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RISK METHODOLOGY FOR AIRCRAFT NOISE ASSESSMENT AND CONTROL

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- *Aircraft noise is one of the subjects of environmental or community noise, which is a kind of physical stressor on environment/community, which may produce a number of negative effects, including health impacts, as for humans as for environmental systems/objects (nonhuman impacts on environment). Among them are the following mostly recognized outcomes for humans: annoyance by noise (noise annoyance), sleep disturbance, direct health impacts, hearing loss (more important for occupational health protection), etc.*

Keywords: aircraft noise annoyance, balanced approach, aircraft noise assessment and management

INTRODUCTION

Noise pollution around airports is a major problem with regards to environment in modern societies, generating significant negative effects on the surrounding communities (health and performance effects, health care costs, properties depreciation, loss of operation by airports, etc.). Among other noise effects, noise annoyance is the most documented subjective response to noise, and the great reason of complaints in airports, and, therefore, of concern for airport authorities. The combination of continuous airport development and public concern about aircraft noise disturbance and annoyance continues to grow, has led to considerable mitigation efforts by governmental administrations and the civil aviation industry as a whole. The aircraft noise is the single or somewhere one of the most important local impact arising from airport operations which, unless managed effectively, has the potential to constrain the ability of airports to grow in response to demand and hence limit the social and economic benefits that future growth could bring. Together with these and various other social, flight safety and economic problems, including a number of specific environmental issues, aircraft noise has the potential to multiplying constrain the operation and growth of the airports and air traffic.

In particular, the optimisation can be used to search for cost-minimal balances of controls of all the factors under consideration over the various scenarios in aviation sector that simultaneously try to achieve user-specified targets for human health impacts (for example, expressed in terms of reduced life expectancy in accordance with WHO guidelines for these factors), ecosystems protection, and maximum allowed violations of WHO guideline values [Berglund, B. et al., 1999], etc. (Fig. 1).

Traditional taken approaches to aircraft noise management include reducing aircraft noise at source, to devise operational procedures and restrictions, routes, and other forms of mitigation, etc., to minimize individual residential exposure via ICAO Balanced Approach (BA) to aircraft noise control around the airports [ICAO Doc 9829, 2004], and to keep the public fully informed about noise management and noise control [Woodward J.M. et al., 2009]. The main objective is that noise problems can be addressed in an environmentally and economically responsible manner within the system, while preserving potential benefits gained from aircraft-related measures.

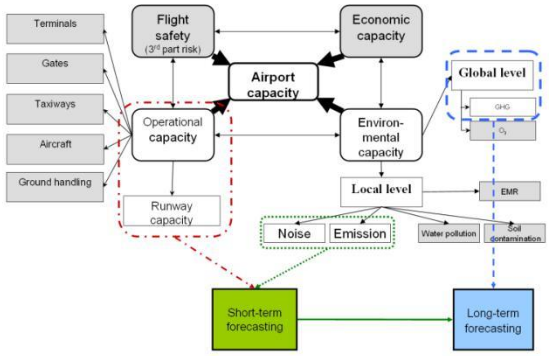

Fig. 1. Airport interdependency capacity analysis scheme [Zaporozhets O., et al., 2014]

Even current ACARE SRA and SRIA noise targets use both technology and operational mechanism to reach them [ACARE, 2012]. For example, if the Goal 2020 to reduce the noise levels for the aircraft up to 10 EPNdB, the 2-3 decibels is considered to be reached with noise abatement operational procedures (NAOP), Fig. 2. An important aspect needs to be taken into account – the efficiency of NAOP for noise reduction is less for quieter aircraft, it is less for aircraft with acoustic performances in accordance with more stringent noise standards.

One more important consideration that ICAO and ACARE targets and goals are not only to reduce the noise levels, the novel and more real approach is based on the idea that noise level reduction at receiver point is not a final result for society, but it is just a tool to achieve the real final goal, which is the reduction of the noise effects. By ICAO this effect is defined currently as a reduction of number of people affected by aircraft noise – or simply a number of exposed people by noise over the protection guide value (Fig. 3), or predefined number of highly annoyed people. In this case even for quiet aircraft in a fleet the high intensity flight traffic in airport under consideration may provide total number of annoyed people by noise of unacceptable value.

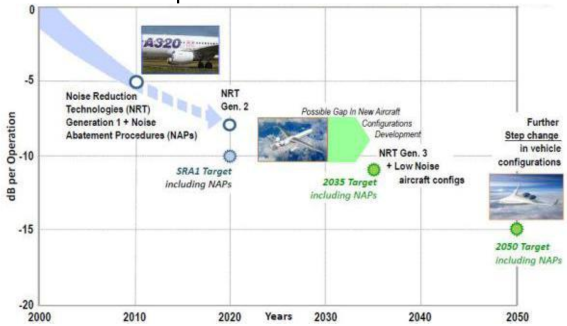

Fig.2. Current ACARE SRA and SRIA noise targets for fixed wing aircraft [Collin D., 2014]

It should be a primary objective of future research into environmental noise impact to investigate the interplay of sound level control and perceived control. New and additional (political) measures to mitigate noise impact may result from the redirection of attention from sound to noise and to noise annoyance. Strategies that reduce noise annoyance, as opposed to noise, may be more effective in terms of protecting public health from the adverse impacts of noise and its interdependency with other environmental, operational, economic and organizational issues of airport and airlines operation and maintenance.

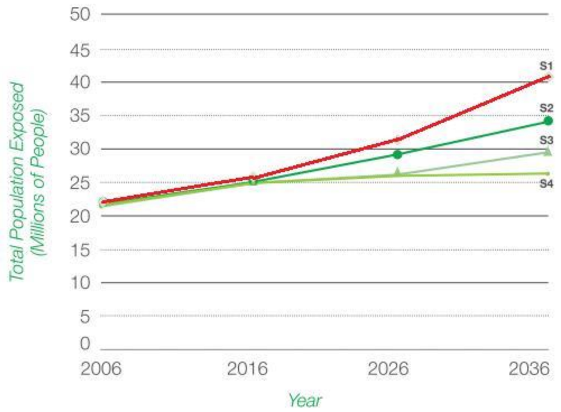

Fig. 3. Total global population exposed to aircraft noise above 55 DNL: CAEP forecasting for noise reduction in preparation to new ICAO standard (Chapter 14 of Annex 16, vol. 1) for aircraft noise control [Fleming G.G., Ziegler U.R.F., 2013]

This is the reason for a number of current concept, approaches and efforts to reduce aviation noise annoyance, keeping the produced noise levels the same. This objective is expected to be achieved by bringing information closer to the people living in airport surroundings. For example, there is some previous assumption that shared unattended noise monitoring results can improve airport noise acceptance, as general public can check the compliance with noise limits in their proximity, raising people awareness [O.Zaporozhets, 2011].

The reviewed and proposed models provide a good model fit and support to the toolboxes of noise annoyance management, currently under the design. It can be concluded that the concern about the negative health effects of noise and pollution, other environmental issues, are still the subjects of scientific and societal attention, their newish deliverables may improve the approach to build the fifth element of ICAO balanced approach to aircraft noise control around the airports, which cover the measures to reach the final goal of aircraft noise management – to reduce the number of people loving in vicinity of the airports and affected by noise.

ICAO BALANCED APPROACH TO AIRCRAFT NOISE CONTROL

With this context it is appropriate to begin with new vision on ICAO BA to aircraft noise control, namely to add to the existing elements of noise reduction: at source, by noise zoning and land use planning, with operational procedure and mitigation measures, the newish element – the reduction of the noise effects via novel concept, approaches and efforts to reduce aviation noise annoyance.

Till now all the existing BA elements are subjects to identify and assess the noise exposure, mostly via noise contour modelling, in some cases via monitoring, which allows to evaluate noise control measures and to determine the most cost effective and efficient for environment protection set of them [ICAO Doc 9829, 2004]. In best known solutions the process is continuing with public notification and consultation procedures and even being a mechanism for dispute resolution. This important approach is implemented in the European Environmental Noise Directive [Directive 2002/49/EC]. According to it, noise action plans will be developed with the participation of the public. The claim of the citizens in participation has steadily grown, especially if their residential area or essential environmental aspects are concerned.

There is important to differentiate between noise exposure and the resulting noise nuisance in different communities, and manage each appropriately. The type of information collected and the way in which it is analyzed and reported will differ according to the objective of the program of noise control. Usual option of quantifying overall noise exposure - through noise contour modelling and quantifying the number of people inside the contour with specified noise level (predefined by rules for noise zoning around airports or by general noise control rules like Environmental Noise Directive or CAEP documents, see Fig. 3).

Acoustic modeling around airports currently is intended to satisfy the needs of many users and ranges between sophisticated noise spectrum modeling and noise environment assessment in terms of cumulative noise exposure or even, by means of dose-response relationships, in terms of the size of the noise-annoyed population in the area of concern. It must be noted that the form and structure of noise indices, which we must assess and investigate around the airport or under the particular flight path have the predominant role on the method we have to use for their assessment. Methods for modeling noise radiation, propagation and attenuation, include both analytical and semi-empirical results. The current tendency is towards less empirical and more analytical techniques. In general prediction schemes are based on three basic components:

- a noise radiation model corresponding to an aircraft noise emission model;
- a model of sound transmission from source to control point in the form of an aircraft noise propagation model;
- a noise impact model at the control point in the form of an aircraft noise imission model.

The imission model, as a component of the overall noise modeling scheme, is a subject of current deeper consideration, with psychological phenomenon of annoyance inside.

People are driven to complain when some nuisance factor (or stressor) in the environment gives rise to annoyance and when this stressor reaches a threshold of tolerance. In this context the stressor is an aircraft noise, which is described by exposure metrics usually. The actual situation is rather more complex. Exposure can lead to more than one effect, and community impacts depend on multiple effects (Fig. 4). While sleep disturbance during night time and annoyance during composite day time are the primary recognized health consequences of community noise exposure, cardiovascular disease and cognitive impairment in children also contribute [Berglund, B. et al., 1999].

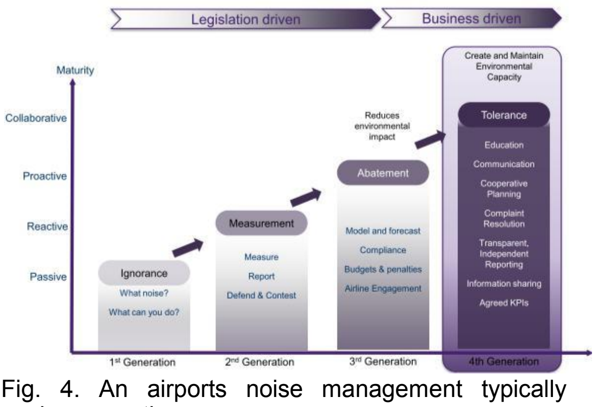

Fig. 4. An airports noise management typically evolves over time

WHO indicates also that positive wellbeing and quality of life can be compromised by noise annoyance and sleep disturbance first of all. Both of them are estimated for grounding the noise zoning and land use planning around the airports, using Critical Limits, Protection Guides and Threshold Values for sleep disturbance and annoyance [Griefahn and Scheuch, 2004] to control the aircraft noise impact in usual way. Among diversity of acoustical metrics describing air traffic noise the L_{eq} based indices like *DNL* and *DENL* (during appropriate estimation time) show the closest connection to annoyance and disturbance judgments. It was found also that the data were not strong enough to establish criteria for annoyance or threshold values for chronic disease from separate event value in form of maximum level L_{Amax}. At the same moment the probability values of night sleep disturbance among population depends from maximum noise level of the noise events, while its definition in annual approach requires more detailed specification and statistical understanding. Even they are not appropriate for the evaluation of distinct (intermittent) noise events as a whole [Jagnatinskas A., Fiks B., Zaporozhets O., 2011].

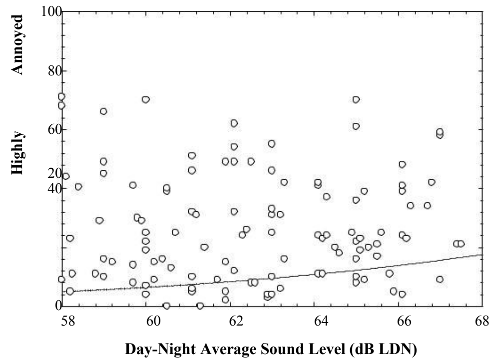

Fig. 5. Percentage highly annoyed at aircraft noise plotted as a function of noise level. The solid curve is a portion of that presented in Fig. 5, while the scattered points represent real measurements [Fidell, S., 2003]

Scrutiny of Fig. 5 reveals that annoyance reactions to noise vary substantially and do not appear to be correlated with noise level. What is more difficult to describe and measure – there are many factors that give rise to annoyance and are the non-auditory effects of noise dealing with nuisance. There is no agreed method to combine everything into an overall response, even if this were meaningful when taken out of the context of the many and varied social and economic factors that often have much greater health impacts.

AIRCRAFT NOISE ANNOYANCE

Noise is an environmental nuisance that has the potential to degrade health and negatively impact the relationship between humans and their environment. Aircraft noise annoyance is a still increasing problem, especially in the densely-populated areas and without reducing population's annoyance, it will become more and more difficult to increase the number of aircraft movements, or to build new runways or other airport infrastructure.

There is also evidence that environmental noise can be considered like in occupational noise case as a risk-factor for health. From this point airport capacity will be limited huge from this noise annoyance acceptability level. In general the aviation noise (as any kind of environmental noise) effects include [Shaw E.A.G. 1996]: psycho-social effects such as annoyance and other subjective assessments of general well-being and quality of life; effects on mental health; effects on sleep which can be both psychological and physical effects; effects on physical health such as hearing loss; and stress-related health effects which can be psychological, behavioural, somatic and physical. According to the WHO, an outdoor noise level exceeding 55 dB L_{DN} is considered to be ‘seriously annoying’ [Berglund B. et al., 1999].

A significant increase over the years was observed in annoyance at a given level of aircraft noise exposure. Crucial evidence that annoyance measured last decade in European airports (the more recent studies in airports of Manchester, Paris, Amsterdam, Frankfurt) is much higher dependent from the noise indices [Flindell I. et al., 2013], the clear difference equivalent to around 5-6 dBA between the average trend of all of these more recent studies and the much older data, it means that high number of annoyed people observed in acoustic conditions which were considered not so serious decades before, Fig. 6. The results are of highest importance to the applicability of current exposure-annoyance relationships for aircraft noise and provide a basis for decisions on whether these need to be updated.

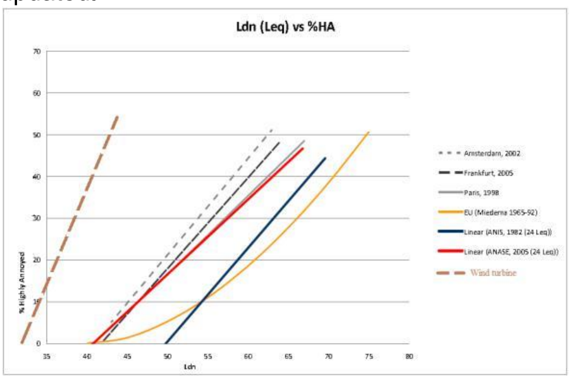

Fig. 6. Aircraft noise annoyance curves for a number of studies in EU

In any case, if doing nothing with annoyance management, the future scenarios for air transportation are looking unsatisfactorily, because existing results of the studies of noise annoyance in other sectors, different from aviation and having the same or quite similar acoustical properties (Fig. 7), for example, wind turbine noise, show the much higher annoyance than existing aircraft noise studies (Fig. 6).

From one point of view the existing exposure-response curve, used in any studies for impact assessments, has to be updated. From other point of view all the non-acoustical factors, influencing on annoyance, at any specific case need to be managed correctly, providing less annoyance if it should be possible.

The extent of noise annoyance is clearly influenced by numerous non-acoustic factors such as personal, attitudinal, and situational factors in addition to the amount of noise per se [Scheuch et al., 2003]. Any possible interpretations of the various relationships between noise and reported annoyance, which usually may vary from one study to another, show both direct and indirect routes from stimulus to effect. Approximately one-third of the variation (even only 18% by some results!) in noise annoyance can be explained by acoustical factors e.g., the sound level, peak levels, sound spectrum, and number of noise events and a second third by non-acoustical factors [Guski,1999]. While individual responses to noise vary considerably amongst the population, the social context in which the noise exposure occurs has also been found to be important [Job R.F.S., 1988].

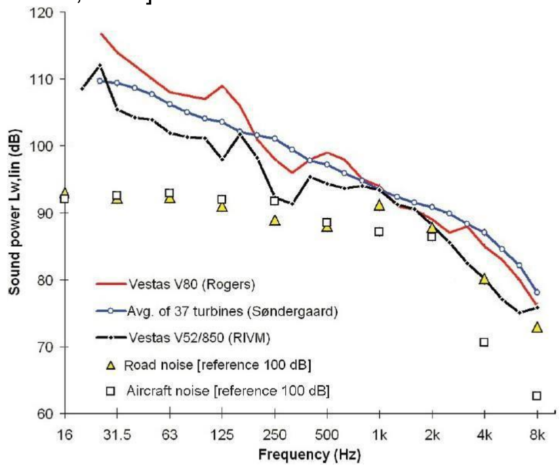

Fig. 7. Comparison of generalized sound spectra for different environmental acoustic sources: transportation noise via wind turbine noise

Different models have been developed that aim to provide insight into the processes that result in noise annoyance [Taylor, 1984; Job, 1988; Guski, 1999]. However, all these models are developed based on empirical evidence related to previously found results of correlation analysis or multiple regression analysis between noise annoyance and other variables. Both these methods have severe deficiencies in modeling noise annoyance, even the direction of causation may remain uncertain. The results of correlation analysis can be misinterpreted since the effect of the factor under investigation is not controlled for noise exposure or other factors [Alexandre, 1976]. Also, in [Taylor, 1984] it was noted, that “many of the models which are tested by using path analysis are exploratory. As such, they probably do not adequately represent the processes leading to the outcome in question e.g., noise annoyance”.

RESULT AND DISCUSSION

To control annoyance the effective adequate model should be designed. In a same manner as the appropriate models were designed to control all other elements of BA to aircraft noise management, for example like US models ANOPP and INM are used for that, or their Ukrainian analogues: BELTRA (combines two large modules: BELTAS - for noise assessment at points of interest around the source and hence derivation of the directivity pattern of a noise event, and TRANOI - which indicates the need for noise control under the flight paths) and IsoBella (full analogue of INM) soft tools, both used for decision-making procedures concerning aircraft noise problems. Models and methods used for assessing environmental noise problems must be based on measured or/and calculated noise exposure indices, which are used by relevant national and international noise control regulations and standards [Zaporozhets O., 2011].

Comparing with traditional BA elements, which are defined by physical effects of sound generation and propagation, an annoyance is a psychological phenomenon (in nature of effect on humans the noise is a psychological phenomenon too!). Acoustical factors of environment noise events like sound intensity, peak levels, duration of time in-between sound events, number of events, etc., were focused for explanation of annoyance mainly [Janssen S.A., 2011]. The non-acoustical factors (‘moderators’ and/or ‘modifiers’ of the effect) have still received an empirical attention, without deep theoretical approach, never mind that various comparative studies reveal that they play a major role in defining the impact on people [Job, 1988].

Noise annoyance is defined as a form of psychological stress, which is determined by the perceived impact of a stressor and the perceived resources to cope with this stressor. From the point of view of psychological stress theory, the generation of noise-induced annoyance is essentially a dynamic process. In [Guski, 1999] it is also emphasized that noise annoyance is not just reflecting acoustic characteristics: “noise annoyance describes a situation between an acoustic situation and a person who is forced by noise to do things he or she does not want to do, who cognitively and emotionally evaluates this situation and feels partly helpless.”

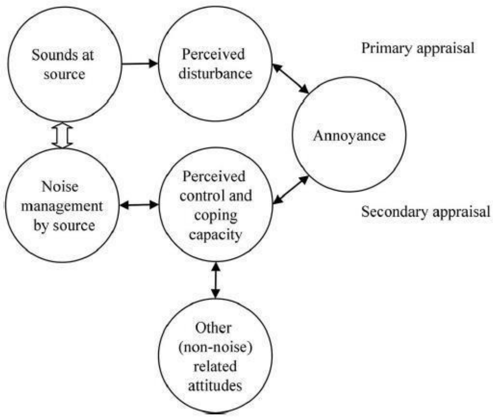

Fig. 8. The conceptual model used to explain noise annoyance [Stallen, 1999]

Acoustical and non-acoustical factors are appraised and re-appraised by the individuals on the basis of their needs and the resources available to satisfy them. Here a primary appraisal is the level of perceived disturbance, which is evaluated by any person for the impact of the threat or harm in relation to their well being. After a threat or harm is recognized, a process of secondary appraisal is triggered. The nature of annoyance is rooted in the fact that the exposure to noise makes it difficult or impossible to attain something valued, – that is the nature of disturbance, and two factors determine the deepness of the disturbance [Stallen, 1999].

In other words noise annoyance as a form of psychological stress is determined by the extent to which a person perceives a threat, i.e. perceived disturbance and the possibilities or resources that a person has with which to face this threat, i.e. perceived control [Stallen, 1999]. Based on the model it was argued [Stallen, 1999] that noise annoyance will arise if the perceived threat, i.e. noise, is larger than the perceived resources to face and to cope the threat, i.e. perceived control and coping capacity. In addition, even though the perceived disturbance may be very high, no noise annoyance will arise if there are sufficient coping resources.

The structure in Fig. 9 represents this popular noise annoyance model [Stallen, 1999]: non-acoustical factors are regarded as affecting the relationship between sound exposure and noise annoyance. The double arrows in Fig. 9 show the capacity of permanently reconsidering appraisals of noise. The protection of the residents is understood as a dynamic process, meaning that the evaluation criteria must be repeatedly tested and - if necessary - adapted to new scientific findings [Zaporozhets O., 2014]. The only significant determinant of perceived disturbance is the level of noise exposure. Thus through the effective management and control of aircraft noise, best practice – through ICAO BA, it must be possible to minimize adverse impacts of aircraft noise on health and quality of life.

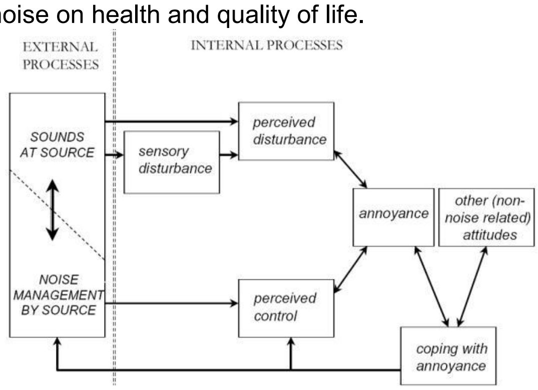

Fig. 9. Noise annoyance modeled as a stress-response to the external stimuli 'sounds' and 'noise management' [Stallen, 1999]

Besides noise level, non-acoustical factors are associated with current aircraft noise annoyance:

e.g. individual noise sensitivity (Pearson correlation r = 0.324 for relation of the sensitivity to annoyance, from [Job, 1988] it is varying between 0.15 and 0.48); in [Guski, 1999] it is cited the found correlations between source evaluation and noise annoyance in the order of (-0.25), this covariation is higher with annoyance by private airplanes; trust in authorities responsible for noise level reduction (-0.307), expected changes in residential situation due to airport extension. The effects of noise annoyance on perceived disturbance and perceived control and coping capacity are equal to 0.90 and 0.94 respectively.

The significant determinants of the perceived level of control and coping capacity (Tab. 1 [Kroesen M., Molin E.J.E., van Wee B., 2008]) are the negative attitude toward noise source authorities and the noise policy −0.22, the negative expectations related to noise development −0.42, the concern about negative health effects of noise and pollution −1.15, and the concern about property devaluation −0.15. Especially, the concern about negative health effects has a large effect on the capacity of people to handle the noise situation. The most important determinant of this factor is the positive social evaluation of noise source −0.40 and the belief that noise can be prevented 0.24.

Table 1. Standardized total effects of each variable on noise annoyance [Kroesen M., Molin E.J.E., van Wee B., 2008]

Variable	Effect
Concern about negative health effects of noise and pollution	0.59
Perceived disturbance	0.56
Perceived control and coping capacity	−0.51
Negative expectations toward noise development	0.26
Negative attitude toward source authorities	0.11
Concern about property devaluation	0.08
Positive social evaluation of the noise source	−0.05
Belief noise can be prevented	0.03
Noise annoyance	0.02
Noise exposure *DENL*	0.02
Annoyance non-noise effects	0.01

Under the standard [ISO 31000:2009] the definition of "risk" is no longer "chance or probability of loss", but "effect of uncertainty on objectives". The purpose of risk assessment is to provide evidence-based information and analysis to make informed decisions on how to treat particular risks and how to select between options. Principal benefits of a performing risk assessment includes a wide set of positive outcomes for person, group or/and community.

Risk is defined as the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions [UN-ISDR, 2009].

Risk can presented conceptually in relation to **H**azard, **V**ulnerability and **A**mount of elements-at-risk with the following basic equation:

$$\mathbf{R = H * V * A_{elements\text{-}at\text{-}risk}}$$

or taking into account the **C**apacity (opposite characteristic to vulnerability) to cope the hazard consequences [Blyukher B., Zaporozhets O.I., 2016]:

$$\mathbf{R = H * V / C}$$

The equations given above are not only a conceptual one, but can also be actually calculated (for example, with spatial data in a GIS to quantify risk from geo-distributed hazards).

Mathematically **R**isk is proportional to a measure for the **P**robability of an event (frequency, likelihood) and the **C**onsequences of an event (impact, effect on objectives):

$$\mathbf{R = P*C}.$$

For individual risk this basic condition may be expressed by the formula [Zaporozhets O.I., Khaidar H.A., 2001]:

$$\mathbf{R = P_f * P_{d/f}},$$

where P_f – the probability of harmful event (eg, aircraft accident); $P_{d/f}$ – the likelihood of the consequences (effect or damage), particularly the fatal consequences caused to individuals in the absence of protection from (or resistance to) a danger.

In more general form probability of accident P_f may be divided to the probability of scenario p_{Sc} and the probability of hazard exposure p_{Ex}:

$$\mathbf{P_f} = p_{Sc}\, p_{Ex}.$$

The effects are usually described in terms of various type damage k (eg, fatality, injury, physical damage, environmental losses, loss of income, etc. depending what are the elements-at-risk) and their vulnerability v_k (for example, a person's vulnerability can be defined as mortality):

$$\mathbf{P_{d/f} = k^* v_k}$$

Vulnerability is determined by physical, social, economic and environmental factors (or simply conditions or processes), which increase the susceptibility of a community to the impact of hazards. Vulnerability can be classified as shown in Tab. 2. Risk assessment is concerned with determining those factors which are especially dangerous and determining the likelihood of unacceptable harmful exposure. Among vulnerability properties of the population under the risk of noise impact is a number of acoustic factors (fleet composition, their respective distribution over given time period of observation) and non-acoustic factors (personal noise sensitivity, attitude towards the noise source, performed activities at the moment, etc.).

Table 2. General classification of vulnerability [van Westen C.J.,2017]

	Human - social	Physical	Economic	Cultural Environmental
Direct losses	• Fatalities • Injuries • Loss of income or employment • Homelessness	• Structural damage or collapse to buildings • Non-structural damage and damage to contents • Structural damage infrastructure	• Interruption of business due to damage to buildings and infrastructure • Loss of productive workforce through fatalities, injuries and relief efforts • Capital costs of response and relief	• Sedimentation • Pollution • Endangered species • Destruction of ecological zones • Destruction of cultural heritage
Indirect losses	• Diseases • Permanent disability • Psychological impact • Loss of social cohesion due to disruption of community • Political unrest	• Progressive deterioration of damaged buildings and infrastructure which are not repaired	• Economic losses due to short term disruption of activities • Long term economic losses • Insurance losses weaken-ing the insurance market • Less investments • Capital costs of repair • Reduction in tourism	• Loss of biodiversity • Loss of cultural diversity

Risk assessment needs to be used in framework of its regulation (Fig. 10) [10]. To investigate the effects of hazards there are important factors of vulnerability - physical, social, economic and environmental conditions and processes that tend to increase the damage from the effects of the hazards impact on the person or society as a whole. There is necessary a covering *capacity* - capabilities of a human, system, society, nature to confront the consequences of dangers and threats, ie resources are needed that may reduce the negative effects.

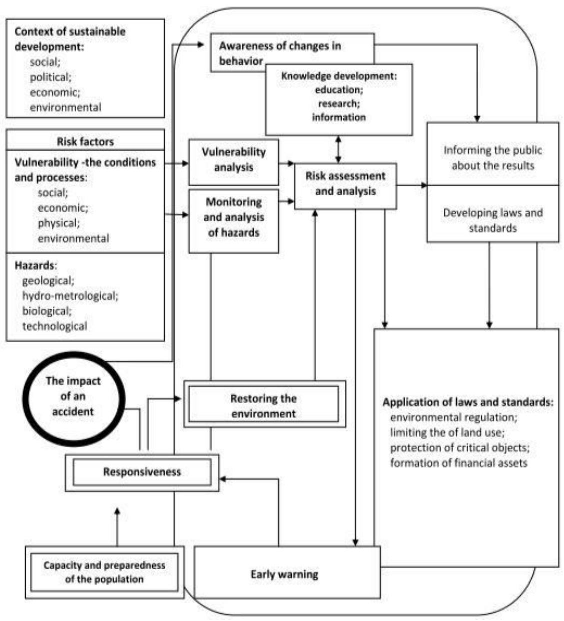

Fig. 10. Framework for risk assessment and reduction [ACS GUIDE, 1998]

CONCLUSIONS

It should be a primary objective of future research into environmental noise impact to investigate the interplay of sound level control and perceived control. New and additional (political) measures to mitigate noise impact may result from the redirection of attention from sound to noise and to noise annoyance. Strategies that reduce noise annoyance, as opposed to noise, may be more effective in terms of protecting public health from the adverse impacts of noise and its interdependency with other environmental, operational, economic and organizational issues of airport and airlines operation and maintenance.

Noise annoyance as a form of psychological stress is determined by the extent to which a person perceives a threat, i.e. perceived disturbance and the possibilities or resources that a person has with which to face this threat. New communication technologies must provide better understanding of the problem to the community, to every individual living around the airports, providing their more positive response to aircraft operation and noise in consequence.

Risk assessment and management methodology is proposed to be used for noise impact assessment and management. It provides necessary tools to include in consideration *vulnerability* & *capacity* values, both very important for management of the impact first of all.

The reviewed and proposed models provide a good model fit and support to the toolboxes of noise annoyance management, currently under the design. It can be concluded that the concern about the negative health effects of noise and pollution, other environmental issues, are still the subjects of scientific and societal attention, their newish deliverables may improve the approach to build the fifth element of ICAO balanced approach to aircraft noise control around the airports, which cover the measures to reach the final goal of aircraft noise management – to reduce the number of people loving in vicinity of the airports and affected by noise.

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