Mechanical Handbook

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REVISION HISTORY

DATE	DESCRIPTION OF CHANGE
V181028	RJV; Added SWOT diagram from Design Handbook
V160710	RJV; updated from 2015 lessons learned
V151107	RJV; updated design process, added eng dwg appendix
V150926	Original

1 INTRODUCTION

1.1 Purpose

The purpose of this handbook it to provide mechanical best practices and reference material.

1.2 Scope

The scope of this document includes best practices and reference material for the mechanical sub-team.

1.3 Audience

The intended audience is the technical sub-teams and mentors.

1.4 References

2007 FIRST Rookie Workshop - Chassis Design

2008CON Pneumatic Power - Team 111

Base Fundamentals / Center of Gravity Andrew Keisic Team294 2009

Chapter 7 Dimensioning and Tolerancing - Ohio University

Chassis-Drive-Train presentation - MVRT 2005

Dial Calipers - Project Lead the way

Drive train design for competitive robots Foss/Miller Team2168

FIRST Robotics Drive Systems - Simbotics – 2010

FIRST Robotics Drive Trains - Team 1540

FRC Drive Train: Design and Implementation - Team 488

FRC Pneumatics - Theory and practice -Team 4039

An idiot's 'Complete' guide to FRC- Arpan Rau Team 4979

http://www.jfccivilengineer.com/structural_mechs__intro_.htm

Introduction to drawing - Union County Vocational Technical Schools, NJ

Introduction to pneumatics - Team 2052

Intro to pneumatics team MVRT

Isometric and Orthographic Sketching - Union County Vocational Technical Schools, NJ

Mechanical Elements - ENSC 305/440-Simon Fraser University 2006

Pneumatics - Team 3313

Pneumatic Component and Systems Team 1640

The 7th wheel - Team 1640

"The Design Tutorials" Ryan Tam FRC Team 610

The Vernier and the Micrometer - umm al-Qura university

Vernier Calipers - Churchill HS livonia MI

Wikipedia - six degrees of freedom

1.5 Definitions

2D	2 Dimension
3D	3 Dimension
BOM	Bill of Matierials

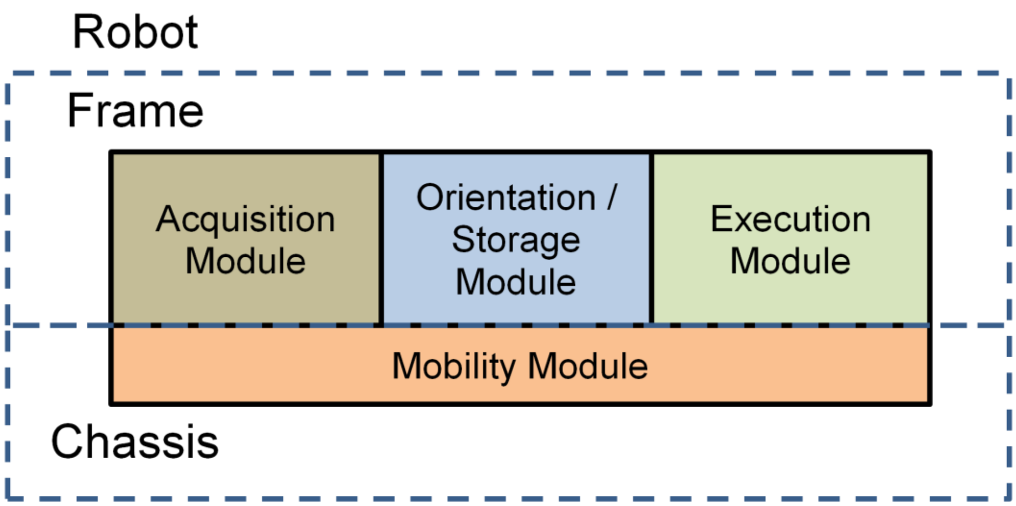
2 OVERVIEW

2.1 Robot Module Organization

The robot consists of four major mechanism modules:

1. **Mobility Module:** The Chassis is the framework that contains the robot base, wheel interface to the playing field and power transmission to the wheels.
2. **Acquisition Module:** The acquisition module is part of the frame that acquires the game object.
3. **Orientation/Storage Module:** The orientation/storage module is part of the frame that orients the game object for the action object and/or will store the game object and orient the game object for the action object.
4. **Execution Module:** The execution module is part of the frame that performs the action on the game object to play the game(e.g. throw, place, push, spin, dump, etc).

A model of the robot is shown in the following diagram.



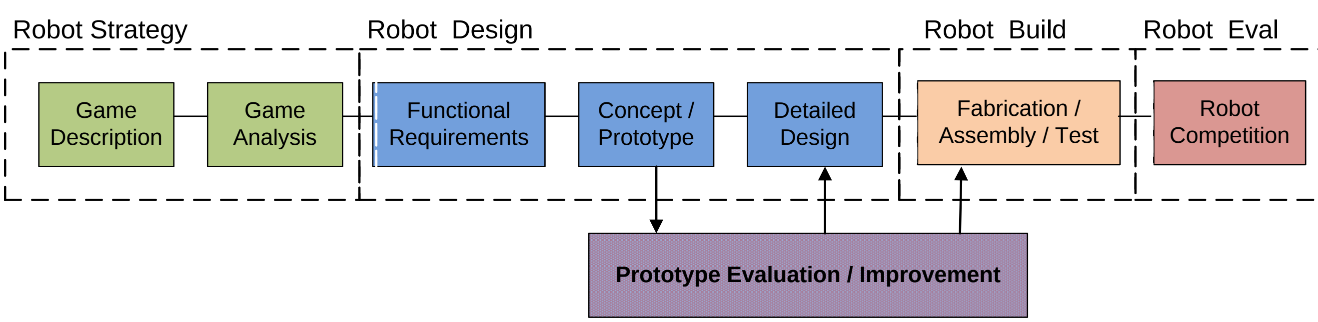
2.2 *Mechanical Handbook content*

The mechanical handbook contains the following:

1. Mechanical Design Process
2. Mechanical Best Practices
3. Training Module description

3 *MECHANICAL DESIGN PROCESS*

3.1 *Overall Robot Design Process Steps*



3.2 *Robot Strategy*

3.2.1 *Team Development of Game Strategy*

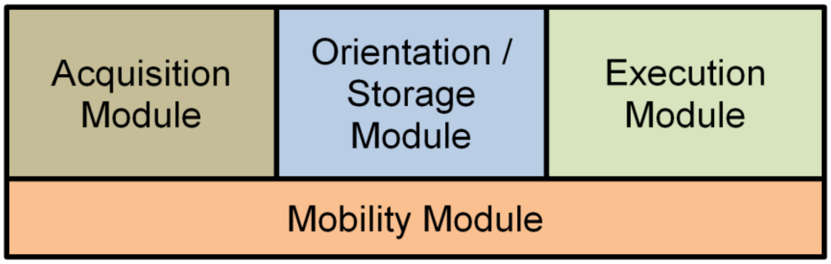
After the kickoff video and READING the game manual, the team will develop the following:

1. A game strategy that includes how the robot will move on the playing field and what actions the robot has to do to play the game.
2. The team will also define the constraints of the robot from the Game Manual.

3.3 Robot Design

3.3.1 Technical Team Robot Module Requirements

The technical team(Mechanical/Electrical/Software) will group the robot actions developed by the team with respect to the basic robot module model shown below. The robot constraints listed by the team will also be grouped with respect to the robot model.



3.3.2 Technical Team Robot Concept Development

During the robot concept development:

1) All technical team members develop the contents of the robot modules
2) The mechanical team is responsible for developing the mechanical components of the robot modules. Modules should be analyzed with a SWOT Diagram:

Engineering SWOT Analysis (For Robot Concept Development)

Description of Module operation

S-Strengths:

- Does concept meet function requirements
- Is the concept simple?
- Does the concept meet FIRST robot design constraints?
- Is the control concept simple? (Few parts)
- Does the concept have a small weight?
- Is the concept easy to build? To maintain?
- Is there tolerance adjustability in the design?
- Will concept be reliable? -- PERFORMS SAME OPERATION EVERY TIME

W-Weaknesses:

- What parts of the required function are not addressed?
- Do we have learn new technology?
- Does the concept require complex controls?
- Does the concept require a complex mechanical system?
- Did you use gravity as a process control?
- What don't we know about the concept?
- What do we have to prototype? How long will it take?
- What does the prototype have to prove?

O-Opportunities:

- HAVE YOU SEEN A SIMILAR CONCEPT BEFORE?
- Have you done pizza dough thinking?(What ifs)
- Can the concept do several functions?
- Can parts of this concept integrate into another concept
- Think of an opposite concept – For example: (typewriter moved carriage - today's printers move print head)

T-Threats:

- HOW CAN THE CONCEPT FAIL?
- Is the game object always constrained?
- How can you overcome weaknesses?
- How can you overcome concept failures?
- If broken in competition, can we fix it quickly?

3) The electrical team is responsible for developing the sensor input and actuator output list for the robot mechanism concepts.
4) The software team is responsible for understanding how the robot will function

Details of the concept process is detailed in the design process handbook

3.3.3 Prototyping / Preliminary Design

DO NOT prototype everything. There is not enough time. Two criteria for prototyping:

1) Prototype what you do not know.
2) Prototype the best concept

Prototype design steps:

1) Develop a criteria on what it is you want to learn
2) Develop sketches of what the prototype will look like
3) Develop manufacturing drawings of parts as sketches
4) A preliminary BOM should be developed. At this point long lead items should be ordered for the fabrication and assembly phase of the robot design.
5) Do your engineering calculations for energy

The prototype design process is part of the preliminary design of the robot.

USE YOUR ENGINEERING NOTEBOOKS.

3.3.4 Detailed Design

In a perfect world the robot would be developed in CAD and then part drawings developed for fabrication and a detailed BOM developed to order material and components. We will use a hybrid parallel process:

1) The mechanical design team will develop detailed sketches and BOM lists.
2) The BOM list will be used to kit module parts
3) From the detailed sketches work will continue in the shop to build the robot. The sketches will also be used by the CAD team to CAD up the robot and verify the design.
4) The CAD team is responsible for maintaining a robot BOM and weigh calculation

USE YOUR ENGINEERING NOTEBOOKS.

3.3.4.1 Detailed Design - BOM

The BOM is the key document of the robot design. It provides a pick list for components, a weight calculation document, and robot cost. The BOM should contain the following items:

1) Quantity
2) Component name
3) Component description
4) Component part number
5) Supplier
6) Supplier part number
7) Web address of supplier
8) Weight
9) Cost.

3.4 Fabrication / Assembly

During fabrication the kited parts will be fabricated per detailed sketches or CAD drawings per the mechanical fabrication processes. These processes are detailed in the mechanical tools and processes training module.

4 MECHANICAL ROBOT BUILD SCHEDULE

4.1 Week1

1. Complete robot strategy and develop robot module list
2. Develop drive train configuration and complete drive train prototype by Saturday for electrical and software teams
3. Develop module concepts(i.e. concept sketches, prelim calculations, SWOT analysis, decision matrix)
4. Determine proof of principle specifications and define information needed to understand
5. Complete prototype mechanisms by Saturday

4.2 Week 2

1. Test proof of principle mock ups
2. Start robot module preliminary designs

4.3 Week 3

1. Complete detailed design of robot modules
2. Start mechanical BOM and estimate robot weight
3. Start to kit parts for robot module assembly

4.4 Week 4

1. Complete part fabrication
2. Complete robot module assembly and integration
3. Determine robot weight
4. Start robot module unit testing

4.5 Week 5

1. Complete robot module unit testing
2. Support electrical and software integration
3. Support electrical and software testing

4.6 Week 6

1. Support electrical and software team during testing.
2. Support driver testing
3. Improve design from testing discovery

5 MECHANICAL BEST PRACTICES

5.1 Concept Design

1. **Know your limitations:** During concept development the question is; Do we have the technology to build the robot mechanism?
2. **Think about robot maintenance:**
    a. How do I get the battery out?
    b. How do I get to the power switch?
    c. How do I replace a gear box or motor?
    d. How do I get to the control system to replace parts?
    e. How do I get to the pneumatics purge valve?
3. **Pneumatics vs Motors:**
    a. Pneumatics has the disadvantage of weight(compressor, storage tanks, tubing). Their advantage increases when they are used in several locations on robot.
    b. Pneumatics many times is a simpler solution to motion applications.
    c. Do not develop a concept that requires the motor to go into a stall condition. Motors draw excessive current in a stalled condition.
4. **Constraining the Game Object:**
    a. **Acquisition:** In acquiring the game object the mechanism design should constrain the game object such that it is oriented correctly and secured. Failure to do this requires re-acquiring the game object which cost time.
    b. **Orientation/Storage:** The game object should be constrained to be oriented correctly for storage or for the execution module.
    c. **Execution:** Mechanism should be considered to have the game object constrained in the correct orientation to perform the required action on it.
5. **Prototype Ideas:**
    a. **DO NOT prototype every idea.** The concept team to decide on the top two concepts. These concepts should have the least amount of issues.
    b. **Define why you are building the prototype**. There should be criteria specifying what you want to learn. The criteria should meet functional criteria the team decided on.
    c. **Engineering Communication is graphical.** Make sketches with dimensions.
    d. Prototype with wood, cardboard, etc. For motion use drills, Team 2228 motor test box and pneumatics test box.
    e. Design prototypes so that they could be used on the robot. The prototype should be a stepping stone to a preliminary design of the mechanism.

5.2 Preliminary Design

5.3 Detailed Design

1. **Design the chassis and drive train first.** This allows software to test mobility software and to have drivers start practicing.

2. **Engineering communications is graphical**. Make drawings(2D/isometric sketches/3D CAD). Sketches should be dimensioned.
3. **Keep Track of Weight:**
4. **BOM RULES:**
5. **Keep Center of gravity low:**
6. **Avoid stalling motors:** A Stalled motor draws a lot of current. This will lower the battery voltage and cause the RoboRio to go into a safe state by disabling all outputs.
7. **Avoid cantilevered shafts:** Shafts should have bearings at both ends.

5.3.1 Robust Design

5.3.1.1 Design of Manufacture

In the design of a robot consider the following:

1) Simplicity
   a) Fewer things to fail
   b) Easier and faster to build and repair
   c) Lighter/more durable/more elegant
2) Constrained design:
   a) The use of 45 degree bracing provides constraint to perpendicular robot members.
   b) Use of angle aluminum channels

5.3.1.2 Design for assembly

In the design of a robot consider the following with respect to design for assembly:

1) All bolts should be accessible
2) Use of lock-nuts to avoid nuts falling off during competition

5.3.1.3 Weight Distribution

In the design of a robot consider the following with respect to weight distribution

1) Keep as much weight as low as possible
2) Put weight of the wheels
3) Placement of the battery is important in determining the center of gravity

5.3.1.4 Multi-functionality

In the design of a robot consider the following with respect to multi-functionality:

1) Multi-functionality cuts down on weight, build time, complexity
2) Use of a common shaft for multiple functions

5.4 Fabrication

1. **BOM kitting:** Before you start constructing your mechanism gather all the components needed.
2. **Build the chassis and drive train first.**
3. **Keep Track of weight:**
4. **Avoid the use set screws!** In competition they can come loose. Attach items to a shaft via keyways, pins or screws.

5. **Standardize hardware:** To improve maintenance of the robot should have a minimal amount of different nuts and bolt types.
6. **Use the correct tool for the job**. Using the incorrect tool could incur injury and damage the part you are working on (e.g. stripping threads, rounding edges on bolt heads)
7. **Take care in drilling:** Cover all electrical systems on the robot. Also see that you do not drill into other components on the robot

6 TRAINING

Level1:
- Mechanical tools and processes

Level2:
- Framing and Fasteners
- Chassis and drive train configuration design
- Mechanisms
- FIRST Pneumatics

Level3:
- Drive Train power transmission
- Motor Sizing
- Physics - rotary-linear motion
- Pneumatics calculations

7 Appendix A: Engineering Drawing

The best way to efficiently convey technical information is by making a drawing. An engineering drawing is a graphical language to communicate ideas and information for other technical students and provides the necessary documentation for those that will fabricate the parts for the robot.

7.1 Engineering Sketching

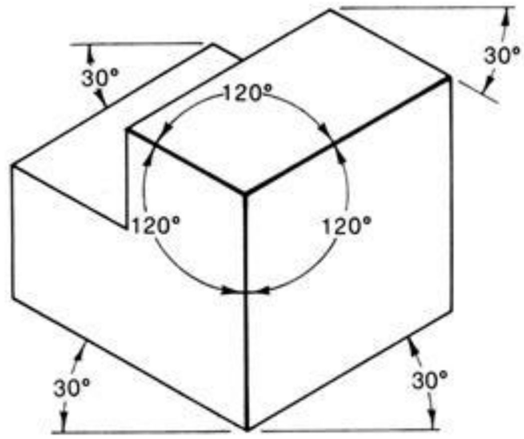
There are two stages to engineering drawing. The first is engineering sketches and the second stage is engineering drawings(Drawings to scale and dimensioned in CAD or 2D orthographic working drawings for fabrication).

Engineering sketches is typically done in the conception stage of a design. It is a freehand drawing that uses general shapes, not to scale, however, the drawing has some relative proportions.

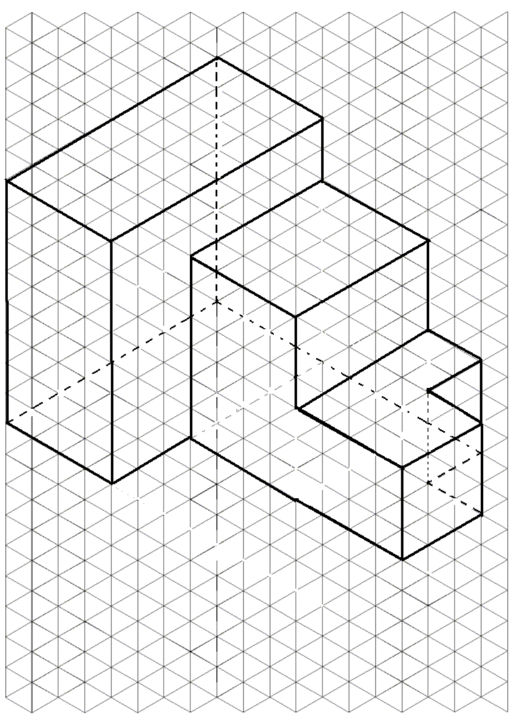
Engineering sketches are based on two drawing forms 1) Isometric drawing(freehand 3D drawing) or an orthographic drawing(freehand 2D drawing). To help in making a Isometric drawing Isometric paper is typically used.

7.2 Isometric Drawing

An Isometric drawing is a method to show a three-dimensional object on a two dimensional piece of paper. The three-dimension appearance is obtained by applying a 30 degree angle to its sides. This is shown in the following figure.



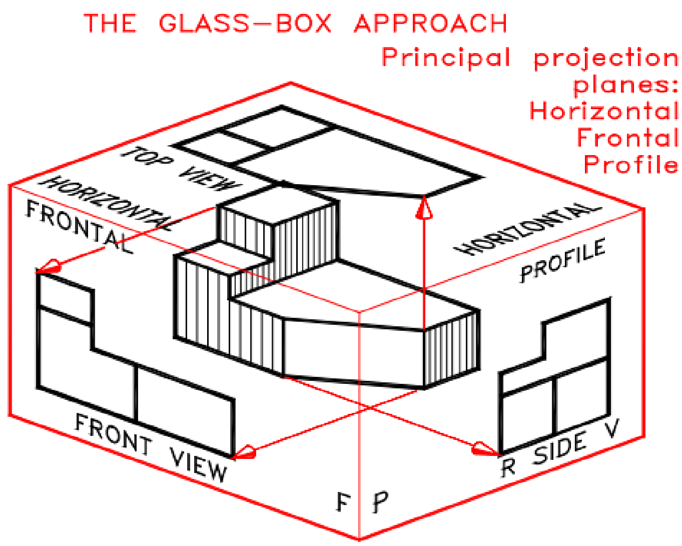
The use of Isometric paper makes it easier to draw an Isometric image.



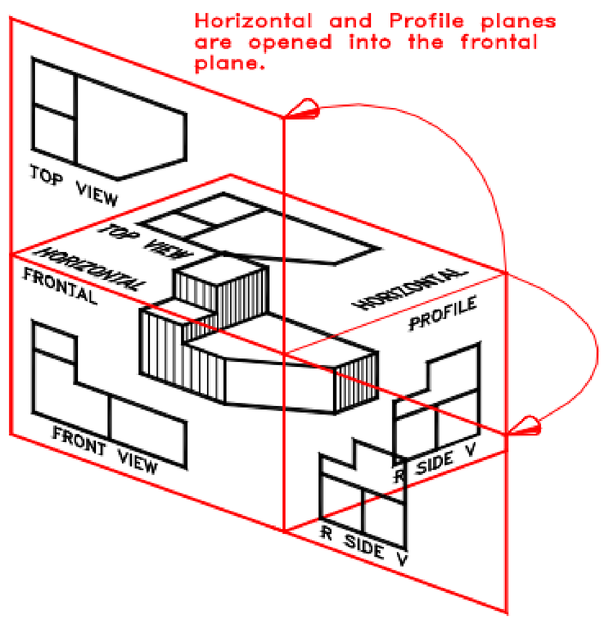
7.3 Orthographic Drawing (2D Drawings)

An Orthographic drawing is a means to show a 3D object in two dimensions by viewing several 2D views of the object on one drawing. This type of drawing is called a working drawing(i.e. construction drawing) in that there is enough information on the drawing to fabricate the object.

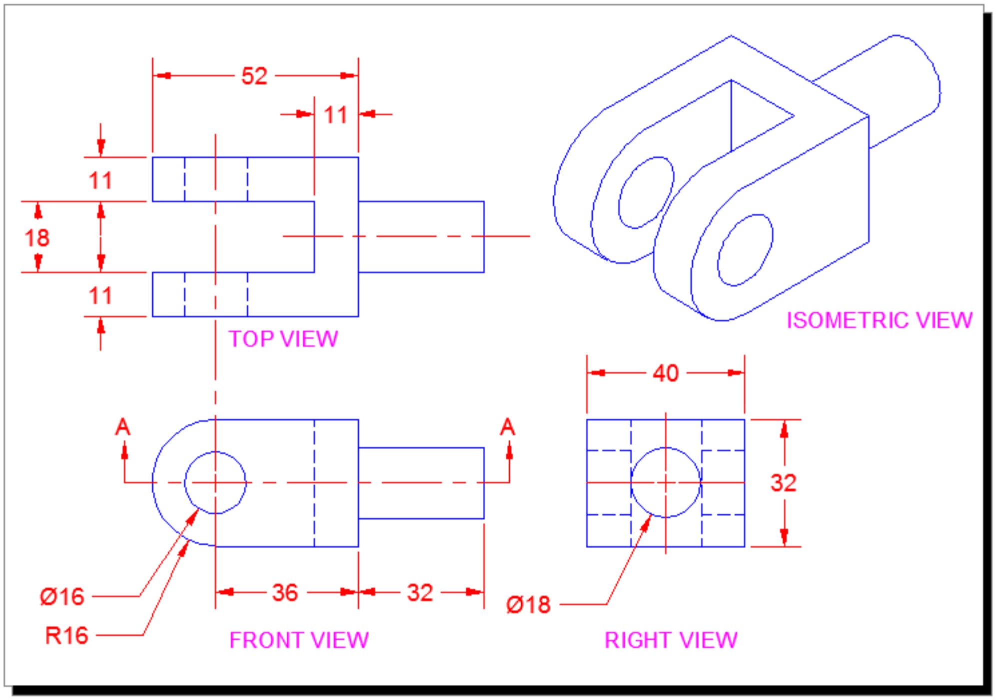
The typical views are the front of the object, the top of the object and the side view. The front of the object should be the view that provides the most amount of information about the object. The following two figures show the translation process from a 3D object to a 2D view.



Then flip the horizontal and profile views to a 2D plane.



An example of an Orthographic(working drawing)

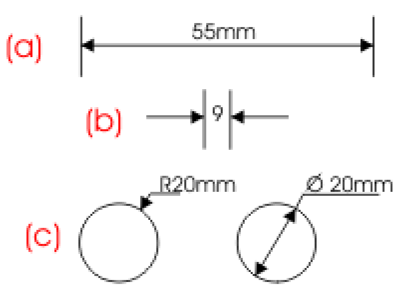


7.4 Orthographic Lines

1) Thick line - all visible lines of the object
2) Thick dash line - all hidden features of the object
3) Thin line - dimension line
4) Thin chain line - center line of circles

7.5 Dimensioning

The following are typical methods of dimensioning



8 Appendix B: Machine Screws

Inch Dimensions

MACHINE SCREW & FRACTIONAL SIZES

SIZE	OVERALL LENGTH	DRILL LENGTH	DRILL SIZE	THREAD LENGTH	SHANK DIA.	LENGTH OF SQUARE	SIZE OF SQUARE
4-40 UNC	1-7/8	1/4	.0910	3/8	.1410	3/16	.110
4-48 UNF	1-7/8	1/4	.0945	3/8	.1410	3/16	.110
5-40 UNC	1-15/16	9/32	.1040	13/32	.1410	3/16	.110
5-44 UNF	1-15/16	9/32	.1060	13/32	.1410	3/16	.110
6-32 UNC	2	5/16	.1115	7/16	.1410	3/16	.110
6-40 UNF	2	5/16	.1170	7/16	.1410	3/16	.110
8-32 UNC	2-1/8	3/8	.1375	1/2	.1680	1/4	.131
8-36 UNF	2-1/8	3/8	.1405	1/2	.1680	1/4	.131
10-24 UNC	2-3/8	13/32	.1545	5/8	.1940	1/4	.152
10-32 UNF	2-3/8	13/32	.1635	5/8	.1940	1/4	.152
12-24 UNC	2-3/8	15/32	.1805	21/32	.2200	9/32	.165
12-28 UNF	2-3/8	15/32	.1860	21/32	.2200	9/32	.165
1/4-20 UNC	2-1/2	17/32	.2080	25/32	.2550	5/16	.191
1/4-28 UNF	2-1/2	17/32	.2200	25/32	.2550	5/16	.191
5/16-18 UNC	2-27/32	11/16	.2660	15/16	.3180	3/8	.238
5/16-24 UNF	2-27/32	11/16	.2770	15/16	.3180	3/8	.238
3/8-16 UNC	3-3/8	13/16	.3225	1-1/16	.3810	7/16	.286
3/8-24 UNF	3-3/8	13/16	.3395	1-1/16	.3810	7/16	.286
7/16-14 UNC	3-3/4	1	.3770	1-1/4	.3230	13/32	.242
7/16-20 UNF	3-3/4	1	.3955	1-1/4	.3230	13/32	.242
1/2-13 UNC	4-1/16	1-1/8	.4350	1-3/8	.3670	7/16	.275
1/2-20 UNF	4-1/16	1-1/8	.4580	1-3/8	.3670	7/16	.275

9 Appendix C: Drill Sizes - Decimal Equivalents

MCDONNELL DOUGLAS

DECIMAL EQUIVALENTS
OF FRACTION, WIRE GAUGE & LETTER

SIZES	DECIMAL INCHES	SIZES	DECIMAL INCHES	SIZES	DECIMAL INCHES	SIZES	DECIMAL INCHES
1/32	.0312	34	.1110	2	.2210	Z	.4130
67	.0320	33	.1130	1	.2280	27/64	.4219
66	.0330	32	.1160	A	.2340	7/16	.4375
65	.0350	31	.1200	15/64	.2344	29/64	.4531
64	.0360	1/8	.1250	B	.2380	15/32	.4688
63	.0370	30	.1285	C	.2420	31/64	.4844
62	.0380	29	.1360	D	.2460	1/2	.5000
61	.0390	28	.1405	E	.2500	33/64	.5156
60	.0400	9/64	.1406	1/4	.2500	17/32	.5312
59	.0410	27	.1440	F	.2570	35/64	.5469
58	.0420	26	.1470	G	.2610	9/16	.5625
57	.0430	25	.1495	17/64	.2656	37/64	.5781
56	.0465	24	.1520	H	.2660	19/32	.5938
3/64	.0469	23	.1540	I	.2720	39/64	.6094
55	.0520	5/32	.1562	J	.2770	5/8	.6250
54	.0550	22	.1570	K	.2810	41/64	.6406
53	.0595	21	.1590	9/32	.2812	21/32	.6562
1/16	.0625	20	.1610	L	.2900	43/64	.6719
52	.0635	19	.1660	M	.2950	11/16	.6875
51	.0670	18	.1695	19/64	.2969	45/64	.7031
50	.0700	11/64	.1719	N	.3020	23/32	.7188
49	.0730	17	.1730	5/16	.3125	47/64	.7344
48	.0760	16	.1770	O	.3160	3/4	.7500
5/64	.0781	15	.1800	P	.3230	49/64	.7656
47	.0785	14	.1820	21/64	.3281	25/32	.7812
46	.0810	13	.1850	Q	.3320	51/64	.7969
45	.0820	3/16	.1875	R	.3390	13/16	.8125
44	.0860	12	.1890	11/32	.3438	53/64	.8281
43	.0890	11	.1910	S	.3480	27/32	.8438
42	.0935	10	.1935	T	.3580	55/64	.8594
3/32	.0938	9	.1960	23/64	.3594	7/8	.8750
41	.0960	8	.1990	U	.3680	57/64	.8906
40	.0980	7	.2010	3/8	.3750	29/32	.9062
39	.0995	13/64	.2031	V	.3770	59/64	.9219
38	.1015	6	.2040	W	.3860	15/16	.9375
37	.1040	5	.2055	25/64	.3906	61/64	.9531
36	.1065	4	.2090	X	.3970	31/32	.9688
7/64	.1094	3	.2130	Y	.4040	63/64	.9844
35	.1100	7/32	.2188	13/32	.4062	1	1.0000

SCALE: 20 DIVISIONS PER INCH, 1 DIVISION EQUALS .05

10 Appendix D: Tap/Drill Recommendations

CLEVELAND TWIST DRILL

Tap/Drill Recommendations

GTD GREENFIELD

Note: Drill size recommendations are for approximately 70-75% thread height. Drills produce a hole slightly larger than their nominal size. Size obtained will depend on drill style, machine, drilling conditions, fixturing and coating selected.

MACHINE SCREW, FRACTIONAL AND METRIC SIZES

Inch Tap Size & Pitch	Metric Tap Size & Pitch	Cutting Taps Drill Size	Cutting Taps Dec. Equiv.	Forming Taps Drill Size	Forming Taps Dec. Equiv.
0-80		3/64	.0469	54	.0550
	M1.6 x 0.35	1.25	.0492	1.45	.0571
	M1.8 x 0.35	1.45	.0571	1.65	.0650
1-64		53	.0595	51	.0670
1-72		53	.0595	51	.0670
	M2 x 0.40	1.60	.0630	1.80	.0709
2-56		50	.0700	5/64	.0781
2-64		50	.0700	47	.0785
	M2.2 x 0.45	1.75	.0689	2.00	.0787
	M2.5 x 0.45	2.05	.0807	2.30	.0906
3-48		47	.0785	43	.0890
3-56		46	.0810	2.30	.0905
4-40		43	.0890	38	.1015
4-48		42	.0935	2.60	.1024
	M3 x 0.50	2.50	.0984	7/64	.1094
5-40		38	.1015	33	.1130
5-44		37	.1040	2.90	.1142
	M3.5 x 0.60	2.90	.1142	3.20	.1260
6-32		36	.1065	1/8	.1250
6-40		33	.1130	3.25	.1280
	M4 x 0.70	3.30	.1299	3.70	.1476
8-32		29	.1360	25	.1495
8-36		29	.1360	24	.1520
	M4.5 x 0.75	3.70	.1476	4.10	.1614
10-24		26	.1470	11/64	.1719
10-32		21	.1590	16	.1770
	M5 x 0.80	4.20	.1654	14	.1820
12-24		16	.1770	8	.1990
12-28		15	.1800	7	.2010
	M6 x 1.00	5.00	.1969	7/32	.2188
1/4-20		7	.2010	1	.2280
1/4-28		3	.2130	15/64	.2340
	M7 x 1.00	6.00	.2362	F	.2570
5/16-18		F	.2570	L	.2900
5/16-24		I	.2720	M	.2950
	M8 x 1.25	6.70	.2638	7.40	.2913
	M8 x 1.00	7.00	.2756	19/64	.2969
3/8-16		5/16	.3125	S	.3480
3/8-24		Q	.3320	T	.3580
	M10 x 1.50	8.50	.3346	U	.3680
	M10 x 1.25	8.70	.3425	9.40	.3701
7/16-14		U	.3680	Y	.4040
7/16-20		25/64	.3906	Z	.4130
	M12 x 1.75	10.20	.4016	11.20	.4409
	M12 x 1.25	10.80	.4252	11.50	.4528
1/2-13		27/64	.4219	15/32	.4682
1/2-20		29/64	.4531	12.25	.4823
	M14 x 2.00	12.00	.4224	33/64	.5156
9/16-12		31/64	.4844	17/32	.5312
9/16-18		33/64	.5156	13.50	.5315

Inch Tap Size & Pitch	Metric Tap Size & Pitch	Cutting Taps Drill Size	Cutting Taps Dec. Equiv.	Forming Taps Drill Size	Forming Taps Dec. Equiv.
5/8-11		17/32	.5312	14.75	.5807
5/8-18		37/64	.5781	15.25	.6004
	M16 x 2.00	14.00	.5512	19/32	.5938
	M16 x 1.50	14.50	.5209	15.25	.6004
	M18 x 2.50	15.50	.6102	39/64	.6094
	M18 x 1.50	16.50	.6496	17.25	.6791
3/4-10		21/32	.6562	45/64	.7031
3/4-16		11/16	.6875	23/32	.7188
	M20 x 2.50	17.50	.6890		
	M20 x 1.50	18.50	.7283		
	M22 x 2.50	19.50	.7677		
	M22 x 1.50	20.50	.8071		
7/8-9		49/64	.7656		
7/8-14		13/16	.8125		
	M24 x 3.00	21.00	.8268		
	M24 x 2.00	22.00	.8661		
1-8		7/8	.8750		
1-12		59/64	.9219		
	M27 x 3.00	24.00	.9449		
	M27 x 2.00	25.00	.9843		
1-1/8-7		63/64	.9844		
1-1/8-12		1-3/64	1.0469		
	M30 x 3.50	26.50	1.0433		
	M30 x 2.00	28.00	1.1024		
1-1/4-7		1-7/64	1.1094		
1-1/4-12		1-11/64	1.1719		
	M33 x 3.50	29.50	1.1614		
	M33 x 2.00	31.00	1.2205		
1-3/8-6		1-7/32	1.2188		
1-3/8-12		1-19/64	1.2969		
	M36 x 4.00	32.00	1.2598		
	M36 x 3.00	33.00	1.2992		
1-1/2-6		1-11/32	1.3438		
1-1/2-12		1-27/64	1.4219		
	M39 x 4.00	35.00	1.3780		
	M39 x 3.00	36.00	1.4173		

FORM TAPS NOT AVAILABLE IN THESE SIZES

PIPE TAPS — NPT, NPTF, NPSM, NPSC, NPSF

Nominal Pipe Tap Size	NPT & NPTF W/O Reamer	NPT & NPTF W/Reamer	NPSM	NPSC	NPSF
1/16–27	C (.242)	A (.234)	—	—	D (.246)
1/8–27	Q (.332)	21/64	T (.358)	T (.358)	R (.339)
1/4–18	7/16	27/64	15/32	15/32	7/16
3/8–18	9/16	9/16	.603*	.577*	37/64
1/2–14	45/64	11/16	19.0mm	19.0mm	.714*
3/4–14	29/32	57/64	61/64	61/64	59/64
1–11-1/2	1-9/64	1-1/8	1-13/64	1-13/64	1-5/32
1-1/4–11-1/2	1-31/64	1-15/32	1.546*	1.506*	—
1-1/2–11-1/2	1-23/32	1-45/64	1-25/32	1-25/32	—
2–11-1/2	2-3/16	2-11/64	2-1/4	2-1/4	—

METRIC - GREEN FRACTIONAL - RED WIRE GAGE - PURPLE LETTER SIZE - BLUE

*special

11 Appendix E: Drill Decimal Equivalent

DECIMAL EQUIVALENT

DRILL SIZE	mm	DECIMAL INCHES	DRILL SIZE	mm	DECIMAL INCHES	DRILL SIZE	mm	DECIMAL INCHES	DRILL SIZE	mm	DECIMAL INCHES
—	0.10	.0039	45	2.08	.0820	4	5.31	.2090	15/32	11.91	.4688
—	0.20	.0079	44	2.18	.0860	3	5.41	.2130	—	12.00	.4724
—	0.25	.0098	43	2.26	.0890	7/32	5.56	.2188	31/64	12.30	.4844
—	0.30	.0118	42	2.37	.0935	2	5.61	.2210	1/2	12.70	.5000
80	0.34	.0135	3/32	2.38	.0938	1	5.79	.2280	—	13.00	.5118
79	0.37	.0145	41	2.44	.0960	A	5.94	.2340	33/64	13.10	.5156
1/64	0.40	.0156	40	2.50	.0980	15/64	5.95	.2344	17/32	13.49	.5312
78	0.41	.0160	39	2.53	.0995	—	6.00	.2362	35/64	13.89	.5469
77	0.46	.0180	38	2.58	.1015	B	6.05	.2380	—	14.00	.5512
—	0.50	.0197	37	2.64	.1040	C	6.15	.2420	9/16	14.29	.5625
76	0.51	.0200	36	2.71	.1065	D	6.25	.2460	37/64	14.68	.5781
75	0.53	.0210	7/64	2.78	.1094	1/4	6.35	.2500	—	15.00	.5906
74	0.57	.0225	35	2.79	.1100	E	6.35	.2500	19/32	15.08	.5938
—	0.60	.0236	34	2.82	.1110	F	6.53	.2570	39/64	15.48	.6094
73	0.61	.0240	33	2.87	.1130	G	6.63	.2610	5/8	15.88	.6250
72	0.64	.0250	32	2.95	.1160	17/64	6.75	.2656	—	16.00	.6299
71	0.66	.0260	—	3.00	.1181	H	6.76	.2660	41/64	16.27	.6406
—	0.70	.0276	31	3.05	.1200	I	6.91	.2720	21/32	16.67	.6562
70	0.71	.0280	1/8	3.18	.1250	—	7.00	.2756	—	17.00	.6693
69	0.74	.0292	30	3.26	.1285	J	7.04	.2770	43/64	17.07	.6719
—	0.75	.0295	29	3.45	.1360	K	7.14	.2810	11/16	17.46	.6875
68	0.79	.0310	28	3.57	.1405	9/32	7.14	.2812	45/64	17.86	.7031
1/32	0.79	.0313	9/64	3.57	.1406	L	7.37	.2900	—	18.00	.7087
—	0.80	.0315	27	3.66	.1440	M	7.49	.2950	23/32	18.26	.7188
67	0.81	.0320	26	3.73	.1470	19/64	7.54	.2969	47/64	18.65	.7344
66	0.84	.0330	25	3.80	.1495	N	7.67	.3020	—	19.00	.7480
65	0.89	.0350	24	3.86	.1520	5/16	7.94	.3125	3/4	19.05	.7500
—	0.90	.0354	23	3.91	.1540	—	8.00	.3150	49/64	19.45	.7656