CONCEPTUAL DESIGN FOR PASSENGER AIRPLANE OF VERY LARGE PASSENGER CAPACITY IN FLYING WING LAYOUT

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Abstract

The paper presents the results of investigations carried out at TsAGI to study possible characteristics of superhigh-capacity airplanes of a flying-wing layout. Using tools for computer-aided design, an integrated evaluation of the arrangement, weight characteristics, flight performance, fuel and economic efficiencies of a flying wing was made. The aerodynamic characteristics are based on designing of wing shapes with application of solution for inverse aerodynamic problems and direct problems using computational fluid dynamics methods (CFD). A series of experiments was performed in TsAGI's sub-and transonic wind tunnels for determining the aerodynamic characteristics of the configuration obtained. Fuel, weight and economic efficiencies are compared with those for known projects of superhigh-capacity conventional airplanes. It is shown, that a considerable reduction in flying-wing fuel efficiency (19%) as against a conventional airplane is feasible. Problems associated with implementing the flying-wing concept are discussed.

Contents:

- Prediction of air transport traffic volume and demand for airplanes;
- Features of "flying wing" concept;
- Comparison of "flying wing" concept and conventional fuselage configuration;
- Conclusions.

Figure 1

Forecasts of Requirements for Airplanes

A majority of forecasts predicts a significant growth in world air traffic. Especially high rate of the growth is projected for the Asia-Pacific Region (approximately 7-8 percent per year). Growth in air travel and congestion of some large airports in a number of regions call for developing airplanes with seating capacity in excess of the largest passenger transport Boeing 747-400.

According to assessments of Airbus Industrie[1], 864 airplanes with more than 500 seats will be required to 2014 (Fig.2).

DISTRIBUTION BY SEATS CATEGORIES
1995–2014 Forecast of AI, 1995

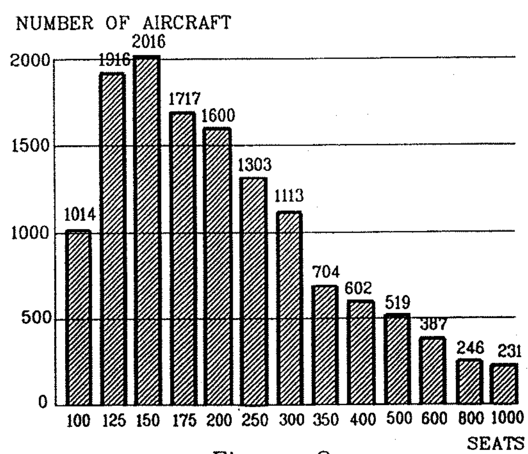


Figure 2

Although this quantity is not too large (-6.5%) relative to the total number of airplanes, nevertheless the number of seats accomodated by these airplanes accounts for about 20 percent of the total quantity of seats in airplanes of all categories.

Boeing projects [2] that the deliveries of airplanes with capacity more than 350 seats will amount to over 44% of the total sale (Fig.3)

The share of deliveries for over 500-seat airplanes may be estimated as much as 17% of the total volume of deliveries.

The growth in demand for airplanes with superhigh passenger capacity as well as the goal to reduce their operating costs by more than 15% [3] compared to B747-400 motivate the interests of airplane manufacturers and major airlines for similar airplanes.

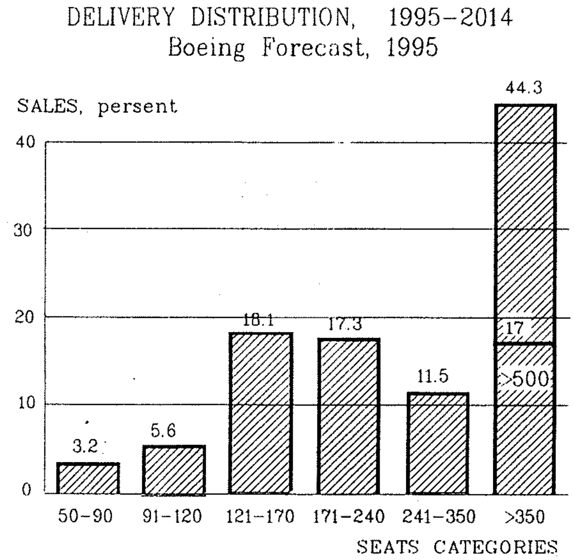


Figure 3

Capabilities of Flying-Wing Airplanes

During the history of aviation the airplane developers addressed themselves to the flying-wing concept (Fig.4).

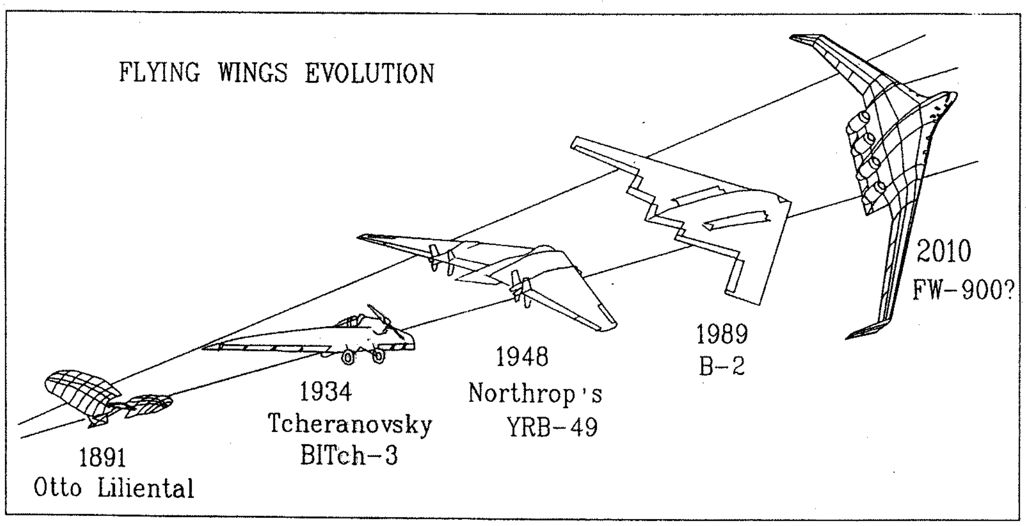


Figure 4

However these airplanes were not sufficiently large to accomodate all passengers and cargoes within the inner volume of the wing and till the 1980s the level of automation and reliability of control systems did not make it possible to solve reliably the problems on trimming and stability of these airplanes.

At present the problem on safe flight of a flying wing without a vertical fin has been solved in the military Northrop B-2

As applied to passenger superhigh capacity airplanes, the flying wing concept attracts the attention of researchers because of the following (Fig.5) reasons:

-increased dimensions of the airplane makes possible accomodation of the

REASONS FOR INVESTIGATING AIRPLANES OF "FLYING WING" CONFIGURATION WITH LARGE PASSENGER CAPACITY:

- Improved lift-to-drag ratio with sufficient center-wing section volume for passenger accomodation;
- Increase in intesity of air traffic in airports and air space;
- Possibility of reducing fuel consumption and DOC as compared with conventional airplanes.

Figure 5

most part of the load in the center-wing section, providing reduction in bending moment due to the aerodynamic loads;

- as theoretical and experimental studies made at TsAGI have shown, it has an improved aerodynamic

efficiency as opposed to conventional airplanes (Fig.6);

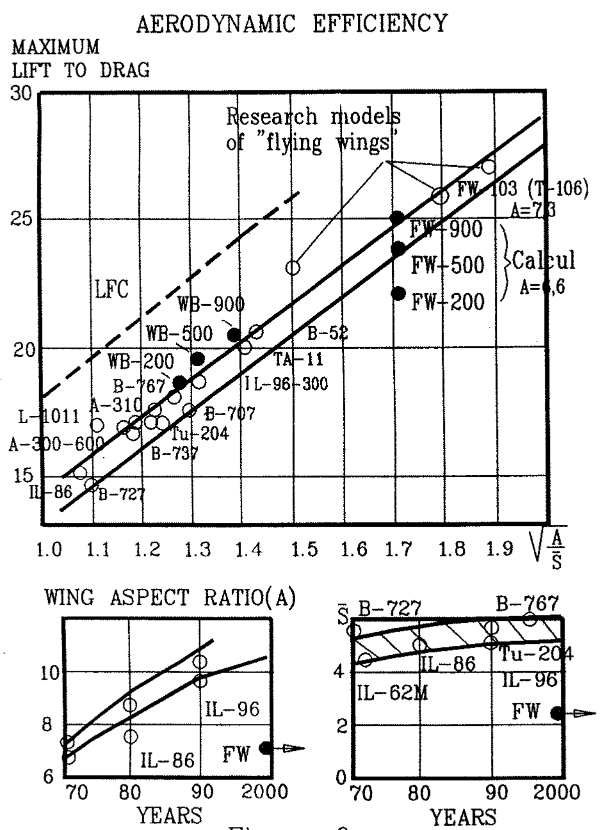


Figure 6

- it may have a better fuel efficiency and DOC relative to a conventional layout;

The implementation of the flying-wing concept necessitates studies of a number of "critical technologies" inherent in this layout, main of which are supposed to be:

- stability, controllability and flight safety;
- peculiarities of load distribution and stress-and-strained state over the integral structural elements in the center-wing section, weight efficiency of this arrangement;
- interaction with airport structures at taxying, parking; allowing for passenger loading and unloading, including in emergency situations.

Some of these problems have been studied at TsAGI since the end of the1980s.[4]

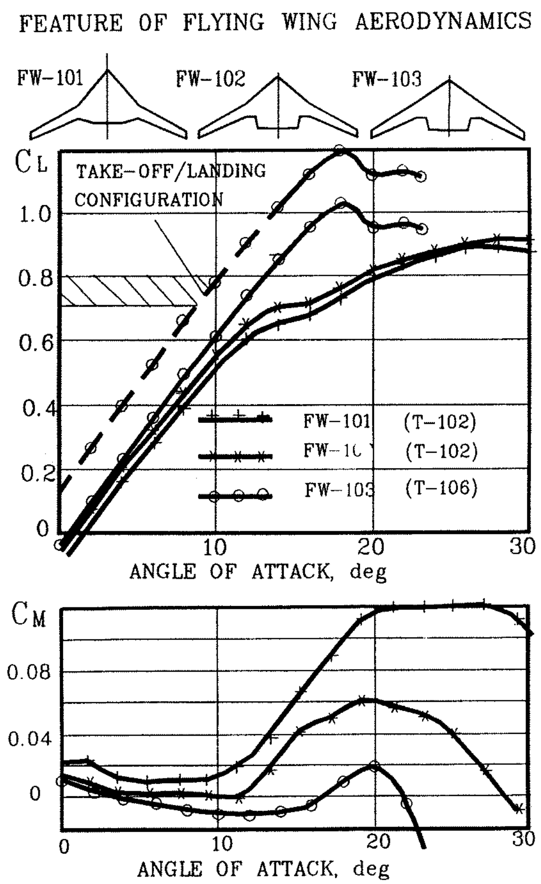


Figure 7

When selecting the wing planform, of great importance is the fact, that the palnform influences the non-linear characteristics of pitch moments in the region of large angles of attack.

Experiments with a number of planforms have enabled finding the planform for which a positive moment at large angles of attack in emergency situations can be counteracted by longitudinal controls (Fig.7).

Aerodynamic wing designing at a specified cruise Mach number with using methods of solving inverse problems to find airfoils with a desired pressure distribution, verification of the wing shapes derived by using CFD methods and tests in TsAGI's transonic wind tunnels, as well as the consideration of operational limitations made it possible to define the configuration of an airplane with superhigh seating capacity (750 passengers with 3-class arrangement, >900 - in tourist class) (Fig.8).

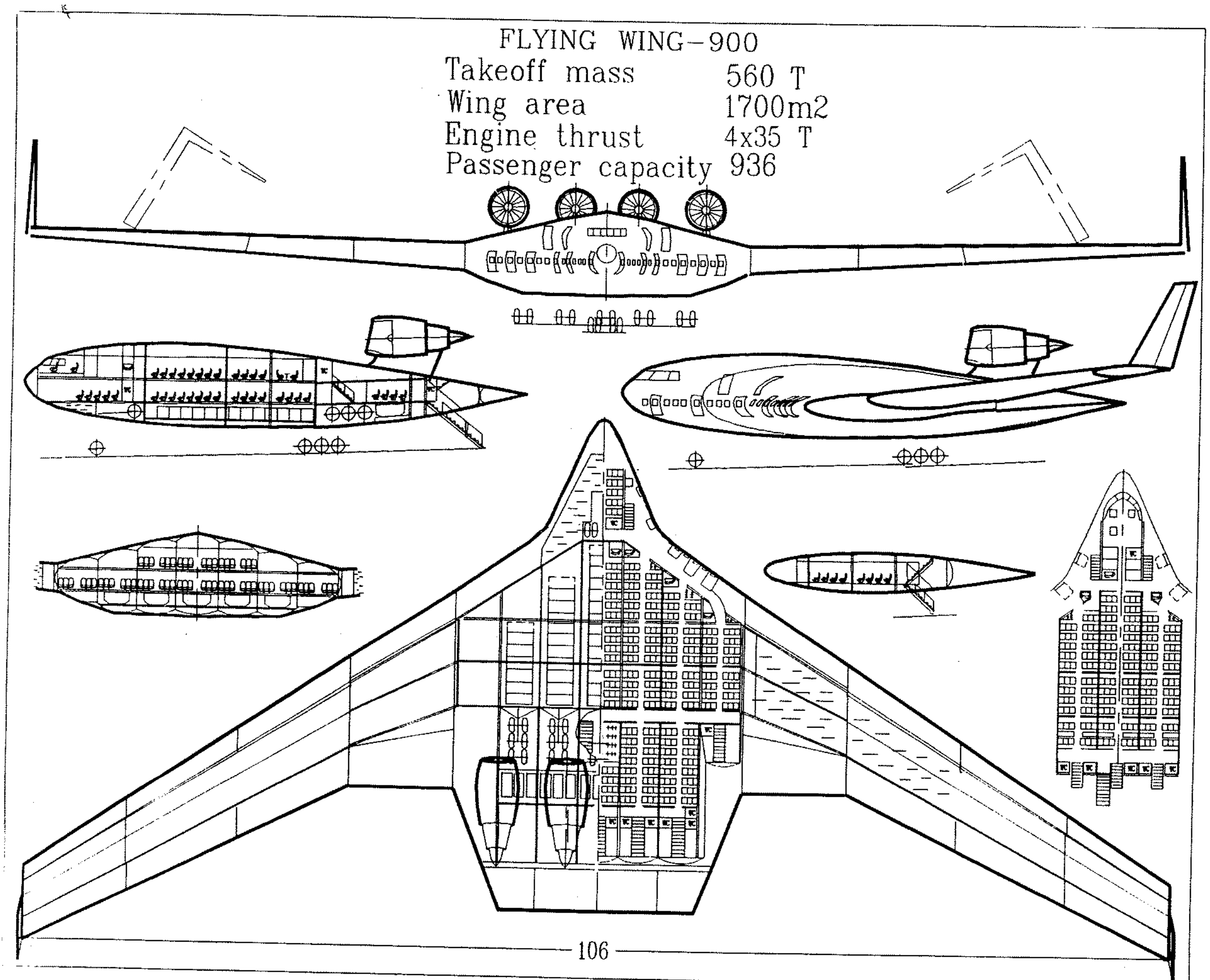


Figure 8

Also considered were problems on optimization of multifunctional control surfaces at the wing trailing edge and winglet (Fig.9).

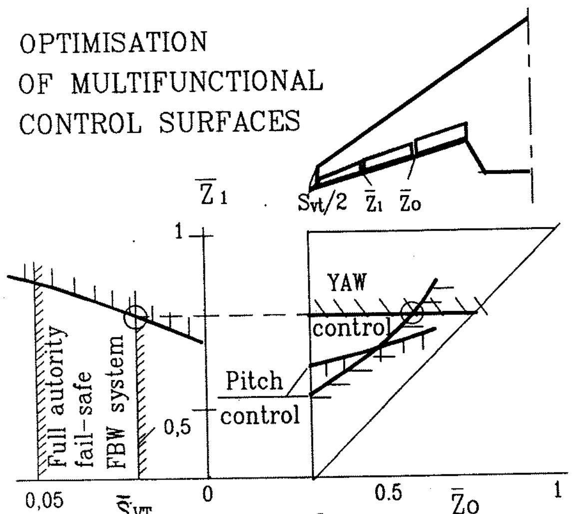


Figure 9

Comparison Between Flying-Wing and Conventional Airplane Layouts

Using a package of programs for computer-aided designing and the results of aerodynamic experiments, weight efficiency, fuel efficiency and direct operating costs for a flying wing concept and conventional airplanes were compared.

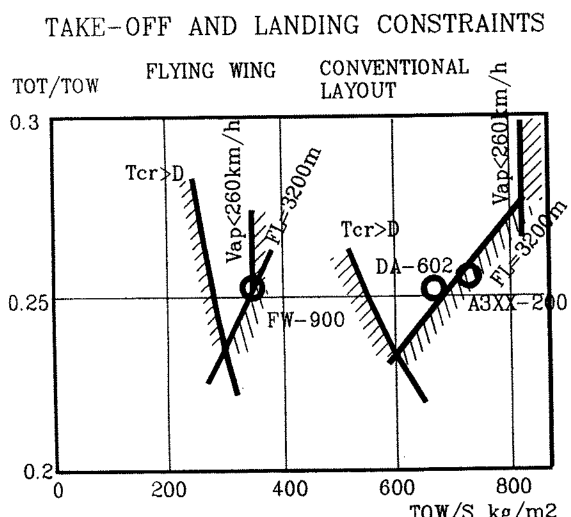
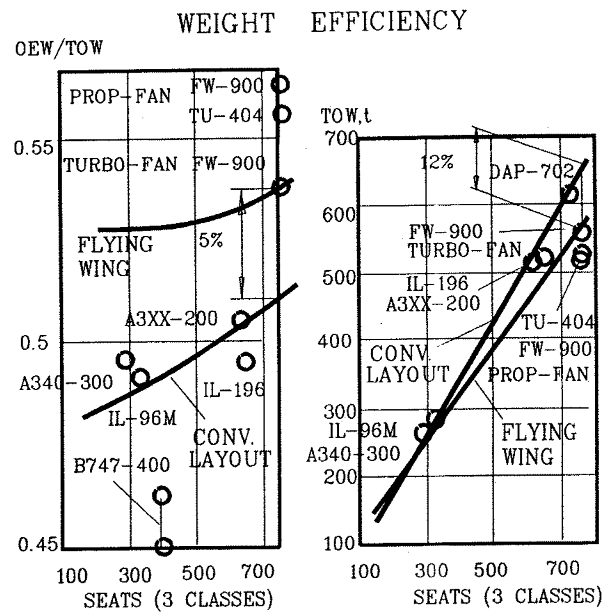


Figure 10

Limited capabilities of balancing the moment induced by high-lift devices of the flying wing require that the wing area be significantly larger (and the wing load-lower TOW/S, Fig.10), to satisfy takeoff/landing limitations. More than one-half the area of the wing plane projection (Fig.8) is the area of the center wing where the passenger cabin is located. The takeoff thrust-to-weight ratio for the flying wing can be equal to that of the conventional airplane, in case of meeting similar requirements to takeoff distance and approach speed (Fig.10).



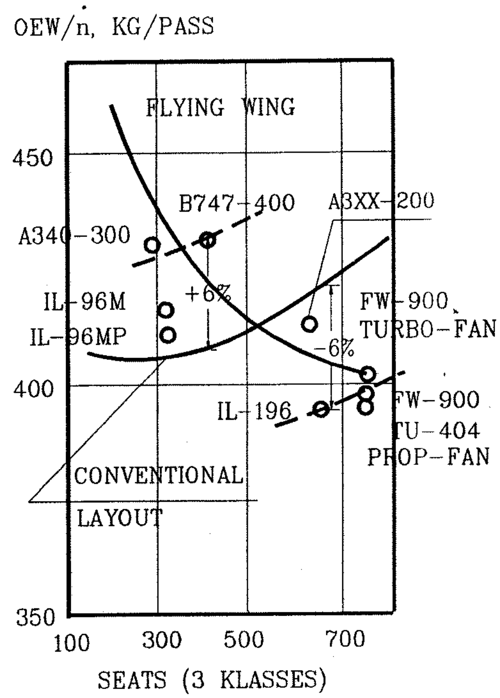


Figure 11

Despite the absence of the fuselage and horizontal tail, the ratio of operating-to-takeoff weight (OEW/TOW, Fig.11) for the 750-seat flying wing is 5% higher as compared with the airplane of a conventional layout.

However, because the lift-to drag ratio of the flying wing is higher by 25%, its fuel consumption is lower and the takeoff weight is less by 12% in flight with equal lateral range of 13000km (Fig.11).

As a result, the flying wing may have ratio of operating empty weight to the number of passengers, governing weight efficiency and operating costs, not worse than that for conventional airplanes. This finding is confirmed by data for current airplanes and airplane designs being developed.

The flying wing fuel efficiency far exceeds this characteristic for conventional airplanes. With 750 seats and similar engine type, the fuel consumption per pass/mile of the flying wing is 19% lower as compared with conventional airplanes (Fig.12). This is explained by a large L/D ratio of the flying wing.

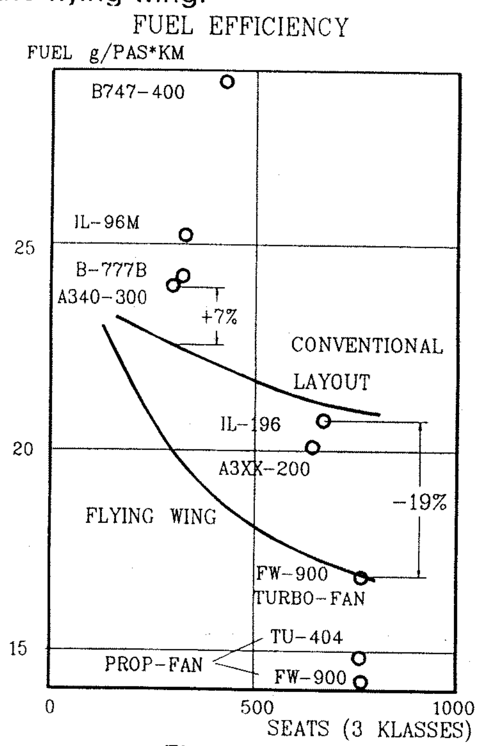


Figure12

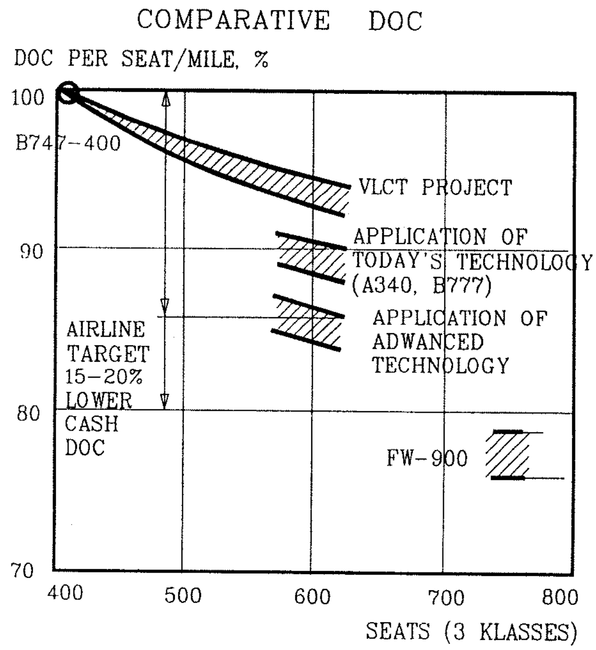


Figure 13

A comparison of direct operating costs reveals that the flying wing concept offers some advantage of DOC (Fig.13), which stems from a lower fuel consumption per pass/mile at values of operating empty weight per pass/mile close to those for conventional airplanes and slightly lower engine takeoff thrust (Figs.10,11).

As the fuel price increases the difference in DOC will become higher in favour of the flying wing configuration.

CONCLUSION

A series of studies carried out made it possible to define the advantage of the flying wing over conventional airplanes with respect to fuel efficiency and direct operating costs. However transition to a full-scale development of the plane requires that more sophisticated studies of some critical techologies peculiar to this configuration should be performed (Fig.14).

PROBLEMS ASSOCIATED WITH DEVELOPMENT OF "FLYING WING" AIRPLANES WITH LARGE PASSENGER CAPACITY

- Compatibility with airport structures;
- Introduction of advanced control sistems for providing stability, controllability and flight safety;
- Development of rational structural design;
- Passenger cabin arrangement and provision of passenger evacuation in emergency cases.

Figure 14

REFERENCES

1. Global Market Forecast 1995-2014
   Airbus Industrie, March 1995
2. Current Market Outlook
   Boeing, 1995
3. VLCT Status Report for Representatives of Russian Aviation Industry, 24.10.1994
4. G.S.Byushgens. Aviation of the XXI Century. Aviation Science and Technology N1, 1990.