CONCEPT OF MEDIUM TWIN-ENGINE STOL TRANSPORT AIRPLANE

O. Pavlenko, A. Petrov, E.Pigusov
TsAGI, 1 Zhukovsky St., Zhukovsky, Moscow Region, 140180, Russia
Keywords: *short takeoff and landing, aerodynamic characteristics, powered lift systems*

Abstract

The results of experimental and numerical investigations of the concept development of medium twin-engine STOL transport airplane (MSTA) with the combined powered lift system (CPLS) are presented. The increase of wing lift for providing short takeoff and landing (STOL) of aircraft is possible due to application of the external blown flap system (EBF) and the boundary layer control system (BLC) on the flap. The effect of an engine failure on the aerodynamic characteristics, stability and controllability of the MSTA are researched. It is shown that the CPLC application can provide increasing lift at takeoff and landing conditions of aircraft by suppression of flow separation on the flaps, the super-circulation effect and the effective deflection of turbofan engines exhaust, as well as improve the cruising characteristics of the aircraft by delaying the flow separation on the wing at high subsonic speeds by tangential jet blowing.

1 Introduction

Development of short take-off and landing aircraft requires extensive experimental and computational researches [1]. Radical improvement of aircraft takeoff and landing performances can be achieved by use of powered lift systems (PLS). These systems are based on using the energy of the aircraft engines to improve its aerodynamics. PLS changes the main aircraft characteristics: lift, drag, pitching moment and others. Therefore, PLS are active control systems of aircraft aerodynamic and flight performance. In this case the performances changing are purposeful, flexible and widely varied depending on the flight conditions (take-off, landing, cruising, maneuvering).

The application PLS on transport aircraft can increase the maximum lift coefficient of the aircraft in 2÷2.5 times or more as compared to conventional high-lift devices, and accordingly provide to operate from short airfields. The transport aircraft efficiency is increased simultaneously by payload growth, expanding the possibilities of using the airfields with runway lengths from 600 to 800 m and reducing the cargo shipping time.

Thus, the problem of PLS usage is relevant and its solution at new technological level will improve the efficiency of transport aviation.

Currently, the most passenger and transport aircraft are usually equipped with twin-engine propulsion system due to the appearance of modern powerful and economical aircraft engines. Thereby, it is complicated to solve the problem of ensuring STOL capability of these aircraft with PLS. The main problems are: reducing the lift increment when the flaps are blown by the jets of two engines in comparison with four-engine aircraft and ensuring the flight safety in case of one of the engines failure. For effectively solutions of these problems CPLC are proposed, consisting of the EBF and BLC flap systems [2]. This system can provide the trimming and control of the MSTA in the case of one engine failure without significant losses of the lift due to use of the BLC on flaps and ailerons. Yawing moment, arising by engine failure, can be compensated by the rudder deflection with BLC. Compressed air for BLC is bled from the compressor or the fan of the running engine or from an auxiliary power unit and through the looped system of air ducts is differentially blown over the flaps and ailerons to create the necessary rolling moment. BLC system can be used not only during takeoff and landing operations, but also at cruising high subsonic speeds by suppressing the shock-induced flow separation on the wing.

This paper presents the results of studies aimed to investigation of the MSTA concept with 20 t payload. Nowadays aircraft of a similar class are developed: medium military transport aircraft Ilyushin Il-276 (Russia), Antonov An-178 (Ukraine) with 18 t cargo capacity and KC-390 (Brazil). However, these aircraft are mainly intended for operation from 1800-2500 m paved runways. The main purpose of this work is to develop the MSTA concept, capable to operate from short paved and unpaved runways with less than 800-1000 m length. The aerodynamic layout design of the aircraft is based on the results of experimental and computational studies carried out in the TsAGI.

2 Experimental Studies of the MSTA Model with the EBF System

2.1 The MSTA Model

Experimental researches of the EBF system efficiency on the MSTA model were carried out in the T-102 TsAGI subsonic wind tunnel (WT) (Fig.1). The MSTA model is equipped with two ejector simulators of ultra high bypass ratio (UHBR) engines (m=16-18) with blowing through double-slotted flaps by exhausts.

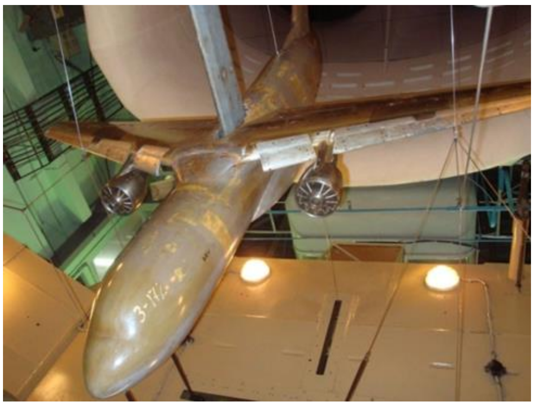

Fig.1.The MSTA model in the T-102 WT

The MSTA model layout is the ordinary aerodynamic scheme with the T-shaped tail and 25° swept wing. The wing high-lift devices consist of two double-slotted flaps with a spoiler droop and slats (Fig.2). Flaps with the relative span of 73% and the chord 32% were tested in three positions (take-off 30/0°; 30/20° and landing 40/30°). The relative height flap slots are equal to 2.5% of chord. The spoiler droop deflects down up to 12º angle together with the flaps. The slat with a 15% relative chord is located throughout the wingspan, deflected at 20° angle in the take-off configuration and 40° in the landing.

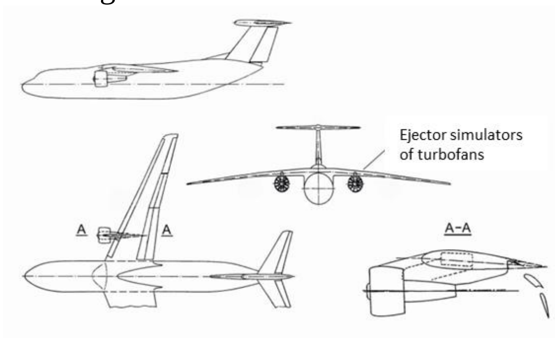

Fig.2.The general view of MSTA model

2.2 Test Results

Tests have been performed in WT at flow speed of 40 m/s (Reynolds number ≈ $0.9\cdot10^6$). In result of experimental studies, it was found that EBF system is an effective method of increasing the lift of the twin-engine aircraft at takeoff and landing operations. When the engine thrust coefficient of C_T≈1 for the model in take-off configuration (δ_f=30º; δ_{sl}=20º; δ_{sd}=8º) the lift coefficient at takeoff angles of attack (α=6-8º) increases approximately by 30% due to the blowing, the maximum lift coefficient increases from C_{Lmax}=2.3 to 3.6 with simultaneously increase of the critical angle of attack from 13° to 16°. The model in the landing configuration (δ_f=40/30º; δ_{sl}=40º; δ_{sd}=12º) has increased lift coefficient ΔCy≈2.3 (α=10°) by blowing at C_T≈1, i.e. lift increased in 2 times than the engine thrust coefficient. At the same time, at the landing angles of attack (α=8-10°), the lift coefficient increases by 50%, the maximum lift coefficient reaches C_{Lmax}≈4.8 at the critical angle of attack α≈17° (Fig.3).

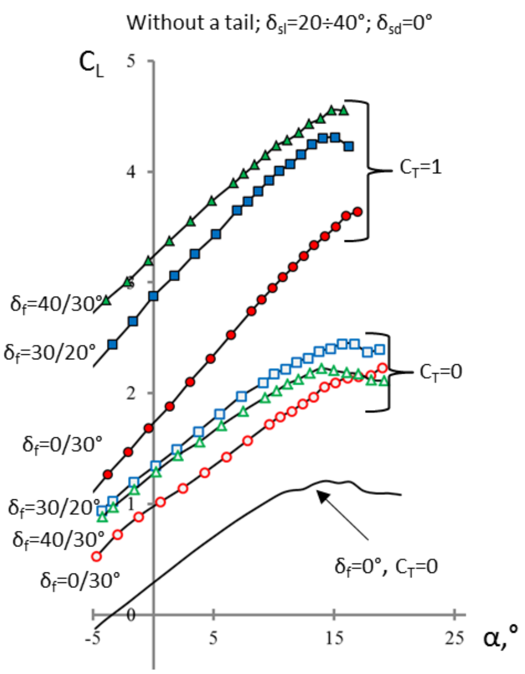

Fig.3.The influence of EBF system on the MSTA lift

The use of the spoiler droop in the model landing configuration with unpowered flow significantly increases the lift coefficient by 30-40% at the angles of attack α=6-10º, but dramatically reduces the critical angle of attack (Fig.4) due to the occurrence of flow separation on the wing at the deflection angle of the spoiler droop more than 8°. When the flaps are blown by the exhaust flows, the deflection of the spoiler droop increases the model lift by 10-15% at the angles of attack α=6-10º without practically changing the critical angle of attack. The maximum lift coefficient with the spoiler droop is $C_{Lmax}\approx 5$ at the angle of attack α=15º and is close to the level of lift of four-engine aircraft with EBF system [2].

The effect of the engine failure on the aerodynamic characteristics of the MSTA is researched. It was found that the failure of one engine relatively small decreases lift in the take-off configuration, which at the angles of attack 8-10° is 5-6%. The model lift in the landing configuration is reduced about 15-16% (Fig. 5) at the same angles of attack and there are significant rolling and yawing moments (Fig. 6), which requires use of the control surfaces with increased efficiency in combination with some additional means (differential deflection of the flaps, spoiler droops and spoilers) to compensate them.

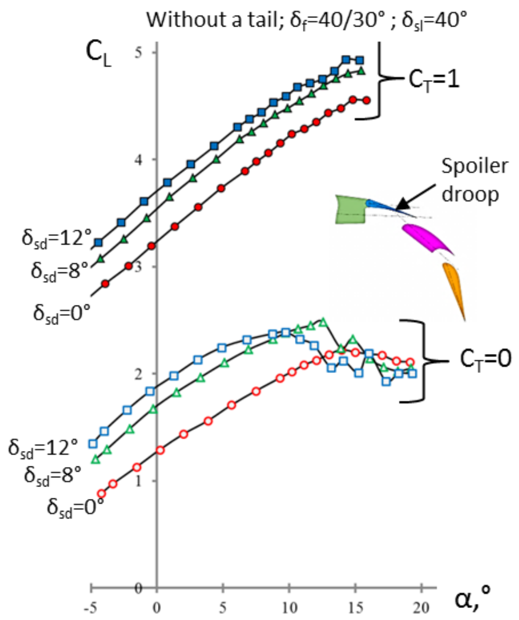

Fig.4.The influence of spoiler droop deflection on MSTA lift at the landing configuration

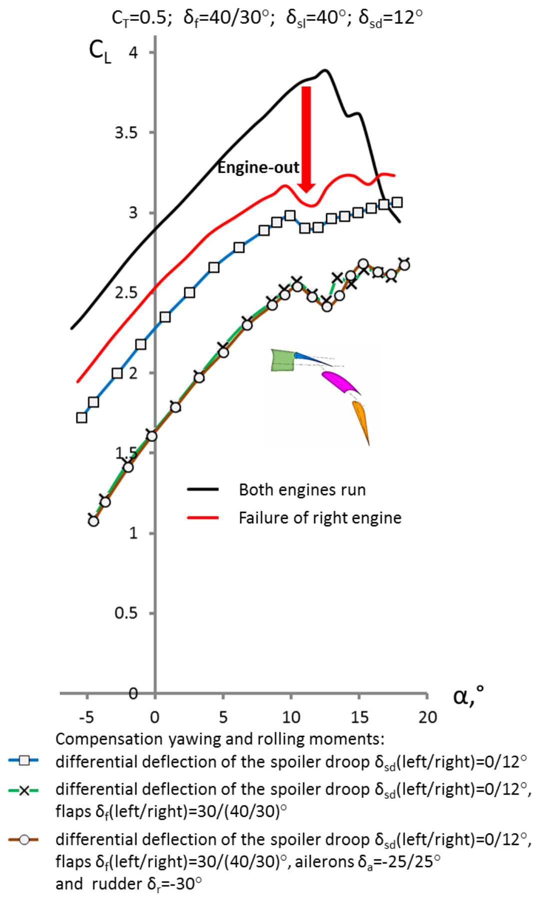

Fig.5.The influence of engine-out on MSTA lift

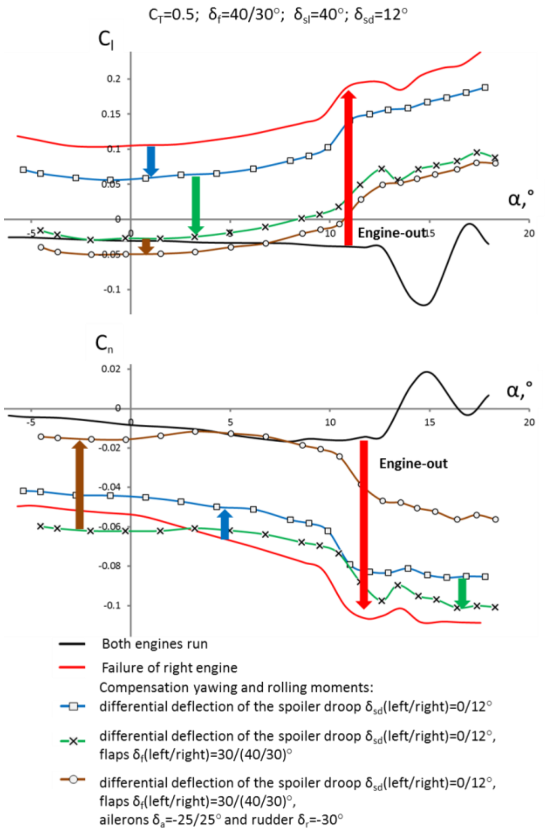

Fig.6.The compensation of rolling and yawing moments by engine failure of MSTA model

In general, the experimental studies have shown the possibility of using the EBF system to achieve the increased lift, required to provide the twin-engine transport aircraft STOL capability. The main problem is to ensure stability and controllability of MSTA in the case of one engine-out, especially on final approach and go around.

3 The MSTA Concept with the CPLS

3.1 The MSTA Concept

The MSTA layout is the ordinary aerodynamic scheme with high-mounted medium swept wing with T-tail, designed to perform similar transport tasks as twin-engine aircraft: An-178, KC-390, Il-276, except the requirement of operation from short airfields. The MSTA propulsion system consists of 2 PD-14 turbofan engines. Each engine is rated at 15 tf takeoff thrust. The aircraft's maximum range is expected to be 2000 km, and its cruise speed will be around 800 km/h.

The aerodynamic layout and the main geometric parameters of the MSTA basic version are similar to the Il-276 (Fig. 7). The BLC is realized by tangential blowing of compressed air jets on the high-lift devices (slats, flaps) and control surfaces (ailerons, elevator and rudder).

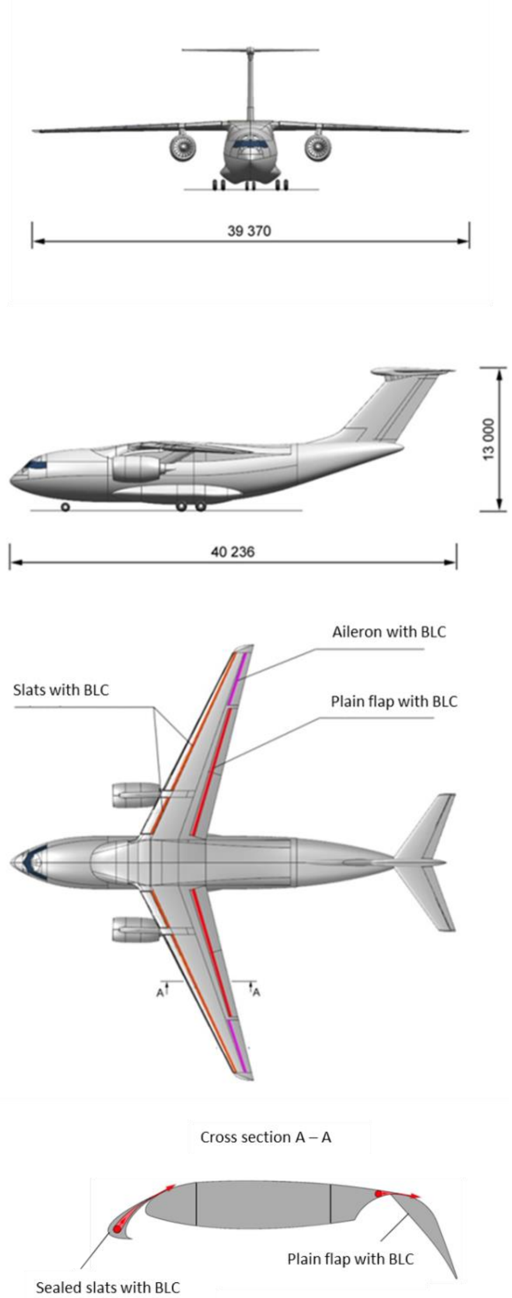

Fig.7.The general view of MSTA

The wing high-lift devices consists of a plain flap with relative chord 35% and the maximum deflection angle of 60° and sealed slats with a relative chord of 19% and a maximum deflection angle of 45°.

The BLC system layout is shown in Fig.8. The compressed air for BLC system is bled from the fan stage or from the high-pressure stage of engine core. The pipeline supplying compressed air to BLC system located in the engine pod. A safety valve is installed in the pipelines to prevent excess of the allowable pressure. The shut-off valve to shut down the BLC system is provided. The pipelines to the slats in the leading edge of the wing are padded. The directly supply to the jet slots located in the slats is realized through telescopic tubes similar to the thermal anti-icing system tubes. The area of pipeline laying to the flaps and ailerons in the wing caisson is separated from the fuel tanks by firewalls. The BLC system of the wing is looped. The pipelines are equipped with control valves to regulate the compressed air flow rate to BLC system.

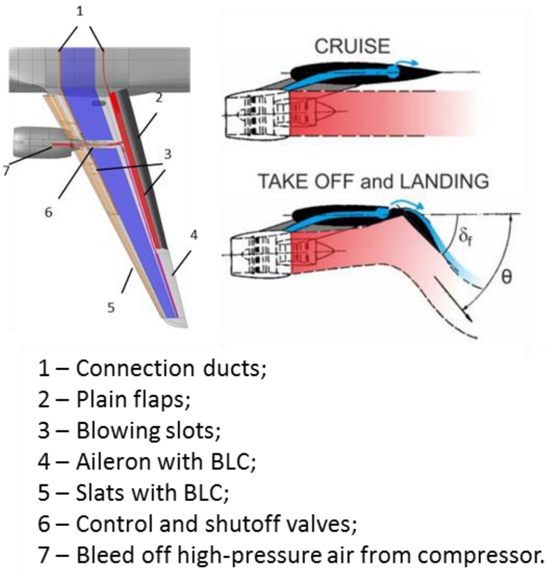

Fig.8.The layout of the BLC system

3.2 Takeoff and Landing Aerodynamic Characteristics of the MSTA

Numerical studies of the aerodynamic characteristics of the MSTA with CPLS at takeoff, landing and cruise flight are performed by program based on the solution of the time-dependent equations Reynolds-Averaged Navier-Stokes (RANS). Basically, the computations were carried out in a two-dimensional model of the wing airfoil with flap, but also for the full layout with modeling of the engine exhausts and the BLC system on the flap. Validation of applied computational methods was presented in [4, 5].

Effect of jet momentum coefficient Cμ variation is calculated at fixed Mach number 0.15, Reynolds number of $16.5\cdot10^6$ and zero angle of attack. The rotation axis of flap is placed at 70% of the wing chord. The jet slot height is 0.1% of the airfoil chord. The pitching moment coefficient relates to the mean aerodynamic chord (MAC) and measured from the center of gravity. The center of gravity is located at 25% MAC. The calculation results of tangential jet blowing effect on the flow of the wing airfoil with the flap deflected in take-off (δ_f=30°) and landing (δ_f=60°) positions are shown in Fig. 9. In both cases, relatively low intensity jet blowing provides the flow separation suppression on the flap, as evidenced by the flow pattern. The recovery of the non-separable flow corresponds to a sharp change in the lift coefficient dependences by the jet momentum coefficient. Flow separation is eliminates at jet momentum coefficient $C\mu=C\mu_R\approx0.03$ in flaps takeoff setting and $C\mu_R\approx0.04$ in the landing setting (see Fig.9). Further increasing the jet blowing intensity increases the lift by the super-circulation effect. Additional aerodynamic load on the airfoil arises due to appear of the jet wake behind the deflected flap (see Fig.9). However, the lift increasing is significantly reduced.

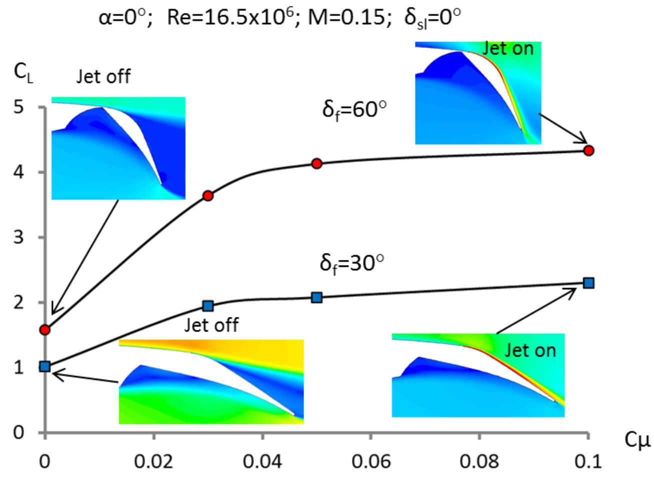

Fig.9.The influence of the jet blowing intensity on the lift coefficient of the airfoil with flap deflected by 30° and by 60°

In general, the use of tangentially jet blowing on the plain flaps at $C\mu=C\mu_R$ increases the lift coefficient by 2-2.5 times with the deflection flaps at the angles $\delta_f=30°\div60°$.

One of the most challenging issues in the implementation of the EBF system is to increase the efficiency of the exhaust flows deflection in take-off condition. In this case, the flaps are deflected at relatively small angles ($\delta_f \leq 30°$), so engine exhaust axis, located at relatively large distances from the wing, practically does not deflect and does not create additional lift. One of the possible ways to solve this problem is a turn of the exhaust flows directly to the deflected flaps by adjustable nozzles or deflectors.

This paper presents the results of numerical studies of the effect on the aerodynamic characteristics of MSTA by jet blowing of compressed air from the slot on the deflected flap (δ_f =30°) in combination with the engine exhaust flows directed at different angles to the flap lower surface. The accepted parameters of the BLC and the angle of flaps deflection correspond to the take-off condition.

The aerodynamic characteristics variation of the aircraft with BLC on the flap (δ_f=30°; $C\mu$=0.1) due to the deflection of the engine exhaust flows $\delta_{def}=10\div20°$ and increasing of thrust coefficient C_T from 0 to 2 is shown in Fig.10. According to the computational results, the aircraft lift decreases at zero exhaust deflector angle due to the ejection effect, so pressure on the lower surface of the flap and wing is reduced. Increasing of exhaust deflector angle leads to aircraft lift grows due to positive jet-flap interaction (see Fig.10). For example, lift coefficient of the aircraft with the BLC system on the flaps with exhaust deflector angle δ_{def}=20° increases by about 30%.

The distribution of the pressure coefficient in the MAC cross-section shows that increase of the lift occurs mainly due to pressure growth in jet-flap interaction area (Fig. 11).

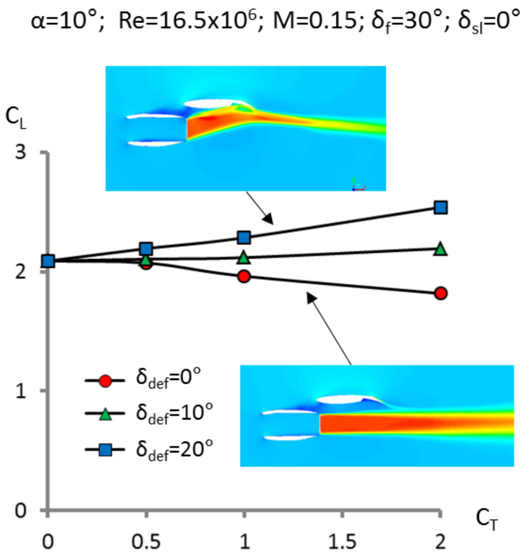

Fig.10.The influence of jet exhaust deflection on the lift coefficient

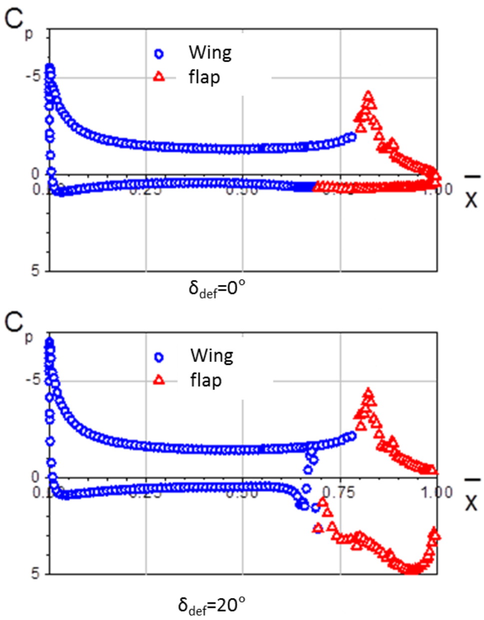

Fig.11.The influence of exhaust flows deflection and flap jet blowing on pressure coefficient distribution over the wing cross section (δ_f =30°; $C\mu$=0.1; C_T=2)

The result of the numerical researches shows that application of CPLC with an adjustable exhaust deflector angle can provide essential increasing of lift in take-off condition due to suppression of flow separation and an effective deflection of exhaust flows.

Downwash behind the wing essentially increases at landing condition flaps (δ_f =60°) and intensive tangential jet blowing on their upper surface. Thus, exhaust flows are effectively deflected down (Fig. 12). The influence of jet exhaust flow deflection (δ_{def}=60°, C_T=2) and flap jet blowing (Cμ=0.1) on the flow pattern over the wing with flap deflected by 60° is shown in Fig 13. The influence of flap deflected by 30° and 60° on the lift coefficient is shown in Fig 14. Resulted lift growth is similar to wing with EBF and more difficult and heavy double-slotted flaps (see Fig. 3, 4). The numerical results are preliminary and will be refined on a more detailed grid after optimizing the MSTA layout.

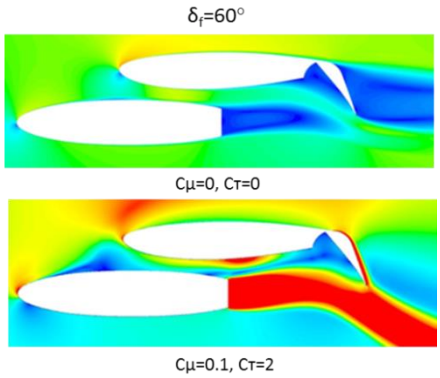

Fig.12.Comparison of velocity distribution with powered and unpowered flows

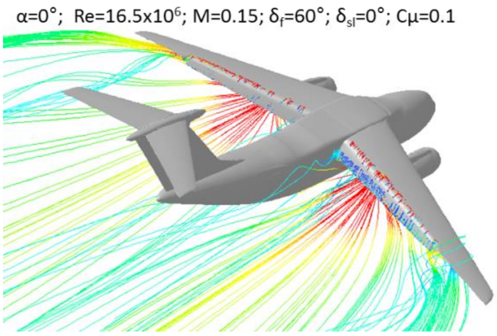

Fig.13. Influence of jet exhaust flow deflection and flap jet blowing on the flow pattern over the wing with flap deflected by 60°

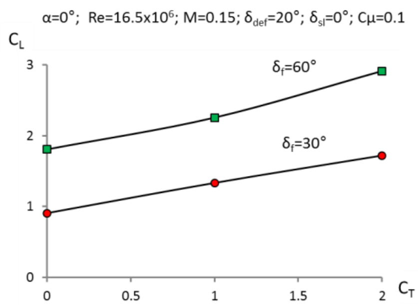

Fig.14. Lift performance of MSTA with flap deflected by 30° and 60°

The use of differential jet blowing on flaps and ailerons can be used as effective method to compensate the forces and moments arising in engine-out condition. For example, preliminary calculations showed that the jet blowing on the starboard flap leads to the decreasing of the rolling moment by 37% and yawing moment by 68% at the zero sideslip angle (Fig. 15). The study of these approaches will be continued to develop a method of compensation of forces and moments arising in case of engine failure and recommendations for the developers of an advanced control system.

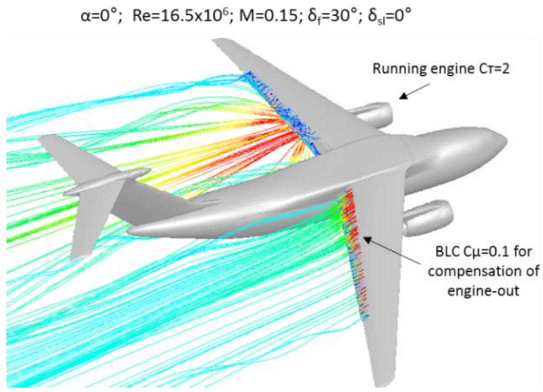

Fig.15. Differential jet blowing on flaps to compensate engine failure

3.3 Cruise Aerodynamic Characteristics of the MSTA

In the [2, 6] have shown that tangential jet blowing is an effective means of suppression of a shock-induced flow separation on the wing. But there is a problem since the optimal position of the BLC slot for cruise flight is not the same as optimal for providing STOL performance. For solution of this problem a shape optimization of the airfoil was made for changing of a load distribution (Fig. 16). Comparison of pressure distribution on the airfoil with BLC and without BLC at a Mach number M=0.78 is shown in Fig.17. A fixed position of the jet slot for both cases is used. Computational results is shown that tangential jet blowing of a supersonic jet with low intensity (jet momentum coefficient Cμ=0.006) eliminates boundary layer separation on the modified airfoil at transonic speeds.

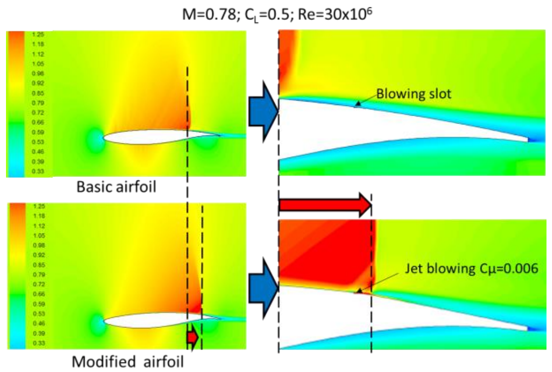

Fig.16. Comparison of velocity distribution over the basic and modified airfoil

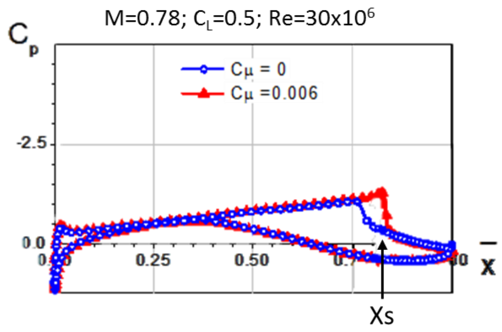

Fig.17. Comparison of pressure distribution over the airfoil with BLC and without BLC

4 Flight Performance of MSTA

Application of the CPLS could significantly reduce takeoff and landing speeds and accordingly required runway length and also to raise the flight safety on these critical modes in comparison with conventional aircraft. The estimated efficiency of CPLS application on MSTA is provided in table 1.

Table 1

Cruise	
Flight range	+10%
Fuel consumption	-5%
Takeoff	
T/O speed	-10%
T/O run	-30%
Payload	+(10÷15)%
Landing	
Landing speed	-30%
Landing run	-50%

5 Conclusion

The complex computational and experimental studies of advance medium twin-engine STOL transport airplane concept are performed. The proposed concept of the MSTA is based on the following innovative solutions:

- CPLS of active flow control over the wing, consisting of tangential jet blowing in cruise flight (to improve aerodynamic of lift-to-drag ratio at high subsonic speeds by suppressing the shock-induced flow separation) and the tangential jet blowing on the plain flap in combination with the external blown flaps system at takeoff and landing flight conditions;
- High-performance flight controls (BLC system on ailerons, rudders and elevators, the differential deflections of the flaps and differential jets blowing on the flaps), providing the required controllability during flight at low speeds and aircraft stability in the case of the engine failure.

The selected aircraft configuration and its parameters correspond to the typical aerodynamic layout of the twin-engine transport aircraft, designed to carry loads up to 20 t at a speed of 750-800 km/h at distances up to 2000 km. According to the estimation results, the implementation of new technical solutions in the aircraft layout provides him significant advantages in operation capabilities from short paved and unpaved runways with less than 800-900 m length compared to the existing and designed for this payload transport aircraft, which requires 1600-2000 m runway length.

References

[1] Kolpakchiyev I.N. *Problemy korotkogo vzleta samoleta*. 1st edition, Mashinostroyeniye, 1978 (In Russian).

[2] Petrov A.V. Aerodynamics of STOL airplanes with powered high-lift systems. *28-th Congress of the ICAS*, Brisbane, Australia, 2012.

[3] Petrov A.V. *Wing powered high-lift methods.* 1st edition. FIZMATLIT, 2011 (In Russian).

[4] Pavlenko O, Pigusov E. Numerical investigation of the aerodynamic loads and hinge moments of the flap with boundary layer control. *AIP Conference*

Proceedings, Saint-Petersburg, Vol. 1959, 050024, 2018.

[5] Pavlenko O.V, Pigusov E.A. The features numerical investigation of the flow around the wing compartment with the system of the jet tangential blowing onto the wing flap. *Automation. Modern Technology*, Vol. 72, No. 4, pp 166-171, 2018.

[6] Petrov A.V. Bokser V.D. Sudakov G.G. Savin P. V. Application of tangential jet blowing for suppression of shock-induced flow separation over supercritical wings at transonic speeds. *27-th Congress of the ICAS*, Nice, France, 2010.

Contact Author Email Address

Evgeny Pigusov: evgeniy.pigusov@tsagi.ru

Copyright Statement