檔　　號：
保存年限：

經濟部標準檢驗局　開會通知單

10461
台北市中山區德惠街16-8號9樓
受文者：台灣智慧風能發展協會

發文日期：中華民國113年9月5日
發文字號：經標標準字第11320014730號
速別：普通件
密等及解密條件或保密期限：
附件：如文(附件請至本機關附件下載區以發文字號及發文日期下載。網址 https://docdl.bsmi.gov.tw/DL) 識別碼：FAECQQXX。

開會事由：召開電機工程國家標準技術委員會(TC03/SC13風力發電分組委員會) 113年第123次及第124次會議

開會時間：113年9月11日（星期三）上午9時30分及下午2時整

開會地點：視訊會議

主持人：張委員欽然

聯絡人及電話：林孟玄　02-23431700#136

出席者：吳委員思葦、李委員仁傑、柯委員明村、常委員挽瀾、黃委員良真、黃委員傳興、楊委員條和、葉委員冠杰、廖委員裕弘、蘇委員長皇

列席者：經濟部能源署、台灣智慧風能發展協會、台灣區電機電子工業同業公會、財團法人工業技術研究院綠能與環境研究所、財團法人金屬工業研究發展中心、財團法人國家實驗研究院國家地震工程研究中心、財團法人船舶暨海洋產業研發中心、台灣電力股份有限公司綜合研究所、力鋼工業股份有限公司、士林電機廠股份有限公司、中興電工機械股份有限公司、中鋼機械股份有限公司、台朔重工股份有限公司、永傳能源股份有限公司、臺灣御風能源股份有限公司、先進複材科技股份有限公司、亞力電機股份有限公司、東元電機股份有限公司、金豐機器工業股份有限公司、富崴能源股份有限公司、華城電機股份有限公司、經濟部標準檢驗局檢驗行政組、經濟部標準檢驗局檢驗技術組

副本：

備註：

一、討論事項：審查CNS草-制1121056「風力機－第12-4部：風力機功率性能試驗之數值試驗場校準」1種草案。

二、請各公(協)會轉知所屬會員。

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三、本次會議採線上視訊方式進行，請於會議前提供出席人員名單、電子郵件信箱及電話，並寄至john.lin@bsmi.gov.tw，俾利通知連線網址等相關事宜，請於會議開始前15分鐘以連線網址申請加入會議。出席人員之名稱請以單位加姓名(例：○○○公司○○○)，並測試影音訊號是否正常。

四、本次會議除本局為製作會議紀錄之需要，得於會議中錄音、錄影或照相，其他人員非經全體與會者同意，不得錄音、錄影或照相；違反者應自負相關法律責任，如有公開揭露，應予去除。

五、配合政府政策，檢附性別平等宣導資料供參。

經濟部標準檢驗局

ICS 27.180

中華民國國家標準

C N S

風力機－第 12-4 部：風力機功率性能試驗之數值試驗場校準

Wind energy generation systems − Part 12-4: Numerical site calibration for power performance testing of wind turbines

CNS 61400-12-4:2023
XXX

中華民國　年　月　日制定公布
Date of Promulgation:　-　-

中華民國　年　月　日修訂公布
Date of Amendment:　-　-

目錄

前言

本標準係依據 2022 年發行之第 1 版 IEC 61400-12-4，不變更技術內容，制定成為中華民國國家標準者。

依標準法第四條之規定，國家標準採自願性方式實施。但經各該目的事業主管機關引用全部或部分內容為法規者，從其規定。

本標準並未建議所有安全事項，使用本標準前應適當建立相關維護安全與健康作業，並且遵守相關法規之規定。

本標準之部分內容，可能涉及專利權、商標權與著作權，主管機關及標準專責機關不負責任何或所有此類專利權、商標權與著作權之鑑別。

1. 適用範圍

本標準為技術報告，總結數值氣流建模之最新技術現狀、現有指導綱要，及數值模型確證與查證之過去基準經驗。根據所進行之工作，在風力應用中使用地形氣流模擬之重要技術層面，以及現有未解決之議題，其包含藉由基準試驗進一步確證之建議，皆於本標準中確定。

2. 引用標準

本標準無引用標準。

3. 用語、定義、縮寫及符號

3.1 用語及定義

本標準未列出任何術語及定義。

3.2 縮寫

下列縮寫適用於本標準。

AIAA	美國航空太空學會(American Institute of Aeronautics and Astronautics)
ABL	大氣邊界層(atmospheric boundary layer)
AEP	年發電量(annual energy production)
AIJ	日本建築學會(Architectural Institute of Japan)
ALEX17	2017 阿萊茲實驗(Alaiz experiment 2017)
ASME	美國機械工程師協會(American Society of Mechanical Engineers)
CEDVAL	微尺度分散模型確證之彙編及實驗資料(compilation and experimental data for validation of microscale dispersion models)
CFD	計算流體力學(computational fluid dynamics)
CHT	計算熱傳(computational heat transfer)
COST	歐洲科技合作組織(European Cooperation in Science and Technology)
CREYAP	比較資源及能量產出之評鑑程序(comparative resource and energy yield assessment procedures)
DES	分離式渦流模擬(detached eddy simulation)
DDES	延遲分離式渦流模擬(delayed detached eddy simulation)
DEWI	德國風能研究所(Deutsches Windenergie-Institut)
DTU	丹麥技術大學(Danish Technical University)
EWEA	歐洲風能協會(European Wind Energy Association)
EWTL	環境風洞實驗室(Environmental Wind Tunnel Laboratory)
FCF	氣流修正因數(flow correction factor)
GWh	百萬瓩時(gigawatt-hour)
IEA	國際能源總署(International Energy Agency)
IEC	國際電工技術委員會(International Electrotechnical Commission)

LES	大渦流模擬(large eddy simulation)
LIDAR	光偵測與測距(光達)(light detection and ranging)
MEASNET	風能研究所量測網路(Measuring Network of Wind Energy Institutes)
MEP	模型評估協定(model evaluation protocol)
NEWA	新歐洲風力圖(New European Wind Atlas)
NSC	數值試驗場校正(numerical site calibration)
RANS	雷諾平均之納維爾-斯托克斯(Reynolds-averaged Navier-Stokes)
RNG	再正規化群(renormalization group)
SC	試驗場校正(site calibration)
SODAR	聲音偵測與測距(聲達)(sound detection and ranging)
TC	技術委員會(technical committee)
TR	技術報告(technical report)
UQ	不確定度量化(uncertainty quantification)
URANS	不穩定雷諾平均之納維爾-斯托克斯(unsteady Reynolds-averaged Navier-Stokes)
V&V	查證與確證(verification and validation)
VDI	德國工程師協會(Verein Deutscher Ingenieure)
WAsP	風力圖分析與應用程式(Wind Atlas Analysis and Application Program)
WFIP	風力預測改善專案(Wind Forecast Improvement Project)
WTG	風力機(wind turbine generator)

3.3 符號及單位

本標準的內容及公式所使用之符號，如表 1 所示。

表 1　本標準使用之符號

符號	定義	單位
$\bar{u}_i$	過濾風速之第 i 項	m/s
$\bar{p}$	過濾壓力	Pa
μ	分子黏度	Pa s
μ_t	擾流黏度	Pa s
C_s	斯馬戈林斯基常數	
κ	馮卡門常數	
d	至最近牆之距離	m
Δ	局部過濾器尺寸	m
l	擾流長度尺度	m
l_{RANS}	從 RANS 模型獲得之擾流長度尺度	m
l_{LES}	從 LES 模型獲得之擾流長度尺度	m
f_d	DDES 模型之模型常數	m
$\overline{U_i}$	方向 i 之平均速度分量	m/s
u_i	方向 i 上之擾流速度分量	m/s
x_i	方向 i 上之空間變數	m
$\overline{P}$	平均壓力	Pa
ρ	密度	kg/m^3
v	運動分子黏度	m^2/s
$\overline{F_i}$	方向 i 上之實體力(body forces)	kg m/s
$\overline{u_i u_j}$	雷諾應力(Reynolds stresses)	m^2/s^2
δ_{ij}	克氏符號(Kronecker delta)	
v_T	運動擾流黏度	m^2/s
k	擾流動能 turbulence kinetic energy	m^2/s^2
L_T	擾流長度尺度	m
P_k	k 生產 production of k	m^2/s^3
ε	擾流動能消散率	m^2/s^3

符號	定義	單位
C_{μ}	RANS 擾流模型常數	
$C_{1\varepsilon}$	RANS 擾流模型常數	
$C_{2\varepsilon}$	RANS 擾流模型常數	
σ_{ε}	RANS 擾流模型常數	
E	確證比較誤差	
δ_{model}	基於建模假設之誤差	
δ_{num}	基於方程式數值解之誤差	
δ_{input}	基於輸入參數之誤差	
δ_{D}	實驗值誤差	
u_{val}	確證標準不確定度	
u_{num}	數值解不確定度	
u_{input}	輸入參數不確定度	
u_{D}	實驗值不確定度	
r	相關係數	
γ_{d}	DDES 參數	
A_1	修正之 DDES 常數/步階化函數	
A_2	DDES 常數	
K_{h}	有效之水平運動黏度	m^2/s
K_{v}	有效之垂直運動黏度	m^2/s
$\tilde{u}_{i}$	方向 i 之速度擾動分量	m/s
$\tilde{p}$	壓力擾動	Pa
U_{j}	方向 j 的無擾動氣流之水平速度分量	m/s
D	轉子直徑	m

4. 數值氣流模擬法之概述

4.1 線性氣流模型

自 1980 年代末以來，當計算資源有限時，線性氣流模型為風力資源評鑑之標準。此等模型基於線性化納維爾-斯托克斯方程式，其最早出現於文獻[2][(1)]。將其設計為中性大氣條件下，能可靠地應用於坡度相當平緩之地形，以確保完全附著之氣流條件。

註(1) 方括號之數字係指參考資料。

$$\frac{\partial \tilde{u}_i}{\partial x_i}=0，\ i = 1,\ldots,3 \qquad (1)$$

$$U_j \frac{\partial \tilde{u}_i}{\partial x_j} = -\frac{\partial}{\partial x_i}\frac{\tilde{p}}{\rho}+K_h \frac{\partial}{\partial x_j}\left[\frac{\partial \tilde{u}_i}{\partial x_j}\right]+K_v \frac{\partial^2 \tilde{u}_i}{\partial x_3^2}，\ i = 1,\ldots,3 \text{ 及 } j = 1,2 \qquad (2)$$

式中，U_j(j＝1,2)為無擾動氣流之水平速度分量，$\tilde{u}_i$(i= 1,…,3)為速度擾動分量，$\tilde{p}$為壓力擾動。K_h 及 K_v 為水平與垂直方向之有效運動黏度

風在不受陡坡、氣流分離、熱驅氣流、低層噴流及其他動力及非線性 ABL 現象顯著影響的情況下，該線性模型表現良好。

風力圖分析與應用程式(WAsP) [3]在線性模型中最廣泛應用。WAsP 程序可視為轉移函數模型，將基準位置之風速與預測位置之風速鏈結。顯著之誤差源可能與地形複雜性、大量氣流分離、風向變化及大氣條件變化有關。其中後者包括通道效應、阻隔效應及熱驅氣流(例：晝夜海風、下坡風)。

由於其性能快速且穩健，線性模型仍在風力產業中使用。

4.2 雷諾平均之納維爾-斯托克斯(RANS)模型

如 4.1 所述，由於線性模型之侷限性，計算流體動力學(CFD)模型在風力產業中之應用越來越廣泛。CFD 在大氣邊界層(ABL)之應用受到機械工程 CFD 與中尺度氣象建模之影響。CFD 考慮動量及質量守恆方程式，其中有 4 個未知變數：壓力與 3 個速度分量。通常不考慮描述大氣狀態之其他變數，如溫度、濕度及氣膠濃度。大氣流動模擬應用之典型 CFD 遵循單一風向法，其可表示離散風向玫瑰圖之扇形區域。考慮地形及地形粗糙度之效應，各扇形區域之氣流模擬皆會造成加速因素。

在雷諾平均之納維爾-斯托克斯(RANS)方法[4]中，由於氣流之擾流性質，以統計函數描述變數，統計函數分為平均及波動(擾流)分量(例：$U_i=\overline{U_i}+u_i$ 得到 RANS 方程式)：

$$\frac{\partial(\rho \overline{U_i})}{\partial x_i}=0 \text{ 及 } U_j \frac{\partial(\rho \overline{U_i})}{\partial x_j} = -\frac{\partial \bar{p}}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\nu \frac{\partial(\rho \overline{U_i})}{\partial x_j}-\rho \overline{u_i u_j}\right]+\bar{F}_i，\ i,j = 1,\ldots,3 \qquad (3)$$

在 RANS 方程式中，須將擾流相關項$\overline{u_i u_j}$(亦稱為擾流通量或應力)參數化，以閉合方程式系統。Boussinesq 假設藉由引入渦流黏度(一階閉合)，以定義擾流通量與平均值梯度之關係。

$$-\overline{u_i u_j}=\nu_T\left(\frac{\partial \overline{U_i}}{\partial x_j}+\frac{\partial \overline{U_j}}{\partial x_i}\right)-\frac{2}{3}k\delta_{ij}，\ i,j = 1,\ldots,3 \qquad (4)$$

引入 2 個基本量來描述擾流：運動擾流黏度 ν_T 及擾流動能 k。運動擾流黏度取決於擾流動能 k 及擾流渦流之大小 L_T，即 $\nu_T = k^{1/2} L_T$。

Two basic quantities are introduced to describe the turbulence: the kinematic turbulence viscosity v_T, and the turbulence kinetic energy, k. The kinematic turbulence viscosity depends on the turbulence kinetic energy, k, and the size of the turbulent eddies, L_T, as $v_T = k^{1/2} L_T$.

有不同類型之閉合，例：一式方程式及二式方程式模型。在一式方程式模型中，擾流動能 k，求解方程式：

There are different types of closures, e.g., one- and two-equations models. In the one-equation model, the turbulence kinetic energy, k, equation is solved:

$$\overline{U_j}\frac{\partial k}{\partial x_j}=P_k-C_\mu\frac{k^2}{v_T}+\frac{\partial}{\partial x_j}\left[\left(\frac{v_T}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right],\ j = 1,\ldots,3 \qquad (5)$$

式中，由平均風速度梯度產生之 k 為 P_k。由分析模型推導出擾流長度尺度 L_T，例如地面高度之函數，有時為熱穩定性之函數[5]。

where P_k is the production of k due to mean wind velocity gradients. The turbulence length scale, L_T, is deduced from an analytical model, such as a function of the height above the ground and sometimes the thermal stability [5].

在二式方程式模型(k − ε、RNG k – ε、k − ω、...)，係藉由 2 個轉換方程式進行閉合，其一用於 k，其一用於擾流動能消散率 ε。

In the two-equation models (k − ε, RNG k – ε, k − ω,...), the closure is made through two transport equations, one for k and one for the turbulence dissipation, ε:

$$\overline{U_j}\frac{\partial k}{\partial x_j}=P_k-\varepsilon+\frac{\partial}{\partial x_j}\left[\left(\frac{v_T}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right],\ j = 1,\ldots,3 \qquad (6)$$

$$\overline{U_j}\frac{\partial \varepsilon}{\partial x_j}=\frac{\varepsilon}{k}(C_{1\varepsilon}P_k-C_{2\varepsilon}\varepsilon)+\frac{\partial}{\partial x_j}\left[\left(\frac{v_T}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right],\ j = 1,\ldots,3 \qquad (7)$$

由閉合方程式 v_T 得到運動擾流黏度 $v_T = C_\mu\frac{k^2}{\varepsilon}$。

The kinematic turbulence viscosity v_T, is given by the closure equation $v_T = C_\mu\frac{k^2}{\varepsilon}$

若無 RANS 模型所使用之穩態假設，可用非穩態 RANS(URANS)來描述運動方程式。

Without the steady-state hypothesis used in the RANS model, the equations of motion can be described with unsteady RANS (URANS).

相較於線性模型，在多數情況下，RANS 穩態模型可預測分離區之氣流分離及再附著，但該區域結果之準確度需存疑。此種限制為模型之統計性質所固有。RANS 模型主要應用於中性層化之假設，在多種情況下限制其適用性。已提出應對中性層化限制假設之解決方案，例：修正基於 Monin-Obukhov 相似性理論[6]之擾流閉合，或求解能量方程式並在 RANS 方程式[7]中添加浮力項。但仍需額外確證。

Compared to the linear model, the RANS steady-state model is able to predict flow detachment and reattachments in the separation zone in most cases, but the accuracy

of the results in this region is questionable. This limitation is inherent in the statistical nature of the model. The RANS model is mostly applied under the assumption of neutral stratification, which in many cases limits its applicability. There are solutions proposed for coping with the neutral stratification limitation assumption, for example, through modifications of the turbulence closure based on the Monin-Obukhov similarity theory [6] or by solving energy equations and adding a buoyancy term to the RANS equations [7]; however, additional validations are needed.

相較於線性模型，RANS 模型需更多計算資源。目前，其用於複雜試驗場之資源評鑑及試驗場適宜性，諸如不平坦之地形、地形粗糙度驟變或森林區域。

RANS models require significantly more computational resources than linear models. Presently, they are used for resource assessment and site suitability in complex sites, such as nonflat terrain, abrupt roughness changes, or forested areas.

4.3 大渦流模擬(LES)與混合 RANS/LES 模型(Large eddy simulation (LES) and hybrid RANS/LES models)

大渦流模擬(LES) [8]旨在藉由低通濾波器以忽略小尺度擾流，僅求解網格可解析之擾流。不可壓縮流之控制方程式(使用 Smagorinsky 次網格尺度模型[8])可表示如下列：

The idea of large eddy simulation (LES) [8] is to ignore small-scale turbulences by a low-pass filter and to only solve the turbulence that can be resolved by the grid. The governing equations for incompressible flow (using the Smagorinsky subgrid scale model [8]) can be written as follows:

$$\frac{\partial \rho \bar{u}_i}{\partial x_i}=0 \tag{8}$$

$$\frac{\partial (\rho \bar{u}_i)}{\partial t}+\frac{\partial (\rho \bar{u}_j \bar{u}_i)}{\partial x_j}=-\frac{\partial \bar{p}}{\partial x_i}+\frac{\partial}{\partial x_j}\left[(\mu+\mu_t)\left(\frac{\partial \bar{u}_i}{\partial x_j}+\frac{\partial \bar{u}_j}{\partial x_i}\right)\right] \tag{9}$$

$$\mu_t=\rho L_s^2|\bar{S}| \tag{10}$$

$$L_s=C_s\Delta \tag{11}$$

$$|\bar{S}|=\sqrt{2\bar{S}_{ij}\bar{S}_{ij}} \tag{12}$$

$$\bar{S}_{ij}=\frac{1}{2}\left(\frac{\partial \bar{u}_i}{\partial x_j}+\frac{\partial \bar{u}_j}{\partial x_i}\right) \tag{13}$$

式中，$\bar{u}_i$ 為過濾風速之第 i 分量，C_s 為斯馬戈林斯基常數，Δ為局部過濾器大小(i,j＝1,..,3)，其他次網格尺度模型之更多資訊於參考資料[9]。

where $\bar{u}_i$ is the i component of the filtered wind velocity, C_s is the Smagorinsky constant, and Δ is the local filter size, i,j＝1,..,3. Further information for other subgrid scale models can be found in reference [9].

不同於 RANS，LES 不求解次網格尺度參數之轉換方程式，即須求解構成流動特性之所有渦流問題。因此，LES 高度依賴於網格解析度，網格的選擇至關重要。

此外，當網格足夠精細時，發生於山丘後方或懸崖邊緣之不穩定氣流分離可由 LES 解決，且相較於 RANS，此種氣流分離區域之流場模擬更接近現實[10]。

Unlike RANS, LES does not solve transport equations for subgrid scale parameters, i.e., all eddies that characterize the flow have to be resolved. As a result, LES is highly dependent on grid resolution, and choice of the grid is critical. On the other hand, when the grid is fine enough, LES can resolve the unsteady flow separation that can typically be seen behind a hill or at the edge of a cliff, and a simulated flow field in such a flow separation region is closer to reality than RANS [10]

然而，表面粗糙度之建模為 LES 的主要問題之一。例：針對低粗糙度表面，LES 需極精細之網格來求解，該工程應用之計算成本過高。

One major problem of LES, however, is the modelling of surface roughness. For example, for a low-roughness surface, LES requires very fine grids to resolve it, which is too computationally expensive for an engineering application

已提出混和 RANS/LES 法來解決此問題。如分離渦流模擬(DES)[11]，在 DES 中求解 k 及 ε 之轉換方程式，長度尺度 l 可由下列計算：

Hybrid RANS/LES approaches have been proposed to overcome this problem. Detached eddy simulation (DES) [11] is one such approach. In DES, the transport equation of k and ε is solved, and the length scale,l,can be calculated by using the following equation.

$$l = \min(l_{RANS}, l_{LES}) \tag{14}$$

式中，

Where

$$l_{RANS} = \frac{k^{\frac{3}{2}}}{\varepsilon} \tag{15}$$

$$l_{LES} = C_s \Delta \tag{16}$$

藉由使用該方法，在邊界附近選擇 RANS 模型，在遠離邊界之區域選擇 LES。然而，Spalart 等人[12]指出 DES 模型在厚邊界層中表現出不正確的行為，並提出一種稱為延遲分離渦流模擬(DDES)之修正。在 DDES 中，長度尺度 l 可藉由以下公式計算[13][14]：

By using this approach, the RANS model is chosen near the boundary and LES is chosen in the region far from the boundary. However, Spalart et al. [12] mentioned that the DES model exhibits an incorrect behavior in the thick boundary layer and proposed a modification called delayed detached eddy simulation (DDES). In DDES, the length scale, l, can be calculated by using the following equation [13][14]:

$$l = l_{RANS} - f_d \max(0, l_{RANS} - l_{LES}) \tag{17}$$

式中，

Where

$$f_d = 1 - \tanh\left[\left(A_1 \gamma_d\right)^{A_2}\right] \quad (18)$$

參考資料[14]的作者提出用 A_1 之分段函數代替常數，以模擬大氣邊界層內之流場。

In reference [14], the authors proposed a piecewise function of A_1 instead of a constant to simulate the flow fields in the atmospheric boundary layer.

5. 數值流建模應用之現有指引(Existing guidelines for numerical flow modelling applications)

5.1 一般(General)

科學界、認證組織及國家工程協會製定數值流模型相關之查證與確證、品質保證及評估之指引。本標準處提供與 NSC 最相關之指引概述。

Scientific communities, certification organizations, and national engineering associations have put together guidelines on verification and validation, quality assurance, and evaluation of numerical flow models. An overview of the most relevant guidelines to NSC is provided here

5.2 AIAA (1998)計算流體動力學模擬查證及確證指引(Guide for the Verification and Validation of Computational Fluid Dynamics Simulations)

美國航空航太學會(AIAA)指引[15]提供 CFD 模型性能基準之指引。係關於儘量多執行查證與確證(V&V)試驗，以取得對模型結果之可靠度及可信度，以達到模型之特定預期用途。模型之高度複雜性使其難以確證所有操作條件。因此，確證過程之主要目標係將數值模型之足夠可靠度予以開發及量化，使其能可靠地預測可接受範圍內之相關變量。

The American Institute of Aeronautics and Astronautics (AIAA) guide [15] provides guidelines for benchmarking the performance of CFD models. It is a matter of performing as many verification and validation (V&V) tests as possible to gain confidence and credibility on the model results toward the specific intended use of the model. The high complexity of the models makes it very difficult to validate the full range of operating conditions. Hence, the main objective of the validation process is to develop and quantify enough confidence in the numerical models so that they can be used reliably to predict the variables of interest within acceptable limits.

V&V 流程應考慮以下要素：

The following elements should be considered for the V&V process:

- 模型之一般描述，包含其預期用途或應用。
- general description of the model including its intended uses or applications,
- 模型求解預測方程式之描述。
- description of the prognostic equations that the model solves,
- 假設與近似之描述。
- description of the hypotheses and approximations,
- 模型參數化之描述。

- description of the model parameterizations,
- 大氣尺度與空間/時間解析度。
- atmospheric scales and spatial/temporal resolutions,
- 計算網格之描述。
- description of the computational grid,
- 邊界及初始條件。
- boundary and initial conditions,
- 輸入資料及來源。
- input data and sources,
- 根據預測及診斷(從預測得出)變量輸出資料。
- output data in terms of prognostic and diagnostic (derived from prognostic) variables,
- 參考本模型及其他相似模型之模型評估結果。
- references to published material addressing model evaluation results from this and other similar models.

5.3 計算流體動力學及傳熱之查證及確證標準－ASME V&V 20-2009 (Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer-ASME V&V 20-2009)

美國機械工程師協會(ASME)標準[16]描述計算流體動力學及計算傳熱(CHT)內之V&V方法。本標準中，量測值及模擬值之間的比較誤差 E，參數編寫可藉由使用建模假設造成之誤差 δ_{model}、數值解之誤差 δ_{num}、模擬輸入造成之誤差 δ_{input} 及實驗值誤差 δ_D，如以下公式所示：

The American Society of Mechanical Engineers (ASME) standard [16] describes the method for V&V in computational fluid dynamics and computational heat transfer (CHT). The idea of this document is that the comparison error, E, between the measured and simulated value can be written by using an error due to the modelling assumptions, δ_{model}, an error due to the numerical solutions, δ_{num}, an error due to simulation input parameters, δ_{input}, and the error in the experimental values, δ_D, as shown in the following equation.

$$E = \delta_{model}+\delta_{num}+\delta_{input}-\delta_D \quad (19)$$

假設 δ_{num}、δ_{input} 及 δ_D 為獨立的，此等項(u_{val})引起之不確定度可表示為：

Assuming that δ_{num}, δ_{input} and δ_D are independent, the uncertainty due to these terms (u_{val}) can be written as:

$$u_{val}=\sqrt{u_{num}^2+u_{input}^2+u_D^2} \quad (20)$$

式中，u_{num} 為數值解(如 δ_{num} 之標準差)等所引起之不確定度

where u_{num} is the uncertainty due to numerical solutions (i.e., the standard deviation

of δ_{num}), etc.

本標準之目的係提出方法，以量化建模假設之不確定度，並解釋該值。本標準內容如下列：

The purpose of this document is to propose methods to quantify the uncertainty of the modelling assumptions and interpretation of this value. Thus, the content of the document is as follows:

- 藉由使用代碼查證及解決方案查證，可量化數值解之不確定度。代碼之查證可藉由比較數值解與分析解進行。解決方案的查證可藉由系統之網格細化進行。
- Uncertainty due to numerical solutions can be quantified by using code verification and solution verification. The code verification can be performed by comparing the numerical solution with analytical solutions. The solution verification can be performed by systematic grid refinement.
- 藉由對輸入參數進行系統靈敏度分析，可估算模擬輸入之不確定度。
- Uncertainty due to simulation input can be estimated by using systematic sensitivity analysis of the input parameters.
- 決定實驗值不確定度之基本概念。
- The basic concept to determine the uncertainty in the experimental values
- 針對不同情況下量化建模假設所導致之不確定度的方法進行描述。
- The method to quantify uncertainty due to modelling assumptions is described for different cases.
- 建模假設不確定度之解釋。
- The interpretation of uncertainty due to modelling assumptions
- V&V 示例。
- An example of V&V.

5.4 COST 732 行動〝微型氣象模型之品質保證〞(COST Action 732 "Quality Assurance of Microscale Meteorological Models")

歐洲科學技術合作(COST)732 行動〝微型氣象模型之品質保證〞[17]旨在提高及保證用於預測都市環境氣流之微型氣象模型之品質。此等最佳示例，係基於針對中性層化流場穩定 RANS 方程式之指引。

European Cooperation in Science and Technology (COST) action 732 "Quality Assurance of Microscale Meteorological Models" [17] has been set up to improve and assure the quality of microscale meteorological models that are applied for predicting wind flow in urban environments. These best practices are based on previous guidelines devoted to steady RANS equations for neutrally stratified flow fields.

本標準制定一般指引，以減少物理建模及數值法中之誤差及不確定度。建模之不確定度可能與以下因素有關：

General guidelines are developed to reduce errors and uncertainties in modelling the physics and in numerical approaches. Uncertainties in modelling can be related to:

- 目標變數。
- target variables,
- 描述流動物理之近似方程，諸如擾流模型。
- approximate equations describing the physics of the flow, such as the turbulence models,
- 障礙物之幾何表示法。
- the geometrical representation of the obstacles,
- 計算區域之定義，包含邊界及初始條件。
- the definition of the computational domain including the boundary and initial conditions

數值法之不確定度可能與以下因素有關：

Uncertainties in the numerical approach can be related to:

- 計算網格。
- computational grid,
- 時間步長。
- time step size,
- 數值近似(離散法) 。
- numerical approximations (discretization schemes),
- 迭代收斂準則。
- iterative convergence criteria.

COST 732 行動之指引仍適用於大多數準則，並鼓勵工程師使用最佳實踐以減少錯誤。多數參數在很大程度上取決於應用問題之細節，在一般指引中並未完全精確。例：未提供擾流模型選擇之最佳示例。但對於某些參數，諸如計算區域之選擇，指引中明確建議：區域大小應定義為都市大小模型之函數，尤其是都市冠層之高度。該指引亦針對空間及時間離散化以及收斂準則予以明確建議，以減少數值誤差。

The COST action 732 guideline remains general for most of the criteria and encourages engineers to use best practices to reduce errors. Most parameters depend, to a large extent, on the details of the application problem and cannot always be precise in the general guidelines. For instance, no best practice for the choice of the turbulence models is given. Nevertheless, for some parameters, such as the choice of the computational domain, the guideline gives precise recommendations: domain size should be defined as a function of the urban size model, especially the height of the urban canopy. The guideline also gives clear advice on spatial and time discretization, as well as convergence criteria, to reduce numerical errors.

該指引鼓勵使用文獻中試驗案例之數值靈敏度試驗及模型性能確證。

The guideline encourages the application of numerical sensitivity tests and validation of the model performance on test cases available in the literature.

5.5 日本建築學會指引(Architectural Institute of Japan guidelines)

5.5.1 一般(General)

日本建築學會(AIJ)提出 2 項 CFD 應用指引，其一為 CFD 在建築物周圍行人風環境中之實際應用指引手冊[18]，另一則為建築物載重建議指引手冊 2[19]。此 2 項指引皆包含設置計算條件及基準程序之最佳示例。計算條件如下：

Two guidelines for CFD applications were proposed by the Architectural Institute of Japan (AIJ). One is The guidebook for practical applications of CFD to pedestrian wind environment around buildings [18] and the other is the Guidebook of recommendations for loads on buildings 2 [19]. Both guidelines contain the best practice for setting the computational conditions and benchmark procedure. The computational conditions are as follows:

- 計算區域擴展。
- computational domain extension,
- 網格產生及解析度。
- grid generation and resolution,
- 邊界條件。
- boundary conditions,
- 數值法。
- numerical scheme,
- 擾流模型。
- turbulence model,
- 解法之收斂性。
- convergence of solution.

5.5.2 建築物周圍行人風環境之 CFD 實際應用指引手冊[18](The guidebook for practical applications of CFD to pedestrian wind environment around buildings [18])

使用 CFD 技術對行人風環境進行適當預測之要點，總結於此指引中。重要變數為平均風速比及擾流動能。該指引基於基準試驗之結果，諸如單一建築物及建築物群，以及實際都市區域之建築物及樹冠，其周圍之氣流。AIJ 網站上可取得確證資料庫。

This guideline summarizes important points for using the CFD technique for appropriate prediction of the pedestrian wind environment. The variables of interest are mean wind speed ratio and turbulence kinetic energy. The guideline is based on the results of benchmark tests, such as flow around a single building and blocks of buildings, and buildings in an actual urban area and tree canopy. The validation database is available on the AIJ web site [21]

5.5.3 建築物載重建議指引手冊 2[19](Guidebook of recommendations for loads on buildings 2 [19])

本文件針對預測建築之設計風載重提供實用指引，包括使用 CFD 之地形影響。根據該指引，CFD 可作為風洞試驗之替代法。重要變數為峰值壓力係數及平均風速以及擾流動能。在該指引中，由於擾流邊界層及建築物周圍氣流分離之可重製性(reproducibility)要求，建議以 LES 預測強風事件期間之峰值風載重。本指引規定模型設置、準確度查證與確證以及風載重設計。

This document provides a practical guide for predicting the design wind loads on a building, including the effect of terrain using CFD based on reference [20]. According to this guideline, CFD can be used as an alternative to a wind tunnel test. The variables of interest are peak pressure coefficient as well as mean wind speed and turbulence kinetic energy. In this guideline, LES is a recommended technique to predict peak wind loads during strong wind events due to the reproducibility of the turbulent boundary layer and separation flow around the buildings requirement. This guide shows requirements for model setup, accuracy verification and validation, and wind loads design.

5.6 VDI 3783 第 9 部環境氣象學－預測微型風場模式－建築物及障礙物周圍氣流評估(VDI 3783 Part 9 Environmental meteorology − prognostic microscale wind field mode- evaluation of flow around buildings and obstacles)

德國工程師協會(VDI)指引包含德意志聯邦共和國之科學技術現狀，並在立法及法律法規與條例實施之準備階段提供決策幫助。

Verein Deutscher Ingenieure (VDI, German Engineers Association) guidelines describe the state of the art in science and technology in the Federal Republic of Germany and serve as a decision-making aid in the preparatory stages of legislation and application of legal regulations and ordinances.

VDI 3783 指引第 9 部[22]目的係評估地形上之微型 CFD 風場模型，該模型明確解決近地面 ABL 中障礙物周圍之流場。VDI 指引之評估程序旨在確保模型之高品質。該指引包含關於收斂準則及網格解析度獨立性之建議。亦提供試驗示例(包含分析及實驗參考資料)，以驗證模型的一致性。實驗參考資料來自漢堡大學氣象研究所環境風洞實驗室(EWTL)之 CEDVAL 資料庫[23]。此等資料經過設計，適用於 RANS 模型之評估。由於缺乏詳細之流入條件，其不適用於 LES 模型確證。確證名額及通過準則規定於 VDI 指引中。

The purpose of guideline VDI 3783 Part 9 [22] is to evaluate microscale CFD wind field models over terrain that explicitly resolve the flow field around obstacles in the near-ground ABL. The purpose of the evaluation procedure given in this VDI guideline is to ensure a high-level quality of the models. The guideline contains recommendations on convergence criteria and grid resolution independence. It also provides test cases (including analytic and experimental reference data) to validate model consistency. The experimental reference data originate from the CEDVAL

database by the Environmental Wind Tunnel Laboratory (EWTL), Meteorological Institute of University of Hamburg [23]. These data were designed and are suitable for the evaluation of RANS models. Due to the lack of detailed inflow conditions, they are not applicable for LES model validation. Validation metrics and passing criteria are provided in the VDI guideline.

5.7 國際能源署任務 31 Wakebench-風場氣流模型評估協定(International Energy Agency Task 31 Wakebench − Model Evaluation Protocol for Wind Farm Flow Models)

基於國際能源署(IEA)風力任務〝Wakebench〞之框架[24]，已規定風場氣流模型之模型評估協定(MEP)。該協定解決微型風場氣流模型之 V&V 框架，通常應用於風力資源/試驗場評估及風場設計。

A model evaluation protocol (MEP) for wind farm flow models has been developed in the frame of the International Energy Agency (IEA) Wind Task 31 "Wakebench" [24]. The protocol addresses a V&V framework for wind farm flow models at the microscale level, typically used in wind resource/site assessment and wind farm design applications.

MEP 係作為與氣流模型 V&V 相關活動框架之基礎而開發。MEP 包括以下內容：

The MEP is developed as a basis for a framework for activities related to V&V of wind flow models. The MEP consists of:

- 藉由科學審查進行模型鑒定。
- model qualification by scientific review,
- 程式碼及解法之查證。
- code and solution verification,
- 確證，其中包括：
- validation, which includes:
  - 組合確證法。
  - a building-block validation approach,
  - 確證資料要求及來源。
  - validation data requirements and sources,
  - 重要變數。
  - variables of interest,
  - 模型設置及運作。
  - setting up and running a model,
  - 度量。
  - metrics,
  - 品質允收準則。
  - quality acceptance criteria,
- 模型校正。

・model calibration.

5.8 MEASNET－試驗場特定風況評估(MEASNET − Evaluation of site-specific wind conditions)

風能研究所量測網路(MEASNET)從事風能領域公司組成之合作組織，旨在確保高品質之量測、標準與建議之統一解釋，以及結果之互換性。MEASNET 檔案〝試驗場特定風況評估〞[25]概述 MEASNET 成員間商定之試驗場評估程序。從所需輸入資料到結果報告之主題，於該檔案中描述。NSC 最相關部分為空間外推指引，其需對風場進行數值模擬。MEASNET 提供關於模型確證、模型假設、模型驗證及靈敏度分析之一般建議。MEASNET 亦確認氣流建模之不確定度將取決於地形及試驗場氣象複雜度(量測位置及外插位置之間的垂直及水平距離、地形粗糙度、穩定性條件及採用之模型近似值)。

Measuring Network of Wind Energy Institutes (MEASNET) is a co-operation of companies that are engaged in the field of wind energy and want to ensure high-quality measurements, uniform interpretation of standards and recommendations, and interchangeability of results. The MEASNET document Evaluation of site specific wind conditions [25] outlines the procedure for site assessment agreed upon between the MEASNET members. The document describes topics from required input data to results reporting. The most relevant part for NSC is the spatial extrapolation guidance that requires numerical modelling of the wind field. MEASNET provides general recommendations on model verification, model assumptions, model validation, and sensitivity analysis. MEASNET also recognizes that the uncertainties of flow modelling will both depend on the topography and site meteorological complexity (vertical and horizontal distance between the measured and extrapolated position, terrain roughness, stability conditions, and the used model approximations).

6. 基準確證試驗總結(Summary of benchmarking validation tests)

6.1 一般(General)

第 6 節包含氣流建模確證活動之比較試驗摘要。本標準撰寫過程中，部分項目已完成，部分項目仍在進行中。

Clause 6 provides a summary of comparison tests from wind flow modelling validation campaigns. Some of the projects have been completed and some are ongoing at the time of writing.

6.2 風能數值流動模擬之 EWI 循環法(DEWI Round Robin on Numerical Flow Simulation in Wind Energy)

此盲測於 2004 年開始，2008 年完成[26]。當時之數值模型已廣泛用於風能分析，從量測到風況之某點推算至風場中未知的其他點。循環試驗之目的係系統性評估所考慮之模型水平及垂直方向上外推風況的能力。因此，提供參與者地形資料，並要求進行模擬，將 1 個參考點處之風量測值作為輸入，以計算其他 2 個目標點之風況，此等目標點之風量測值為可用，但參與者不知道。

This blind test was commenced in 2004 and finished in 2008 [26]. Numerical models at that time were already widely used in wind energy analysis to extrapolate the wind conditions from a point where wind conditions are measured to other points of a wind farm where wind conditions are unknown. The aim of the round robin test was to systematically evaluate the capabilities of the considered models of extrapolating wind measurements horizontally and vertically. Therefore, the participants were given topographical data and requested to perform a simulation that takes as input wind measurements at one reference point in order to calculate wind conditions for two other target points for which wind measurements were available but unknown to the participants

有 8 名參與者使用各種數值模型(例：中型模擬、RANS 及 LES)，參與者並無使用相同之模型。將預測結果與此 2 個位置之量測資料進行比較。輸入高度為 43 m，要求之輸出高度為 80 m。

There were eight participants using various numerical models (e.g., mesoscale simulations, RANS, and LES), with no participants using the same model. The predicted results were compared to the measured data at these two locations. Input height was 43 m and outputs were requested at up to 80 m.

扇形區域平均風速誤差絕對值之平均值在 5 %至 18 %之間。然而，各區間之偏差大於此。絕對平均能量輸出誤差在 1 %至 36 %之間。

The average of sector-wise absolute values of mean wind speed error was between 5 % and 18 %. However, the individual sector deviations were larger than this. The absolute mean energy yield error was between 1 % and 36 %.

6.3 Bolund Hill 盲測實驗(Bolund experiment)

Bolund Hill 盲測實驗由丹麥技術大學(DTU)於 2009 年組織，側重於氣流建模[27] [28]。丹麥羅斯基勒附近 1 個小島(高 12 m、長 130 m，寬 75 m)，在地面以上 2 m、5 m 及 9 m 處進行廣泛之風力量測活動。向參與者提供試驗場氣流模擬所需之所有輸入資料，且需提供反映量測點之特定點結果。需注意，該實驗之山坡陡度及粗糙度驟變，此違反線性模型假設。

The Bolund Hill blind test was organized by the Danish Technical University (DTU) in 2009 and focused on flow modelling [27], [28]. A small island (12 m high, 130 m long, and 75 m wide) near Roskilde, Denmark, had an extensive wind measurement campaign at 2 m, 5 m, and 9 m above ground level. Participants were provided with all input data required for a flow simulation of the site and had to provide results at specific points reflecting the measurement points. It should be noted that the steepness of the hill and the abrupt roughness change in that experiment violated the linear model assumptions.

該實驗定義 4 個風向，採用 57 個從數值到物理的模型，包括 LES 模型、RANS 模型及線性模型，以及風洞及水道實驗。所有參與者皆有義務在 600 個位置回傳結果。

Four wind directions were defined and 57 models ranging from numerical to physical were used, including LES models, RANS models, and linear models, in addition to wind tunnel and water channel experiments. All participants were obliged to return their results at 600 positions

在此特定試驗中，具有二式方程式擾流閉合之 RANS 法給出最一致的結果。最佳性能模型顯示所有情況下，加速因數之平均誤差為 10.2 % (試驗案例 1 至 4：分別為 9.6 %、10.6 %、13.8 %及 7.0 %)。對於坡度最適中之風向(試驗案例 4)，發生的誤差最小。項目最終報告中，強調讓經驗豐富的建模人員使用有根據性之數值法係極為重要。

In this particular test, the RANS methods with two-equation turbulence closures gave the most consistent results. The best-performing model showed mean errors for all cases of 10,2 % (test case 1 to 4: 9,6 %, 10,6 %, 13,8 %, and 7,0 %, respectively) on speed-up factor. For the wind direction with the most moderate slope (test case 4), the smallest error occurred. The importance of having experienced modellers using well-founded numerical approaches was underlined in the project's final report

6.4 歐洲風能協會資源與能源產量比較評鑑程序Ⅰ及Ⅱ(2011，2013)(European Wind Energy Association Comparative Resource and Energy Yield Assessment Procedures I and II (2011, 2013))

資源及能源產出比較評鑑程序(CREYAP)第 1 部[29]試驗由 DTU 進行，在 2011 年歐洲風能協會(EWEA)風能資源評鑑技術研討會上發表該結果，來自 16 個國家的 36 個組織總共提交 37 套結果。該試驗係在 1 個 28 MW 風場進行(14 台風力機)，有 1 個氣象桿。其中包括風場案例研究，包括：

The Comparative Resource and Energy Yield Assessment Procedures (CREYAP) Part 1 [29] test was conducted by DTU and results were presented at the European Wind Energy Association (EWEA) Wind Resource Assessment Technology Workshop 2011, with 37 sets of results submitted by 36 organizations from 16 countries. The test was carried out on a 28MW wind farm (14 wind turbine generators) with 1 meteorological (met) mast. It included a wind farm case study comprising:

- 風場及風力機資料。
- wind farm and turbine data,
- 風氣候輸入。
- wind climatological inputs,
- 地形輸入。
- topographical inputs.

比較模型結果：

A comparison of model results was done on:

- 50m 及 60m 處之長期修正風速。
- long-term corrected wind speeds at 50 m and 60 m,

- 垂直外推(風切) 。
- vertical extrapolation (wind shear),
- 交叉能源產量。
- cross energy yield,
- 潛在能源產量。
- potential energy yield,
- 淨能源產量 P50 及 P90。
- net energy yield P50 and P90.

報告之風切結果在 0.015 至 0.237 範圍內(標準差 0.037−變異係數 22 %)，風電場之總發電量在 113 GWh 至 127 GWh 範圍內(標準差 3.5 GWh－37 組變異係數 3.5 %。

The reported wind shear results were in the range of 0,015 to 0,237 (standard deviation 0,037 − variation coefficient 22 %) and the gross energy yield of the wind farm was in the range of 113 GWh to 127 GWh (standard deviation 3,5 GWh − variation coefficient 3 5 %) amongst the 37 sets.

CREYAP 第 2 部[30]試驗由 DTU 進行，於 2013 年在 EWEA 研討會上發表該結果。來自 17 個國家 60 個團隊，包括諮詢公司、風場開發商及學術界。該試驗在 1 個 28.6 MW 之風場進行(22 台風力機)，該風場有 7 個氣象桿。

The CREYAP Part II [30] test was conducted by DTU and results were presented in 2013 at the EWEA workshop. There were 60 teams from 17 countries including consulting firms, wind park developers, and academia. The test was carried out on a 28,6 MW wind farm (22 wind turbine generators) with 7 met masts.

循環試驗強調年發電量預測過程中數值結果之傳播性。將年發電量估算過程之各個步驟進行比較，包括：

The round robin test highlighted the spread of the numerical results during the prediction process of annual energy production. Comparisons were made at each step of the annual energy production estimation process including

- 長期修正。
- long-term correction,
- 垂直外推(風切) 。
- vertical extrapolation (wind shear),
- 流動及尾流模型。
- flow and wake models,
- 技術損失估算。
- technical loss estimates,
- 不確定度量化。
- uncertainty quantifications.

報告之風切結果在 0.105 至 0.179 範圍內(標準差 0.013−變異係數 10 %)，60 組風場之總發電量在 79.3 GWh 至 106 GWh 範圍內(標準差 5.7 GWh−變異係數 5.8 %)。

The reported wind shear results were in the range of 0,105 to 0,179 (standard deviation 0,013 − variation coefficient 10 %) and the gross energy yield of the wind farm was in the range of 79,3 GWh to 106 GWh (standard deviation 5,7 GWh − variation coefficient 5,8 %) amongst the 60 sets.

6.5 國際能源署第 31 次工作小組尾流實驗(IEA Task 31 Wakebench experiments)

Wakebench[31]試驗案例之選擇，係根據 ABL 及風力機尾流、風洞及試驗場研究實驗以及風電產業之操作量測活動的相似性理論。案例包括標準基準(例：無限風場)、陸地及海上(例：Alaiz，Lillgrund)、平坦到極複雜之地形(例：Sexbierum，San Gregorio)以及平衡到層化 ABL (例：萊比錫之 Askervene)。其結果可線上查閱資料[31]。

Wakebench [31] test cases are selected based on similarity theory for the ABL and wind turbine wake flows, wind tunnel and field research experiments, and operational measurement campaigns from the wind industry. The cases include canonical benchmarks (e.g., the infinite wind farm), both on land and offshore (e.g., Alaiz, Lillgrund), flat to very complex terrain (e.g., Sexbierum, San Gregorio), and neutral to stratified ABL (e.g., Askervein, Leipzig). Results can be found online in reference [31].

6.6 新歐洲風圖實驗[32] (New European Wind Atlas experiments [32])

6.6.1 佩爾迪岡 Perdigão (雙脊)(Perdigão (double ridge))

新歐洲風圖集(NEWA)的 1 項實驗係在葡萄牙 Perdigão 附近圍繞 2 個平行之陡峭山脊進行。2016 年秋季開始實驗，2017 年春季開始主要活動。使用 50 多個高度從 10 m 至 100 m 不等之氣象桿及 19 台掃描 LIDAR 儀器量測該區域之氣流。使用音波風速計、都卜勒 LIDAR、剖面濕度 LIDAR、雷達都卜勒剖面儀、無線電探空儀、壓力感測器及繫留氣球等多種儀器。

One of the New European Wind Atlas (NEWA) experiments is taking place in Portugal near Perdigão around two steep, parallel ridges. The experiment started in the fall of 2016 and the main campaign began in the spring of 2017. More than 50 met masts with heights ranging from 10 m to 100 m and 19 scanning light detection and ranging (LIDAR) instruments were used to measure the flow in this area. A variety of instruments including sonic anemometers, Doppler LIDARs, a profiling humidity LIDAR, a radar Doppler profiler, radiosondes, pressure sensors, and tethered balloons were used.

6.6.2 阿利茲 Alaiz (具強烈中尺度分量之複雜地形)(Alaiz (complex terrain with a strong mesoscale component))

計劃於 2018 年 7 月開始 1 項開放式實驗 ALEX 17。該實驗包括 5 台遠程風掃描儀、6 台 80 m 高之氣象桿、1 台 LIDAR、1 台 SODAR 裝置，以及西班牙納

瓦拉的 10 個氣象站。目的係描述 Alaiz 山脈及上游山脊之間綿延約 6 km 的山谷內之氣流特徵，此會影響試驗場及下游風場之風況。

An open-access experiment, ALEX17, was planned to commence in July 2018. This experiment consists of five long-range wind scanners, six 80 m met masts, one LIDAR, one sound detection and ranging (SODAR) device, and ten meteorological stations in Navarra, Spain. The objective is to characterize the flow in the valley stretching around 6 km between the Alaiz mountain range and an upstream ridge, which influences the wind conditions at the test site and operational wind farms downstream.

6.6.3 提斯特德 Østerild (流經非均勻粗糙度上)(Østerild (flow over heterogeneous roughness))

本實驗研究在幾乎完全平坦之地形上，不同表面粗糙度(田野及森林交替)如何影響輪轂高度處之風力資源。目前在丹麥於斯特裏德實驗現場進行量測，有 2 個安裝於氣象桿上之水平掃描都卜勒 LIDAR，其雷達範圍為 5 km。

This experiment studies how varying surface roughness (alternating fields and forests) affects the wind resources at hub height over an otherwise almost completely flat terrain. Two mast-mounted horizontally scanning Doppler LIDARs with a range of 5 km are currently measuring at the experiment site in Østerild, Denmark.

6.6.4 卡塞爾 Kassel (流經森林山丘)(Kassel (flow over forested hill))

自 2016 年 8 月起，在德國卡塞爾附近 1 座森林山丘上，12 架遠程掃描都卜勒光達對風進行量測。結合 200 m 及 140 m 之氣象桿，繪製出風力資源被低估之地形類型中的氣流圖。

Twelve long-range scanning Doppler LIDARs measured winds over a forested hill near Kassel, Germany, starting in August 2016. In conjunction with a 200 m and 140 m met mast, they mapped the flow in a terrain type where underestimation of wind resources is not uncommon.

所有 NEWA 實驗之初步結果可至該計劃網站[33]進行查詢。

References to preliminary results from all NEWA experiments can be found on the project website [33].

6.7 風力預測改善計劃 2 [34](Wind Forecast Improvement Project 2 [34])

風力預測改善計劃 2 (WFIP2)之主要目標係改善複雜地形中風速模型之預測。為支持 WFIP2 的目標，參與者在華盛頓州東部及俄勒岡州哥倫比亞盆地進行實地考察，以評估大範圍空間尺度內之物理過程如何改變轉子直徑上之風速。WFIP2 之總體設計側重於 1 組天氣現象，對於哥倫比亞峽谷複雜地形之風力及風力預測，此等天氣現象係極具挑戰性。WFIP2 已部署 1 套大型、多樣化之氣象觀測儀器，包括風剖面雷達、SODAR、剖面及掃描 LIDAR、微波輻射計、微氣壓計、音波風速計及表面能量平衡系統。WFIP2 代表行業、學術界及聯邦實驗室之合作關係。

The Wind Forecast Improvement Project 2 (WFIP2) has as primary goal to improve model forecasts of wind speeds in complex terrain. In support of WFIP2's goals, participants have conducted a field campaign in the eastern Washington and Oregon Columbia Basin to assess how physical processes over a broad range of spatial scales alter wind speeds across the rotor diameter. The overall design for WFIP2 focuses on a set of weather phenomena that poses particular challenges for wind and wind power forecasting in the complex terrain of the Columbia Gorge. A large, diverse suite of meteorological observing instrumentation has been deployed for WFIP2, including wind profiling radars, SODARs, profiling and scanning LIDARs, microwave radiometers, microbarographs, sonic anemometers, and surface energy balance systems. WFIP2 represents a partnership of industry, academia, and federal laboratories.

6.8 風洞試驗確證資料(Wind tunnel test validation data)

6.8.1 驗證微尺度擴散模型之實驗資料彙編用於確證微尺度色散模型的實驗資料彙編[23](Compilation of Experimental Data for Validation of Microscale Dispersion Models [23])

用於確證微尺度擴散模型之實驗資料彙編(CEDVAL)，包括可用於確證數值流模型之風洞資料組。CEDVAL 內之所有資料組皆遵循高品質標準，包括邊界條件之完整記錄及量測期間之品質保證。此等資料用於 5.6 之指引所述的 V&V 公式。

Compilation of Experimental Data for Validation of Microscale Dispersion Models (CEDVAL) includes wind tunnel data sets that can be used for validation of numerical flow models. All data sets within CEDVAL follow a high-quality standard in terms of complete documentation of boundary conditions and quality assurance during measurements. These data are used for V&V procedures in the guideline described in 5.6.

6.8.2 日本建築學會風洞(AIJ wind tunnel)

藉由各種 k-ε 模型及 LES[35]，可取得風洞實驗、試驗場量測及 CFD 結果之交叉比較，包括表面邊界層內單一高層建築周圍之氣流、實際都市地區建築群內的氣流以及樹木周圍之氣流。此等資料用於 5.5 之指引。

Cross comparisons of wind tunnel experiments, field measurements, and CFD results of flow around a single high-rise building placed within the surface boundary layer, flow within a building complex in an actual urban area, and flow around a tree, are obtained from various k-ε models and LES [35]. These data are used for the guidelines in 5.5

6.8.3 流經山丘之風洞試驗(Wind tunnel test for flow over hill)

在比值為 1/1,000 的邊界層風洞中，評鑑 1 個簡單的二維山脊及三維山丘上之氣流。已試驗 2 個不同之表面粗糙度值：z_0=0.3 mm 之粗糙表面及 z_0=0.01 mm 光滑表面。記錄地形上各點之平均流入量及波動分量[36]。藉由使用該風洞試驗

資料對 RANS、URANS、LES、DES 及修正之 DDES 模型進行確證[14]。對於粗糙表面，結果表明在山的背風側，所有模型皆與量測結果有良好一致性。對於光滑表面，RANS 及 URANS 高估加速因數。在 LES、DES 及修正 DDES 之中，後者在背風側表現最好。

Wind flow over a simple two-dimensional ridge and three-dimensional hill was assessed in a boundary layer wind tunnel with the scale of 1/1 000. Two different surface roughness values were tested: a coarse roughness with z_0=0,3 mm and a smooth one with z_0=0,01 mm. The mean and fluctuating components of inflow at the points over the terrain were recorded [36]. Validation of RANS, URANS, LES, DES and modified DDES models was performed by using this wind tunnel test data [14]. For the rough surface case, it was shown that on the lee side of the hill, all the models exhibited good agreement with the measurements. For the smooth surface case, RANS and URANS overestimated the speed-up factors; among LES, DES and modified DDES, the latter shows the best performance at the lee side.

7. 為風能應用執行地形氣流模擬之重要技術層面(Important technical aspects for performing flow simulations over terrain for wind energy applications)

7.1 一般(General)

第 7 節描述設定、運作及提取地形上氣流模擬資料之重要技術層面。在 NSC 時，依據 IEC 61400-12-1[1]建議設定量測桿之位置極為重要。

Clause 7 describes the important technical aspects for setting up, running, and extracting data from flow simulations over terrain. In the context of NSC, it is important to set the measurement mast position according to IEC 61400-12-1 [1] recommendations.

7.2 地形輸入資料之品質(Quality of topographical input data)

使用高品質之地形(地形及粗糙度)資料來建立數值模型，此為模型計算出最準確風況並獲得高模型效能之關鍵因素。強烈建議在重要地標周圍應使用水平解析度為 10 m 或以上之地形資料。距離較長時，可接受較粗糙之相對高度資訊解析度(惟水平解析度不可超過 30 m)。

Using high-quality topographical (orography and roughness) data to set up a numerical model is a key element in allowing the model to calculate the most accurate wind conditions and gaining high model performance. Using orography data with a horizontal resolution of 10 m or finer around the points of interest is strongly recommended. At longer distances, coarser resolution of elevation information will be sufficient (but no more than a 30 m horizontal resolution).

此外，宜建立並確證詳細之粗糙度圖，尤其是表面高粗糙度之靈敏區域(例：森林區域)。

Moreover, a detailed roughness map should be created and validated, particularly in the sensitive areas with high roughness surface values (e.g., forested areas)

7.3 計算區域(Computational domain)

在水平及垂直方向上計算區域之擴展，應確保重要區域之流場未受影響。因此，建議對各特定點之區域擴展大小進行靈敏度研究。為提高模擬收斂性，推薦最佳做法係在地形周邊使用平滑之緩衝區。

Extensions of the domain in the horizontal and vertical direction should ensure that the flow field in the area of interest is not affected. Therefore, it is recommended to perform a sensitivity study for domain extension size for each particular site. Using a smooth buffer zone at the terrain perimeter is a recommended best practice to improve simulation convergence.

7.4 計算區域之邊界條件(Boundary conditions for computational domain)

應檢查表面邊界條件，以正確表示地形粗糙度。可藉由試驗場圖像或訪問試驗場進行該檢查。應規定所有其他邊界條件，避免顯著影響重要區域內之流場。

Surface boundary conditions should be checked to correctly represent the roughness of the terrain. This check can take place by site images or visiting the site. All other boundary conditions should be prescribed so that the flow field in the area of interest is not significantly affected.

7.5 網格參數(Mesh parameters)

應對水平及垂直網格解析度、第一單元尺寸及垂直展寬比進行靈敏度研究，以確認網格變化不會顯著影響重要區域之流場。

A sensitivity study on horizontal and vertical mesh resolution, first cell size, and vertical expansion ratio should be performed to make sure that the flow field in the area of interest is not significantly affected by changing the mesh.

7.6 收斂判別準則(Convergence criteria)

收斂判別準則應確保重要區域之流場不受影響。

Convergence criteria should ensure that the flow field in the area of interest is not affected.

7.7 大氣穩定度(Atmospheric stability)

大氣層穩定度經常被忽視，因在強風事件中假設為平衡條件，但對於 NSC，較低之風速條件極為重要，故應考慮穩定度。研究界仍在開發 ABL 穩定度之適當建模，並且存在多種方法。1 種方法係藉由修改 RANS 擾流閉合，來考慮不同穩定度條件下擾流通量之變化[6]。另 1 種已知方法係藉由在雷諾茲平均－斯托克斯方程式中加入浮力項，並求解能量方程式(Boussinesq 近似) [37]。

Atmospheric stability is often ignored because of the assumption of neutral conditions during strong wind events, but for NSC lower wind speed conditions are important hence stability should be considered. Proper modelling of stability of the ABL is still under development in the research community and several approaches exist. One approach is through modification of the RANS turbulence closure to account for changes in turbulence fluxes in different stability conditions [6]. Another known approach is through adding a buoyancy term to the Navier-Stokes equations and solving an energy equation (Boussinesq approximation) [37]

7.8 柯氏效應(Coriolis effects)

隨現代風力機輪轂高度遠超過 100 m，可觀察到柯氏效應導致轉子高度上之風向變化(埃克曼螺線)，尤其在穩定之大氣條件下。建議將柯氏效應加入模型中。

With modern turbines reaching hub heights well above 100 m, Coriolis force effects can be observed to cause wind direction changes (Ekman spiral) over the rotor height, especially during stable atmospheric conditions. It is recommended that Coriolis force effects be included in the model.

7.9 障礙物效應(Obstacles effects)

在本標準中，阻擋風並造成氣流扭曲之干擾即為障礙物。可藉由網格劃分及對障礙物表面施加適當之邊界條件，來解決障礙物周圍之氣流。另 1 種模擬障礙物周圍氣流的方法係藉由障礙物效應之參數化。在後者，冠層模型已廣泛用於表示障礙物對氣流之影響。充分確證後，冠層模型可用於模擬森林效應[7][38][39][40]。

In this document, obstacles are considered obstructions that block the wind and create distortion of the flow. Flow around obstacles can be resolved through meshing and imposing proper boundary conditions to the obstacle surface. Another way of modelling the flow around obstacles is through parametrization of obstacle effects. In the latter approach, canopy models are widely used for representing the effect of obstacles on the flow. With sufficient validation, canopy models can be used to model forest effects [7], [38], [39], and [40].

7.10 NSC 相關模型範圍適用性之建議(Suggestion on model range applicability for NSC)

基本上，當地形坡度超過 10 %時，線性模型比非線性模型具更多限制。若此種情況下使用線性模型，可能為 NSC 結果帶來附加不確定度[41]。

By nature, linear models have more limitations than nonlinear models when terrain slopes above 10% are present. The use of linear models in such conditions may introduce additional uncertainty in the NSC results [41].

預測地形坡度高於 10 %之加速因數時，RANS 模型比線性模型具較高之潛力。但風洞確證表明，RANS 模型亦可能錯誤計算山丘及障礙物下游之氣流。在此種情況下使用 RANS 模型，可能會給 NSC 結果帶來附加不確定度[42]。

RANS models have higher potential than linear models for predicting speed-up factors on terrain slopes higher than 10%. However, wind tunnel validations show that RANS models could also miscalculate wind flow downstream of hills and obstacles. The use of RANS models in such conditions may introduce additional uncertainty in the NSC results [42].

針對解析複雜地形之流場，LES 及混合 RANS/LES 模型具極大潛力。相較於 RANS，此等模型對輸入參數(例：基準試驗所指出之網格解析度[43])表現出更高靈敏度。

LES and hybrid RANS/LES models have the highest potential in terms of resolving the flow field over complex terrain. Compared to RANS, these models exhibit significantly higher sensitivity to input parameters (e.g., grid resolution, as pointed

out by a benchmarking test [43])

較高的模型傳真度需較高之專業知識及計算能力。

Higher model fidelity requires higher expertise and higher computational power

在以穩定條件為主之試驗場上進行 NSC，需氣流模型以考量 ABL 層化[37]。

NSC on sites with predominantly stable conditions would require the flow model to consider the stratification of the ABL [37].

8. 已知問題(Open issues)

8.1 一般(General)

如 IEC 61400-12-1 所述，建議試驗場校正使用 2 個裝有儀表之氣象桿：永久氣象桿及位於風力機位置之臨時氣象桿。試驗場校正完成後，指定風速轉移函數及相關不確定度，拆除臨時氣象桿，安裝風力機，開始進行功率性能確證量測。

The site calibration, as described by IEC 61400-12-1, suggests the use of two instrumented met masts: the permanent met mast and the temporary met mast at the turbine position. Upon completion of the site calibration, the wind speed transfer function and the associated uncertainty is specified, the temporary met mast is removed, and the turbine is installed to commence the power performance validation measurements.

在複雜地形之性能確證過程中，NSC 預期避免使用臨時氣象桿以產生風速轉移函數。永久氣象桿與數值模擬結果的結合將產生風力機位置之風速。第 8 節中，包含使用現有數值流建模法之潛在缺點，及其在 NSC 之應用。建議進行基準確證，以支持在未來應用時可突破現有差距。

During performance validation in complex terrain, the NSC is envisaged to avoid using a temporary met mast to produce the wind speed transfer function. The combination of the permanent met mast with the numerical simulation results will produce the wind speed at the turbine location. In Clause 8, the potential drawbacks of using the existing methodologies for numerical flow modelling and their application for NSC are presented. A benchmarking validation campaign is suggested to support breaching the existing gaps prior to future applications.

8.2 根據功率曲線測試之數值模擬結果確定氣流修正因數(Determination of flow correction factors from numerical simulation results for power curve testing)

8.2.1 一般(General)

試驗場校正(SC)程序依據 IEC 61400-12-1。本標準描述如何計算 SC 結果，以及何時將結果視為對功率性能測試有效。建議 NSC 考慮 IEC 61400-12-1 規定之資料品質檢查。

The site calibration (SC) procedure is a normative part of IEC 61400-12-1. This document describes how to calculate the SC results and also when the results are considered as valid for power performance testing purposes. It is suggested that NSC considers the data quality checks specified in IEC 61400-12-1

SC 試驗之關鍵結果係量測扇形區域內所有風向之氣流修正因數(FCF)表。對於

各 10°風向區間，將以風力機位置風速作為因變量，基準風速作為自變量進行普通最小二乘線性回歸。若風切影響較大，則採用風向及風切區間法。該試驗可提供部分資訊，以證明對允許的量測扇形區域進行之更改具合理性。依據 IEC 61400-12-1:2017 之附錄 C 引入品質檢查程序，此等程序可能會觸發排除風向扇形區域、量測資料或增加不確定度。主要品質檢查如下所述。

A key result of an SC test is a table of flow correction factors (FCFs) for all wind directions in the measurement sector. For each 10° wind direction bin, an ordinary least squares linear regression will be made with the turbine location wind speed as the dependent variable and the reference wind speed as the independent variable. If wind shear has a significant influence, the method of bins of wind direction and wind shear will be applied. The test may provide information that justifies a change to the allowable measurement sector. IEC 61400-12-1 :2017, Annex C, introduces quality check procedures that can trigger exclusion of wind sectors, measurement data, or an increase of uncertainty. The main quality checks are described below.

8.2.2 線性回歸相關檢查(Correlation check for linear regression)

對於各風向區間，應根據回歸之相關係數(通常稱為 *r* 值)評估相關水平。藉由 IEC 61400-12-1 之 k 折分析，根據品質檢查結果調整不確定度值。

For each wind direction bin, the level of correlation should be assessed based on the correlation coefficient of the regression, commonly known as the *r* value. Through the k-fold analysis, IEC 61400-12-1, the uncertainty values are adapted according to the quality check results.

8.2.3 相鄰風向區間內之修正變化(Change in correction between adjacent wind direction bins)

當相鄰區間之間的氣流修正變化超過 2 %時，建議從量測扇形區域中將風向區間剔除。

It is recommended to eliminate wind direction bins from the measurement sectors when flow corrections change by more than 2% between neighboring bins】

8.2.4 不同季節之試驗場校正及功率性能量測(Site calibration and power performance measurements in different seasons)

由於植被、降水(雪及冰)及水體凍結，風況之季節性變化及地表粗糙度變化，其可能導致對試驗場校正流量修正之季節相依性。因此，建議在一年中的同一季節(例：夏季)進行試驗場校正及功率性能量測。

Seasonal changes in wind conditions and changes in surface roughness due to vegetation, precipitation (snow and ice), and freezing of bodies of water may cause a seasonal dependency on the site calibration flow corrections. Therefore, it is recommended to conduct the site calibration and power performance measurements during the same season of the year (e.g., both occurring in summer).

將進一步研究用於定義 NSC 有效扇形區域(用於功率曲線確證)之類似程序。根據 8.4 之 NSC 基準確證案例的結果，可制定 NSC 之詳細程序。不確定度量化之

相關程序於 8.3 討論。

Similar procedures for defining the valid sectors to be used for NSC (for the purpose of power curve validation) will be investigated further. Based on the results of the NSC benchmarking validation case proposed in 8.4, detailed procedures for NSC could be established. Procedures related to uncertainty quantification are discussed in 8.3.

8.3 不確定度量化(Uncertainty quantification)

試驗場校正之不確定度量化定義於 IEC 61400-12-1:2017 之 C.6。為計算 NSC 之不確定度量化，應開發另 1 種方法來確定與各有效扇形區域的氣流修正因數相關之不確定度值。此種新方法量測所引起之不確定度，以及下列其他不確定度來源皆應考慮：

Uncertainty quantification for site calibration is defined in IEC 61400-12-1:2017, Clause C.6. For calculating uncertainty quantification for NSC, another approach should be developed to determine an uncertainty number associated with the flow correction factor for each valid sector. This new approach should consider the uncertainties due to measurements along with the following other sources of uncertainties:

- 與初始與邊界條件、環境條件、強制函數及所用數值模型之本構方程式相關之參數。
- parameters associated with initial and boundary conditions, environmental conditions, forcing functions, and constitutive equations of the numerical model used,
- 缺乏線性或非線性方程式求解法收斂性，以及缺乏網格收斂性。
- lack of linear or nonlinear equation solver convergence and the lack of grid convergence.

參數及網格收斂不確定度所致之模型不確定度估算法，參照參考資料[15] [44] [45]。

The methodology to estimate model uncertainty due to parameter and grid convergence uncertainty is provided in references [15], [44], and [45]

8.4 國家安全委員會程序確證活動之提案 Proposal for validation campaign for nsc procedures

8.4.1 一般(General)

8.4 旨在解決與 NSC 程序確證相關之缺失量測活動。使用 NSC 代替量測值之做法尚未得到查證及確證。因此，建議進行確證試驗，將 NSC 結果與使用 IEC 61400-12-1 所定義之 2 個氣象桿之試驗場校正結果進行比較。

The intention of 8.4 is to address missing measurement campaigns related to NSC procedure validation. The use of the NSC as a replacement of measurements has not been validated and verified against measurements. Therefore, a validation test is suggested, wherein the NSC results are compared against the results of a site calibration using two met masts as defined in IEC 61400-12-1.

此類試驗之擬定試驗場及實驗佈局如下所述。

The proposed site and experimental layout for such a test is described below.

8.4.2 試驗場之地形評鑑(Assessment of terrain at the test site)

應執行之試驗場校正之準則(根據地形坡度及平面的最大地形變化，作為風力機及風量測設備之間距離的函數)描述於 IEC 61400-12-1:2017 之表 B.1。不同複雜度之試驗場超過 IEC 61400-12-1:2017 之表 B.1 準則，則應進行調查。

IEC 61400-12-1:2017, Table B.1, describes the criteria (in terms of terrain slope and maximum terrain variation from the plane as a function of the distance between the turbine and the wind measurement equipment), when a site calibration shall be performed. Sites with different degrees of complexity exceeding the criteria in IEC 61400-12-1:2017, Table B.1, should be investigated.

8.4.3 實驗佈局(Experimental layout)

現有之實驗試驗場校正資料可用於確證 NSC 程式，惟建議使用更詳細之實驗設定來確證所有數值模型，並宜包括以下內容：

Existing experimental site calibration data could be used to validate the NSC procedures but a more detailed experimental setup is recommended to validate all numerical model aspects and should include the following:

- 複雜地形內之 2 個氣象桿之距離，宜相當於現代風力機之 2.5*D* (例：若 *D*= 轉子直徑，假設距離為 130 m，則 2.5*D* = 325 m)。
- Two met masts in complex terrain should be at a distance that corresponds to 2,5*D* of a modern turbine (e.g., if *D* = rotor diameter, assumed 130 m then 2,5*D* = 325 m).
- 頂部風速計的高度宜等於風力機之預期輪轂高度(例：100 m 輪轂高度)。
- The height of the top anemometer should be equal to the expected hub height of the turbines (e.g., 100 m hub height).
- 量測設備安裝宜符合 IEC 61400-12-1 建議之標準。
- The installation of the measurement equipment should fulfill the criteria of the IEC 61400-12-1 recommendations.
- 氣象桿宜排列於主要風向上。
- The met masts alignment should be in the prevailing wind direction
- 宜在同一時間段內進行所有量測。
- All measurements should be taken in the same time period.
- 各氣象桿之儀表宜至少包括以下內容：
- Instrumentation for each met mast should include at least the following:
  - 根據 IEC 61400-12-1，頂部風速計及基準風速計之品牌及安裝類型宜相同。
  - The top and reference anemometers should be the same make and type installed according to IEC 61400-12-1.

- 宜依據 IEC 61400-12-1 安裝風向標。
- Wind vanes should be installed according to IEC 61400-12-1.
- 宜在另外 2 處(相同品牌及類型)安裝風速計，即較低之葉尖高度，及下葉末端與輪轂高度之中間位置，以估算風切。
- Anemometers at two additional locations (same make and type) − lower tip height and the middle between lower tip and hub height- should be installed to estimate wind shear
- 音波風速計應安裝於距輪轂高度 5 m 至 10 m 之間，並安裝於較低之葉尖高度，以評估三維氣流效應及大氣穩定性。
- Sonic anemometers should be mounted between 5 m and 10 m from the hub height and at a lower tip height to evaluate the three-dimensional flow effects and atmospheric stability.
- 另 1 個三維音波風速計宜放置在離地面 3 m 處，以取得 10 Hz 以上之熱通量。
- Another three-dimensional sonic anemometer should be placed 3 m above the ground, to obtain heat fluxes with a rate of at least 10 Hz.
- 宜將溫差感測器放置於基準風速計高度以及較低之葉尖高度處，以查證大氣穩定性。
- Differential temperature sensors should be placed at reference anemometer height and lower tip height to be able to verify atmospheric stability
- 宜將濕度感測器放置於距離地面 3 m 處。
- A humidity sensor should be placed 3 m above the ground
- 量測試驗持續時間宜與 IEC 61400-12-1 所要求之時間一致，以收集最少資料量。但建議試驗持續時間允許蒐集明顯更多之資料量，以便進行更詳細之評估(例：晝夜、季節變化、穩定性變化)，此為 IEC 61400-12-1 時間要求的 2 倍。
- The test duration of the measurement should be aligned with the time required by IEC 61400-12-1 to collect a minimum amount of data; however, it is suggested that the test duration allows the collection of significantly higher data amounts to allow for more detailed evaluations (e.g., day-night, seasonal variations, stability variations), which is twice the time requirements in the IEC 61400-12-1.
- 宜使用與 IEC 61400-12-1 性能量測相同之條件，將資料進行過濾。
- Data filtering should be applied using the same conditions as IEC 61400-12-1 performance measurements.
- 建議使用最小連續 60°之量測扇形區域。
- A minimum continuous 60° measurement sector is recommended
- 建議使用降水感測器，以便能過濾並單獨分析降水期之資料。
- A precipitation sensor is recommended to be able to filter out and separately

analyze data in precipitation periods

－ 宜蒐集 IEC 61400-12-1 所建議之最小頻率的時間序列資料，並將其儲存於原始取樣頻率中。

- Time series data with a minimum frequency as recommended in IEC 61400-12-1 should be collected and stored in the original sampling frequency.

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2010

相對應國際標準

IEC TR 61400-12-4:2020 Wind energy generation systems − Part 12-4: Numerical site calibration for power performance testing of wind turbines

CNS 草-制 1121056「風力機－第 12-4 部：風力機功率性能試驗之數值試驗場校準」標準草案審查意見彙編

審查委員單位	節　次	審　　查　　意　　見
右列委員及單位均無意見	財團法人船舶暨海洋產業研發中心	
楊委員條和	3.3	”滴劑常數”建議改為”DDES 常數”
李委員仁傑	4.1	建議修正為: 此等模型是以線性化文獻 2 內之原始 Navier-Stokes 方程式作為基礎。
楊委員條和	5.3	標題應改為”計算流體動力學及傳熱之查證及確證標準”

意見彙編截止日：112 年 09 月 30 日

職場多元
性別平等

~友善開放的世界　從改變職場開始~

—擁抱他人不同　打造多元性別友善社會—

尊重性別隱私、多元共融

互相尊重性傾向或性別認同，不該強迫揭露他人性別隱私、強行替他人出櫃；雇主也不能強迫員工表達性傾向，作為為勞務存續交換條件。

司法院釋字第748號解釋施行法

年滿18歲之同性2人可至戶政事務所登記結婚。

勞工請假規則

1.婚假：登記結婚者，可請婚假8日。

2.喪假：配偶、配偶之父母、養父母或繼父母、祖父母喪亡，雇主都應分別給予喪假。

性別工作平等法

1.陪產假：配偶分娩者，可請陪產假7日。

2.育嬰留職停薪：任職滿6個月以上，其每一子女滿3歲前得申請。