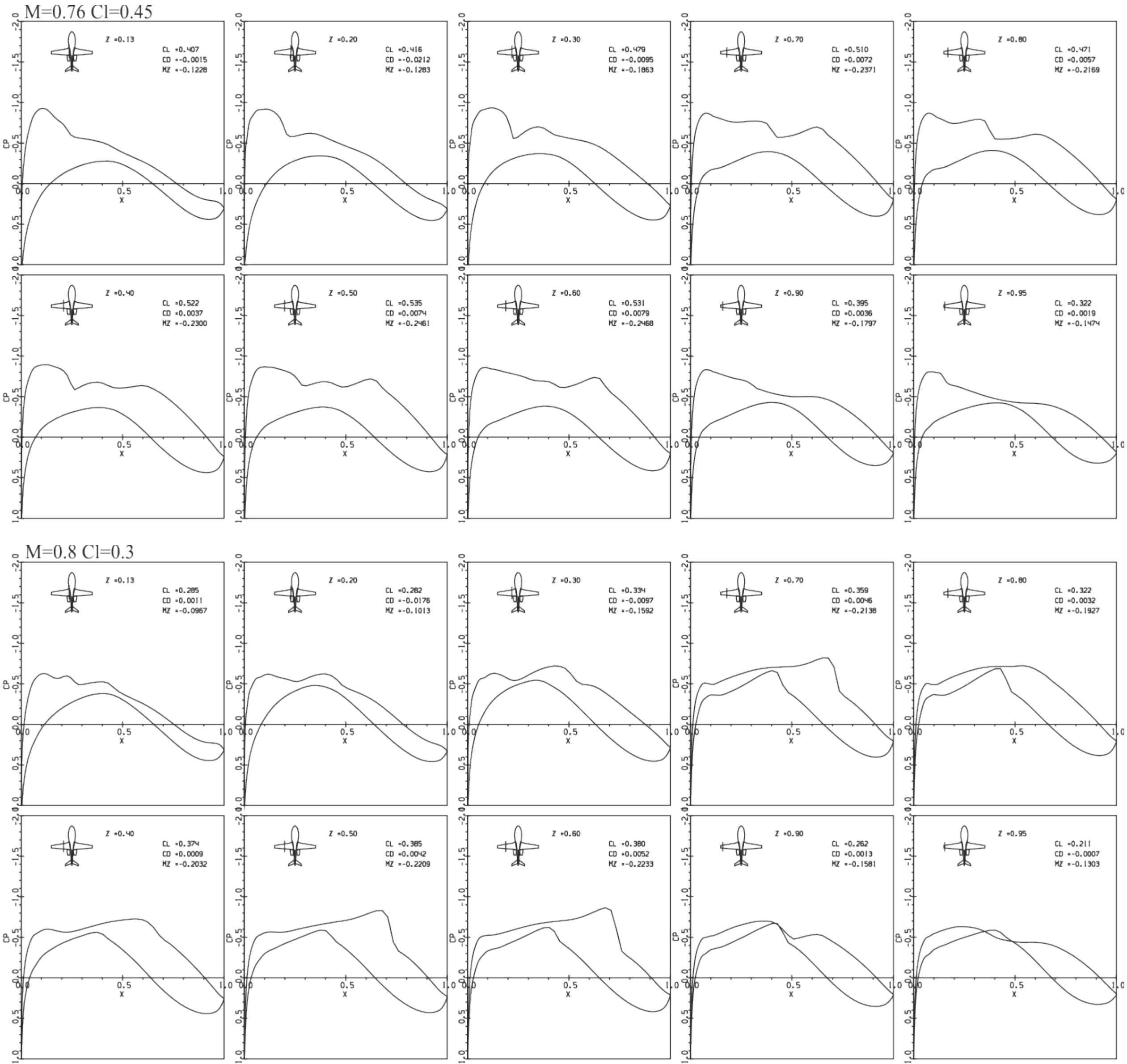

Fig. 8 : Pressure distribution over the wing

One of the distinctive features of a proposed business jet configuration is an original shape of the fuselage with an increased section of the front part (Fig.9) and a comparatively thin afterbody. This special feature makes it possible to design a passenger cabin for small aircraft with fuselage cross section close to that of large “wide body” business jets (Fig.10). Thus the possibility of providing high level of comfort for passengers is realized.

The passenger cabin with the length of 4.3 m in standard seating is dedicated for six seats of business class with width of0.7 m. The seats are arranged with the pitch of 40 inches (101.6 sm) which corresponds to the level of comfort of business cabins of long-range aircraft. The maximum height of the cabin of ~1.9 m enables the movement of passengers along the aircraft standing up straight which is important even for medium–range flight and is a significant factor of comfort.

The unsweptwing generates sufficient lift making it possible to refuse of the slats and provide natural laminar flow. The wing trailing edge is equipped with ailerons and twin-slotted flaps. The volume of tanks in the wing of large span and thickness ratio, with taking into account a fuselage tank above the wingbox, is sufficient for~1.5 t of fuel accommodation allowing one not to use inconvenient inserted tanks installed on many business jets under the passenger cabin floor.

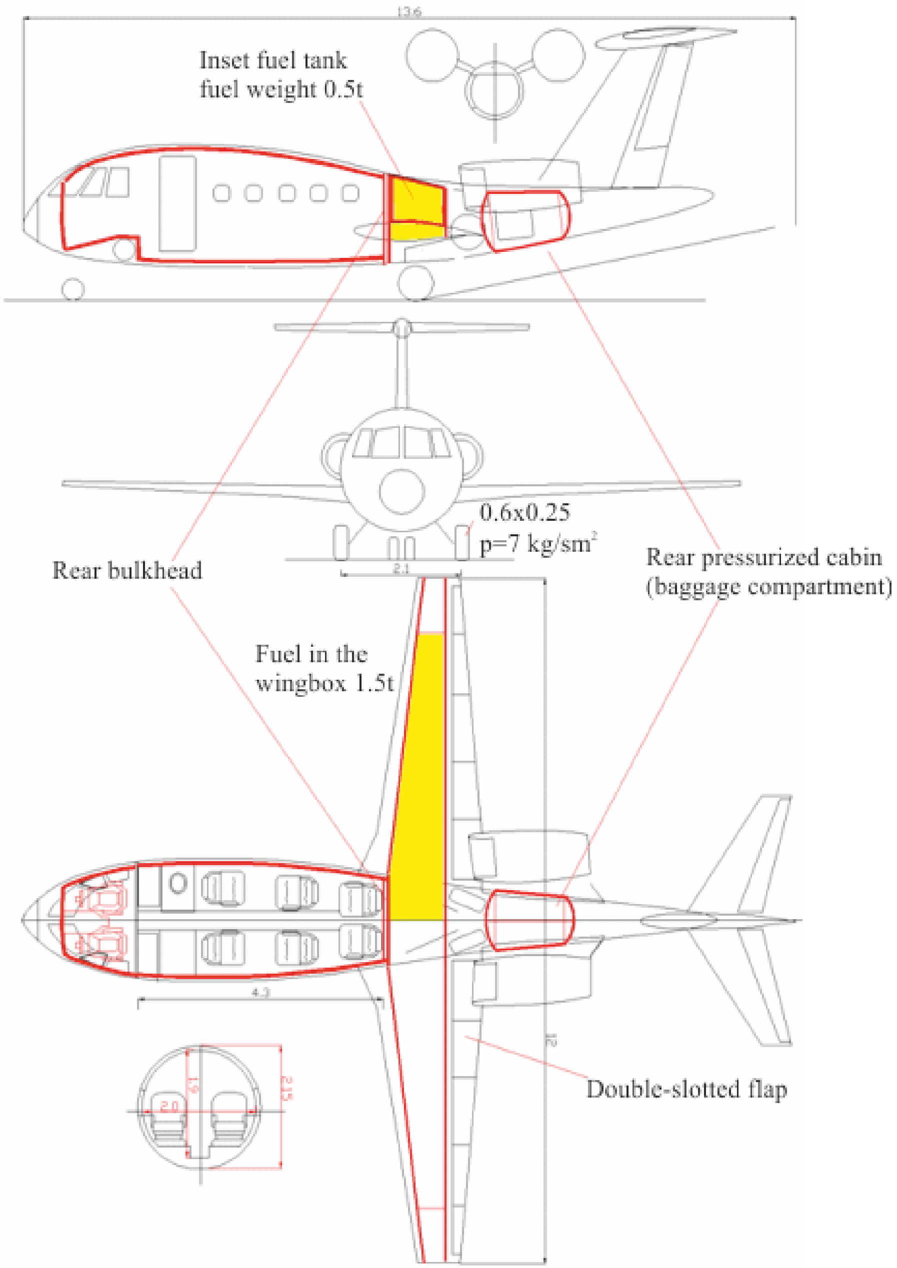

Fig.9 : Business jet layout

The configuration has a nose wheel landing gear and single-wheel main struts retracted into the fuselage behind the wing box. Moderate tire pressure (p≈7kg/sm^2) provides the aircraft basing not only on paved fields but also on unprepared runways with ground strength of σ ≥8kg/cm^2.

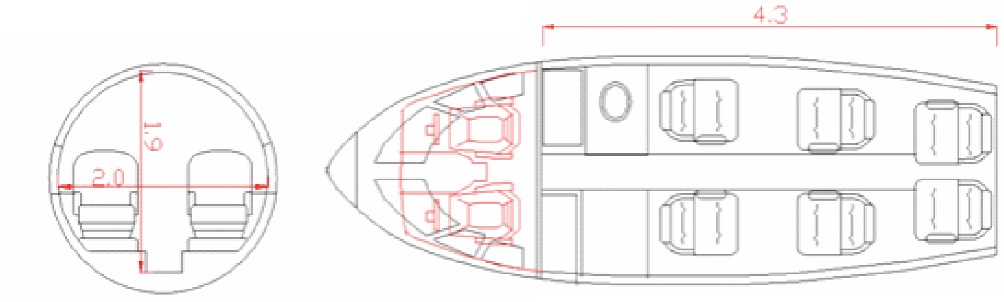

Fig.10 : Passenge

r cabin of the designed layout

Two by-pass turbojet nacelles are arranged by the fuselage sides above the wing trailing edge. Such an arrangement completely eliminates debris ingestion.

The empennage has a T-shaped form. In case of necessity of increasing yaw stability it is possibleto install the underfin of considerable size and area.

When determining main parameters and performance of the business jet considered, it was supposed that the aircraft should transport 6 passengers for the range of 3200 km with speed of ~810-820km/hour. The computation of aircraft structural weight was carried out assuming moderate use of composite materials.

On the basis of solving the given task main parameters of the aircraft have been determined: takeoff weight, wing area, operating weight, etc. (see the Table 1). It is assumed that a powerplant consisting of two turbojets will provide takeoff thrust-to-weight ratio about 0.40. With such thrust-to-weight ratio and comparatively moderate wing loading G/S~300kg/m^2, the possibility of basing on runways with the length of no more than 1200-1400m is realized corresponding to current business jets practice. The straight wing enables the realization of high lift coefficients at takeoff and landing even without use of leading edge high-lift devices.

Table 1

Engine type	By-pass turbojet
Number x takeoff thrust, t	2x1.0
Passenger capacity	6
Cabin length, m	4.3
Cabin height, m	1.9
Cabin width, m	2.0
Maximum takeoff weight, kg.	5200
Operating weight, kg.	3000
Cruising speed, km/h	810
Runway length, m	1300
Range of flight, km	4200

Conclusion

An original scheme of a new business jet with a drop-shaped fuselage is proposed. It enables considerable improvement of passenger comfort and,due to favorable interference, the realization of maximum speed of flight corresponding to M=0.8 on the straight wing with airfoil thickness-to-chord ratio $\bar{c}$ =15-11%. Aircraft-analogs with similar flight speed have a swept wing with sweep no less than 25°.

The use of unswept wing simplifies and lightens the structure making it possible to realize high takeoff and landing characteristics without using a slat and provide natural laminar flow around the configuration.

At present, the aerodynamicmodel is being fabricated in order to verify calculated aerodynamic characteristics in wind tunnels, including longitudinal and lateral stability characteristics.

Acknowledgement

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