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NLR-CR-2017-027 | February 2017

Second opinion SSJ-100 noise report

CUSTOMER: SWEDAVIA AB

NLR – Netherlands Aerospace Centre

Netherlands Aerospace Centre

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Second opinion SSJ-100 noise report

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NLR-CR-2017-027

AUTHOR(S)
R.H. Hogenhuis
S.J. Heblij

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KNOWLEDGE AREA(S)
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Problem area

In 2017, CityJet wants to operate RRJ-95 aircraft to and from Bromma Airport. The commercial name of this aircraft is Sukhoi Superjet-100 (SSJ-100). Since these aircraft do not fulfil the noise limits for Bromma Airport, Sukhoi provided a report to indicate how the SSJ-100 could comply with these criteria. In this report, NLR verifies the conclusions of the Sukhoi report.

Description of work

NLR took the following steps to verify the results of the Sukhoi report:

1. NLR experts reviewed the Sukhoi report to see whether they agreed with the line of reasoning in this report.

2. Questions that arose during the review were provided to Sukhoi, so that a response could be provided and, where necessary, changes were made to the report.
3. NLR conducted computations and verified the results against existing data to determine if the results in the Sukhoi report were realistic.

Results and conclusions

After processing all comments and questions of NLR, Sukhoi provided a final version of their report which indicates that an average certification noise level of 89.0 EPNdB can be achieved for the Sukhoi Superjet 100 (version RRJ-95B-100) when the maximum take-off weight of the SSJ-100 is reduced to 43,500 kg. NLR concludes that this noise level is credible.

The conclusion is based on certification data that EASA still has to validate and therefore, the conclusions of this report are only valid as long as the actual certification values remain the same as indicated in the Sukhoi report.

Applicability

This report can be used as a document that provides an independent opinion on the Sukhoi report about the noise production of the SSJ-100. Besides that, the methodology described in this report can be applied in the future when new aircraft types are introduced at Bromma Airport for which the certification data do not directly provide sufficient clarity whether the aircraft will always comply with the noise limits for Bromma Airport.

NLR
Anthony Fokkerweg 2
1059 CM Amsterdam
p) +31 88 511 3113 f) +31 88 511 3210
e) info@nlr.nl i) www.nlr.nl

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AUTHOR(S):

R.H. Hogenhuis NLR
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R.H. Hogenhuis							M. den Boer							P.L.J. Eijssen					
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Contents

Abbreviations

ACRONYM	DESCRIPTION
ANP	Aircraft Noise and Performance
dB	Decibel
EPNdB	Equivalent Perceived Noise
LR	Long Range
NLR	Netherlands Aerospace Centre
SSJ-100	Sukhoi Superjet 100

1 Introduction

1.1 Motivation and scope

In 2017, CityJet wants to operate RRJ-95 aircraft to and from Bromma Airport. The commercial name of this aircraft is Sukhoi Superjet-100 (SSJ-100). More specifically, CityJet plans to operate the RRJ-95B-100 version of this aircraft. Since this aircraft does not meet the noise limits for this airport, Sukhoi provided a report to indicate how this aircraft could comply with these criteria (ref. 1).

SWEDAVIA requested NLR to verify the findings of the Sukhoi report. The outcomes of this verification are provided in this report. In order to verify the results of the Sukhoi report, NLR took the following steps:

1. NLR experts reviewed the Sukhoi report to see whether they agreed with the line of reasoning and the calculations in this report.
2. Questions that arose during the review were provided to Sukhoi, so that a response could be provided and, where necessary, changes were made in a new version of the report (ref. 2).
3. Independent of the Sukhoi analysis, NLR conducted computations and verified the results against existing data to determine whether the results in the Sukhoi report were realistic.

1.2 Document structure

First, in chapter 2, the review of the Sukhoi report is discussed. This includes an overview of the noise level limits of Bromma Airport, the proposed noise reduction measure and the credibility of the conclusions in the Sukhoi report. The analyses that have been performed by NLR to further investigate the credibility of the results are presented in chapter 3. Chapter 4 presents the overall conclusions.

2 Review of Sukhoi report

2.1 Noise level limits at Bromma airport

The Sukhoi report intends to show that the RRJ-95B-100 aircraft can comply with the noise limits of Bromma Airport. The limits are discussed in section 2.1 of the Sukhoi report. NLR cross-checked these limitations with to other sources (ref. 3) and the Aeronautical Information Publication of Bromma Airport (ref. 4). In the section on noise abatement procedures the most relevant part noise limit described is:

"The noise emission must not exceed 89 EPNdB, an average for the three points of measurement in accordance with ICAO Annex 16 Vol I chapter 3. Special rules concerning schedule air transport issued by Airport manager."

This refers to noise levels which are determined during the certification of an aircraft. These noise levels are determined using the so-called equivalent perceived noise level (EPNdB), expressed in decibels (dB). For the certification of an aircraft, the noise level is determined for three conditions:

- Lateral (departing aircraft)
- Flyover (departing aircraft)
- Approach

The average of the three noise levels is the metric that is used for the noise limits of Bromma Airport. The Sukhoi report also focuses on this metric. In line with the Sukhoi report, this report will also consider certification noise levels to determine whether the investigated SSJ-100 aircraft complies with the noise regulations for Bromma Airport.

Sukhoi proposes a reduction of the maximum operational take-off weight to comply with the noise limits for Bromma Airport. According to the Sukhoi report, this measure only affects the flyover certification noise level, while the (rounded values of the) other noise levels remain equal to the certified noise levels.

Aircraft used for scheduled service shall (according to ref. 3):

- *"either be certified for noise emission which does not exceed 86 EPNdB as an average for the three measuring points in accordance with ICAO Annex 16 Volume I, Part 2, Chapter 3,*

- *or be able to operate at the airport not exceeding 86 EPNdB for the three measuring points in accordance with ICAO Annex 16, Volume I, Part 2, Chapter 3.*

- *However 20,000 annual movements are permitted to be operated by subsonic jet aircraft with a seating capacity exceeding 60 seats with a noise emission which exceeds 86 by not 89 EPNdB as an average for the three measuring points in accordance with ICAO Annex 16, Volume I, Part 2, Chapter 3. The number of such operations on Saturdays and Sundays may not exceed the number of such operations during 2001."*[1]

[1] All aircraft types discussed in the Sukhoi report are subsonic jet aircraft with a seating capacity exceeding 60 seats.

2.2 Measures to reduce certification noise levels

As indicated in the previous paragraph, the proposed operational solution of Sukhoi only affects the flyover certification noise level, while the other noise levels remain equal to the certified noise levels. Based on expert opinion and cross-checks with publicly available data, NLR assessed the solution proposed in the Sukhoi report. Sukhoi proposes to lower the take-off weight of the aircraft. A lower take-off weight means that an aircraft needs less runway length to take-off and that it will climb faster. Furthermore, the thrust of the aircraft is reduced above the noise certification point and the speed is higher compared to the certification trajectory. Altogether, this reduces the noise level in the flyover certification point.

NLR agrees with Sukhoi that reducing the take-off weight is a valid way to reduce the noise level in the flyover certification point. This is confirmed by the fact that the European Aviation Safety Agency (EASA) provides separate tables with noise certification levels for different take-off weights for several aircraft types (ref. 5). Even though such tables are not available for the SSJ-100, this still shows that lowering the take-off weight results in lower noise levels in the flyover certification point.

2.3 Expected reductions in noise certification levels

Sukhoi proposes a take-off weight not exceeding 43,500 kg to achieve the required noise limits for Bromma Airport. The landing weight equals 41,000 kg, which is equal to the certified landing weight, so that the certification noise level for approach does not change.

The final Sukhoi report indicates that this results in an average noise emission in the three certification points of 89.0 EPNdB. This means that the aircraft complies with the limits for Bromma Airport. This result is based on preliminary results of the noise certification of the RRJ-95B-100 version of the SSJ-100. In February 2017, EASA indicated to NLR that they are still validating the certification of the aircraft, but that they expect that this process will be finished end of February or early March 2017. This means that they could not yet confirm the noise certification levels provided by Sukhoi, when this report was issued.

After reading the first version of the Sukhoi report, NLR provided Sukhoi with a list with three types of questions and comments:

- Questions and comments on the technical content of the report.
- Suggestions about the lay-out and clarity of the report. These suggestions did not have an impact on the conclusions of the report, but intended to make the report easier to read for non-expert readers.
- Suggestions on what information could be removed from the report. Again, the goal was to make the report easier to read for non-expert readers. The sections that were removed contained content that was not relevant or too detailed.

Several questions and comments were clarified to Sukhoi during a number of teleconferences. Based on the teleconferences NLR provided additional suggestions and comments. When all questions by NLR were answered, a final version of the Sukhoi report was produced, in which all relevant comments of NLR were taken into account. This version of the report concludes that an average certification noise level of 89.0 EPNdB can be achieved when the maximum take-off weight of the SSJ-100 is reduced to 43,500 kg.

Based on the above, NLR concludes that it is credible that an average certification noise level of 89.0 EPNdB can be achieved.

NLR did find several mistakes in the final Sukhoi report that do not affect the conclusions of the Sukhoi report. This mostly concerns typing errors, but also the following issues:

- An incorrect value of the cutback starting altitude of 2,240 ft on page 24 (this value should be equal to 2,175 ft). The altitude is correctly displayed in figure 7.
- The airspeeds used for approach throughout the report (for instance at pages 27 and 39) are inconsistent and the values of KCAS and KTAS do not match. Since the approach trajectory and certification noise level have not changed relative to the certification, the certification noise level for approach remains correct despite the inconsistent airspeeds.
- The noise level mentioned for the approach certification point on page 38 is not correct. This should be 93.04 instead of 93.05 EPNdB, which means that the rounded value is indeed equal to 93.0 EPNdB as mentioned elsewhere in the report.

This NLR report is written under the assumption that the certification values of the RRJ-95B-100 version of the SSJ-100 provided by Sukhoi are correct. These values could not be confirmed, as they still have to be validated by EASA. As long as the validated values remain the same as the values indicated by Sukhoi, NLR assumes that the underlying data also remain the same. In that case the conclusions in this report will hold. If the certification noise levels change, NLR has to reassess the situation before it can confirm whether the SSJ-100 meets the noise criteria for Bromma Airport.

Next to that, NLR has no access to the software that was used to compute the trajectory or engine performance. This means that NLR cannot reproduce the trajectory that was computed for the aircraft with a take-off weight of 43,500 kg. NLR did, however, perform several analyses to estimate whether the data used by Sukhoi is consistent, both relative to the data used for the certification, but also in comparison with other aircraft (see chapter 3).

3 Additional analyses

Additional to the findings in section 2.3, NLR performed an assessment to answer the following question.

Are the results of the Sukhoi report realistic?

The focus of this additional analysis is on the computation of the new flyover certification noise level, as the other two noise levels (lateral and approach) remained equal to the certification levels.

To answer the above question, the following analyses are performed:

- Sukhoi proposes a take-off trajectory with a thrust cutback. By reducing the take-off weight the thrust level is further reduced when the aircraft overflies the certification point. The aircraft performance before and after the thrust cutback for the trajectory with a lower weight can be compared to check whether the reported thrust levels are consistent with the aircraft performance (see paragraph 3.1).
- The reduced thrust levels are converted by Sukhoi to a corrected fan speed before the effects of the thrust reduction on the noise level are determined. By using the values from the certification trajectory as approved by EASA, it is possible to check the consistency of this conversion (see paragraph 3.2).
- In the Sukhoi report the effect of atmospheric absorption is not included. Since this effect results in lower certification noise levels for the flyover certification noise level, Sukhoi uses a conservative approach. An indication is made to estimate what the effect of including atmospheric absorption would be on the flyover certification noise level (see paragraph 3.3).
- The overall effect of a weight reduction on the flyover certification noise level is compared to the effect of weight reductions for other aircraft types from other manufacturers that are available in the EASA database (see paragraph 3.4).

Paragraphs 3.1 to 3.4 contain some technical content. The main conclusions of the analyses are summarized in paragraph 3.5.

3.1 Analysis of engine thrust levels

Sukhoi proposes a take-off trajectory with a thrust cutback. By reducing the take-off weight the thrust level is further reduced when the aircraft overflies the certification point. NLR has performed a check on the consistency of the aircraft flight performance and corresponding thrust levels before and after the thrust cutback. With this check, it can be confirmed whether the thrust levels applied for the calculation of the flyover certification level match with the climb performance shown in the trajectory for the flyover certification noise level.

Based on figure 7, table 8 and table 10 of the final Sukhoi report (ref. 2), the following data were obtained:

Table 1: Flight path angle and thrust before and after the cutback for the reduced take-off weight of 43,500 kg

	Before cutback (full power)	After cutback
Flight path angle	10.8°	4.2°
Total thrust	2 x 5,831 = 11,622 kg	2 x 3,326.5 = 6,653 kg
Thrust reduction	11,622-6,653 = 4,969 kg	

As the flight path angle is reduced from 10.8° to 4.2°, less thrust will be required for climbing. Using basic trigonometry, it can be estimated that for the given aircraft weight of 43,500 kg, the reduction in thrust required for climbing is 4,965 kg. This computed value is within 1% of the thrust reduction as applied by Sukhoi, meaning that the applied thrust reduction is indeed consistent with the reduction in climb gradient.

The angle of 4.2° used for the above computation is not equal to the climb angle of 3.66° mentioned on page 37. Sukhoi clarified that this angle is not constant nearby the certification point. The climb angle equals 3.66° when the aircraft passes the certification point. Based on figure 7, NLR estimated the value of 4.2° for the average flight path angle in a larger part of the trajectory nearby the certification point.

3.2 Analysis of engine performance

As described in the previous paragraph, the engine thrust levels for the flyover change due to the weight reduction of the aircraft. The Sukhoi report provides three certified combinations of thrust and engine setting (described with the parameter $N1\%/\sqrt{\Theta_{t2}}$). For the lower weight trajectory, one combination of these parameters is available. The certified values are plotted and a trend line is fitted through these points. After that, the data point for the lower weight trajectory is also plotted to verify whether this point is on or close to the trend line. Figure 1 shows the result of this analysis.

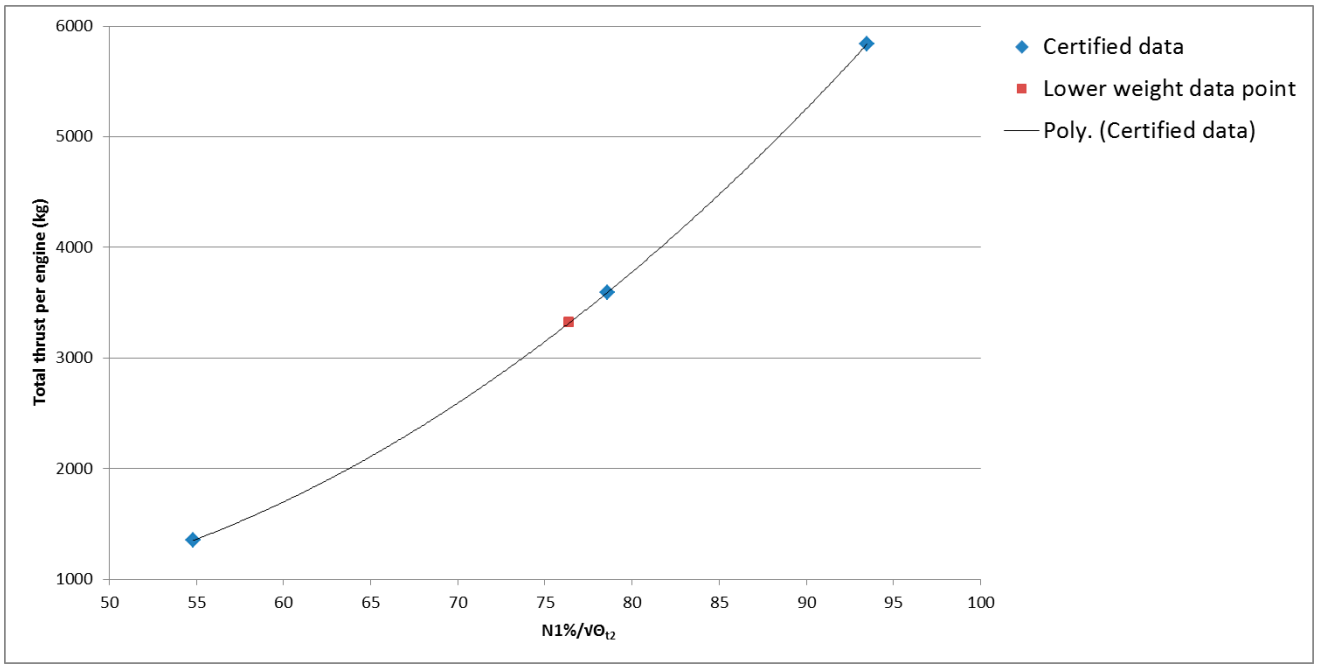

Figure 1: Comparison of engine setting versus total thrust per engine

The figure shows that the data point for the lower weight trajectory (the red dot) is on the trend line for the other data points. This indicates that the combination of thrust and corrected N1% setting provided by Sukhoi is realistic.

3.3 Estimation of the effect of atmospheric absorption

In the Sukhoi report, the effect of additional atmospheric absorption is neglected in the computation of the flyover certification noise level. Atmospheric absorption refers to the phenomena that the energy of sound waves is partially absorbed by the atmosphere when sound waves travel through the atmosphere. Including this effect in the computation of the certification noise levels would result in a lower flyover certification noise level. This means that Sukhoi uses a conservative approach that underestimates the noise level reduction that is achieved by the increase in flyover altitude. Sukhoi confirmed the issue, but chose not to include this, because it involves a lot of additional computations and since the conservative computation already indicates that the SSJ-100 complies with the Bromma Airport noise limits if the take-off weight is reduced to 43,500 kg.

NLR prepared a global estimate of the potential effect of not including atmospheric absorption. This was done by comparing the maximum tone-corrected perceived noise level reduction as used by Sukhoi (excluding atmospheric absorption) to the noise level reduction for several similar sized aircraft types for the same increase in flyover altitude. The data for these other aircraft was obtained from the international aircraft noise and performance (ANP) database and includes the effect of (additional) atmospheric absorption. Figure 2 shows the results.

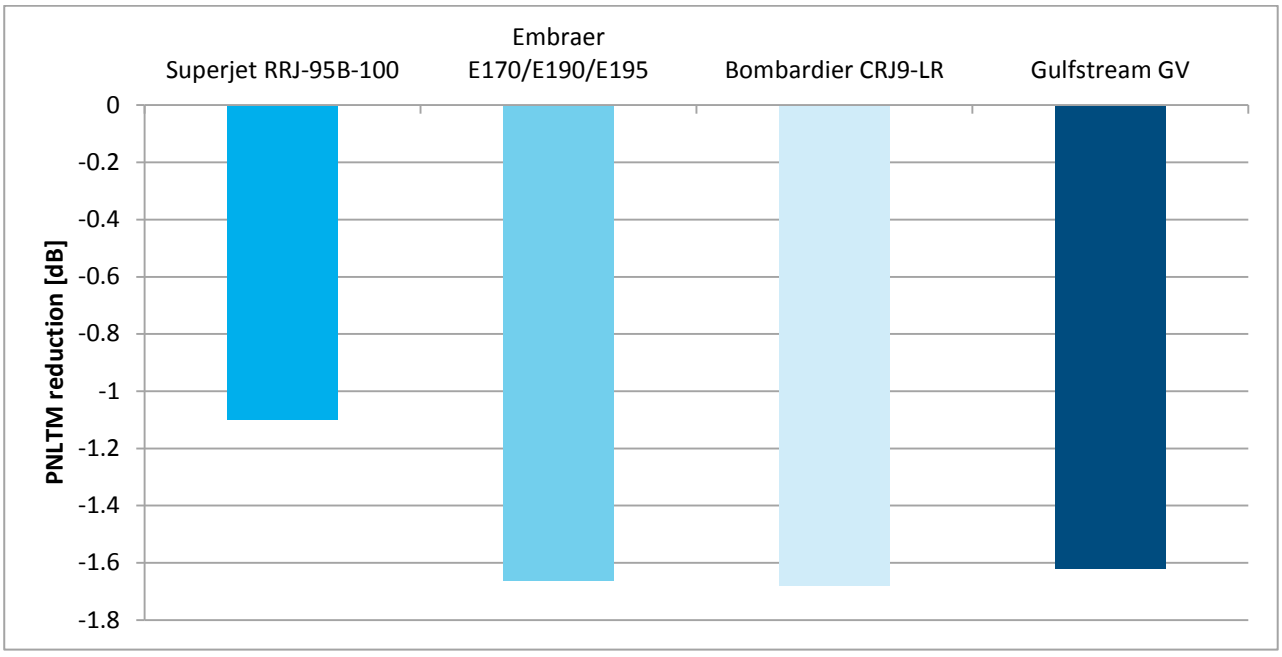

Figure 2: Reduction of PNLTM noise level for an increase in flyover altitude from 2,263 to 2,575 ft

The figure clearly shows the effect of neglecting the additional atmospheric absorption. Based on these results, NLR estimates that the conservative approach as used by Sukhoi underestimates the reduction of the flyover certification noise level by approximately 0.5 EPNdB. This is only relevant for the flyover certification noise level, since the effect of absorption is fully included in the computation of the lateral and approach certification noise levels.

3.4 Analysis of the effect of a weight reduction

In order to fulfil the noise criteria for Bromma Airport, Sukhoi proposes to reduce the maximum take-off weight of the SSJ-100. Other aircraft manufactures also regularly apply this tactic in order to reduce the certification noise levels. In order to verify whether the expected noise reduction due to a weight reduction is realistic, NLR compared the effect of a weight reduction for the SSJ-100 to the effect of a weight reduction for the following other aircraft types:

- Airbus A318-111 (with CFM engines)
- Airbus A318-122 (with PW engines)
- Airbus A319-111
- Airbus A320-211
- Airbus 350-900
- Boeing 787-8
- Bombardier CS100
- Embraer 170-100
- Embraer 190-100

These aircraft types are a random selection of aircraft types, where most types have a comparable size to the SSJ-100 and aircraft from several aircraft manufactures have been selected. The data for the other aircraft types is taken from the EASA noise certification database and the comparison was made by plotting the relative weight reduction to the reduction of the flyover certification noise level due to the weight reduction.

The data is compared to two cases:

1. The effect of the weight reduction of the 45,580 kg and 43,500 kg versions of the SSJ-100 compared to the Long Range (LR) variant.
2. The effect of the weight reduction of the 43,500 kg version of the SSJ-100 compared to 45,580 kg variant.

The result of the comparison is shown in Figure 3. The black line shows the average noise reduction due to a weight reduction for all aircraft types, except for the SSJ-100.

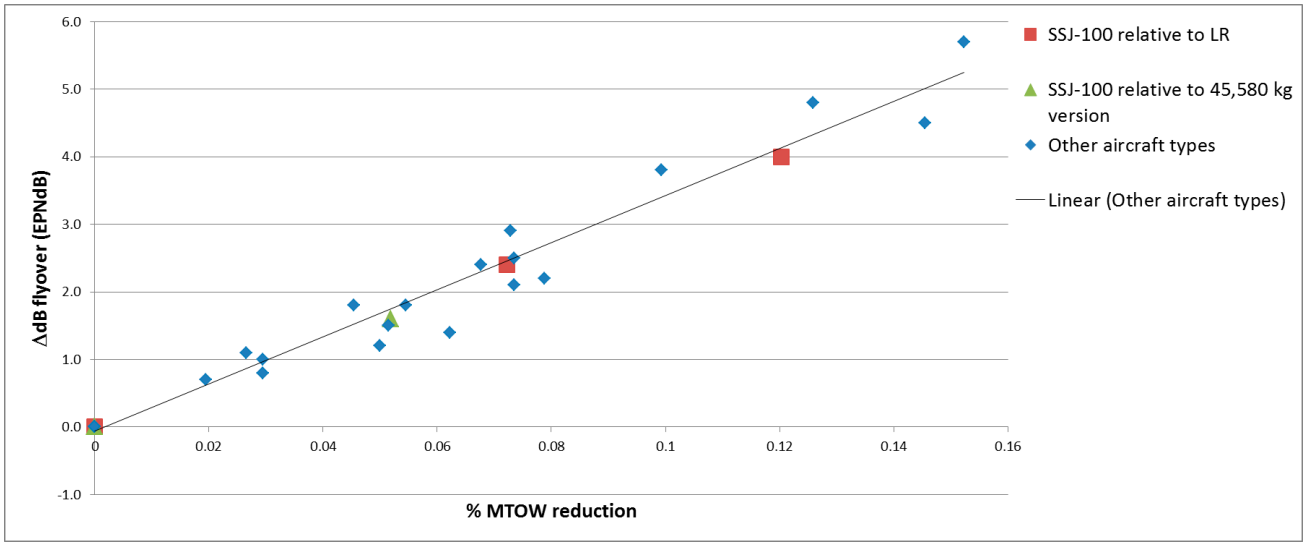

Figure 3: Comparison of effect of weight reduction on flyover certification noise levels

The figure shows that in all cases the noise reduction for the SSJ-100 is at or below the black line. This means that the reduction of the flyover certification noise level due to the effect of the weight reduction is average or even a little below the average of all other aircraft types. Therefore, this analysis confirms that the reduction achieved by Sukhoi seems realistic.

It should be noted that the effect of absorption (see paragraph 3.3) is not included the data points for the SSJ-100 with a maximum take-off weight of 43,500 kg in Figure 3 (the light green triangle and the most right red square). If the effect would have been included, the reduction would be larger, but would still be in line with the highest reductions achieved for other aircraft types.

3.5 Summary of analyses

This section summarizes the most important conclusions of the NLR analyses of the Sukhoi report.

Given the available data and results of the analyses, NLR concludes the following with respect to the take-off trajectory proposed by Sukhoi and the certification noise levels:

- The applied thrust reduction is consistent with the aircraft performance in terms of the reduction of the climb gradient.
- The combination of thrust and corrected N1 engine setting used to calculate the flyover noise level is consistent with certified data points.
- NLR estimates that the certification noise level for flyover would be approximately 0.5 EPNdB lower if the effect of atmospheric absorption would have been included.
- The effect of the weight reduction on the flyover certification noise level shows that the results provided by Sukhoi are comparable with the results for other aircraft types from other manufacturers available in the EASA noise certification database.

All the above results confirm the credibility of the proposed trajectory, of the achieved certification noise level for flyover and thus of the reduction of the average certification noise level provided by Sukhoi.

4 Conclusions

Sukhoi has provided a report to show that the Sukhoi Superjet 100 (version RRJ-95B-100) aircraft can comply with the noise limits for Bromma Airport. NLR verified this report and investigated whether this aircraft can operate to and from Bromma Airport within the existing noise limits. The verification is done by a review of the Sukhoi report and by additional analysis.

Main conclusion

NLR concludes that it is credible that an average certification noise level of 89.0 EPNdB can be achieved for the Sukhoi Superjet 100 (version RRJ-95B-100) if the maximum take-off weight is reduced to 43,500 kg.

After reading the final Sukhoi report, NLR agrees with the main findings in this report. NLR agrees that reducing the take-off weight can result in a lower flyover certification noise level and concludes that it is credible that an average certification noise level of 89.0 EPNdB can be achieved if the maximum take-off weight is reduced to 43,500 kg.

This conclusion is based on results of the certification of the RRJ-95B-100 version of the SSJ-100 provided in the Sukhoi report. In February 2017, EASA indicated to NLR that they are still validating the certification of the aircraft, but that they expect that this process will be finished end of February or early March 2017. This means that they could not yet confirm the noise certification levels provided by Sukhoi, when this report was issued.

This report is written under the assumption that the certification values of the RRJ-95B-100 version of the SSJ-100 provided by Sukhoi are correct. As long as the validated values remain the same as the values indicated by Sukhoi, NLR assumes that the underlying data also remain the same. In that case the conclusions in this report will hold. If the certification noise levels change, NLR has to reassess the situation before it can confirm whether the SSJ-100 meets the noise criteria for Bromma Airport.

Next to that, NLR has no access to the software that was used to compute the trajectory. This means that NLR cannot reproduce the trajectory that was computed for the aircraft with a take-off weight of 43,500 kg. In order to be able to indicate whether the trajectory and engine settings are realistic, NLR performed several additional analyses. These analyses confirm the credibility of the proposed trajectory and of the achieved certification noise level for flyover.

Sukhoi used a conservative approach to compute the certification noise level for flyover, since the noise level reduction due to atmospheric absorption is not included in the computation. An analysis by NLR shows that the flyover noise certification level is expected to be approximately 0.5 EPNdB lower if that effect would have been included. This is only relevant for the flyover certification noise level, since the effect of absorption is fully included in the computation of the lateral and approach certification noise levels.

5 References

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NLR

Anthony Fokkerweg 2
1059 CM Amsterdam, The Netherlands
p) +31 88 511 3113 f) +31 88 511 3210
e) info@nlr.nl i) www.nlr.nl