STUDY OF SSBJ NOISE REDUCTION WITH RATIONAL AIRCRAFT&ENGINE CONTROL

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Abstract

The preliminary researches on an evaluation of capabilities of community noise reduction with using rational low noise engine and flight trajectory control for two given versions of supersonic business jet, differing in used engines were conducted in this activity.

The community noise levels were evaluated with prediction of engine jet noise in reference points at takeoff and initial climb.

The limitations of flight safety and regulated noise certification procedure were taken into account at research of the engine and flight trajectory control.

1 Introduction

The development of economically viable and environmental friendly supersonic civil aircraft is essentially depends on the solution of key acoustic problem i.e. reduction of sonic boom and community noise up to an acceptable levels.

This problem solution is facilitated for supersonic business jet (SSBJ), however market dictates the stringer requirements:

- Range should not be less than 9200 km;
- Cruise Mach number should not be less than 1.6;
- Runway length should be no more 1800m;
- Sonic boom overpressure should not be more than 15-25 Pa;
- Community noise as margins on cumulative noise level relative Stage 3 FAR&JAR-36[2,3,4]; should not be less than 18 - 24 EPNdB;
- Engine life should not be less than 2000 hours;
- Aircraft cost should not be more than 70-80$M.

The satisfaction of these requirements is essentially connected to rational choice of the propulsion system architecture, its parameters, size and schedule control.

A propulsion system under study based on mixed turbofan with medium bypass ratio and without significant jet noise suppression from nozzle as potential propulsion for SSBJ is studied in Russia and Europe as one of promising approaches to meeting these requirements. If this is the case, a most important component of matching and rational selection of propulsion & aircraft design parameters becomes using a joint propulsion & aircraft control for maximal community noise reduction [1].

The efficiency and safety validation of recommended low noise initial flight procedures are subject for correct policy to accept of the future airworthiness and noise certification rules for supersonic civil transport.

2 Statement of the problem

Main goal of this activity is the research and analysis of potential capabilities to jet noise reduction with low noise takeoff procedures obtained by optimization of engine thrust throttling and initial flight path for two SSBJ differing in used engines.

Main parameters of the SSBJ and engine under study are:

- Takeoff weight is around 65t

- Engine – two versions of mixed turbofan with different BPR (version 1 - 1var – around 3, version 2 -2var – around 4);
- Available takeoff thrust is around 16t.

Main conditions, assumptions, restrictions accepted in this activity are:

- The margins on sideline(in 1st reference point) and cutback (in 2nd reference point) effective perceived jet noise levels relative Stage 3 FAR/JAR-36 ΔE_1 и ΔE_2 were considered as selection criteria of rational schedule control.
- Margins on noise in each reference point relative Stage 3 level in 6 and 8 EPNdB , margin on cumulative sideline & cutback noise level in 12 and 18 EPNdB are considered as minimal and advanced requirements (according to requirement of cumulative margin 18 - 24 EPNdB for cumulative noise level).
- Two basic type of engine control are considered:
  - first type of engine control with minimal initial throttle altitude of 300m (such cutback throttle is used by subsonic civil aircraft for cutback noise reduction);
  - second type of engine control with minimal initial throttle altitude of 10.8m. Notice that such specific low noise engine control during initial climb (when altitude is less 300m) can be considered no as additional engine thrust changing using manual control by the pilot (takeoff thrust throttling with throttle control lever), and as engine control which is provided by electronic engine schedule control without pilot action.
- Aircraft & engine control under study in this activity are considered as stepped change of engine rating defined by relative thrust and of flight trajectory defined by flight path angle.
- Main parameters rational selected are following:
  - number of engine rating change steps of schedule control (hereinafter “ control step”);
  - control steps location on the trajectory, which are defined by flight altitude in initial point of a control step;
  - relative thrust value kept constant on a control step;
  - flight path angle value kept constant on a control step.
- Engine thrust control (throttling) is realized by most effective jet noise reduction point of view method namely by nozzle control provided constant engine air flow. Such engine throttling method allows at given engine throttle ratio more essentially to reduce jet velocity.
- All active restrictions (in relation to flight safety, passengers comfort and noise certification procedure) were taken into account [2,3,4,5,6]. These restrictions are concerned minimal acceptable initial climb gradients, flight speed and altitude, maximal load factor etc.
- A problem of obtained aircraft & engine control realization in the real aircraft & engine control systems were not considered in this activity and requires separate detailed study and search of the practical solutions during the consequent phases of activity.

3 Results

Main optimization results as different optimal engine thrust and nozzle throat schedule control, trajectories and change of flight path angle along flight trajectory are shown in fig.1-4.

Changes of relative engine thrust $T_{rel} = T/T_{max}$ (where T is engine thrust for given engine rating, T_{max} is engine thrust for maximal engine rating) (fig. 1), of flight path angle (fig. 2), flight altitude (fig. 3), of relative nozzle throat area $A_{8\ rel} = A_8/A_{80}$ (where A_8 is engine nozzle throat area at given engine rating, A_{80} is engine nozzle throat area at takeoff engine rating) (fig. 4) vs flight range (distance from brake release) are shown in fig.1-4. The first type of schedule control with one (think solid lines) and two (think dashed lines) control steps, the second type of schedule control with one (heavy solid lines) and two (heavy dashed lines) control steps are shown on the fig.1-4.

It is seen from figures that rather high engine throttle ratio are used in obtained schedule control (throttle ratio can be reached up to 60% with respect to maximal thrust and accordingly increasing ratio of nozzle throat area can be reached 45%). The more engine throttle is restricted by minimum acceptable initial climb gradients and/or speed restrictions.

As a whole essentially for all obtained rational schedule control can be noted that flight with more lower engine rating and more lower altitude is more effective (from minimum sideline & cutback noise point of view) than flight with more high altitude and more higher engine rating (fig.1-4).

Rational initial point of control step is located on trajectory as soon as possible after runoff (fig. 1).

The influence of change of initial flight altitude of control step A_1 on the sideline & cutback noise levels ΔE_1 и ΔE_2 and cumulative sideline & cutback noise $\Delta E_{1,2\Sigma}$ for version 1var and 2var are shown on the fig. 5. It is seen from figures that change of ΔE_1 и ΔE_2 through change of altitude A_1 into the range 300-800m is insignificant and is less than 0,5-1 EPNdB, besides these small alteration of ΔE_1 и ΔE_2 are contrary (upper graph). Therefore it is possible to consider, that the rational initial altitude for control step of first type of rational schedule control is equal 300m.

In case of decreasing A_1 lower than 300m (lower graph) the essential effect of A_1 on a sideline noise ΔE_1 is watched, particularly in range of altitudes A_1 less than 50-100m. (notice that at the time cutback noise is a little increased because of decreasing of flyover altitude). In case of decreasing A_1 from 300m up to 150-200m the sideline jet noise ΔE_1 is reduced on 2 EPNdB, up to 100m – on 4 dB, up to 50m – on 7-9 dB, and up to 10.8m – on 12-17 dB.

The studies are indicated that the thrust decreasing rationally to make practically simultaneously with decreasing flight path angle (fig.2).

Second control step of schedule control with two control steps is used generally to satisfy to restrictions by insignificant increasing engine thrust and/or change of flight path angle (fig. 1).

Rational change of flight path angle (fig. 2) in general provides satisfaction of minimal climb gradient and flight speed restrictions.

The comparative effectiveness estimation of obtained rational schedule control from noise levels ΔE_1 и ΔE_2 reduction point of view is shown on fig. 5. The margins ΔE_1 и ΔE_2 for aircraft versions 1var and 2var in case of using first and second type of rational schedule control with 1, 2 and 3 control steps (RSC1 1, RSC1 2, RSC1 3, RSC2 1, RSC2 2, RSC2 3) are shown on diagramme of fig. 6.

Margins ΔE_1 и ΔE_2 in case of using first type of rational schedule control equal for 1var +3 EPNdB (sideline noise) и -9.5 EPNdB (cutback noise), for 2var - -3 EPNdB (sideline noise) and -12 EPNdB (cutback noise). Such difference in sideline and cutback noise levels for aircraft versions under consideration are explained by difference in BPR. Thus, the noise requirements to sideline noise can not be met using first type of schedule control for both aircraft versions.

Increasing a number of control steps from 1 to 3 for second type of rational schedule control allow additional to reduce noise on 1dB in each reference point. Subsequent increasing of control steps number gives insignificant noise reduction. The lower efficiency of increasing of control steps number more than 2-3 is conducted with the fact that most rational low noise schedule control are realized closely of restrictions (particularly on minimal gradient and flight speed).

Because of this and taking into account the control system realization complexity the second type of obtained rational schedule control with two control steps can be recommended as best low noise rational schedule control.

These rational schedule control for aircraft 1var allow to obtain margins on sideline jet noise ΔE_1 in -14.5 EPNdB, and on cutback jet noise ΔE_2 – in -8 EPNdB.

In case of using second type of rational schedule control for version 2var it is possible to provide the margins on sideline jet noise in -16 EPNdB, on cutback jet noise - in -9 EPNdB, on cumulative sideline and cutback noise in -25 EPNdB.

4 Conclusion

1. The obtained rational thrust schedule control use of engine thrust throttle on those flight segments, which have decisive impact to a sideline and cutback noise.

The rational degree of thrust throttle can achieve up to 60% from a maximum thrust. The rational change of a flight path angle as a whole provides first of all restrictions satisfaction and maximum of thrust throttle.

2. Margins on noise level relative the requirements Stage 3 in use of the first type of schedule control with minimal initial throttle altitude of 300m are for version 1var +3 EPNdB (for sideline noise) and -9.5 EPNdB (for cutback noise), for version 2var - -3 EPNdB (for sideline noise) and -12 EPNdB (for cutback noise), i.e. aircraft version 1var is not met to the considered minimal noise requirements on sideline noise (even on a jet noise, disregarding of noise from remaining noise sources).

3. Improving of first type of schedule control only with rational selection of parameters and number of control steps is insignificant (within the limits of 1 dB). That is connected to impossibility to decrease of engine thrust on a flight path before reaching altitude 300m, determining a sideline noise.

4. A using the second type of rational schedule control with minimal initial throttle altitude of 10.8m allow considerably to reduce a sideline jet noise (up to 12-17 EPNdB in comparison with using a best first type of schedule control).

5. Conducted study of effectiveness of obtained schedule control and taking into account its realization complexity the schedule with only one control step can be recommended as best low noise schedule. These schedule control allows to satisfy to all restrictions and to provide minimal sideline & cutback jet noise (margins on cumulative sideline & cutback noise are 24-25 EPNdB).

6. A using the best schedule control allow to satisfy to considered requirements from sideline & cutback jet noise point of view. These schedule using for version 2var allow to provide some jet noise reserves relative considered noise requirements. These reserves can be have an effect on the requirements to remaining noise sources and acoustic lining efficiency.

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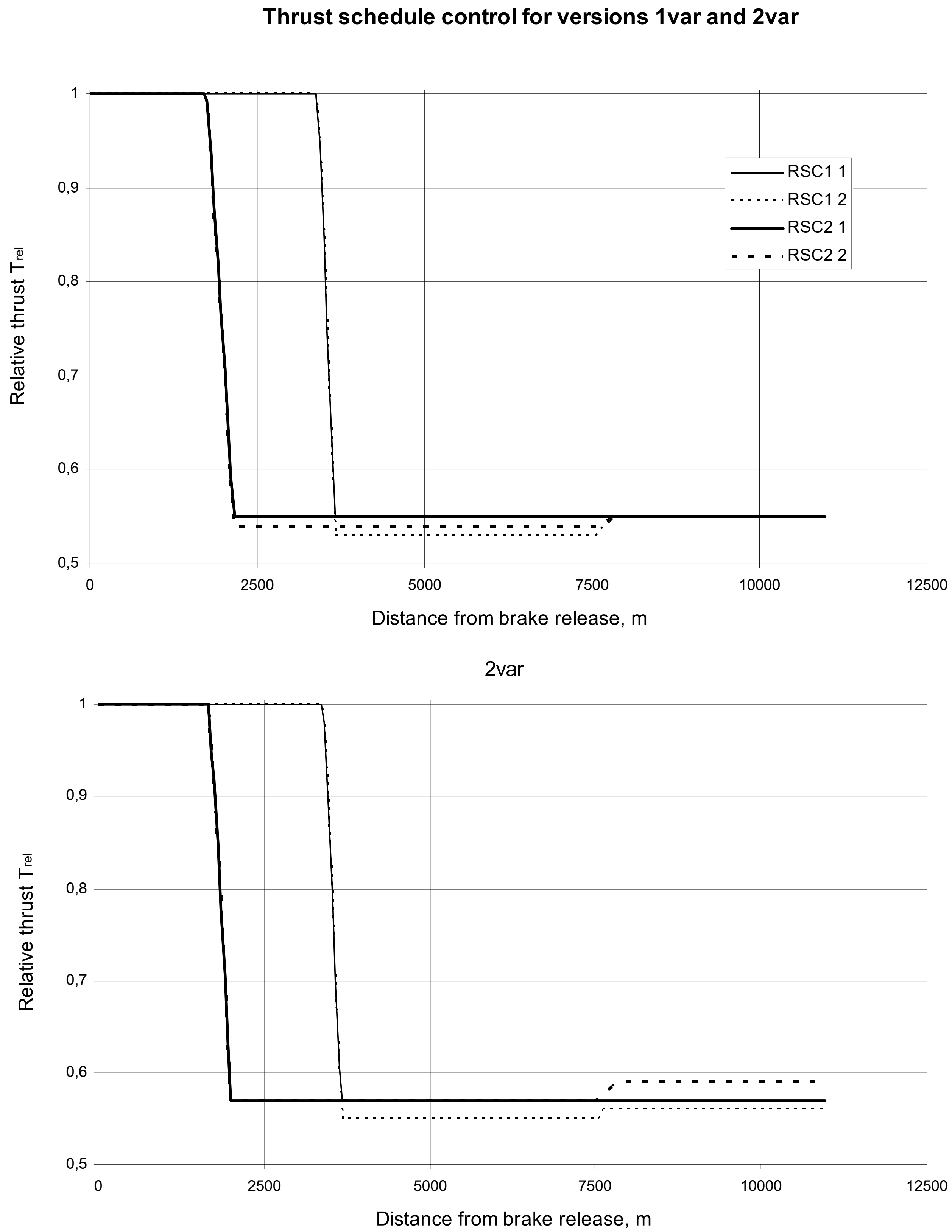


Fig.1. Rational Engine Thrust Schedule Control

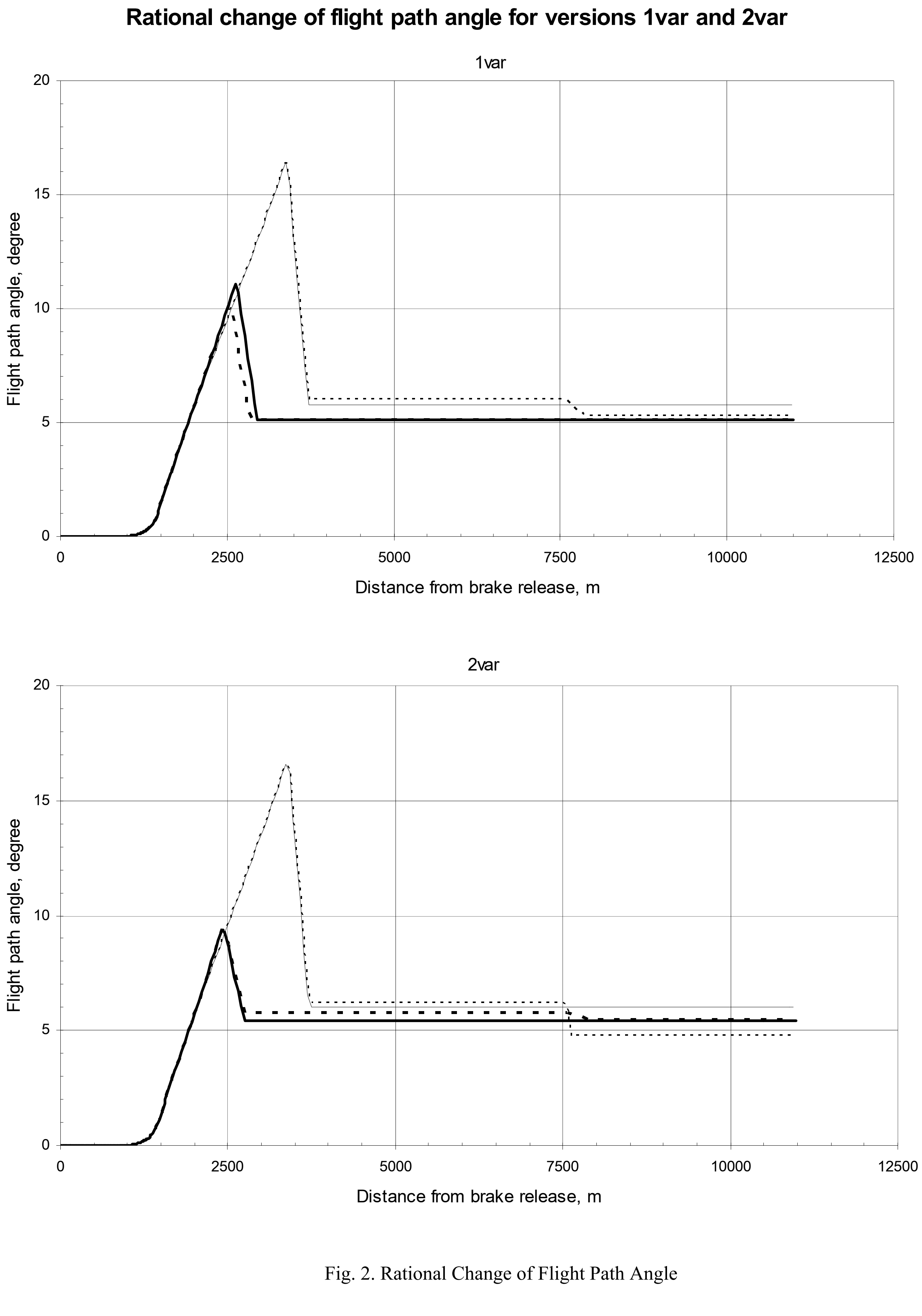


Fig. 2. Rational Change of Flight Path Angle

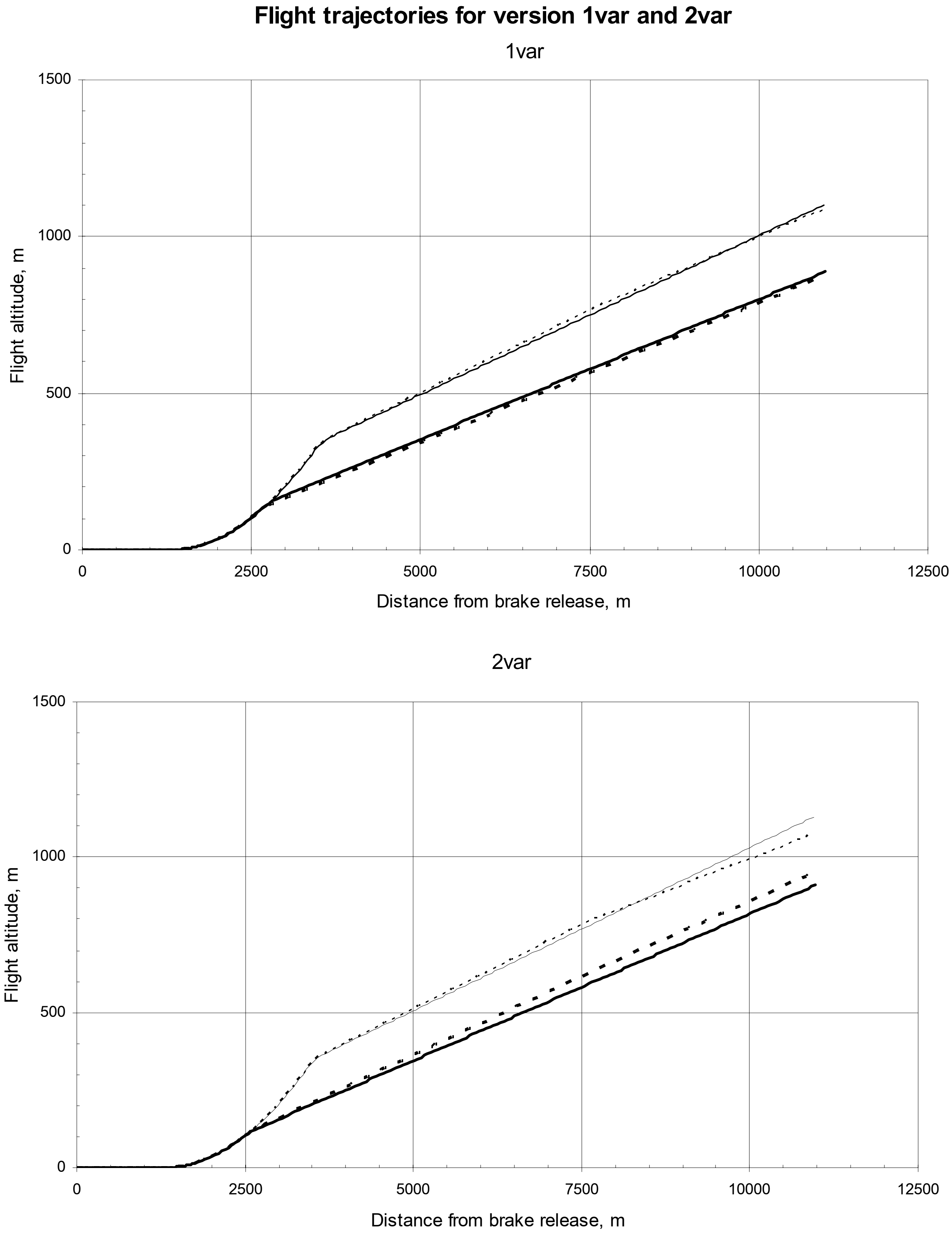


Fig. 3. Rational Flight Trajectories

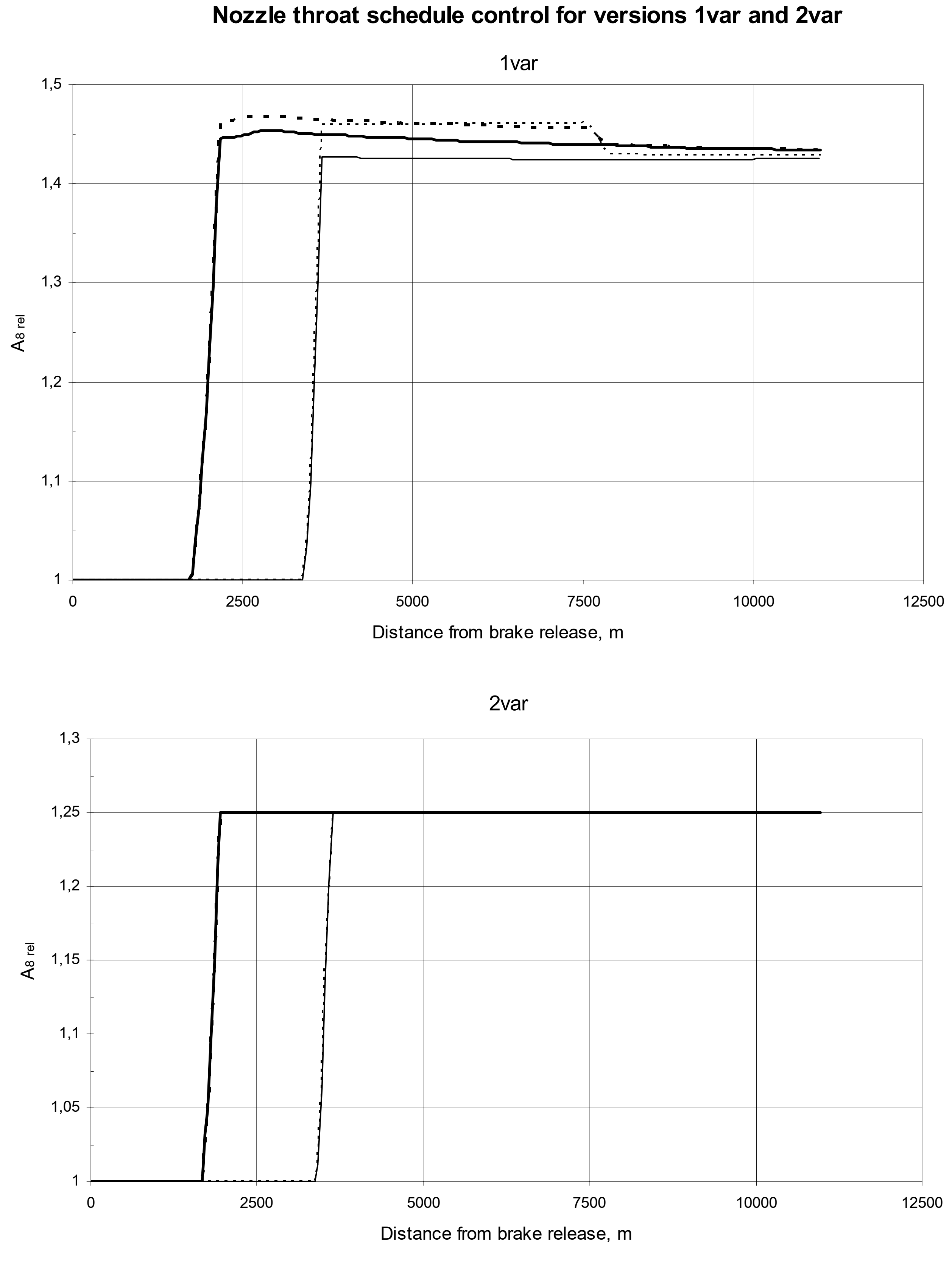
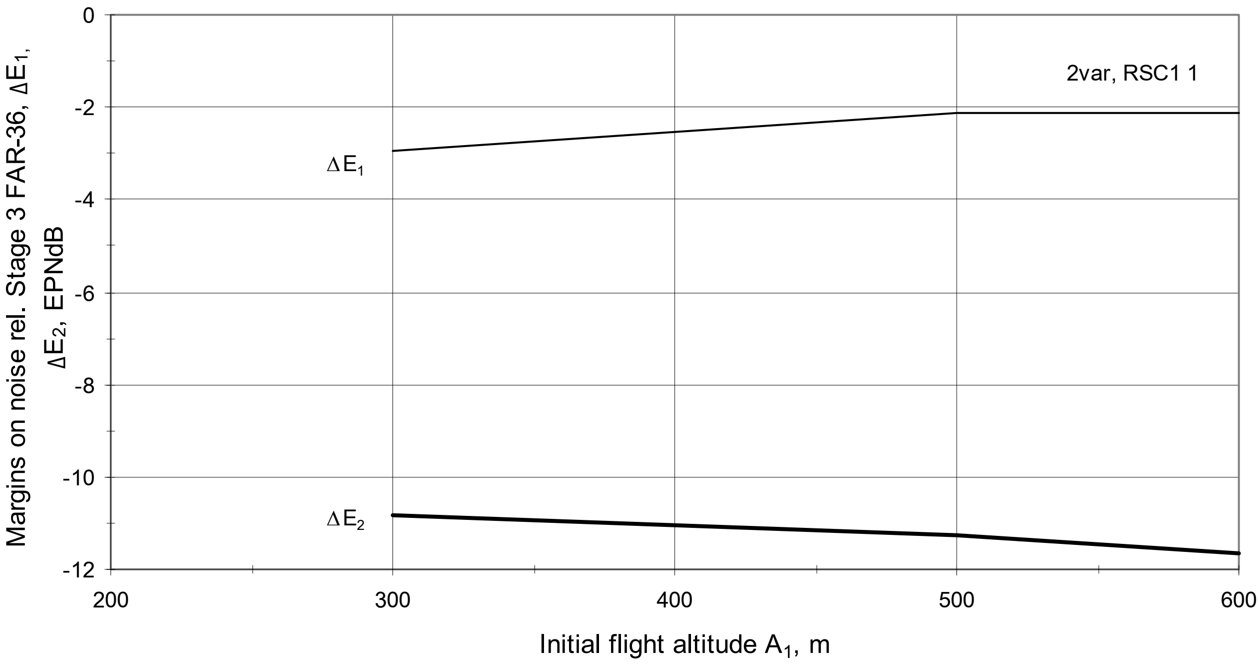


Fig.4. Rational Engine Nozzle Throat Schedule Control

Influence of initial flight altitude of control step on noise



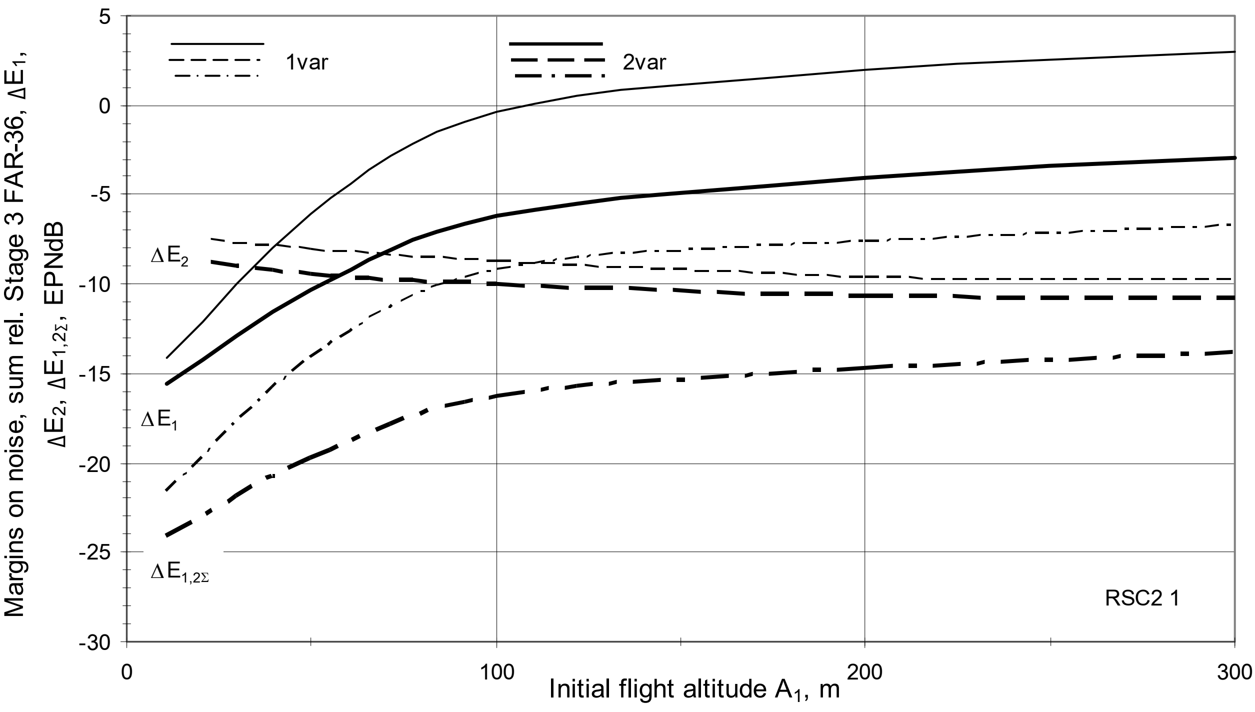


Fig. 5. The Influence of Initial Flight Altitude of Control Step on Noise Level

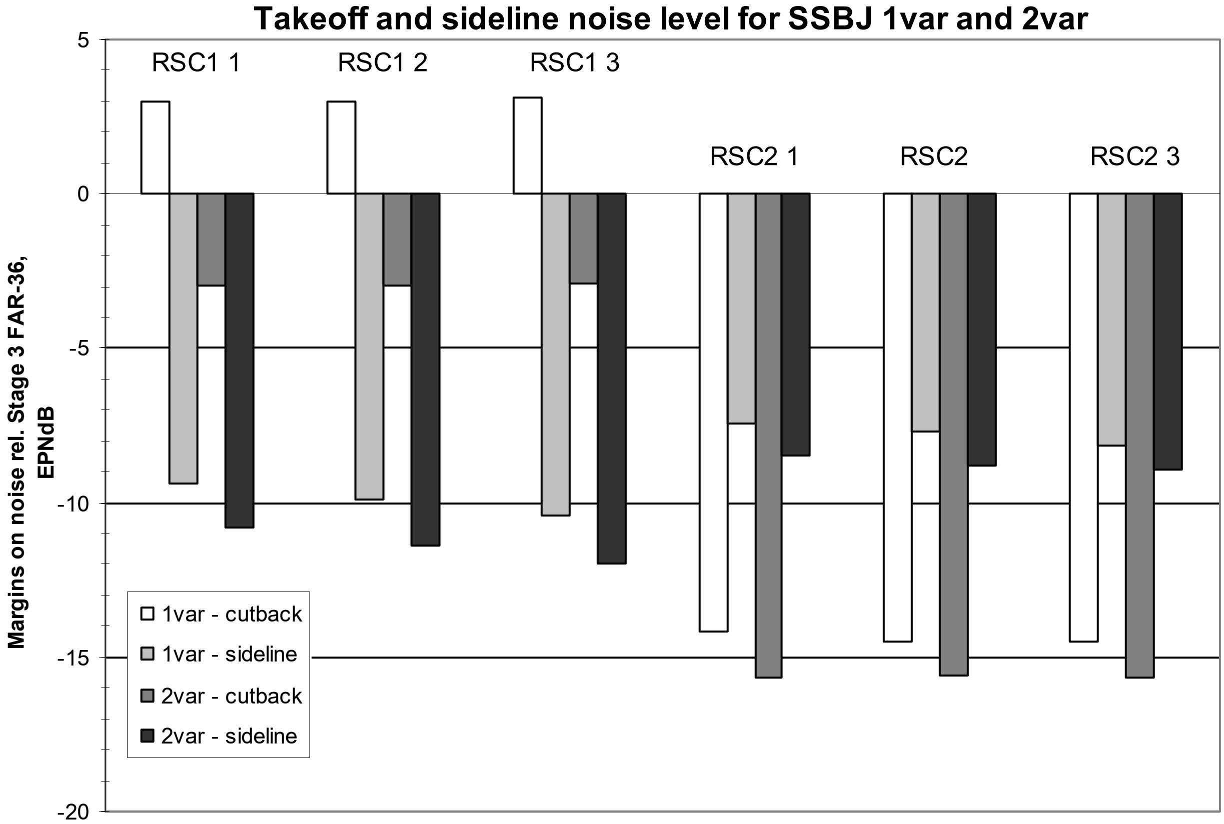


Fig. 6. Effectiveness of Obtained Rational Schedule Control from Noise Level Point of View