THE DOLPHIN: A NEW 100-SEAT AIRCRAFT IN LIFTING-FUSELAGE LAYOUT

Kalyguina G.V., Bogdanov S.I., Dzhamgarov S.G., Karklin A.M, Lysenkov A.V.
IRKUT-AviaSTEP, Moscow, Russia

Birjuk V.I., Bolsunovsky A.L., Buzoverya N.P.
Central Aerohydrodynamic Institute (TsAGI), Zhukovsky, Russia

Abstract

This paper summarizes the preliminary design activity on a new 100-seat passenger/cargo aircraft, which is being investigated thoroughly by IRKUT-AviaSTEP company in a joint cooperation with TsAGI. The lifting fuselage concept is a milestone of this aircraft, named 'Dolphin'. Due to 7.2-meter-wide near elliptic fuselage cross-section a high degree of flexibility in cabin

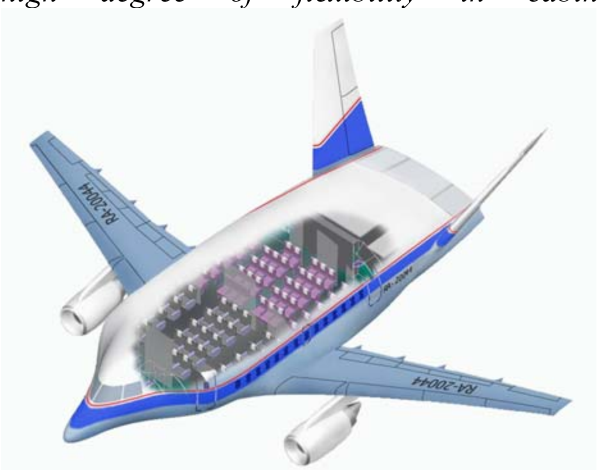

Fig.1

layout is achieved. Very pleasant wide-body type of cabin comfort is offered by 3-aisle 10-abreast seating in passenger layout. In cargo layout the Dolphin can carry all types of aviation containers, including the largest. A very attractive cabin interior is obtained also for business variant of the aircraft. Additional advantage of the Dolphin is its small length, which reduces the required ground and hangar area. The description of the designed airplane is given and its possible performance is assessed in comparison with conventional airplanes of the same capacity.

1 Introduction

On the threshold of the XXI-st century the most rapidly growing segment of the civil aviation market is the segment of regional jets (RJ), aimed at servicing direct links between regional city pairs. Typical seat number for RJ is about 50-80. The 100-seat aircraft segment is adjacent to the regional jets on one side, but is perhaps the most problematic one, because it is in-between the regional and full-size jet transport segments occupied by the major world manufacturers. In this capacity niche the largest members of RJ family (Dornier 928JET) as well as shortened derivatives of the trunkliners (A-318, B-737-600) at their lower capacity end are possible and also the 'true' 100-seat (B-717-200, Tu-334-100, EMB-190-200) airplanes [1]. Market saturation asserts very high demands to any new design in this category not only from the standpoint of technical and economic characteristics, but from the viewpoint of attractiveness for airlines and passengers too. Under such situation a new quality may be obtained considering unconventional airplane schemes. Russian company IRKUT-AviaSTEP, incorporated in Irkutsk Aviation Industrial Association, producing well known Su-27/Su-30 and Be-200 aircraft, is developing a project '111' of the entirely new 100-seat aircraft with convertible cargo/passenger cabin in lifting fuselage layout (Fig.1). The aircraft was named gently the 'Dolphin' due to the likeness of its fore-body with a dolphin nose. Radically new technical approach to the passenger cabin layout makes it possible to reach high level of comfort for passengers and to propose potential customers a wide spectrum of passenger cabin arrangements and a broad range of cargoes, to exploit high commonality flexible fleet, suited to solve their own transport mission with minimal expenses. Currently the program of the Dolphin aircraft developing is on the preliminary design stage. The investigations are carrying out in close cooperation with TsAGI, other research institutes and airline representatives.

2 Design requirements and objectives

Project specifications were set in joint discussions with airline representatives for the most complete satisfaction of current and future market demands. In accordance with these requirements two versions are being considered: with basic gross weight for short-haul routes and with increased gross weight for medium-haul routes. The requirements for two versions are listed in the following table:

Aircraft version	Short-range	Medium-range
Cruise M number	0.8	0.8
Design range with nominal payload (km)	3000	4300
Cruise altitude (m)	10000-12000	10000-12000
Take-off distance at SL, ISA (m)	1800	2200
Approach speed (km/h)	230	240
Capacity (economy class)	104	104
Standard payload (kg)	10000	10000
Take-off thrust (kgf)	7000	7200
MTOW (t)	45.8	50.0
Prescribed flights number	20000	20000

The aircraft should provide:
-high level of safety, reliability and comfort for passengers;
-minimum level of operational expenses for airlines operators in comparison with current and projected competitors;
-fast turn-around time, suitable cargo servicing and minimum ground handling;
-wide spectrum of seating arrangements and cabin interiors, easy conversion into cargo/combi version;
-minimal maintenance and repair required level.

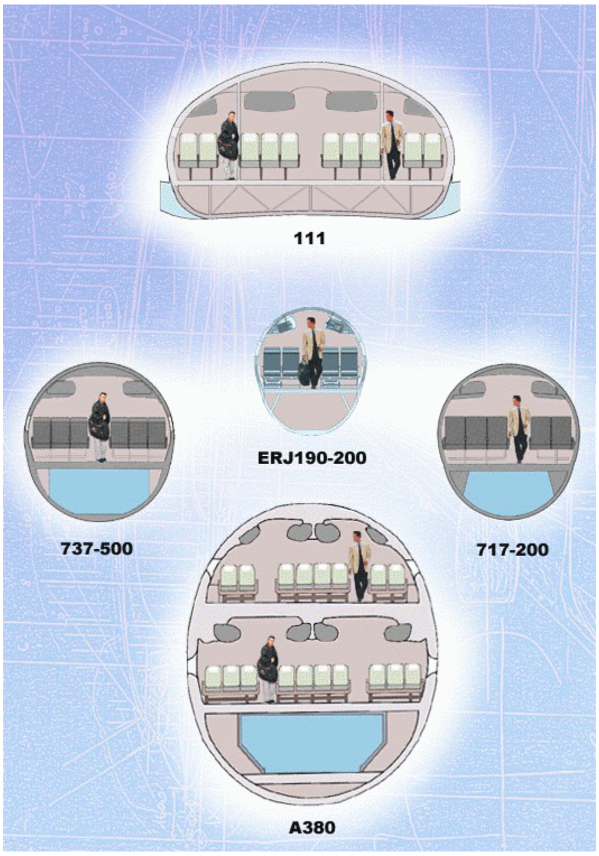

Fig.2

3 Lifting-fuselage layout advantages

In comparison with the usual narrow-body airliner the radically new technical concept of lifting-fuselage layout yields a number of advantages.
7.2-meter-wide near elliptic fuselage cross-section provides passengers with a pleasant area to be traveling in and much higher

comfort level than that of competitors (Fig.2). It is possible to install 10 passenger seats abreast in the cabin at 3 aisles and slightly increased pitch (up to 34") even in economy class. A very attractive cabin interior is also obtained for another aircraft arrangement versions (Fig.3): two-class layout (see Fig.1), 'coupe' and VIP layout. 'Coupe' layout with enhanced level of isolation and ability for sleeping is especially preferable for transatlantic flights at limited payload (~50 passengers). All proposed versions of the passenger cabin meet safety requirements and provide high degree of passengers' survivability at accidents. Three aisles availability helps significantly to improve food on-board servicing and simplifies passenger embarkment and emergency escape.

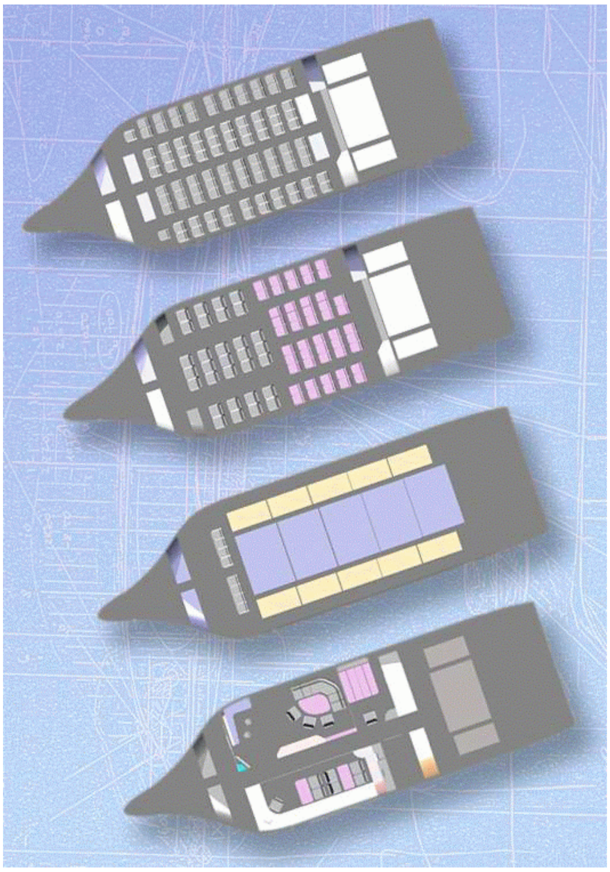

Fig.3

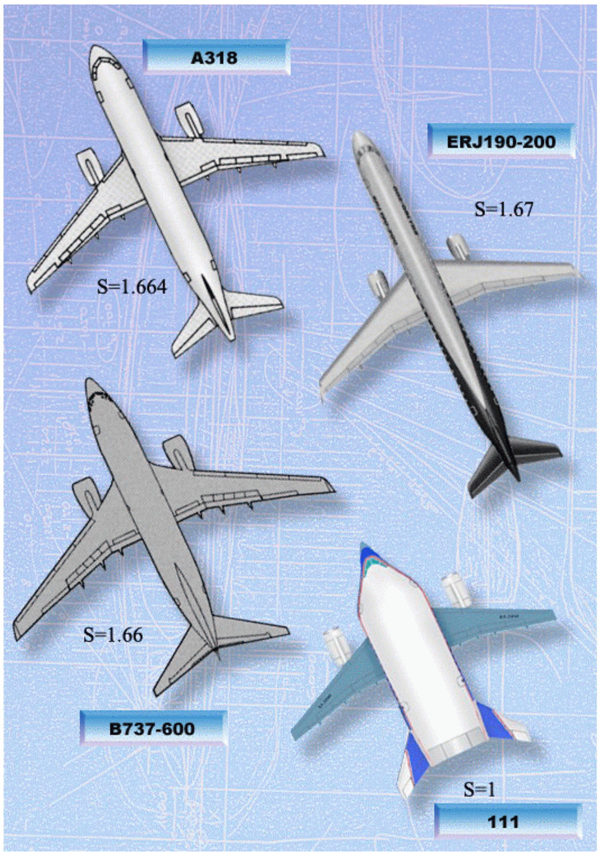

Fig.4

In cargo version the Dolphin can carry all types of aviation containers (125"x88" pallets in the middle and 53"x88" pallets outside). The only one deck servicing with integral stairs on the forward entry door and rear lifting device speeds up the loading and unloading with less ground support equipment and personnel.

The length, and hence the occupied ground/hangar area of the lifting-fuselage aircraft is considerably lower than that of other aircraft of the same class (Fig.4).

The ability to change freely aircraft designation, passenger arrangement and/or cabin interior enables an operator to build a flexible air-transportation system that meets any market demands even in the framework of a single structural layout, although the principal possibility exists to stretch the basic aircraft by inserting fuselage 'plugs'.

Summarizing all the above factors the conclusion can be made, that the lifting-fuselage layout enables one to realize naturally a new concept of creating advanced passenger aircraft, focused at passengers and being of high economic efficiency in operation at the same time.

4 Configuration description

A general view of the airplane is shown in Fig.1. It is a low-wing aircraft with two under wing pylon-mounted high-by-pass ratio turbofan engines. The aircraft falls within clearance limits 29.3m x 24m. Narrow 2-member crew cockpit, chosen due to pilot's side view considerations, looks like a dolphin face. The center body 7.2m x 3.7m middle cross section is presented in Fig.2. In typical all-economy passenger layout the number of seats equals 104. Load-carrying struts for enforcing elliptic fuselage shell can be designed as elegant interior elements. The cargo deck is absent, while passenger luggage and cargo is accommodated in the aft cargo compartments with space up to 13 m^3. The carry-on luggage can be also arranged in the voluminous head bins. Cabin layouts presented (Fig.3) are only examples to indicate flexibility in arrangement. The four-door solution enables different layouts with adequate galley, toilet and stowage space and also ensures quick turn around by simultaneous boarding/deboarding, cabin cleaning and galley replenishing. The embarkment is provided through the left-side forward passenger door, while baggage, freight and catering are handled on the right side. There are two over wing extra emergency exits.

The high aspect ratio (λ=10) moderately swept wing ($\chi_{1/4}$=23°) has a high dihedral and a pronounced gull to accommodate the large engine nacelles without installation drag penalties nor excessive landing gear length. The wing primary structure is made of conventional aluminum alloys. The wing has slats along the entire span and single-slotted flaps, which provide necessary field performance without extra complexity of the high-lift system. Ailerons providing roll control occupy the outer part of wing consoles.

Additional roll control is supplied by side sections of the fuselage deflected rear part (analogue of high speed ailerons). The central part serves for the purpose of trimming in pitch channel (analogue of 'adjustable stabilizer'). Two fins angled 40 degrees from the vertical also have control surfaces, upper sections of which are elevators and lower ones are rudders. The final configuration and designation of each control section will be determined after the specially planned wind tunnel investigations. Fly-by-wire flight control system with triple redundancy is considered at present as the primary one.

Main engines of 7000-7200 kgf take-off thrust should meet current and future requirements regarding noise, emissions, fuel consumption, reliability and monitoring. Three representatives are now under study, namely CF 34-10 from CFMI, PW-800 from Pratt and Whitney and D-436 from ZMKB 'Progress'. The basic design philosophy about engine and its components, APU, integrated system of airborne equipment along with furnishing and passenger equipment is that they are developed, certified and supported by worldwide known companies.

The aircraft components can be produced at Russian plant or delivered within cooperation from any world partner. The same is valid for final assembly also.

5 Aerodynamic design

Currently the aerodynamic design technique of the conventional subsonic transports is well developed and approved by numerous computational analyses and comparisons with experimental data. As for lifting-fuselage layouts the situation differs. While having much commonality with the conventional low-wing swept wing design the lifting-fuselage concept aerodynamic design has some distinctive features, the main of which accounts for increased wing-fuselage interference level, which, if not properly accounted for, can result in significant deterioration of aerodynamic efficiency. In this case wing and fuselage should be designed not separately, but as an integral unit. The influence of close-coupled nacelles also has to be taken into account.

The aerodynamic design task has been solved by joint use of the direct solvers [2,3], inverse and optimization methods [4]. The very fast full-potential method [2] provides good basis for numerous estimates of hundreds of different variants under study. The possibility of accounting for viscous effects and nacelles also exists. In Fig.5 is shown the pressure distribution for one of the layout variants at cruise regime M=0.8 Cl=0.5. In addition to the full-potential method the multi-block Euler method [3] with viscosity taken into account have been utilized widely too. The Euler method enables a designer to analyze local flow features in more details. The final solution concerning selection of the best geometry was also based upon the Euler method results.

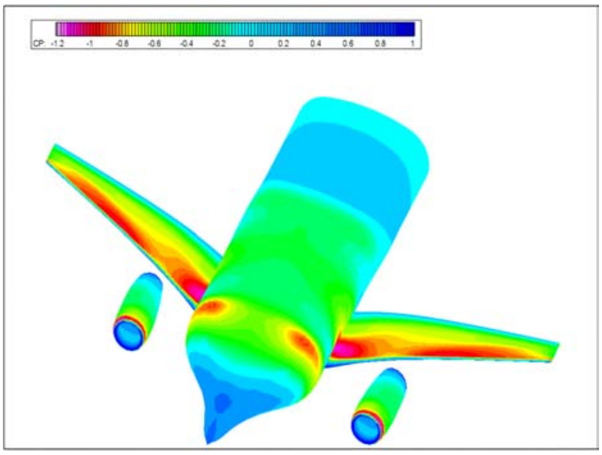

Fig.5

A set of aerodynamic design peculiarities has been revealed. First of all, due to large enough relative thickness of the fuselage (t/c~0.17) shock waves may appear in the cockpit region as well as in the wing intersection region (see Fig.5). Secondly, the desire of a constructor to a maximum volume utilization results in the sharp closeness of the rear fuselage, which may cause flow separation and deterioration of the effectiveness of the controls located there. The rear fuselage flow features are not understood well enough especially with respect to the impact of the empennage, side strakes etc. More complicated Navier-Stokes calculations or even dedicated experimental research could clarify the details of the flow in this region.

The key problems for the lifting-fuselage layout are a trimming and related losses. Rear fuselage and tail loading, as a rule, should be kept as minimal as possible for reducing vortex-induced drag. At the same time the intention to obtain sufficient lift at the forward part of a lifting fuselage (with favourable positive pitch moment) comes into conflict with the requirement of small cabin floor inclination at cruise.

A special attention should be paid to mutual wing-fuselage interference. At transonic speeds the contouring of the lifting fuselage is of the same importance as the wing geometry. The fuselage buttocks are suit to design with the aid of 2-dimensional inverse method (unfortunately, the shape obtained in this way often conflicts with technology and layout considerations). Besides, in spite of reduced fuselage height, the relative vertical position of the wing is as strong influencing factor as for the conventional cylindrical fuselage. That is why it is necessary to model true geometry in analysis thoroughly, although it's not always possible, for example, due to the imperative requirement of the whole wing-body intersection in the code [2]. As a rule, the lower the wing position relative to the fuselage, the higher are wing disturbed velocities and shock waves may appear. The wing should not be installed in the region of increased velocities induced by the fuselage. To the contrary, it is reasonable to modify fuselage shape so that the region of reduced velocities is organized in the wing installation zone, if such a possibility exists. For example, the modification of the side fuselage buttock derived by means of inverse method results in increasing cruise Mach number by ΔM≈0.015. Such modification resembles the fuselage waist according to the transonic 'area rule'.

An account of the aforementioned features enabled us to design a rather thick wing (t/c=0.17 – 0.11 – 0.10 at root, kink and tip sections respectively) with moderate wave drag at cruise. Due to compactness of the layout the ratio of the span to the square root of the wetted area is even slightly better than that of the usual counterparts. In case of obtaining streamlined flow over the rear fuselage without excessive drag, the L/D ratio of the airplane under study may be as high as 16-17 at M = 0.8.

6 Structural design

The aim of the structural design is to find the airframe layout with a minimum structural weight. The following design criteria were utilized:

-ensuring static strength of the structure under extreme loads;

-ensuring fatigue strength for prescribed service life;

-meeting the damage tolerance criteria for standardized damages;

-ensuring safety with regard to aeroelastic phenomena including flutter, divergence etc.

Some variants of wing and fuselage structures and their integration have been investigated. Usual 2-spar wing structure with wing box passing the lower part of the fuselage was chosen. As for the fuselage a difficult task of approving the strength under pressurization exists. The analysis of different variants revealed the best solution of the structure being the addition of the enforced floor and load-carrying struts.

The task of the structure weight minimization was being solved with the aid of the optimisation procedure in a framework of finite-element method. The allowable design stress levels have been chosen with account for the durability and damage tolerance requirements. Thickness and cross-sectional area of the load-carrying elements are the design variables in the optimization process.

Our investigations have revealed the possibility of designing the elliptical cross-section fuselage approximately within weight limits typical of the cylindrical fuselages. It is achieved by the proper material distribution between the fuselage elements and owing to the load-carrying struts.

7 Performance data and comparison with analogues

As follows from the preliminary aerodynamic and weight characteristics estimates, the Dolphin performance data correspond to the state-of-the-art of newly developed aircraft of this class and will allow efficient operation on short- and medium-haul routes. The basic and extended version of the aircraft performance on payload-range diagram is presented in Fig.6. Additional fuel equipment makes it possible to operate the aircraft in transatlantic flights (up to 6500km) at limited (up to 4700kg) payload.

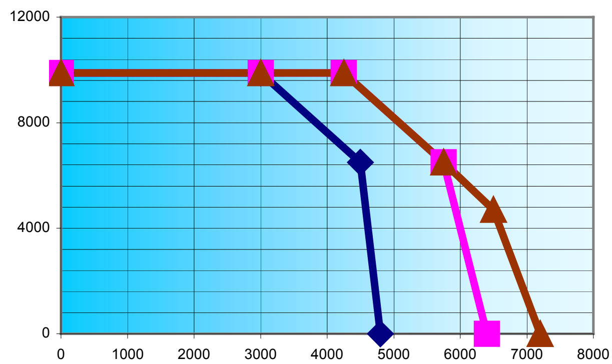

Fig.6

The closest analogues of the Dolphin aircraft are believed to be new ERJ-190 (Embraer) and 928JET (Fairchild Dornier) aircraft and Boeing B717-200 currently in operation. The following table lists comparative performance data of these aircraft in comparison with the project under-study:

Aircraft	Dolphin	ERJ190 -200	928JET	B717-200
Length(m)	25.6	38.4	32.0	37.8
Span (m)	29.3	28.1	29.7	28.5
Fuselage section	7.2x3.7	3.35x 2.93	∅3.5	3.35x 3.8
Capacity	104	108	100	106
Mcruise	0.8	0.8	0.78	0.8
Range (km)	3000	3300	2960	2905
MTOW (kg)	45800	47990	47560	51700
Payload (kg)	10000	9800	12200	12220

As follows from above data the aircraft being developed is in one line by its characteristics with competitors, and at the same time it is significantly superior in the passenger comfort level and operational flexibility. The estimates fulfilled in accordance with the Russian accepted methodology for domestic and international flights show that the Dolphin DOCs are among the lowest in its class. The additional economical effect could be achieved due to full-size introduction of on-condition operation and use of new strategy for providing product longevity, supposing exclusion of heavy repairs or labor-intensive overhauls within life cycle, choice of optimal system of maintenance and post-sale servicing. According to researches of experts involved the Dolphin aircraft will meet its purchasers at CIS market, the key factor of a success being a gradual replacement of Tu-154 and Tu-134 aircraft.

8 Program current state

Currently the Dolphin Program is at the stage of the preliminary design. Design and production preparation are realizing using advanced information technologies within single digital database, provided by CAD software. IRKUT-AviaSTEP (Aviation Systems and Technologies of Electronic Projection) possesses experienced human and powerful technical (workstations, high-end PCs, peripheral devices) resources for working in the CAD/CAM system field. Concurrent engineering, Digital Mock-up and Pre-Assembly greatly reduce design cycles and possible future manufacturing, assembly and installation problems. The most critical airplane structure details are defined: wing center section, wing and fuselage joint, fins installation, nacelle pylons fitting, main and nose landing gears, cockpit arrangement.

The multi-purpose aerodynamic model for high-speed wind-tunnel tests has been also designed in digital format. As an example, the assembly of model parts is shown in Fig.7. Currently the model is just at the end of manufacturing at Irkutsk aviation plant.

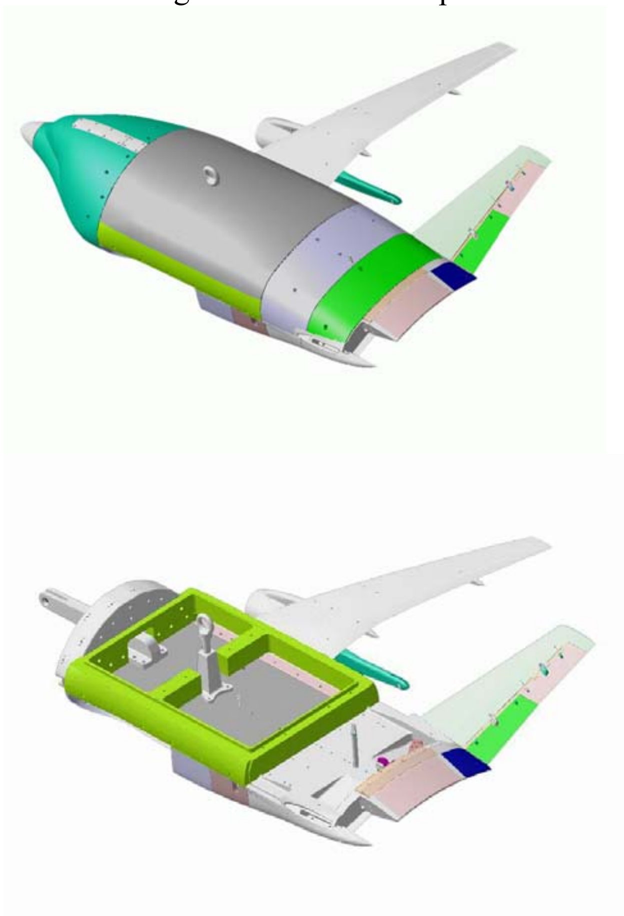

Fig.7

The preparation for detail design is being carried out. The aircraft technological concept and features have been developed and required equipment lists are itemized. The major partners and subcontractors are sought for.

References

[1] *Jane's All the World's Aircraft*, 2000-2001.

[2] Karas O.V., KovalevV.E. Computation of transonic flows around a wing-plus-fuselage configuration taking viscous effects and a thin separated region into account. *La Recherche Aerospatiale,* 1994,No 1, pp 23-28.

[3] Bosniakov S., Fonov S., Jitenev V., Shenkin A., Vlasenko V. and Yatskevich N. Method for noise suppressing nozzle calculation and first result of its implementation, *Journal of Propulsion and Power*, v.14, No 1, January – February, 1998.

[4] Bolsunovsky A.L., Buzoverya N.P. Transonic wing design using inverse and optimization methods. *Journal of Advanced Engineering Design*, vol.40, No 1/2000.