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On turbulence criteria and model requirements for numerical simulation of turbulent flows above offshore helidecks

Fredrik Mentzoni, Ivar S. Ertesvåg*

Department of Energy and Process Engineering, Norwegian University of Science and Technology, Kolbjørn Hejes vei 1b, NO-7491 Trondheim, Norway

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ABSTRACT

Turbulence criteria for CFD of helideck flows in the Norwegian Norsok standard are reviewed and discussed. It is argued that the turbulence energy has benefits compared to the standard deviation of the vertical velocity component when used in criteria for turbulence in CFD. Revised expressions for the criteria are proposed, based on the turbulence energy. On the background of Norsok Standard C-004, requirements for turbulence modeling for helideck flow simulations are discussed. It is demonstrated that a requirement alone for using a Reynolds stress equation model, with no other specific requirements to the modeling, will not ensure improved CFD results compared to two-equation eddy-viscosity models. In addition, some issues of the turbulence terminology in Norsok Standard C-004 are discussed.

1. Introduction

Helicopter is the preferred means of transportation of personnel to and from offshore oil and gas installations. To ensure safety, industry and authorities have implemented regulations and standards for, among other things, which weather conditions that can allow helicopter operations.

For the Norwegian offshore sector, the set of requirements for design, arrangement and engineering of helidecks is found in Norsok Standard C-004 (Standards Norway, 2013). In the UK sector, regulations are issued by the UK Civil Aviation Authority, CAA.

The newest issue of the Norsok standard includes a requirement for use of computational fluid dynamics (CFD) simulations of the wind and turbulence, and criteria for the turbulence allowing helicopter operations. The aim of the present work was to evaluate the new requirements on the basis of turbulence model performance. Helideck simulations are presented in a separate paper (Mentzoni et al., 2015), together with comparisons with experiments for some separated turbulent flows for validation, and also a review of other studies. This forms the basis of the present paper, where the formulations of the turbulence criteria and turbulence model requirements for helideck CFD analyses will be discussed. Although the focus was on the Norwegian Norsok standard, the discussion will be relevant for the regulations and standards for the UK and other countries with an offshore industry as well.

The scope of this study did not include the need for a criterion or the level of the acceptable turbulence, but is limited to the formulation and interpretation with respect to CFD analyses and turbulence modeling.

In the following, the requirements of the standard and their background are presented. Then turbulence modeling will be reviewed, together with own results and other results from literature, relevant for offshore helideck flow simulations. This forms the basis for the discussion of the requirements and formulations of the standard. Subsequently, an alternative expression of the

Abbreviation: ASM, Algebraic Reynolds stress model; CAA, (UK) Civil Aviation Authority; CAP, Civil Aviation Publication (UK); CFD, Computational fluid dynamics; DNS, Direct numerical simulation; EVM, Eddy-viscosity model; HQR, Handling quality rating; LES, Large-eddy simulation; LRN, Low-Reynolds-number (model); PDE, Partial differential equation; RANS, Reynolds-averaged Navier Stokes; RMS, Root-mean-square; RSE, Reynolds-stress equation

* Corresponding author. Tel.: +47 73593839; fax: +47 73593580.
E-mail addresses: Fredrik.Mentzoni@gmail.com (F. Mentzoni), Ivar.S.Ertesvag@ntnu.no (I.S. Ertesvåg).

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Nomenclature

k	turbulence kinetic energy (m^2/s^2)
p	pressure (Pa)
S_{ij}	rate of strain (s^{-1})
t	time (s)
u_j	velocity component in x_j direction (m/s)
u	velocity component in x direction (m/s)
v	velocity component in y direction (m/s)
w	velocity component in w direction (m/s)
x, x_j	spatial coordinate (m)
y	spatial coordinate (m)
z	spatial coordinate (m)
δ_{ij}	Kronecker delta (–)
ε	dissipation rate of turbulence energy (m^2/s^3)
μ	viscosity (Pa s)
μ_t	turbulence viscosity (Pa s)
ρ	mass density (kg/m^3)

Superscripts

$\overline{}$	average
$'$	turbulent fluctuation

Subscripts

rms	root-mean-square
NT	noticeable turbulence
FL	flight limitation

turbulence criteria for CFD analysis is presented and discussed. Finally, conclusions are drawn on terminology, model requirements and turbulence criteria.

2. Helideck requirements

2.1. Norsok Standard C-004

Norsok Standard C-004 (Standards Norway, 2013) defines requirements for helidecks on offshore installations on the Norwegian continental shelf. The standard was first released in September 2004 (Standards Norway, 2004) and updated with a second edition in May 2013 (Standards Norway, 2013). The second edition included new regulations regarding wind analysis and turbulence above helidecks. At least three new requirements were important in this context: (1) CFD analyses should comprise a given volume of air space surrounding the helideck, and a presentation of different quantities above the helideck should be given. (2) The vertical "velocity fluctuations" should not exceed certain values within an observation region above the helideck. (3) A "differential turbulence model" should be used in CFD analyses of helideck flows.

The first requirement is on the simulation domain and observation region. The standard states that the immediate air space surrounding the offshore installation that may induce unfavorable operational conditions at the helideck, and in the helicopter approach and departure sector, should be included in a simulation. The helicopter landing and committal points are deemed to be up to 20 m above the helideck. According to Norsok Standard C-004, plots of the velocity magnitude, the vertical velocity component and the vertical velocity fluctuations above the helideck should be provided. The standard does not give any further specification of "above helideck". In our calculations (Mentzoni et al., 2015), we have interpreted the observation region as 0–20 m above the helideck center.

The vertical velocity fluctuations requirement is quantified as 1.75 m/s and 2.4 m/s. This regulation was based on operational experience that has indicated that velocity fluctuations of 1.75 m/s will generate noticeable turbulence (Standards Norway, 2013). Norsok Standard C-004 states that "this criterion should therefore normally not be exceeded. Flight limitations are likely at values exceeding 2.4 m/s". As will be explained in Section 2.2, these criteria were meant to be on the standard deviation of the vertical velocity component.

The third requirement is stated as follows in Norsok Standard C-004 (Standards Norway, 2013, p. 7): "A differential turbulence model shall be used for the simulations to provide a physical representation of the anisotropy of the turbulence field close to the helideck." An issue here was the interpretation of the term "differential turbulence model", and whether this term is suitable in a standard.

2.2. Background

To figure out the background of the wind analysis requirements in Norsok Standard C-004, we looked at previous reports and standards. Citations to CAP 437 7th (UK Civil Aviation Authority, 2013) and 5th (UK Civil Aviation Authority, 2005) editions were noted explicitly in Norsok Standard C-004 (Standards Norway, 2013).

CAP 437 is the standard for offshore helicopter landing areas for helicopters registered in the UK. It is issued by the UK Civil Aviation Authority, CAA, and the first edition was released in September 1981. The current version is the 7th edition, amendment 01/2013, released in February 2013 (UK Civil Aviation Authority, 2013).

The simulation domain and observation region requirements are found in CAP 437 as well, although somewhat different than in Norsok Standard C-004.

The vertical turbulence velocity requirement is also found in CAP 437, but the formulation differs from the one in Norsok Standard C-004. According to CAP 437, the standard deviation of the vertical airflow velocity should not exceed 1.75 m/s. Since the value is the same as the noticeable turbulence criterion in Norsok Standard C-004, it may be assumed that the Norwegian standard also was meant to refer to the standard deviation of the vertical airflow velocity. Moreover, Norsok Standard C-004 has a footnote stating that it at this point was "aligned with recommendations in CAP 437", which must be read as a confirmation that the "fluctuation" actually means standard deviation.

The 1.75 m/s criterion was originally set to 2.4 m/s, first mentioned in CAP 437 5th edition, but was lowered in the 6th edition following completion of a validation exercise (UK Civil Aviation Authority, 2008). The validation exercise was reported in CAA Paper 2008/02 (UK Civil Aviation Authority, 2009). According to this report, the requirement was originally set to 2.4 m/s, which corresponded to the limit between safe and unsafe flying conditions, 6.5 on the Cooper–Harper handling qualities rating scale, HQR (Cooper and Harper, 1969). However, the relation between the standard deviation of the vertical velocity component and HQR was based on piloted simulations with three experienced pilots in ideal visual cueing conditions. The criterion was therefore lowered to 1.75 m/s, HQR = 5.5, to allow for flights in reduced cueing conditions, and for the less able or experienced pilot (UK Civil Aviation Authority, 2009). Another result of the validation process was withdrawal of a mean vertical wind speed criterion.