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Paper Airplane Building Machine: Paper Folding Mechanism

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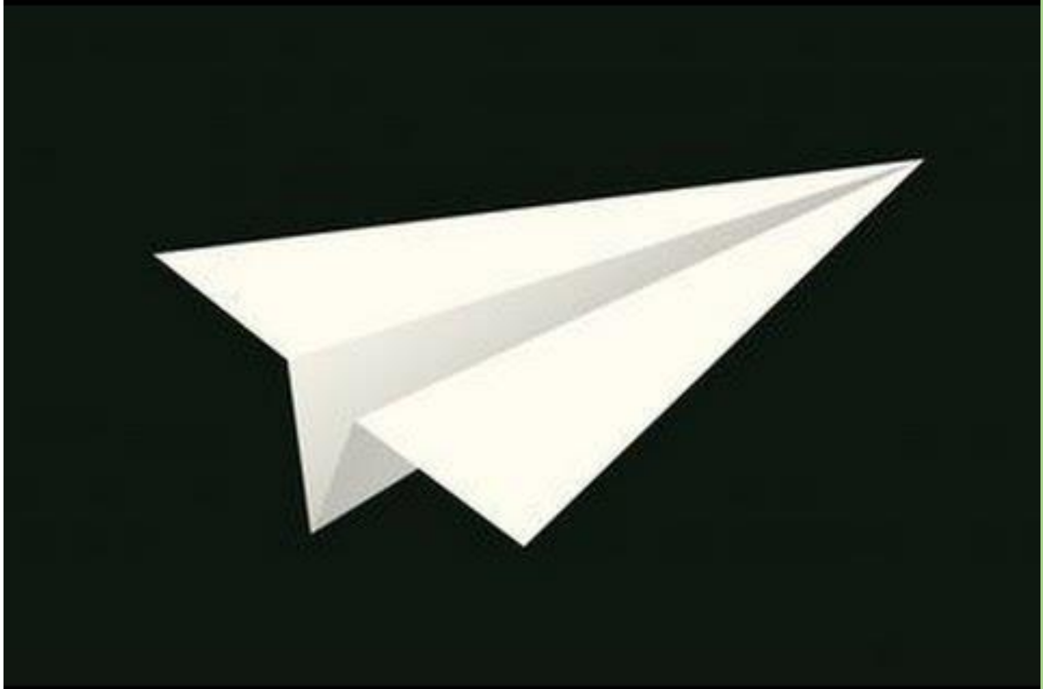
Paper Airplane Building Machine: Paper Folding Mechanism



Abdullah Alshahrani

Senior Project

Lab Partners:

Abdullah Aldakhail

Hassan Bujayli

Abstract:

The project was motivated by an ASME 2016 design challenge. The challenge was to design and manufacture a device that would turn a single sheet of paper into a paper airplane and launch it. The project is divided into three portions. The three portions are the frame and paper loading, folding mechanism, and launching. The circumference equation is used, to determine what the proper speed of the paper loading motor is. Notably, a slow rpm motor is needed for the loading mechanism to prevent the paper from being damaged. To avoid any deflection in the frame, the total weight of the machine had to be considered. The shear and moment diagram is used to calculate the reaction forces, and to calculate the proper thickness of the material being used. Four motors are used for the paper loading and folding processes, in which each motor has fifteen RPM. Additionally, two linear actuators are used in the paper folding process. Moreover, the launching process requires two motors, each has fifteen thousand RPM. All of the motors that have been mentioned require a twelve-volt battery. Both the launcher motors and the actuators are connected to a single battery. For the other motors, each two motors are connected to one battery. Each battery is connected to on-off switch. As a result, the machine is able to fold a standard sheet of paper into an airplane shape and launch it within 2 minutes. The launcher is able to shoot the paper airplane 10 meters.

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Introduction

Motivation

Manufacturing has been an essential part of development and growth of economy. Building a machine that make an airplane will raise our skill and knowledge about manufacturing process. Moreover, this project will be entertaining and interesting.

ASME Function Statement

This project function statement is to build a precise engineering system in order to create a projectile from a standard sheet of paper and lunch it as per ASME design competition rules.

ASME Requirements

The ASME design requirements for the paper airplane-building machine are the following.

- The machine must be design to create projectile using 20 lb. A-4 paper only.
- The system must be zero on-board emissions.
- Battery should be the source of power for the system.
- The system must be build that it can be disassemble and fit into a rectangular box with volume of 3375 in^3.
- System must manufacture a paper projectile that travel at least 15 ft.
- Paper loading must be manually.
- The height of the system must be less than 25 in.

Subproject Function Statement

The objective of this project is to build a mechanical system that folds a stander sheet of paper into specific airplane design.

Subproject Requirements

The design requirements for the project are the following:

- Machine must build three different paper projectiles.
- The device must be 30 cm in width, 92 cm in length, and 75 cm in height.
- The process of making each projectile must be within 30 second.
- In order to meet the success criteria, the device should fit in a box with length of 38 cm, width of 30 cm, and height of 25 cm.
- Must cost less than 200$

ASME Success Criteria

Success criteria can be achieved by getting high score result from the equation below

$$S = \frac{\text{distance } 1 \times \text{distance } 2 \times \text{distance } 3}{\text{Volume}}$$

Where:
Distance: is the distance that paper projectile 1,2,3 traveled.
Volume: is the volume of the box where the system was packed in.

Scope of Effort

The scope of this project is designing and building Paper airplane folding mechanism.

The Success of the project

Success depends on the whole processing time from where the paper was loaded up to lunching. Also, the traveled distance of the paper airplane must be 15 ft. or more

Design and Analysis

The folding machines process will be divided to three stations and each station will be doing different job. After the paper is loaded and reach station one to arms lever will fold the top two corners into the centerline of the paper (45 degree). After that, paper will move to the next station. In the second station, the paper tray will collapse to fold the paper in half. Finally, the wings will made by folding the 2 cm of each end of the paper 90 degree. In order to move the paper along the folding process up the lunching device, an electric motor will be used.

Approach: Proposed Solution

The paper folding machine will consist of three stations each station will have electric motor that drive a shaft that has several roller attached to it to move and fold the paper. In order to reduce the input speed to ensure that paper get enough pressure after it has been folded, gear train will be used. Each station will be 11'' long and 8'' wide so stander A4 paper can fit in it. Time wise is critical in this part of the project so to meet the required time for each projectile to be made which is 60 second, which mean each station will have only 20 second to get the job done, and for that to happen certain input RPM is required using the Constant circular acceleration formula (assuming that acceleration is constant).

Description (picture, sketch, rendering)

Precise Design of the machine is important to meet the requirements and success criteria. To many aspects should be considered while designing the machine such as dimensions, time, and performance. As for comparison, there are two designs that one of them will be preferred at the end.

First Design:

The folding machines process will be divided to three stations and each station will be doing different job. After the paper is loaded and reach station one two arms lever will fold the top two corners into the centerline of the paper (45 degree). After that, paper will move to the next station. In the second station, the paper tray will collapse to fold the paper in half. Finally, the wings will made by folding the 2 cm of each end of the paper 90 degree. In order to move the paper along the folding process up the lunching device, an electric motor will be used. As for the second airplane design, in the first tray and before the top two corners of the paper are folded three inches of the back end of the paper will be folded to reduce the length of the paper from 11” to 8”. Then the rest will be the same as the first airplane design process. The third design will be the same process except the paper will be folded three inch from the top to put the center of the mass of the airplane forward as much as possible to help the balance of the airplane while in the air.

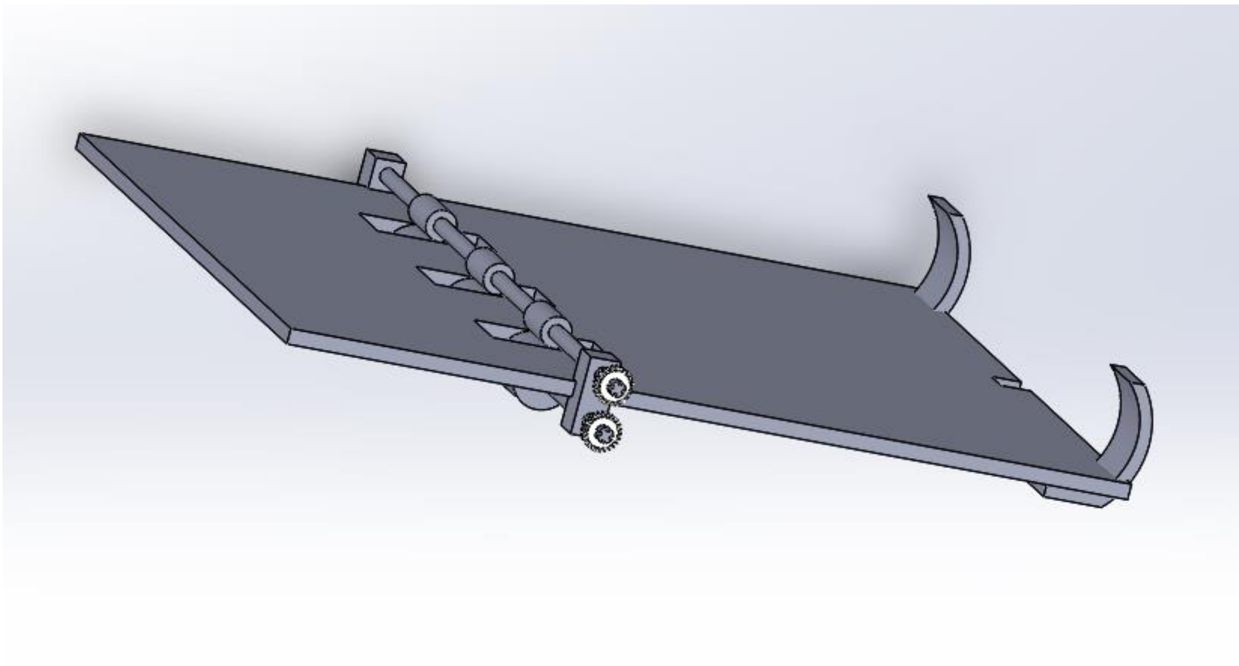


Figure1: First stage

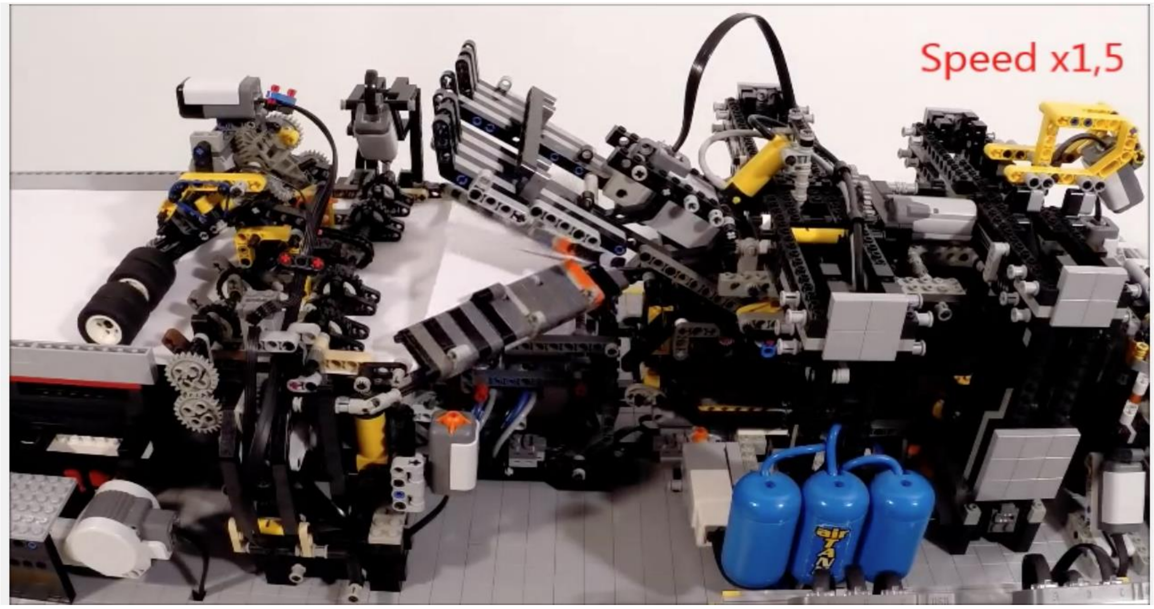
Second Design:

In the second design there is only one station that does the whole folding process. After the paper is loaded and the paper reaches the folding area, two arms lever will come up to fold the two end of the paper 45 degree. Then, the whole tray will collapse to fold the paper from the have. Finally, the paper will go through a T-shape tray to fold the wings 90 degree before it is send to the lunching device. As for the second design of the paper airplane the process will be the same except the paper will be loaded so the long side will be front which will end up with same design with different geometry.

The second Design of the machine would be better as for meeting the success criteria since the dimension of the machine will be less and the volume will decrease. However, in the design and fabrication point of view first design would be much easier to build.

Benchmark

As for comparison a paper airplane folding machine were made by Hknssn and posted a video on YouTube. The Hknass machine was built using lever arms that move by rotating motor. The Hknass machine takes almost 2 minutes to finish the whole folding process; this delay is caused by low motor speed and not enough torque to move the arms faster. In my design speed of the motors will be more than Hknssn motor which will finish the process faster. Also, to assure that the paper get enough pressure to stay folded torque must be increased.



Hknass, paper airplane folding machine, (https://www.youtube.com/watch?v=nxywiTLe3oM&feature=youtu.be&list=UUAoFbcIc8hPOT8WU9yB2iQg

Performance Predictions

After loading the paper, it will be processed to three station each station will do different job in order to form paper airplane by the end of the process. Each process will take approximately 10 second that's mean after loading the standard paper it will be by the launcher within 30 second.

The machine will be built using different type on material which are: aluminum for the frame and gear shafts, plastic for the gear, and rubber for the paper roller. The estimated cost for the project is around 200$. Aluminum will be given, plastic gears will cost around 65$, and electric motor will take the higher portion of the budget which will be 135$.

This project design and construction will take around 50 hours. Designing part which including drawing and calculation will take roughly 20 hours. The left 30 hours will be spent on the building and fabrication of the machine.

Description of Analyses

The parameters of the device are limited by the frame of the machine parameters which are: 30 cm in width, 92 cm in length, and 75 cm in height. In order to have enough torque to move the pressing lever arm to press the paper with enough pressure to keep it folded, electric motors with torque of 8.1 mNm will be used. However, these motors have high rotational speed which may harm the machine or cause defection in the production. In that cause a gear train must be used to reduce the speed to 6 RPM (calculated in Appendix A-1). As shown in appendix A-2 and A-3 a quadruple-reduction gear train will be used in this case.

Analysis

In this project time of each process and quality of the paper airplane are critical. As for the time, the subproject requirement indicate that the process from loading up to launching must take less than 30 second which mean 10 second for each process. In order to meet the required time the angular velocity of the part that will fold the paper into specific shape was calculated using the following equation (assuming that the acceleration is constant):

$$\theta_f = \theta_i + \frac{1}{2}(\omega_f + \omega_i)t$$

The result as shown in (appendix A-1) is 6 RPM. The electric motor that will be used in this project revelation per minute is 190 which lead to difference between the input and the output (184 RPM difference). In result, gear train must be used to reduce the input revelation per minute to meet the output revelation per minute. In the calculation, assumption were made that the pinion has 12 teeth because the less teeth the less cost. Using the train value ratio equation, Triple-reduction gear train must be used with the following teeth number.

$$TV = \frac{Input\ RPM}{Output\ RPM}$$

Gear	Teeth Number
A	12
B	48
C	12
D	48
E	12
F	24

Device Shape:

Based on the ASEM success criteria volume of the device is important. The parameters of the device are limited by the frame parameters. However, the frame that will hold the folding machine will be disassemble and packed in a box with parameters of 28 cm long, 20 cm width, and 23 height when machine is brought to the competition. So, the folding mechanism machine must be easy and fast to disassemble and assemble again. In order to reach that goal, each stage on the process will be independent from the other.

Device Assembly, Attachments

The folding mechanism machine is a part of the paper airplane building machine. By the end, the folding mechanism machine must be attached to the frame that will be made by different colleague. The parameters of the machine must be in tolerance with the frame as shown in figure-1.

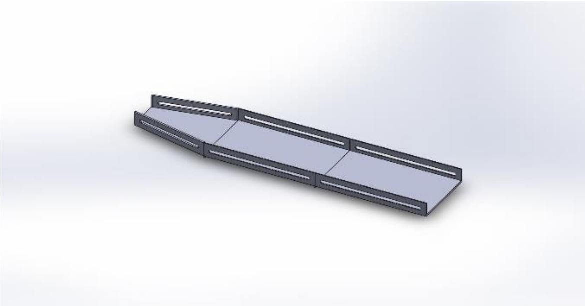


Figure-1: Frame Assembly

The folding machine consist of electric motors, gear box, paper tray with levers. The gear box will be fasten in the outer side of the frame using ½ millimeter socket head cap screws. The paper tray must be equal or less the frame width 26 cm (+- 0.013). The paper tray lever will be attached to the frame through a shaft that goes through the frame and connected to the gear train output. For the second stage, the folding mechanism will be horizontal so it fold the collapse the paper so the width of the paper will be half the original width; in order to do that, a worm gear will be used to transfer the motion from vertical to horizontal that will be connected to the frame the same way as the first stage lever.

Risk Analysis

Financial expense in this project ought to be handled carefully. The budget of this project is 200$. The budget includes everything that is illustrated in the device part. However, off-campus resources cost is not included in the budget since the project might not need any. In any case, human resources must be avoided in this project. Also, missing the time schedule is a great risk that might affect the completion of this project in the right time which is to be determined by ASEM. Although there is an extra time in the schedule for emergencies, Time schedule must be followed accurately.

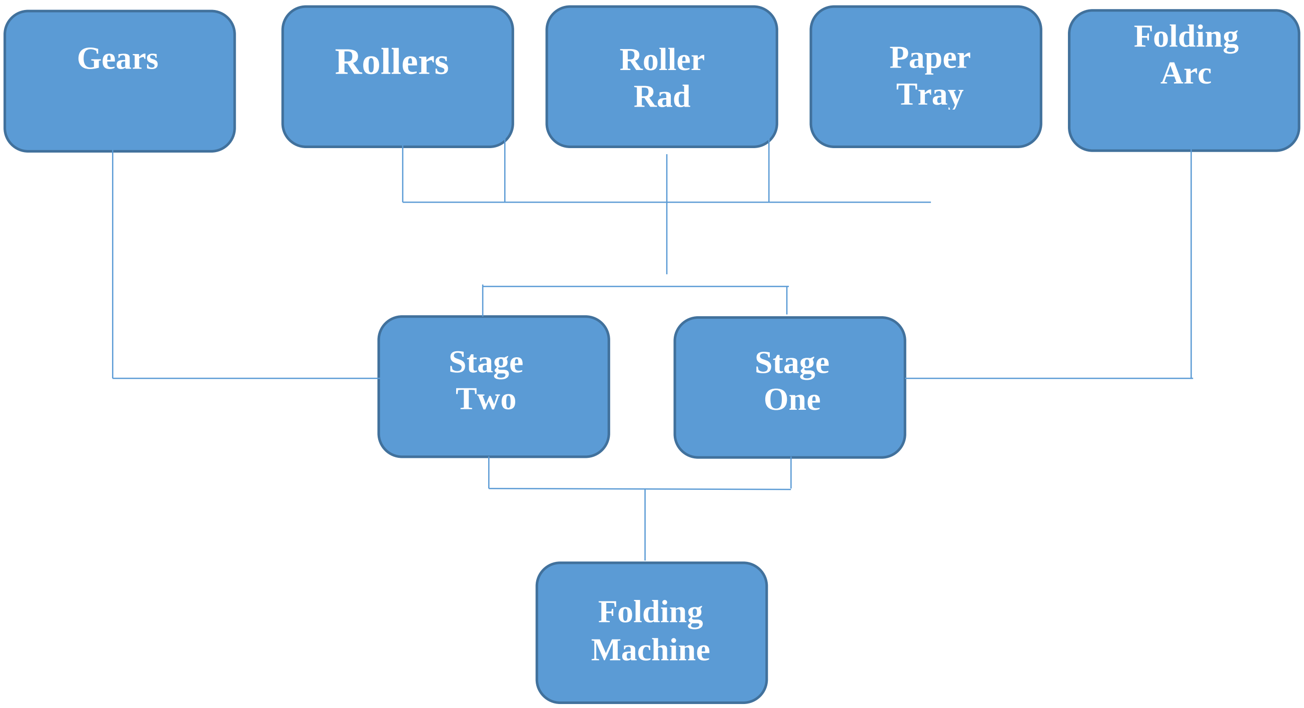
Methods and Construction

Description

In the three stages of the paper folding mechanism, the parts almost the same with different orientation. Each stage will consist of paper tray, set of roller, electric motor, and gear train. The paper tray will have two levers arm that moves 180^o to fold the paper. The lever will be connected to the paper tray using a shaft that connected to the output shaft of the gear box. Electric motors and gear train boxes will be connected to the outer side of the machine frame. The set of roller will be placed along the paper tray to move the paper from one stage to another. The rollers will be connected to each other using gears and the first roller will be connect to a shaft that is connected to the electric motor.

Drawing Tree, Drawing ID’s

The folding mechanism is comprised of three stages, each stage has specific number of part. First stage consist of two rod, six roller, paper tray and folding arc as shown in Appendix 3-B. Second stage parts are: five gears, rod and paper tray. The following drawing tree ends at the finished product.



Parts list and labels

The parts for building the folding machine are the following

Part Name	Quantity	Identification labels	Estimated Cost	Actual Cost	Source
Lego kit	3	1-A	$ 100.0	$150.0	LEGO
3” Actuators	2	4-B	$ 20.00	$50.35	Stock Drive Products (SDP/SI)
6” actuators	12	A 1N 1-N48016	$ 24.73	$ 54.12	Stock Drive Products (SDP/SI)
Wood work	2	A 1N 1-N32032	$ 7.00	$ 110.0	Jim Wood Shop
12V electric motors 15 RPM	3	A 1M 2-Y24045	$ 13.92	$ 72.00	Stock Drive Products (SDP/SI)
Roller, 2" Diameter x 9"	3	Customize part	$ 22.00	$ 50.0	Harwood
5/8" Steel Shaft for Rubber Rollers	3	QQ-A-225/8	$ 15.40	$ 15.40	BuyMetal.com
Aluminum Sheet 6061 -T6 0.063" (t) x 12" x 12"	3	ASTM-B209	$ 50.0	$100.0	BuyMetal.com
Shaft collar		________________________			
Total	32	________________________	$ 400	$ 642.66	

As shown on the part table above the total cost is $136.98. Some of the part above will be purchase online, but some of them is not available online. The parts that are not available online may be found in the stores in town or out of the town which mean transportation expenses may applied.

Due to change in design more materials were needed to be purchased, which cost more than the estimated budget. The devices that were add are included but not limited to: 3” actuators, 6” actuators, and shaft collar.

Manufacturing issues

Machining of the parts will be difficult task due to several reasons. For instant, if the first stage arc that supposed to fold the top corner of the paper from the top middle 45 degree is off the right dimensions this might lead to error in the final design of the paper airplane which might threaten the whole process. On the other hand, the machine must be build that exactly fit the paper with no extra space for the paper to slip out of track. After assembling all the parts together several manufacturing issue were discovered. The width of the paper tray supposed to be as the width of A4 paper, but unfortunately the width of the paper tray is slightly bigger that the width of the paper which makes the paper slip off the track. The shafts alignments are off that create a lot of friction with the service of the paper tray. Paper stuck at the folding arc after it is being fold 45 degree from the top corner due to design and manufacturing issues. Electric motors that were purchase have high speed with low torque, sometime when they are under high load they stop working. Also, second stage groove that make the bottom of the paper airplane is not slippery enough to push the paper down and move the paper to the lunching.

After the machine was constructed as per the design discussed in the method and construction, the machine did not function as it was supposed to. After the paper passed the loading the two folding arcs supposed to fold the top corner of the paper 45 degree and then allow the paper to go between the arcs to the next process, however, when the paper passed the loading and the top corner got to the arc, the paper stuck between the arc which don’t allow it to move to the next step. In addition to that, paper stuck in the second stage as well. So, a new design was needed since the first design was unfixable. In order to fix the arc issue, an actuator were used to hold the top corner folded. Also, in the second stage a T-shape plate were attached to two actuators that comes down and form the airplane then rise to allow the paper to move to the launcher.

Discussion of assembly, sub-assemblies, parts, drawings (examples)

It is important for the assembly that all parts is accurate and within the designed dimensions. The assembly of all parts must be done with considering that the assembly will be attached to frame that has certain dimensions. The assembly procedure of the paper airplane folding machine will as following:

1. First stage
    a. The folding arc will be welded to the paper tray (Spot welding)
    b. The roller shaft holder will be pinned to the side of the paper tray

Testing Method

Introduction

The testing of the Paper airplane-folding machine will be performed in multiple stages of its development. A virtual test can be done through soildwork drawing to test the weight, geometry, and fits. A prototype were made, in smaller scale, for each folding stage to test its functionality and accuracy.

Method/Approach

- Manual feeding test

- After completion of each stage construction test will be conducted. The plane paper will be passing through the stage manually to check the folding precision and accuracy.

- Gear reduction test.
  - The gear reduction will be tested for proper rpm.

- Final assemble test.
  - The final assemble will be attached to the frame of the machine and connected to the power source, then paper will be feed to the machine, after the process is completed the product (paper airplane) will be analyzed.

Test Procedure

Test Procedure

Test procedure will be divided into three categories as the following:

- Folding accuracy test.
  - To test the machine folding accuracy a prototyping machine was built. Then, a paper was run through the machine. After that, the final shape of the paper was analyzed. After that test a few changes were made such as the center distance between the folding arcs.

- Folding machine assembly test.
  - After the folding machine construction is done, it will be attached to the paper airplane building machine frame that contains paper loading machine and launcher. A number of test will be applied while keep tracking of process time to make sure that the whole process are done within the desired time.

Deliverables

Deliverables for testing are the performance evaluation sheets. Average of ten tests time will be calculated. Also, the final product will be analyzed to meet the satisfaction of the requirement, as well as virtual issue.

Budget:

Proposed Budget

part

The whole aluminum part will be made from aluminum 6061 T6 because of its good mechanicability and weldability. All the raw material will be supplied by the OnlineMetal.com Co. the material be bought in bulk, therefore the price of material will be listed in the budget by $/lb. The rubber roller will be made and customize to fit the design tolerance by the Harwood Rubber Products, INC. Gears will be printed using the Central Washington University 3D printer.

Labor

Labor and outsourcing has the greatest potential for savings in the production of the paper airplane-building machine. As the construction was planed outsourcing will not be needed, since all the needed machinery skill to accomplish the building of the machine was pretty much covered in the MET 355 Machining class.

Estimate total project cost

The estimated total project cost of materials is estimated to be 300$ at the beginning of the project. However, the estimated project cost might increased to 500$ since design change and more expensive material was selected.

Proposed Schedule

Time plays a great role in success in any matter. The proposed schedule will aid in keeping track of the project timeline. Also, it is a good way to tell of the project has fallen behind.

As shown in the proposed schedule in Appendix E, the estimated time to finish the project from just idea to full functional machine is 250 hours. The project design and analysis has taken 127 hours which is more that the half of the estimated time for the whole project to be done. That’s indicate that the project is behind schedule and the completion of the project might take more time than what was expected.

Although the design and analysis part of the project are taking longer time than estimated, the construction part must be done quicker than anticipated.

Project Management

Human Resources

Teammates Abdullah Aldakhail and Hassan Bujyli have been great help in getting goals accomplished, brainstorming, communicated, and advices. Team like that is a great tool in the success of this project.

Classmates have been very helpful, especially in the basic skills in the SolidWork. If obstacle was holding the progress of the project, classmates will be there to help answer any question for that matter.

Physical Resources

Senior project lab was a huge asset in building the prototype of the machine. Machine shop will be used in many of the parts machining. Some of the part will be welded as the part of the fabrication, so the welding shop will be used for that to be done.

Soft Resources

In the design stage, SolidWork has been incredibly helpful. After drawing the first design using a 3-D software such as SolidWork errors or design problems could be easy to find, track, and modified.

Financial Resources

Saudi Arabia cultural mission will provide a financial budget for this project.

Discussion

Design Evolution

The design started as complicated folding machine that has a lot of moving parts that each part accomplishes one job. However, every designer tends to keep everything as simple as possible as long the job will be done perfectly. Which will lead to budget saving and help easy identify a problem if there is a one.

The design of the machine changed after building the prototype. The previous design first stage has to levers arms that once the paper is at the paper tray would rise up to fold the top corners of the paper 45 degree. Then paper would move to stage two, and then the paper tray would collapse to fold the paper from the center. The final stage would be similar of stage one except the levers arm will fold the end of the paper (3 cm from the edge) to form the wings. In the final design the number of the stages had reduced from three to two. In stage one, the lever arms were changed with arcs that will fold the top corners of the paper approximately 43 degree while the paper moving. The wings and the paper airplane nose will be formed in the second stage while the paper in motion.

After three designs, the folding machine design is complete.

Project Risk analysis

Time has been a great risk factor for the completion of the project. The design and analyses of the project took more time than anticipated. Changing the design more than once has led a lack of time.

Also, cost of the project is another risk factor that may lead to delay in delivery. Outsources were not included in the project budget since all the work can be done by the team members, however, if difficulty appears while building the machine and outsources might needed this could effect the project estimated cost.

Successful

The project has already been success. The amount of work, calculation, and thought were performed in this project has led to magnificent increased in engineering knowledge. Which is the goal of this project that failure is in somehow will be consider as a success since knowledge will be gained from that failure.

Next phase

The part will be ordered before the start of the winter quarter. The folding machine will be manufactures and assembled in the winter quarter. Then it will be attached to the airplane building machine frame. In the spring quarter the machine will be ready for testing and evaluation.

After that, the machine will be taken to participate in the ASME 2016 competition.

Conclusion

The purpose of this project is to build a machine that make paper airplane out of stander A-4 paper. This project is divided into three major subprojects, which are paper loading and machine frame, paper folding mechanism, and airplane launching. This proposal is devoted to the folding mechanism part of the project. The folding machine must be able to fold a standard A-4 paper into desire paper airplane design.

The folding machine is going to be attached to the frame of the paper airplane building machine, so the geometry of the machine must fit within the geometry of the frame. The frame is supposed to support a specific load, therefore the machine must be within the required weight.

Time of delivering is important factor of success in this project. The whole process after the paper got loaded until it is delivered to the launching device must take less than 20 second. In order to accomplish that the product will be delivered in the required time, a motor with high speed was chosen for that job. However, the motor speed affects the torque applied to the machine which may lead to process inefficiency. To minimize the production inefficiency a triple gear train reduction is used.

The folding machine is only one part of the paper airplane folding machine. The frame, power source, and the launcher and other minor component s have also been selected and drawn by the team. These drawings are not included in this proposal but will be included in the final report and presentation.

Acknowledgements

Acknowledgements of gratitude go out the following people and faculty, who have been great aid in this project completion:

- Team member Abdullah Aldakhail and Hassan Bujyali, for the dedication and efforts that has been essential in this challenging project.
- Dr. Johnson, for his determination to see the team do more.
- Prof. Pringle, for helping clear up any critical project issues.

- Prof. Beardsley for his personal hours invested in helping overcome any obstacle.
- Saudi Cultural Mission, for the funding of the project.

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Appendix A

A-1

Given: Lever arm Driven by electric motor.

Input RPM = 190 rpm

Lever arm displacement (θ_i) = 0

Lever arm displacment (θ_f) = 180°

Time = 10 second

$W_0 = 0$

Find:

Final angular Velocity of the arm.

out put RPM

design gear train if requaired.

Sol'n:

– Computing Final angular Velocity.

$$\theta_f = \theta_i + \frac{1}{2}(w_f + w_i)t$$

$$\pi = 0 + \frac{1}{2}(w_f + 0)10$$

$$\pi = 5 w_f$$

$$w_f = \frac{\pi}{5} \boxed{= 0.63 \ \frac{rad}{sec}}$$

– Finding Out put rpm

$$\text{output rpm} = \left(0.63 \ \frac{rad}{sec}\right)\left(\frac{1 rev}{2\pi}\right)\left(\frac{60 sec}{1 min}\right)$$

Out put rpm = 6.00 RPM

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- Devising a gear train to reduce the speed of rotation of a drive at 190 RPM to 6 RPM

$$TV = \frac{\text{input speed}}{\text{output speed}} = \frac{190\ RPM}{6.00\ RPM} = 32$$

The maximum ratio that any one pair of gears can produce occure when the gear has 40 teeth and the pinion has 12 teeth

$$VR_{max} = \frac{48}{12} = 3.33 \quad (\text{too low})$$

$$TV_{max} = (3.33)^2 = 11.11 \quad (\text{too low})$$

$$TV_{max} = (3.3)^3 = 37.03 \quad (\text{low})$$

So, Design Triple-reduction gear train.

$$TV = (VR_1)(VR_2)(VR_3) = (4)(4)(2) = 32$$

$(2)(2) = 4$

32	2
16	2
8	2
4	2
2	2

$N_B = (4)(12) = 48$ teeth

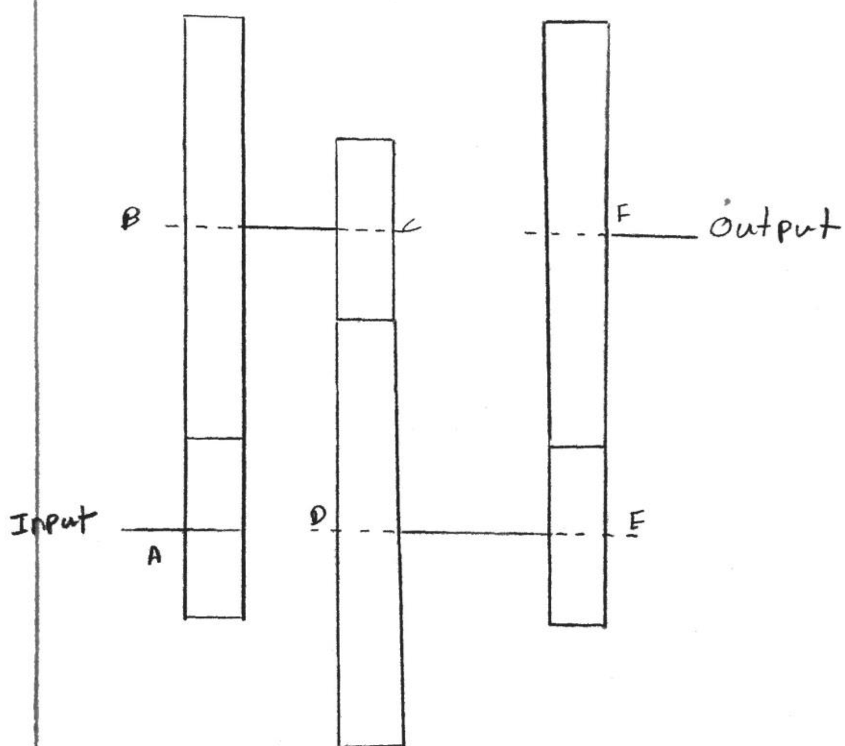
$N_D = (4)(12) = 48$ teeth

$N_F = (2)(12) = 24$ teeth

Summary:

$N_A = 12$ $N_C = 12$ $N_E = 12$

$N_B = 48$ $N_D = 48$ $N_F = 24$



Gear Design

Given:

$N_A = 18$ $N_C = 18$ $N_E = 18$

$N_B = 48$ $N_D = 48$ $N_F = 32$

Req'd:

a) Pitch diameter

b) Circular pitch

c) Addendum

d) dedendum

e) clearance

f) Whole depth

g) Working depth

h) Tooth thickness

i) outside diameter

Sol'n:

Since calclation is in SI unit,

Module (m) = 1.6

* First gear $N_A = 18$

a) $M = \frac{D}{N}$

$D_n = MN = (1.6)(18) = 28.8$ mm

b) $P_d = \pi m$

$= \pi(1.6) = 5.024$ mm

c)

$a = 1.00\ m$

$a = 1.00(1.6) = 1.6\ mm$

d)

$d = 1.25\ m$

$= 1.25(1.6) = 2.0\ mm$

e)

$C = 0.25\ m$

$= 0.25(1.6) = 0.4\ mm$

f)

$h_t = a + b$

$= 1.6 + 2.0 = 3.6\ mm$

g) $h_k = 2a$

$= 2(1.6) = 3.2\ mm$

h)

$t = \frac{P_c}{2}$

$= \frac{5.024}{2} = 2.512\ mm$

i)

$D_o = m(N+2) = 1.6(18+2) = 32\ mm$

* For N_D and $N_B = 48$

a)
$$m = \frac{D}{N}$$
$$D_n = mN = (1.6)(48) = 76.8$$

b)
$$P_d = \pi m$$
$$= \pi(1.6) = 5.024 \text{ mm}$$

c)
$$a = (1.00)m$$
$$= (1.00)(1.6) = 1.6 \text{mm}$$

d)
$$d = (1.25)m$$
$$= (1.25)(1.6) = 2.0 \text{mm}$$

e)
$$c = (0.25)m$$
$$= (0.25)(1.6) = 0.4 \text{ mm}$$

f)
$$h_t = a + b$$
$$= 1.6 + 2.0 = 3.6 \text{ mm}$$

g)
$$h_k = 2a$$
$$= 2(1.6) = 3.2 \text{ mm}$$

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h)

$t = \frac{P_c}{2}$

$= \frac{5.024}{2} = 2.512$ mm

i)

$D_o = m(N+2) = 1.6(18+2) = 32$ mm

---

* For gear $N_F = 32$

a)

$m = \frac{D}{N}$

$D_F = NM = (32)(1.6) =$

b) $P_c = \pi m$

$= \pi(1.6) = 5.02$ mm

c)

$a = (1.00)\,m$

$= (1.00)(1.6) = 1.6$ mm

d)

$d = (1.25)(m)$

$= (1.25)(1.6)$

$= 2$ mm

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e)

$c = 0.25m$

$= 0.25(1.6) = 0.4\ mm$

f)

$h_t = a + b$

$= 1.6 + 2.0 = 3.6\ mm$

g)

$h_k = 2a$

$= (2(1.6) = 3.2\ m$

h)

$t = \frac{P_c}{2}$

$= \frac{5.02}{2} = 2.512mm$

i)

$D_o = m(N+2) = 1.6(18+2) = 32\ mm$

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Given:

Input = 190 RPM $N_P = 18$

Output = 47.5 RPM $N_G = 48$

τ = 50 N.cm from designer manual. ⇒ 0.5 N.M

Find:

- Design a plastic gear
- compute the power

Sol'n:

Specify $N_P = 18$ and $M' = 1.6$. (Design decisions)

$D_P = NM = (18)(1.6) = 28.8$ mm

- calc: the power

$$P = T\omega$$

$$= (0.5 N.m)\left(190 \frac{rev}{min}\right)\left(\frac{2\pi\ rad}{rev}\right)\left(\frac{1\ min}{60\ sec}\right)$$

$$= \left(9.95 \frac{N.m}{sec}\right) \Rightarrow 9.95\ W$$

- Computing the transitted load.

$$W = \frac{P}{V_t}$$

$$V_t = \frac{\pi D n}{60000}$$

$$= \frac{\pi(12)(190)}{60000} = 0.119\ m/s$$

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$$W = \frac{P}{V_t}$$

$$= \frac{9.95 \frac{N.m}{s}}{0.119 \frac{m}{s}} = 83.35\ N$$

- Specify 20° full-depth teeth. Then $Y = 0.521$ for 18 teeth
- Specify a safety factor. The folding machine will likely experience light shock

So, $SF = 1.5$

- Specify unfilled ABC $S_{at} = 21$ MPa
- Calculating the face width

$$F = \frac{W_t P_d (SF)}{S_{at}\ Y}$$

$$= \frac{(83.35)(28.8)(1.5)}{(21 MPa)(0.521)} = 3.92\ mm$$

- Using $F = 5$ mm for stander

In Summory

$m = 1.6$, $N_p = 18$ $D_p = 28.8$mm $F = 5$mm

Stress in gear teeth $N = 48$

From "Fundamental of Machine Elements" 3rd ed

Table 14.7

$Y_G = 0.7485$

$$\sigma_t = \frac{W_t P_d (SF)}{F Y}$$

$$= \frac{(83.85N)(28.8)(1.5)}{(5.0)(0.7485)} = 2099 \text{ Pa}$$

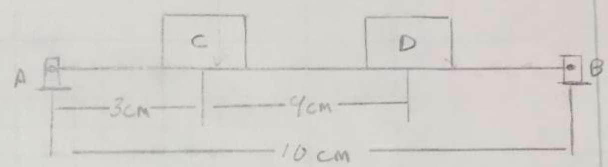
alshahrana@cwu.edu

Determine the required Forces at A and B to Keep the rod equilibrium. Find the required Diameter.

Given:

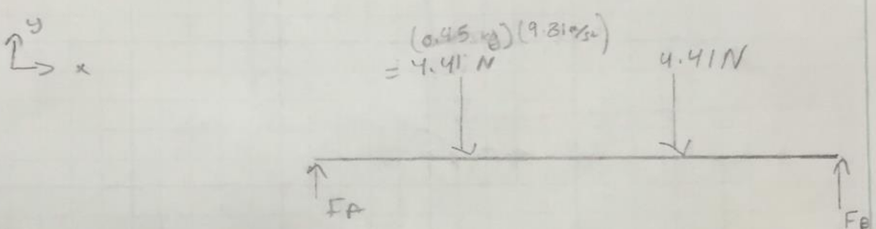
C mass = 450 g

D mass = 450 g



Sol'n:

FBD



$\circlearrowleft \sum M_A = 0$

$-(4.41)(0.03\,m) - (4.41)(0.07\,m) + F_B(0.1\,m) = 0$

$F_B = 4.41\ N$

Since the dimintion is identical

$\therefore\ F_A = F_B$

$F_A = 4.41\,N$

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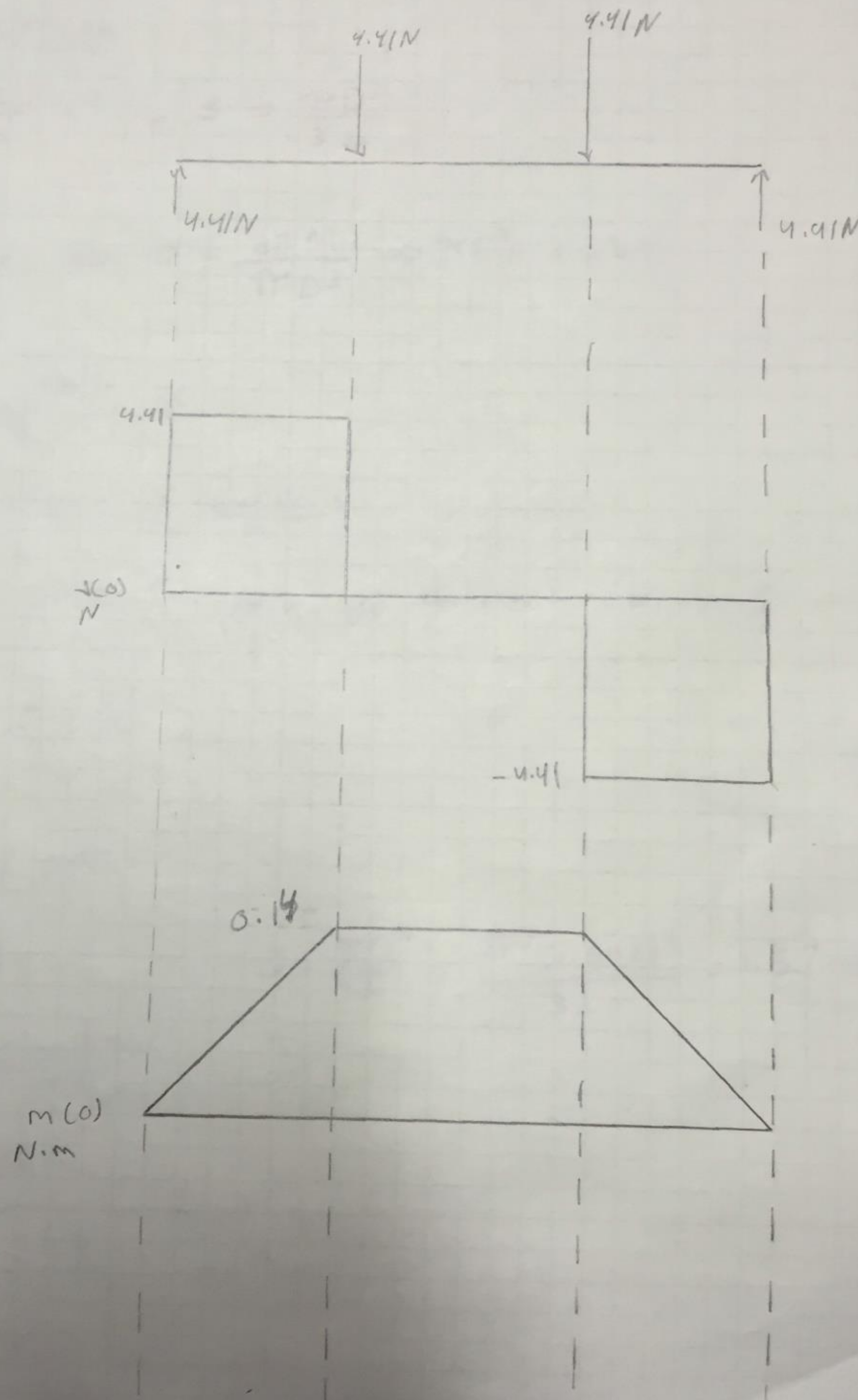
* Shear and Moment Diagram



The Material is aluminum 6061 T6

$\sigma = 207$ mpa

$\sigma = \frac{M}{S} \Rightarrow S = \frac{\pi D^3}{32}$

$\sigma = \frac{M}{\frac{\pi D^3}{32}} \Rightarrow \sigma = \frac{32M}{\pi D^3} \Rightarrow \pi D^3 \sigma = 32M$

$D = \sqrt[3]{\frac{32M}{\pi \sigma}}$

$D = 0.002 \text{ m} \left(\frac{1000 \text{ mm}}{1 \text{ m}}\right)$

$D = 2.00$ mm min go to next standarad

- Mohr's circle

$\sigma_x = 0$

$\sigma_y = 207$ MPa

$\tau_{xy} = \frac{TC}{J}$

$J = \frac{\pi D^4}{32} = \frac{\pi (0.002)^4}{32} = 1.57 \times 10^{-12} m^4$

$= \frac{(0.14)(0.001)}{1.57 \times 10^{-12} m^4}$

$= 89$ mpa

Tedata

Program : MDESIGN Module version: 13.0	User : Date : 08.12.2015	Customer: Proj. Nr:

Combined Stresses and Mohr's Circle

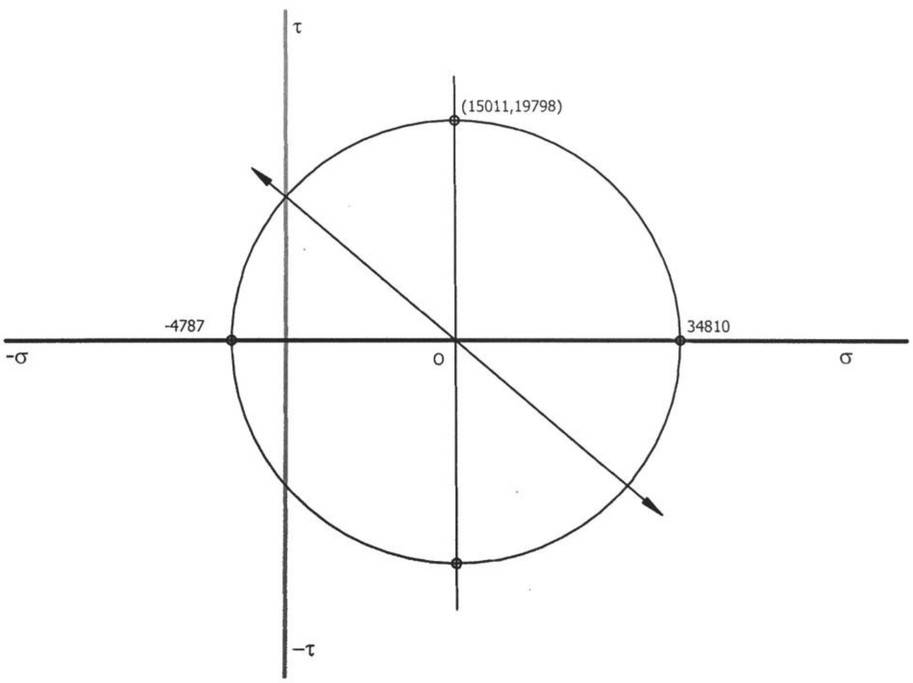
Input data:

Combined Stresses and Mohr's Circle

Normal stress acting along x-axis	σx = 0	MPa
Normal stress acting along y-axis	σy = 207	MPa
Shear stress	τxy = 89	MPa

Results:

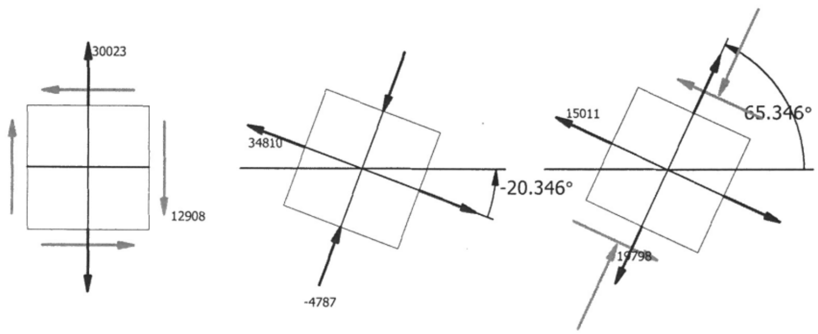
Maximum principal stress	σ1 =	240.004	MPa
Minimum principal stress	σ2 =	-33.004	MPa
Maximum shear stress	τmax=	136.504	MPa
Average normal stress	σavg =	103.500	MPa
Principal planes	ϕσ =	-20.346	°
Angle of maximum shear stress	ϕτ =	65.346	°



Tedata		
Program : MDESIGN Module version: 13.0	User : Date : 08.12.2015	Customer: Proj. Nr:

Combined Stresses and Mohr's Circle

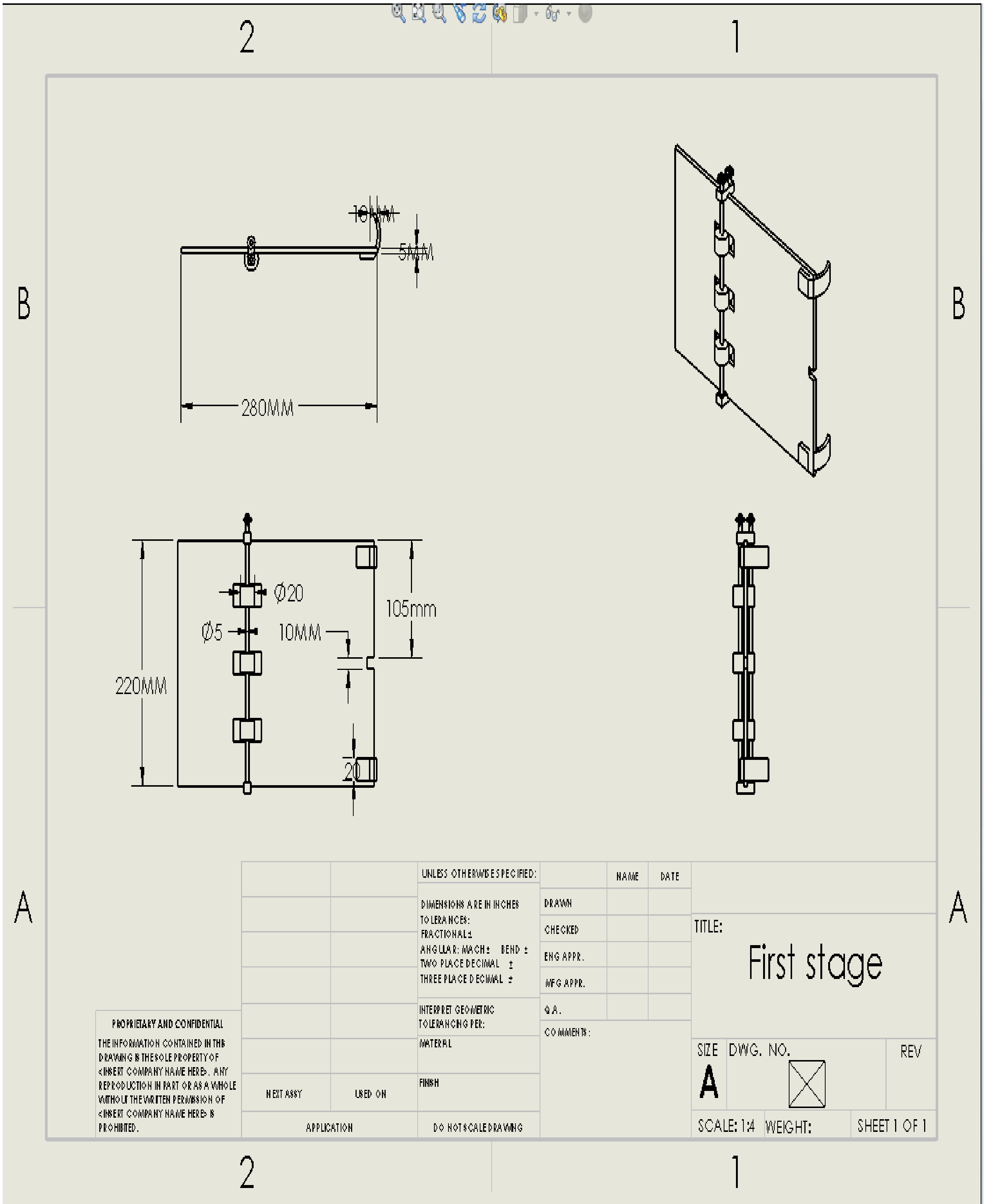
Relationships among original stress element, principal stress element, and maximum shear element for a given loading



Original stress element

Principal stress element

Maximum shear stress element



10MM
5MM
280MM
Ø20
Ø5
10MM
105mm
220MM
20
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
First stage
SIZE
A
DWG. NO.
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1
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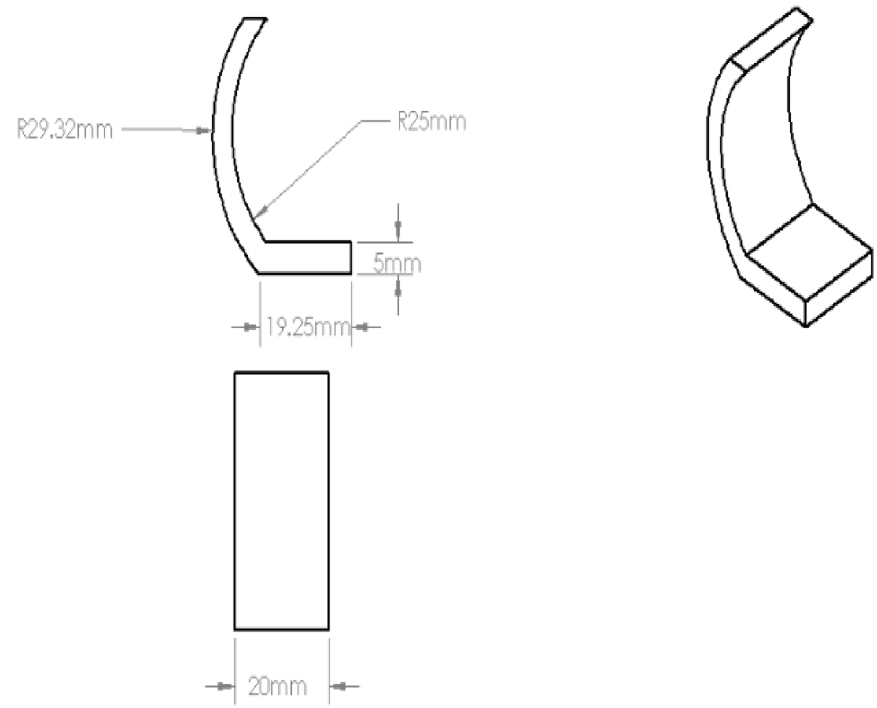
NEXT ASSY
USED ON
APPLICATION

B



B

A

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN METREC TOLERANCES: ± 1.5 MM FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.50 THREE PLACE DECIMAL ±0.700	DRAWN			TITLE:
			CHECKED			Folding Arc
			ENG APPR.	AA		
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A DWG. NO. REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:1 WEIGHT: SHEET 1 OF 1

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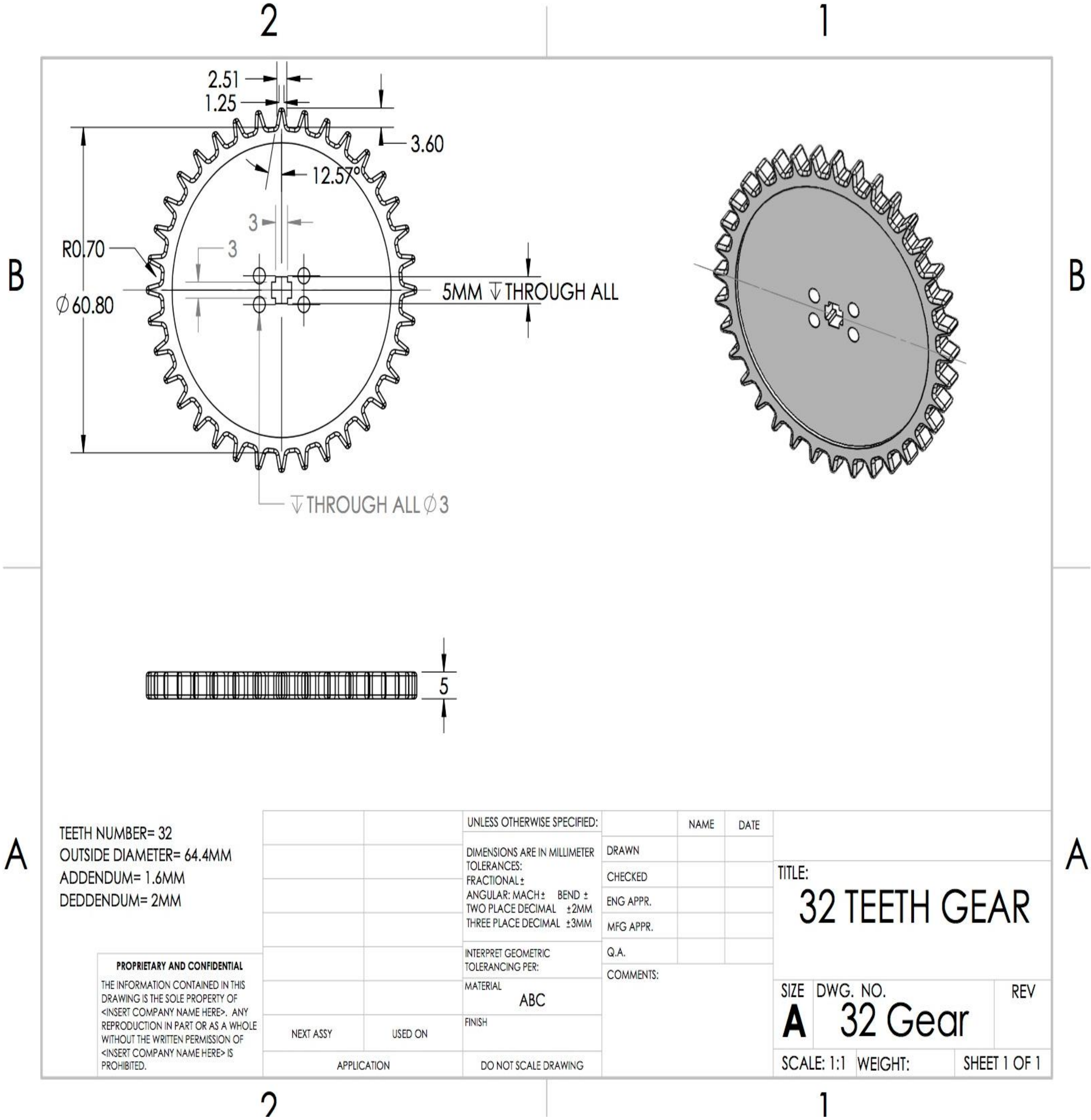
A

2 1

B-3


2.51
1.25
3.60
12.57°
3
3
R0.70
Ø60.80
5MM ⊽ THROUGH ALL
⊽ THROUGH ALL Ø3
5
TEETH NUMBER= 32
OUTSIDE DIAMETER= 64.4MM
ADDENDUM= 1.6MM
DEDDENDUM= 2MM
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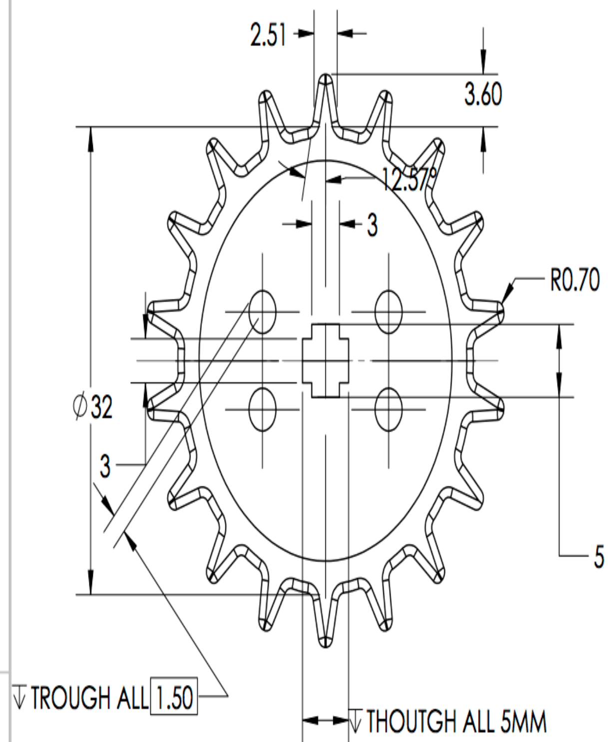
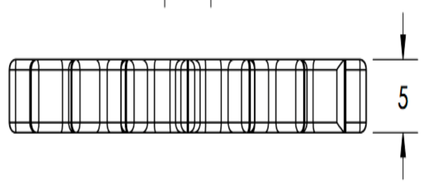
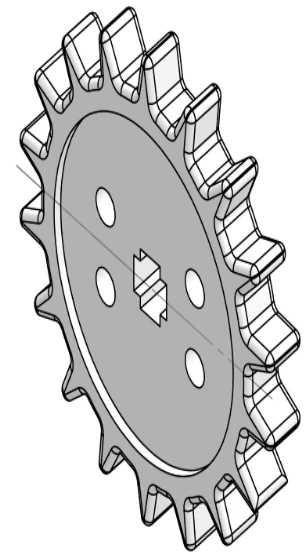
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETER
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±2MM
THREE PLACE DECIMAL ±3MM
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ABC
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
32 TEETH GEAR
SIZE
A
DWG. NO.
32 Gear
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1

B-4







TEETH NUMBER=18
OUTSIDE DIAMTER =35.6MM
ADDENDUM= 1.6MM
DEDENDUM= 2MM
MEDUAL= 1.6MM
TEETH DEPTH= 3.6MM

UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN MILLIMETER TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ±2 MM THREE PLACE DECIMAL ±3MM	DRAWN			TITLE:
	CHECKED			ABC
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE DWG. NO. REV
FINISH				A Gear 18 THEETH
DO NOT SCALE DRAWING				SCALE: 2:1 WEIGHT: SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

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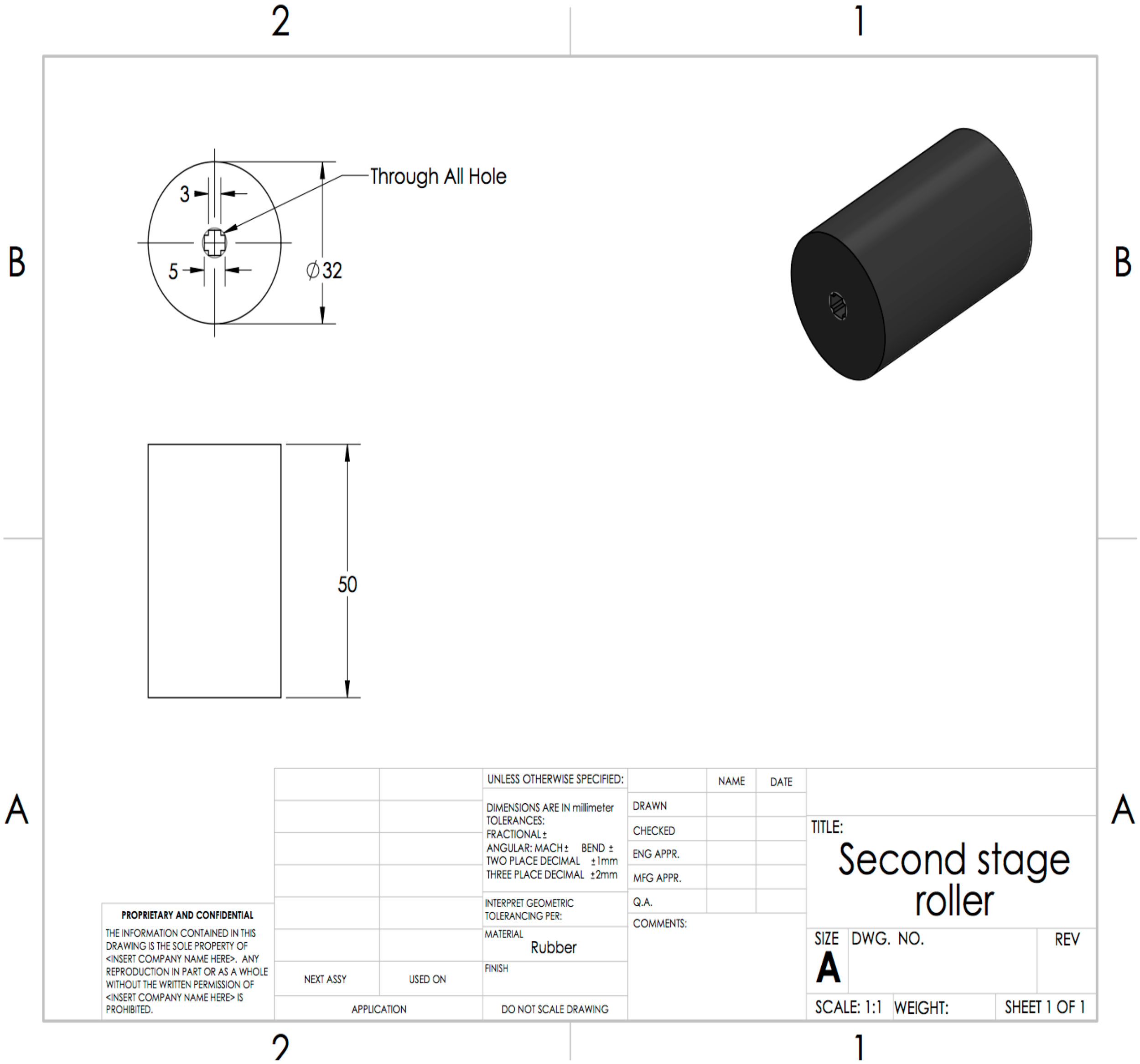
B-5



2
1
B
A
Through All Hole
3
5
∅32
50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN millimeter
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±1mm
THREE PLACE DECIMAL ±2mm
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Rubber
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Second stage roller
SIZE
A
DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
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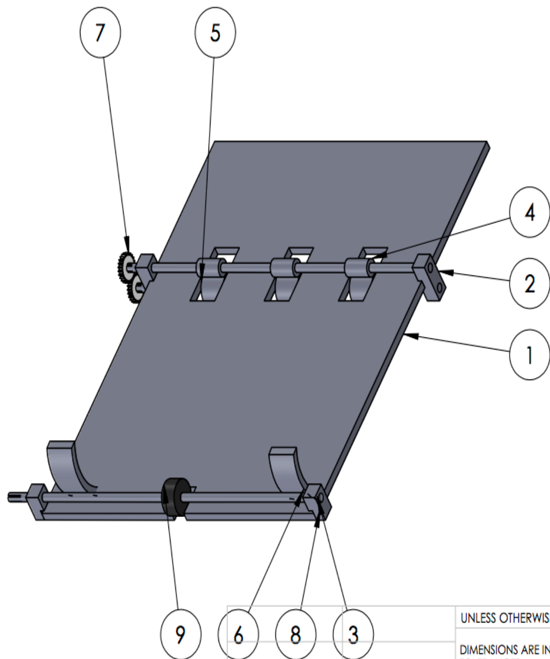
2 1

B

ITEM NO.	PART NUMBER	Material	QTY.
1	paper tray	Aluminum 6061	1
2	Rod Holder	Aluminum 6061	2
3	Roller Rod	Aluminum 6061	3
4	Roller	Rubber	3
5	under Roller	Rubber	3
6	Folding Arc	Aluminum 6061	2
7	Gear 24 teeth	ABC	2
8	Rod Holder front	Aluminum 6061	2
9	Front Roller	Rubber	1



A

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN Meterc
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± 1mm BEND ±
TWO PLACE DECIMAL ±2mm
THREE PLACE DECIMAL ±3mm

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Refer to table above

FINISH

NEXT ASSY | USED ON
APPLICATION
DON'T SCALE

	NAME	DATE
DRAWN	A.A	
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
First stage FIN Assembely

SIZE A | DWG. NO. First stage FIN | REV

SCALE: 1:5 | WEIGHT: | SHEET 1 OF 1

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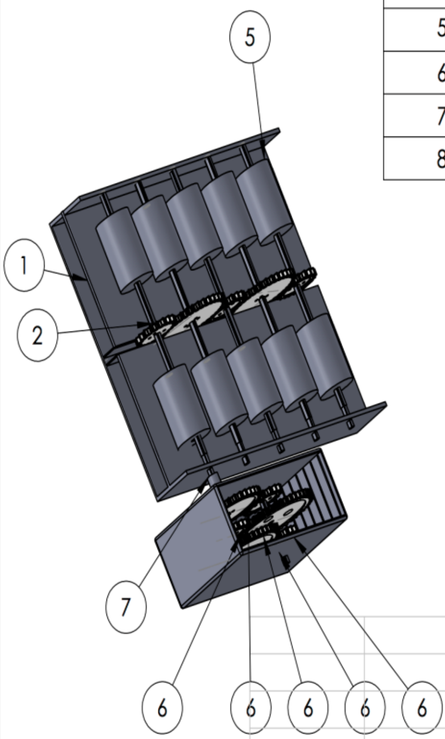
2 1

Project Schedu			
Paper Airplane Folding			
Task Number	Description	Duration (hr.)	
		Estimated	Actual
1	Proposal/Drawing		
1a	Discuss/Finalize design	30	42
1b	Parameter calculation	25	34
1c	Make SolidWork drawing	50	
1d	Part selction	10	
1e	part price qoute	5	
1f	Budget Plan	3	
1g	Proposal completion	5	
2	Construction		
2a	First Stage Construction		
i.	Cutting paper tray plate out of raw material	1	
ii.	Folding the arc	1	
iii.	Machining the Roller Rod	2	
iv	Machinging the Rod Holder	2	
iiv	Welding the arc to the paper tray plate	2	
	Welding the rad holder to the paper tray	2	
	inserting the Rubber Roller to the rod	1	
	installing the rod to the rad holder	1	
	attaching first stage to the machine frame	2	
2b	Second Stage Construction		
	Cutting paper tray top two plates out of raw material	3	

	Cutting paper tray bottom plate out of raw material	3		
	Welding the uper and bottom paper tray plate	4		
	Machining the gear shaft	2		
	welding the rod holder to the top part of the paper tray	2		
	Inserting rods to the rod holder	1		
	instailling the gears to the shaft	1		
	attaching stage two to the machine main frame	2		

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	paper tray2	Aluminum 6061	1
2	Stage two gear shaft	Aluminum 6061	5
3	Gear 18 Teeth	ABC	3
4	32 Teeth Gear	ABC	2
5	Second stage roller	Rubber	10
6	Gear Train	Aluminum 6061	1
7	Shaft connecter	Aluminum 6061	1
8	Small chaft connector	Aluminum 6061	1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±2MM THREE PLACE DECIMAL ±3MM	DRAWN	AA		TITLE: Wing Folding ASSY
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A DWG. NO. WING FOLDING ASSY REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:5 WEIGHT: SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

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Appendix E

Project Schedule												
Paper Airplane Folding Machine												
Task Number	Description	Duration (hr.)		October	November	December	January	February	March	April	May
		Estimated	Actual								
1	Proposal/Drawing										
1a	Discuss/Finalize design	30	42								
1b	Parameter calculation	25	34								
1c	Make SolidWork drawing	50									
1d	Part selction	10									
1e	part price qoute	5									
1f	Budget Plan	3									
1g	Proposal completion	5									
2	Construction										
2a	First Stage Construction										
i.	Cutting paper tray plate out of raw material	1	1								
ii.	Folding the arc	1	1								
iii.	Machining the Roller Rod	2	4								
iv	Machinging the Rod Holder	2	2								
iiv	Welding the arc to the paper tray plate	2	2								
	Welding the rad holder to the paper tray	2	2								
	inserting the Rubber Roller to the rod	1	1								
	installing the rod to the rad holder	1	1								
	attaching first stage to the machine frame	2	1								
2b	Second Stage Construction										
	Cutting paper tray top two plates out of raw material	3	3								
	Cutting paper tray bottom plate out of raw material	3	2								
	Welding the uper and bottom paper tray plate	4									
	Machining the gear shaft	2									
	welding the rod holder to the top part of the paper tray	2									
	Inserting rods to the rod holder	1									
	instailling the gears to the shaft	1									
	attaching stage two to the machine main frame	2									

Appendix F –

CWU machine shop and welding shop will be use as resources to build this project. With help from expertise such as Ted Bramble and Matt Burvee this project was able to move forward.

Appendix G –Testing Data

Testing Data Sheet

Speed testing				
Process	Time 1	Time 2	Time 3	Average
Airplane nose				
Wing folding				
Center collapsing				
Total				

Testing Data Sheet				
Design measurement				
Process	Data 1(mm)	Data 2(mm)	Data 3(mm)	Deferent percentage
Airplane nose				
Wing folding				
Center collapsing				
Total				

Appendix H – Evaluation Sheet (a form or spreadsheet to compute desired values)

Evaluation Sheet				
Time Evaluation				
Process	Time 1	Time 2	Time 3	Pass/ Fail

Airplane nose				
Wing folding				
Center collapsing				
Total				

Each process should take less than 10 second (tolerance +-2 second)

Appendix I – Testing Report

Introduction:

The scope of this report is to describe the testing phase of the paper airplane-building machine: folding mechanism that was created thought this project. The device has a set of specific requirements. These requirements for the folding machine are as the following:

- Machine must build three different paper projectiles.
- The device must be 30 cm in width, 92 cm in length, and 75 cm in height.
- The process of making each projectile must be within 60 second.
- In order to meet the success criteria, the device should fit in a box with length of 38 cm, width of 30 cm, and height of 25 cm.
- Must cost less than 200$

The parameters that are important in this testing are the time of processing one projectile. Because this machine was built based on the ASME 2016 student competition, size is important to meet the success of criteria. The test will also include the precision of the process.

The predicted performance of the folding machine is that the folding process for one paper airplane will take less than one minute (from the loading to the launcher). It is also estimated to meet the 30 cm width maximum and 92 cm length maximum. The machine is estimated to fold the paper within a specific design.

Data acquisition for the testing process will be taken by hand and recorded into the table below. Stopwatch will be used to record times of the folding in each stage. Measuring tape will be used in order to measure the width and the length of the machine. Testing help might be used to help speed up the testing process.

In Appendix 2 is a Gnatt chart of the testing schedule that will be followed throughout the testing process to ensure all testing is completed on time and in orderly manner.

Method/Approach:

The resources that will be needed for the testing process are as the following:

1) Testing data tables to record data as testing goes.
2) Measuring tap that read to 1/6 '' increments to measure the width and the length of the machine
3) Stopwatch to record times it takes the machine to fold one paper airplane.
4) 20 lb. A-4 sheet of paper.
5) Battery charger to recharge the batteries after each complete test.
6) A testing helper to take pictures/ video of testing process who can also help writing the data in the tables.

There are no external costs associated with the testing process as CWU has battery charger and recycle paper are used for the testing.

During the tests a helper usually teammate will record the data such as the time each stage takes to finish folding and will record it into the data tables created for testing process. Once the testing processes are finished data is recorded into the data table in Excel.

The following list is the tests that will be performed on the folding mechanism machine in order to evaluate its effectiveness:

1) The first test that will be performed is a test of dimensions. The width of the machine by itself without the frame will be measured using measuring tape. This test will ensure that the machine is within the required dimensions.
2) The second test that will be performed is the time of the process of folding paper airplane. This test will be divided into two sections. Each stage will be tested individually. The first stage is the stage after the paper passed the loading which the paper top corner will be fold 45 degrees. The second stage is the stage where the paper has passed stage one completely. Stopwatch will be used to record time.
3) The third test is to evaluate the precision of the machine. In this test five trails will be done to evaluate the reproducibility and repeatability of the machine.

The operational limitations of the folding machine are that the machine cannot fold paper rather than 20-lb. A-4 paper as this was the type of paper the machine was designed for. Paper also must not to be modified, for example cutting paper or adding anything to the paper. It also should not be operated in rain as the liquid could break the electric motors and actuators.

Once the data is recorded by hand, the data will then be transferred to their Excel tables so the averages and percentage of error can be calculated. After the date is digitally recorded they can be compared to the predicted values that was made before the test and see how well the folding machine performs.

Test Procedure:

The test procedure for the paper airplane building machine: Folding mechanism will take 5 minutes. Test is highly recommended to be held in door to avoid any distribution to the process such as wind and rain. Also, before conducting the test makes sure that there are no obstacles in the front of the machine (at least 10 ft). The test procedure as the following:

1) Visually inspect the rollers and paper tray. Any object on the paper tray or on the rollers may affect the process.
2) Turn on the first stage roller by turning the first toggle switch up.
3) Turn on the Lego Motor Controller by pressing the orange button.
4) Use the arrow in the Lego Motor Controller to navigate through the saved programs.
5) Choose "Paper-Airplane'' program by clicking the orange button.
6) Load the paper.
7) Wait for 20 second then turn the first stage roller off.
8) The levers that connected to the Lego motors should come up to fold the top corners of the paper.
9) Wait until the levers come back to the original position, then turn on the first stage roller again.
10) Once the paper completely passed the third roller, Turn the second stage rollers by turning the second toggle switch up.
11) Turn on the pressing plate by turning the third toggle switch up. Then actuators will bring the plate down until it stops.
12) From the Lego Motor Controller saved program choose "Paper-Airplane 2" (refer to step 2-4 for further instruction).
13) After the paper is launched, make sure that all switches are off.

Failure of the electricity wiring system may cause fire or damage to the equipment, so while conducting the folding mechanism machine test don't leave the machine without attendance.

Testing Deliverables:

Below are the results of the testing conducted on the folding machine. The raw data and calculated values can be found in the Appendix below.

Parameter value

One of the device requirements was that folding one paper airplane should take less than 60 second, that's mean that since there is two stages each stage should take less than 30 seconds. After testing, the first stage took around 50 seconds and stage two took around 40 seconds. Therefore the device didn't meet the requirement of being able to fold sheet of paper to airplane within 60 seconds.

Another device requirement was that the width of the machine must be less than 30 cm and the length must be less than 90 cm to fit exactly the paper without any additional space. After measuring, the width is 30 cm and the length is 86 which satisfy the requirement.

Calculated Value:

The first test described above is for the time of the folding of paper in each stage. The time must be less than 30 seconds in each stage in order to finish the process within the ASME student competition requirements. As illustrated above, the test results do not meet the requirement. The reasons are that the motors that were used have low speed relative to the required speed. Also, two actuators were added to the first stage process which added more time to the process. Comparing the predicted time with the resulted time, the difference in the first stage is 40 %.

Success Criteria Values:

The folding mechanism met the success criteria outlined by the project, and it is considered a success since it can fold a plane sheet of paper into paper airplane. The success criteria equation is:

$$S = \frac{distance_1 + distance_2 + distance_3}{volume}$$

After gathering the data required to calculate the success of criteria, the success criteria value that was achieved by the machine is 0.69.

Conclusion:

The machine was put through many test to see how it would perform and it passed every test it was put through except the time test. However, the machine still does its job that was design for which is folding sheet of paper to an airplane. To conclude this testing report the investigator of the project and the teammate view this project as a success.

Appendix 1: Testing Documentation:

Table 1: Stage one Timing test

Stage One Timing Test Data		
Stage One completion Calculated Time		30 s
Trail	Time (Second)	Comment
1	58	
2	56	Process Sequence error
3	60	
4	62	
5	59	
Average	50	

Table 2: Stage two Timing Test

Stage two Timing Test Data		
Stage two completion Calculated Time		30 s
Trail	Time (Second)	Comment
1	41	
2	42	Process Sequence error
3	43	
4	42	
5	41	
Average	41.8	

Appendix2: Gantt chart.

3	Testing										
3a	Discuss testing approch with teammate	1									
3b	Live test run	1									
3c	checking three random product for quiality	0.5									
3d	testing the duration of folding one paper	0.25									
3e	testing the battery duration	0.25									
3f	Update web page	3									

Appendix J – Resume

ABDULLAH ALSHAHRANI

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OBJECTIVES

I want to share my high level of skills on most machines and work on automobiles or Airplane.

EDUCATION

Texas A&M Engineering Extension Service (TEEX)

- Firefighter I
- Firefighter II
- Fire Protection.
- Hazardous Material.

Central Washington University

- Mechanical Engineering Technology, Candidate, Expected graduation, Jun 2016

EXPERIENCE

ARABIAN AMERICAN OIL COMPANY | DAHRAN, EAST PROVINCE

Fire Truck Operator, *Nov 2006 – Mar 2012*

Safely drive firefighting apparatus to and from fires or other emergencies following laws and regulations, operating pumps, aerial devices, power and other mechanical equipment as required, keep inventory of tools, and equipment on apparatus. Perform required apparatus maintenance, cleaning duties, inventory checks and weekly inspections.

SKILLS

- Experienced in Windows 10, Windows 8, and OS X Yosemite environment.
- Office application (MS Word, MS Excel, MS PowerPoint, MS outlook).
- Fluent in two languages (Arabic and English).
- Experienced in CAD (SolidWork, AutoCAD, Rhino).
- Used Miller Driller machine, lathes, CNC machine, Laser Cutter to fabricate parts.