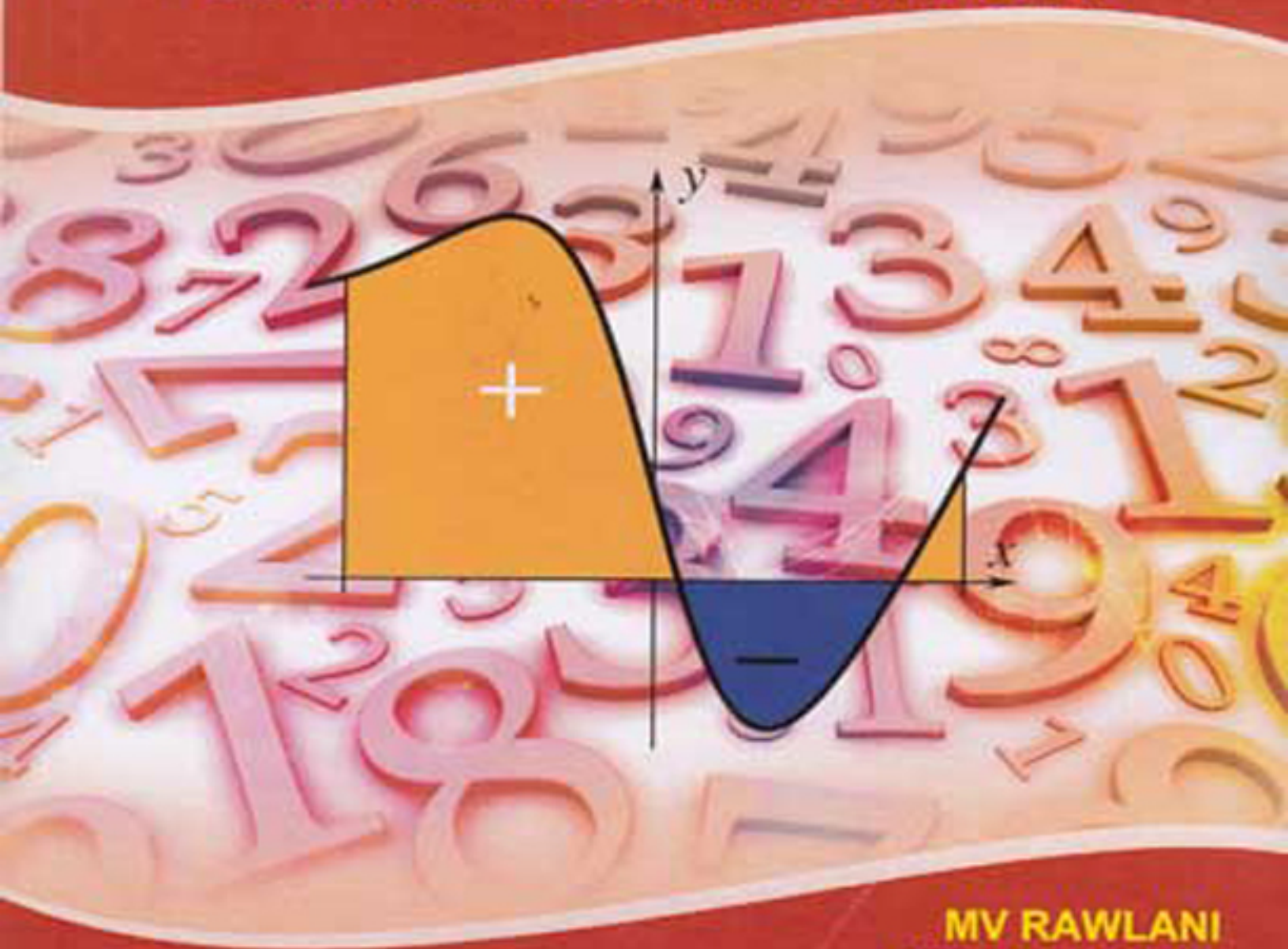



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Mechanical Engineering (SEM - VI)
**NUMERICAL ANALYSIS
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NUMERICAL ANALYSIS AND COMPUTATIONAL METHODS

For
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THIRD YEAR DEGREE COURSE
IN MECHANICAL ENGINEERING
AS PER NEW REVISED SYLLABUS OF
NORTH MAHARASHTRA UNIVERSITY, JALGAON

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NUMERICAL ANALYSIS & COMP. METHODS (TE MECH. SEM - VI NMU)

ISBN 978-93-5164-400-2

First Edition : February 2015

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Published By :

NIRALI PRAKASHAN

Abhyudaya Pragati, 1312, Shivaji Nagar,
Off J.M. Road, PUNE – 411005
Tel - (020) 25512336/37/39, Fax - (020) 25511379
Email : niralipune@pragationline.com

Printed By :

REPRO INDIA LTD

50/2 T.T.C. MIDC
Industrial Area, Mahape, Navi Mumbai
Tel - (022) 2778 2011

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Authors

PREFACE

We take an opportunity to present this book entitled '**Numerical Analysis and Computational Methods**' for the students of Third Year Degree Course in Mechanical Engineering. It is strictly written as per the New Revised Syllabus of North Maharashtra University, Jalgon.

The object of this book is to present the subject matter in a most concise and simple manner.

The Book Contains Five Constructive Units :

Unit I : It include Software Development in that Algorithm, Flowchart etc. and Solution of Transcendental Equation in that different methods such as Bisection, Hornerls etc.

Unit II : It include Numerical Integration and Solution of Ordinary Differential Equation.

Unit III : It include Interpolation in that Different types of Interpolation and Curve Fitting.

Unit IV : It include Solution of Linear Algebraic Equation and Iterative Method.

Unit V : It include Finite Element Analysis (FEA). Solution of various Equations and Introduction to Finite Difference Method.

We take this opportunity to express our thanks to Shri Dineshbhai Furia, Shri Jighnesh Furia and Shri. M.P. Munde for publishing this book in time.

We also take this opportunity to express our thank all the staff members of Nirali Prakashan namely, Mrs. Deepali Lachake (Co-ordinator), Mrs. Neeta Kulkarni and Miss. Mandakini Jadhvar, for their tremendous dedication and hard work in bringing out this book in an excellent form.

We are also thankful to **Mr. Pruthviraj M. More**, Branch Manager, Jalgaon office for his valuable help and efforts for promotion of our book.

Any undected and unintentional errors, omissions, suggestions etc. from students and for improvement brought to our notice in good sprint are most welcome.

February 2015

Pune

Authors

SYLLABUS

Unit I : Software Development and Solution of Transcendental Equation Marks 16

- (a) Software Development : Principles, Mathematical Modeling Problem Solving, Algorithm, Flowchart, Errors, Graphical method.
- (b) Solution of Transcendental Equation : Bisection method, False position method, successive approximation method, Newton-Raphson method, Horner's method, rate of convergence.

Unit II : Numerical Integration and Solution of Ordinary Differential Equation Marks 16

- (a) Numerical Integration : Trapezoidal Rule, Simpson's 1/3rd , Simpson's 3/8th Rule, Gauss Quadrature method : 2 point.
- (b) Solution of Ordinary Differential Equation : Taylors series method, Euler's method, Improved and modified Euler's method, Fourth order Runge-Kutta method.

Unit III : Interpolation and Curve Fitting Marks 16

- (a) Interpolation : Linear and quadratic interpolation, Lagrange's interpolation, Newton's forward interpolation, Newton's backward interpolation, Newton's divided difference interpolation, Stirling interpolation.
- (b) Curve Fitting : Linear and quadratic regression, Logarithmic curve fitting, Exponential curve fitting.

Unit IV : Solution of Linear Algebraic Equation and Iterative Method Marks 16

- (a) Solution of Linear Algebraic Equation : Gauss elimination method, Gauss Jordan method LU, decomposition method.
- (b) Iterative Method : Jacobi iteration method, gauss seidal interactive method, cholesky method.

Unit V : Finite Element Analysis and FDM Marks : 16

- (a) Finite Element Method : Introduction, steps used in finite element analysis, general approach, interpolation function and finite element application on one dimension, solution of elliptical equations, for various boundary conditions, solution of parabolic equation by explicit implicit.
- (b) Introduction to Finite Difference Method : Comparison with Finite Element Analysis, Crank-Nicholson method.

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Chapter 1

SOFTWARE DEVELOPMENT

1.1 INTRODUCTION

In this subject, we are going to study various numerical methods to solve variety of engineering mathematical problems. The objectives of learning of this subject can be assumed as below :

1. To understand the engineering problem situation.
2. To convert it into mathematical form, i.e. prepare a mathematical model.
3. To solve the mathematical expressions to reach conclusive solutions.
4. Predict and understand existence of inaccuracies in the final solutions.
5. Simplification and reduction in laborious repetitive calculation work so that the solutions will be obtained efficiently and without much loss of time.

To understand these objectives, let us take a simple example as below.

Example

A person is owning and running a mass production unit to make candles. He is in a financial crunch due to a huge rejection of candles produced per day. One day, he observed that 1250 candles are rejected. Then he decided to cut down the rejection to half every next day.

As numerical solution provider to engineering problems, he needs your assistance to determine number of days to practically reach zero rejection in candles production. Also he needs number of candles rejected from this day onwards till reaching the day of zero rejection.

Mathematical Thought Process

The situation of the problem demands division of 1250 by 2 and iteratively the answer divided by 2 till we reach zero.

So mathematical equation is

$$a_{i+1} = \frac{a_i}{2}$$

where, $a_i = 1250$ when $i = 1$.

Thus, a_i is number of candles rejected on the day number 'i'.

So number of days to reach zero rejection is value of 'i' when $a_i = 0$.

And number of candles rejected till that day is $\sum a_i$.

Now, practical problem in the process of getting the solution will surface out when we start the calculation.

The day number i	→	1	2	3
Candles rejected	→	1250	625	312.5

Here, we understand that a half candle cannot be rejected, so rejected candles must be either 312 or 313. The basic rounding rule forces us to select upper value. So the observation table may be prepared as :

Table 1.1

Day No. i	Candles Rejected a_i	Rounding Done (Yes / No)
1	1250	No
2	625	No
3	$312.5 \div 313$	Yes
4	$156.5 \div 157$	Yes
5	$78.5 \div 79$	Yes
6	$39.5 \div 40$	Yes
7	20	No
8	10	No
9	5	No
10	$2.5 \div 3$	Yes
11	$1.5 \div 2$	Yes
12	1	No
13	$0.5 \div 1$	Yes
14	$0.5 \div 1$	Yes
15	$0.5 \div 1$	Yes
.	.	.
.	.	.
.	.	.

Table 1.1 indicates that we cannot reach zero rejection even after infinite number of days.

Practical Considerations

To reach the practical solution, we will modify the basic rounding rule to select lower value. So the table will become as below :

Table 1.2

Day No. i	Candles Rejected a_i	Rounding Done (Yes / No)
1	1250	No
2	625	No
3	$312.5 \div 312$	Yes
4	156	No
5	78	No
6	39	No
7	$19.5 \div 19$	Yes
8	$9.5 \div 9$	Yes
9	$4.5 \div 4$	Yes
10	2	No
11	1	No
12	$0.5 \div 0$	Yes

Here, we get a solution as "on 12th day, there will not be any rejection". Simultaneously, we know, we have done some wrong assumption to reach the solution. So for practical solution, we may use basic rounding rule without modification till we reach rejection = 1 and then take decision to modify the rule.

Thus, the answer is that the plant will observe zero rejection on the 13th day (Refer Table 1.1) and the number of candles rejected is summation of the second column as :

$$1250 + 625 + 313 + 157 + 79 + 40 + 20 + 10 + 5 + 3 + 2 + 1 = 2505.$$

Inaccuracies

Now, the error or inaccuracy in the solution is difference between the theoretical and practical answers. In this case, practical answer is 2505 candles and the theoretical answers is $\sum a_i$ without rounding. Thus, theoretical answer is :

$$\begin{aligned} \sum_{i=1}^{\infty} a_i &= 1250 + 625 + 312.5 + 156.25 + 78.125 + 39.0625 \\ &\quad + 19.53125 + 9.76525 + 4.8828125 \\ &\quad + 2.44140625 + 1.220703125 + 0.610351562 \\ &\quad + 0.30517781 + 0.15258789 + 0.076293945 + \dots \\ &= 2499.37439 \end{aligned}$$

For more precise answer, we may add a few more a_i terms and we will get the theoretical answer as 2500 which is twice of 1250, the first day rejection.

Thus, in numerical solutions due to reasons like rounding and other assumptions, the final solution may vary from theoretical answer. An engineer, while presenting the final solution, must be aware of this existence of inaccuracy and predict its magnitude.

Computer's Assistance

Referring back the objectives of learning, we have discussed first four objectives. Now the last objective tells us to use computer softwares either as solver or programming language. In this book, we will learn use of C programming for various numerical methods. In addition, we will learn use of solvers like MS-Excel and MATLAB.

As an engineer or a numerical solution provider, we must know that the mathematical expression cannot be directly fed into the computer. Hence, it must be properly arranged and iteratively or directly solved in step by step manner. Developing this step by step process of approaching, the solution can be achieved using some techniques as Pseudo Codes or flow charts etc. Coming back to the problem of candles, to reduce repetitive work of division of answer by 2 and summation of all answers to get final solution, we may develop a computer program which will include the practical assumptions and will provide us the desired solutions.

Algorithm or Pseudo Code



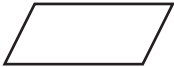
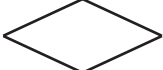
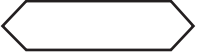

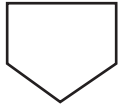
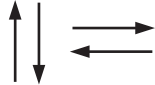
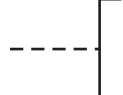
The steps for development of the program will be :

1. Get the first day's number of candles rejected i.e. 'a' and set $i = 1$ for day no. 1 and $\text{sum} = 0$.
2. Check whether a is even or odd, if odd $a = a + 1$.

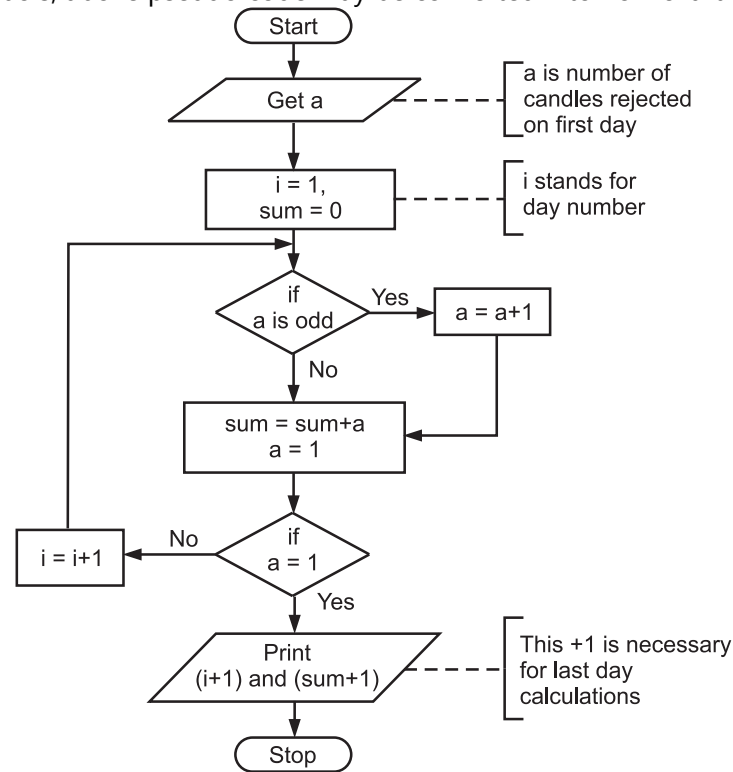
3. Perform summation as $\text{sum} = \text{sum} + a$ and division as $a = \frac{a}{2}$.
4. If $a = 1$, we have reached the solution, so go to step 5 else for further calculations of next day rejections, increment day number as $i = i + 1$ and go to step 2.
5. Print the answers for number of days as $(i + 1)$ and number of candles rejected as $(\text{sum} + 1)$.
6. End.

The step by step process of approaching the solution presented above is called Pseudo Code technique because it uses mathematical expressions those can be directly used in computer program but rest part of the sentences cannot be "as it is" typed in the program.

The graphical presentation of this pseudo code is known as flow chart. Naturally, presentation of flow chart needs some standard symbols listed below :

Name	Purpose	Symbol
Terminal box	Start or Stop of flowchart	
Process box	Mathematical expressions	
User interface	Input from user or output to user	
Diamond box	Decision-making	
Hexagonal box	Loop structure	
Circle	Connector	
Pentagon	Off page connector	
Arrows	Flow lines	
Bracket	Annotation	

Using these symbols, above pseudo code may be converted into flow chart as below :



Flow chart 1

1.2 C PROGRAMMING

As engineering students, you have already learned C programming. In this section, we will revise various functions required in C program.

The outline of C program is always as below :

```

#include<----->
#include<----->
main()
{
    int a;
    float b;
    clrscr();
    printf(-----);
    scanf(-----);
    a = -----;
    b = -----;
    printf(-----);
    getch();
}
  
```

Standard Terms in C Programming

Here, #include statements are required to include predefined codes. These statements are known as pre-processor statements and normally they instruct the compiler to include header files like "stdio.h", "conio.h", "math.h" where various functions like printf(), scanf(), clrscr(), getch(), sqrt() etc are predefined. Next statement is main() which indicates that the program is executed in this MAIN function. We must remember or we must know that there can be other user defined functions which can be called by main(). Further, it is quite compulsory to write complete program inside the pair of curly bracket. The program inside the curly bracket starts with declaration statements. These statements declare names and data types of the variables those will be used in the program.

Then comes clrscr(), which is a statement that clears the program execution screen. The program uses printf() function to instruct user or to display answers. And uses scanf() function to receive data from user.

There can be multiple mathematical expressions or decision making statements or loop structures in a program.

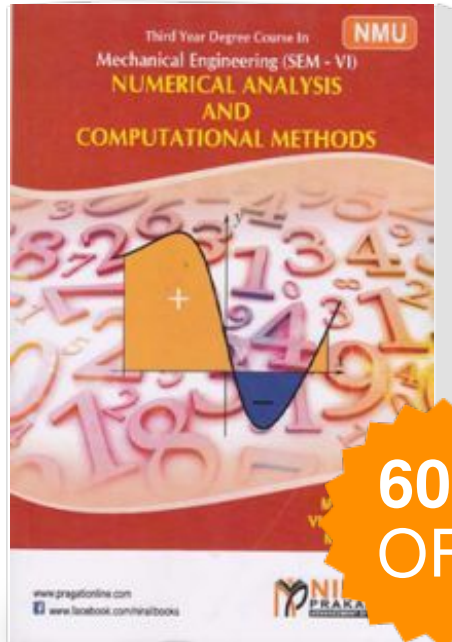
At the end, we observe getch() function which is used to hold the execution screen till user presses any key on the keyboard. Without this statement, program control (compiler) may automatically close the execution screen.

Here, we will develop C program for the problem of candles and then will go in details of datatypes, functions, arithmetic operators, loop structures etc.

Program for the example of rejection of candles :

```
CANDLES.C
#include <stdio.h>
#include <conio.h>
#include <math.h>
main()
{
  int a,i=0,sum=0;
  clrscr();
  flushall();
  printf("*****");
  printf("\n\tTE (Mechanical) CONM Book by");
  printf("\n\tM. T. Puranik & V. N. Chougule");
  printf("\n\t\tNirali Prakashan");
  printf("\n*****");
  printf("\nProgram to find no. of days for ZERO rejections of candles");
  printf("\n*****\n\n");
  printf("Enter first day's rejection: ");
  scanf("%d",&a);
  repeat:
  i++;
```

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Publisher : Nirali Prakashan

ISBN : 9789351644002

Author : M. V. Rawlani, V.
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