KANDULA SRINIVASA REDDY MEMORIAL COLLEGE OF ENGINEERING
(AUTONOMOUS)

KADAPA-516003. AP

(Approved by AICTE, Affiliated to JNTUA, Ananthapuramu, Accredited by NAAC)

(An ISO 9001-2008 Certified Institution)

DEPARTMENT OF CIVIL ENGINEERING

VALUE ADDED COURSE

ON

"COMPUTER AIDED STEEL STRUCTURES"

Resource Person:

Dr. K. Rajashekar, Professor, SAGI-Tirupathi

Course Coordinator:

P. Kishore Kumar Reddy, Assistant Professor, Dept. of CE, KSRMCE

Duration: 19/07/2019 to 06/08/2019

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Kadapa, Andhra Pradesh, India– 516 003

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Lr./KSRMCE/CE/2019-20/ Date: 15-07-2019

To

The Principal,
KSRMCE,
Kadapa.

Sub: Permission to Conduct Value Added Course on "Computer Aided Steel Structures" from 19/07/2019 to 06/08/2019–Req- Reg.

Respected Sir,

The Department of Civil Engineering is planning to offer a Value Added Course on "Computer Aided Steel Structures" to B. Tech. students. The course will be conducted from 19/07/2019 to 06/08/2019. In this regard, I kindly request you to grant permission to conduct the value added course.

Thanking you,

Yours faithfully

P. Kishore Kumar Reddy

(Assistant Professor, CED)

Forwarded to Principal Sir, 15/07/2019

Permitted
V. S. S. Murthy

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Cr./KSRMCE/CE/2019-20/ Date: 16/07/2019

Circular

The Department of Civil Engineering is offering a Value Added Course on "Computer Aided Steel Structures" from 19/07/2019 to 06/08/2019 to B.Tech students. In this regard, interested students are requested to register their names for the Value Added Course with following registration link.

https://docs.google.com/forms/d/e/2FAIpQLSdJGHEz-1v_1TQMk2C-_jvE1gGlOLujiHOiZYn_YKVkppvW0g/viewform

For further information, contact Course Coordinator.

Course Coordinator:
P. Kishore Kumar Reddy,
Assistant Professor,
Department of Civil Engineering,
KSRMCE.

HOD

Dept. of Civil Engineering

Cc to:

IQAC-KSRMCE

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DEPARTMENT OF CIVIL ENGINEERING

List of students registered for Value Added Course on

"Computer Aided Steel Structures" from 19/07/2019 to 06/08/2019

Sl. No.	Roll Number	Name of the student	Semester	Branch
1	169Y1A0137	Kotapati Yogesh	VII	CE
2	169Y1A0146	Medam Sreenivasulu Reddy	VII	CE
3	169Y1A0182	Shaiktappa Sohel Ahmad	VII	CE
4	169Y1A0184	Syed Ameen	VII	CE
5	169Y1A0192	Veluru Janardhan Naidu	VII	CE
6	179Y5A0102	Ammaladinne Rohit Reddy	VII	CE
7	179Y5A0105	Attae Damodhar	VII	CE
8	179Y5A0110	Barigala Kejiya Rani	VII	CE
9	179Y5A0111	Battu Chaithanya Kumar	VII	CE
10	179Y5A0112	Bindela Lakshmi	VII	CE
11	179Y5A0113	Bugulu Somasekharreddy	VII	CE
12	179Y5A0115	Chinnamallugari Malreddy	VII	CE
13	179Y5A0116	Dampetla Ajay	VII	CE
14	179Y5A0119	Golla Madhusiva Yadav	VII	CE
15	179Y5A0121	Gora Pavithra	VII	CE
16	179Y5A0122	Gudlobigandla Subhash	VII	CE
17	179Y5A0123	Guggilla Chenna Kesava Reddy	VII	CE
18	179Y5A0124	Gunisetty Balaji	VII	CE
19	179Y5A0126	Illuru Venkat Sunil	VII	CE
20	179Y5A0127	Indla Harshavardhanreddy	VII	CE
21	179Y5A0128	Iragamreddy Sreenivasula Reddy	VII	CE
22	179Y5A0130	Kakumani Chandra Vinay Kumar	VII	CE
23	179Y5A0131	Kandula Rama Suresh Kumar	VII	CE
24	179Y5A0132	Katigandla Praveen	VII	CE
25	179Y5A0134	Kondreddy Yeswanth Reddy	VII	CE
26	179Y5A0135	Kondreddyvijaybhagathreddy	VII	CE
27	179Y5A0136	Koneti Brahmakalyani	VII	CE
28	179Y5A0137	Kongisi Praveen Kumar	VII	CE
29	179Y5A0138	Kothapalli Kiran Kumar Reddy	VII	CE
30	179Y5A0139	Kummari Pavan Kumar	VII	CE
31	179Y5A0140	Kunduru Sai Prabhath	VII	CE
32	179Y5A0141	Macha Menaka	VII	CE
33	179Y5A0142	Maddi Reddy Neelakanteswara Reddy	VII	CE
34	179Y5A0143	Madiga Veeresh	VII	CE
35	179Y5A0145	Malyavath Sreenivasanaik	VII	CE

36	179Y5A0146	Mancha Katam Raju	VII	CE
37	179Y5A0150	Mugi Shirisha	VII	CE
38	179Y5A0151	Mulamreddy Nageswara Reddy	VII	CE
39	179Y5A0153	Nandyala Madhusudhan Reddy	VII	CE
40	179Y5A0154	Nandyala Venkata Kalyan	VII	CE
41	179Y5A0155	Nikarakanti Mounika	VII	CE
42	179Y5A0156	Nimmala Palli Vidya Sagar Reddy	VII	CE
43	179Y5A0157	Obulareddy Lakshminarasimha Reddy	VII	CE
44	179Y5A0158	Pagadala Munibhaskar	VII	CE
45	179Y5A0159	Palugula Suneel Kumar	VII	CE
46	179Y5A0161	Peteti Balasubbarayudu	VII	CE
47	179Y5A0162	Ponna Nagendra	VII	CE
48	179Y5A0163	Pothireddy Karthik	VII	CE
49	179Y5A0164	Proddatur Dastagiri	VII	CE
50	179Y5A0165	Pullasi Hari Prasad	VII	CE
51	179Y5A0169	Samudrala Chinna Rayudu	VII	CE
52	179Y5A0170	Sane Vineeth Kumar	VII	CE
53	179Y5A0171	Sangati Tejendra Reddy	VII	CE
54	179Y5A0172	Saribala Vijaya Vardhan Reddy	VII	CE
55	179Y5A0173	Savanth Naveen Kumar	VII	CE
56	179Y5A0174	Seela Suneel	VII	CE
57	179Y5A0175	Shaik Nagin Basha	VII	CE
58	179Y5A0176	Siripireddy Mano Chaithanya Kumar Reddy	VII	CE
59	179Y5A0180	Vaddireddy Sivabhargav Reddy	VII	CE
60	179Y5A0181	Vallepu Subbarayudu	VII	CE

Coordinator

HOD

Head
Department of Civil Engineering
K.S.R.M. College of Engineering
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KADAPA - 516 003. (A.P.)

Registration for Value Added Course on "Computer Aided Steel Structures " From 19/07/2019 to 06/08/2019

pkkreddy@ksrmce.ac.in (not shared) Switch account

* Required

Roll Number *

Your answer

Name of the Student *

Your answer

B.Tech Semester *

- I SEM
- II SEM
- III SEM
- IV SEM
- V SEM
- VI SEM
- VII SEM
- VIII SEM

Branch *

- ◯ CIVIL
- ◯ EEE
- ◯ MECH
- ◯ ECE
- ◯ CSE

Email ID *

Your answer

Submit

Clear form

Never submit passwords through Google Forms.

Syllabus of Value Added Course

Course Name: Computer Aided Steel Structures

Course Objectives:

- Gain a comprehensive understanding of steel as a construction material, its properties, and its applications in structural engineering.
- Learn to analyze steel structures for various types of loads and boundary conditions, using both manual calculations and computer-aided tools.
- Develop proficiency in using computer-aided design (CAD) software for creating detailed drawings and 3D models of steel structures.
- Acquire skills in using structural analysis software to model and analyze steel structures, interpreting the results effectively

Course Outcomes: Upon completing the course students will be able to:

- Perform structural analysis of steel structures using both manual methods and structural analysis software, ensuring structural stability and safety.
- Create detailed 2D and 3D models of steel structures using CAD software, facilitating effective communication and visualization of designs.
- Design steel structures in compliance with relevant design codes and standards, accounting for factors such as load combinations and safety margins.
- Analyze and design steel connections, ensuring their integrity and efficiency in transferring loads.

Contents

Module 1:

Introduction to Steel Structures: Overview of steel as a construction material, Types of steel structures, Structural elements and connections, Safety considerations in steel construction, Static equilibrium and loads on structures, Analysis of simple steel structures using hand calculations, Introduction to structural analysis software

Module 2:

Introduction to Computer-Aided Design (CAD) Software: Overview of CAD software for steel structures, Drawing basic steel structural elements, Creating 2D and 3D models of steel structures

Module 3:

Structural Analysis Software: Introduction to structural analysis software, Input data and analysis settings, Analyzing and interpreting results for steel structures.

Module 4:

Structural Design Codes and Standards: Overview of relevant design codes, Load combinations and safety factors, Design criteria for steel structures.

Textbooks:

- "Structural Steel Design" by Jack C. McCormac and Stephen F. Csernak (2016)
- "Steel Design" by William T. Segui (2017)
- "Computer Analysis & Reinforced Concrete Design of Beams" by Fady R. S. Rostom (2017)

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SCHEDULE

Department of Civil Engineering

Value Added Course on "Computer Aided Steel Structures" from 19/07/2019 to 06/08/2019

Date	Timing	Resource Person	Topic to be covered
19/07/2019	4 PM to 6 PM	Dr. K. Rajashekar	Overview of steel as a construction material
20/07/2019	4 PM to 6 PM	Dr. K. Rajashekar	Types of steel structures, Structural elements and connections
21/07/2019	9 AM to 4 PM	Dr. K. Rajashekar	Safety considerations in steel construction, Static equilibrium and loads on structures Analysis of simple steel structures using hand calculations
22/07/2019	4 PM to 6 PM	Dr. K. Rajashekar	Introduction to structural analysis software
23/07/2019	4 PM to 6 PM	Dr. K. Rajashekar	Overview of CAD software for steel structures
24/07/2019	4 PM to 6 PM	Dr. K. Rajashekar	Drawing basic steel structural elements
25/07/2019	4 PM to 6 PM	Dr. K. Rajashekar	Creating 2D and 3D models of steel structures
26/07/2019	4 PM to 6 PM	Dr. K. Rajashekar	Creating 2D and 3D models of steel structures
27/07/2019	4 PM to 6 PM	Dr. K. Rajashekar	Creating 2D and 3D models of steel structures
28/07/2019	9 AM to 4 PM	Dr. K. Rajashekar	Introduction to structural analysis software
29/07/2019	4 PM to 6 PM	Dr. K. Rajashekar	Input data and analysis settings
30/07/2019	4 PM to 6 PM	Dr. K. Rajashekar	Input data and analysis settings
31/07/2019	4 PM to 4 PM	Dr. K. Rajashekar	Analyzing and interpreting results for steel structures
01/08/2019	4 PM to 6 PM	Dr. K. Rajashekar	Analyzing and interpreting results for steel structures
02/08/2019	4 PM to 6 PM	Dr. K. Rajashekar	Overview of relevant design codes
03/08/2019	4 PM to 6 PM	Dr. K. Rajashekar	Load combinations and safety factors
04/08/2019	9 AM to 4 PM	Dr. K. Rajashekar	Load combinations and safety factors
05/08/2019	4 PM to 6 PM	Dr. K. Rajashekar	Design criteria for steel structures
06/08/2019	4 PM to 6 PM	Dr. K. Rajashekar	Design criteria for steel structures

Resource Person(s) Coordinator(s) HOD

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ESTD: 1980

DEPARTMENT OF CIVIL ENGINEERING

Value Added Course

on

"Computer Aided Steel Structures"

Resource Person

Dr. K. Rajashekar, Professor,
SAGI-Tirupathi

Date

From 19/07/2019
to 06/08/2019

Coordinator

P. Kishore Kumar Reddy,
Department of Civil Engineering

Venue

CADD LAB,
Department of Civil Engg.

K.S.R.M. COLLEGE OF ENGINEERING

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Report of
Value Added Course on "Computer Aided Steel Structures"
From 19/07/2019 to 06/08/2019

Target Group	:	**B. Tech. Students**
Details of Participants	:	**55 Students**
Co-coordinator(s)	:	**P. Kishore Kumar Reddy**
Resource Person(s)	:	**Dr. K. Rajashekar**
Organizing Department	:	**Civil Engineering**
Venue	:	**CADD Lab, Department of Civil Engineering**

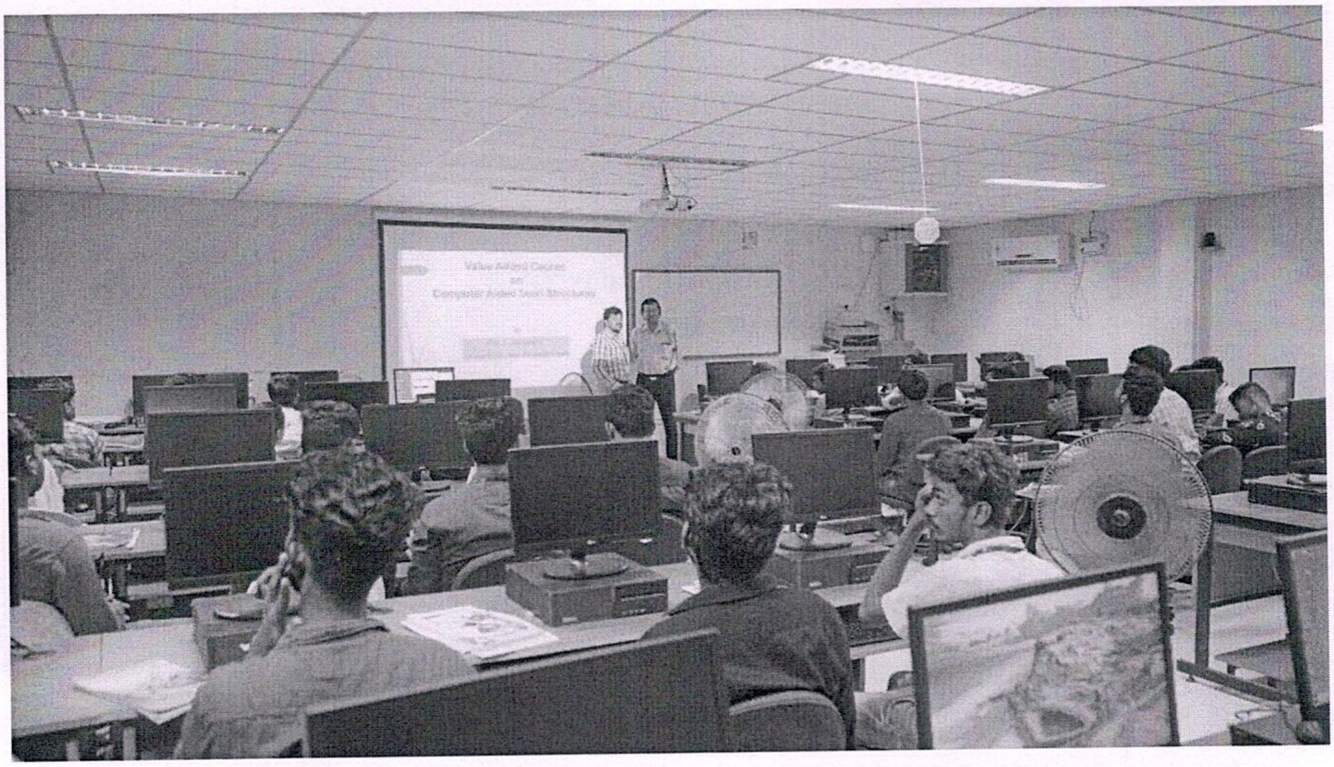
Description:

The Department of Civil Engineering conducted a Value Added Course on "Computer Aided Steel Structures" from 19th Jul 2019 to 6th Aug 2019. The course was instructed by Dr. K. Rajashekar, Professor, SAGI-Tirupathi and coordinated by P. Kishore Kumar Reddy, Assistant Professor, Department Civil Engineering, KSRMCE.

Computer-Aided Steel Structures hold paramount importance in the realm of structural engineering and construction for various compelling reasons. Firstly, they usher in unprecedented efficiency and accuracy into the design and analysis of steel structures. Advanced software packages enable engineers to meticulously model complex steel structures, reducing the risk of errors and ensuring precision in calculations and blueprints. This not only enhances the safety and durability of the structures but also optimizes resource utilization, saving both time and costs in the construction process. Secondly, the use of computer-aided tools empowers engineers to tackle intricate geometries with ease. Steel structures often encompass intricate and irregular shapes, which can be challenging to handle manually. CAD software simplifies the modeling and visualization of such geometries, thereby facilitating the realization of innovative and aesthetically pleasing designs. Furthermore, it fosters better collaboration among multidisciplinary teams and enables stakeholders to visualize the end product more comprehensively, resulting in superior decision-making and project outcomes. In essence, Computer-Aided Steel Structures represent a transformative advancement in the field, driving efficiency, precision, and innovation in structural engineering and construction endeavors.

Photos:

The picture taken during the course is given below:



Introduction to Computer Aided Steel Structures by Prof. K. Rajashekar

Coordinator(s)

HoD

Head
Department of Civil Engineering
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Attendance sheet of Value Added Course on "Computer Aided Steel Structures"

Sl. No.	Roll No.	Name	19/07/2019	20/07/2019	21/07/2019	22/07/2019	23/07/2019	24/07/2019	25/07/2019	26/07/2019	27/07/2019	28/07/2019	29/07/2019	30/07/2019	31/07/2019	01/08/2019	02/08/2019	03/08/2019	04/08/2019	05/08/2019	06/08/2019
1	179Y5A0102	Ammaladinne Rohit Reddy																			
2	179Y5A0105	Attae Damodhar		a																	
3	179Y5A0110	Barigala Kejiya Rani							a												
4	179Y5A0111	Battu Chaithanya Kumar																			
5	179Y5A0112	Bindela Lakshmi					a														
6	179Y5A0113	Bugulu Somasekharreddy															a				
7	179Y5A0115	Chinnamallugari Malreddy																			

8	179Y5A0116	Dampetla Ajay																			
9	179Y5A0119	Golla Madhusiva Yadav														a					
10	179Y5A0121	Gora Pavithra																			
11	179Y5A0122	Gudlobigandla Subhash		a																	
12	179Y5A0123	Guggilla Chenna Kesava Reddy							a												
13	179Y5A0124	Gunisetty Balaji																			
14	179Y5A0126	Illuru Venkat Sunil																			
15	179Y5A0127	Indla Harshavardhanreddy				a															
16	179Y5A0128	Iragamreddy Sreenivasula Reddy																			
17	179Y5A0130	Kakumani Chandra Vinay Kumar									a						a				
18	179Y5A0131	Kandula Rama Suresh Kumar																			
19	179Y5A0132	Katigandla Praveen																	a		
20	179Y5A0134	Kondreddy Yeswanth Reddy													a				a		

21	179Y5A0135	Kondreddyvijay bhagathreddy																			
22	179Y5A0136	Koneti Brahmakalyani																			
23	179Y5A0137	Kongisi Praveen Kumar																			
24	179Y5A0138	Kothapalli Kiran Kumar Reddy			a																
25	179Y5A0139	Kummari Pavan Kumar																			
26	179Y5A0140	Kunduru Sai Prabhath																			
27	179Y5A0141	Macha Menaka																			
28	179Y5A0142	Maddi Reddy Neelakanteswar a Reddy			a																
29	179Y5A0143	Madiga Veeresh																			
30	179Y5A0145	Malyavath Sreenivasanaik																a			
31	179Y5A0146	Mancha Katam Raju								a											
32	179Y5A0150	Mugi Shirisha																			
33	179Y5A0151	Mulamreddy Nageswara Reddy																	a		
34	179Y5A0153	Nandyala Madhusudhan Reddy																			

35	179Y5A0154	Nandyala Venkata Kalyan																			
36	179Y5A0155	Nikarakanti Mounika						a													
37	179Y5A0156	Nimmala Palli Vidya Sagar Reddy																			
38	179Y5A0157	Obulareddy Lakshminarasimha Reddy															a				
39	179Y5A0158	Pagadala Munibhaskar																			
40	179Y5A0159	Palugula Suneel Kumar																			
41	179Y5A0161	Peteti Balasubbarayudu																			
42	179Y5A0162	Ponna Nagendra							a												
43	179Y5A0163	Pothireddy Karthik																			
44	179Y5A0164	Proddatur Dastagiri											a								
45	179Y5A0165	Pullasi Hari Prasad																			
46	179Y5A0169	Samudrala Chinna Rayudu																	a		
47	179Y5A0170	Sane Vineeth Kumar													a						
48	179Y5A0171	Sangati Tejendra Reddy																			

49	179Y5A0172	Saribala Vijaya Vardhan Reddy																			
50	179Y5A0173	Savanth Naveen Kumar					a									a					
51	179Y5A0174	Seela Suneel									a										
52	179Y5A0175	Shaik Nagin Basha																	a		
53	179Y5A0176	Siripireddy Mano Chaithanya Kumar Reddy													a						
54	179Y5A0180	Vaddireddy Sivabhargav Reddy					a														
55	179Y5A0181	Vallepu Subbarayudu																			

Coordinator(s)

HoD

Head
Department of Civil Engineering
K.S.R.M. College of Engineering
(Autonomous)
KADAPA - 516 003. (A.P.)

Feedback form on Value Added Course "Computer Aided Steel Structures" from **19/07/2019 to 06/08/2019**

pkkreddy@**ksrmce.ac.in** (not shared) Switch account

* Required

Roll Number *

Your answer

Name of the Student *

Your answer

The objectives of the Value Added Course were met*

- Excellent
- Good
- Satisfactory
- Poor

The content of the course was organized and easy to follow*

- Excellent
- Good
- Satisfactory
- Poor

The Resource Person was well prepared and able to answer any question *

- Excellent
- Good
- Satisfactory
- Poor

The exercises/role play were helpful and relevant *

- Excellent
- Good
- Satisfactory
- Poor

The Value Added Course satisfy my expectation as a value added Programme *

- Excellent
- Satisfactory
- Good
- Poor

Any other comments

Your answer

Submit

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Feedback of Value Added Course on "Computer Aided Steel Structures"

Sl. No.	Roll No.	Name	The objectives of the Value Added Course were met	The content of the course was organized and easy to follow	The Resource Person was well prepared and able to answer any question	The exercises/role play were helpful and relevant	The Value Added Course satisfy my expectation as a value added Programme
1	179Y5A0102	Ammaladinne Rohit Reddy	Excellent	Good	Excellent	Excellent	Excellent
2	179Y5A0105	Attae Damodhar	Good	Excellent	Excellent	Excellent	Excellent
3	179Y5A0110	Barigala Kejiya Rani	Excellent	Good	Good	Good	Excellent
4	179Y5A0111	Battu Chaithanya Kumar	Good	Excellent	Excellent	Excellent	Excellent
5	179Y5A0112	Bindela Lakshmi	Good	Excellent	Excellent	Excellent	Excellent
6	179Y5A0113	Bugulu Somasekharreddy	Good	Excellent	Excellent	Excellent	Excellent
7	179Y5A0115	Chinnamallugari Malreddy	Excellent	Excellent	Good	Excellent	Excellent
8	179Y5A0116	Dampetla Ajay	Excellent	Good	Excellent	Excellent	Good
9	179Y5A0119	Golla Madhusiva Yadav	Excellent	Good	Excellent	Excellent	Excellent
10	179Y5A0121	Gora Pavithra	Good	Good	Excellent	Good	Excellent

11	179Y5A0122	Gudlobigandla Subhash	Excellent	Satisfactory	Good	Good	Excellent
12	179Y5A0123	Guggilla Chenna Kesava Reddy	Excellent	Excellent	Excellent	Excellent	Good
13	179Y5A0124	Gunisetty Balaji	Excellent	Good	Excellent	Excellent	Excellent
14	179Y5A0126	Illuru Venkat Sunil	Good	Excellent	Excellent	Excellent	Excellent
15	179Y5A0127	Indla Harshavardhanreddy	Excellent	Good	Good	Good	Excellent
16	179Y5A0128	Iragamreddy Sreenivasula Reddy	Good	Excellent	Excellent	Excellent	Excellent
17	179Y5A0130	Kakumani Chandra Vinay Kumar	Good	Excellent	Excellent	Excellent	Excellent
18	179Y5A0131	Kandula Rama Suresh Kumar	Good	Excellent	Excellent	Excellent	Excellent
19	179Y5A0132	Katigandla Praveen	Excellent	Excellent	Excellent	Excellent	Excellent
20	179Y5A0134	Kondreddy Yeswanth Reddy	Excellent	Good	Excellent	Excellent	Good
21	179Y5A0135	Kondreddyvijaybhagathreddy	Excellent	Good	Excellent	Excellent	Excellent
22	179Y5A0136	Koneti Brahmakalyani	Good	Excellent	Excellent	Good	Excellent
23	179Y5A0137	Kongisi Praveen Kumar	Excellent	Excellent	Good	Excellent	Good
24	179Y5A0138	Kothapalli Kiran Kumar Reddy	Excellent	Excellent	Good	Good	Excellent
25	179Y5A0139	Kummari Pavan Kumar	Good	Good	Excellent	Excellent	Good
26	179Y5A0140	Kunduru Sai Prabhath	Excellent	Excellent	Excellent	Good	Excellent
27	179Y5A0141	Macha Menaka	Good	Excellent	Excellent	Good	Excellent

28	179Y5A0142	Maddi Reddy Neelakanteswara Reddy	Excellent	Excellent	Good	Good	Excellent
29	179Y5A0143	Madiga Veeresh	Excellent	Excellent	Excellent	Good	Excellent
30	179Y5A0145	Malyavath Sreenivasanaik	Good	Excellent	Excellent	Excellent	Excellent
31	179Y5A0146	Mancha Katam Raju	Excellent	Good	Excellent	Excellent	Excellent
32	179Y5A0150	Mugi Shirisha	Good	Excellent	Excellent	Good	Excellent
33	179Y5A0151	Mulamreddy Nageswara Reddy	Excellent	Excellent	Excellent	Excellent	Good
34	179Y5A0153	Nandyala Madhusudhan Reddy	Good	Good	Excellent	Good	Good
35	179Y5A0154	Nandyala Venkata Kalyan	Good	Excellent	Good	Excellent	Excellent
36	179Y5A0155	Nikarakanti Mounika	Good	Good	Excellent	Good	Excellent
37	179Y5A0156	Nimmala Palli Vidya Sagar Reddy	Good	Excellent	Good	Good	Excellent
38	179Y5A0157	Obulareddy Lakshminarasimha Reddy	Excellent	Good	Excellent	Good	Good
39	179Y5A0158	Pagadala Munibhaskar	Excellent	Good	Good	Excellent	Excellent
40	179Y5A0159	Palugula Suneel Kumar	Excellent	Good	Excellent	Excellent	Excellent
41	179Y5A0161	Peteti Balasubbarayudu	Excellent	Good	Excellent	Good	Excellent
42	179Y5A0162	Ponna Nagendra	Good	Excellent	Excellent	Good	Excellent
43	179Y5A0163	Pothireddy Karthik	Excellent	Satisfactory	Excellent	Good	Excellent
44	179Y5A0164	Proddatur Dastagiri	Excellent	Excellent	Excellent	Excellent	Good

45	179Y5A0165	Pullasi Hari Prasad	Excellent	Good	Good	Excellent	Excellent
46	179Y5A0169	Samudrala Chinna Rayudu	Good	Excellent	Good	Excellent	Excellent
47	179Y5A0170	Sane Vineeth Kumar	Excellent	Good	Excellent	Good	Excellent
48	179Y5A0171	Sangati Tejendra Reddy	Good	Good	Excellent	Excellent	Excellent
49	179Y5A0172	Saribala Vijaya Vardhan Reddy	Excellent	Good	Excellent	Excellent	Good
50	179Y5A0173	Savanth Naveen Kumar	Good	Good	Good	Excellent	Excellent
51	179Y5A0174	Seela Suneel	Excellent	Good	Excellent	Good	Excellent
52	179Y5A0175	Shaik Nagin Basha	Good	Excellent	Excellent	Good	Excellent
53	179Y5A0176	Siripireddy Mano Chaithanya Kumar Reddy	Excellent	Satisfactory	Excellent	Good	Excellent
54	179Y5A0180	Vaddireddy Sivabhargav Reddy	Excellent	Good	Excellent	Good	Excellent
55	179Y5A0181	Vallepu Subbarayudu	Good	Excellent	Excellent	Good	Excellent

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Course Duration: 50 Hours;
From: 19/07/2019 to 06/08/2019

Course Instructor:
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Chapter 1
Introduction

The development of mankind has depended on the ability to modify and shape the material that nature has made available, in ways to provide them their basic needs, and security and comfort required for their survival and advancement. They have devised tools for hunting, implements for agriculture, shelter for safeguard against the vagaries of nature, and wheels for transportation, an invention mankind has always been proud of. Much of the aforementioned *design* accomplishments have resulted even before mankind may have learnt to count. The then trial-and-error and/or empirical design procedures have been systematized to a great extent using the human understanding of the laws of physics (on force, motion and/or energy transfer) with concepts from mathematics. An idea to fulfill a need and then translating the idea into an implement forms the core of activities in design. *Design and manufacture is innate to the growth of human civilization.*

1.1 Engineering Design

Design is an activity that facilitates the realization of new products and processes through which technology satisfies the needs and aspirations of the society. Engineering design of a product may be conceived and evolved in four steps:

1. *Problem definition:* Extracting a coherent appreciation of *need* or *function* of an engineering part from a fuzzy mix of facts and myths that result from an initial ill-posed problem. The data collection can be done via *observation* and/or a *detailed survey*.
2. *Creative process:* Synthesizing *form*, a design solution to satisfy the need. Multiple solutions may result (and are sought) as the creative thought process is aided by the designers' vast experience and knowledge base. *Brainstorming* is usually done in groups to arrive at various forms which are then evaluated and selected into a set of a few workable solutions.
3. *Analytical process: Sizing* the components of the designed *forms*. Requisite functionality, strength and reliability analysis, feasible manufacturing, cost determination and environmental impact may be some design goals that could be improved optimally by altering the components' dimensions and/or material. This is an iterative process requiring design changes if the analysis shows inadequacy, or scope for further improvement of a particular design. Multiple solutions may be evaluated simultaneously or separately and the *best* design satisfying most or all functional needs may be chosen.
4. *Prototype development and testing:* Providing the ultimate check through physical evaluation under, say, an actual loading condition before the design goes for production. Design changes are

needed in the step above in case the prototype fails to satisfy a set of needs in step 1. This stage forms an interface between design and manufacture. Many groups encourage prototype failure as many times as possible to quickly arrive at a successful design.

1.2 Computer as an Aid to the Design Engineer

Machines have been designed and built even before the advent of computers. During World War-II, ships, submarines, aircrafts and missiles were manufactured on a vast scale. In the significant era (19th and 20th century) of industrial revolution, steam engines, water turbines, railways, cars and power-driven textile mills were developed. The method of representing three-dimensional solid objects was soon needed and was formalized through orthographic projections by a French mathematician Gaspard Monge (1746-1818). After the military kept it a secret for nearly half a century, the approach was made available to engineers, in general, towards the end of nineteenth century.

The inception of modern computers lies in the early work by Charles Babbage (1822), punched card system developed for the US census by Herman Hollerith (1890), differential analyzer at MIT (1930), work on programmable computers by Allan Turing (1936), program storage concept and re-programmable computers by John von Neumann (1946) and micro-programmed architecture by Maurice Wilkes (1951).

The hardware went through a revolution from electronic tubes, transistors (1953), semi-conductors (1953), integrated circuits (1958) to microprocessors (1971). The first 8-bit microcomputer was introduced in 1976 with the Intel 8048 chip and subsequently 16 and 32-bit ones were introduced in 1978 and 1984. Currently, 32 bit and 64 bit PCs are used. Tremendous developments have taken place in hardware, especially in the microprocessor technology, storage devices (20 to 80 GB range), memory input/output devices, compute speed (in GHz range) and enhanced power of PCs and workstations, enabling compactness and miniaturization. The display technology has also made significant advances from its bulky Cathode Ray Tube (CRT) to Plasma Panel and LCD flat screen forms.

Interactive Computer Graphics (ICG) was developed during the 1960s. Sutherland (1962) devised the Sketchpad system with which it was possible to create simple drawings on a CRT screen and make changes interactively. By mid 1960s, General Motors (GM), Lockheed Aircraft and Bell Laboratories had developed DAC-1, CADAM and GRAPHIC-1 display systems. By late 1960s, the term Computer Aided Design (CAD) was coined in literature. During 1970s, graphics standards were introduced with the development of GKS (Graphics Kernel System), PHIGS (Programmer's Hierarchical Interface for Graphics) and IGES (Initial Graphics Exchange Specification). This facilitated the graphics file and data exchange between various computers. CAD/CAM software development occurred at a fast rate during late 1970s (GMSolid, ROMULUS, PADL-2). By 1980s and 1990s, CAD/CAM had penetrated virtually every industry including Aerospace, Automotive, Construction, Consumer products, Textiles and others. Software has been developed over the past two decades for interactive drawing and drafting, analysis, visualization and animation. A few widely used products in Computer Aided Design and drafting are Pro-Engineer™, AutoCAD™, CATIA™, IDEAS™, and in analysis are NASTRAN™, ABAQUS™, ANSYS™ and ADAMS™. Many of these softwares have/are being planned to be upgraded for potential integration of design, analysis, optimization and manufacture.

1.2.1 Computer as a Participant in a Design Team

As it stands, a computer has been rendered a major share of the design process in a man-machine team. It behooves to understand the role of a human vis-à-vis a computer in this setting:

(a) *Conceptualization*, to date, is considered still within the domain of a human designer. Product design commences with the identification of its 'need' that may be based on consumer's/market's demand. An old product may also need design revision in view of new scientific and technological developments. An expert designer or a team goes through a creative and ingenious thought process (brainstorming), mostly qualitative, to synthesize the form of a product. A computer has not been rendered the capability, as yet, to capture non-numeric, qualitative 'thought' design, though it can help a human designer by making available relevant information from its stored database.
(b) *Search, learning and intelligence* is inherent more in a human designer who can be made aware of the new technological developments useful to synthesize new products. A computer, at this time, has little learning and 'qualitative thinking' capability and is not intelligent enough to synthesize a new form on its own. However, it can passively assist a designer by making available a large set of possibilities (stored previously) from a variety of disciplines, and narrow down the search domain for the designer.
(c) *Information storage and retrieval* can be performed very efficiently by a computer that has an excellent capability to store and handle data. Human memory can fade or fail to avail appropriate information fast enough, and at the right time from diverse sources. Further, a computer can automatically create a product database in final stages of the design.
(d) *Analytical power* in a computer is remarkable in that it can perform, say, the finite element analysis of a complex mechanical part or retrieve the input/output characteristics of a designed system very efficiently, provided mathematical models are embedded. Humans usually instruct the computers, via codes or software, the requisite mathematical models employed in *geometric modeling* (modeling of curves, surfaces and solids) and *analysis* (finite element method and optimization). Geometric modeling manifests the *form* of a product that a designer has in mind (qualitatively) while analysis works towards the systematic improvement of that *form*.
(e) *Design iteration* and improvement can be performed by a computer very efficiently once the designer has offloaded his/her conception of a product via geometric modeling. Finite element analysis (or other performance evaluation routine) and optimization can be performed simultaneously with the aim to modify the dimensions/shape of a product to meet the pre-specified design goals.
(f) *Prototyping* of the optimized design can be accomplished using the tools now available for Rapid Manufacturing. The geometric information of the final product can be passed on to a manufacturing set up that would analogically *print* a three dimensional product.

Computers help in manifesting the qualitative conception of a design form a human has of a product. Further, they prove useful in iterative improvement of the design, and its eventual realization. Computers are integrated with humans in design and manufacture, and provide the scope for automation (or least human interaction) wherever needed (mainly in analysis and optimization). Computer Aided Process Planning (CAPP), scheduling (CAS), tool design (CATD), material requirement planning (MRP), tool path generation for CNC machining, flexible manufacturing system (FMS), robotic systems for assembly and manufacture, quality inspection, and many other manufacturing activities also require computers.

1.3 Computer Graphics

Computer Graphics, which is a discipline within Computer Science and Engineering, provides an important mode of interaction between a designer and computer. Sutherland developed an early form of a computer graphic system in 1963. Rogers and Adams explain computer graphics as the *use* *of computers to define, store, manipulate, interrogate and present pictorial output*. Computer graphics involves the creation of two and three dimensional models, shading and rendering to bring in realism to the objects, natural scene generation (sea-shores, sand dunes or hills and mountains), animation, flight simulation for training pilots, navigation using graphic images, walk through buildings, cities and highways, and creating virtual reality. War gaming, computer games, entertainment industry and advertising has immensely benefited from the developments in computer graphics. It also forms an important ingredient in Computer-Aided Manufacturing (CAM) wherein graphical data of the object is converted into machining data to operate a CNC machine for production of a component. The algorithms of computer graphics lay behind the backdrop all through the process of virtual design, analysis and manufacture of a product. Two primary constituents of computer graphics are the *hardware* and the *software*.

1.3.1 Graphics Systems and Hardware

Hardware comprises the *input*, and *display* or *output devices*. Numerous types of graphics systems are in use: those that model one-to-many interaction and others that allow one-to-one interface at a given time. *Mainframe-based systems* use a large mainframe computer on which the software, which is usually a huge code requiring large space for storage, is installed. The system is networked to many designer stations on time-sharing basis with display unit and input devices for each designer. With this setting, intricate assemblies of engineering components, say an aircraft, requiring many human designers can be handled. *Minicomputer* or *Workstation* based systems are smaller in scale than the Mainframe systems with a limited number (one or more) of display and input devices. Both systems employ one-to-many interface wherein more than one designer can interact with a computer. On the contrary, *Microcomputer* (PC) based systems allow only one-to-one interaction at a time. Between the Mainframe, Workstation and PC based systems, the Workstation based system offers advantages of distributed computing and networking potential with lower cost compared with the mainframes.

1.3.2 Input Devices

Keyboard and *mouse* are the primary input devices. In a more involved environment, digitizers, joysticks and tablets are also used. Trackballs and input dials are used to produce complex models. Data gloves, image scanners, touch screens and light pens are some other input devices. A keyboard is used for submitting alphanumeric input, three-dimensional coordinates, and other non-graphic data in 'text' form. A mouse is a small hand held pointing device used to control the position of the cursor on the screen. Below the mouse is a ball. When the mouse is moved on a surface, the amount and direction of movement of the cursor is proportional to that of the mouse. In optical mouse, an optical sensor moving on a special mouse pad having orthogonal grids detects the movements. There are push buttons on top of the mouse beneath the fingers for signaling the execution of an operation, for selecting an object created on the screen within a rectangular area, for making a selection from the pulled down menu, for dragging an object from one part of the screen to other, or for creating drawings and dimensioning. It is an important device used to expedite the drawing operations. A special z-mouse for CAD, animation and virtual reality includes three buttons, a thumb-wheel and a track-ball on top. It gives six degrees of freedom for spatial positioning in x-y-z directions. The z-mouse is used for rotating the object around a desired axis, moving and navigating the viewing position (observer's eye) and the object through a three-dimensional scene.

Trackballs, *space-balls* and *joysticks* are other devices used to create two and three-dimensional drawings with ease. Trackball is a 2-D positioning device whereas space-ball is used for the same in 3-D. A joystick has a vertical lever sticking out of a base box and is used to navigate the screen cursor.

Digitizers are used to create drawings by clicking input coordinates while holding the device over a given 2-D paper drawing. Maps and boundaries in a survey map, for example, can be digitized to create a computer map. *Touch panels* and *light pens* are input devices interacting directly with the computer screen. With touch panels, one can select an area on the screen and observe the details pertaining to that area. They use infrared light emitting diodes (LEDs) along vertical and horizontal edges of the screen, and go into action due to an interruption of the beam when a finger is held closer to the screen. Pencil shaped *light pens* are used to select screen position by detecting the light from the screen. They are sensitive to the short burst of light emitted from the phosphor coating as the electron beam hits the screen. *Scanners* are used to digitize and input a two-dimensional photographic data or text for computer storage or processing. The gradations of the boundaries, gray scale or color of the picture is stored as data arrays which can be used to edit, modify, crop, rotate or scale to enhance and make suitable changes in the image by software designed using geometric transformations and image processing techniques.

FaroArm®, a 3-D coordinate measuring device, is a multi-degree of freedom precision robotic arm attached to a computer. At the tip of the end-effector is attached a fine roller-tipped sensor. The tip can be contacted at several points on a curved surface to generate a point data cloud. A 3-D surface can then be fitted through the data cloud to generate the desired surface. A non-contact 3-D digitizer, Advanced Topometric Sensor (ATOS) uses optical measuring techniques. It is material independent and can scan in three-dimensions any arbitrary object such as moulds, dies, and sculptures. It is a high detailed resolution and precision machine. It uses adhesive retro targets stuck on the desired surface. Digital reflex cameras then record the positions of these retro targets from different views. The images consisting of the coordinates of targets are transferred from the digital camera to the computer. The image coordinates are then converted to the object coordinates by calculating the intersection of the rays from different camera positions. Finally, the required object surface is generated. Techniques for scanning objects in three-dimensions are very useful in reverse engineering, rapid prototyping of existing objects with complex surfaces such as sculptures and other such applications.

1.3.3 Display and Output Devices

Three types of display devices are in use: Cathode ray tube (*CRT*), Plasma Panel Display (PPD) and Liquid Crystal Display (LCD). CRT is a popular display device in use for its low cost and high-resolution color display capabilities. It is a glass tube with a front rectangular panel (screen) and a cylindrical rear tube. A cathode ray gun, when electrically heated, gives out a stream of electrons, which are then focused on the screen by means of positively charged electron-focusing lenses. The position of the focused point is controlled by orthogonal (horizontally and vertically deflecting) set of amplifiers arranged in parallel to the path of the electron beam. A popular method of CRT display is the Raster Scan. In raster scan, the entire screen is divided into a matrix of picture cells called *pixels*. The distance between pixel centers is about 0.25 mm. The total number of pixel sets is usually referred to as *resolution*. Commonly used CRTs are those with resolution of 640 × 480 (VGA), 1024 × 768 (XGA) and 1280 × 1024 (SXGA). With higher resolution, the picture quality is much sharper. As the focused electron beam strikes a pixel, the latter emits light, i.e. the pixel is 'on' and it becomes bright for a small duration of time. The electron beam is made to scan the entire screen line-by-line from top to bottom (525 horizontal lines in American system and 625 lines in European system) at 63.5 microseconds per scan line. The beam keeps on retracing the path. The *refresh rate* is 60Hz, implying that the screen is completely scanned in $1/60^{th}$ of a second (for European system, it is $1/50^{th}$ of a second). In a black and white display, if the pixel intensity is '0', the pixel appears black, and when '1', the pixel is bright. As the electron beam scans through the entire screen, it switches off those pixels which are supposed to be black thus creating a pattern on the screen. For the electron beam to know precisely which pixels are to be kept 'off' during scans, a *frame buffer* is used that is a hardware programmable memory. At least one memory bit ('0' or '1') is needed for each pixel, and there are as many bits allocated in the memory as the number of pixels on display. The entire memory required for displaying all the pixels is called a *bit plane* of the frame buffer.

One bit plane would create only a 'black' and 'white' image, but for a realistic picture, one would need *gray levels* or shades between black and white as well. To control the intensity (or shade) of a pixel one has to use a number of bit planes in a frame buffer. For example, if one uses 3 bit planes in single frame buffer, one can create 8 (or 2^3) combinations of intensity levels (or shades) for the same pixel- 000 (black)-001-010- 011-100-101-110-111(white). The intermediate values will control the intensity of the electron beam falling on the pixel. To have an idea about the amount of memory required for a black and white display with 256×256 (or 2^{16}) pixels, every bit plane will require a memory of $2^{16} = 65{,}536$ bits. If there are 3 bit planes to control the gray levels, the memory required will be 1,96,608 bits! Since memory is a digital device and the raster action is analog, one needs digital-to-analog converters (DAC). A DAC takes the signal from the frame buffer and produces an equivalent analog signal to operate the electron gun in the CRT.

For *color display*, all colors are generated by a proper combination of 3 basic colors, viz. red, green, and blue. If we assign '0' and '1' to each color in the order given, we can generate 8 colors: black (000), red (100), green (010), blue (001), yellow (110), cyan (011), magenta (101) and white (111). The frame buffer requires a minimum of 3 bit planes—one for each RGB color; this can generate 8 different colors. If more colors are desired, one needs to increase the number of bit planes for each color. For example, if each of the RGB colors has 8 bit planes (a total of 24 bit planes in the frame buffer with three 8-bit DAC), the total number of colors available for picture display would be 2^{24} = 1,67,77,216! To further enhance the color capabilities, each 8-bit DAC is connected to a color look up memory table. Various methods are employed to decrease the access and display time and enhance the picture sharpness.

CRT displays are popular and less costly, but very bulky and suitable only for desktop PCs. Flat Panel Displays (FPD) are gaining popularity with laptop computers and other portable computers and devices. FPD belongs to one of the following two classes: (a) active FPD devices, which are primarily light emitting devices. Examples of active FPD are flat CRT, plasma gas discharge, electroluminescent and vacuum fluorescent displays. (b) Passive FPD devices are based on light modulating technologies. Liquid Crystal (LC) and Light Emitting Diodes (LED) are some examples.

Plotters and *printers* constitute the output devices. Line printers are the oldest succeeded by 9-pin and 24-pin *dot matrix plotters* and printers. *Ink jet plotters*, *laser plotters* and *thermal plotters* are used for small and medium sized plots. For large plots, *pen and ink plotters* of the flat bed, drum and pinch roller types are used.

1.4 Graphics Standards and Software

Till around 1973, software for producing graphics was mostly device dependent. Graphics software written for one type of hardware system was not portable to another type, or it became useless if the hardware was obsolete. Graphics standards were set to solve portability issues to render the application software device independent. Several standards have been developed; most popular among them are GKS (Graphics Kernel System), PHIGS (Programmer's Hierarchical Interactive Graphics System), DXF (Drawing Exchange Format), and IGES (Initial Graphics Exchange Specification).

For designing mechanical components and systems, one requires 3-D graphics capabilities for which GKS 3-D, PHIGS and DXF are suitable. For 3-D graphics and animation, PHIGS is used.

It provides high interactivity, hierarchical data structuring, real time graphic data modification, and support for geometric transformations. These standards provide the core of graphics including basic graphic primitives such as line, circle, arc, poly-lines, poly-markers, line-type and line-width, text, fill area for hatching and shading, locators for locating coordinates, valuators for real values for dimensioning, choice options and strings. Around such standard primitives, almost all standard software for CAD is written. They also include the device drivers for standard plotters and display devices.

Another comprehensive standard is IGES to enable the exchange of model databases among CAD/CAM systems. IGES contains more geometric entities such as, curves, surfaces, solid primitives, and Boolean (for Constructive Solid Geometry) operations. Wire-frame, surface modeling and solid modeling software can all be developed around IGES. It can transmit the property data associated with the drawings which helps in preparing, say, the bill of materials. Though these standards appear veiled or at the *back end*, they play a crucial role in creation of the application software.

1.5 Designer-Computer Interaction

A CAD/CAM software is designed to be primarily interactive, instructive and user-friendly wherein a designer can instruct a computer to perform a sequence of tasks ranging from designing to manufacture of an engineering component. The front end of a software is a graphical user interface or GUI while the back end comprises computation and database management routines. The front end is termed so as a user can visually observe the design operations being performed. However, computation and data storage routines are not very apparent to a designer, which is why they may be termed collectively as the back end of the software. In most CAD software, the GUI is divided into two parts (or windows) that appear on the display device or screen (Figure 1.1): (i) the visual manifestation or the

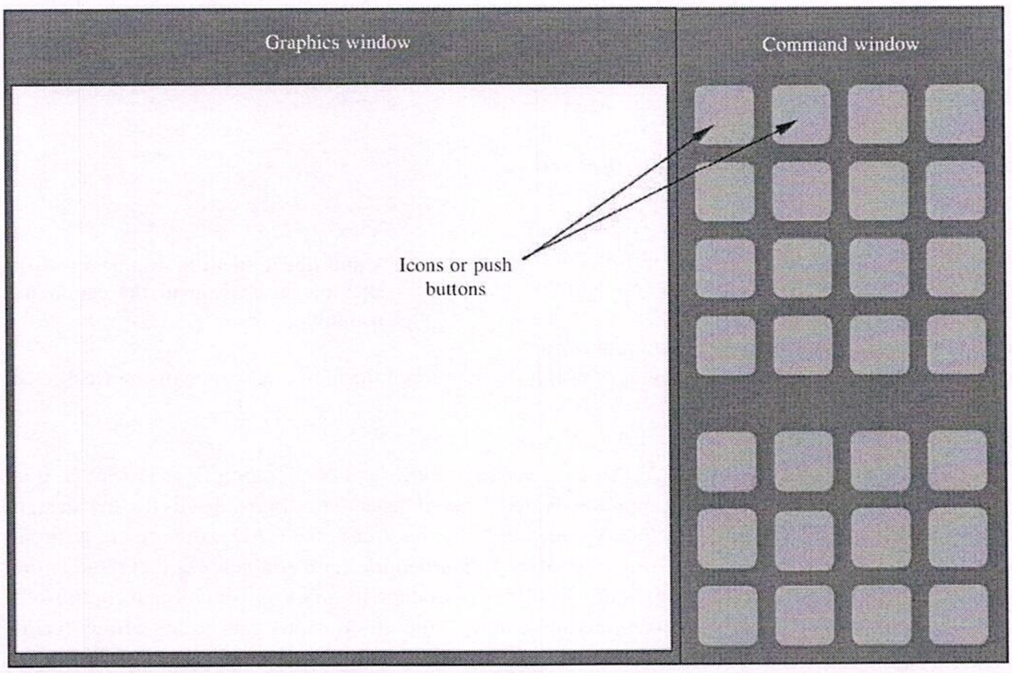


Figure 1.1 Generic appearance of the Front end of a CAD software

Graphics Window and (ii) the Command window. The Graphics window provides the visual feedback to the user detailing desired information about an object being designed. One can manipulate the position (through translation/rotation) of an object relative to another or a fixed coordinate system and visualize the changes in the Graphics window. In essence, all design operations involving transformations, curve design, design of surfaces and solids, assembly operations pertaining to relative positioning of two or more components, drafting operations that provide the engineering drawings, analysis operations that yield results pertaining to displacements and stresses, optimization operations that involve sequential alterations in design, and many others can be visualized through the Graphics window.

The design instructions are given through a user-friendly Command Window that is subdivided into several *push buttons* or *icons*. To accommodate numerous applications in CAD and to allow a guided user interface, the icons appear in groups. For instance, icons pertaining to the design of curves would be grouped in the Command window. Push buttons pertaining to curve trimming, extension, intersection and other such actions would be combined. Icons used in surface and solid design would appear in two different groups. Options under transformations, analysis, optimization and manufacture would also be clustered respectively. A user may make a design choice by clicking on an icon using the mouse. There may be many ways to design a curve, for instance. To accommodate many such possibilities, a CAD GUI employs the *pull down menus* (Figure 1.2). That is, when an icon on curve segment design is clicked on, a menu would drop down prompting the user to choose between, say, the Ferguson, Bézier or B-spline options. Similarly, for a surface patch design, a pull down menu may have choices ranging between the analytical patches, tensor product surfaces, Coon's patches, rectangular or triangular patches, ruled or lofted patches and many others. For solid modeling, a user may have to choose between Euler operations or Boolean sequences. After a design operation is chosen using a push button and from a respective pull down menu, the user would be prompted to enter further choices through *pop up* menus. For instance, if a user chooses to sketch a line, a pop up window may appear expecting the user to feed in the start point, length and orientation of the line. Note that for a two dimensional case, a much easier option to draw a curve segment may be to select a number of points on the screen through a sequence of mouse clicks.

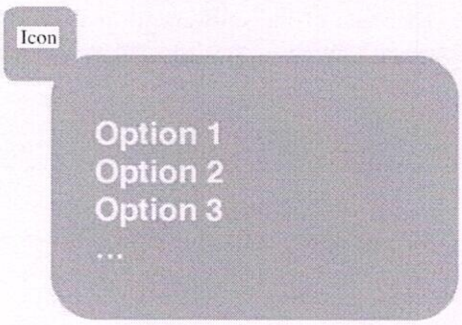


Figure 1.2 A pull down menu that appears when clicking on an icon in the command window

1.6 Motivation and Scope

Developing the front end GUI of a CAD software is an arduous and challenging task. However, it is the back end wherein the core of Computer Aided Design rests. This book discusses the design concepts based on which various modules or objects of the back end in a CAD software are written. The concepts emerge as an amalgamation of *geometry*, *mathematics* and *engineering* that renders the software the capability of *free-form* or generic design of a product, its analysis, obtaining its optimized form, if desired, and eventually its manufacture. Engineering components can be of various forms (sizes and shapes) in three-dimensions. A Solid can be thought of as composed of a simple *closed connected surface* that encloses a finite volume. The closed surface may be conceived as an interweaved

Chapter 2

Transformations and Projections

Geometric transformations provide *soul* or *life* to *virtual objects* created through geometric modeling discussed in later chapters. It is using transformations that one can manoeuver an object, view it from different angles, create multiple copies, create its reflected image, re-shape or scale an object, position an object with respect to the other, and much more. Projections, like orthographic and perspective on the other hand, help comprehend an object for purpose of its fabrication. Transformations have many uses, mainly pertaining *motion*, such as manipulating the relative positions of two objects in solid modeling to create a complex entity, displaying motion of mechanisms, animating an assembly to demonstrate its working or imparting motion to a virtual human for a walk through a virtual city or a building. Motion simulators for aircrafts, tanks and motor vehicles extensively employ geometric transformations.

Transformations may be employed to perform *rigid-body motion* wherein an object may be moved from one position to another without altering its shape and size. Typical rigid body transformations involve *translation*, *rotation* and *reflection*, the latter being a combination of the first two. Transformations may also cause *deformations* like *shear*, *scaling* and *morphing* wherein the object is altered in size and/or shape. For special effects, *free-form* deformation may be used where a geometric model is embedded inside a grid of control points, and transformations are applied to these control points to distort the object in a desired manner.

When dealing with transformations, an engineer would require a full description of the object, its position relative to a fixed point called *origin*, and a specified set of coordinate axes. An object may

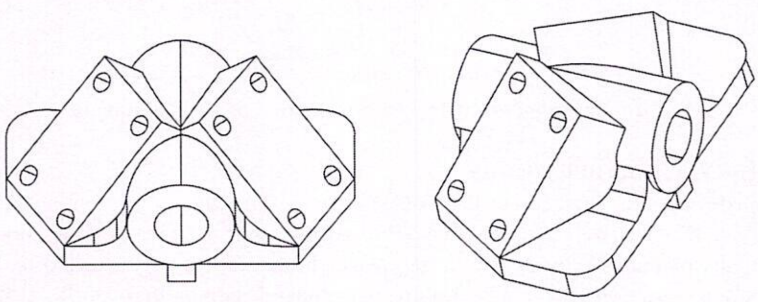
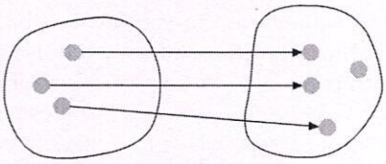


Figure 2.1 Use of transformation to view an object from different angles

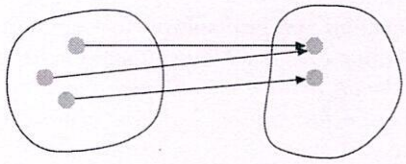
be treated as an assemblage of finitely many points arranged in a non-arbitrary manner in space. The origin and coordinate axes may or may not be a part of the object. If the coordinate frame is attached to the object, it is called the *local frame* of reference. For coordinate frame not a part of the object, it is called *global frame*. Usually, since there are many objects to manoeuver at a given time, the user prefers a fixed global coordinate frame for all objects and one local coordinate system for each object. Geometric transformations may then involve: (a) moving all points of an object to a new location with respect to the global coordinate system or (b) relocating the local coordinate frame of an object to a new position without changing the object's position in the global frame. Transformations, in this chapter, are regarded as *time independent* in that the motion of an object from one position to another is *instantaneous* and does not follow a specified path in space. In other words, there can be more than one ways to manoeuver an object from its current location to a specified one.

2.1 Definition

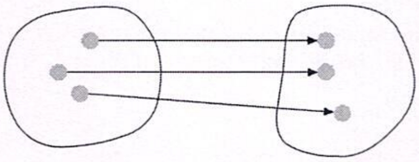
A geometric transformation may be considered as a mapping function between a set of points both in the domain and range. The points may belong to the object or the coordinate system to be relocated. The function needs to be *one-to-one* in that any and all points in the domain (initial location) should have the corresponding images in the range (final location). Thus, if $T(\boldsymbol{P}_1)$ and $T(\boldsymbol{P}_2)$ represent the final locations of points $\boldsymbol{P}_1$ and $\boldsymbol{P}_2$ belonging to the object where T is a transformation function, then, if $\boldsymbol{P}_1 \neq \boldsymbol{P}_2$, $T(\boldsymbol{P}_1) \neq T(\boldsymbol{P}_2)$. In addition, the transformation should be *onto* in that for every final location $T(\boldsymbol{P})$, there must exist its pre-image $\boldsymbol{P}$ corresponding to the initial position of the object. In other words, any point in the newly located object must be associated with only one point belonging to the object in its original location. Thus, a one-to-one and onto map makes it possible to perform *inverse transformation*, that is, to move the object from its final to original location.



(a) One-to-one and not onto



(b) Onto and not one-to-one



(c) One-to-one and onto

Figure 2.2 Nature of geometric transformation as a function map

2.2 Rigid Body Transformations

In rigid body transformations, the geometric model stays undeformed, that is, the points constituting the model maintain the same relative positions with respect to each other. A solid model may be conceived to consist of points, curves and surfaces which should not get distorted under a rigid-body trans-formation. Rotation and translation are two transformations that can be grouped under this category. First, rotation and translation are discussed in two-dimensions. Vectors and matrices are most convenient to represent such motions. The *homogenous coordinate system*, which has some distinct advantages, is also introduced to unify the two transformations.

2.2.1 Rotation in Two-Dimensions

Consider a rigid body S packed with points P_i (i = 1, ..., n) and let a point P_j (x_j, y_j) on S be rotated about the z-axis to P_j^* (x_j^*, y_j^*) by an angle θ. From Figure 2.3, it can be observed that

$$x_j^* = l\cos(\theta + \alpha) = l\cos\alpha\cos\theta - l\sin\alpha\sin\theta$$

$$= x_j\cos\theta - y_j\sin\theta$$

and $y_j^* = l\sin(\theta+\alpha) = l\cos\alpha\sin\theta + l\sin\alpha\cos\theta$

$$= x_j\sin\theta + y_j\cos\theta$$

Or in matrix form

$$\begin{bmatrix} x_j^* \\ y_j^* \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x_j \\ y_j \end{bmatrix} \Rightarrow \mathbf{P}_j^* = \mathbf{R}\mathbf{P}_j \qquad (2.1)$$

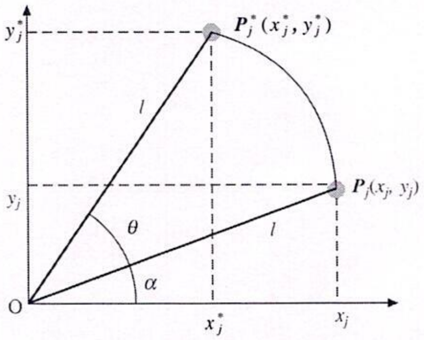


Figure 2.3 Rotation in a plane

where $\mathbf{R} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}$ is the two-dimensional *rotation matrix*. For S to be rotated by an angle θ, transformation in Eq. (2.1) must be performed simultaneously for all points P_i (i = 1, . . . , n) such that the entire rigid body reaches the new destination S^*.

Example 2.1 A trapezoidal lamina $ABCD$ lies in the x-y plane as shown with A(6, 1), B(8, 1), C(10, 4) and D(3, 4). The lamina is to be rotated about the z-axis by 90°. Determine the new position $A^*B^*C^*D^*$ after rotation (Figure 2.4(a)).

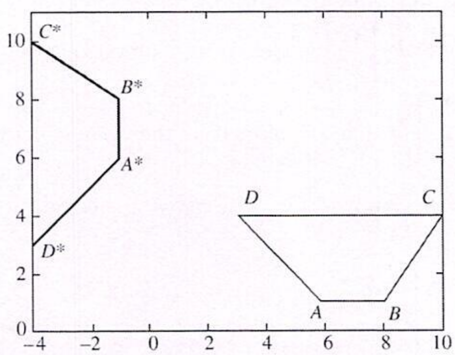


Figure 2.4 (a) Lamina rotation in Example 2.1

The transformation matrix **R** is given by Eq. (2.1) with θ = 90°. Thus,

$$\begin{bmatrix} A^* \\ B^* \\ C^* \\ D^* \end{bmatrix}^T = \mathbf{R}\begin{bmatrix} A \\ B \\ C \\ D \end{bmatrix}^T = \begin{bmatrix} \cos 90° & -\sin 90° \\ \sin 90° & \cos 90° \end{bmatrix} \begin{bmatrix} 6 & 1 \\ 8 & 1 \\ 10 & 4 \\ 3 & 4 \end{bmatrix}^T$$

$$= \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} 6 & 1 \\ 8 & 1 \\ 10 & 4 \\ 3 & 4 \end{bmatrix}^T = \begin{bmatrix} -1 & 6 \\ -1 & 8 \\ -4 & 10 \\ -4 & 3 \end{bmatrix}^T$$

2.2.2 Translation in Two-Dimensions: Homogeneous Coordinates

For a rigid body S to be translated along a vector **v** such that each point of S shifts by (p, q),

$$x_j^* = x_j + p,\quad y_j^* = y_j + q \Rightarrow \begin{bmatrix} x_j^* \\ y_j^* \end{bmatrix} = \begin{bmatrix} x_j \\ y_j \end{bmatrix} + \begin{bmatrix} p \\ q \end{bmatrix} \Rightarrow \mathbf{P}_j^* = \mathbf{P}_j + \mathbf{v} \qquad (2.2)$$

Example 2.2 For a planar lamina *ABCD* with *A* (3, 5), *B* (2, 2), *C* (8, 2) and *D* (4, 5) in *x*-*y* plane and *P* (4, 3) a point in the interior, the lamina is to be translated through $\mathbf{v} = \begin{bmatrix} 8 \\ 5 \end{bmatrix}$. Eq. (2.2) yields

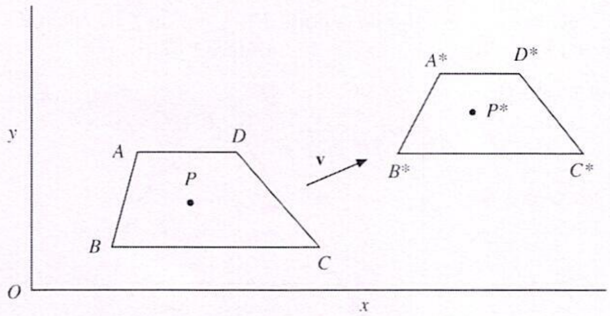


Figure 2.4 (b)

$$\begin{bmatrix} A^* \\ B^* \\ C^* \\ D^* \\ P^* \end{bmatrix}^T = \begin{bmatrix} 3 & 5 \\ 2 & 2 \\ 8 & 2 \\ 4 & 5 \\ 4 & 3 \end{bmatrix}^T + \begin{bmatrix} 8 & 5 \\ 8 & 5 \\ 8 & 5 \\ 8 & 5 \\ 8 & 5 \end{bmatrix}^T = \begin{bmatrix} 11 & 10 \\ 10 & 7 \\ 16 & 7 \\ 12 & 10 \\ 12 & 8 \end{bmatrix}^T$$

We may note that like rotation, translation as in Eq. (2.2) does not work out to be a matrix multiplication. Instead, it is the addition of a point (position vector) and a (free) vector. One may attempt to represent translation also in the matrix multiplication form to unify the procedure for rigid body transformations. Consider Eq. (2.2) rewritten as

$$\begin{bmatrix} x_j^* \\ y_j^* \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & p \\ 0 & 1 & q \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_j \\ y_j \\ 1 \end{bmatrix} = \begin{bmatrix} x_j + p \\ y_j + q \\ 1 \end{bmatrix} \tag{2.3}$$

Here, the first two rows provide the translation information while the third row gives the dummy result 1 = 1. Note also that the definition of position vector $\boldsymbol{P}_j \begin{bmatrix} x_j \\ y_j \end{bmatrix}$ is altered from an ordered pair in the two-dimensional space to an ordered triplet $\begin{bmatrix} x_j \\ y_j \\ 1 \end{bmatrix}$ which are termed as the *homogenous coordinates* of $\boldsymbol{P}_j$. We may use this new definition of position vectors to express translation in Eq. (2.3) as $\mathbf{P}_j^* = \mathbf{TP}_j$ where

$$\mathbf{T} = \begin{bmatrix} 1 & 0 & p \\ 0 & 1 & q \\ 0 & 0 & 1 \end{bmatrix}$$

The rotation relation in Eq. (2.1) can be modified as well to express the result in terms of the homogeneous coordinates, that is

$$\mathbf{P}_j^* = \mathbf{RP}_j \Rightarrow \begin{bmatrix} x_j^* \\ y_j^* \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_j \\ y_j \\ 1 \end{bmatrix}$$

where
$$\mathbf{R} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{2.4}$$

Rigid body translation and rotation thus get unified as *matrix multiplication* operations only, involving no addition or subtraction of matrices and vectors. Further, one can *concatenate* a sequence of transformations, for instance, translation of an object followed by its rotation. If one can identify the matrices for each of these transformations in the multiplication form, it becomes much easier to track the intermediate positions as well as to predict the final transformed position of the rigid body.

2.2.3 Combined Rotation and Translation

Consider a point $P(x, y, 1)$ in the x-y plane to be rotated by an angle θ about the z-axis to a position $P_1(x_1, y_1, 1)$ followed by a translation by $\mathbf{v}(p, q)$ to a position $P_2(x_2, y_2, 1)$. Using Eqs. (2.3) and (2.4), we may write

$$\mathbf{P}_1 = \mathbf{RP}, \begin{bmatrix} x_1 \\ y_1 \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

and
$$\mathbf{P}_2 = \mathbf{TP}_1, \begin{bmatrix} x_2 \\ y_2 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & p \\ 0 & 1 & q \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & p \\ 0 & 1 & q \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \mathbf{TRP}$$

$$\text{Thus, } \mathbf{P}_2 = \begin{bmatrix} \cos\theta & -\sin\theta & p \\ \sin\theta & \cos\theta & q \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \tag{2.5}$$

On the contrary, if translation by **v** is followed by rotation about the z-axis by an angle θ to reach P_2^*, then

$$\mathbf{P}_2^* = \mathbf{RTP} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & p \\ 0 & 1 & q \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & p\cos\theta - q\sin\theta \\ \sin\theta & \cos\theta & p\sin\theta + q\sin\theta \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \tag{2.6}$$

We observe from Eqs. (2.5) and (2.6) that the final positions P_2 and P_2^* are not identical. From above we can arrive at two important conclusions: (a) the homogeneous coordinate system helps to unify translation and rotation as multiplicative transformations and (b) transformations are not commutative. The sequence in which the transformations are performed is significant and must be maintained while concatenating the respective matrices. Otherwise a different orientation or position of the object is reached. If $T_1, T_2, \ldots, T_n$ are the transformations to be performed in the order, the combined transformation matrix T is given as $T = T_n\, T_{n-1}\, T_{n-2} \ldots T_2\, T_1$.