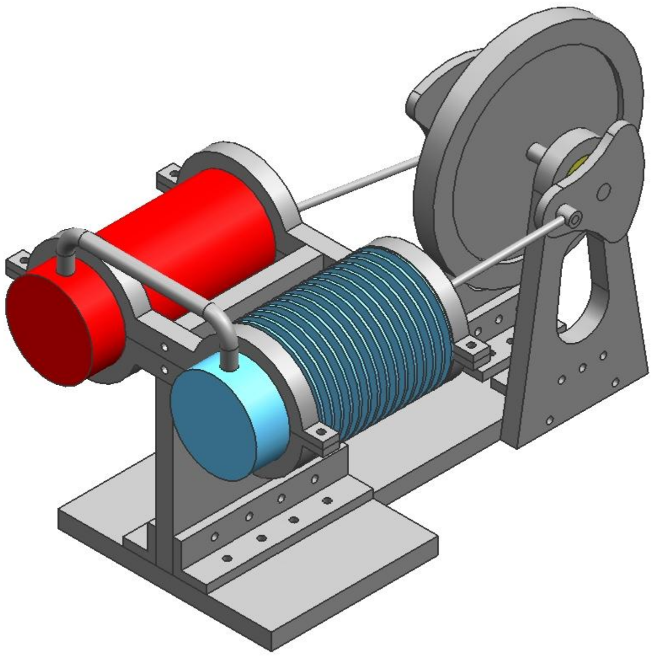
TEAM 04

SOLAR AND WASTE HEAT POWERED STIRLING ENGINE



BUILD REPORT #1

"The Little Engine that Could"

The goal of team 04 is to design and build a working Stirling Engine suitable for classroom demonstration. As an added challenge the group is planning to have the engine run entirely from solar energy as well as other heat sources.

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Submission Date: November 17th
Submitted To: Dr. Militzer

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1. INTRODUCTION

After weighing the pros and cons of the designs outlined in the design selection memo, Team 04 chose the inline alpha arrangement. The inline arrangement was chosen for display purposes as well as simplicity of design.

This report will outline team progress, build requirements, initial budget, a list of things to be determined as well as a Gantt chart for the upcoming winter 2009 term. Engineering drawings of our design components are provided in the Appendix of this report.

Team 04 plans to do a complete build and thorough testing of the design in the 2009 winter term.

2. DESIGN APPROACH

The success or failure of the design will depend on the care and consideration taken to overcome the following three challenges associated with building a Stirling engine:

- Friction in all of its forms
- Heat transfer and energy storage
- Maintaining a large temperature differential

To minimize friction in the design the team decided to reduce the number of moving parts. The pistons for our engine were designed with four grooves that will serve two purposes: hold a layer of lubrication to decrease friction as well as aid in maintaining pressure within the cylinders. Low friction bearings will be selected for the flywheel shaft to ensure minimal rotational friction. Another design consideration to minimize friction was the size of the transfer tube. The size of the transfer tube was selected as low as possible to minimize the amount of dead space but at the cost of an increase in friction between the working gas and the walls of the transfer tube when transferring from the hot cylinder to cold cylinder and vice versa.

To increase heat transfer between the cold cylinder and the surrounding atmosphere the cylinder was designed with several fins. The fins will increase the surface area of the cylinder thus increasing the heat transfer to the surroundings. Another design consideration to increase heat transfer would be the use of internal fins on the hot cylinder. This consideration has yet to be determined useful or not.

To achieve the maximum power output for our engine a large temperature differential must be achieved and maintained. To accomplish this, the team has implemented the following:

- Submerse the cold cylinder in an ice water bath
- Wrap the hot cylinder in an insulating material
- Isolate the cylinders from the frame using a high thermal resistance material

3. TEAM PROGRESS

Team 04 is making steady progress in designing a solar powered Stirling engine. See Table 1 for an evaluation of the team progress with respect to design specific tasks. Each task will be evaluated and assigned a color coded progress indicator. Evaluation of a task is based upon dependence of other tasks on the task of consideration, the criticality of the task to the success of the overall design, and the current progress of the task in terms of finalization of concept and design (dimensions, application of theory, numerical results, etc.). The evaluation is an imprecise qualitative measure intended only as a means of assigning priority to outstanding tasks. The progress indicator is color coded with the following definitions:

- **Red** – Progress is severely behind schedule and could greatly impact the success of the overall design. Time and resources should be dedicated to the task immediately.
- **Orange** – Progress is behind schedule but will not affect the progress of the overall design.
- **Yellow** – Progress is as scheduled but minor design considerations are still unknown.
- **Green** – Progress is ahead of schedule.

Table 1: Team 04 Progress Indicators

Task	Progress Indicator
1. Engineering Calculations	Red
2. Final Design	Yellow
a. Frame	Yellow
b. Piston/Cylinders	Yellow
c. Rotating Assembly	Yellow
d. Sensors	Green
e. Solar Collector	Green
f. Heating/Cooling	Orange
3. Mock-Up	Orange
4. Budget	Yellow

The following is a description of each task consideration:

1. Engineering Calculations: (hot and cold cylinder temperatures, power output and efficiency, RPM, heat transfer rates, mean pressure, internal gas temperature, etc.).

2. Final Design: The successful implementation of the design will be determined through testing and troubleshooting.

    a. Frame: (support for stationary and dynamic components, thermal isolation)
    b. Piston/Cylinders: (hot and cold pistons
    c. Rotating Assembly: (flywheel, shaft, connecting rods, bearing selection, lubrication)
    d. Sensors: (temperature and pressure indicators)
    e. Solar Collector: (Fresnel lens)
    f. Heating/Cooling: (internal vs. external fins, ice water bath, insulation)

3. Mock-up: The mock-up would serve only as a scale reference and would not be a working model. Expected to have completed early in winter term before commitment to final build report.

4. Budget: The cost of materials.

Refer to the Gantt chart in Section 7 for a list of tasks scheduled for completion in the winter term and Section 6 for a list of outstanding design considerations to be determined.

4. DESIGN COMPONENTS

This design requires machining for most of the engine parts. The piston cylinder arrangement needs precision machining with tolerances that will ensure an adequate pressure seal. The alignment of the pistons with respect to the shaft is also extremely important to reduce friction in the system. Once each part is fabricated the engine will be assembled by the team. All part drawings attached in the Appendix are to be fabricated from materials that will be provided by the team.

The Fresnel lens and stand will be assembled by the team from wood lumber. This will be done as soon as possible to test temperature outputs and the final selection of material grades and surface finishes. The ice water bath will also be constructed by the team.

There will be no assembly time requested of the technicians as the design has been planned as a bolt-up assembly that requires no welding; however, minor assemblies like interference press fits will be requested of the technicians. Refer to Fig. 1 and Table 2 for an outline of the design components.

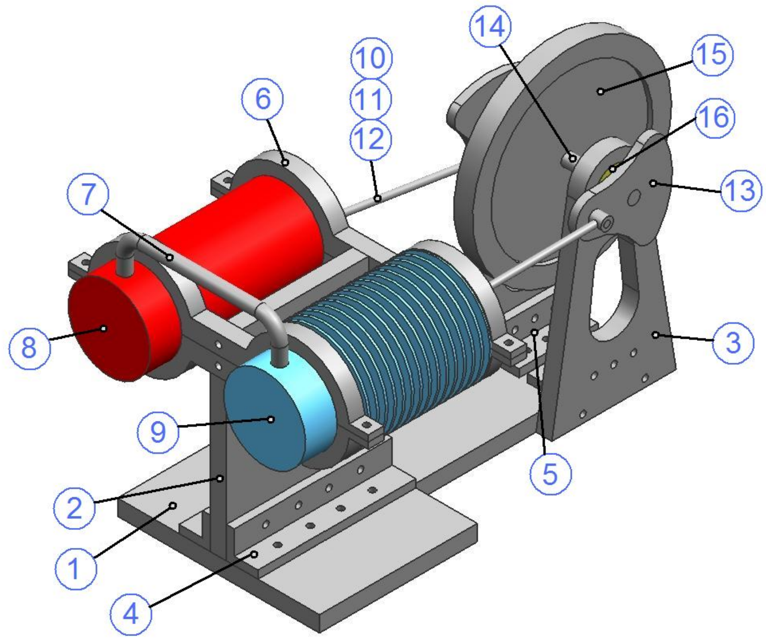


Figure 1: Isometric view of Stirling engine

Table 2: List of Parts and Materials

No.	Part Name	Material	Qty	Build Group
1	Frame - Base	Aluminum	1	Technicians
2	Frame - Cylinder Support	Aluminum	1	Technicians
3	Frame - Shaft Support	Aluminum	2	Technicians
4	Angle - Cylinder Support	Aluminum	2	Technicians
5	Angle - Shaft Support	Aluminum	2	Technicians
6	Clamp - Cylinder	Aluminum	4	Technicians
7	Tube - Transfer	Copper	1	Technicians
8	Cylinder - Hot	Steel	1	Technicians
9	Cylinder - Cold	Steel	1	Technicians
10	Piston	Steel	2	Technicians
11	Connector - Piston	Brass	2	Technicians
12	Connector - Rod	Steel	2	Technicians
13	Counter Weight	Steel	2	Technicians
14	Shaft	Steel	1	Technicians
15	Flywheel	Steel	1	Technicians
16	Bearings	N/A	2	Stock
-	Fresnel Lens	N/A	1	Team 04
-	Frame - Fresnel Lens	Pine	N/A	Team 04
-	Ice Water Bath - Cold Cylinder	Plexus-glass	N/A	Team 04
-	Insulation - Hot Cylinder	Wool Fibre	N/A	Stock
-	Fasteners	Steel	N/A	Stock

5. BUDGET

The following budget presented in Table 3 is unofficial and is subject to change.

Table 3: Unofficial Project Budget

No.	Part Name	Description	Vendor/Supplier	Qty	Subtotal
	(Piston/Cylinder)				
9	Cold Cylinder	Steel Round stock 3.5x7"	Metals 'R' US	1	$23.90
8	Hot Cylinder	Steel Round stock 2.75x7"	Metals 'R' US	1	$19.50
10	Pistons	Steel Round stock 2.25x2.5"	Metals 'R' US	2	$15.20
12	Connecting Rods	Steel Round stock 0.25x7"	Metals 'R' US	2	$4.00
11	Rod Ends	Brass Round stock 1x2"	Metals 'R' US	2	$3.50
	(Rotating Assembly)				
13	Piston Counter weight	Steel Plate 1x1x1/4" (ft.)	Metals 'R' US	2	$18.90
14	Shaft	Steel Round stock 3/8x8"	Metals 'R' US	1	$9.00
15	Flywheel	Steel Plate 1x1x3/4" (ft.)	Metals 'R' US	2	$55.00
16	Bearings	Low Friction Ball Bearings	Kinecor	2	$50.00
	(Frame)				
4,5	Frame Angle	Aluminum Angle Stock 1x1x0.25"x2'L	Metals 'R' US	1	$5.00
1	Frame Base	Aluminum Plate 6.5x12.25x0.5"	Metals 'R' US	1	$43.80
2	Frame Cylinder	Aluminum Plate 6x6x0.5"	Metals 'R' US	1	$30.00
3	Frame Shaft	Aluminum Plate 7x13x0.5"	Metals 'R' US	2	$135.00
6	Cylinder Clamps	Aluminum Plate 12x10x0.5"	Metals 'R'US	1	$80.00
-	Cylinder insulation	Semi-ridged high temp wool insulation	McMaster Carr	1	$35.00
-	Nuts and Bolts	Various	Various	1	$100.00
-	Ice Water Bath	Plexus Glass Sheet 1'x0.125"x4'L	Home Depot	1	$39.00
	(Measurement Tools)				
-	Pressure Sensor	IC Engines Lab	IC Engines Lab	2	$0.00
-	Pressure Power supply	IC Engines Lab	IC Engines Lab	1	$0.00
-	Pressure Fitting Tools	KISTLER drill set ??	Still Looking	1	$300.00
-	Thermocouples	PFT-2CPLK (1/4 MPT)	Omega	4	$140.00
-	Thermocouple DAQ Block	unknown	unknown	1	$400.00
	(Solar Power Collector)				
-	Fresnel lens	47x35" Lens	Ebay/Greenpower	1	$200.00
-	Stand	Wood 2x4"- 12ft.	Home Depot	3	$60.00
	(Miscellaneous)				
-	Shipping Costs	Various	Various		$250.00
-	Stationary Cost		Various		$50.00
-	Lubrication/ Consumables		Various		$75.00
7	Transfer Tube	Copper 10 mm D x 200 mm L	Metals' R' US		$30.00
	Net Cost				**$2,171.80**
	Tax 13%				$282.33
	Total Cost				**$2,454.13**

Supervisor Signature ______________________________

6. TO BE DETERMINED

The engineering calculations required to describe the thermodynamic process of the Stirling cycle are extremely complicated and imprecise. Hence, the accepted design process is to determine scaled parameters from existing Stirling engine designs. The overall design of a Stirling engine begins with an estimation and ends with an approximation; therefore, the success of this design project is critically dependent on a thorough testing and troubleshooting phase. Most of the things that have yet to be determined are non-essential to the final design performance; however, the final specifications for critical components, e.g. the flywheel, may only be specified following testing.

- **Flywheel –** The design of the flywheel has been conservatively chosen to meet the requirements for rotating mass energy storage; however, the finalized flywheel geometry will be specified upon the crucial testing phase in the winter term to account for potential weight adjustments and balancing.

- **Cylinders –** For ease of fabrication the piston cylinders are being considered for re-design as two piece assemblies. A pipe and cap/plug cylinder design will create potential leak paths but reduce fabrication time and increase design adaptability.

- **Internal Fins –** The team has considered adding internal fins to the hot cylinder to maximize heat transfer to the working gas. However we have yet to decide whether this consideration will aid or hinder engine performance.

- **Regenerator –** The addition of a regenerator section in the transfer between the two cylinders has the potential to increase the engine efficiency. However, the addition of a regenerator will increase the amount of dead space in the system, possibly determining the success or failure of the design. The team plans to test the engine both with and without the regenerator.

- **Ice Water Bath –** The final dimensions of the ice water bath have not been specified in this build report. The bath will be constructed from transparent plastic sheet. The dimensions of this component are not essential to the success of the Stirling engine and will be freestyle fit following the assembly of the engine.

- **Fasteners –** Although the budget sets aside funds for fasteners, the group still needs to determine the quantity and specifications before the final design is constructed.

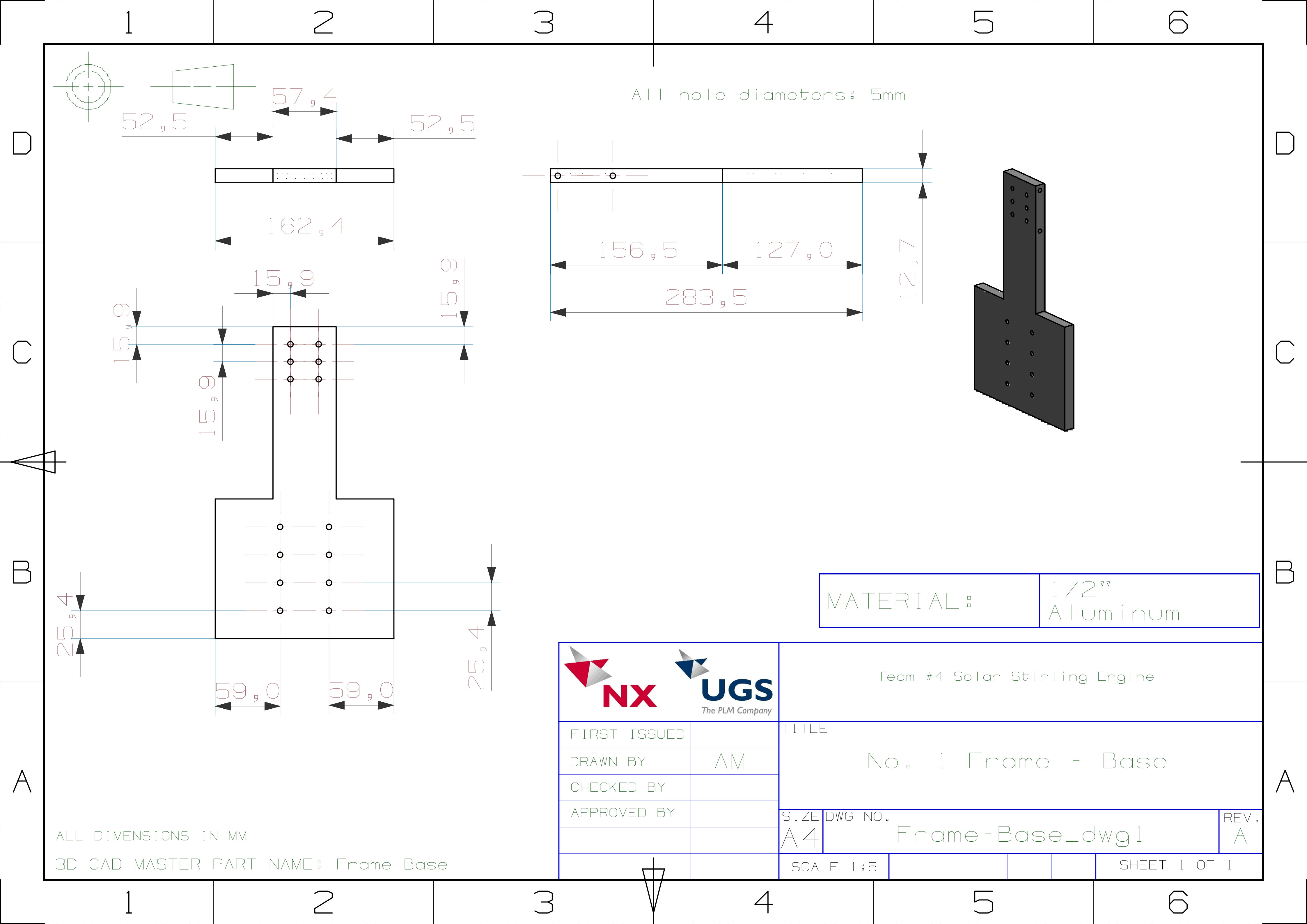
- **Miscellaneous –** Paint, sensor display panel, minor part adjustments, specific material grades and surface treatments, etc.

7. GANTT CHART

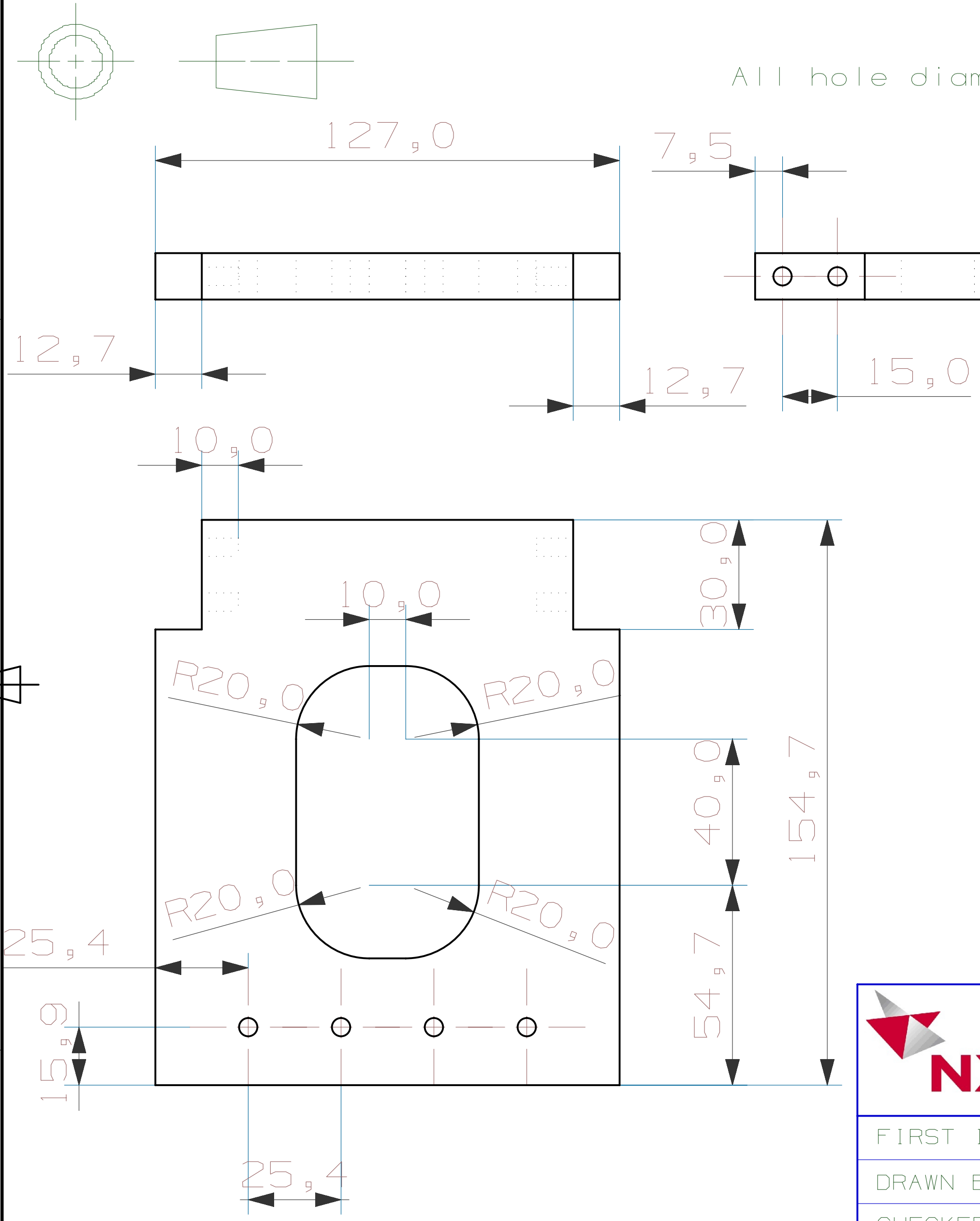
Figure 2: Gantt Chart for 2009 Winter Term

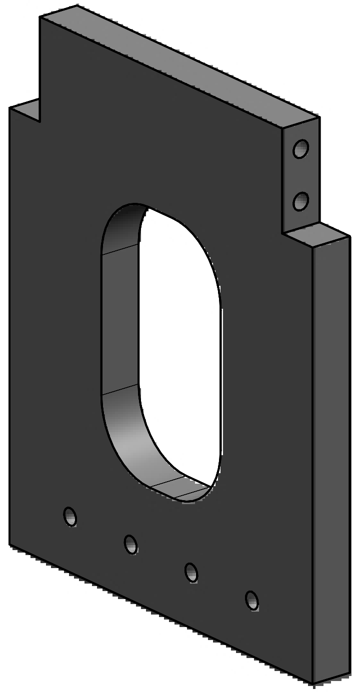
APPENDIX

See attached for complete assembly and part engineering drawings.


All hole diameters: 5mm
57,4
52,5
52,5
162,4
156,5
127,0
283,5
12,7
15,9
15,9
15,9
15,9
25,4
25,4
59,0
59,0
MATERIAL:
1/2" Aluminum
Team #4 Solar Stirling Engine
FIRST ISSUED
DRAWN BY
AM
CHECKED BY
APPROVED BY
TITLE
No. 1 Frame - Base
SIZE
A4
DWG NO.
Frame-Base_dwg1
REV.
A
SCALE 1:5
SHEET 1 OF 1
ALL DIMENSIONS IN MM
3D CAD MASTER PART NAME: Frame-Base

All hole diameters: 5mm





MATERIAL:	1/2" Aluminum

Team #4 Solar Stirling Engine

FIRST ISSUED	
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APPROVED BY	

TITLE

No. 2 Frame-Cylinder Support

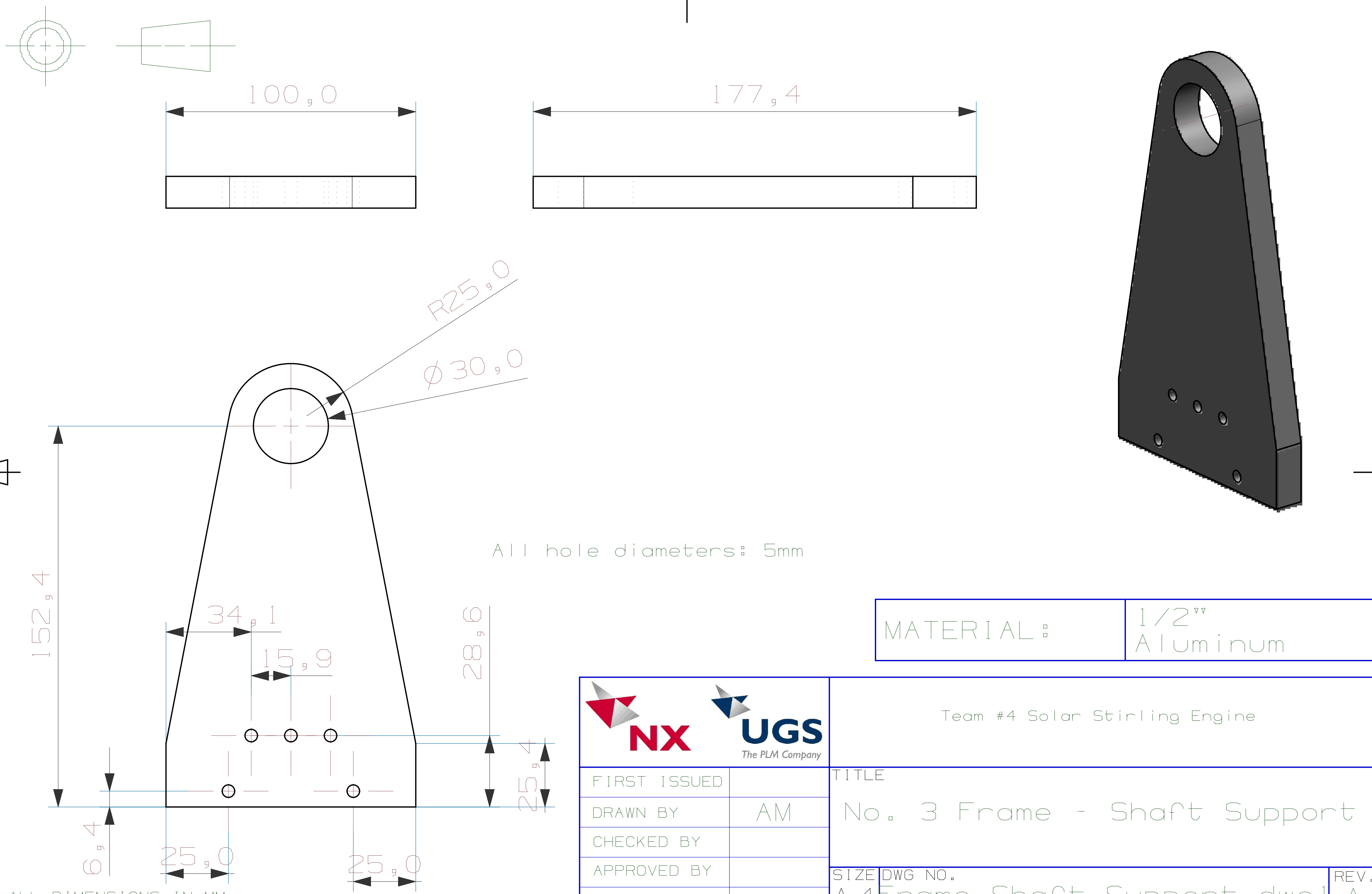
SIZE	DWG NO.	REV.
A4	Frame-Cylinder Support_dwg1	A

SCALE 1:2

SHEET 1 OF 1

ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME: Frame-Cylinder Support



MATERIAL:	1/2" Aluminum

ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME: Frame-Shaft Support

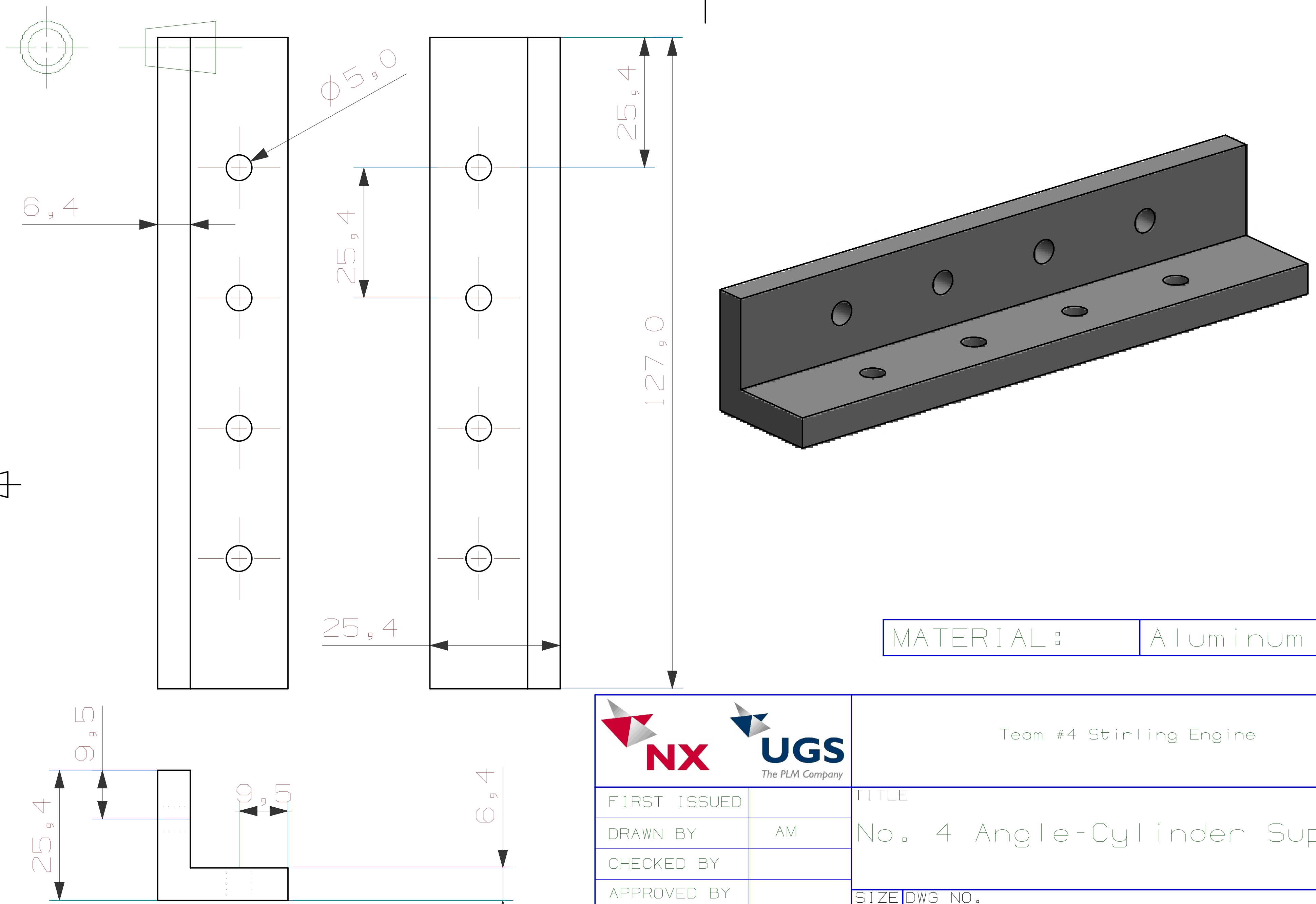
Team #4 Solar Stirling Engine

FIRST ISSUED		TITLE: No. 3 Frame - Shaft Support
DRAWN BY	AM	
CHECKED BY		
APPROVED BY		

SIZE	DWG NO.	REV.
A4	Frame-Shaft Support_dwg1	A

SCALE 1:2

SHEET 1 OF 1



MATERIAL:	Aluminum

Team #4 Stirling Engine

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APPROVED BY	

TITLE

No. 4 Angle-Cylinder Support

SIZE	DWG NO.	REV.
A4	Angle Aluminum_dwg1	A

SCALE 1:1

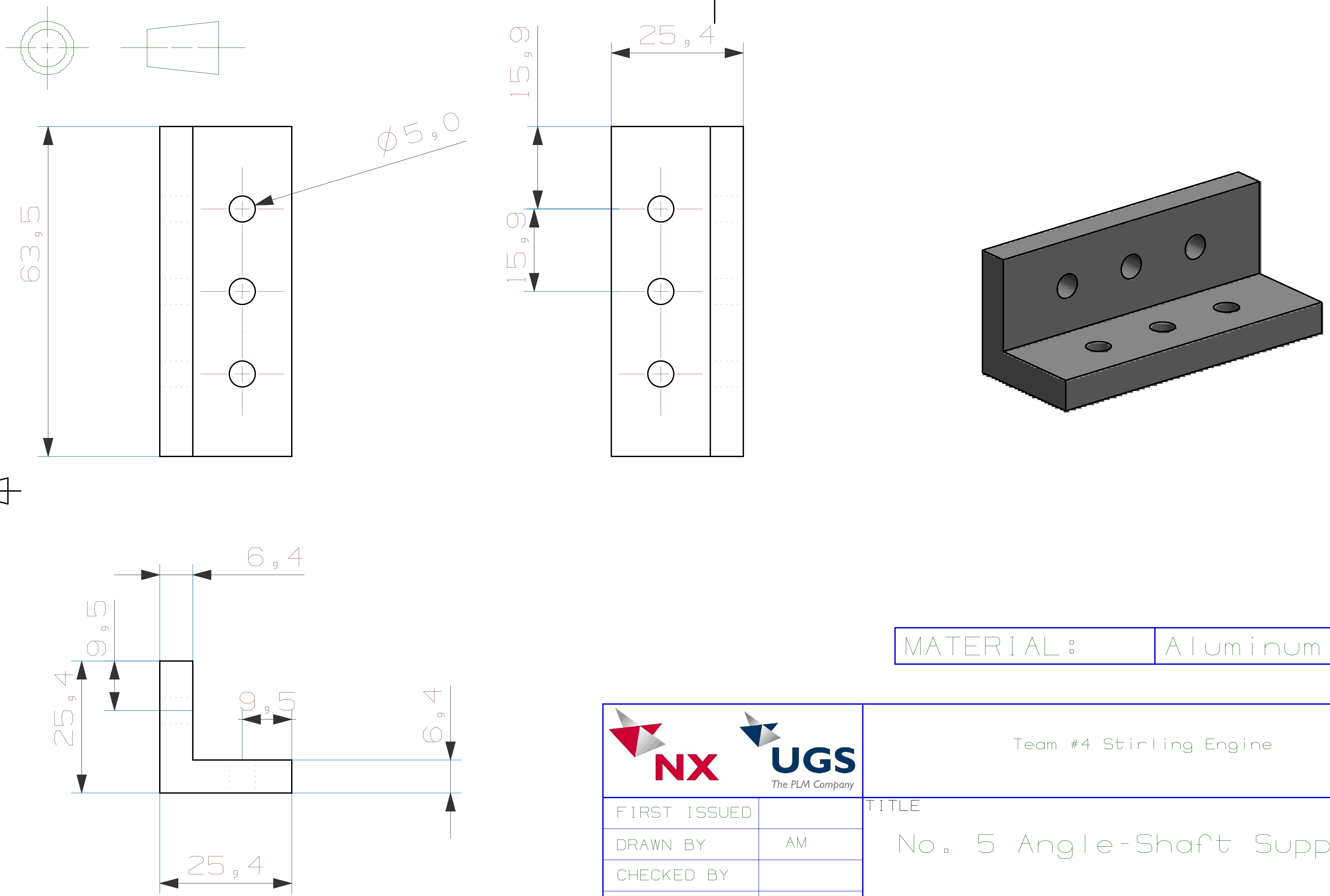
SHEET 1 OF 1

ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME: Angle Aluminum

1 2 3 4 5 6

D C B A



MATERIAL:	Aluminum

NX UGS The PLM Company

Team #4 Stirling Engine

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APPROVED BY	

TITLE

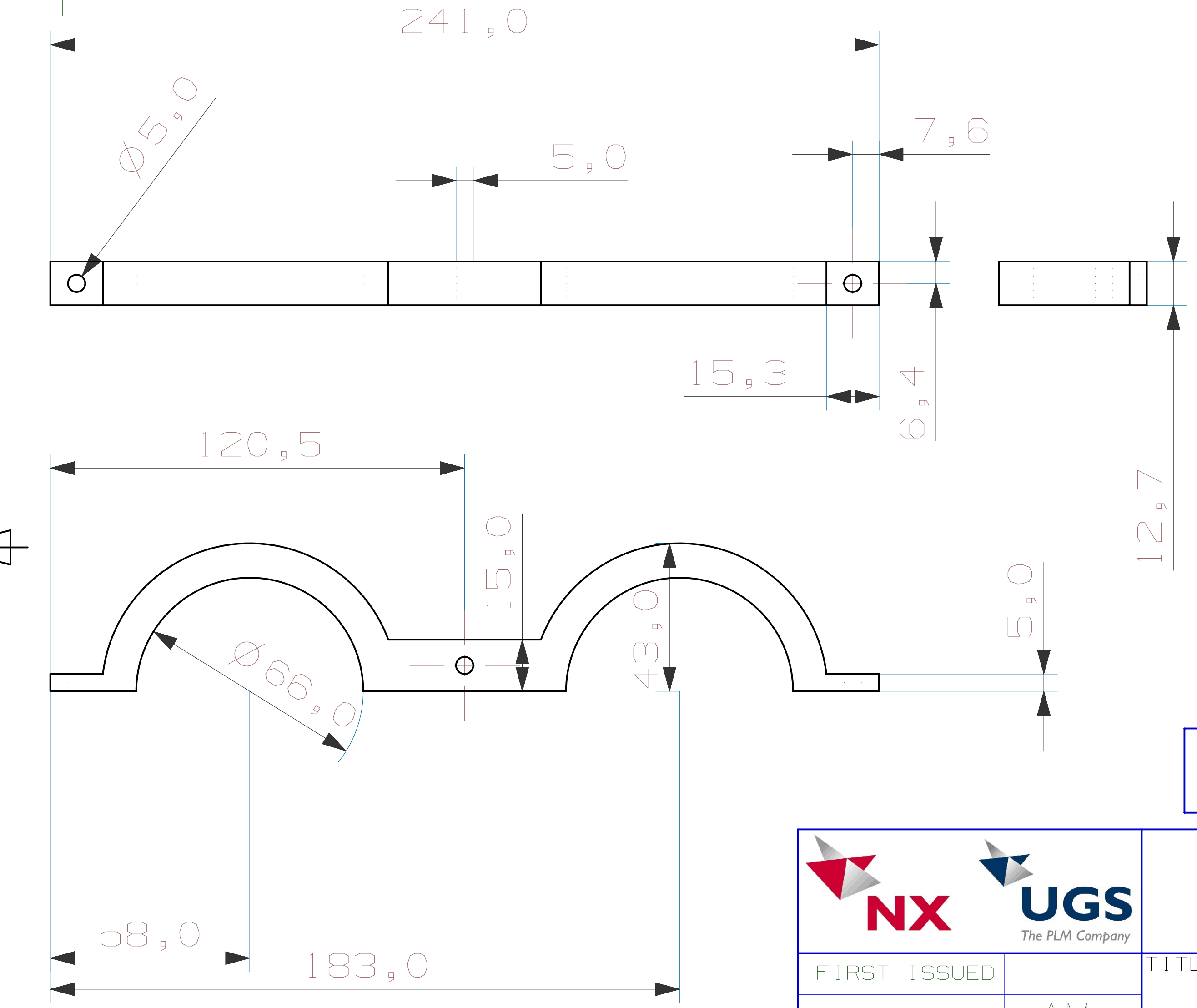
No. 5 Angle-Shaft Support

SIZE	DWG NO.	REV.
A4	angle aluminum 2_dwg1	A
SCALE 1:1	SHEET 1 OF 1	

ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME: angle aluminum 2

1 2 3 4 5 6



MATERIAL:	1/2" Aluminum

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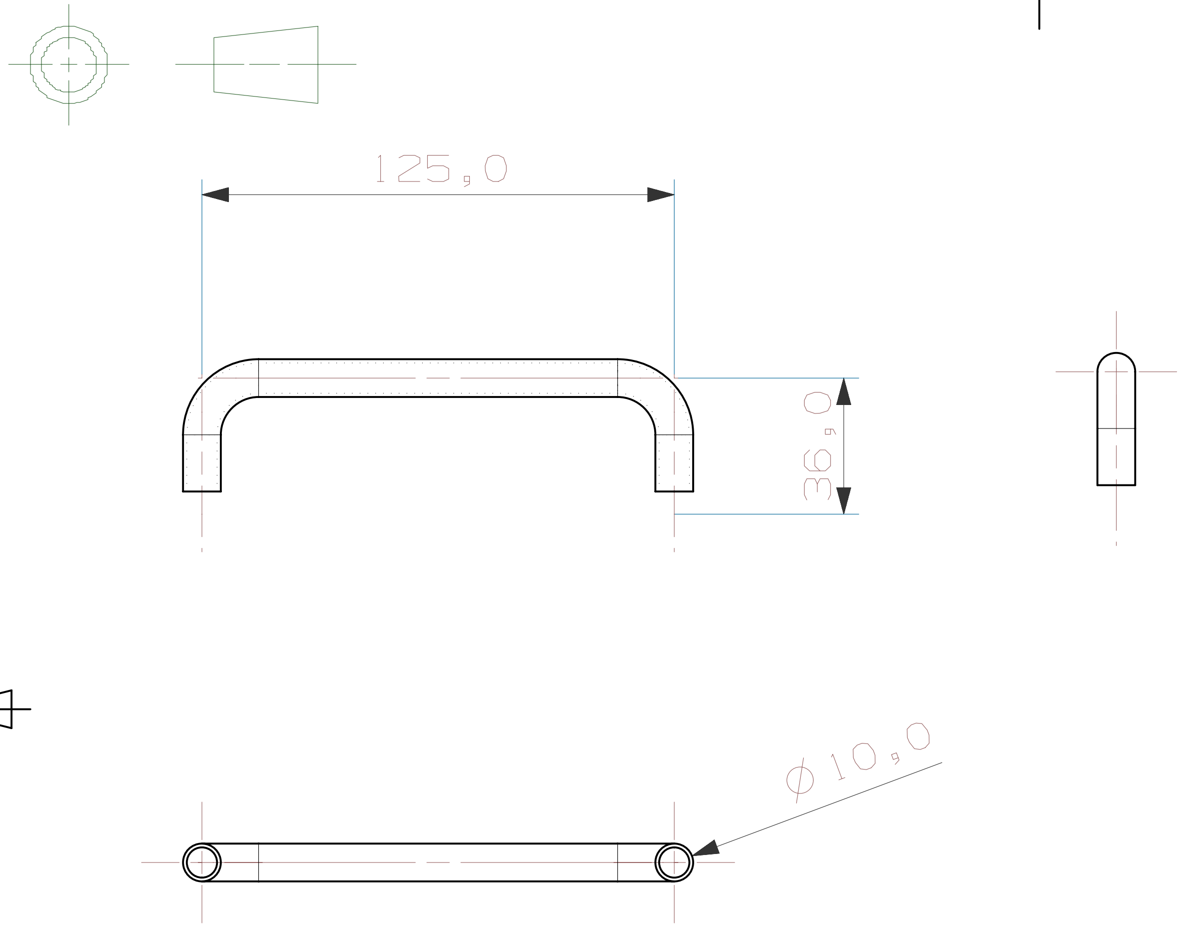
TITLE
No. 6 Clamp - Cylinder

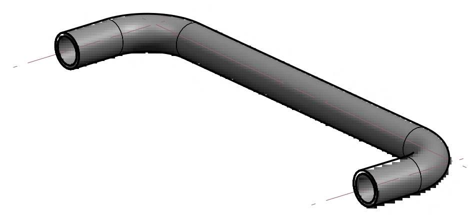
SIZE	DWG NO.	REV.
A4	Cylinder Clamp_dwg1	A

SCALE 1:2 | SHEET 1 OF 1

ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME: Cylinder Clamp





MATERIAL:	Copper Tube

ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME: Transfer Tube

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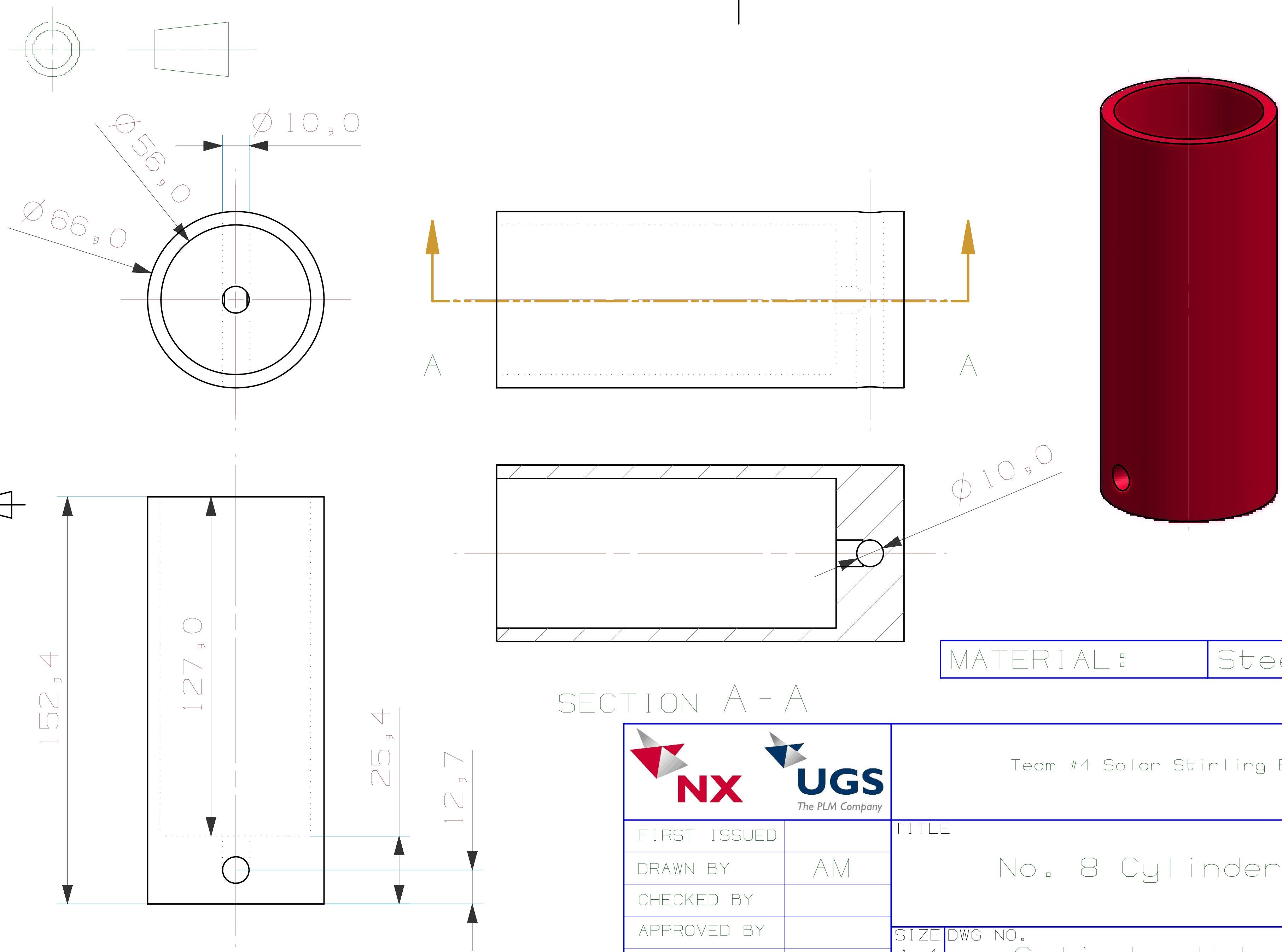
TITLE

No. 7 Transfer Tube

SIZE	DWG NO.	REV.
A4	Transfer Tube_dwg1	A

SCALE 1:2

SHEET 1 OF 1



MATERIAL:	Steel

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APPROVED BY	

TITLE

No. 8 Cylinder Hot

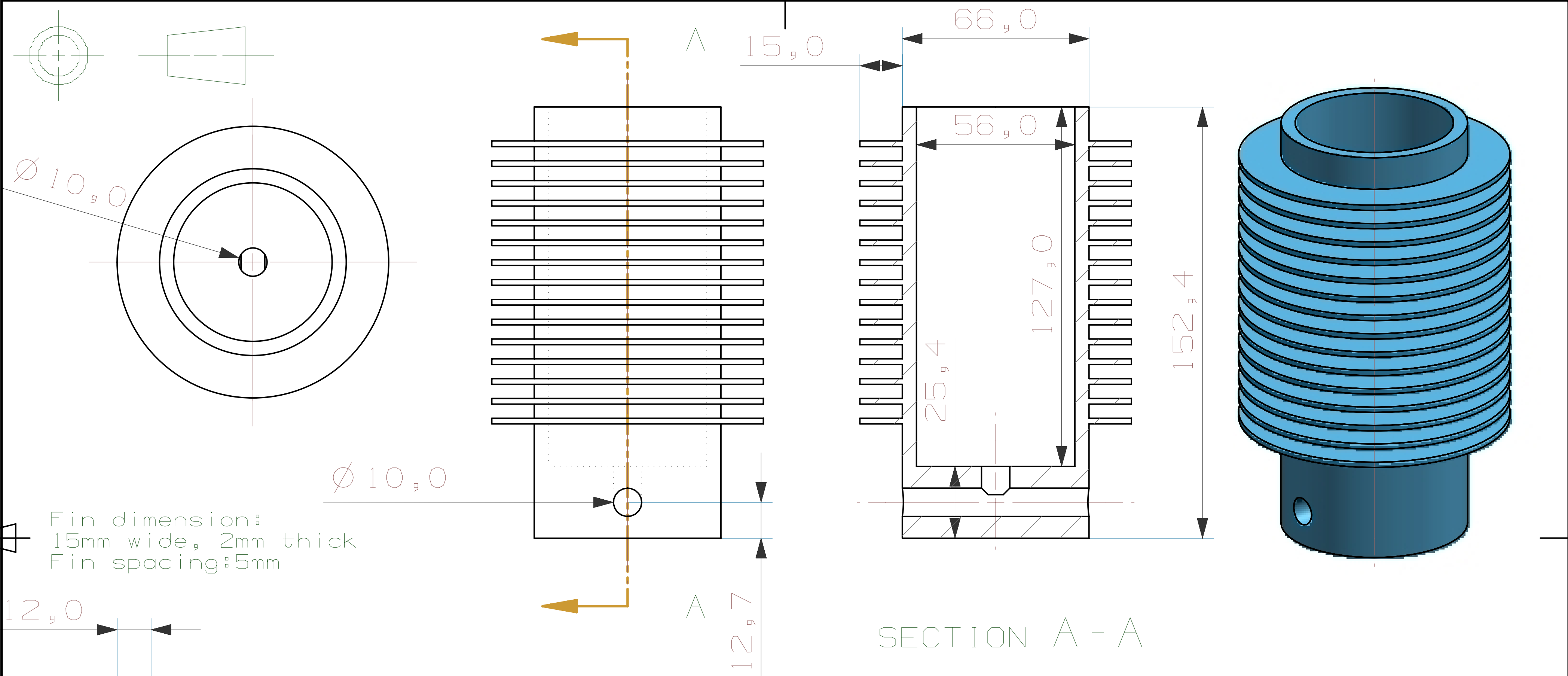
SIZE	DWG NO.	REV.
A4	Cylinder-Hot_dwg1	A

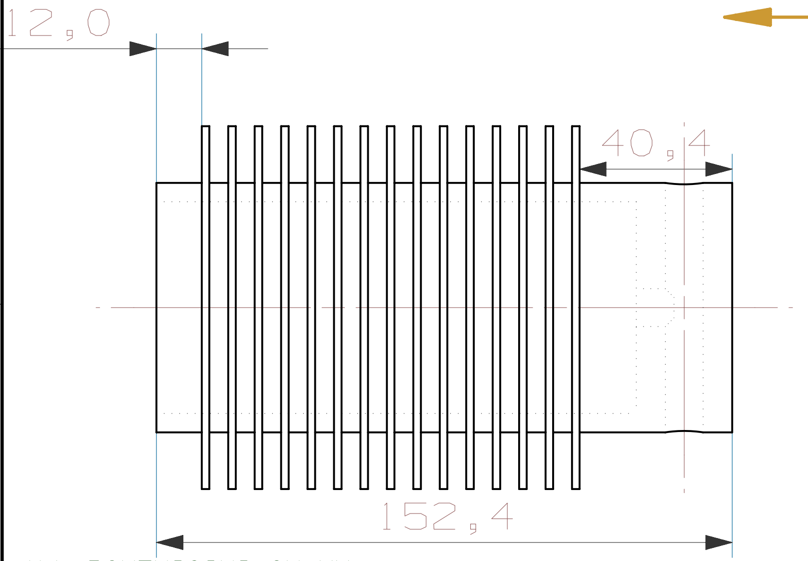
SCALE 1:2

SHEET 1 OF 1

ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME: Cylinder-Hot





MATERIAL:	Steel

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APPROVED BY	

TITLE

No. 9 Cylinder Cold

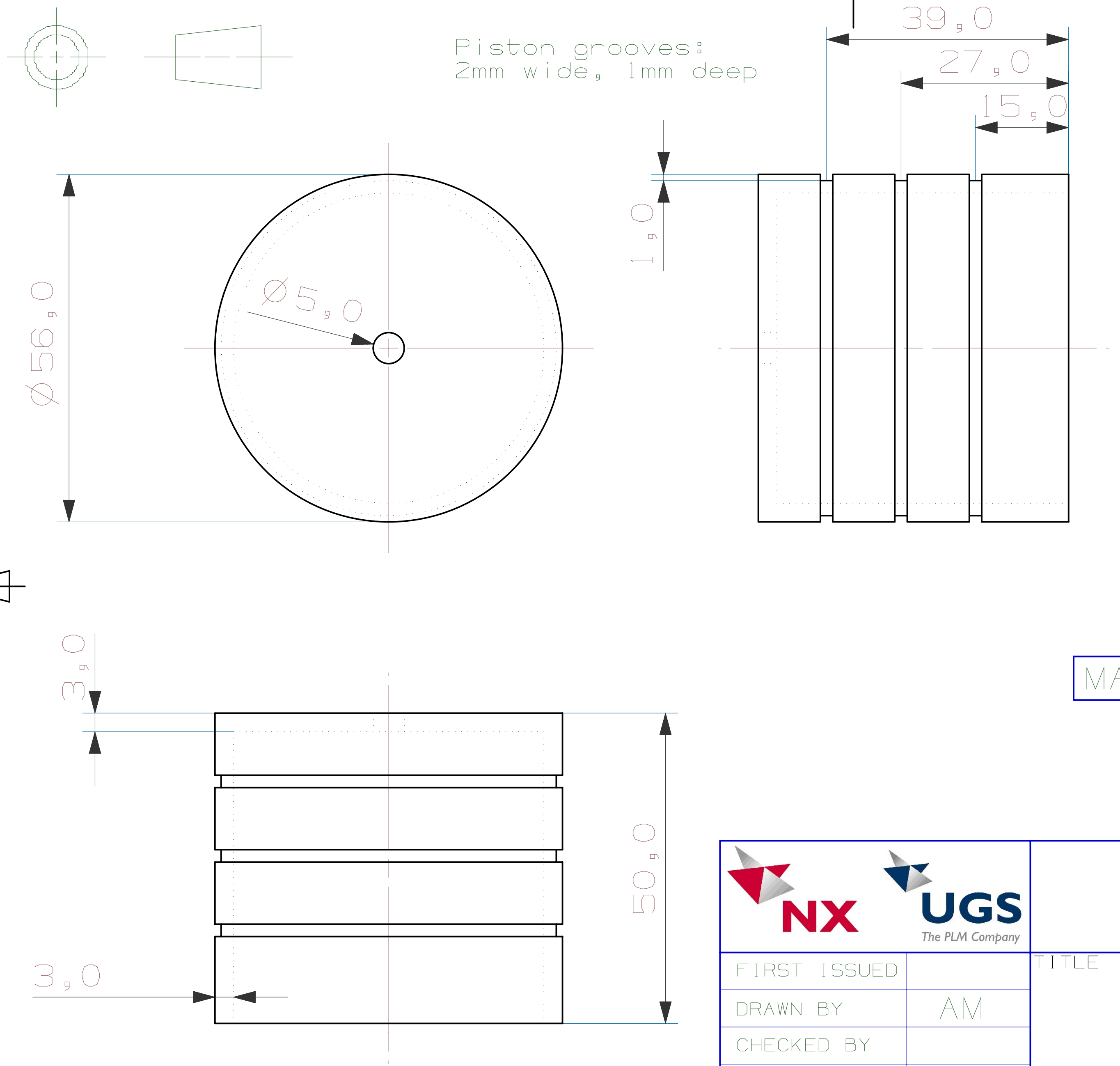
SIZE	DWG NO.	REV.
A4	Cylinder-Cold_dwg1	A

SCALE 1:2

SHEET 1 OF 1

ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME: Cylinder-Cold



MATERIAL:	Steel

Team #4 Solar Stirling Engine

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TITLE

No.10 Piston

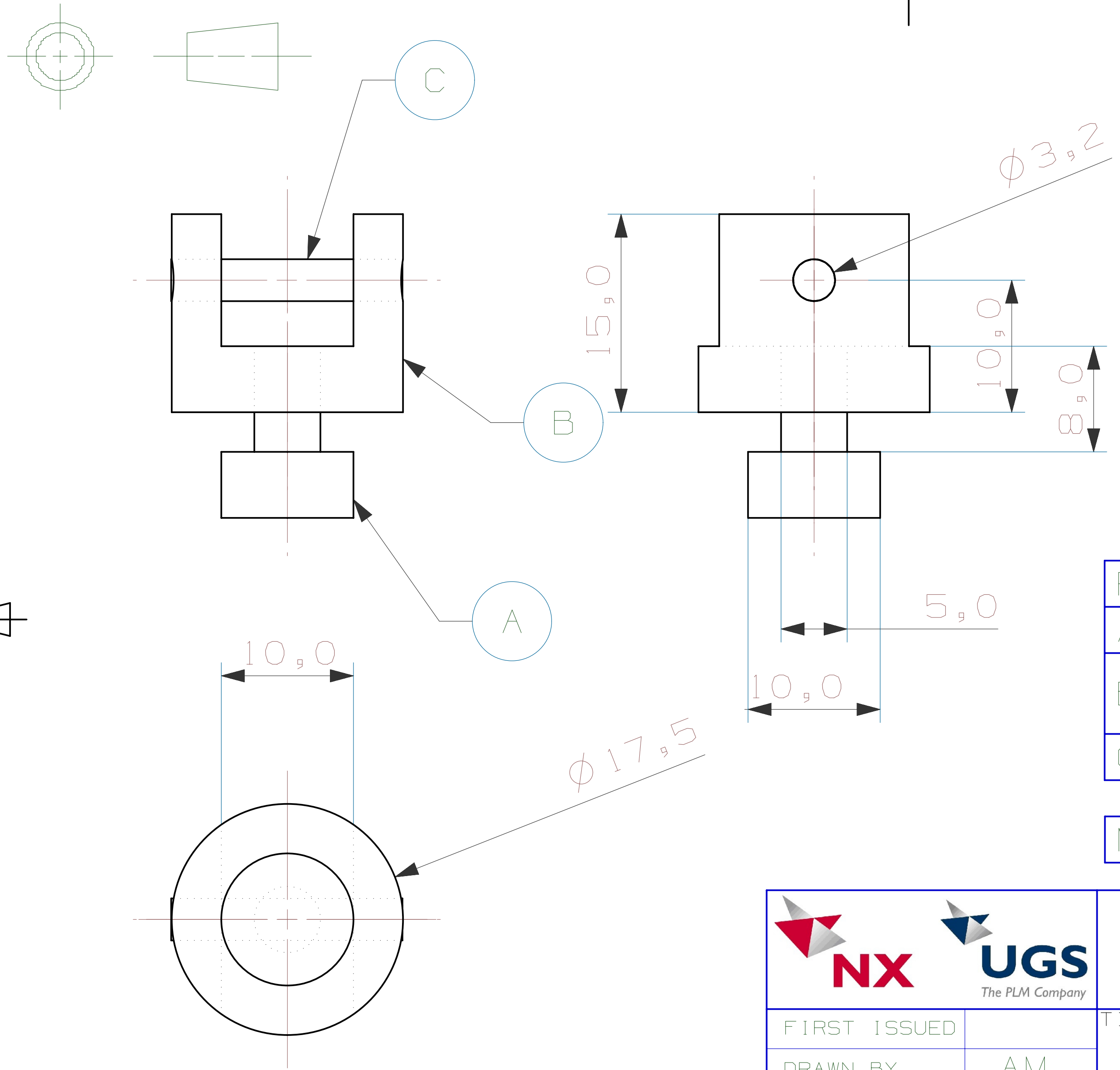
SIZE	DWG NO.	REV.
A4	Piston_dwg1	A

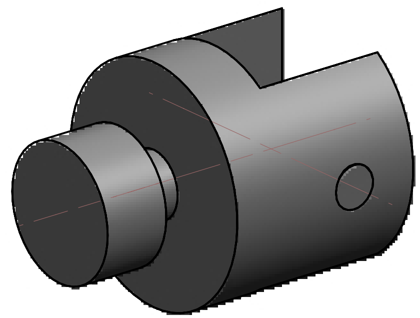
SCALE 1:1

SHEET 1 OF 1

ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME: Piston





Part #	Part Name
A	5mm Bolt
B	Piston Connector
C	Pin

MATERIAL:	Brass

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APPROVED BY	

TITLE
No. 11 Piston Connector

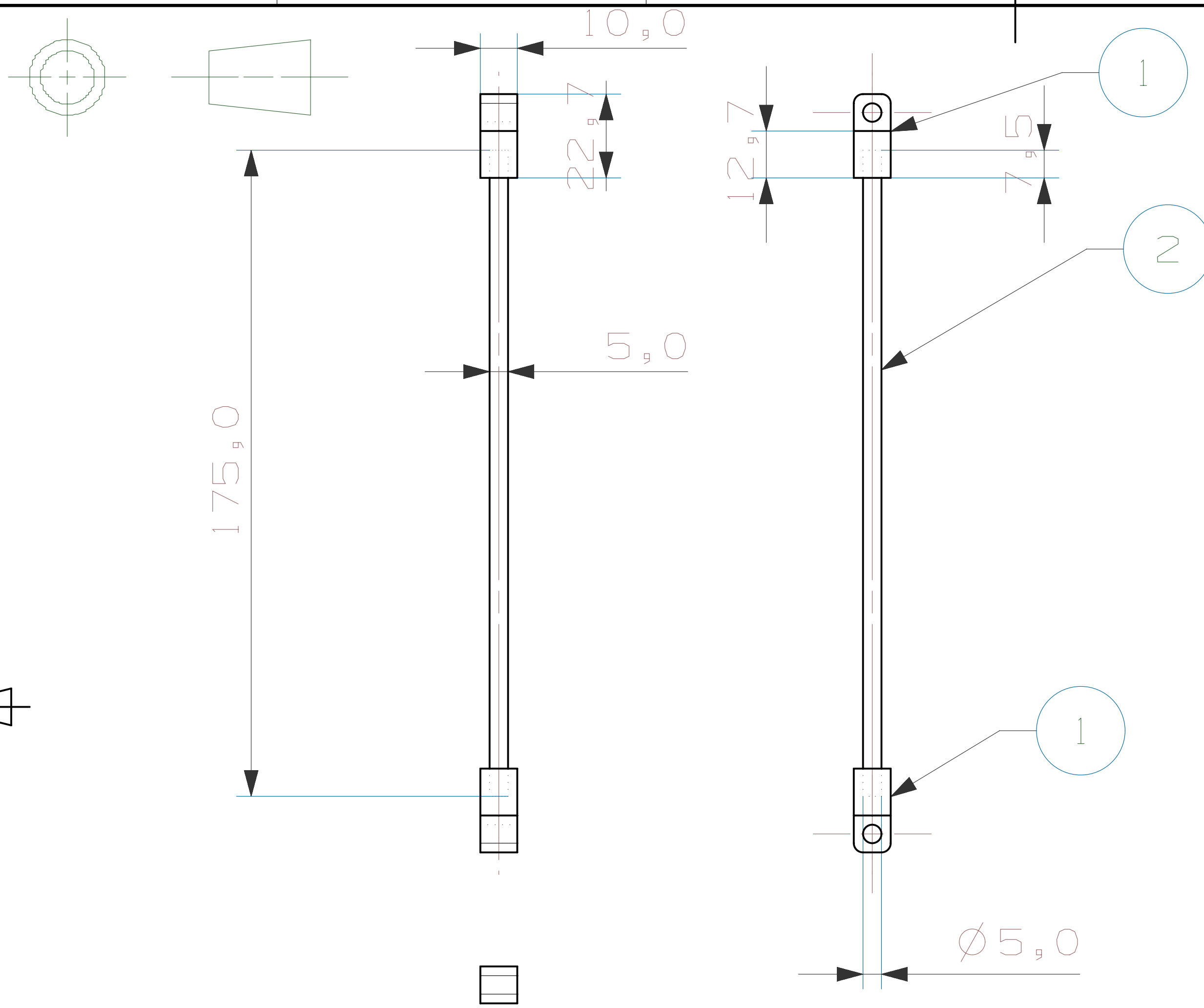
SIZE	DWG NO.	REV.
A4	Piston Connector_dwg1	A

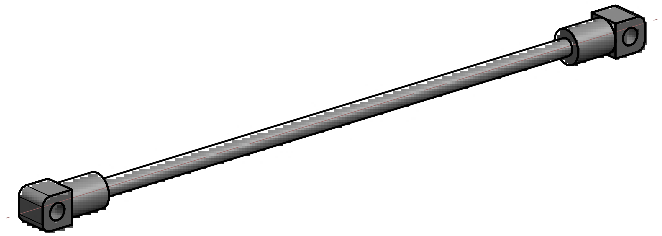
SCALE 2:1

SHEET 1 OF 1

ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME: Piston Connector





Part #	Part Name
1	Rod Connector
2	Connecting Rod

MATERIAL:	Steel

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Team #4 Solar Stirling Engine

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APPROVED BY	

TITLE
No. 12 Connecting Rod

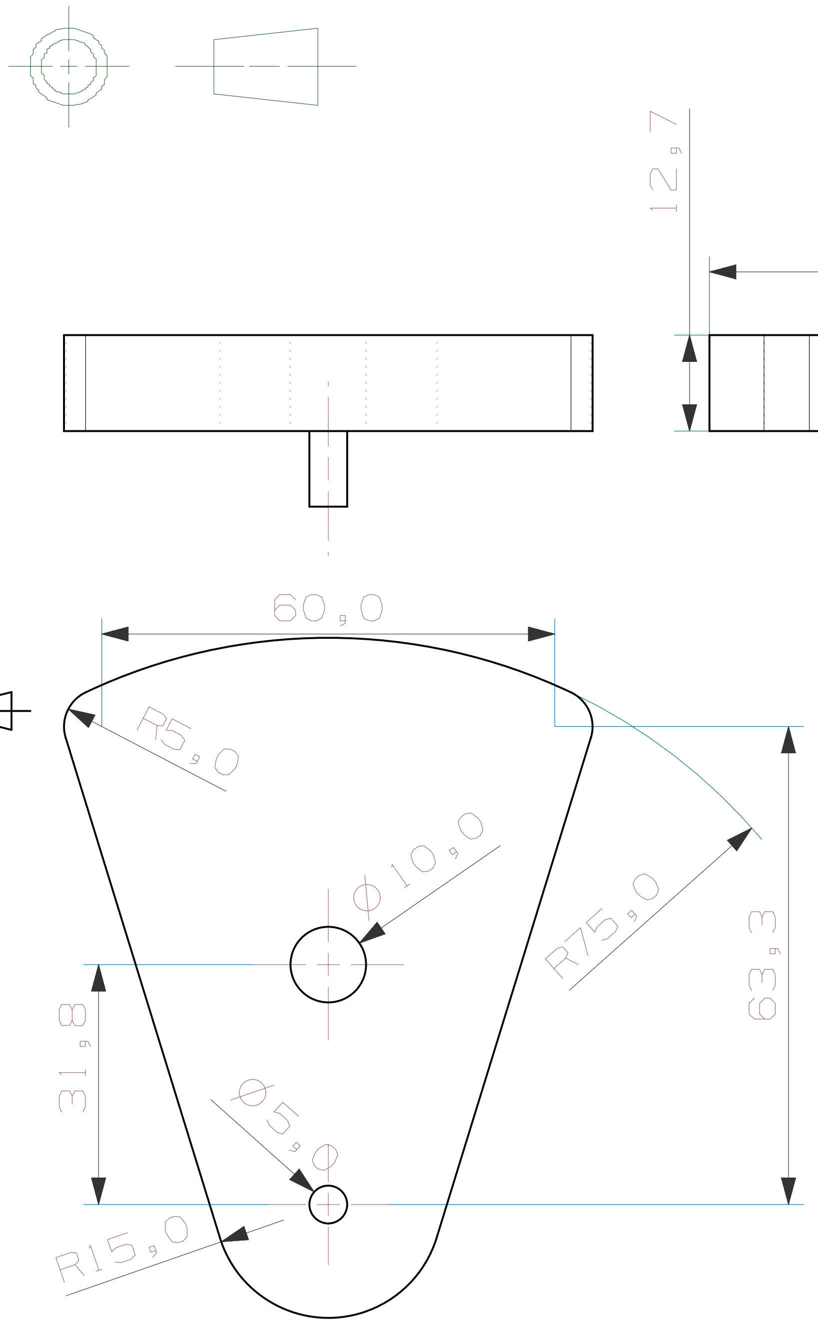
SIZE	DWG NO.	REV.
A4	Connecting Rod Assembly_dwg1	A

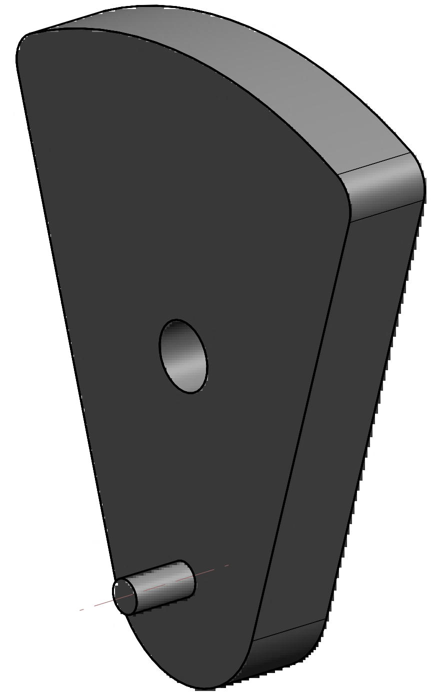
SCALE 1:2

SHEET 1 OF 1

ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME: Connecting Rod Assembly





MATERIAL:	1/2" Steel

ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME: Counter Weight

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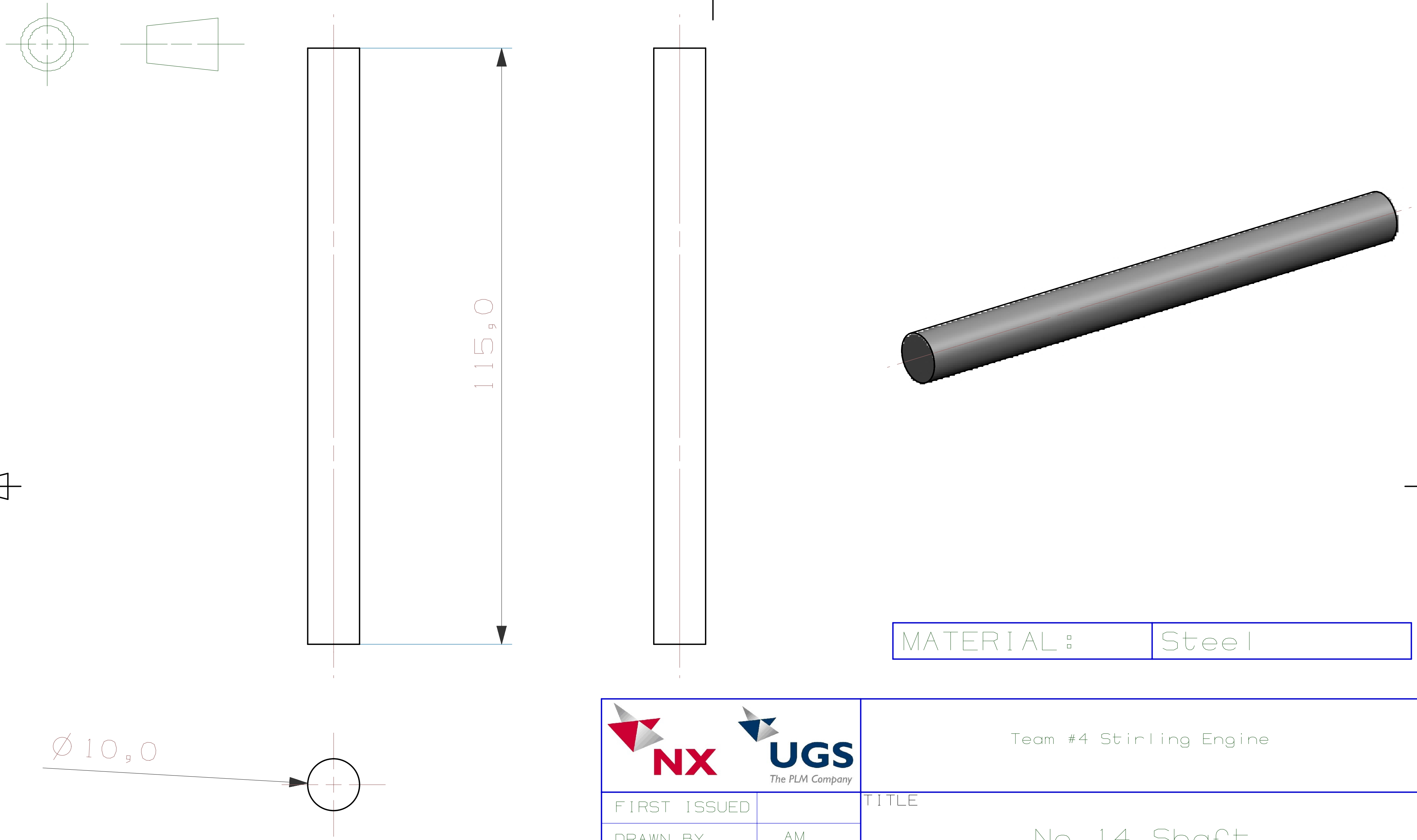
TITLE

No. 13 Crank/Counter Weight

SIZE	DWG NO.	REV.
A4	Crank	A

SCALE 1:1

SHEET 1 OF 1



MATERIAL:	Steel

NX UGS The PLM Company	Team #4 Stirling Engine
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CHECKED BY	
APPROVED BY	

TITLE

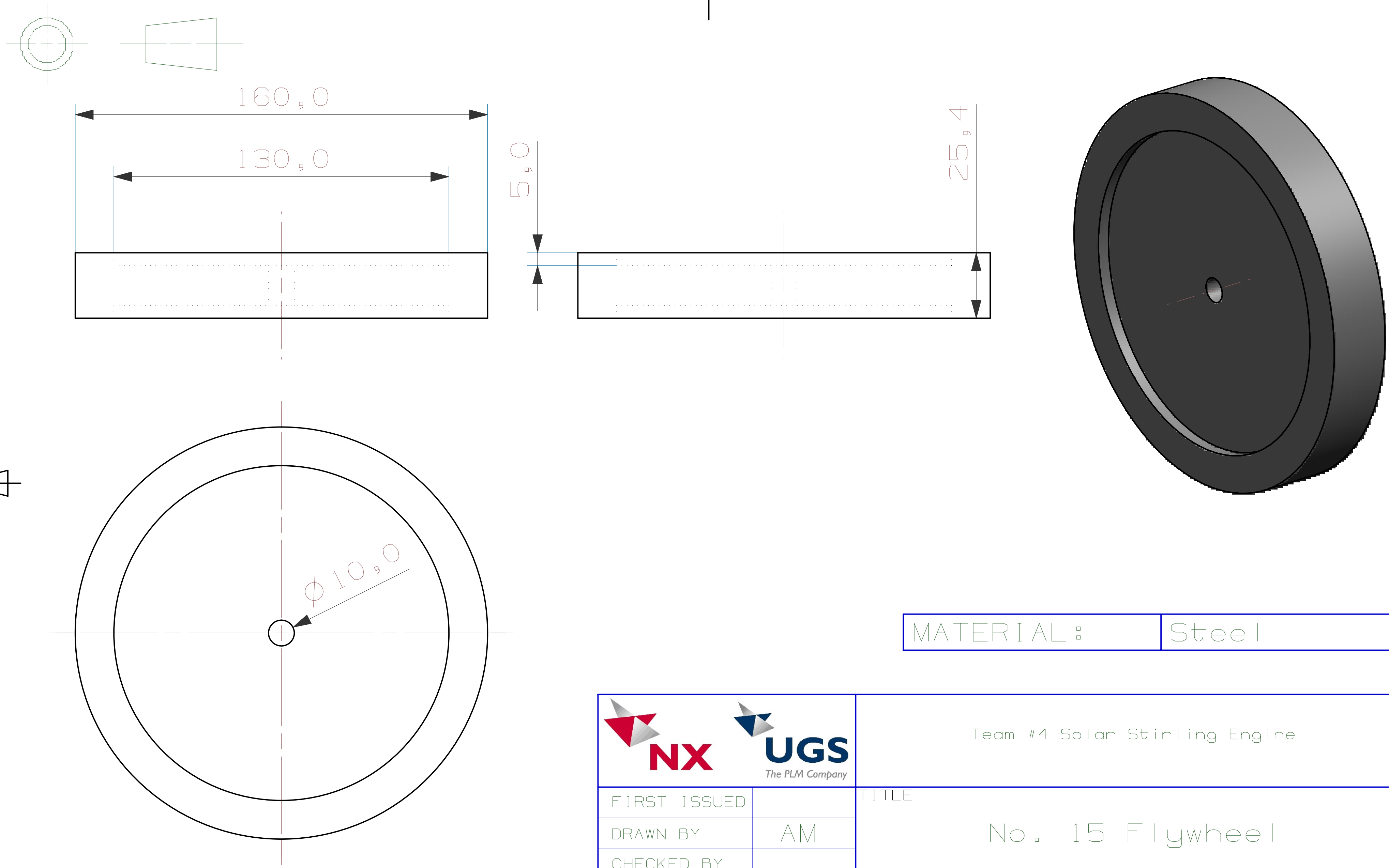
No.14 Shaft

SIZE	DWG NO.	REV.
A4	driveShaft_dwg1	A

SCALE 1:1 | SHEET 1 OF 1

ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME: driveShaft



MATERIAL:	Steel

Team #4 Solar Stirling Engine

FIRST ISSUED		TITLE
DRAWN BY	AM	No. 15 Flywheel
CHECKED BY		
APPROVED BY		

SIZE	DWG NO.	REV.
A4	Flywheel_dwg1	A
SCALE 1:2		SHEET 1 OF 1

ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME: Flywheel