"I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Bachelor Mechanical Engineering (Thermal - Fluids)"

Signature

Name of supervisor

Date

Lee Yuk Choi

. 9/12/2005

# NUMERICAL SIMULATION OF TWO – DIMENSIONAL TRANSIENT HEAT CONDUCTION USING FINITE ELEMENT METHOD

#### OOI HOOI WOON

A project report submitted in partial fulfillment of the requirements for the award of the Degree of Bachelor Mechanical Engineering (Thermal & Fluid)

Faculty of Mechanical Engineering Kolej Universiti Teknikal Kebangsaan Malaysia

December 2005

"I hereby declared that this thesis is my own work except the ideas and summaries which I have clarified their sources"

Specially dedicated to my family, friends and companion

#### ACKNOWLEDGEMENTS

I would like to express my special thanks to my project supervisor Mr. Lee Yuk Choi for his invaluable advice on guiding this project. I also sincerely would like to thank him for his patience and time in correcting and consulting on the step that I should took and proceed with thorough analysis based on his professional experiences and knowledge. His time spent for teaching me the detail usage of MSC/NASTRAN simulation tool base on finite element method was much appreciated. His contribution on guiding this simulation project have make the completion of this project moved a step forward.

It is my pleasure and gratitude to thank my fellow project mate Mr. Wong Sau Keong where we have been gone through a lot of discussion and testing before we can actually start the our project's simulation. Although sometime argument happens due to different simulation tools been used, but it will not terminate my determination to complete this thesis. His valuable and wise inputs had made my simulation analysis proceed smoothly.

Nevertheless, I would also like to thanks those who have contributed their efforts and help in assisting me to complete this simulation project. With the assistant and guidance from all related stake holder have make the project complete successfully per scheduled timeline.

Finally, I would like to express my highest sincere thanks again to all that had contributed their guidance and help upon completion of this project.

### **ABSTRACT**

A simulation study is undertaken by using MSC/NASTRAN to analyze the transient heat transfer analysis which has embedded with finite element method in order to run the numerical simulation in a two dimensional slab materials. This study investigates the temperature changes with time for a given boundary condition using different delta time for 32 and 200 elements. Comparison between MSC/NASTRAN and Mathlab was also performing in this analysis. An attempt was made to analyze the transient heat conduction for different materials namely aluminium, glass and building brick. Quadrilateral and triangular elements are being used in the analysis. From the simulation results it was showed that 200 elements with combination of delta time 0.4 seconds yield a better result and achieve steady state faster by providing more accurate analysis. Not much significant difference was observed between MSC NASTRAN and Mathlab with an error less than 1%, which is deemed satisfactory. The results also showed that delta time 10 seconds achieve steady state slightly faster due to the time spacing. Quadrilateral elements is suitable in twodimensional because it provide sufficient flexibility as comparing to triangular mesh. Aluminium was found is the best material to release heat to surrounding faster comparing with building brick and glass. For more temperature difference applied on the both side of the materials, we can have a better cooling conditions.

#### ABSTRAK

Kajian simulasi ini adalah dengan menggunakan MSC/NASTRAN untuk menjalankan analisis permindahan haba fana yang telah terkandung dengan kaedah unsur terhingga bagi menjalankan analisis secara simulasi berangka dua dimensi dalam bahan papak. Keutamaan analisis ini adalah berasaskan perubahan suhu melintasi masa bagi graf suhu lawan masa dengan menggunakan unsur 32 dan 200..Perbandingan antara MSC/NASTRAN dengan Matlab juga merupakan sebahagian dalam anlisis Bahan yang berbeza seperti aluuminium, kaca dan bata bangunan akan dianalisis untuk menentukan fana konduksi haba. Unsur segiempat dan unsur segitiga juga dipilih dalam analisis ini. Daripada keputusan analisis, ia menunjukkan kombinasi unsur 200 dan delta t = 0.4s mencapai keadaan mantap lebih cepat dengan meberikan analisis yang lebih tepat. Tiada perbezaan yang munasabah antara MSC NASTRAN dan Matlab dengan ralat yang kurang daripada 1%. Delta masa 10 saat mencapai keadaan mantap lebih pantas disebabkan selang masa yang diambilkira adalah lebih besar. Dalam analisis 2-D, unsur segiempat adalah lebih sesuai di mana ia adalah lebih mantap kerana memberikan kefleksibelan yang memadai dengan berbanding dengan unsur segitiga. Aluminium merupakan bahan yang dapat membebaskankan haba ke alam dengan kadar yang cepat berbanding dengan bata bangunan dan akhir sekali ialah kaca. Dengan perbezaan suhu yang lebih diaplikasikan ke tepi kedua dua belah kepingan, kita boleh mendapat keadaan penyejukkan yang lebih baik.

#### ABSTRAK

Kajian simulasi ini adalah dengan menggunakan MSC/NASTRAN untuk menjalankan analisis permindahan haba fana yang telah terkandung dengan kaedah unsur terhingga bagi menjalankan analisis secara simulasi berangka dua dimensi dalam bahan papak. Keutamaan analisis ini adalah berasaskan perubahan suhu melintasi masa bagi graf suhu lawan masa dengan menggunakan unsur 32 dan 200..Perbandingan antara MSC/NASTRAN dengan Matlab juga merupakan sebahagian dalam anlisis Bahan yang berbeza seperti aluuminium, kaca dan bata bangunan akan dianalisis untuk menentukan fana konduksi haba. Unsur segiempat dan unsur segitiga juga dipilih dalam analisis ini. Daripada keputusan analisis, ia menunjukkan kombinasi unsur 200 dan delta t = 0.4s mencapai keadaan mantap lebih cepat dengan meberikan analisis yang lebih tepat. Tiada perbezaan yang munasabah antara MSC NASTRAN dan Matlab dengan ralat yang kurang daripada 1%. Delta masa 10 saat mencapai keadaan mantap lebih pantas disebabkan selang masa yang diambilkira adalah lebih besar. Dalam analisis 2-D, unsur segiempat adalah lebih sesuai di mana ia adalah lebih mantap kerana memberikan kefleksibelan yang memadai dengan berbanding dengan unsur segitiga. Aluminium merupakan bahan yang dapat membebaskankan haba ke alam dengan kadar yang cepat berbanding dengan bata bangunan dan akhir sekali ialah kaca. Dengan perbezaan suhu yang lebih diaplikasikan ke tepi kedua dua belah kepingan, kita boleh mendapat keadaan penyejukkan yang lebih baik.

# TABLE OF CONTENTS

CHAPTER	CONTENTS	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENTS	iv
	ABSTRACT	v
	ABSTRAK	vi
	LIST OF CONTENTS	vii
	LIST OF CHARTS	xi
	LIST OF TABLES	xii
	LIST OF FIGURES	XV
CHAPTER I	INTRODUCTION	1
	1.1 Overview	2
	1.2 Objectives Of The Project	4
	1.3 Scopes of the Project	4
	1.4 Gantt Chart	5
CHAPTER II	LITERATURE REVIEW	6
	2.1 Literature Review	7
CHAPTER III	THEORY	14

	3.1 Heat Conduction	15
	3.2 Heat Convection	17
	3.3 Finite Element Modeling	18
	3.4 Quadrilateral and Triangular Elements	21
CHAPTER IV	MSC/NASTRAN	22
	4.1 Heat Transfer Analysis	22
	4.2 Thermal Material Properties	23
	4.2.1 Conductivity	23
	4.2.2 Specific Heat and Heat Capacitance	23
	4.2.3 Thermal Boundary Conditions	24
	4.2.4 Temperature Boundary Conditions	25
	4.2.5 Free Convection	26
	4.2.6 Forced Convection	26
	4.3 Analysis	27
	4.3.1 Transient Analysis	28
	4.3.2 Initial Conditions in Transient	29
	Analysis	
	4.3.3 Creating Time and Temperature	30
	Functions	
	4.3.4 Steady-State and Transient	32
	Convergence Criteria	
CHAPTER V	METHODOLOGY	33
	5.1 Finite Element Modeling In MSC Nastran	33
	5.1.1 Coordinate System Creation	34
	5.1.2.Finite Element Entities (Nodes,	35
	Elements, Materials, Properties)	
	5.1.3 Loads and Constraints	35

	5.1.4 Contact	36
	5.1.5 Optimization	36
	5.1.6 Functions	36
	5.1.7 Modifying FEA Entities	37
	5.1.8 Deleting FEA Entities	37
	5.2 Finite Element Modeling	38
	5.3 Simulation Model	39
	5.4 Analysis Procedure	43
CHAPTER VI	RESULTS AND DISCUSSIONS	44
	6.1 Temperature versus Time for Different	45
	Nodes with 32 & 200 Elements for $\Delta t$ =0.4s	
	& 5s	
	6.2 Comparison Between MSC Nastran and	50
	MatLab for Temperature versus Time for 32	
	and 200 Elements at $\Delta t$ =0.4s and 5s	
	6.3 Comparison between Different $\Delta t$ =0.4s, 0.8s,	57
	5s, 10s	
	6.4 Comparison between Quadrilateral and	62
	Triangular for Coarse, Medium and Fine	
	Mesh	
	6.5 Comparison of material for Glass, Aluminum	65
	& Building Brick for Node 41 with 32	
	Elements at $\Delta t=5s$	
	6.6 Comparison with different temperature set up	70
	at both side of slab	
CHAPTERVII	CONCLUSION	71
	7.1.Suggestion and Recommendation for the	73
	future work	

REFFERENCES	74
APPENDIX	76

# LIST OF CHARTS

CHART	NO. TITLE	PAGE
1.1	Progress of the 1 <sup>st</sup> Project	5
1.2	Progress of the 2 <sup>nd</sup> Project	5

## LIST OF TABLES

TABI	LE NO. TITLE	PAGE
4.1	Time and temperature for time less than 100	33
4.2	Time and temperature for time more than 100	34
6.2.1	Quadrilateral Error Calculation Nodes 5, 23 & 41	52
	for 32 elements, $\Delta t = 0.4$ s at time step = 40s	
6.2.2	Quadrilateral Error Calculation Nodes 5, 23 & 41	54
	for 32 elements, $\Delta t = 5s$ at time step = 40s	
6.2.3	Quadrilateral Error Calculation Nodes 5, 23 & 41	55
	for 200 elements, $\Delta t = 0.4$ s at time step = 100s	
6.2.4	Quadrilateral Error Calculation Nodes 5, 23 & 41	57
	for 200 elements, $\Delta t = 5s$ at time step = 100s	
6.4.1	Temperature for end time 100 seconds for comparison	63
	between quadrilateral and triangular for coarse, medium	
	and fine mesh	
6.5.1	Material properties	66

## LIST OF FIGURES

FIGU	RE NO. TITLE	PAGE	
3.0	Heat transfer from hot to cold area	15	
		15	
3.1	4-noded bilinear element	17	
3.2	Two-dimensional region subdivided in finite elements	19	
3.3	Three types of boundary conditions	20	
3.4	(a) Quadrilateral Elements (b) Triangular Elements	21	
5.1	Typical Finite Element Method process flow	38	
5.2	Rectangular building slab	39	
5.3	2D axis symmetric models	40	
5.4	32 elements (Quadrilateral)	42	
5.5	200 elements (Quadrilateral)	43	
6.1.1	Temperature Contour Distributions at the end time100	45	
	seconds for (a) $\Delta t$ =0.4s, 32 Elements and (b). $\Delta t$ =5s, 32		
	Elements		
6.1.2	Temperature versus Time at Different Nodes with 32	46	
	Elements for $\Delta t=0.4s$		
6.1.3.	Temperature versus Time at Different Nodes with 32	46	
	Elements for $\Delta t=5s$		
6.1.4	Temperature Contour Distributions at the end time100	47	
	seconds for (a) $\Delta t$ =0.4s, 200 Elements and (b). $\Delta t$ =5s, 200		
	Elements		
6.1.5	Temperature versus Time at Different Nodes with 200	48	
	Elements for $\Delta t=0.4s$		
6.1.6	Temperature versus Time at Different Nodes with 200	48	
	Elements for $\Delta t=5s$		

6.2.1	Comparison between MSC Nastran and MatLab for	50
	Temperature versus Time 3 Different Nodes with 32	
	Elements at $\Delta t$ =0.4s	
6.2.2	Comparison between MSC Nastran and MatLab for	52
	Temperature versus Time 3 Different Nodes with 32	
	Elements at $\Delta t=5$ s	
6.2.3	Comparison between MSC Nastran and MatLab for	54
	Temperature versus Time for Different Nodes with 200	
	Elements at $\Delta t=0.4s$	
6.2.4	Comparison between MSC Nastran and MatLab for	55
	Temperature versus Time for Different Nodes with 200	
	Elements at $\Delta t=5s$	
6.3.1	Temperature versus Time with 32 Elements for Node 21	57
	at $\Delta t=0.4s$	
6.3.2	Temperature versus Time with 32 Elements for Node 21	58
	at $\Delta t=0.8s$	
6.3.3	Temperature versus Time with 32 Elements for Node 2	58
	at $\Delta t=5s$	
6.3.4	Temperature versus Time with 32 Elements for Node 21	59
	at $\Delta t=10 \text{ s}$	
6.3.5	Temperature versus Time for Comparison between	59
	Different $\Delta t$ at 0.4s, 0.8s, 5s and 10s for Node 21 with	
	32 Elements	
6.3.6	Temperature Contour Distribution with Different delta time	61
	with 32 elements at end time 100 seconds (a) $\Delta t$ =0.4s,	
	(b) $\Delta t$ =0.8s, (c) $\Delta t$ =5s and (d) $\Delta t$ =10s	
6.4.1	Temperature Contour Distribution for end time 100	63
	seconds for comparison between quadrilateral and	
	triangular for coarse, medium and fine mesh	
6.5.1	Temperature versus Time for Comparison of Glass,	65
	Aluminum & Building Brick for Node 41 with 32	
	Elements at $\Delta t=5s$	
6.5.2	Temperature Contour Distribution for 3 different	67

	materials which is Aluminum (a). 5 seconds,	
	(b).50 seconds and (c).100 seconds, Building Blocks	
	(d). 5 seconds, (e).50 seconds and (f).100 seconds and	
	Glass (g).5 seconds, (h).50 seconds and (i).100 seconds	
6.6.1	Different Temperature Set Up at Both Side	69
6.6.2	Temperature Contour Distribution for different	70
	houndary condition at both sides	

#### **CHAPTER I**

#### INTRODUCTION

This chapter discussed about the overview of the heat conduction treatment which had been applied into various different field from engineering to building constructions. It also provides dynamics of heat intensity and flow within objects knowledge of the temperature and its transient distribution for heat energy analysis. Objective and scopes of the simulations analysis based on MSC/Nastran in compliance with finite element method was discussed.

#### Overview 1.1

In our treatment of heat conduction we have gradually considered more complicated conditions. We began with the simple case of one dimensional, steady state condition with no internal generation, and we subsequently considered complications due to multidimensional and generation effects. However, we have not yet considered situations for which conditions change with time.

We now recognize that many heat transfer problems are time dependent. Such unsteady, or transient, problem typically arises when the boundary conditions of a system are changed. For example if the surface temperature of a system is altered, the temperature at each point in the system will also begin to change.

Although many simple steady-state and transient heat conduction problems can be solved analytically, solution for more complex problems are the best obtained numerically. Numerical solution methods are particularly useful when the shape of the solid is irregular, when thermal properties are temperature or position-dependent, and when boundary conditions are nonlinear.

Several of the detailed energy analysis programs use a time series solution for transient heat conduction. One of the main advantages of time series solutions over other numerical techniques such as finite difference and finite element methods is a substantial increase in the simulation speed. Other numerical techniques require the calculation and storage of every single nodal temperature at every time step. This increases the number of calculations required and the amount of storage necessary. In most cases, the temperature distribution inside a building element is of no intrinsic value to the overall simulation. Moreover, the time steps required to provide accurate simulation results tend to be shorter than with time series solutions.

Many engineering applications today only on the dynamics of heat intensity and flow within objects knowledge of the temperature and its transient distribution are vital in design and implementation. Therefore, in this study we would like to predict the temperature of an object given a set of initial and boundary conditions.

Finite element methods (FEM) are widely used in structural mechanics and also applicable to heat conduction problems. An object is divided into discrete spatial regions called finite elements. The most commonly used is the triangular element for two-dimensions and for three-dimensional element tetrahedron. The finite-element method allows the heat conduction equation to be satisfied in an average sense over the finite element; thus, the elements can be much larger than the control volumes used in finite-difference methods. The used of triangles or tetrahedrons for elements allows the approximation of complex and irregularly shape object.

Application of the methods leads to a set of algebraic equations, which are solved by matrix inversion and iteration. Compared to finite-difference methods, the formulation of these equations is considerably more involved and required more effort, as does writing a computer program to implement the procedure. However, once written, finite-element computers programs tend to be more versatile than their

finite-difference counterparts. Choice of which method to use is perhaps dictated by the objective rather than by the intrinsic virtues of the method. For example, calculation of temperature variations in solids is often required for the purpose of determining thermal stresses. Since the finite-element method is preeminent for stress calculations, many standard computer codes use the finite-element method to calculate both temperatures and stresses in one package.

This study presents the uses of MSC/NASTRAN and advantages of using this software for Heat Transfer Analysis. Finite element method is a powerful numerical technique for analyzing structures/continua. Several commercial software is available for FE analyses MSC/NASTRAN is the most widely used general purpose software of FE analysis. It has versatile applications in the filed of static, dynamic, heat transfer. MSC/NASTRAN also offers linear and non-linear (material, geometric, and boundary conditions exchange in enclosures, specified temperatures, surface and volumetric heat loads, and elements of thermal control systems ) analysis.

## 1.2 Objectives of the Project

The project is concerned with the two dimensional transient heat conduction in a slab to evaluate how successful the simulation by using the MSC/NASTRAN. The objectives are as follows:

- 1) To perform a numerical simulation of the heat flow.
- 2) To determine the temperature distribution as a function of time.

## 1.3 Scopes of the Project

The scopes of project are as follows:

- Literature review specifically on numerical simulation of two-dimensional transient heat conduction.
- 2) Familiarize the use of MSC Nastran package as a tool.
- 3) Comparison with available analytical solution of previous work.

## 1.4 Gantt Chart

The progress of the project was shown in Chart 1.1 and Chart 1.2

<b>Project Activities</b>								We	eek														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15								
Topic discussion	JE I																						
Gathering information																							
Literature review								18															
Familiarize with MSC					T																		
Nastran software		$\perp$			$\perp$																		
First draft																							
Power point																							
First presentation																							

Chart 1.1: Progress of the 1st Project

Project Activities		Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Running MSC/N4W															
Data collection															1
Data analysis &				†	Т						16	100			1
Discussion												1			
Second draft															
Power point							1	+		+					
Second presentation							1	+	1	+					
Writing of project		$\top$	T												
report															

Chart 1.2: Progress of the 2<sup>nd</sup> Project.

#### **CHAPTER II**

#### LITERATURE REVIEW

This chapter reviewed various study and analysis's results and findings from previous researcher's researches. Most the review was based on finite element methods. Different condition of steady state and boundary conditions either for 1-D. 2-D or 3-D also been discussed. Other method such as Boundary Element Method (BEM), Laplace Transform Boundary Element Method (LTBEM), Modified Boundary Element Method (MBEM) and other methods also been taken for reviewed and analyzed.

#### 2.1 Literature Review

In year 1993, Moncef Krarti presented a general solution for the steady state heat conduction problem under a slab-on-grade floor with horizontal insulation contributed thermal performance of the above-grade portion of buildings has been significantly improved after the energy crisis of the 1970s. The soil temperature field, the heat flux along the slab and the total slab heat loss are obtained and analyzed using the Inter zone Temperature Profile Estimation (ITPE) technique. In particular, it is shown that outer insulation is effective in reducing heat loss from slab edge and the thermally is better extend the length of outer edge insulation rather than increase the insulation thermal resistance over a short distance from the slab edge. Finally, the total heat loss was found to be significantly affected by the water table level.

Bomberg, et.al (1978) investigated the moisture redistribution process in an insulation slab that was sprayed with water before placing it in a heat flow meter apparatus which emphasized on the influence of moisture on the heat transfer through building materials. Vafai and co-workers (1986) have performed detailed numerical studies of the moisture transfer in insulations for several different boundary conditions.

In year 1994, N.E.Wijeysundera and S.J.Wilson investigated accuracy of three models for the interpretation of moisture redistribution experiments with fiber glass slabs, although each parameterisation arguably has its weaknesses. They predict the Quasi-steady model agreed well with the results of the transient numerical model in the heat flux and temperature distribution during the final drying-redistribution process. However, the semi- empirical model which incorporates the 'falling rate' evaporation period gives more accurate predictions of the experimental data and it used to obtain additional physical information on the moisture redistribution and drying process in the slab. The overall trend of physical behavior predicted by the above models agrees with the experimental trends of variation. Thus, the predicted changes in the heat flux and the temperature distribution occur at a much faster rate than is observed experimentally.

Sreekanta Das and Muhammad.N.S.Hadi (1996) developed a non-linear finite element (FE) analysis of reinforced concrete (RC) members like beams, slabs etc. using the majority of available commercial finite element software poses many numerical difficulties. Major difficulty is faced because of strain-softening behavior of concrete once it is yielded. This commercial finite element software of FE analysis remains totally inadequate in handling strain-softening behavior of concrete.

This is because this software offers only the traditional non-linear solution techniques like Newton-Raphson (N-R), modified Newton-Raphson (mN-R) methods etc. which can not handle the non-linear post-yielding analyses of members made of materials like concrete, soil, rock etc. which exhibit strain-softening behaviors after their yielding. MSC/Nastran, however, offers many advanced solution techniques like Crisfield's arc-length (CA) method, Riks' arc-length (RA) method, and modified Riks' arc-length (mRA) method. These methods can handle the strain softening behavior adequately.