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AERODYNAMIC STUDIES ON LOW-NOISE AIRCRAFT WITH UPPER ENGINE INSTALLATION

Bolsunovsky A.L., Bragin N.N., Buzoverya N.P., Chernyshev I.L., Ivanyushkin A.K., Skomorohov S.I.*
***TsAGI, Zhukovsky, Russia**

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Abstract

Environmental requirements, such as community noise and emission limits will play ever increasing role in the foreseen future of the civil aviation. Options for reducing noise are limited from the current configurations, hence new radical green designs might be required to meet the severe next-generation aircraft targets, claimed at present by NASA, ACARE and other organizations which will undoubtedly be followed by ICAO authorities to a greater or lesser degree.

Engine contributes a lot in the whole aircraft noise level. TsAGI carries out systematic investigations on the "silent" aircraft with engine noise shielding by the airframe parts. Various arrangements with different engine installations and propulsion system architecture were studied. A description of the aerodynamic peculiarities of each scheme alongside with the details of aerodynamic design procedure is given in this paper. Selected results of the experimental studies are presented.

1 Introduction

While considerable progress has been made to reduce the noise emission of airliners, mainly by engine technologies advance, an amount of airport-neighboring public complaints continues to grow that, for instance, has already resulted in night-time flying restrictions at 107 international airports in Europe (2012). Environmental requirements, such as community noise and emission limits will play an ever increasing role in the foreseen future. That is why a low-noise level airplane will become more competitive with other characteristics being equal. Unfortunately, changing the configuration for reasons related to noise emissions has as a rule negative effect in terms of weight and aerodynamics efficiency [1].

Focusing on aggressive noise reduction may lead to cardinal changes in our vision of "normal" airplane configuration. Many investigators believe that induced by the engine itself noise reduction potential is depleted and that engine noise should be shielded by airframe parts in order to achieve real "silent" aircraft which is virtually imperceptible to human ears. Such technologies introduce a number of technical challenges and are of considerable risk.

Intensive studies on "silent" aircraft configurations to meet stringent NASA and ACARE (see [2]) environmental goals for the next decades have been initiated in the USA and Europe. TsAGI also carries out systematic investigations on this topic and tries to account for the necessary technologies development in different disciplines, especially in aerodynamics and propulsion system. Various arrangements with different engine installations and propulsion system architecture, including distributed propulsion system and boundary layer ingesting (BLI) engines, have been studied. Configurations with upper engine position are the most attractive ones in terms of ground noise suppression.

Several aerodynamic models with upper engine installation were designed, manufactured and tested in TsAGI's wind tunnels. They include conventional "tube and wing" configurations as well as non-conventional "lifting fuselage" and "flying wing" layouts. A description of the aerodynamic peculiarities of each such scheme alongside with the details of aerodynamic design procedure are provided in this paper without emphasis on aeroacoustics simulations. Selected results of the experimental studies are presented.

2 Aerodynamic design problems with low-noise configurations

The most popular idea for the engine noise significant reduction is its shielding by different airframe parts. From this point of view various unique configurations have been proposed by numerous researches. Shielding may be organized by a fuselage and an empennage (Figs. 1-2 [3]), by a wing itself (Fig. 3 [4]) or by the whole airframe (Figs. 4 [5], 5 [6]).

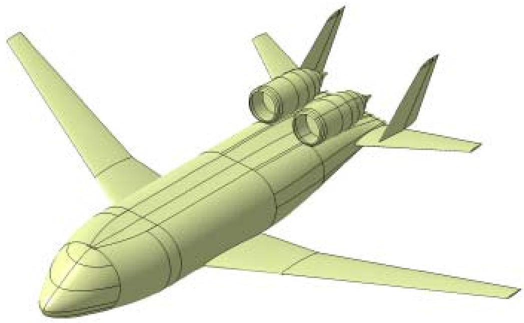


Fig. 1. Configuration with engines on top of an oval fuselage

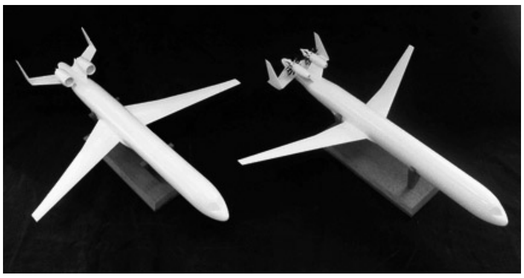


Fig. 2. Low noise configurations studied in European project NACRE [3]

Fig. 3. NASA low noise configuration [4]

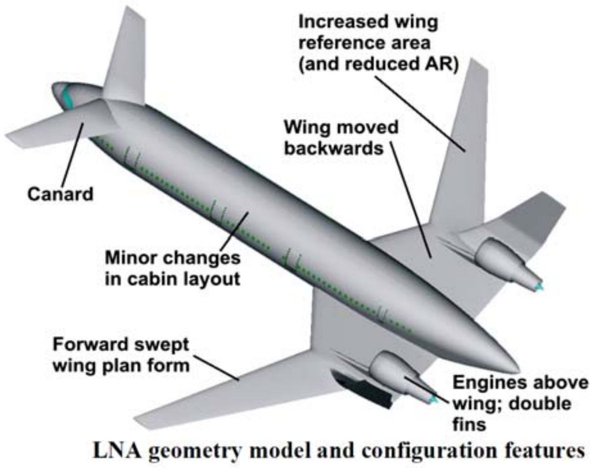


Fig. 4. DLR low noise aircraft [5]

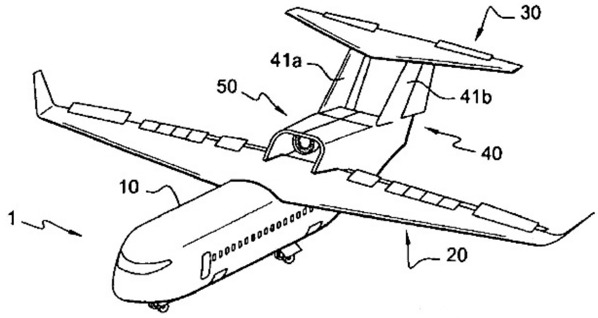


Fig. 5. Low-noise configuration [6]

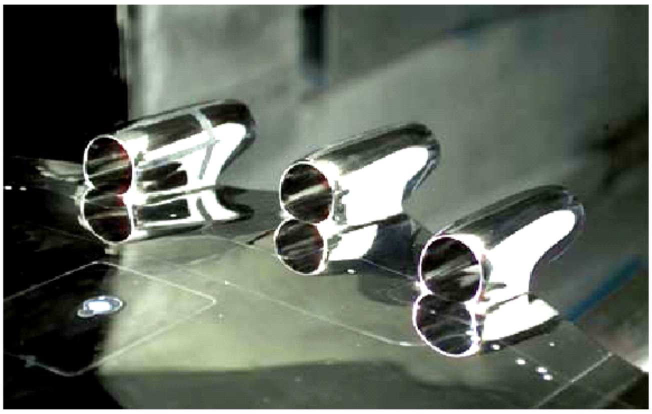
A design should meet economic efficiency requirements no matter how it tends to satisfy environmental goals. A low-noise configuration with the round-the-clock operation ability may bring profits even with slightly increased price and fuel consumption [5]. However, many technical challenges might be overcome before a cardinally new silent aircraft concept become real. New generation engine development is the very finance- and time-consuming process and that is true even for conventional engines. Considering civil aviation conservatism and manufacturers' disability to run large technical and financial risks, it is reasonable to expect noisy-less configurations with proven ultra-high bypass ratio engines first. Because of their large dimensions it is natural to setup superfans on top, at the same moment upper position of engines will prevent noise downward propagation. Over-wing engines has been avoided for a long time due to their adverse transonic interference with the wing, but the success of Honda-jet [7] gave a new credibility to such configurations.

Upper engine installation not only abates ground noise by the shielding but as well possesses a number of the additional benefits like hazard reduction of foreign objects penetration into the air intake, withdrawal of limitations on engine diameters and bypass ratios, possibility to truncate landing gears, lack of a gap of the slat, etc. However, such layouts have essential shortcomings as well. Over-wing engine arrangement leads to increased cabin noise [8] demanding additional weight of sound-absorbing material. Besides, biased upwards thrust leads to the undesirable negative pitching moment, both in take-off and cruise conditions. Engine maintenance would become noticeably complicated. Rear engine installation causes centre-of-gravity movement problem. At last, close engines accommodation increases the risk of a double failure from a blade loss or a disk burst of single engine.

Unfavourable aerodynamic interference of engines with shielding surfaces is one of the main technical barriers. The engine disposed over the upper wing surface operates in a field of increased velocities and, accordingly, an unfavorable aerodynamic interference would exhibit. For instance, in European Project ROSAS [9] mounting engines over the wing leading edge was found unacceptable due to the occurrence of intense shock waves. The authors experienced the same troubles with the “flying wing” (FW) layout in TsAGI (Fig. 6) (see also [10]). Both calculations and experiments showed presence of the intense shock waves even though nacelles proportions to the local chords were smaller as well as local lift coefficients.

Fig. 6. TsAGI “flying wing” aerodynamic model with forward position of the upper nacelles

Arranged near centre wing trailing edge pylon mounted engines cause somewhat less troubles, although thorough development of local aerodynamics is required too. Boundary layer ingestion nacelles could lead to a number of benefits, including reduced ram drag, lower structural weight, and less wetted area than a strut-mounted engine configuration (see Fig.7 taken from [11]).



BWB model with boundary layer ingestion nacelles.

BWB model with pylon mounted nacelles.

Fig. 7. Different nacelle locations on the top surface of BWB center wing section [11]

In this case an inlet flow distortion and inlet pressure recovery losses are proved to be the main problems. These questions were carefully studied in TsAGI through experiments with a special "lifting fuselage" model (Fig. 8).

Fig. 8. Aerodynamic model of the regional aircraft with over-the-fuselage nacelles

Experiments showed that side-edge trailing vortices cause the boundary layer along fuselage symmetry axis to thin and that inlet pressure recovery losses are acceptable (Fig. 9).

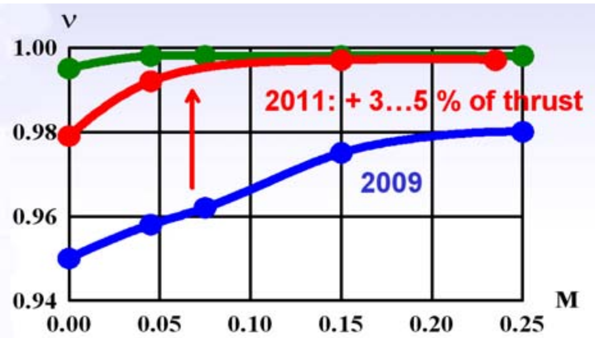


Fig. 9. Experimental inlet pressure recovery values

Among all studied low-noise layouts, configuration with engines over the trailing edge of a wing seems to be the most catching one. More thorough description of TsAGI' research on aerodynamic peculiarities of this layout is given in the next chapter.

3 Over-wing-trailing-edge engine configurations

Over last years there was a boom in publications [8,12-15] concerning over-wing-trailing-edge engine configurations. The main driven forces of this new surge in interest are the expectation of fuel-efficient ultra-high-bypass-ratio turbofans (or superfans) advent in the near future with a corresponding provided drop in fuel consumption and jet noise. Large fan diameter makes it difficult to mount engines in the conventional under-the-wing configuration, whilst over-the-wing engines have no constraints on their dimensions. Besides, the wing would shield fan noise which is the main noise source for superfans. At the same time truncated landing gears would serve to diminish airframe noise.

TsAGI studied aerodynamic interference between wing and over-wing-trailing-edge engines for long-range aircraft with high cruise Mach number and for short-range aircraft with smaller M_{cruise}.

Calculations and wind tunnel experiments (Fig. 10) showed that large wing sweep of high-speed aircraft makes it difficult to mount engines over the wing because intense negative aerodynamic interference appeared not only at near-the-nacelles regions but along the whole wingspan. Besides, flow over the wing is strongly sensitive to the cruise mass flow ratio through the engines.

Fig. 10. The aerodynamic model of long-range aircraft

Small sweep, on the contrary, causes a more local interference between the wing and the over-wing engine that allows designing and optimizing wing surface with more credibility. For the further abatement of the unfavourable interference, the basic pylon construction was decided to move mainly on the lower, subsonic wing surface (Fig. 11). It is reasonable in this case to consider a possibility to combine functions of pylons and wing landing gear nacelles (à la Tu-134, Tu-154 designs) and almost to remove wing fuselage fairing.

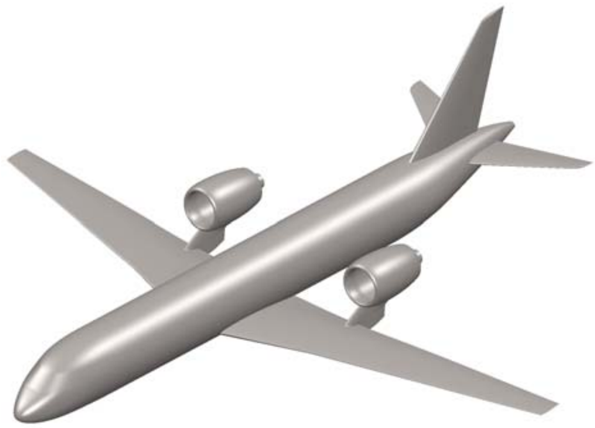


Fig. 11. The aerodynamic model of short-range aircraft

Calculations show that cruise Mach numbers as high as M = 0.78-0.79 are reachable with low wing sweep $\chi_{1/4} \sim 15°$ which allows to hope on outer wing flow natural laminarization. The aerodynamic model of the short-range aircraft is manufacturing at present, wind tunnel tests are planned to carry out in the fall of 2014.

Conclusions

Aerodynamic peculiarities of low-noise layouts with upper engines shielded by the airframe parts are considered. The classic "tube and wing" configurations as well as "flying wing" and "lifting fuselage" layouts could be used. The authors believe that over-wing-trailing-edge engine configurations are of the greatest interest in the near future. These engines could have ultra-high bypass ratios and be fuel-efficient, the jet noise could be lower and the fan noise could be shielded by the wing. The model of a perspective regional low-noise aircraft with a wing of small sweep providing natural laminar flow is manufacturing for comprehensive wind tunnels tests.

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Contact Author Email Address

skomorohov@tsagi.ru

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