International Energy Agency (IEA)
Implementing Agreement for Co-operation in the Research and Development of Wind Energy Systems (IEA Wind)

New Task Proposal 2016
For ExCo #78, Brussels, Belgium

Quiet Wind Turbine Technology

November 2016

N. McMahon, J. Kennedy, H. Rice
Trinity College Dublin
with the
Sustainable Energy Authority of Ireland

Quiet Wind Turbine Technology
Task Proposal

N. McMahon, J. Kennedy, H. Rice
Trinity College Dublin
with the
Sustainable Energy Authority of Ireland

November 2016

Contents

1 Overview and Context **3**

2 Objectives and Expected Results **4**

3 Description of Work Packages **5**
WP 0: Management, Coordination and Dissemination 5
WP 1: Interdisciplinary Education and Guidance 5
WP 2: Technical Work 6
Physics of Noise 6
Human Response to Wind Turbine Noise 7
Shared Resources 8
WP 3: Recommended Practice 9
Overview 9
A Note on Amplitude Modulation 9

4 Organisation **9**
Management 9
Task Coordination 9
Risk Management 10
Meetings, Oversight and Review 11
Obligations and Responsibilities 11
First Steps 11
Timelines and Dates 11

5 Funding and Budget **13**
Budget . . . 13
Coordination . . . 13
Meetings . . . 13
Website and Communications . . . 13
Funding . . . 14

6 Outputs **14**
Information and IP . . . 14
Dissemination of Results . . . 16

7 Participants and Authors **17**
Potential Participants . . . 17
Proposal Authors . . . 17
Dr. Niall McMahon . . . 17
Dr. John Kennedy . . . 18
Professor Henry Rice . . . 18
Mr. John McCann . . . 18

8 Appendices **20**

This document has been prepared by the Distributed Wind Energy Group in the Department of Mechanical & Manufacturing Engineering at Trinity College Dublin, in conjunction with the Sustainable Energy Authority of Ireland.

1 Overview and Context

More renewable power generation systems were deployed than thermal power generators for the first time in 2013. The rapid rise to the dominant position of these developing technologies in new power sector investments reflects the policy priority of decarbonising global electricity systems.

Societal acceptance of new technologies can be key to their ultimate successful adoption, the utility of a technology may not automatically guarantee this if its deployment affects those in society who do not accrue direct benefits from it. Emergent societal acceptance issues are commonplace for new technologies as they reach the mass deployment stage, particularly where this is rapid and these issues must be satisfactorily resolved for the technologies that are ultimately to be successful.

Particular public concerns have been raised on the impacts of wind turbine noise in some jurisdictions. While the sources of excessive noise for the majority of society will be from other man-made technologies, it is important to ensure that those who live in the proximity of wind turbines will not be subjected to excessive noise from these.

Regulation has an important role in the technology development process. Good regulation will anticipate progressive and societally beneficial technology advances and facilitate their adoption

It is important that regulations are based upon objective analysis and that guidelines are put in place to allow policy makers focus the debate on to the right topics.

A survey of national regulations dealing with noise control for wind turbines reveals that, while there are specific international standards for noise measurement, there are a diversity of national noise limits and defined approaches to the overall wind turbine noise assessment process. This diversity indicates that there may be room for convergence towards a common framework underpinning national guidance.

From an industry perspective, the wind turbine supply market is international and not local. The diversity of local noise regulations may bring unwarranted compliance costs and confound progressive technical advances to develop wind turbines with lower noise impact.

This proposal is for a new IEA Wind RD&D research collaboration to accelerate the development and deployment of quiet wind turbine technology. The collaboration will carry out its work in a series of focussed work packages.

2 Objectives and Expected Results

The objective of the proposed task, the *Task*, is to convene an international expert panel to: (i) exchange learning, (ii) identify and report best practice in the measurement and assessment of and noise; (iii) develop an IEA *Recommended Practice* contributing to the ongoing development of IEC standards for wind turbine noise.

Of course, there is a considerable body of work already completed; the broader work on wind turbine noise is considerable and growing [25]. On amplitude modulation specifically, work has been completed by organisations in several countries and across many disciplines. These organisations include NREL, Risø, the Institute of Acoustics in the UK and several efforts in Canada, e.g. [5], among many others.

This task will build consensus through interdisciplinary cooperation, involving insofar as possible engineers and scientists, environmental scientists and acousticians, psychologists, physiologists, audiologists, sociologists and policy makers. Initial work will structure discussion between disciplines, groups and countries. An aim is to understand and recognise the value in the work completed across disciplines. Conflicting or incomplete ideas can be identified for further research work as part of the task. Such a process will lead to robust, scientific, widely accepted and transparent metrics for wind turbine noise. It is in this spirit that we make this proposal.

It is worth highlighting that noise is not only or even primarily an engineering problem. The engineer quantifies noise source mechanisms and characteristics and develops instrumentation, data analysis tools, models and procedures for measuring and predicting wind turbine noise. Effective environmental noise metrics for wind turbines, however, require psycho-acoustic testing and an understanding of the physiological response of the human ear, among other things. Individual technologies have individual peculiarities to their noise characteristics and methods and simplifying assumptions developed for existing technologies may have to be reassessed and adapted for the noise characteristics of new technologies. For example, consideration of amplitude modulation is not commonplace for existing technologies but specific consideration of this may be required for wind turbines.

For this reason, two technical work streams are proposed, understanding the problem of wind turbine noise from the perspective of both the physics of the noise generation and the effect of turbine noise on human receptors.

In the end, the aim is well-informed agreement. This will happen through engaged participation.

3 Description of Work Packages

In addition to a management work package, an interdisciplinary education/guidance work package (WP 1) is proposed; this will help set the direction of the investigative work (WP2 2) that will in turn feed into a knowledge base and an evolving recommended practice (WP 3). The evolving recommended practice will form the basis of discussions during WP1. The Distributed Wind Energy Group (DWEG) at Trinity College Dublin will lead all work packages, guided by the expertise of the task participants. Priorities will be finalised after consultation with potential participants.

WP 0: Management, Coordination and Dissemination

The Task will be managed within this work package. The coordinator will ensure that the technical objectives and deliverables are achieved and will facilitate ongoing technical communication among the Work Package Leaders and the IEA Wind ExCo.

One of the first jobs of this WP will be to establish a web site with both public and private access for the Task. This website will facilitate discussion and collaboration between the Task partners as well as provide public information, e.g. papers. The WP will help define standard data and reporting formats for the Task. The WP will use appropriate project management procedures. Dissemination and regular liaison with the IEA Wind ExCo will be an integral part of this work package.

WP 1: Interdisciplinary Education and Guidance

How wind turbine noise affects people and how best to monitor exposure; these questions are not yet fully answered. Much work has been conducted at international level across disciplines including engineering, physiology, psychology and sociology. This work package will support interdisciplinary discussion, e.g. [18, 15, 25]. The aim is for a consensus with robust, scientific, widely accepted and transparent metrics for wind turbine noise.

At the outset, each partner will present their interpretation of best practice and summarise the outcomes of the research work in their field and in their country. These discussions will take place at six-monthly workshops. The individual contributions to these workshops will be collated into a state of the art report. The Task 34 approach of topical white papers will be considered. The value that each discipline brings to solving the principal problem will be reinforced by these discussions.

This work package will provide guidance for the two technical work packages, WP2 and WP3. The group will identify direction and work to find consensus on areas where further research is required.

Engagement with policy makers is an important function of this WP. The location of the workshops will rotate through partner countries to facilitate dissemination to local policy makers and others. The normal practice in Tasks is to make meetings open to

selected local experts and informed officials with a tandem local event for wider local dissemination.

As a starting point, we propose that WP2 (and WP3) begin with *amplitude modulation* (see Appendix).

WP 1 Summary

WP 1 deliverables:

- 6 x meetings / workshops, i.e. every 6 months for 36 months.

WP 2: Technical Work

Physics of Noise

As mentioned, it is proposed that WP2 will begin with amplitude modulation. The work package objectives are gated, i.e. a decision to change the focus of the research can change depending on progress. One year of work is planned into amplitude modulation to begin. After one year, following agreement among participants and work package leaders, WP 1 may recommend a change of focus. The focus will be refined during the six-monthly meetings.

Measurement and Data Analysis Normal wind turbine noise measurement processes use ten-minute averages with A-weighted sound pressure levels. See Zajamsek et al. [26] for more as well as the IEC standard and local guidelines [9, 6]. This averaging does not capture, for example, amplitude modulation of wind turbine noise. An open question is how best to capture data with sufficient fidelity to allow later processing for effects peculiar to wind turbines.

Several methodologies for quantifying amplitude modulated noise from turbines have been proposed. See for example papers from Sgurr Energy [23] and RES [2]. A standard approach does not exist. This is in part because how such sounds are perceived by the listener is not well understood; understanding what it is means to have an acceptable level of AM is important.

These ideas are tackled in WP 3 and will inform this technical work.

Modelling Building on recent work completed at Trinity College Dublin, the KTH and new work reported in the literature, WP 2 will work on standardising sound source, propagation and receptor models. This work will be informed by and validated against outputs from WP 3.

Broadband aerodynamic noise is the most influential noise source at modern wind turbines [17]. Standard industry tools, such as NREL's FAST code, can be used to predict

aerodynamic noise emission from wind turbines [10]. Much work remains, not least conducting rigorous reviews of the underlying theory that informs these codes and the addition to the standard codes of routines to capture additional phenomena such as amplitude modulation, if this is determined to be necessary.

In addition to sound source models, sound propagation models must also be considered. Again, in addition to reviewing underlying theory, this work will help us understand if and how existing models are to be modified to account for additional phemomena. Aside from amplitude modulation, other possible topics for consideration include indoor sound propagation, sound propagation in complex terrain and peri-urban areas, where obstacles can shield sound or cause back-scatter [22] as well as masking effects [8, 4, 3].

Finally, we will work on improving and standardising receptor models using outputs from WP 3.

Wind Turbine Design There are variations in the sound generated by different types of wind turbine; for this reason the acoustic performance of blades is important [13]. in addition, recent developments, e.g. receptor noise warranties from manufacturers, require robust understanding and an ability to tune wind turbines and wind farms where possible. This work will look to make recommendations for future development of wind turbine technology based on outputs from the other parts of WP 2 and WP 3.

Human Response to Wind Turbine Noise

Again, the focus of this work package will be initially on amplitude modulation. WP3 also takes its lead from the deliberations that form part of WP1.

Physiological Effects In order to resolve the on-going debates on the sensitivity of human listeners to characteristics of wind turbine noise such as amplitude modulation and low frequency sound, definitive answers are required on the physiological response of the ear to wind farm noise. Potential mechanisms for a physiological response of the ear to low frequency sound have been proposed, e.g. in particular by A.N. Salt and others [19, 21, 20]. There are several important relevant studies on health and wind turbines completed and in progress [1, 24]. More work is required in this field. Agreed thresholds for physiological response are needed for a robust noise metric for wind farms. This work package will include audiologists and medical experts specialising in otolaryngology.

Psychological Effects Even in the event that noise from a wind farm exceeds a threshold for a physiological response this is no guarantee that this will affect the individual in a negative manner. A consensus must also be reached on the psychological impact of wind farm noise exposure. In the past, psychological research has suffered from an incomplete understanding of the noise source mechanisms and propagation problems for wind farm noise. This work package will produce a standard database of suitable noise sources for use in participant testing. It will also aim to reach consensus on the

psychological impact of wind turbine noise and threshold levels for noise annoyance. It may be interesting to investigate the use of new technology, e.g. virtual and augmented reality techniques.

Public Engagement This work package will answer the questions of what type of noise information, presented in what format, is required to positively influence public response to wind turbines. We will combine focus group, laboratory and real world studies to assess the performance of a variety of presentation types over time. An advantage with this approach is that it gives better access to the people's holistic experiences of a phenomenon, such as noise. The conclusions drawn must be valid across social and cultural demographics. To this end studies will be conducted across partner countries and demographics. Much work has been completed in this space, including the WISEPower project [7].

Cooperation with Task 28 may be useful.

Shared Resources

The efforts of the wind turbine noise community would be greatly helped by the creation of the reliable and open dataset of wind turbine noise and other data and information. Many groups such as SMEs and academic researchers do not have the resources to develop their own datasets. In the case of noise measurement, this hinders the development of data analysis and prediction tools and also prevents correct investigation of the human response to wind turbine noise. This work package aims to collated and deploy an open and extensive data and information sets that will be available to the community. This website will also serve as a public dissemination tool for the Task and help to engage the wider wind noise community.

Example: A Template for a Noise Data Set A flexible database structure capable of incorporating data from sensors, user surveys and historic datasets is required. The objective is to provide validation data for research on wind farm noise modeling and prediction as well as a dataset suitable for use in auralisation for psychological studies. Constructing a rich, environmentally and geographically-aware database structure will allow the efficient retrieval and mining of collected data of wind farm noise which will be to great benefit to the wind farm noise community.

The information in the dataset will be provided through different interfaces for different user groups (e.g. acousticians, environmental noise specialists, policy makers). The Task will reconcile an open access approach for data and results generated with the business interests of the participating industries and partners.

This open dataset will be a core output of the Task for the wind farm noise community. It will facilitate further national and international research programmes as well as providing vital validation data to industry.

WP 3: Recommended Practice

Overview

The Task Co-ordinator and Work Packager Leaders will form a working group to provide a recommended practice document. The outputs of WP 1, WP 2 and WP 3 will be integrated and summarised over the course of the Task to provide a continuous update to the recommended practice document. This working group will engage with policy makers to facilitate the implementation of integrated policies in different regions by translating the output of the task into practical policy applications.

The guidelines for recommend practice will be the core output of the Task for policy makers. There may be more than one recommended practice, e.g. there may be one on the framework for wind turbine noise regulations and another for specific phenomena including amplitude modulation.

A Note on Amplitude Modulation

At the recent INCE Wind Turbine Noise conference in Glasgow, a workshop about the implementation of noise standards, there was agreement that work needs to be carried out to (i) build consensus around the measurement and assessment of amplitude modulation; (ii) establish a "dose-response" relationship for the setting of guidelines. The Task will liaise with the IEC to contribute to the development of new standards.

4 Organisation

The task will be centrally managed by the Trinity College Dublin with work package leaders that will be identified during this drafting phase and during the scoping work package.

The task operating agent is proposed to be:
Niall McMahon,
Distributed Wind Energy Group,
Dept. Mechanical & Manufacturing Engineering,
Trinity College Dublin,
Dublin 2
Ireland
Email: mcmahon2@tcd.ie

Management

Task Coordination

The Task will be managed by TCD, representing the task to the IEA Wind ExCo. TCD's DWE team, which includes Prof. Henry Rice, has broad experience running successful

technical projects including FP5 - FP7 and SEAI projects. Niall McMahon has led several industrial efforts and has directed an academic research centre. John Kennedy is an experienced scientist and research manager. See biographies for more.

Overall management of the Task will be handled by the Task Coordinator who will hold responsibility for:

1. Coordination of the task through regular meetings with partners.
2. Tracking progress against planned actions.
3. Managing all aspects of the task including risk, planning, monitoring and budgeting.
4. Facilitating communication and collaboration between work package leaders and team members.
5. Interfacing with IEA Wind ExCo.

In addition to on-going communication about developments in the task, the official progress meetings of the consortium will be a key tool for the Task Coordinator in terms of ensuring that the IEA Wind ExCo is informed of progress.

Risk Management

Risks primarily include time slippage and budget overspend. This will be mitigated by formation of an oversight committee that includes members of the IEA Wind ExCo. Additionally, TCD's DWE team intends to continue development of these efforts beyond this two month period as they align with our strategy.

John Kennedy is happy to act as Quality & Risk Manager to establish and validate quality control procedures; risk management procedures and risk register management. The *Quality and Risk Manager* will take care of the monitoring of quality control and risk register follow-up.

The risk assessment and mitigation process used within the Task has been utilised within past projects coordinated by TCD. There will be two phases of the risk management process, namely risk identification and risk assessment. The probability of occurrence as well as the potential impact will be used to assess the severity of a risk.

A standard tool for risk assessment, utilised by TCD within European H2020 and FP7 projects will be used.

The project management review carried out in WP 0 will be responsible for the continuous monitoring and identification of risks to the task. This assessment will be led by the project coordinator in conjunction with the work package leaders.

Meetings, Oversight and Review

Reports will be made on a regular basis via memo. to the IEA Wind ExCo. We are defining milestones but these will include having up four meetings per annum, at least two face-to-face, with two annual reports and a final report. In addition, the aim is to produce guidelines around wind turbine noise. More detail in next draft following partner contribution.

Obligations and Responsibilities

The main responsibilities of the operating agent include management, coordination and dissemination and reporting to the ExCo, in addition to technical work undertaken by the lead organisation. All of the partners are responsible for:

1. Maintaining progress against the work plan and schedule.
2. Attending annual progress meetings and quarterly updates (via teleconference).
3. Contributing as agreed to deliverables and reports.

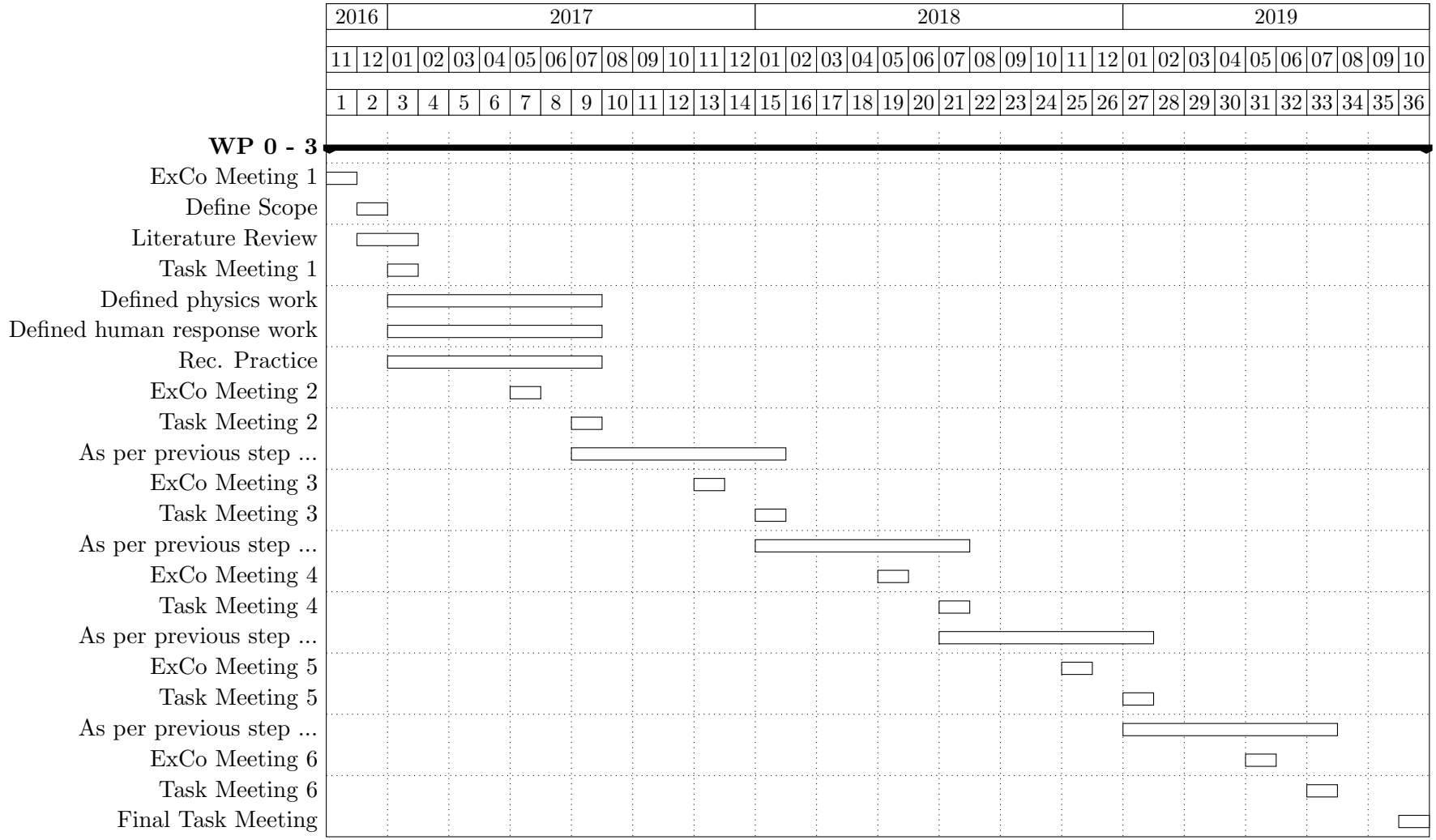
First Steps

This draft proposal was circulated to potential participants following the 77th ExCo. We will meet with potential participants at Wind Turbine Sound 2016 [25] and present at ExCo 78 seeking approval to initiate the Task with a view to a kick-off meeting by January 2017.

Timelines and Dates

If the ExCo accepts this proposal, the Task will begin immediately and will continue for 3 years. A kick-off meeting will be organised in the near future, ideally to coincide with a relevant conference or event.

Assuming an immediate start in November, the outline timeframe will be:


2016
2017
2018
2019
11 12 01 02 03 04 05 06 07 08 09 10 11 12 01 02 03 04 05 06 07 08 09 10 11 12 01 02 03 04 05 06 07 08 09 10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
WP 0 - 3
ExCo Meeting 1
Define Scope
Literature Review
Task Meeting 1
Defined physics work
Defined human response work
Rec. Practice
ExCo Meeting 2
Task Meeting 2
As per previous step ...
ExCo Meeting 3
Task Meeting 3
As per previous step ...
ExCo Meeting 4
Task Meeting 4
As per previous step ...
ExCo Meeting 5
Task Meeting 5
As per previous step ...
ExCo Meeting 6
Task Meeting 6
Final Task Meeting

Further detail around timelines are in development and a draft may be ready for presentation before ExCo 78. We have budgeted for an additional ExCo meeting and Task meeting.

5 Funding and Budget

Budget

The total costs to the operating agents for coordination, management, reporting and so on is 59,977 per annum over the three years, and may not exceed this level except by unanimous agreement of the partners. The budget is shared between the operating agent and the work package leaders. WP leaders receive payments once per year.

Coordination

To Trinity College, DWEG:

- Half-salary* ≈ cost to budget 159,429 euro (3 x 53,143).
- Travel to ExCo meetings (7 x in 36 month period) ≈ 10,500 euro (3 x 1,500).
- Travel to Task meetings (7 x in 36 month period) ≈ 10,500 euro (7 x 1,500).

* Salary for a senior research fellow grade in Ireland is currently 65,032 euro per annum. With national social insurance, obligatory pension contributions and university overheads of 25%, this amounts to 106,286 euro per annum or 53,143 euro for half salary. This includes all coordination, management, reporting and technical work by Trinity College Dublin.

Meetings

Financed by hosting organisation, i.e. not included in budget:

- 7 x meetings in 36 month period.
- Meeting rooms.
- Refreshments.

Website and Communications

- Website construction - ≈ 5,000 euro **.
- Hosting (5 years minimum) - ≈ 500 euro **.

** It's very probable that this website can be run from a university partner at no appreciable cost. Additionally, it's probable that the website can be built for little cost by students/staff at a university partner.

Description	Total Amount (Euro)	Annual Amount (Euro)
Half-salary	159,429	53,143
Travel to ExCo meetings	10,500	3,500
Travel to Task meetings	10,500	3,500
Website construction	5,000	1,667
Website hosting	500	167
Total	185,929	61,977

Table 1: Projected costs.

Funding

- Each partner will cover their own costs for carrying out the scientific work, including reporting and travel expenses.
- The host country shall bear the costs of workshops and meetings.
- The total costs of the operating agent shall be borne jointly and in equal shares by the partners.
- Each Participant shall transfer to the Operating Agent their annual share of the costs in accordance with a time schedule to be determined by the Participants.

6 Outputs

Information and IP

This section from standard IEA contracts. To be refined.

1. Executive Committee's Powers. The publication, distribution, handling, protection and ownership of information and intellectual property arising from activities conducted under this Annex, and rules and procedures related thereto shall be determined by the Executive Committee, acting by unanimity, in conformity with the Agreement.
2. Right to Publish. Subject only to copyright restrictions, the Annex Participants shall have the right to publish all information provided to or arising from this Task except proprietary information.
3. Proprietary Information. The Operating Agent and the Annex Participants shall take all necessary measures in accordance with this paragraph, the laws of their respective countries and international law to protect proprietary information provided to or arising from the Task. For the purposes of this Annex, proprietary information shall mean information of a confidential nature, such as trade secrets

and know-how (for example computer programmes, design procedures and techniques, chemical composition of materials, or manufacturing methods, processes, or treatments) which is appropriately marked, provided such information:

(a) Is not generally known or publicly available from other sources;

(b) Has not previously been made available by the owner to others without obligation concerning its confidentiality; and

(c) Is not already in the possession of the recipient Participant without obligation concerning its confidentiality.

It shall be the responsibility of each Participant supplying proprietary information, and of the Operating Agent for arising proprietary information, to identify the information as such and to ensure that it is appropriately marked.

4. Use of Confidential Information. If a Participant has access to confidential information which would be useful to the Operating Agent in conducting studies, assessments, analyses, or evaluations, such information may be communicated to the Operating Agent but shall not become part of reports or other documentation, nor be communicated to the other Participants except as may be agreed between the Operating Agent and the Participant which supplies such information.

5. Acquisition of Information for the Task. Each Participant shall inform the other Participants and the Operating Agent of the existence of information that can be of value for the Task, but which is not freely available, and the Participant shall endeavour to make the information available to the Task under reasonable conditions.

6. Reports on Work Performed under the Task. Each Participant and the Operating Agent shall provide reports on all work performed under the Task and the results thereof, including studies, assessments, analyses, evaluations and other documentation, but excluding proprietary information, to the other Participants. Reports summarizing the work performed and the results thereof shall be prepared by the Operating Agent and forwarded to the Executive Committee.

7. Arising Inventions. Inventions made or conceived in the course of or under the Task (arising inventions) shall be identified promptly and reported to the Operating Agent. Information regarding inventions on which patent protection is to be obtained shall not be published or publicly disclosed by the Operating Agent or the Participants until a patent application has been filed in any of the countries of the Participants, provided, however, that this restriction on publication or disclosure shall not extend beyond six months from the date of reporting the invention. It shall be the responsibility of the Operating Agent to appropriately mark Task reports that disclose inventions that have not been appropriately protected by the filing of a patent application.

8. Licensing of Arising Patents. Each Participant shall have the sole right to license its government and nationals of its country designated by it to use patents and patent applications arising from the Task in its country, and the Participants shall notify the other Participants of the terms of such licences. Royalties obtained by such licensing shall be the property of the Participant.

9. Copyright. The Operating Agent may take appropriate measures necessary to protect copyrightable material generated under the Task. Copyrights obtained shall be held for the benefit of the Annex Participants, provided however, that the Annex Participants may reproduce and distribute such material, but shall not publish it with a view to profit, except as otherwise directed by the Executive Committee, acting by unanimity.

10. Inventors and Authors. Each Annex Participant will, without prejudice to any rights of inventors or authors under its national laws, take necessary steps to provide the co-operation from its inventors and authors required to carry out the provisions of this paragraph. Each Annex Participant will assume the responsibility to pay awards or compensation required to be paid to its employees according to the law of its country.

Dissemination of Results

As Task co-ordinator TCD will establish a web site for the task early on in the project. This will allow for both public and restricted access, the former to ensure information on the progress of the work is in the public eye and the latter to provide for an efficient means of data and information exchange between the partners and the IEA Wind ExCo.

The main results of the task will also be published in the scientific journals and presented at conferences. The consortium has an excellent track record for publication in the premium journals relating to noise, aero-acoustics, aerodynamics and human behaviour.

In addition to annual reports and end guidelines, each work package will produce reports/memos on useful findings. A proposed list of publications and conferences will be agreed following kick-off. We aim to engage closely with industry throughout the process.

The outputs of this task will integrate with world leading graduate level education at the university partners. This will enable graduate level researchers to develop skills targeted at the needs of the Wind Energy community. In addition, the project will serve to sustain the momentum of a number of significant national and international programmes which have been focused on the study of the wind turbine noise problem.

The means to reach the target audiences will be through:

1. Direct contacts with key industrial and research organisations exploiting the network of contacts of the partners.

2. Publications in scientific journals.
3. Participation in scientific conferences.
4. Development and deployment of an open dataset of wind turbine noise for use by the community.
5. The public website will maintained and updated to promote the main benefits from Task in terms of the impacts for community noise and in terms of scientific, technical and industrial achievements.

7 Participants and Authors

Potential Participants

We expect participants from:

- Ireland
- Canada
- Denmark
- Finland
- Germany
- The Netherlands
- Sweden
- UK
- USA

Solicitation for partners and contributions is in progress and we encourage all interested to take part if possible. We hope to have participants from across disciplines and industries.

Proposal Authors

Dr. Niall McMahon

Niall is a senior research fellow at Trinity College Dublin and lead of the DWEG. He has worked building small wind turbines with Ampair in England and others and was previously director a small wind research centre in Ireland. He holds a Ph.D. in computational flow modelling from Dublin City University and a degree in mechanical engineering from Trinity College Dublin.

Dr. John Kennedy

Dr. John Kennedy holds a Ph.D. in aero-acoustics from Trinity College Dublin. His research has applied advanced correlation and spectral analysis techniques to experimental data of turbulence (LDV, X-hotwire and high speed PIV) and included advanced beamforming and partial coherence techniques for source localisation using microphone array data. He is also actively engaged in interdisciplinary research with psychologists from the University of Bath and the University of Aberystwyth into the influence of noise exposure on human performance in transport applications including hazard detection, risk perception and annoyance. He is the Irish coordinator for the industrially focused Institute of Acoustics Diploma in Acoustics and Noise Control.

Professor Henry Rice

Prof. Henry Rice is an Associate Professor of Mechanical Engineering and has worked in the field of vibro-acoustic analysis for over thirty years. His expertise is in efficient modelling of source and propagation of sound, non-linear system identification and environmental acoustics. He has published over 80 refereed papers and has been an invited keynote lecturer at a number of conferences.

Mr. John McCann

John McCann is the Vice Chair of IEA Wind and Programme Manager for Electricity and Wind with the Sustainable Energy Authority of Ireland.

References

[1] R. H. Bakker, E. Pedersen, G. P. van den Berg, R. E. Stewart, W. Lok, and J. Bouma, *Impact of Wind Turbine Sound on Annoyance, Self-reported Sleep Disturbance and Psychological Distress*, Science of the Total Environment, 425 (2012), pp. 42 – 51.

[2] J. Bass, *Wind Turbine Noise - from Source to Receiver Far-field Noise Issues - AM, Tonality and Impulses*, (RES) EWEA Noise Workshop, (2013).

[3] K. Bolin, A. Kedhammar, and M. E. Nilsson, *The influence of background sounds on loudness and annoyance of wind turbine noise*, Acta Acustica united with Acustica, 98 (2012), pp. 741–748.

[4] K. Bolin, M. E. Nilsson, and S. Khan, *The potential of natural sounds to mask wind turbine noise*, Acta Acustica united with Acustica, 96 (2010), pp. 131–137.

[5] Council of Canadian Academies, *Understanding the Evidence: Wind Turbine Noise*, 2015. http://www.scienceadvice.ca/en/assessments/completed/wind-turbine-noise.aspx.

[6] EPA (Ireland), 2011. Guidance Note on Noise Assessment of Wind Turbine Operations at EPA Licensed Sites (NGS3).

[7] EWEA/Wind Europe, *WISE Power, Fostering Social Acceptance for Wind Power*, 2016. http://wisepower-project.eu/.

[8] B. R. Glasberg and B. C. J. Moore, *Development and evaluation of a model for predicting the audibility of time-varying sounds in the presence of background sounds*, Journal of the Audio Engineering Society, (2005), pp. 906 – 918.

[9] IEC, 2012. IEC 61400-11 2002-12 Wind Turbine Generator Systems Part 11: Acoustic Noise Measurement Techniques.

[10] J. Jonkman, *Fast. an aeroelastic computer-aided engineering (cae) tool for horizontal axis wind turbines*, National Wind Technology Center, (2015). https://nwtc.nrel.gov/FAST.

[11] M. V. Lowson, *Applications of Aero-Acoustic Analysis to Wind Turbine Control*, Wind Engineering, 16 (1992), pp. 126 – 140.

[12] ——, *Assessment and Prediction of Wind Turbine Noise*, Flow Solutions Report 19/92. ETSU W/13/00284/REP, (1992), pp. 1 – 59.

[13] H. Møller, , and C. S. Pedersen, *Low-frequency noise from large wind turbine*, J Acoust Soc Am, (2011), pp. 3727 – 3744.

[14] A. Moorhouse, M. Hayes, S. von Hunerbein, N. Piper, and M. Adams, *Research Into Aerodynamic Modulation of Wind Turbine Noise*, Report URN 07/1235 (Uni. Salford), (2007).

[15] S. Oerlemans, *Wind turbine noise: primary noise sources*, National Aerospace Laboratory NLR, (2011).

[16] ——, *Wind Turbine Amplitude Modulation: Research to Improve Understanding as to its Cause and Effects*, RenewableUK, (2013).

[17] S. Oerlemans, P. Sijtsma, and B. Mendez Lopez, *Location and quantification of noise sources on a wind turbine*, National Aerospace Laboratory NLR, (2007).

[18] A. L. Rogers and J. F. Manwell, *Wind Turbine Noise Issues*, 2004. Renewable Energy Research Laboratory, U. Mass.

[19] A. Salt and J. DeMott, *Longitudinal endolymph movements and endocochlear potential changes induced by stimulation at infrasonic frequencies*, J Acoust Soc Am, (1999), pp. 847 – 856.

[20] A. Salt and J. Lichtenhan, *How does wind turbine noise affect people?*, Acoustics Today, Winter (2014).

[21] A. Salt, J. Lichtenhan, R. Gill, and J. Hartsock, *Large endolymphatic potentials from low-frequency and infrasonic tones in the guinea pig*, J Acoust Soc Am, (2013), pp. 1561 – 71.

[22] M. Schiff, M. Hornikx, and J. Forssén, *Excess attenuation for sound propagation over an urban canyon*, Applied Acoustics, 71 (2010), pp. 510–517.

[23] Sgurr Energy, *Measurement of Amplitude Modulation Frequency Spectrum*, 2012.

[24] M. Sørensen, O. Raaschou-Nielsen, R. Nordsborg, and A. Peña, *Noise from Wind Turbines and Risk of Cardiovascular Disease*, 2013. Danish Cancer Society and DTU.

[25] Wind Europe, *Wind Turbine Sound 2016*. Gdańsk, November 17 - 18, 2016. https://windeurope.org/workshops/wind-turbine-sound-2016/.

[26] B. Zajamsek, D. J. Moreau, and C. J. C.J. Doolan, *Characterising Noise and Annoyance in Homes Near a Wind Farm*, Acoustics Australia, 42 (2014).

8 Appendices

Summary Note on Amplitude Modulation

The amplitude of wind turbine noise is modulated, i.e. its loudness varies with time in a regular way. This is perceived as a characteristic swooshing sound. State of the art has it that this modulation results from competing directional aerodynamic effects: stall, produced by varying angles of attack especially during the upper part of blade revolution, and inflow turbulence [12, 11, 16].

A recent report defines amplitude modulation as, "a greater than normal degree of fluctuation of sound level at about once per second which makes it more noticeable" [14]. The report goes on to note that complaints about the "low frequency" and "infrasound"[1] noise from wind turbines were often about amplitude modulation, i.e. a signal that was changing more frequently than usual.

The rate of amplitude modulation for wind turbine noise is relatively low but higher than for typical environmental noise sources. Amplitude modulation does not change the frequency or pitch of the sound, only its loudness, i.e. amplitude modulation is not concerned with the frequency or pitch of the source noise.

In general, amplitude modulation is perceived close to the wind turbine (in the near field) and generally not perceived further away (in the far field). Far-field amplitude modulation (AM) is termed "other" amplitude modulation (OAM). The reasons for OAM probably include atmospheric disturbances and/or terrain effects; this requires clarification.

[1] Sound with a frequency of less than 20 Hz.

Normal wind turbine noise measurement processes use ten-minute averages with A-weighted sound pressure levels. This averaging does not capture the modulation of the wind turbine noise. Capturing noise data with sufficient fidelity to allow later processing to identify AM/OAM at low frequency noise requires non-standard data acquisition. See Zajamsek et al. [26] for more as well as the IEC standard and local guidelines [9, 6].

Several methodologies for quantifying amplitude modulated noise from turbines have been proposed. See for example papers from Sgurr Energy [23] and RES [2]. A standard approach does not exist. How such sounds are perceived by the listener is not well understood. Understanding what it is means to have an acceptable level of AM is important. Recent developments, e.g. receptor noise warranties from manufacturers, require robust understanding.

Dr. Niall McMahon,
Distributed Wind Energy Group,
Dept. Mechanical & Manufacturing Engineering,
Trinity College Dublin,
Dublin 2,
Ireland.
Email: mcmahon2@tcd.ie
November 11th 2016.

To: IEA Wind ExCo C/o Cezanne Murphy-Levesque.
Re: Proposed IEA Wind Task on Quiet Wind Turbine Technology.

Dear Cezanne and All,

Please find attached our latest draft of the proposal for the new IEA Task on *Quiet Wind Turbine Technology*.

As you know, the overall aim is to accelerate the development and deployment of quiet wind turbine technology. The principal near-term objective is to convene an international expert panel to: (i) exchange learning, (ii) identify and report best practice in the measurement and assessment of and noise; (iii) develop an IEA *Recommended Practice* contributing to the ongoing development of IEC standards for wind turbine noise.

We have sought input from potential partners worldwide and this revision was reviewed by workers at DTU in Denmark, the KTH in Stockholm and the VTT in Finland, among others. We had useful meetings at Wind Europe 2016 in Hamburg.

As it stands, we have financial support from two countries, Ireland and Denmark, and we are likely to have others. Several other groups expect to participate.

Next week, we will present the task overview at Wind Turbine Sound 2016 in Gdańsk and the organisers, Wind Europe, have kindly arranged for a meeting room for break-out discussions with participants. We will incorporate what happens at Gdańsk into our proposal. Jeremy Bass, of RES in the UK, was very helpful here.

With all this in mind, we would like to submit the proposal as it stands for consideration by the ExCo - we will present any new material in person at ExCo 78.

Sincerely and faithfully,

Niall McMahon
`http://niallmcmahon.com/`