PARAMETRIC STUDY FOR THE LOW BVI NOISE BERP BLADE - KBERP DESIGN USING DEAF

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Abstract

Compared to the noise limits (CAN7) specified in ICAO Annex 16 for civil helicopters, the Lynx equipped with BERP blades has only 0.2 EPNdB margin in the approach case although it has more than 4 EPNdB margin in fly-over and take-off conditions. The objectives of the study described in this paper were to devise a low noise main rotor blade for the Lynx using DEAF combined with the high resolution airload model ACROT. A design requirement is that the new blade, KBERP (Korean BERP) should achieve a significant reduction in noise during approach (at least 6 EPNdB margin) without any noise penalty in fly-over and take-off conditions and minimal performance penalty. It was decided to investigate a tip modification to the BERP blade, employing the twin vortex concept to reduce BVI noise and to retain the excellent high-speed performance characteristics of BERP. Through the parametric study, the KBERP blade with optimized twin vortices has at least a 9 EPNdB noise margin in approach flight condition with only a small penalty in fly over and takeoff conditions. The KBERP tip is thus a very cost effective way to reduce BVI noise during approach.

Nomenclature

ACROT : Airload Analysis Code
BERP : British Experimental Rotor Program
CAEP 5 : 5th Meeting of Committee on Aviation Environmental Protection
CAN 6/7 : 6th/7th Meeting of Committee of Aircraft Noise
DEAF : Definition and Evaluation of the Acoustic Field, Noise Analysis Code
EPNL : Effective Perceived Noise Level(dB)
KBERP : Korean BERP
PNLT : Tone Corrected Perceived Noise Level(dB)
SPL_p : Sound Pressure Level of Peak Pressure(dB)
W_{togw} : Take off Gross Weight

Introduction

The BVI (Blade Vortex Interaction) phenomenon, especially parallel interactions between the helicopter main rotor blade and the tip vortex, is the cause of significant noise and vibration problems in helicopter operation. In particular, the descent and banked turn flight conditions are known to produce significant BVI [1-2]. A recent study shows that a swept and tapered tip with anhedral may make a BVI even in level flight condition [3].

Nowadays, civil noise certification regulations as well as local airport rules are tending to become ever more severe due to the community perception of helicopter noise nuisance. In the case of military operations, certain situations may demand low perceived noise levels to avoid the possibility of detection. Moreover, there is increasing pressure for military helicopters operating in peacetime conditions to observe civil noise limits.

Various efforts to reduce BVI noise are being pursued by both industry and academia. Methods may be categorized broadly as follows: passive techniques such as tip modification, active techniques including higher harmonic control, individual blade control etc. and control of the flight path to avoid high BVI generating conditions and to reduce the noise foot print [1].

The objective of the study described in this paper was to devise a low BVI noise main rotor blade that is intended to be a direct replacement for the existing Lynx blade, i.e. a BERP blade without any significant change to the rest of the aircraft or rotor system.

Design Requirement and Objective

Compared to the noise limits (CAN 7) specified in ICAO Annex 16 for civil helicopters, the Lynx equipped with BERP blades has only 0.2 EPNdB

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margin in the approach case although it has more than 4 EPNdB margins in fly over and take off conditions. Table 1 summarizes the corresponding noise limits and margins (W_{togw}=10,750lb) [4].

Considering the next generation of civil noise regulations (e.g. CAN 6, CAEP5) and the desire to increase the competitiveness of Lynx in future, a design requirement is that the new blade, KBERP, should achieve a significant reduction in noise during approach without any noise penalty in fly-over and take-off conditions and minimal performance penalty.

It was decided that noise margin during approach should be at least 6 EPNdB considering a design margin due to the analysis tool inaccuracy.

Table 1. Noise limits and margins

(EPNdB)

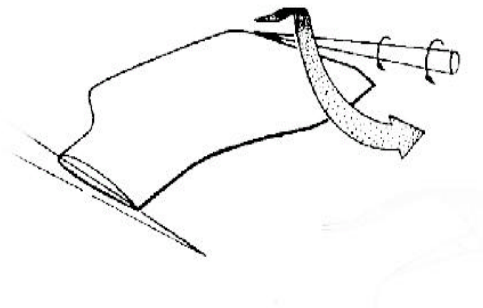
	Measured Data[4]	Noise Limit(CAN7)	Noise Margin
Take Off	92.0	96.9	4.9
Fly Over	91.7	95.9	4.2
Approach	97.7	97.9	0.2

Design Approach

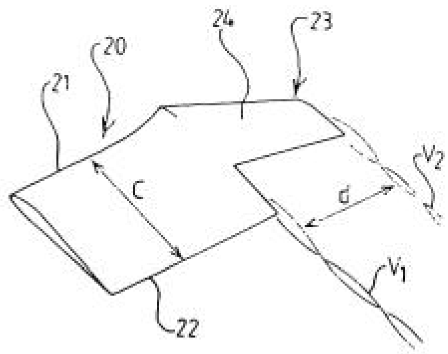
The most powerful noise reduction parameters in all modes of flight are the reduction of main rotor tip speed and the increase of the number of blades. Clearly, in order to achieve the optimum balance between noise and performance, the choice of tip speed and blade number should be determined in the early phase of new helicopter development. As mentioned before, the KBERP blade is intended to be a direct replacement for the existing Lynx blade so that no changes to the control system, transmission etc. are permitted. Any change in tip speed and number of blades would lead to a significant change of the existing Lynx due to consequent changes in rotor hub, control system and transmission, with further consequences due to changes in rotor forcing frequency.

To achieve the design requirements and satisfy the constraints, it was decided to investigate a tip modification to the BERP blade.

The previous operational experiences of GKN Westland [5] show that BERP blade with a notch and swept tip as shown in Fig. 1 (a) has excellent high speed forward flight and hover performance. Also, previous GKN Westland studies [2, 6] show that an unswept vaned tip using the twin vortex concept as shown in Fig. 1 (b) has excellent low BVI noise and good performance features. The basic idea for the KBERP design was to combine the vane tip twin trailed vortex system with BERP tip geometry to reduce BVI noise and to retain the excellent high-speed performance characteristics as shown in Fig.2. Several variants of the concept are already patented by GKN Westland [7].



(a) BERP tip



(b) Vane tip

Fig.1 BERP and vane tip concepts

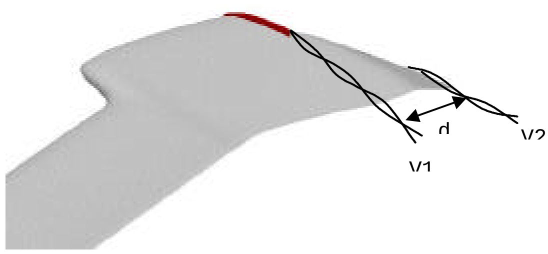


Fig.2 Advanced vane tip-KBERP tip

DEAF and ACROT

The program DEAF is used as a noise analysis tool for this study. DEAF is the state-of-the-art noise prediction tool of GKN Westland. It is based on the Ffowcs-Williams and Hawkings (FWH) formulation considering the monopole and dipole terms only. For the kind of calculation considered here, the quadrupole term is not needed. The program is able to calculate acoustic pressure waveforms for force and thickness terms at arbitrary, user specified observer points. Other options include noise directivity contours on a hemispherical surface of specified radius (‘contour run option’) and the simulation of flight test case results along a user specified flight path (‘continuous run option’) [8]. Propagation effects due to atmospheric absorption and ground reflections can be included in the analysis if required [9]. The program has been validated using flight test data, and has demonstrated good agreement with test data in terms of peak pressure and waveform [9].

For DEAF calculations, high resolution airloads are required. These are supplied by ACROT. The ACROT code is based on Beddoes’ 3rd generation unsteady aerodynamic model. The code has a simple longitudinal trim option and it can calculate the chordwise airload change due to the BVI accurately [10]. It can deal with the twin vortex flow field around rotor blade also [6].

Flight Conditions for Noise Certification

To calculate the noise certification levels, three kinds of flight path: approach, fly over and take off must be considered. In the Lynx case, the best rate of climb speed is 70kts, and the climb angle in take off condition is 16.5 degree as shown in Table 2. The flight speed in fly over condition is set to 128kts. Table 2 also shows the disk tilt angle in each case calculated by the trim routine of ACROT.

Table 2. Flight condition

	Approach (AP)	Fly Over (FO)	Take Off (TO)
AUW(lb)	10750	10750	10750
V(kts)	70	128	70
Vt(ft/s)	735	717.5	717.5
Disk Tilt (deg)	-2.01	-6.04	-1.98

Fig. 3 shows the flight path of each condition and position of the microphone (1.2m) that is used for the ‘continuous run option’ of DEAF.

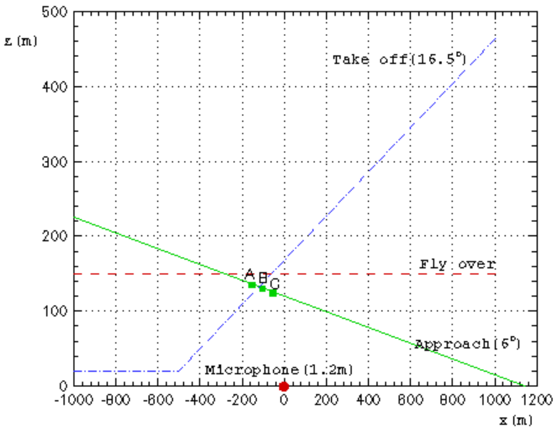


Fig. 3 The flight path for noise certification

Parametric Study in Approach Condition

The BVI noise performance of a twin vortex tip may be described by four parameters: v2s, v2r, v2g and v2c, defined below [6].

v2s = vortex separation(d)/ rotor radius(R)
v2r = relative vortex rotation rate(rev./ rotor rev.)
v2g = inboard vortex circulation/ total circulation
v2c = ratio of inboard to outboard vortex core size

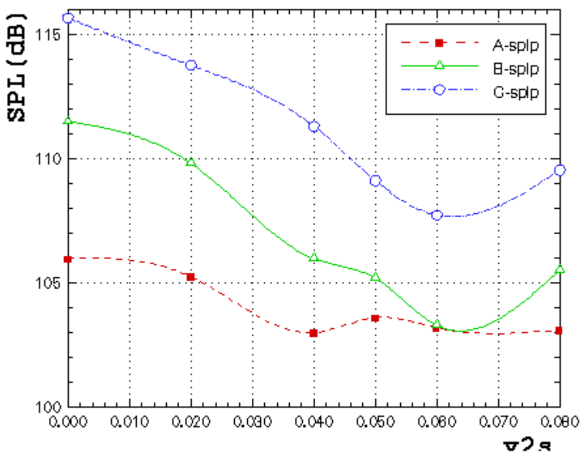
To find the optimized twin vortex configuration for the KBERP in the approach condition, 17 combinations of the parameters listed in Table 3 were considered. Basically, the parameter set is same as that of the previous study on the unswept vane tip [6] with one exception. It is the baseline value of v2s is set to 0.05. The ‘b1ap’ case is the case of the original single vortex BERP tip in approach condition.

Fig. 4 shows the SPL_p calculated at A, B and C helicopter positions as shown in Fig. 3. The results show values of vortex separation, v2s, between 4% and 6% of the blade radius (R) and relative circulation, v2g, of 0.5, i.e. two, equal strength vortices, provide the best combination of the parameters investigated, although the results vary with the observer position. The effect of relative core size, v2c, is small for practical purposes. Conversely, the effect of rotation rate, v2r, is to introduce a degree of variability in the order of 6 dB, although the precise form of the relationship is a function of observer location (A, B, C) as shown in Fig. 4 (b).

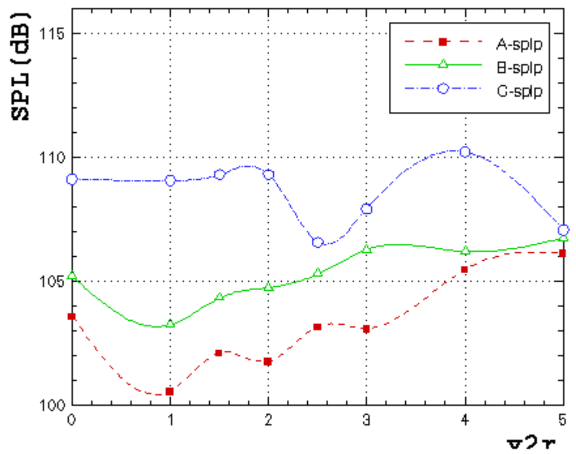
Table 3. Parametric values for each case

Case_Id	v2s	v2r	v2g	v2c
b1ap	0.00	0.00	0.00	0.00
b2s1ap	0.02	0.00	0.50	1.00
b2s2ap	0.04	0.00	0.50	1.00
b2s2.5ap	0.05	0.00	0.50	1.00
b2s3ap	0.06	0.00	0.50	1.00
b2s4ap	0.08	0.00	0.50	1.00
b2r1ap	0.05	1.00	0.50	1.00
b2r1.5ap	0.05	1.50	0.50	1.00
b2r2ap	0.05	2.00	0.50	1.00
b2r2.5ap	0.05	2.50	0.50	1.00
b2r3ap	0.05	3.00	0.50	1.00
b2r4ap	0.05	4.00	0.50	1.00
b2r5ap	0.05	5.00	0.50	1.00
b2g1ap	0.05	0.00	0.30	1.00
b2g2ap	0.05	0.00	0.70	1.00
b2c1ap	0.05	0.00	0.50	0.50
b2c2ap	0.05	0.00	0.50	1.50

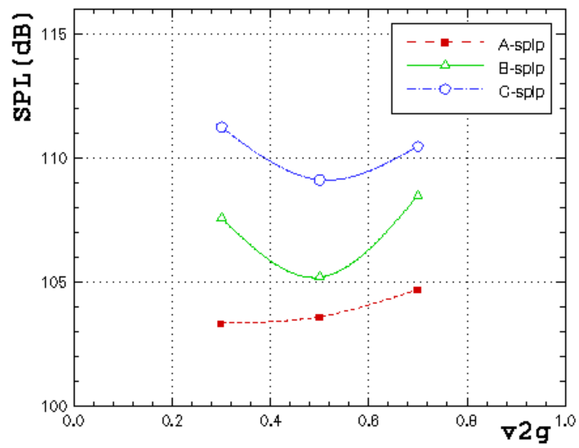
These results are very similar to those from a previous study made assuming a rectangular planform blade [6]. The optimized combination of parameters predicts the KBERP blade to be significantly quieter than the unmodified BERP blade. However, results will depend ultimately on the actual rotation rate of the two trailed vortices.



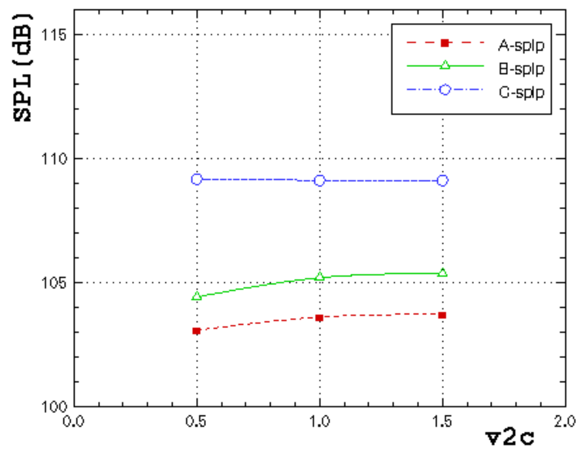
(a) v2s



(b) v2r



(c) v2g



(d) v2c

Fig. 4 Results of parametric study

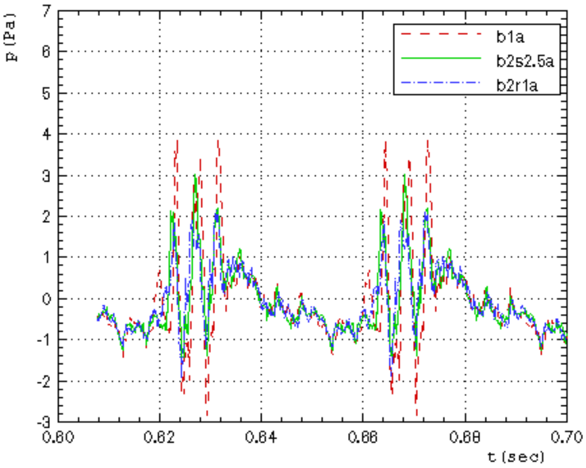


Fig. 5 Pressure time history of typical case

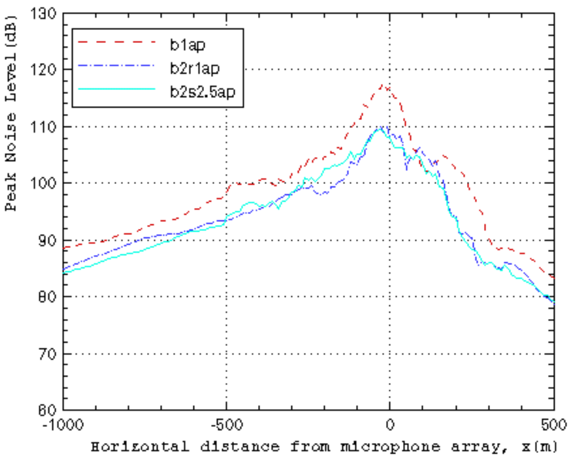


Fig. 6 Continuous run results

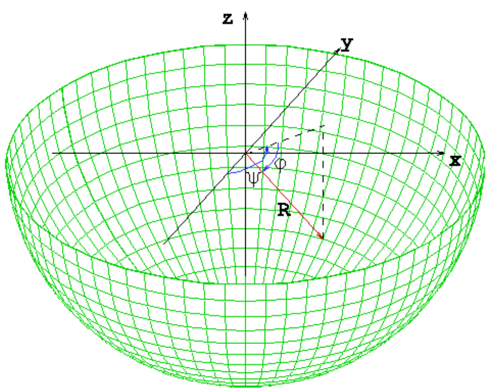
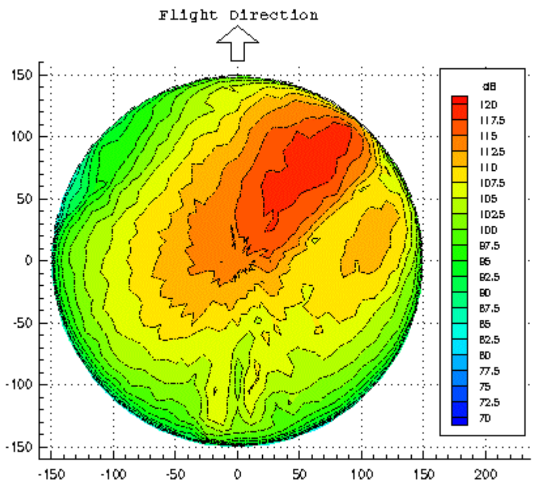
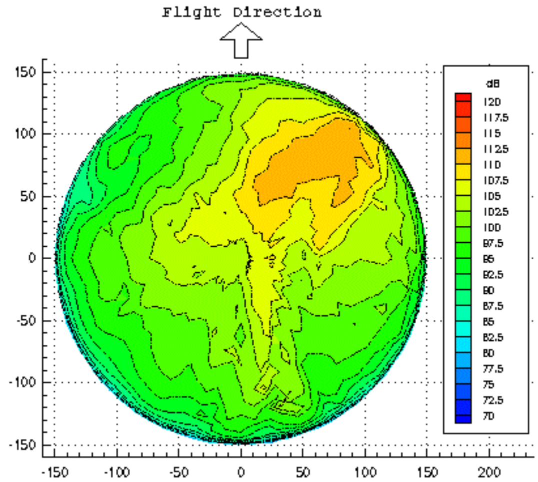


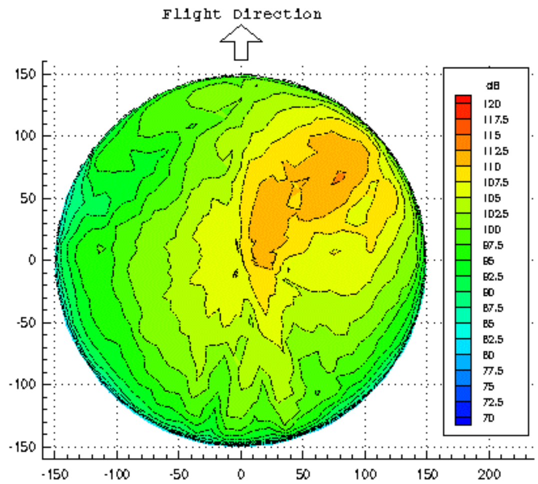
Fig. 7 Coordinate system for contour plot



(a) b1ap



(b) b2s2.5ap



(c) b2r1ap

Fig.8 Noise directivity plot in approach condition

To see the change of wave pattern, the pressure time histories of typical cases, b1ap, b2s2.5ap and b2r1ap in case of helicopter position A, are compared in Fig. 5. It can be observed that while there are significant reductions in amplitude, there is virtually no change in acoustic waveform. Thus, although the modified tips will produce much lower noise levels, no distinctive features that would allow an observer to identify the modified blades by their sound quality have been added to the waveform. This is a characteristic of the vortex separation distances considered in the study and is believed to be highly desirable in terms of public acceptance.

Fig. 6 shows the SPL_p calculated by using a continuous run option along the approach flight path as shown in Fig. 3. The calculated value of SPL_p includes the ground reflection effect. The results show that KBERP is quieter than BERP all along the approach flight path.

To check the change of noise directivity pattern, the contours of SPL_p without ground reflection effect are compared in Fig. 8. Results are shown as contours projected on the x-y plane as shown in Fig. 7 and R=150m, Δy =5° and Δj =5° in this study. The slight differences of directivity can be found in Fig. 8. The results show there is noise reduction in all regions.

The optimized combination of parameters is determined to include values of v2s = 0.05, v2g = 0.5 and v2c = 1.0 and these values are considered to be practically attainable in a blade design. However, the v2r is influenced by the strength of each vortex in each specific flight condition.

Pseudo EPNL and Relative Vortex Rotation Rate(v2r)

DEAF does not currently include all of the noise sources necessary to completely calculate noise levels in EPNdB. In order to estimate the effect of KBERP in terms of time-integrated units, a new metric, pseudo EPNL, is devised in which the PNLT time history is replaced by peak pressure as follows:

$$EPNL(dB) = 10\log\left[\frac{1}{(k_2 - k_1)\Delta t}\sum_{k=k_1}^{k_2}\{\Delta t \log^{-1}(\frac{PNLT(k)}{10})\}\right] \quad (1)$$

$$pseudo\_EPNL(dB) = 10\log\left[\frac{1}{(k_2 - k_1)\Delta t}\sum_{k=k_1}^{k_2}\{\Delta t \log^{-1}(\frac{SPL_p(k)}{10})\}\right] \quad (2)$$

where k_1 and k_2 are the 10dB down points. The new metric, pseudo EPNL (p_EPNL), which is very easily calculated by using the DEAF results, gives a time integrated noise level similar to EPNL. The substitution of DEAF main rotor results for the noise levels of the complete helicopter in the time – integrated calculation is tantamount to assuming that the sources not accounted for in the DEAF calculation are minor. This assumption is reasonable during approach when noise levels are often dominated by BVI effects. Accordingly, we can expect the difference between p_EPNL of two cases would be representative of changes in EPNL. The simplified metric is very useful for this kind of study which is predominately concerned with reducing BVI noise.

Table 4 shows the calculated p_EPNL values of typical cases and the difference between SPL_p (Delta 1) is quite different from the difference between p_EPNL (Delta 2). The calculated p_EPNL in the approach condition shows an 8~9dB noise reduction compared to the noise level of original single vortex BERP blade.

Table 4. Calculated p_EPNL values

Case_id	SPL_{p_max}	Delta1	p_EPNL	Delta2
b1ap	117.7	0.0	114.3	0.0
b2s2.5ap	109.5	8.2	105.3	9.0
b2r1ap	110.2	7.6	106.3	8.0

Table 5. v2r value in each flight condition

	Approach (AP)	Fly Over (FO)	Take Off (TO)
v2r	0.8725	0.8369	0.9165

As mentioned in the previous section, the variation of noise level with respect to v2r is quite large. However, v2r is determined by the strength of each vortex and its induced velocity in specific flight condition, therefore, a practical range of v2r can be determined using an analytical relationship between the vortex strength and induced velocity. Eq.(3) is derived to calculate the realistic v2r value in each flight condition.

$$v2r = \frac{(v2g)\Gamma_{average_{at\_tip}}}{p\,(v2s)^2\,RV_t} \quad (3)$$

$$where\ \Gamma_{average_{at\_tip}} = 3(\Omega R\bar{c})\frac{c_t}{s}(1+\frac{3}{2}m_x^2)^{-1}$$

Table 5 shows the calculated v2r value using Eq.

(3). For final comparisons, the v2r value used is taken from Table 5.

Noise Analysis in Each Certification Condition

To calculate the noise reduction for KBERP in each flight condition and to evaluate its noise characteristics, calculations are made using the optimized set of v2s, v2g and v2c and the values of v2r in Table 5.

Approach Condition

Fig. 9 shows the comparisons of noise level of each case during approach. Table 6 shows a 9.3 dB noise reduction compared to the noise level of original single vortex BERP blade.

Table 6. p_EPNL values in approach

Case_id	SPL_{p_max}	Delta1	p_EPNL	Delta2
b1ap	117.7	0.0	114.3	0.0
b2r0.8ap	109.3	8.5	105.1	9.3

As shown in Fig.10, the significant noise reduction and a slight change of directivity pattern over most of the region can be found.

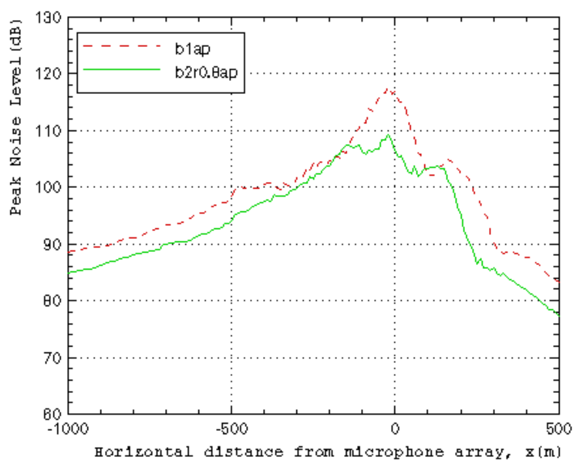
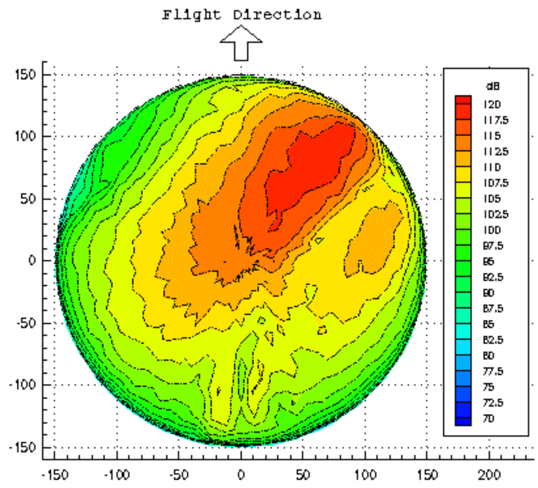
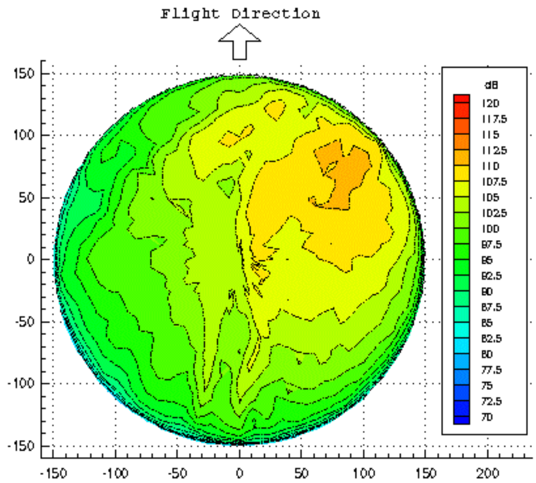


Fig.9 Noise level in continuous run(approach)



(a) b1ap



(b) b2r0.8ap

Fig. 10 Noise directivity plot in approach condition

Take off Condition

Fig. 11 shows the comparisons of noise level of each case during take off. And Table 7 shows an 0.8 dB noise increase compared to the noise level of original single vortex BERP blade.

Table 7. p_EPNL values in take off

Case_id	SPL_{p_max}	Delta1	P_EPNL	Delta2
b1to	91.9	0.0	88.2	0.0
b2r0.9to	92.3	-0.4	89.0	-0.8

As shown in Fig.12, there is a slight change of noise level and directivity pattern in this condition .

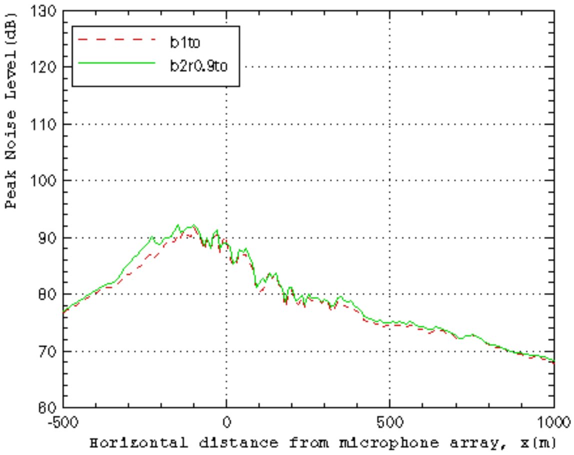
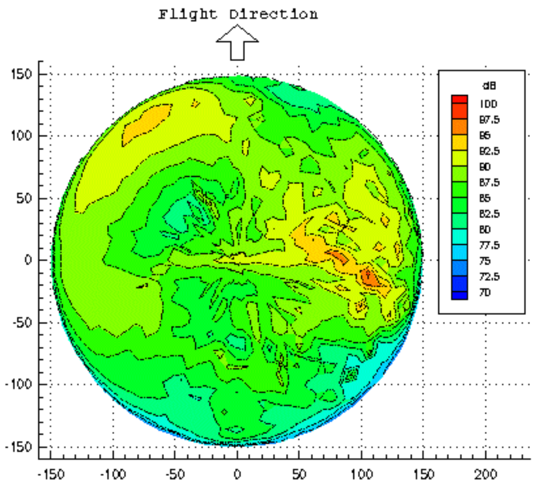
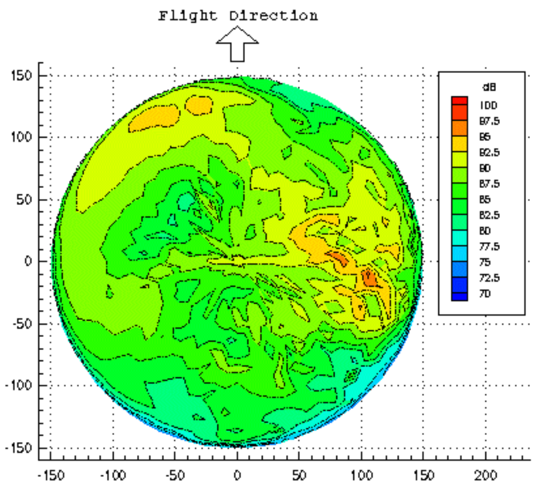


Fig. 11 Noise level in continuous run(take off)



(a) b1to



(b) b2r0.9to

Fig. 12 Noise directivity plot in take off condition

Fly over Condition

Fig. 13 shows the comparisons of noise level of each case during fly over. Table 8 shows a 1.9 dB noise increase compared to the noise level of original single vortex BERP blade.

Table 8. p_EPNL values in fly over

Case_id	SPL_{p_max}	Delta1	p_EPNL	Delta2
b1fo	99.3	0.0	93.5	0.0
b2r0.8fo	100.2	-0.9	95.4	-1.9

As shown in Fig.14, small changes in noise level and directivity pattern are found in this condition..

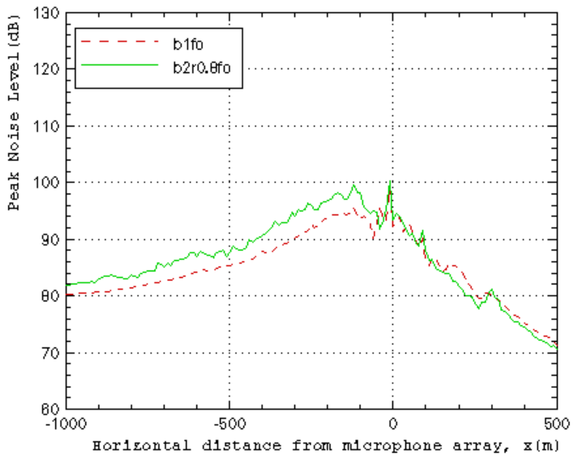
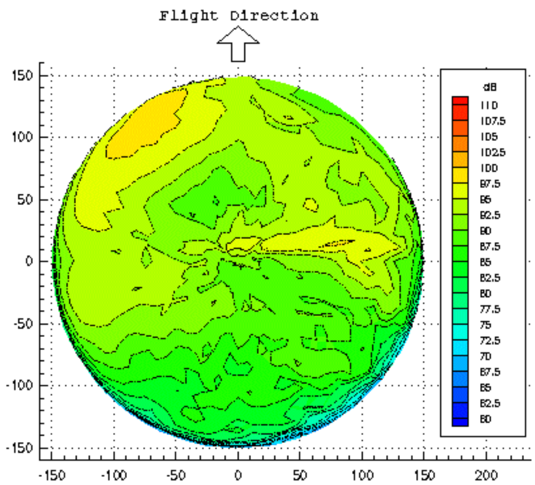
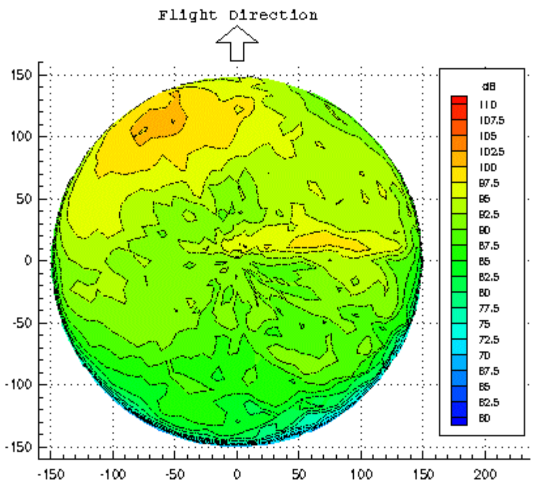


Fig. 13 Noise level in continuous run(fly over)



(a) b1fo



(b) b2r0.8fo

Fig. 14 Noise directivity plot in approach condition

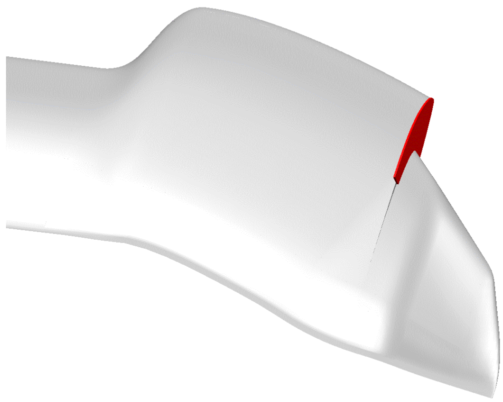


Fig. 15 Initial drawing of KBERP

Conclusion

The study reported in this paper has shown that significant reductions in noise level during approach can be obtained by modifications to blade tip geometry. The predicted results expressed in pseudo EPNL using DEAF combined with ACROT show the KBERP is a very cost effective way to reduce BVI noise during approach. The small increases in noise level predicted during take-off and level flight are probably pessimistic because the source terms included in the calculations are not dominant in these flight regimes.

The practical application of the KBERP blade to Lynx or other helicopters requires some additional work covering performance, dynamics and manufacturing aspects. The next task is to confirm the detailed aerodynamic design of the tip to produce the trailed vortices indicated by this study as optimal. Fig. 15 shows the initial scheme for the KBERP tip geometry that is likely to achieve these objectives.

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