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# ARRANGEMENT AND AERODYNAMIC STUDIES FOR LONG-RANGE AIRCRAFT IN "FLYING WING" LAYOUT

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**Keywords**: *flying wing configuration, long-range aircraft, aerodynamic model, wind tunnel experiments*

## Abstract

*The "flying wing"(FW) configuration is one of the most promising alternatives to conventional "tube and wing" scheme. New concept of moderate capacity long-range FW aircraft is investigated in TsAGI over the last years. Various arrangements have been studied with different passenger accommodation, engine positions, control system architecture, etc.*

*Special aerodynamic model with flexible arrangement of tail units, wing tips and nacelles has been tested in several wind tunnels. This paper presents some results of the experimental studies alongside with accompanying CFD results.*

## 1 Introduction

The "flying wing" or blended-wing-body configuration is considered by aviation community as a most promising alternative to conventional "tube and wing" scheme in the long-range aircraft segment of market in the 21st century. Despite of the long list of shortcomings FW/BWB passenger configurations, at least potentially, possess of three serious advantages: high lift-to-drag ratio due to decreased relative wetted area, favourable weight distribution along span and reduction in the perceived ground level noise due to shielding of over-wing engines by the airframe [1-3].

There is no established point of view on optimal FW layout at present. Over many years the conventional configuration reached its maturity and refinement, therefore the FW configuration can compete with it on equal terms only with the same thorough consideration of different aspects. Even now, as seen from preliminary investigations, the FW is competitive. There is no doubt that due to FW intrinsic integrated nature benefits provided by MDO will be higher for it as compared with a conventional configuration. That is why in the USA [4, 5] and Europe [6, 7] large multidisciplinary studies looking for the different aspects of mutual synergism between aerodynamics, structure, propulsion system and controls were initiated. Novel ideas and concepts progressively evolve inspiring enthusiasts of FW schemes.

New concept of moderate capacity long-range FW aircraft in a single-deck layout is considered in TsAGI over the last years. Unlike the huge 800-seater configuration [8-10] that could be realized only by international efforts, a small-size airplane features a lower technical risk and requires less investments for its launch. Various arrangements have been studied with different passenger accommodation, engine positions, control system architecture, etc.

Special aerodynamic model with flexible arrangement of tail units, wing tips and nacelles (Fig. 1) has been designed, manufactured and tested in several sub- and transonic wind tunnels. The main task of the experimental program is to investigate the effect of different nacelles and tail accommodation at cruise ($M = 0.85$) as well as at low speed regimes and to compare wind tunnel results with CFD data. The effectiveness of different control surfaces is of interest too.

This paper presents some results of the experimental studies alongside with accompanying CFD results. A description of the aerodynamic design procedure is given and some thoughts about engine-to-wing interference are presented. The paper concludes with suggestions for the most promising nacelle and tail positions and proposals for future research.

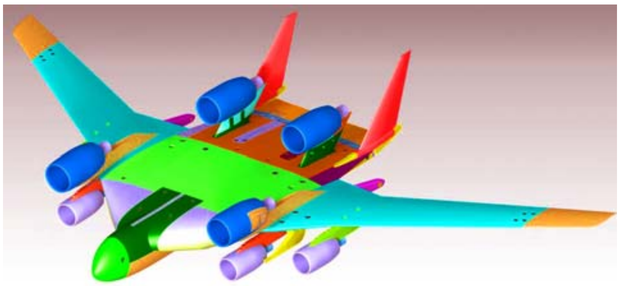

Fig. 1. Principle assembly of the aerodynamic model

## 2 Description of the layout and aerodynamic model

In recent years FW investigations lasted in TsAGI, although not so intensively as under the grant ISTC №548 [8, 9] at the threshold of the centuries. In these investigations the emphasis is made on the advanced long-range middle capacity aircraft configuration (200-250 seats) with modest requirements for an airfield length. Unlike the 800-seater configuration a small-size airplane features lower technical risk and requires less investment for its launch. Besides, it meets the 80-meter non-tip-folded box requirement. The problem of a passenger emergency evacuation is solved easier for a smaller FW.

Two points of view compete on the future prevailing transportation scheme. A large-size aircraft of the A-380 type gives the best fit to the hub-and-spoke transportation concept, while the aircraft of a smaller size could be exploited for direct links between pairs of cities. Thus, the FW under TsAGI study fits the second concept.

In choosing between conventional and FW configuration the required range is a governing factor. At a very long range (~15000-16000 *km*) the take-off weight of a conventional aircraft grows exponentially, while for FW aircraft the gradient is less due to a higher L/D-ratio. Cruise Mach number as high as M = 0.85 is necessary to be competitive with current classical “tube and wing” fleet. Examples of the 200-seat designed configurations (3-class arrangement) in a single-deck layout are shown in Figs. 2-3. Preliminary estimations show that maximum take-off-weight of the aircraft would be about 150*t* with maximum span of about 60*m*.

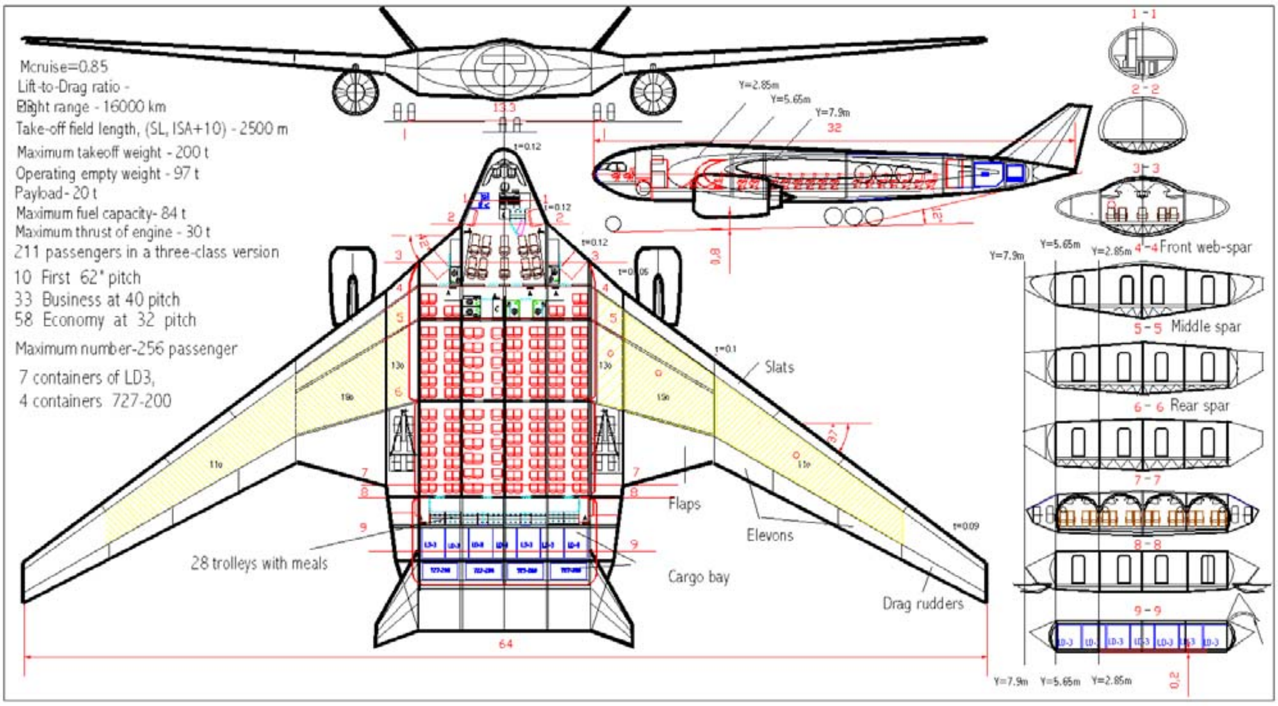


Fig. 2. General views of 200-seat long-range aircraft in FW layout with under wing engine accommodation

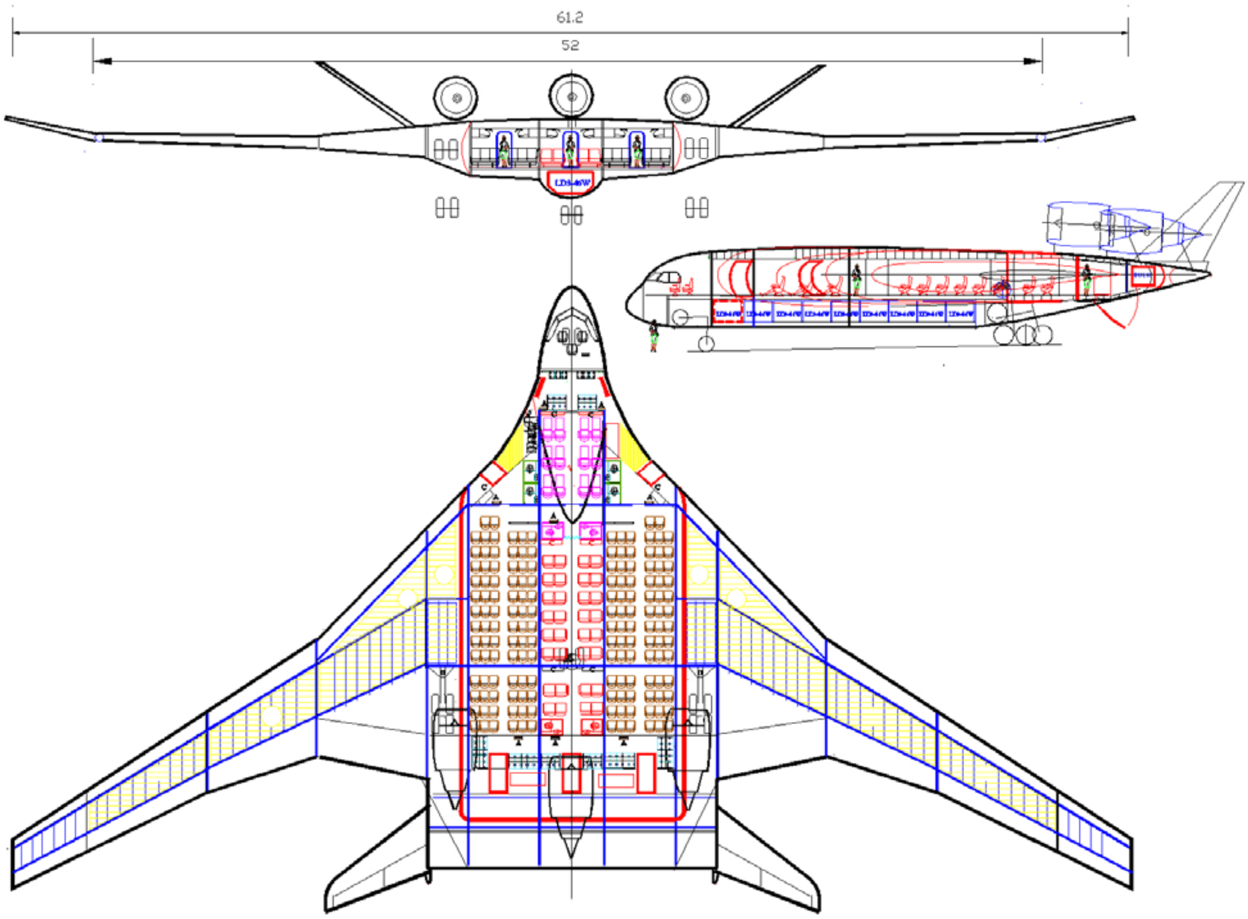


Fig. 3. General views of 200-seat long-range aircraft in FW layout with over-center-wing engines

Typical cabin cross-section is presented in Fig. 4. The main deck height is 2.1*m*. There are no windows at all, so the cabin interior problem and entertainment systems arrangement are of great importance. Boarding is provided through the exits in the fuselage nose body and in the leading edge of the center wing section. There are extra emergency exits arranged at the rear of the passenger cabin. LD3-46W containers are located under the central section of the cabin in the pseudo-body continuation of the nose part.

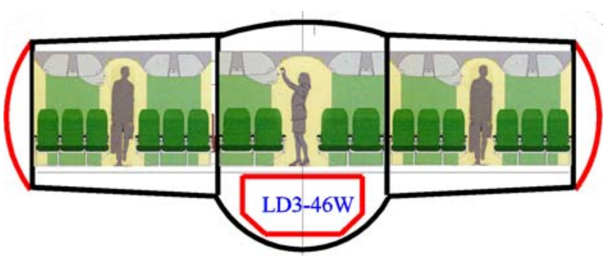


Fig. 4. Cabin cross-section

Seating capacity variation (i.e. airplane family creation) might be achieved through either lateral inserts (Fig. 5), or full (Fig. 6) and partial second-deck setup in centre body.

It should be noted that FW configuration strongly depends upon chosen location of the engines (see Figs. 2, 3). For example, rear position of the engines over the wing shifts centre of gravity rearward that requires a proper adjusting of the wing planform, revision of the center wing structure, etc. That is why the wing-engine interference task is of the first priority for the design. Another important issue concerns the configuration and designation of control sections along the trailing edge of a wing and, probably, tail/fin units.

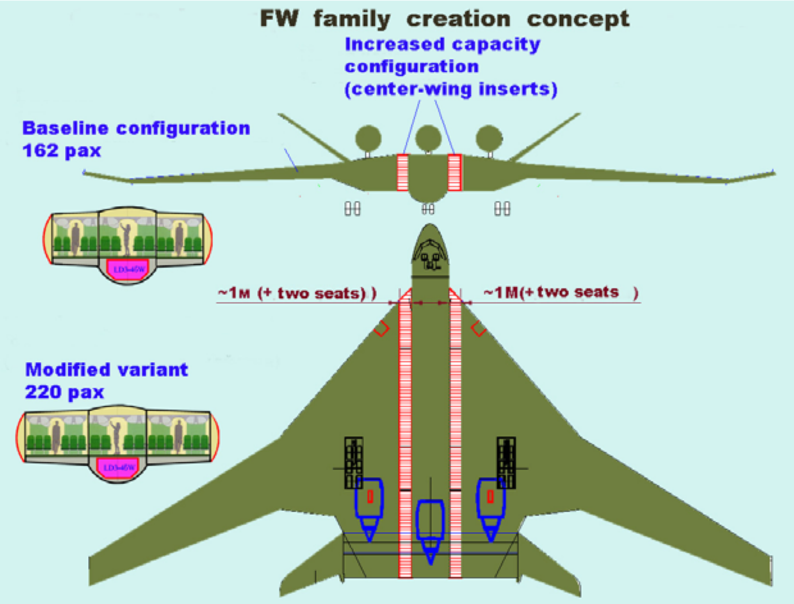


Fig. 5. FW family creation concept

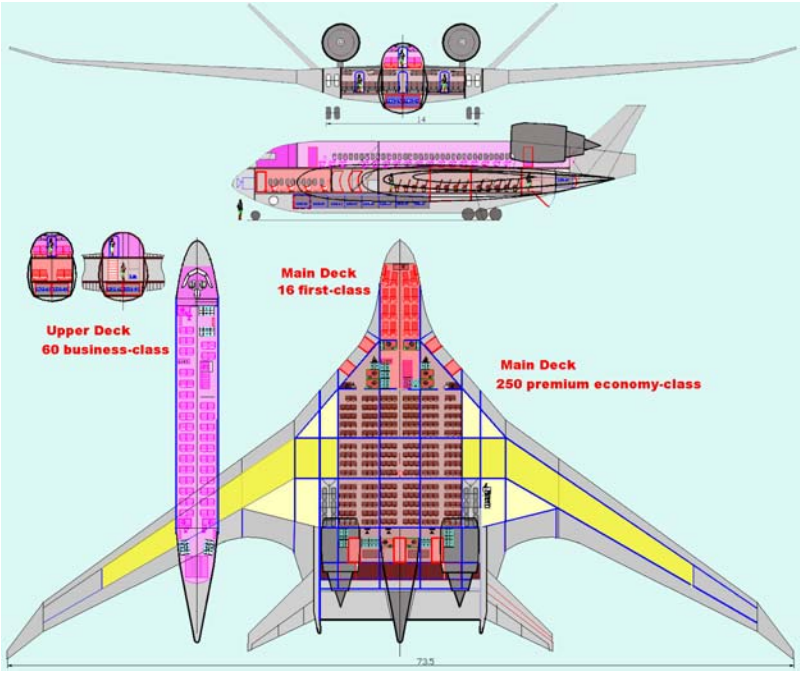


Fig. 6. Double-deck central body

Special aerodynamic model with flexible arrangement of tail units, wing tips and through-flow nacelles has been designed and manufactured in TsAGI (Figs. 1, 7). Besides, 10% elevator deflected by up to ±25° is placed at the rear of the center wing section. The span of the model of 1.8*m* gives a possibility to test it in several sub- and transonic TsAGI wind tunnels with sufficiently large MAC Reynolds number value. Aerodynamic design targets were defined to be as follows:

- obtain high lift-to-drag ratio at cruise Mach number M = 0.85;
- investigate engine-airframe interference at different nacelle locations;
- investigate different tail configurations;
- investigate different wing tip devices;
- estimate center wing and tail elevators sensitivities;
- compare experimental results with preliminary CFD data.

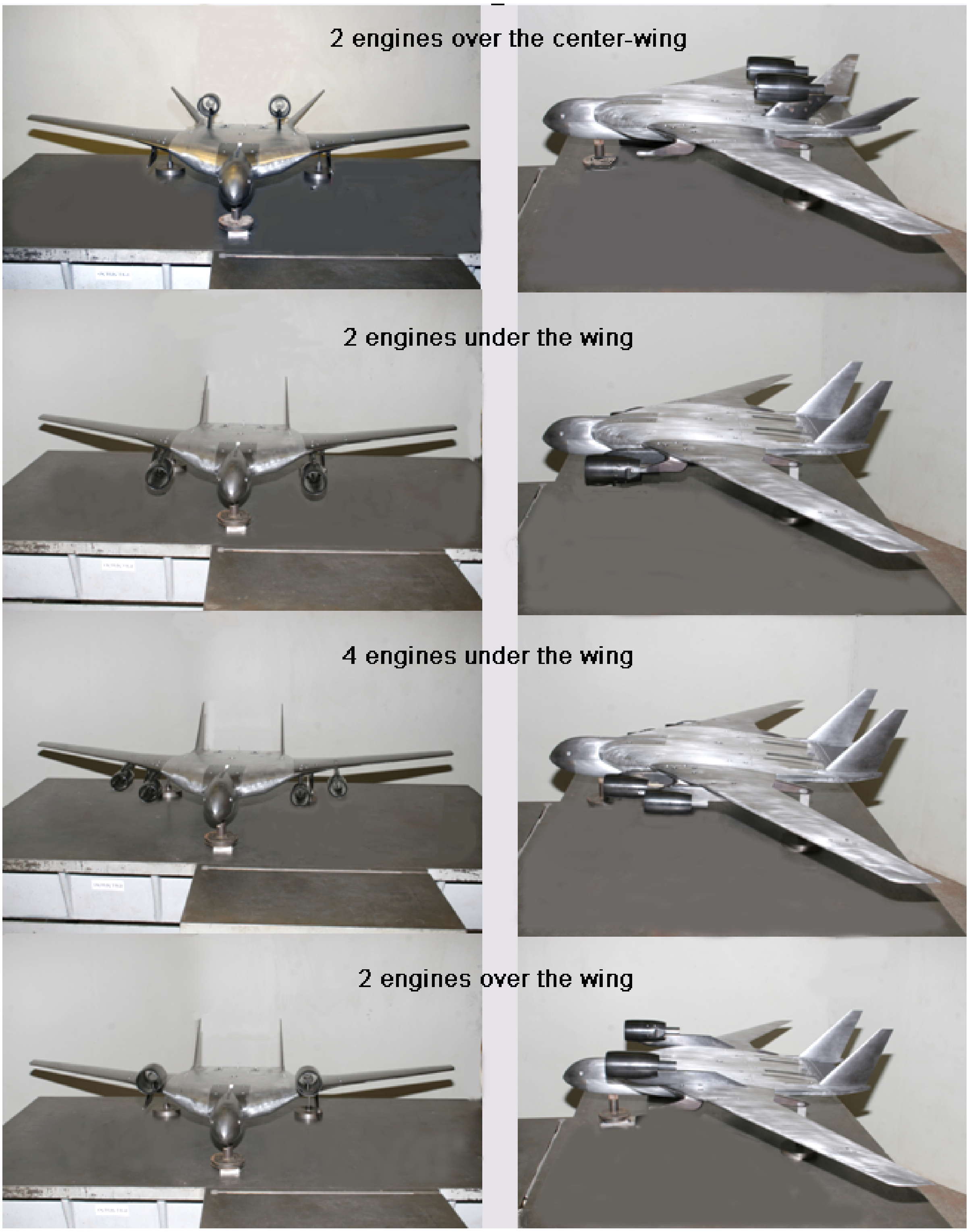


Fig. 7. Variants of the aerodynamic model FW-2011

The wing is configured basing upon seven base sections (Fig. 8). Center wing sections have flatten surface for convenience of passenger cabin arrangement, large leading edge radii for forward extra exits and small reflex at the trailing edge to obtain self-balance at cruise. Outer wing profiles are of usual supercritical nature but with somewhat smaller rear loading, again to meet balance requirement. Local lift coefficient is much higher at the outer wing thus critical flow phenomena (shocks & separation) arise there earlier leading to shock-induced separation at high speed and moment pitch-up at increased angles of attack.

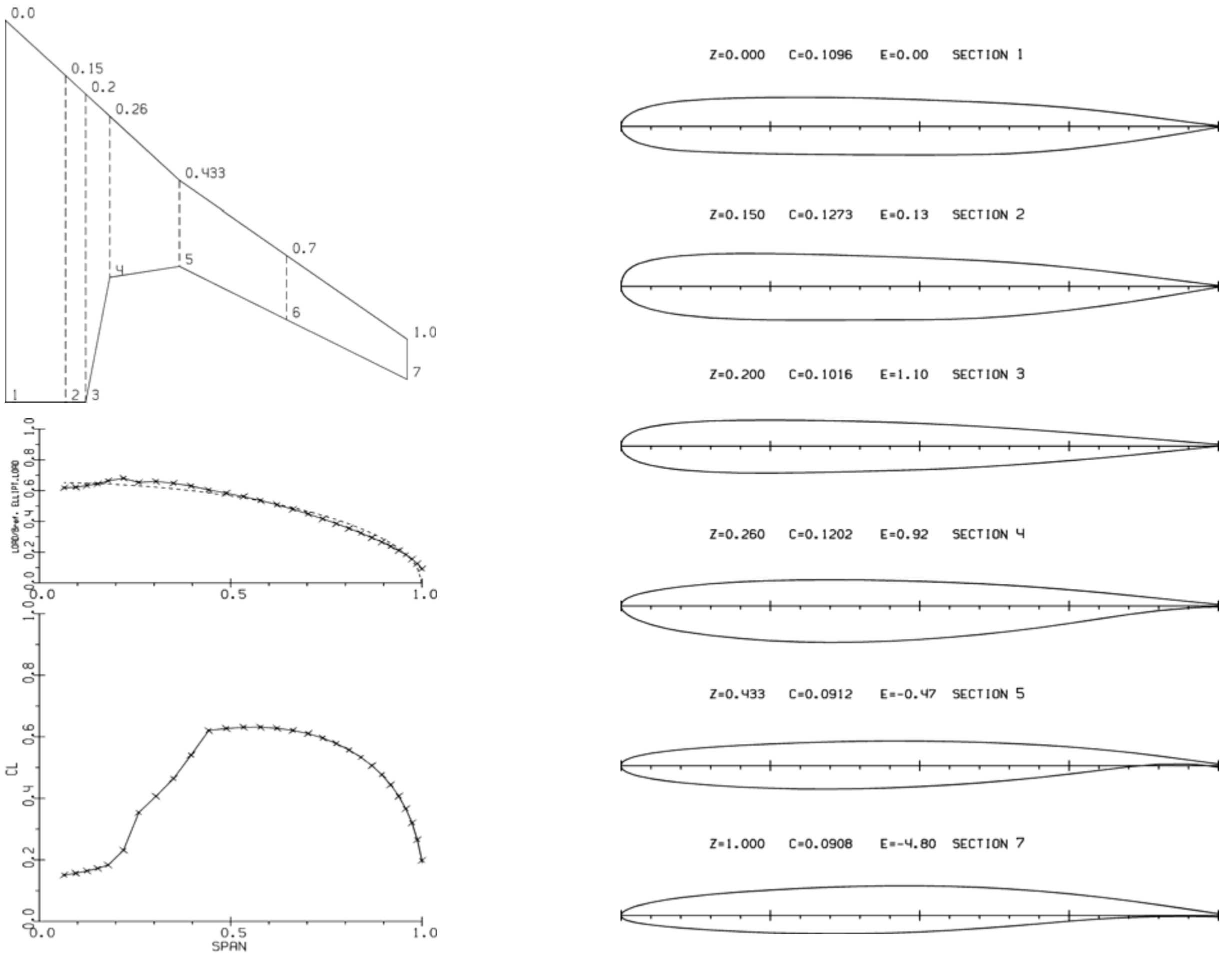


Fig. 8. Wing geometry and span load&$C_L$ distribution

The geometry of the wing was defined by usual design procedure, consisting of three phases [11]: choosing of an initial geometry, refining of pressure distribution at cruise point with the aid of inverse method and utilization of multi-regime optimization procedure for final definition of the base airfoils shapes. Fast full-potential + boundary layer direct code BLWF-56 [12] is a key element of this design aerodynamic procedure. No measures were taken at designing to account for unfavourable engine-airframe interaction, with the intention to obtain estimation of “pure” interference effects magnitude. Simple axisymmetric through-flow-nacelles with symmetric pylons have been aligned in parallel with center body axis.

Calculated pressure distribution in wing sections at $M = 0.85$, $C_L = 0.5\&0.55$ (based upon wing trapezium area) is shown in Fig. 9. Positive pitching moment is necessary to provide self-balancing at cruise – that is why peaky pressure distribution with no rear loading develops over the center-wing section. Thus, it is evident that placing engine nacelles near the leading edge over the wing would be the most critical one because of high local velocities in this region.

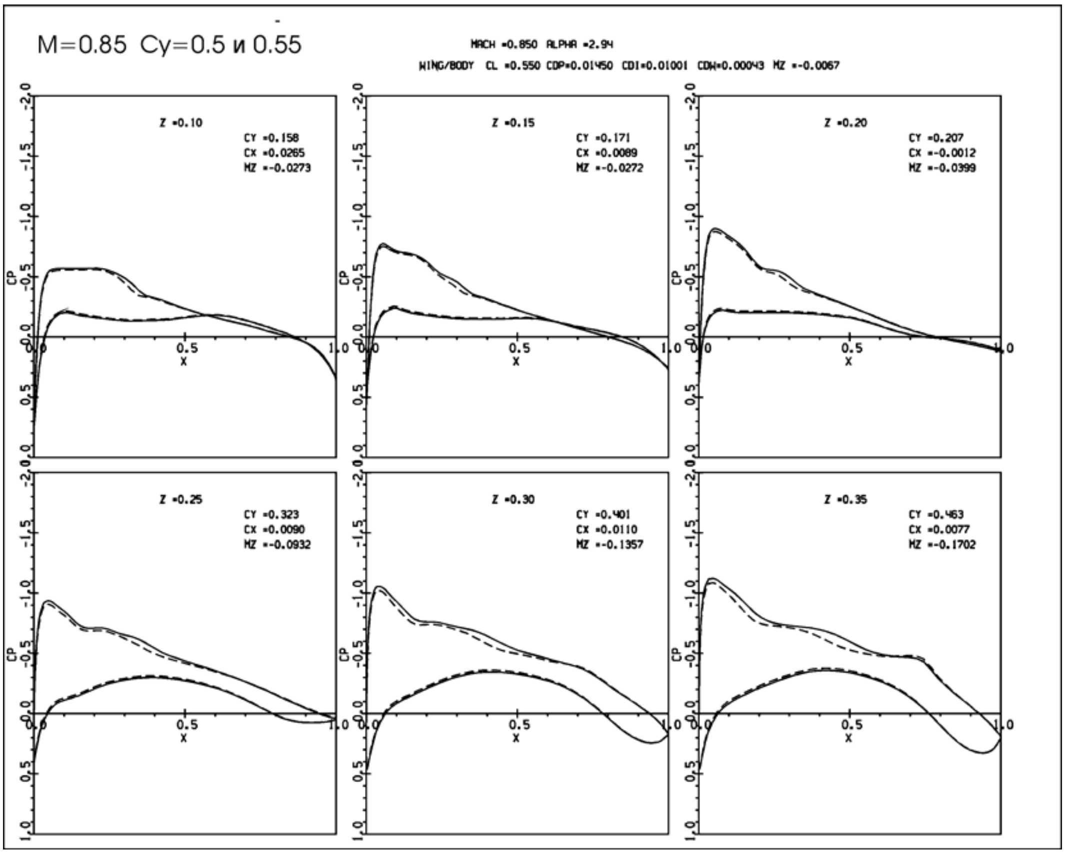


Fig. 9. Calculated pressure distribution over the inner sections of the configuration

Perturbed velocities are much less near centre section trailing edge. Aircraft-balancing reflex provides a local decelerated velocity region which is suitable for engines’ arrangement. The rear location of engines weakens their adverse effect on swept outer wings also. At the same time centre-of-gravity backward displacement leads to the need of the wing sweep increase which enhances the pitch up at high angles-of-attack. Problems related to the shift of c.g. position between empty and loaded airplane grow as well.

## 3 Selected results of experimental studies

Low-speed tests have been carried out in T-102 wind tunnel (Fig. 10) at speed V = 50 *m/sec*. Encouraging results were obtained concerning effectiveness of the center-wing elevator – it does not lose power at high angles-of-attack (Fig. 11), enabling sufficient negative pitching moment for recovering the airplane from stall regimes. Fins installation enhances the efficiency of center-wing elevator. For the next phase of experimental studies fins with installed rudders are also planned.

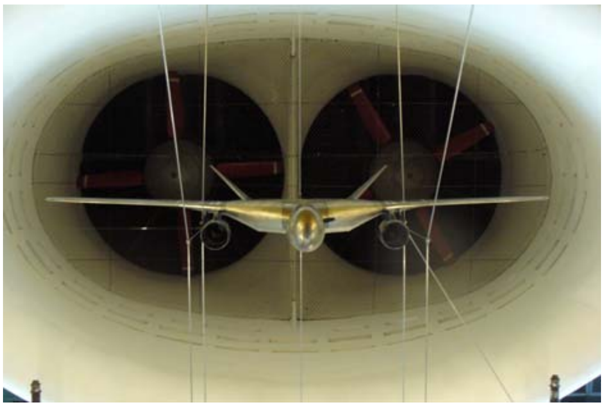

Fig. 10. FW-2011 model in T-102 low speed wind tunnel

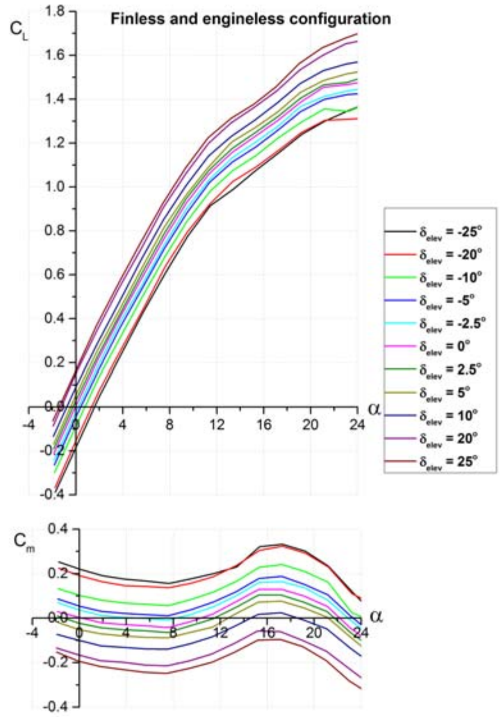


Fig. 11. Center wing elevator effectiveness at low speed

Transonic and high-Reynolds-number aerodynamic characteristics were obtained in T-106 wind tunnel with perforated circular test section (Figs. 12, 13).

Fig. 12. FW-2011 model in T-106 transonic wind tunnel

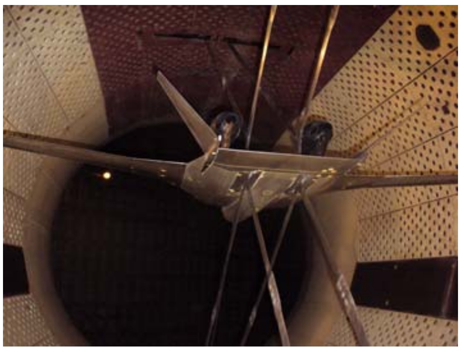

Fig. 13. FW-2011 model in T-106 transonic wind tunnel, back view

Lift and pitching moment behaviors improve at high Reynolds numbers, stall angle increases and center wing elevator keeps its effectiveness (Fig.14).

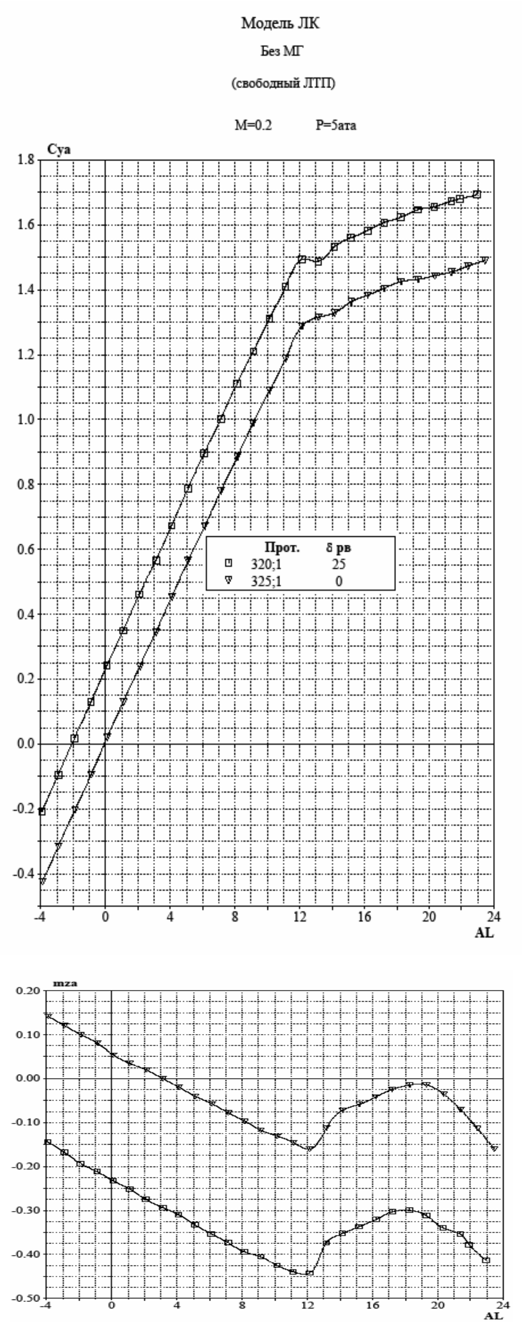


Fig. 14 – Lift and moment characteristics at high Re

Cruise aerodynamics of the model was estimated by typical for wind tunnel T-106 "*α = const*" runs from M = 0.45 till M = 0.9. Isolated wing as well as configurations with different nacelle positions has been investigated.

Wind tunnel tests reveal configurations with the most favourable aerodynamic interference – two under-wing pylon-mounted engines. Four under-wing engines are also satisfactory, while both over-wing initial engine positions although reducing community noise, suffer from the early onset of the wave crisis phenomena (Fig. 15). It is evident that thorough aerodynamic design work is needed to weaken unfavorable mutual interaction by an appropriate shaping of the neighboring elements in the interference zone. Some simple modifications of the model were fulfilled with clear improvement in the rear-upper-nacelle configuration characteristics, but it still lose in comparison with engine-under-wing configuration.

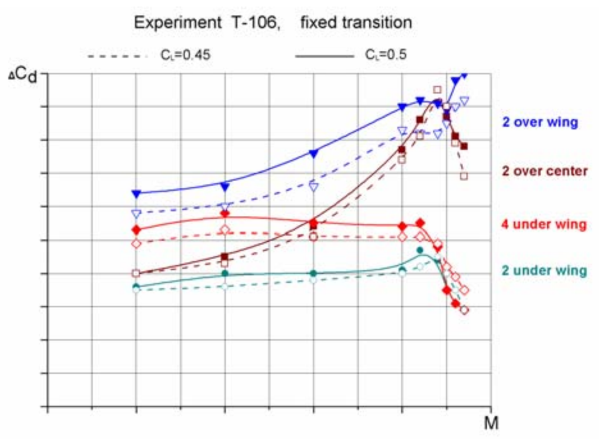


Fig. 15. Drag increment due to nacelle installation

## 4 Conclusions

Different FW configurations were studied in TsAGI for 200-seat long-range aircraft. For one of the promising configurations a new aerodynamic model FW-2011 was designed and manufactured. The model has flexible construction that permits nacelles, fins and wingtips geometry variation. The first phase of the wind tunnel campaign is fulfilled at sub- and transonic regimes. Some valuable data for identification of future studies directions and areas of ongoing activities were obtained.

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