# The history of co ordinate system environmental sciences essay

UNIVERSITYFaculty of Engineering and ComputingDepartment of Aerospace, Electronic and Electrical EngineeringAerospace Systems Engineering303CDE - Individual Project - 1213AAA

# " Turbulent Jets: Mesh influence on the accuracy of simulations"

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# Declaration of Originality

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Abstract[Write here a summary of the project and its product or findings. It is a simple summary of the findings in the research paper, more like a sales pitch towards to readeres of this research paper. It is aimed to be concise, between 250 and 500 words. I would like to see a brief of, the aim of the

project. What is the aim and objectives in a small paragraph. It should also be mentioned what the Re number in question is and also what the main aim is. For example, humberto had to compare steady jets with pulsed jets. In my paper i will be comparing URANS, RANS, LES as well as comparing the solvers used, discriasation techniques, and mainly grid indipendance for LES. Turbulance values: U = free stream velocity = 0. 1377I = turblent length scale = 0. 16*(Re)^(-1/8)= 5. 639%k = turbulent energy = 3/2*(U*I)^2 = 8. 2735e-5epsilon = turbulent dissipation rate = Cmu^(3/4)*k^(3/2)*l^-1 = 5. 79e-6omega = specific turbulent dissipation rate = Cmu^(-1/4)*({SQRT(8. 2735e-5)}/{0. 02135}) = ({rho*k}/{mu})*(mu_t/mu)^-1 = 7. 7783e-1The question arises: how fine does themesh need to be in the LES region? And, how do we, after having made anLES (assuming that there are no experimental data with which to compare), verify that the resolution was good enough? Thefirst measure is probably to compare the modelled turbulence and stresses with the resolved ones. The smaller the ratio, the better the resolution. Another, similar way, is to compare the resolved turbulent kinetic energyto the modelled one. The energy spectra are commonly computed to findout whether they exhibit a −5/3 range and if they do the flow is consideredto be well resolved. Another measure of the resolution may be to look atthe two-point correlations to identify, for example, the ratio of the integrallength scale to the cell size. A less common approach is to compare theSGS (i. e. modelled) dissipation due to fluctuating resolved strain-rates tothat due to resolved or time-averaged strain-rates. This can be verified or disproved by making energyspectra of the SGS dissipation to find the wavenumbers at which the SGSdissipation does in fact take place. Since this process takes placein the viscous-dominating near-wall region, the required grid resolution mustbe expressed in inner variables, i. e. viscous units. In LES, the required gridresolution is $\Delta x+ \simeq 100$, $y + \simeq 1$ (wall-adjacent cell centers) and $\Delta z + \simeq 30$where x, y, z denote the streamwise, wall-normal and spanwise directions, respectively.[Lars Davidson, Int. J. of Heat and Fluid Flow, Vol. 30(5), pp. 1016-1025, 2009

## ]

## Table of Contents

Impinging Jets has been a study for many researchers over the counting years, due to the complexity around obtaining u

## List of Figures

[to be populated on completion of paper]

# Nomenclature

## Latin Letters

d m jet diameterDim m2 /s mass diffusivityf Hzfrequencyh W/mK heat transfer coefficientH m plate-to-nozzle spacingN u = hd/kf -Nusselt numberp m nozzle-to-nozzle spacingP e = U d/α -Peclet numberP r = ν/α -Prandtl numberr mradial distance measured from the jet axisr1/2 mjet half radiusRe = Ue d/ν -jet Reynolds numberSc = ν/Dim - Schmidt numberSh - Sherwood numberSt = f d/Ue-Strouhal numberStc = d/Ue -Strouhal number for which reduction in entrainment Reynolds stresses is expectedt stime

## Greek Letters

δ mboundary layer thicknessλ m wave lengthν m2 /s kinematic viscosityρ kg/m3 water densityω m jet width

## Subscripts and Superscripts [should i include this????]

avg-averaged valuec -related to centreline conditionse - related to jet exitex -excitationnp - non-pulsating flowp - pulsating flowrms -root mean squares -related to surfacestag -related to stagnation point

## Co-Ordinate System

[I need to change this to my current mesh – y axis must be the vertical and not x. So i justneed to swop the x and y axis of this graph. Include H(m) where the left arrow is that link the confinement plate to the impingement plate. Denote the inlet and outlet in basic temanology.]

# Acknowledgements

[This is an optional section, used to acknowledge the support or contribution of your family, friends, colleagues, university staff (usually including the supervisor), your client and any other external sources of help. Usually about 500 words long. ]

# Chapter 1

# Introduction

Impinging Jets has been a study for many researchers over the counting years, due to the complexity around obtaining useful results, the variables in question are of great concern. Jets, as commonly named, discharge fluid from a nozzle of specific dimensions and generate a pre-calculated fluid flow characteristic. Namely denoted by Navier Stoke Equations, which is detailed in 'Chapter 2 - Literature Review'. Impinging Jets have the denotation of a normalized jet by which the exiting fluid from the nozzle penetrates a 'plate', known and denoted as the Impingement Plate. This is more greatly known as the rapid deceleration of fluid by an object, which in turn disturbes the fluid flow, alters the heat dissipation as well as fluid characteristics. The creation of an impingement plate does not have to be characterized by a flat plate perpendicular to the exit fluid flow of the nozzle, how it is seen in this dissertation. However, when the exiting fluid build up is interupted, an impinging 'plate' is created. The evolution of the nozzle is user defined, in the case at hand, a free-jet has been selected as to be more appropiate and for simplicity reasoning. A free-jet is denoted/define as a jet that discharges fluid from a nozzle, irrispective of the nozzle's geometry. The three most widespread numerical simulation methods to predict turbulance is namely, Reynolds Averaged Navier Stokes (RANS), Direct Numerical Simulation (DNS) and Large Eddy Simulation (LES), whereas RANS is the common method used in industry, benefitting from being the less resourcefull whilst DNS being the least common method used due to the high resource demand. RANS only resolves for the mean flow, which in turn averages out the turbulance fluctuations. Although used for over three decades, RANS is constantly under development and due for improvement. If the requirement is to resovle the turbulent fluctuations, LES and DNS are the preferred numerical simulation methods. LES' ground base principle is to resolve the energy carrying eddies, large eddies, while modelling the smaller eddies. LES is a step up from RANS, but a step down from DNS on computational time and requirement. The accuracy for LES is greatly grid dependant, thus user dependant, for wall bounded flows, like those experienced in Impinging Jets, a fine near wall grid is imperative. The previous has a direct relationship towards cost and resource availability, thus an appropiate meshing solution is vital, due to the sole fact that coarse LES meshs will not provide accurate predictions. Impinging jets have a simple configuration but yet challenging geometry when the meshing aspects are taken into account. Due to the nature of fluid exiting the nozzle and impinging a surface, a basic symmetry or 'wedge' approach is not all that easy. The significance of this will be touched on in 'Chapter 4 - Methodology' and 'Chapter 5 - Meshing Guidelines'. The approach taken has been a simple, but yet effective manner by generating a simple, small Hexahedral mesh of the specific geometry chosen, at hand the fictive geometry is a 360 degree gemoetry. The basics of meshing and the simplicity of understanding how to generate a suitable mesh is still a wide field of study for CFD Engineers, esspecially those interested in LES and DNS. This is due to the sole fact that with RANS simulations one can increase the mesh size and the results will be directly propotunal. LES and DNS have a sligtly scewed approach, the mesh size can be increased to a certain point at where a plateu is reached. It is then to be noted that the benefit seen in RANS by having a directly propotunate relationship with the accuracy of results to grid size is not evident with LES and DNS. One will only increase resource requirements and incure greater expences and times on the simulation, which is not idealic towards many. Literture studies provide some form of guidance onto meshing but none of them have directly stipulated on how to approach a problem from first base. The case at hand concentrates on transient stages (tending towards laminar flow) of flow, Re <4200, the main reason for this is due to computational resource, the greater the Reynolds Number, the more computational time requirement and resource requirement. Above the previous mentioned, a concentration of fluid vortecies is to be also to be briefly commented on in the boundry layer of the impinging plate, due to the geometry being ficitive. Turbulent flows withing LES has to be understood prior to the completion of the disseration, thus saying it is vital to distiguish the variiance of smll-scale and large scale turbulance motion in the models at hand. In the high Reynolds number regieme, a larger seperation is prone with lengthscales, whereas the the geometry has a great influence on the large-scale motions, whilst the small-scales are vitually independant from the geometry. The Turbulent mixing, mainly found in the boundry layer, and transport is greatly controlled by the large eddies, large scale motions. The small-scale motions gradually decrease in size as the Reynolds number increases, most related to an exponential increase in Re, and a decrease in small-scale motions. Two main research areas of interest to small lengthscales, would be the energy cascade and the Kolmogorov hypothesis which will be touched on in 'Chapter 3 - Turbulence Lengthscales'.

# Aims and Objectives

## Aims

The aims are: To provide a rough meshing guide to the average OpenFoam user. Idealic aimmed for Impinging Jet cases, but the guide may be adapted accordingly. To expand the current field knowledge of meshing with LES and RANS, using an Impinging Jet example.

## Objectives

The objectives are: To validate a the ficitive geometry with previous research journals and papers published. To identify key points and conciderations when modelling and meshing, using Salome Meca v6. 6. 0. To present a colaboration of data, graphical illuisons, directly relating towards x/d and U. Proving the results obtained has a direct relationship towards grid dependancy in LES and not that much of RANS. To present a comparison of URANS, RANS and LES with coarse and dense meshs. To present a comparison of the results obtained from a coarse and dense mesh in LES solved using LES. To present a comparison of results obtained using diffirent two-equations models for RANS. Namely 'K-Epsilon' and 'K-OmegaSST'. To present the direct relationship of Turblence Length scales and grid scales, using a basic quality criteria method set out.

## Dissertation Overvew

This section details the dissertation layout accompanied with a brief desciption of each chapter found in the pages to follow. The reader should not use this section of the dissertation as a 'deep-dive', but rather use it as a guideline for direction towards the correct chapter and section required.

## Chapter 1 – Introduction

This chapter keys out the relevance of the dissertation aswell as the motiaiton behind this work, it clearly identifies the aims and objectives of this paper.

## Chapter 2 - Literature Review

Most known literature on the subject of meshing and impinging jets, where relevant to the dissertation, notably including literature on free-jets, URANS, RANS, LES, Turbulance lengthscales, grid resolution for LES and also guidlines for designing a grid.

## Chapter 3 - Turbulence Lengthscales

This Chapter highlights the importance of hand calculations for meshing, those specifically relating to Kolmogorov hypothesis, Taylor's hypothesis, turbulence scales, Turbulence spectrum, lengthscales. This is a deep dive into lengthscales, combinded with the relation to grid dependancy for LES.

## Chapter 4 – Methodology

Here the methods are justfied, as well as the values chosen for comparison. The method for obtaining the results can be found here, with the added referance to the specific annex which will specifiacally detail the method of creating the geometry as well as the mesh. Pre- and Post-Processing will be touched on, but a deep dive on post-processing can be found to the end of the chapter. The software and hardware used will also be detailed for the user's benefit, if the models were to be recreated for validation purposes.

## Chapter 5 - Meshing Guidelines

This chapter details a brief meshing proceedure for obtaining useful LES results with Salome Meca v6. 6. 0, including the use of Turbulence Calculations, Length Scale comparisons.

## Chapter 6 - Results and Discussion

The main body for the obtained results are to be found here, with the benefit of a RANS/LES comparison, LES – coarse/dense comparison, as well as an adaptive geometry creation for the investivation on sectioned meshing with RANS.

## Chapter 7 - Project Management

This chapter details the time scales set out for the project, combinded with the resource availability and how the created Gantt Chart has evolved over time. A quality management review can also be found, as this benefits the user to see how projects can either be complicated, over engineered and/or blown out of perspective.

## Chapter 8 - Critical Appraisal

A dispassionate and detailed discussion and analysis of the work and its outcomes, both positive and negative. The section will demonstrate the knowledge and expertise that you have gained from your project.

## Chapter 9 – Conclusions

The findings from the work is summerized in this chapter as well as the future work to be considered relating to this topic.

## Chapter 10 - Student Reflections

A reflective and critical appraisal of my personal performance, problems encounter along the way and a brief mention of how they were approached, resolved and what could have been done better or differently.

## Appendices

Useful information to the reader can be found within the appendices, those including meshing illustrations, geometry design process, etc.

## Chapter 2

## Literature Review

[Every Honours project needs to do a certain amount of " research" into relevant problem areas, appropriate solutions and the technologies that support them, and also a review of existing systems covering these areas or other projects that have tackled similar problems. Try to show us how this investigation has led to or justified the decisions you’ve taken. ]

## Introduction

[emphasis should be placed on the topics touched in this section and what the main concern is, meaning the sole reason for writing this research paper. In this case our main focus would be the effect of using RANS and LES for impinging jets simulations, and how the grid dependancy effects the results obtained. But furthermore, how does this relate to a client, is LES actually that beneficial or is it not that beneficial?]

## Numerical Analysis of Turbulence

## The Navier-Stokes Equations

## Reynolds Averaged Navier Stokes

## Large Eddy Simulation

## Impinging Jets (Single)

[this section will be utilized to just speak about the jet itself, why the use of iminging jets and not another case study. Unknown researchers have spent many hours in the soul research into impinging jets and grid dependancy, but have not clearly detailed why and how. This section will just briely explain the Impinging Jet configuration and happenings. An illustration of the jet will be useful, perhaps something that has some flow diagrams in the impinging jet and with the flow converging. The discussion on H/d and Nusseltnumber:, r/d, Re.]

## Free Stream Jets

[this is just a brief explanation of the free stream jet system utilized, although pulsating jets has not been touched on, this will x/d = 0. 85 − 1. 60, be an interesting field of study and can be mentioned in the 'futher research' section.]

## Key Parameters

## Nozzle Type

[here it will be discussed that a longer nozzle has been taken, the reasoning for choosing the specific l/d value (l/d = 0. 305/0. 0305 = 10)]

## Nozzle Diameter

[Nu increases with an increase in diameter of the nozzle, relate to the increase in turbulance intensity.]

## Non-Dimensional Distances

[Nozzle-plate seperation (H/d) ; plate to nozzle distance (z/d) ; nozzle to plate distance (x/d) ; nozzle to nozzle spacing or pitch (p/d) ; radial distance from the stagnation point (r/d)]

## Impingement Surface

## Confinement Plate (and Recirculation)

[include an illustration of the jet and the flow, where recirculation is possible and where not.]

## Reynolds Number

[this indicates if the flow is laminar or turbulent and one can generalize the flow characterization depending upon the Re values.]

## Grid size

## Add more things on meshing

## Quality and Reliability of Numerical Simulation

## Grid resolution for LES

## Error estimation and accuracy limitations for LES

## Guidelines for designing grids

## Turbulence Lengthscales

[brief disctription as this will be touched on in the methodology in much mroe detail. Note that the following will be dived into: Kolmogorov hypothesis; Integral lengthscales; Taylor microscales; Velocity spectra; Energy spectrum; Turbulent energy lengthscale; Taylor’s hypothesis; One-dimensional spectra; Kolmogorov spectra; Lengthscales and spectra.]

# Chapter 3

## Turbulence Lengthscales

## Introduction

Once the flow regieme has been broken down into two distinctive parts, namely, small and large lengthscales, it is easier to analyze the flow and apply the given calulation methods for grid refinement. Firstly, it is vital to understand the importance of the mathemaical relations and as noted below this will be detailed. Resolving for the large-scale motions is of utmost importance in LES, with the combination of modelling the small-scale motions, the turbulance. This is more evident in high Reynolds numbers, but is seen in most flow ranges.

## Kolmogorov hypothesis

Richardson [1922] has denoted the large eddies, with a size to be comparable to the overall flow region L, to break up and have instability, thus transferring their energy to the smaller eddies, this process circulates and smaller eddies transfer engery to smaller eddies. This process continues until the Reynolds number,, is of a magnitude to be stable. When stable the molecular viscosity has reached a suitable effectivness in dissipating kinetic energy. Kolmogorov [1941] has added great value to the work by Richardson, in identifying what is known as the Kolmogorov Scales. The small-scale depends only at the rate at which energy is supplied to it from the mean vlow and the kinamatic viscosity of the fluid in question. Noted from Tennekes and Lumley [1972], which is what the universal equilibrium theory of small turbulance is based on by Kolmogorov, the rate of dissipation form large-scale motions is equal in magnitude to the rate of energy supply to the small-scale motions. Kolmogorov's hypothesis for local isotropy states the following:" at sufficiently high Reynolds number, the small-scale turbulent motions are statistically isotropic" [Pope, 2000]. This states that the statistics for the small-scale motions are universal in most high-Reynolds flows, Re> 4500. Vital to point out that the lengthscale,, with the direct relationship towards Kolmogorov's Hypothesis for isotropy, this can be simplified into writing, . Noted by Kolmogorov, the first simularity hypothesis for small-scale motions and high-Reynolds numbers states:" in every turbulent flow at sufficiently high-Reynolds number, the statistics of the small-scale motions have a universal form that is uniquely determined by the viscosity, v, and the rate of energy dissipation, 'epsilon'" [Pope, 2000]. After the above hypothesis, the Kolmogorov microscales are derived, giving the following relationships: Kolmogorov microscales of length:(3. 1)Kolmogorov microscales of velocity:(3. 2)Kolmogorov microscales of time:(3. 3)Kolmogorov has another hypothesis, from the coninuation of the first, it states:" in every turbulent flow at sufficiently high Reynolds number, the statistics of the motions of scale 'l' in the range have a universal form that is uniquely determined by , independant of " This denotes that introducing the lengthscales, splits what is known as the universal equllibrium range, into two unique subranges, namely the inertial subrange and the dissipations subrange. The hypothesis may be written as, . Universal equllibrium range(3. 4)Dissipation Range(3. 5)Inertial subrange(3. 6)Energy-containing range(3. 7)

## Taylor’s hypothesis

Taylor's hypothesis [Taylor, 1938] is the approximation of spatial correlations by mundane approximations, the importance is great for the emperical solution of spatial correlations, which in turn would require the incorporation of the two-point correlation for. One technique discussed in the Taylor's hypothesis, is known as the 'flying hot-wire' approach which simply involves a moving, single wired probe. This moves rapidly through the turbulent field with a constant velocity along a line parallel to the direction 'x' with the unit vector set to . It can be noted that if the probe is at position at then: the time is at location:(3. 8)and the velocity in question,(3. 9)From the above, the mundane autocovariance can be obtained from the measured velocityis:(3. 10)where is the probes distance travelled, measured with time, in seconds. For stationary flows, where as the turbulance intensity is small when compared to the mean velocity in the given direction, , a single stationary probe shall be utilized. The 'flying hot-wire' approach can therefor be applied with . As seen by, Lumley [1965], when relating to grid turbulance, is quite accurate when facilitating high order corrections in free shear flows, yet, Tong and Warhaft [1995], proved that under experimental data the free shear flows had failed.

## The two-point correlation

The two-point correlation is one of the simplest and proven to be one of the accurate measurements in determining grid resolution. This can be referred to the spatial structure of any random field, a simple second order formula can be seen below:

;;

(3. 11)For turbulent fields, equation 3. 11 can be rearranged as follows:(3. 12)Equation 3. 12, the corrolation function may be defined as the effect of one point in the field on another point in the same field in question. This directly relates to the relationship between adjoining velocity fluctuations if referred and linked to turbulance. The two-point correlation formula fouund in 3. 12 can be rearranged when considering homogeneous isotropic turbulance, as this is expressed with two scalar functions:(3. 13)Functions, andare known as longitudinal and transverse autocorrections. Introducing the co-ordinate system, with directions,, unit vector, and the relationyields the following:(3. 14)(3. 15)andThe continuity equation implies:(3. 16)Therefore, equation 3. 12 equates to:(3. 17)Equation 3. 17 implies that during isotropic turbulance, is completly determined by. The two lengthscales that are of great importance would be the integral lengthscales and the Taylor microscales. See Chapter 3. 5. 2 and 3. 5. 3.

# Turbulence Scales

## Turbulent energy lengthscale

Once a simple RANS case has been run, it is possible to obtain the energy carrying eddies more commonly known to be the turbulent energy lengthscales:(3. 18)Equation 3. 18 is denoted as an estimated lengthscale from the RANS model simulated, the subscript " ERANS" is denoted for a RANS model. To get a true indication of the integral scale, Kang et al [2003], noted that when the constant 'A' in equation 3. 18 is taken to harmony one may achieve this due to the sole fact that the turbulent energy lengthscale defines the aize for the large eddies, carrying energy. Following from equation 3. 18, the turbulance Reynolds number is:(3. 19)From equation 3. 19, we can deduce the following:(3. 20)(3. 21)Combining equation 3. 20 and 3. 21, the following findings may concluded:; (3. 22)

## Integral lengthscales

From Chapter 3. 4, we can define the integral scale, one example would be if we utilize the same co-ordinate system with directionand unit vector , then the Integral scale, is define as:(3. 23)The longitudinal integral scale:(3. 24)The tranverse integral scale:(3. 25)when considering equation 3. 17, 3. 23, 3. 25,.

## Taylor microscales

Second to that of the Integral lengthscale, the Taylor microscalehas just such a great importance, it is defined as: The longitudinal Taylor scale:(3. 26)The tranverse integral scale:(3. 27)Considering equation 3. 17, the Taylor microscale can be derived as:(3. 30)when referring to equation 3. 28, then equation 3. 26 and equation 3. 27 can be related as:(3. 33)

## Turbulence Spectrum

Further equations used for the dissertation are:

## Velocity spectra

## Energy spectrum

## One-dimensional spectra

## Kolmogorov spectra

## Lengthscales and spectra

## Chapter 4

## Methodology

[ Too many students waste valuable words talking about the " waterfall model" when in fact they used a prototyping or iterative/incremental approach. What really interests us isn’t the theory of the process model you used, but the reasons for choosing it – can you justify it? ]

## Introduction

[This is just a small introduction into the methodology, what it is all about and what wil be touched on, for example the calculations for

## Software/Hardware Used

## Case set up

## URANS

## RANS

## LES

## Experimental Error and Uncertainty

## Data Analysis

# Chapter 5

## Meshing Guidelines

## Introduction

## Turbulance Calculations

## Legth Scale comparisons

## Salome Meca v6. 6. 0 Meshing Illustration

## Grid density relation towards results (qualitative/quantitative)

# Chapter 6

## Results and Discussion

[ Depending on the project you might include here a business process model or other high-level conceptual view of the required system, a use case model showing the main usage scenarios (but not the detailed use-case specifications), an entity-relationship diagram, a logical data model, etc. You need to explain the models, but diagrams save words! ]

## Introduction

## URANS

## RANS

## LES

## Best Comparison from URANS/RANS/LES

## CFD Method Comparison

## URANS vs LES

## RANS vs LES

## URANS vs LES

## Grid Manipulation

## LES – Coarse vs Dense Grid

## Geometry Manipulation

## RANS

## LES

## Quantitative vs Qualitative

[Here i would like to see a graph that plots all the simulations on one plot but has axis manipulaiton to include quantitative vs qualitative results. Meaning how do the results obtained relate directly towards the time and resource consuption of the simulation and mesh.]

# Chapter 7

# Project Management

[ The subsections shown below are only one possible structure for this section covering the conduct of the project. ]

## Project Schedule

[ This could include the work breakdown structure, Gantt chart, and comments about how well you managed to keep to the original plan, or what adjustments were necessary. ]

## Quality Management

[ Standards adopted, techniques used to review progress and evaluate outcomes, etc. ]

# Chapter 8

# Critical Appraisal

[ A dispassionate and detailed discussion and analysis of the work and its outcomes, both positive and negative. The section will demonstrate the knowledge and expertise that you have gained from your project.]

# Chapter 9

# Conclusions

[ Optional introduction ]

## Achievements

[ Comment on what you have achieved in terms of product or other results, with reference to the original project objectives. ]

## Future Work

[ Outline possible enhancements or extensions to the product, or further work needed to address outstanding issues, etc. ]

# Chapter 10

## Student Reflections

[ A reflective and critical appraisal of your personal performance, problems encountered and how they were resolved, lessons learnt, what could have been done better or differently, etc. ]