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RECENT INVESTIGATIONS OF THE VERY LARGE PASSENGER BLENDED-WING-BODY AIRCRAFT

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Abstract

The “Flying Wing” (FW) or Blended-Wing-Body (BWB) layouts for subsonic long-haul ultra-high capacity passenger airplane promise significant benefits in terms of DOC and fuel efficiency. Nevetheless, so cardinal change of the configuration can entail serious difficulties in development and operation. Hybrid layouts, which represent an intermediate link between a “pure” FW and a conventional airplane can overcome these difficulties to a great extent, while retaining a primary advantage of FW – high L/D ratio. We call such hybrid schemes the Integrated-Wing-Body (IWB) schemes. The IWB layout has less technical risk, higher commonality with a conventional aircraft in production and operation and higher level of comfort and safety for passengers. The description of the designed 750 passenger IWB airplane is given and its possible performance is assessed in comparison with conventional airplane of the same capacity.

Introduction

In response to a constantly growing world passenger and cargo traffic, especially in Asia-Pacific region, a concept of a huge airliner capable of carrying up to 1000 passengers (UHCA) was proposed by the aircraft manufacturers. At present the development of UHCA has already passed a research stage and transformed into a series of economical, production and operational problems, which, apparently, will be successfully solved at the very beginning of the next century with putting into service new AIRBUS INDUSTRY and, perhaps, Boeing airplanes. Besides, it is now, when a basis for the development of their successors – aircraft of a new-generation to be operated up to the middle of the XXI-st century is being laid. Many investigators from different countries(1-4) believe that these new-generation airplanes will be of FW (See Fig.1(1)) or BWB configuration.

The investigations of the UHCA in the FW layout have been carried out at TsAGI since the middle of 80-s(5). Earlier these investigations were focused on the cruise Mach number M = 0.8 and were of a conceptual nature rather than studies of a particular airplane with operational problems involved. Presently the research of a FW concept at TsAGI got a new impulse thanks to a 3-year ISTC-sponsored study for recognition of critical key technologies and challenges within all the disciplines of such schemes. These studies involving a number of specialists in different fields and dealing with a very wide range of layouts are just in full swing as this paper is being written, therefore it reflects only one of possible alternatives being considered within the grant and is of a preliminary nature.

The BWB concept does represent a “potential revolution in subsonic transport efficiency for large commercial airplanes”(2), although such a cardinal change in the aircraft layout can entail serious difficulties in implementing it in the aerospace world with an established airport infrastructure, passenger and luggage loading aids, adopted operational procedures, etc. Many of these difficulties can be overcome within hybrid layouts (Fig.2), which represent an intermediate link between a “pure” FW and a conventional aircraft. To distinguish such a class of configurations we call them Integrated-Wing-Body (IWB) schemes. The IWB scheme retains a distinctly defined fuselage as a volume for passengers and luggage accomodation although being shorter and lighter in comparison with a conventional fuselage, in addition large volumes of the center wing section are utilized. The IWB scheme has less considerable project risk with fewer innovations than FW and at the same time, as it will be shown below, incorporates primary advantages of a FW – L/D ratio and fuel efficiency.

Project specifications

Project specifications were set in joint discussions with grant collaborators. Main of them are as follows:

- 750 passengers in 3-class layout and up to 1000 passengers in all-economy layout;
- 13700 km (7400 n.m.) nominal range;
- 0.85 cruise Mach number with MMO up to M=0.88;

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- ground span less than 80 m;
- 3350 m takeoff field length, ISA, sea level +15°C condition;
- approach speed less than 270 km/h;
- state-of-the art engines, materials and technology; aluminium alloy primary structure;
- ground 180° turn on current runways (width 60 m);
- carriage of under-floor LD3 containers and 96″×125″×64″ pallets;
- carriage of 96″×125″×96″ AMA containers on the main deck in all-cargo or combi versions;
- turn-around time less then 90 min.

IWB scheme substantiation

In comparison with the FW scheme (Fig.1) the IWB scheme (Fig.2) provides the following advantages:

- less technical risk;
- better Mach number characteristics due to 3-dimensionality of flow over the fuselage and narrow center wing section;
- conventional aids for embarkment and cargo loading;
- considerable simplification of passenger emergency escape problem, especially in ditching;
- simplification of cabin pressurization problem;
- higher operational flexibility with possible change to cargo or combi version;
- stretching versions possibility;
- higher level of comfort for passengers in the forward part of the main deck and in the all upper deck with the possibility of the first and business class arrangement there;
- reduction of lateral g-loads for passengers in roll maneuvres due to less distance from the airplane axis;
- less risk in belly landing.

At the same time some increase of a wetted area and cantilever span can be largely offset by choosing appropriate technical solutions. Thus, the fuselage can have a more steep taper of the afterbody and, consequently, a larger coefficient of the volume utilization than a thick airfoil; engines accomodation on the outer board wing reduces bending moment, simplifies maintenance, unifies engine nacelles, which, to a high probability, will have a built-in hybrid laminarization system.

Various variants of the wing and fuselage structure integration of the IWB scheme have been considered (Fig.3). In the first case, the height of the wing box is the same as for the main deck and the structure shell of the center wing section forms a single structure with the floor and ceiling of the main deck. With a rational relative thickness of the root airfoil c=14÷18%, the root chord equals to ~25m and the capacity of the center wing section amounts to ~200÷250 pax, which is too small relative to the overall selected capacity of 750÷1000 pax. Besides, in this variant it is difficult to meet the FAR restriction of about 60ft distance between two neighbouring fuselage exits. In the third case, which represents another extreme possibility, the height of the wing box is actually equal to the fuselage height, namely, about 8m. In this case the root chord increases up to 40-45m and the capacity of the center wing section is about 500-550 pax, which is too large relative to the overall capacity resulting in the fuselage degradation and the revival of the BWB scheme of works(1,2) type with all above stated shortcomings. While the studies on these extreme variants are being still continued the authors prefer an intermediate second variant, in which the wing box passes through the main and cargo decks providing a space for about 350 passengers accomodation in the center wing section (Fig.2). A detailed description of such a layout is given in the next section.

Configuration description

A general view of the airplane in the IWB layout is shown in Fig.2. The center body middle cross section is presented in Fig.4. The passenger cabin layout assumes double-deck passenger accomodation in the fuselage (from 400 to 600 pax depending upon the arrangement) and a single-deck accomodation in the center wing section with 340 passengers. The main deck height is 2.6m to provide the possibility of carrying 8×8 ft containers in a cargo version. The upper deck height is 2m. The overall number of passengers in one cross section is up to 37 persons in all-economy layout.

The embarkment is provided through the exits in the fuselage nosebody and, possibly, in the leading edge of the center wing section. There are extra emergency exits arranged along the fuselage board on the main and the upper decks as well as some side center wing section exits. Cargo loading is performed through the nose and afterbody doors, because the rear spar is continuous through the cargo deck.

The swept wing of 40°/36° leading edge sweep has a total area of 1500 m^2 ($S_{tr} = 1000$ m^2), a 3-spar construction with verticals acting as fins with double-hinged rudders and as winglets to increase effective aspect ratio. The wing tips are folded on the ground to meet a 80m span restriction, the extra weight of the mechanisms providing the folding is estimated of about 500 kg. The wing has slats on the outer part and simple flaps (elevons) along the entire span. There are split-drag rudders to provide extra yaw control in the low-speed engine-out condition. The aft part of the center wing section has also control surfaces deflected both upwards to generate a nose-up pitch moment at the nose-wheel lift-off and downwards to create a nose-down moment at high angles of attack entry. The wing primary structure is made of conventional aluminium alloys, wing tips and control surfaces are built from composites.

The engines of the TRENT 900 type, 4×35 t, are located in underwing pylons providing the thrust line under the center of gravity with favourable pitch-up moment at take-off, reduction of wing root bending moment and entire commonality with other airplanes in nacelles and maintenance.

The main gear has four 6-wheel bogeys retracted into the fuselage and the lower part of the center wing section, while the nose gear has one leg with 4-wheel bogey.

Aerodynamic design

The aim of the aerodynamic design is to find a wing shape with the highest possible cruise L/D ratio at $M = 0.85$, which could satisfy all the configurational, stability and control and low-speed characteristic requirements. While having much commonality with the conventional swept wing design the BWB/IWB wing design has some distinctive features. They are as follows:

- close interrelation of aerodynamic and configuration solutions, especially at the center wing section;
- small value of the total drag at cruise regime resulting in increased L/D sensitivity to drag increments due to non-optimal lift-along-span distribution or appearance of very weak shocks;
- wide spectrum of flow conditions and types of airfoils along span;
- sharp changes of planform, resulting in "planform induced" effects in pressure distribution;
- stringent requirement of self-balance at cruise regime;
- the requirement of small pitch-up at high angles of attack;
- the requirement of small ($\alpha \leq 2°$) cabin floor inclination at cruise.

The aerodynamic design task has been solved by joint use of the fast direct solver(6), the technique of direct geometry control, inverse method of residual-correction type(7) and optimization procedure. The very fast direct method (the time of one run is ~30 sec on PC Pentium 200 on the intermediate mesh) provides good basis for numerous estimates of hundreds of different variants and moderate time consumption for iterative inverse and optimization procedures. The possibility of accounting for viscous effects and nacelles also exists. In Fig.5 is shown a fine mesh of the considered IWB airplane CFD model.

The three-stage design procedure was adopted. First of all, the initial geometry of a wing was chosen and direct geometry control of baseline sections was used to attain a desired global nature of pressure distribution. After that the inverse method generates new geometry with refined pressure distribution and small wave drag at cruise regime $Cl \sim 0.3$. At the final stage an optimization procedure finds the optimal vector of design variables including lift coefficient and angle of attack at cruise, aiming at the maximization of L/D ratio with restriction on the pitching moment. Note, that some precautions are neccessary during optimization, for example, the range of design variables alteration must be carefully chosen. Usually we use global airfoil parameters, such as twist, camber, value of rear loading etc., rather than local geometry shape functions. Such technique permits pressure distribution type, set by aerodynamicist previously at the inverse mode stage, to be saved during optimization. A typical number of design variables is 15÷20 and a value of increase in L/D ratio varies from 0.25 to 1.0 depending on the quality of preliminary design.

The key parameter in the design of the tailless configuration with high cruise Mach number and high aerodynamic efficiency is a specified value of static stability margin. Small negative and even positive values are beneficial due to short arms of the reaward control surfaces and corresponding large trim penalties. Gradients of L/D ratio relative to static stability margin as large as 0.5 per 1% of MAC are possible on the BWB/IWB layouts. In our studies we orient to a zero stability margin at cruise, which is, at present, an extreme value assumed by TsAGI's control specialists. With this value in mind, the L/D ratio of the airplane shown in Fig.2 may be as high as 24 at $M = 0.85$. The surface pressure distribution of the designed wing is given in Fig.6.

Performance

The estimation of the airplane primary structure weight was made with using a global FEM model presented in Fig.7. The weight of other structure components and the equipment was determined by semiempirical technique based on statistical correlations. Thus, relying upon aerodynamic and weight estimates the possibility of evaluating the airplane performance appears.

In order to adequately assess the IWB concept benefits an airplane of conventional configuration has been designed with the same passenger capacity of 750 pax and a similar level of basic technologies. Table 1 summarizes the basic performance of the IWB airplane and the conventional baseline.

Table 1

	Conventional	IWB
TOGW	100%	–14%
L/D	100%	+15%
Fuel Burned	100%	–21%

Conclusions

In authors opinion the IWB scheme, being an intermediate link between conventional airplanes and "pure" FW configurations, is an independent competitive concept to be thoroughly studied. Retaining a primary advantage of FW, namely high L/D ratio, the IWB scheme has less technical risk, higher commonality with a conventional aircraft in production and operation, higher level of comfort and safety for passengers.

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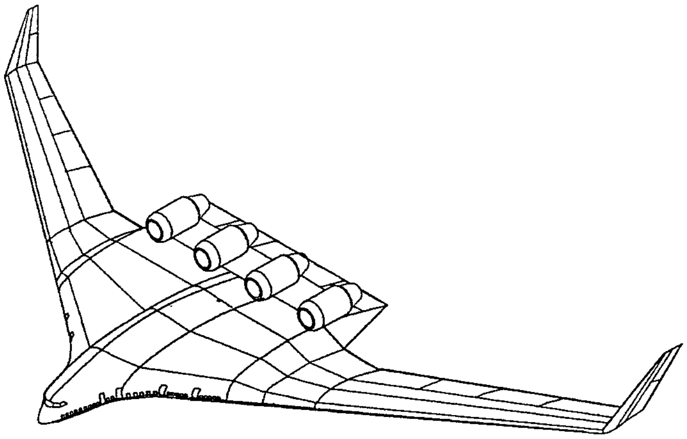


FIGURE 1 – Flying Wing Layout(1)

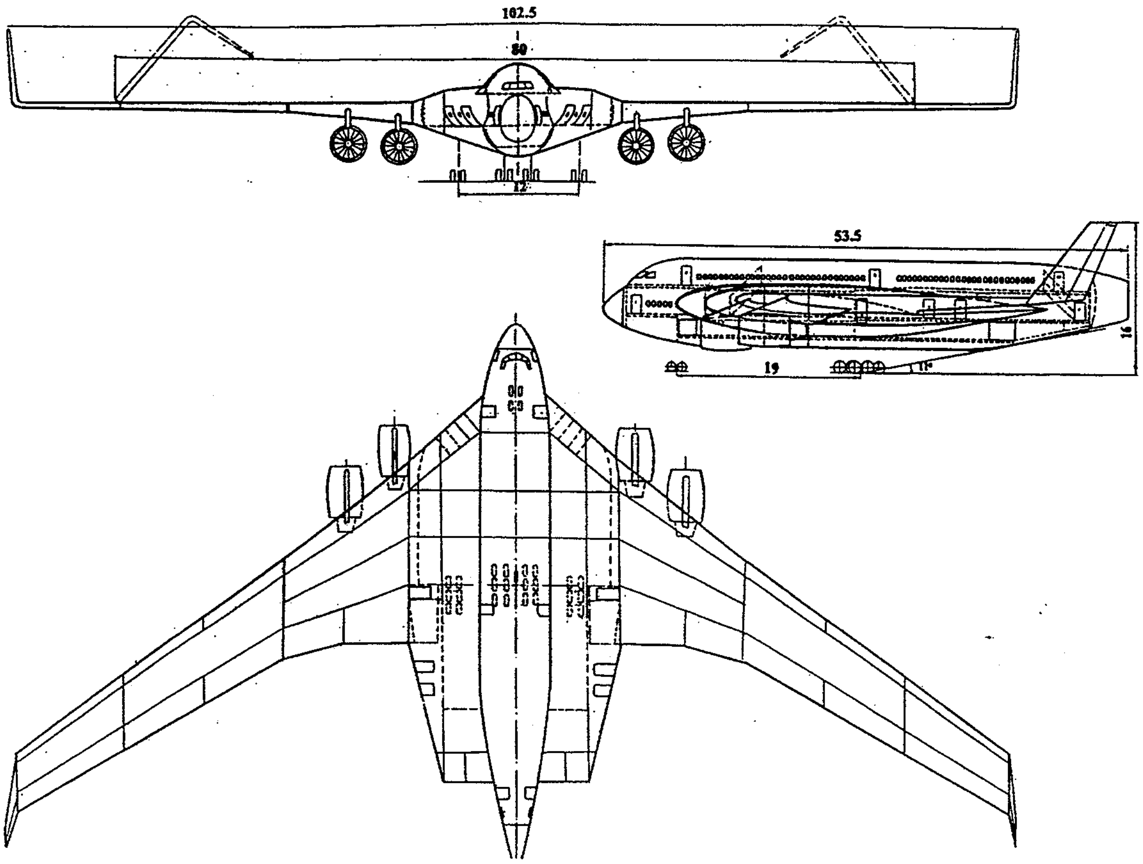
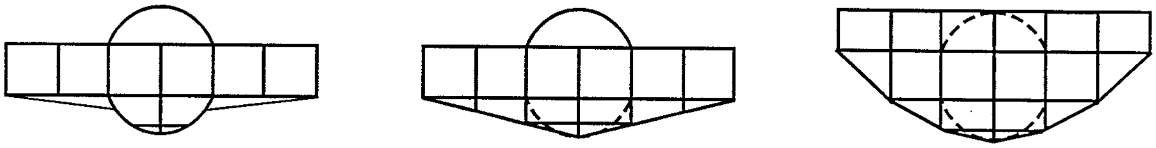


FIGURE 2 – Integrated-Wing-Body Layout



Var.1 Var.2 Var.3

FIGURE 3 – Variants of Wing-Fuselage Structure Integration

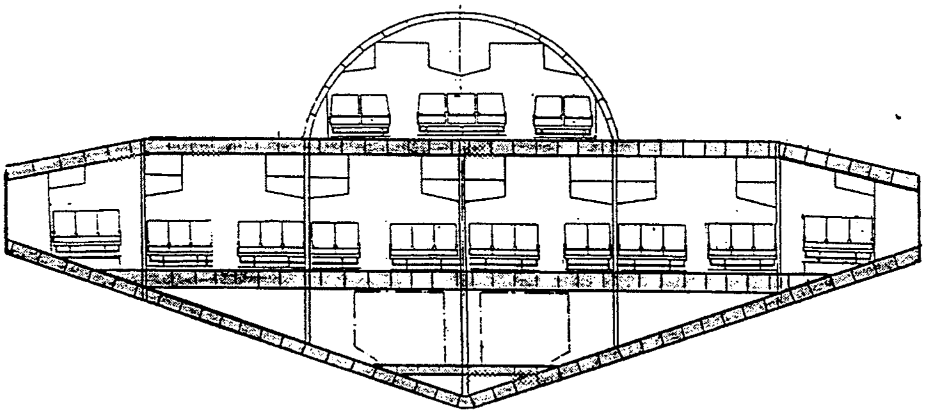


FIGURE 4 – Cross Section of Center Body

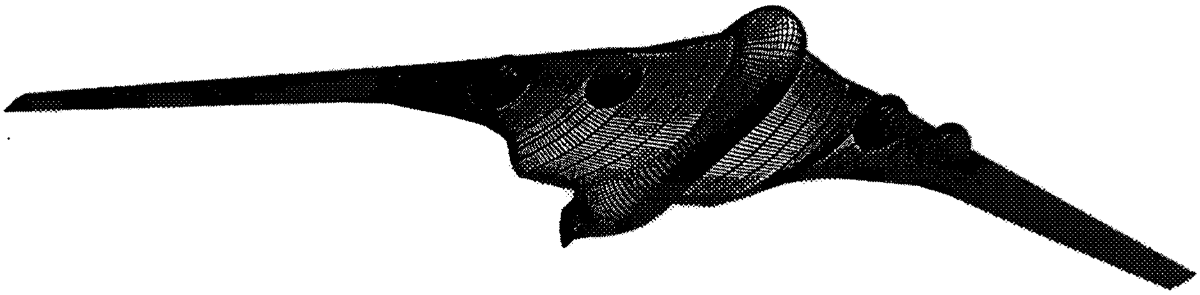


FIGURE 5 – CFD Fine Mesh Model

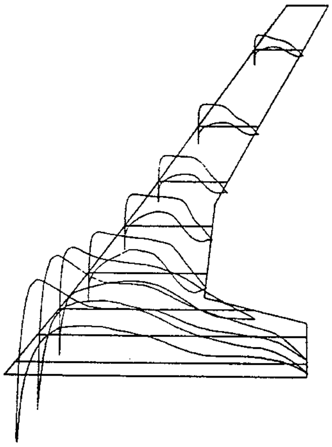


FIGURE 6 – Wing Pressure Distribution at Cruise

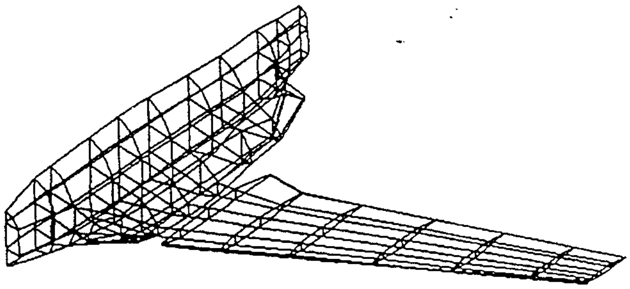


FIGURE 7 – 715-element FEM Model