ICAS 2021 SHANGHAI
International Council of the Aeronautical Sciences
32nd Congress of the International Council of the Aeronautical Sciences
September 6-10, 2021
Pudong Shangri-La, Shanghai, China

METHODS OF PROGRAMMED THRUST MANAGEMENT FOR NOISE REDUCTION OF SUPERSONIC CIVIL AIRCRAFT

A. Mirzoyan[1] & Iu. Khaletskii[1]

[1] Central Institute of Aviation Motors, 2, Aviamotornaya Str., Moscow, 111116, Russia

Abstract

The methods for reduction of the cumulative noise level at certification points applying to the supersonic civil aeroplane are considered. The noise reduction is obtained by using a programmed thrust management implementing by the variation of engine power setting at take-off and approach. The use of proposed programmed low noise thrust management will require a change of the current noise certification procedures and will be implemented into the aircraft/engine automated control system. It is shown that the cumulative noise level at proposed programmed thrust management is lower by 10.7-12.2 EPNdB than at conventional thrust control now in use for subsonic jet aeroplanes at take-off and approach.

Keywords: supersonic civil aeroplane, noise reference points, take-off and approach, engine thrust (power) setting, bypass ratio

1. Introduction

The one of the crucial issue of development of new Supersonic Civil Aeroplanes (SCA) is to meet requirements to community noise level during Landing and Take - Off cycle (LTO). According to Chapter 12 of ICAO noise standard, SCA noise levels at certification Reference Points (RP) should be correspond to the limitations for subsonic jet aeroplane with the same Maximum certificated Take-Off Mass (*MTOM*) (i.e. to Chapter 14, Annex 16, Volume I [1]).

The SCA design features results in higher noise during the LTO cycle in comparison with the subsonic jet aeroplane. That is why it is still impossible for SCA to follow the requirements at the current level of aviation technologies development. Nowadays ICAO Committee on Aviation Environmental Protection is still developing the new standard for SCA noise.

In March 2020, FAA published a preliminary version of the national noise standards for SCA [2]. The applicable SCA class is limited by *MTOM* (68 t) and cruise speed (M = 1.8).

NASA and other research centers assessments showed that meeting the requirements of Chapter 14, Annex 16, Volume I, may not be satisfied on the current technology level [3, 4].

The SCA engine thrust management during LTO cycle was considered in a number of publications [3 - 8].

2. Problem statement

The take-off thrust (power) throttling has a contradictory effect on the noise levels in each take-off RP, i.e. on Lateral and Flyover noise levels. Therefore a compromise solution on the engine Thrust Management (TM) during the take-off is required to reduce the take-off (Lateral plus Flyover) noise level.

In accordance with the noise certification procedure, the approach noise level is measured at approach using the constant flight speed along the path and the fixed glide slope angle θ which is equal to -3° [1].

To provide the flight along such path with the constant flight speed and glide slope angle, there is a direct relationship between the levels of the required engine thrust and the glide slope angle.

The approach RP is determined by the point on the ground, on the extended center line of the runway at the distance L_{app} = 2000 m from the threshold. Therefore, the approach noise level at varying the glide slope angle θ will mainly depend on the flight altitude above the approach RP and the change of the engine parameters associated with a change in the required engine thrust.

Therefore, the variation of the approach power setting leading to a change of the glide angle is considered as a measure of the reduction of the approach noise level.

In the activities the methods of programmed reduction of cumulative noise using so-called Programmed Lapse Rate (PLR) during the take-off as well as the approach are studied. The methods provide the reduction of the cumulative community noise taking into account the fan and exhaust jet noise.

The intention to follow the stringent noise requirements push researchers to consider the propulsion systems based on the turbofan with higher ByPass Ratio (*BPR*).

At the same time, there is a cardinal redistribution of the contributions between engine noise sources as increasing *BPR*. The dominance of the jet noise for the turbofan with lower *BPR* (~ 0.5...1.5) is replaced with an approximate equality of the fan and jet contributions for the turbofan with mediate *BPR* (~ 2.5…3.5) and then with predominant fan noise for the turbofan with higher *BPR* (~ 4.0…5.0).

The comparison of the effective perceived noise levels in case of use of the reference and the proposed programmed reduced cumulative noise thrust management using PLR (from here on programmed TM) is carried out as applied to a notional twin-engine Supersonic Business Jet (SBJ). with range *L* = 7400 km, seating capacity *n* = 8 pax and balanced field length *BFL* = 2000 m.

The considered SBJ propulsion system is based on the turbofan with *BPR* = 2.5 ... 5.0. The values of the range *L*, the seating capacity n and the balanced field length *BFL* are kept constant under the *BPR* variation. The take-off thrust loading is defined under provision of the specified balanced field length value.

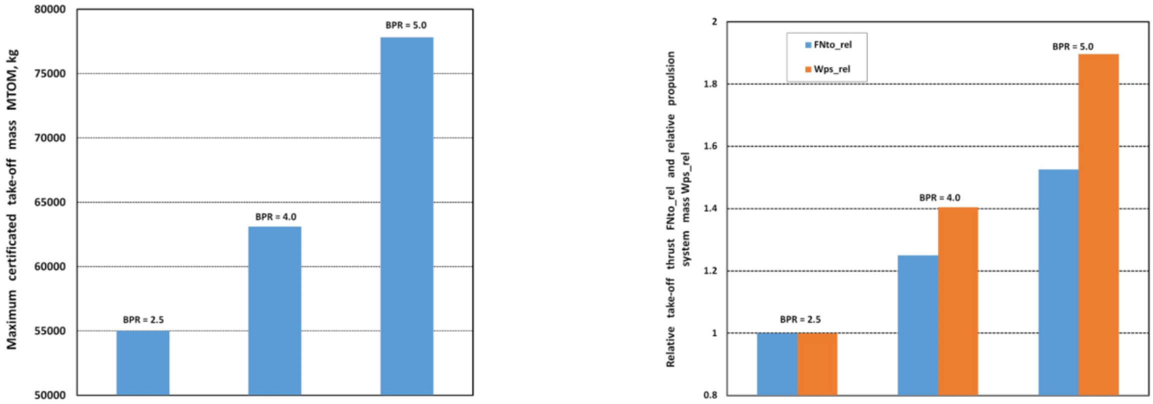
The turbofan with *BPR* up to 5.0 is considered to maximize the SBJ noise reduction. At the same time, it is obvious that it is necessary to find a compromise solution, accounting the contradictory factors like nacelle size/drag, which is increased with increasing *BPR*.

3. SBJ mission performance assessment for fixed flight range and using turbofan with different BPR

The calculation of mission performance is performed for the SBJ with fixed flight range taking into account the flight segments like take-off, initial climb, climb, supersonic cruise, descent, approach, landing, and NBAA alternate. The engine size (and the corresponding SLS thrust and the take-off thrust loading) is defined from the balanced take-off condition and the given balanced field length *BFL* = 2000 m. At the definition of balanced field length, the minimal one engine inoperative climb gradient at the altitude of 10.7 m is considered as the constraint [5].

Keeping the specified values of the flight range L, the seating capacity n and the balanced field length *BFL* with an increase of *BPR* leads to an increase of the maximum certificated take-off mass *MTOM*. It is primarily happened due to an increase of the required engine take-off thrust FN_{to} and propulsion system mass W_{ps}.

The Figure 1 shows the changes of *MTOM* (Figure 1 a), relative take-off thrust FN_{to_rel} and propulsion system mass W_{ps_rel} (Figure 1 b) depending on the *BPR*.



a) b)

Figure 1 - The change of *MTOM* (a), FN_{to_rel} and W_{ps_rel} (b) vs. *BPR*.

The relative values of the take-off thrust FN_{to_rel} and the propulsion system mass W_{ps_rel} are equal:

$$FN_{to\_rel} = FN_{to}/FN_{to\ BPR=2.5} \quad (1)$$

$$W_{ps\_rel} = W_{ps}/W_{ps\ BPR=2.5}, \quad (2)$$

where FN_{to}, $FN_{to\ BPR=2.5}$, W_{ps} and $W_{ps\ BPR=2.5}$ are the take-off thrust and propulsion system mass for the turbofan with current *BPR* and *BPR* = 2.5 correspondingly.
It can be seen that as *BPR* changes from 2.5 to 5.0 with fixed values of *L*, *n* and *BFL*, the take-off thrust FN_{to} and propulsion system mass W_{ps} increase by 57 and 90%, respectively, while the *MTOM* increases from 55 000 to 77 000 kg, i.e. on 40%.
A noticeable increase of the *MTOM* at highest *BPR* may lead to an increase of the direct operating cost, which could be economically unacceptable. Therefore, the cost efficiency of use of turbofan with the higher *BPR* should be evaluated in the future activities more detail.

4. The reference and programmed reduced cumulative noise thrust management at take-off and approach

4.1 Take-off

The reference take-off TM corresponds to the conventional thrust control applied to subsonic jet aeroplanes and includes the take-off and cutback power settings.

The proposed programmed TM using the PLR has 7 flight path segments:

- segment 1 with engine take-off power
- segment 2 with engine thrust throttling to power setting providing reduced lateral noise
- segment 3 with engine power setting providing reduced lateral noise
- segment 4 with restoring engine maximum climb power setting
- segment 5 with engine maximum climb power setting
- segment 6 with engine thrust throttling to power setting providing reduced flyover noise
- segment 7 with engine power setting providing reduced flyover noise.

The Figure 2 shows reference and proposed TM as dependence of take-off thrust throttle ratio TR_{to} on the distance from the brake release point applying to SCA with *MTOM* of 55 000 kg and turbofan with *BPR* = 2.5.

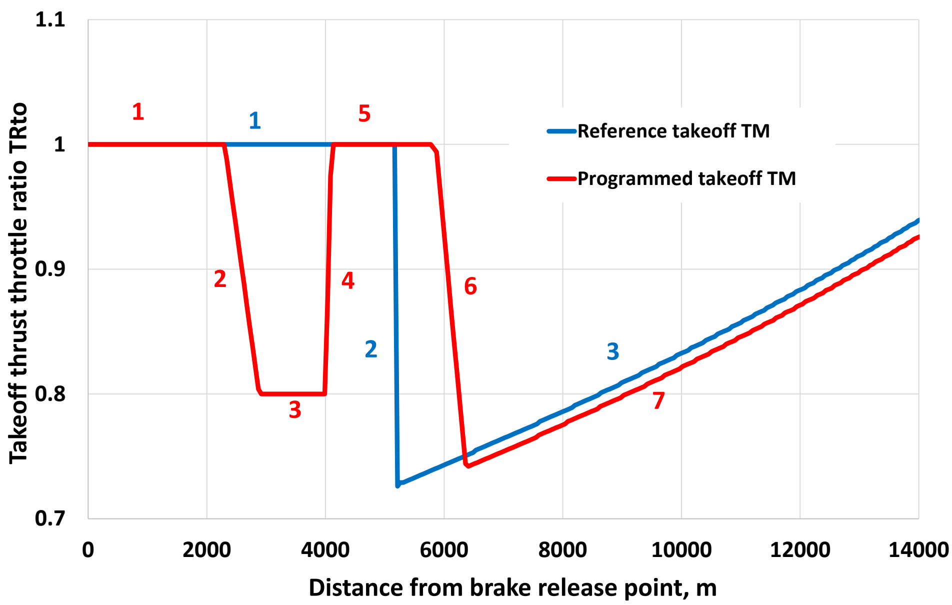


Figure 2 - The change of the take-off thrust throttle ratio TR_{to} depending on the distance from the brake release point for reference and programmed take-off TM.

The power settings on the segments 3 and 7 correspond to the lower power settings, providing the lateral and flyover noise reduction accounting the airworthiness and noise certification procedure restrictions in term of the minimal climb gradients [6].

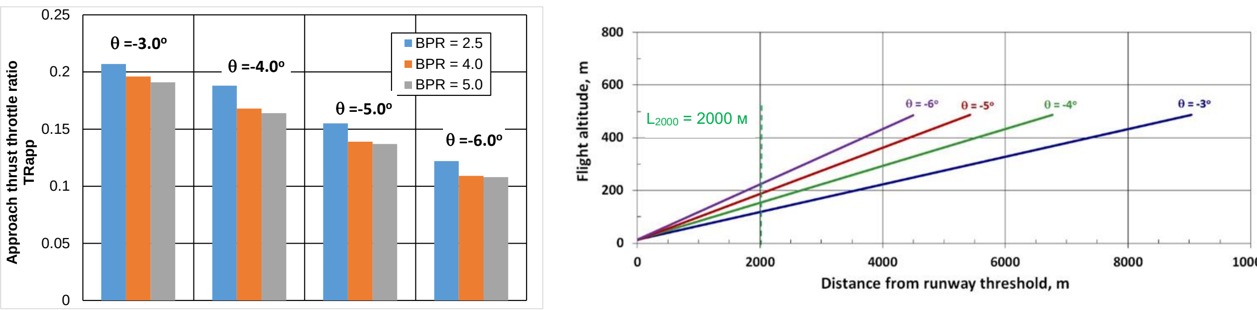
The proposed programmed TM was generated based on the optimization of the values of the TM parameters such as locations of the segment 3 and the beginning of the segment 6, the thrust throttle ratio on the segments 3 and 7, the thrust acceleration and throttling rates on the segments 2, 4 and 6 under the minimum take-off noise criteria. The optimal values of take-off throttle ratio TR_{to} for the segment 3 and for beginning point of the segment 7 are equal to 0.8 and 0.74 accordingly. The optimal distances for location of the beginning and end points of the segment 3 and the beginning point of the segment 7 are equal to 2300, 4000 and 5800 m respectively, the optimal take-off thrust throttling rates on the segments 2 and 6 are equal to 15 and 2.5% of thrust per a minute respectively.

Due to the optimal choice of the programmed TM parameters, it is possible to keep the altitude above the flyover RP and flyover noise.

4.2 Approach

The reference approach TM corresponds to the conventional thrust control applied to the subsonic jet aeroplanes at approach providing the approach flight path with the glide slope angle $\theta = -3^o$. It usually requires to use engine power setting close to the flight idle thrust setting.

Figure 3 shows the values of approach thrust throttle ratio TR_{app} (Figure 3a) and SCA approach paths (Figure 3b) for different glide slope angle θ and engine *BPR*.



a) b)

Figure 3 – The values of approach thrust throttle ratio TR_{app} (a) and SCA approach flight paths (b) for different glide slope angle θ and engine bypass ratio *BPR*.

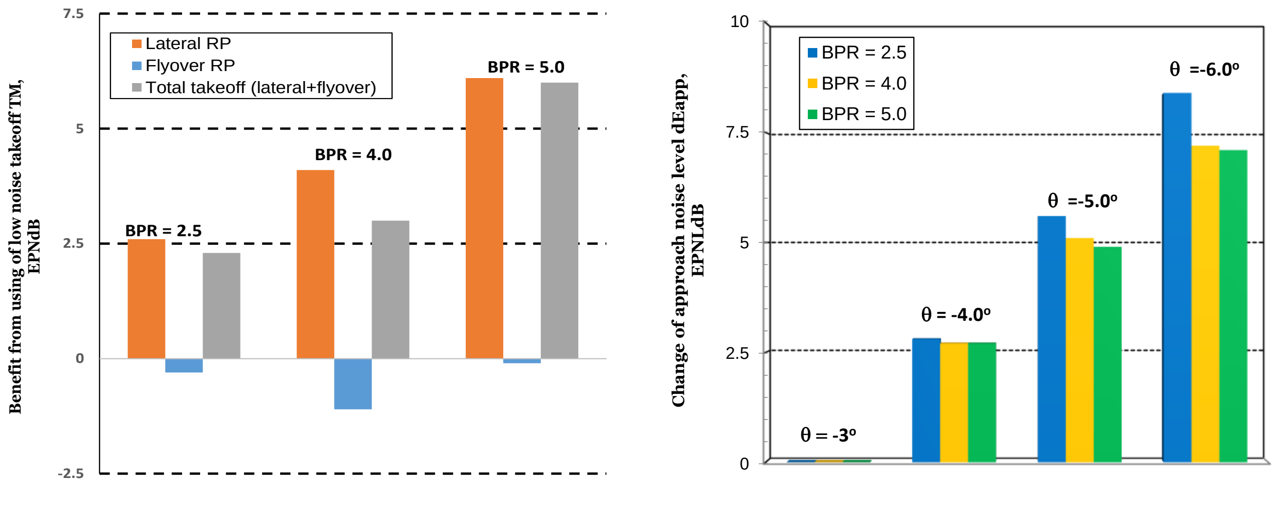
It can be seen from Figure 3a that with an increase in the angle θ from -3 to-6^o, the approach throttle ratio TR_{app} decreases from 0.2 to 0.11 - 0.12, a change of *BPR* in the range from 2.5 to 5.0 does not affect the change of the engine power setting. Changing the engine power setting and θ leads to an increase of the flight altitudes above the approach RP, located at a distance of 2000 m from the runway threshold (Figure 3b). The flight altitudes above the approach RP does not change with a change of *BPR*, at the same time it significantly increases (by about 100 m) with an increase of the angle θ from -3 to -6^o (Figure 3b).

5. Comparison of SCA noise benefit at using reference and programmed TM

The Figure 4 shows the comparative acoustic efficiency of using the programmed take-off (Figure 4a) and approach (Figure 4b) TM vs. reference TM. Changes of the flyover noise in case of replace of reference with programmed take-off TM does not exceed 1 EPNdB that is associated with the same flight conditions above the flyover RP. The changes of the lateral noise level are equal to 2.6 to 6.1 EPdB depending on *BPR*.

The increase of the noise reduction benefit as increasing *BPR* is connected with increasing the contribution of fan noise to the total engine noise as well as increasing the influence of engine throttling in the fan noise. As a result, the change of the take-off (lateral plus flyover) noise level using programmed take-off TM instead of the reference take-off TM is equal to 2.3...6.0 EPNdB, depending on the *BPR*.

The Figure 4 b shows the change of SCA approach noise level deviation from the approach noise in case of using turbofan with *BPR* = 2.5 and angle θ = -3.0° depending on *BPR*.



a) b)

Figure 4 - The benefit in SCA lateral, flyover and take-off (lateral plus flyover) noise levels (a) depending on the engine bypass ratio *BPR* and approach noise level (b) from the use of programmed TM depending on the engine bypass ratio *BPR* and on the glide slope angle θ.

The changes of the approach noise level in case of replace of reference with programmed approach TM may reach up to 8 EPNdB depending on glide slope angle θ. The assessment shown the potential effectiveness of a programmed approach TM, which reduces the approach noise level due to higher glide slope angle and flight altitudes above the approach RP (Figure 3b).

The use of higher glide slope angle may lead to a more complex approach and landing procedures and requires the mandatory use of an instrumental automatic landing system, which is currently applied to many subsonic aircraft.

6. Conclusion

In connection with the development of a new ICAO international standard for the noise levels of SCA at certification points during the LTO cycle and the USA national standard, it becomes relevant to study new opportunities to reduce the noise for such type of aircraft. The use of programmed thrust management (control) at the LTO cycle is evaluated in the paper as a tool for reducing the SCA noise levels. A comparative assessment of effective perceived noise levels in case of using the reference (conventional for subsonic jet aeroplanes) and programmed thrust management is applied to notional twin-engine supersonic business jet (with seating capacity of 8 pax, a range of 7 400 km, and the balanced field length of 2 000 m).

The following main results are obtained:

- The use of a programmed take-off thrust management during takeoff and initial climb instead of the reference one, reduces the takeoff (lateral and flyover) noise level by 2.3 - 6.0 EPNdB depending on the engine bypass ratio *BPR*. It is mainly achieved by lateral noise reduction while flyover noise level is possible to keep unchanged.
- The use of the proposed programmed approach thrust management during approach is associated with an increase in the glide slope angle due to additional thrust throttling. It is shown that an increase in the glide slope angle leads to reduction of approach noise. As the glide slope angle is changed from -3° to -6°, the SCA noise reduction may reach up to 8.4 EPNdB for turbofan with engine bypass ratio *BPR* of 2.5, and up to 6.2 EPNdB for *BPR* of 5.0. It should be noted that increasing the glide slope angle relative to the standard value of -3° may lead to a more complex approach and landing procedures and requires the mandatory use of an instrumental automatic landing system, which is currently used on many subsonic jet aeroplanes.

- The use of a low-noise thrust management at LTO cycle instead of reference thrust schedule (i.e. use of cutback around flyover certification point and approach path with glide slope angle of -6°) may reduce cumulative noise level by 10.7 – 12.2 EPNdB depending on engine bypass ratio *BPR.*
- As changing the engine bypass ratio *BPR* from 2.5 to 5.0 while maintaining the specified aircraft mission performance such as flight range, seating capacity and runway length the aircraft maximum take-off mass is increased from 55 to 77 tons, a take-off thrust and propulsion system mass are increased by 57% and 90% accordingly; a noticeable increase of takeoff mass at highest engine bypass ratio *BPR* may lead to an increase of direct operating cost which could be economically unacceptable.
- Programmed thrust management using Programmed Lapse Rate should include the optimal location of two flight segments with low power settings in the area of lateral and flyover reference points, optimal low power settings, optimal thrust throttling rates as well as flight segment with climb power setting between lateral and flyover reference points.
- The optimal values of the parameters of programmed take-off thrust management are following: thrust ratio in the area of lateral and flyover reference points are equal 0.8 (power reduction by 20%) and 0.74 (power reduction by 26%) respectively. The optimal distances for beginning and end of flight segment with low lateral noise power and for beginning of flight segment with low flyover noise power are equal to 2300, 4000 and 5800 m respectively. The optimal thrust throttling rates for transition on power settings providing reduced lateral and flyover noise are 15 and 2.5% of thrust per minute respectively.

The study of programmed thrust management should be continued in the direction of taking into account the effect of noise shielding by airframe elements and application of acoustic liners in propulsion system.

7. Contact Author Email Address

The contact author email address is mirzoyan@ciam.ru

8. Copyright Statement

References

[1] Annex 16 to the Convention on International Civil Aviation, Vol. I: Aircraft Noise, International Standards, and Recommended Practices-Environmental Protection, 8th ed., International Civil Aviation Organization, Montreal, July 2017.

[2] Noise Certification of Supersonic Airplanes: 14 CFR Parts 21 and 36: [Docket no.: FAA-2020-0316; Notice no. 20-06]: RIN 2120-AL29 . Department of Transportation, Federal Aviation Administration. Federal Register. 2020. Vol. 85, no. 71 (April 13). p. 20431–20447.

[3] Berton J., Jones S., Seidel J., Huff D. Mint: Noise Predictions for a Supersonic Business Jet Using Advanced Take-Off Procedures. *The Aeronautical Journal.* 2018. DOI: 10.1017/aer.2018.6.

[4] Berton J., Jones S., Seidel J., Huff D. Advanced Noise Abatement Procedures for a Supersonic Business Jet . In*: Proceedings of 23rd International Symposium on Air Breathing Engines (ISABE 2017): Economy, Efficiency and Environment*, 3 - 8 September 2017, Manchester, UK, 2017, Bedfordshire, UK, ISABE, p. 477 - 489.

[5] Mirzoyan A. Studies on MDO of Engine Design Parameters with Mission, Noise and Emission Criteria at SSBJ Engine Conceptual Design. In: *CD-ROM Proceedings of 26th International Congress of the Aeronautical Sciences (ICAS 2008) including the 8th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference*, 14 - 19 September 2008, Anchorage, Alaska, USA.

[6] Mirzoyan A., Stouflett B. Environmental Problems of the SSBJ Engine in the HISAC Project. Noise and

Emission Potentialities of Optimal Takeoff Thrust Management for Twin Engine Low Boom SSBJ. *ICAS 2009 Workshop “Aviation and Environment”*, 28 September 2009, Amsterdam, Netherland. Available from:
http://icas.org/media/pdf/Workshops/2009/REF4.%20DASSAULT_HISAC_ICAS2009%20workshop.pdf [Accessed: 2021-01-30].

[7] Mirzoyan A., Khaletskii I. Potentialities of Noise Reduction Using Low Noise Takeoff Thrust Management for Advanced Supersonic Civil Aeroplanes. *22th CEAS-ASC Workshop “Future Aircraft Design and Noise Impact”*, 6 - 7 September 2018, Amsterdam, Netherland. Available from: https://www.nlr.org/wp-content/uploads/2018/09/CEAS-p11_Mirzoyan-Khaletskii-Potentialities-of-Noise-Reduction-Using-Low-Noise-Takeoff-Thrust-Management-for-Advanced-Supersonic-Civil-Aeroplanes.pdf [Accessed: 2021-01-30].

[8] Mirzoyan A., Khaletskii I. Take-off thrust and noise control for supersonic civil transport engines. *AVIATION ENGINES Journal*. ISSN 2658-6061. 2020. N2(7) (In Russian).