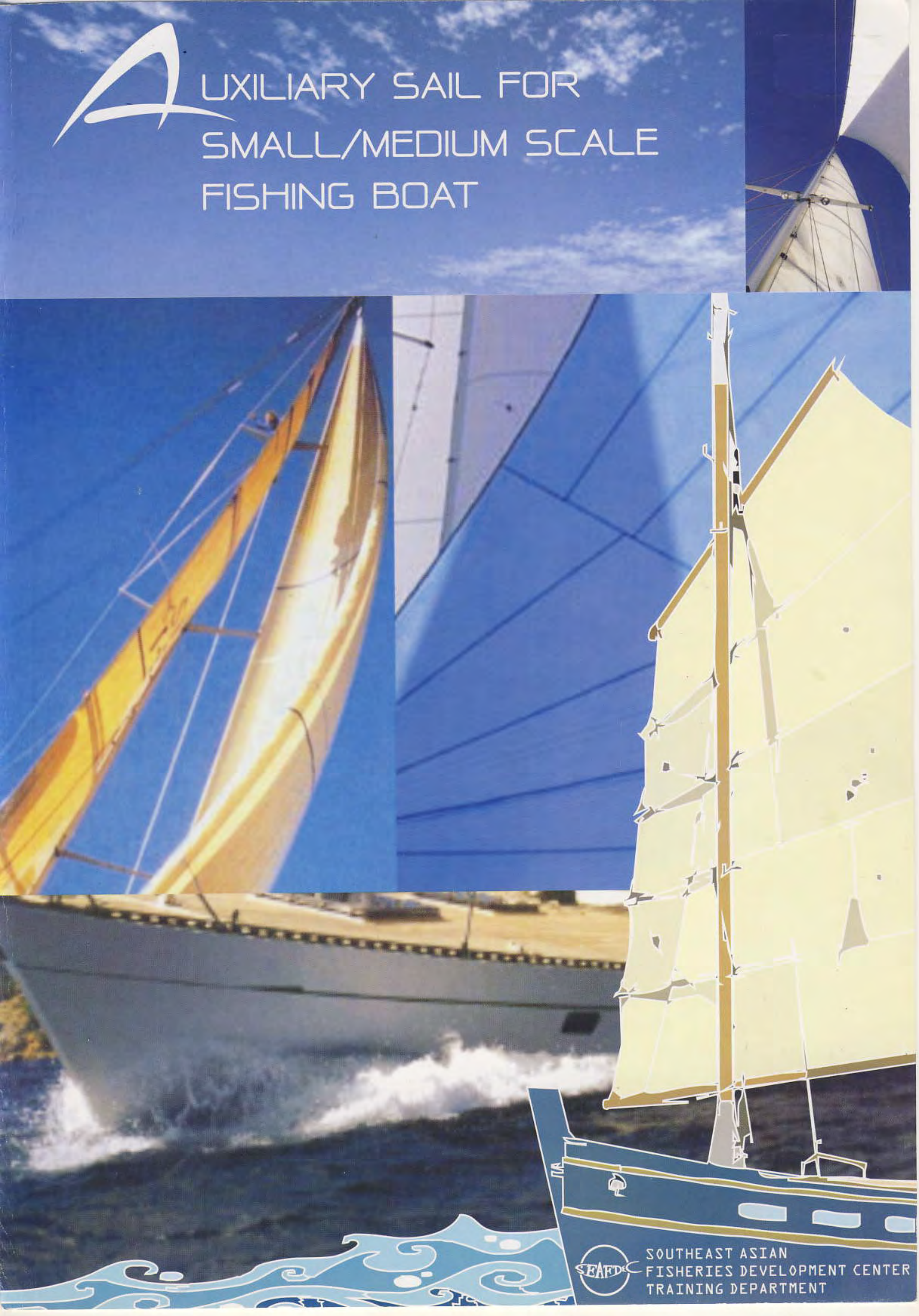
AUXILIARY SAIL FOR SMALL/MEDIUM SCALE FISHING BOAT



SEAFDEC
SOUTHEAST ASIAN
FISHERIES DEVELOPMENT CENTER
TRAINING DEPARTMENT

Auxiliary Sail for Small/Medium Scale Fishing Boat

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Training Department

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Preface

In the long history of mankind, there was no machinery. Since wind is an abundant power resource in the open sea, vessels and boats in fisheries, trade, and warfare were installed with sails for propulsion. For several hundred years, humans had always applied wind energy in most of their water-related activities.

In the last hundred years, technologies on internal combustion engine have been enhanced. Promoted for active propulsion in water cruising, the engine practically replaced the functions of the sail, until the sails have become less visible especially in fisheries activities.

Presently, the fuel oil price crisis has created impact on the world economies. The relentless situation leads to increased fuel consumption costs for operating vessels and boats, especially the fishing boats, affecting most the small-scale fishermen in Southeast Asia. In order to recover from the increasing operation costs due to oil price, the fishermen have no other choice but to increase their income by catching large volume of fish. Heavy utilization of the natural resources and the use of destructive fishing gear oftentimes occur with a "domino effect". Since the continuing fuel oil price hike is putting much pressure on the fishery sector, efforts should be made to alleviate the situation. In order to minimize the operation costs in fishing even with fuel prices continuously increasing, the efficient exploitation of wind energy and its resource is being promoted as an option.

As a contribution to alternative clean energy utilization, the SEAFDEC Training Department is issuing this technical manual, which is concerned in particular, with the utilization of wind energy for fishing boats. Considering the various advantages of wind energy for sailing small- and medium-scale fishing boats, this book illustrates the use of auxiliary sail in order to save on fuel, reduce pollution due to combustion of hydrocarbons, and promote a sail design that is practical for use in the Southeast Asian region.

Hopefully, this publication will provide useful information and contribute to the development of the region's fishery sector as well as provide a better livelihood to the small-scale fishermen in the region.

S. Ekmaharaj

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Secretary-General and
Chief of Training Department of SEAFDEC

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Introduction

With a long history as a renewable energy, wind energy has always been an attractive resource put to use even before the invention of the internal combustion engine. The current fuel oil and economic crisis has put much pressure on the operations of many fishing boats. Fuel is necessary to operate the boat's engine as source of its propelling force. Although wind, wave and solar energy are abundant in the sea, wind is a more suitable choice because it can supply adequate horsepower needed to propel a fishing boat.

The use of wind energy therefore gives more benefits to the fishermen. Wind is an important energy source, which does not cause pollution. However, the unexpected fluctuation of the wind is a constraint, which should be managed. Thus, utilization of wind energy should also be complemented with the use of an engine because of the uncertainties of the weather as well as the changing direction and fluctuation of the wind flow.

The use of sails has now started to become popular again in the light of the increasing cost of fuel. Minimizing dependence on fuel would eventually lead to the decreased costs of fishing operations benefiting the small-scale fishermen. The captured wind energy using a sail would require wide conversion of the sail area into kinetic energy. Many factors should therefore, be taken into consideration in designing appropriate sails especially that sail design is governed by the science of aerodynamics. More importantly, the sail should be designed in such a way that it has the characteristics of optimizing and stabilizing the hull while sailing. Boats could capsize when there is imbalance force brought about by the sail due to its unsuitable size and shape. The design of the sail being promoted by SEAFDEC is discussed in this manual.

Previous works

An auxiliary sail used for fishing boats in Kerala, India was promoted by FAO under its Technical Cooperation Program (TCP) in India. Experiments on the use of the auxiliary sail were conducted under the FAO-assisted project in 1989-90, by installing the sail in sea crafts. The results of their experiments are also illustrated in this manual. Other similar works also presented the possibilities of using sails in propelling fishing boats. In some previous works, the boat installed with sail is called sailfisher, designed mainly for fishing albacore tuna. The boat can be wind-powered proficiently with the use of the sail. In all the previous works, it was always emphasized that sail fishing could be used in developing fisheries as it offers economical operations and unlimited range as well as the capability of the boat to be able to return to port even during mechanical breakdown. Few examples of fishing boats installed with sails are shown below.

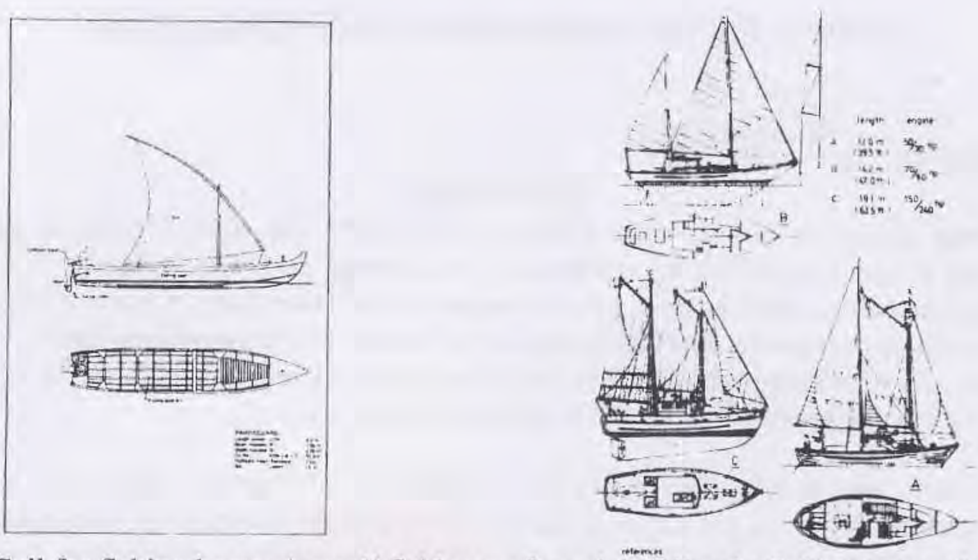


Figure 1 Sail for fishing boats: A small fishing craft model of Kerala (left), Modern fishing craft using auxiliary sail power (right)

In the other work of FAO on "Fuel and Financial Savings for Operators of Small Fishing Vessels", the results indicated very large fuel savings of up to 80% in small vessels on longer journeys, but suggested that very specific circumstances are required for motor sailing. The report also recommended that stability of the fishing boat using sail should be improved by adding an external ballast keel. The sail can only be effectively flown off the wind on at least a beam reach. The heavier the wind, the broader the reach must be to keep the sail from overpowering the boat. At some point when there is increasing wind flow, flying the chute (sail) at all times might also cause the boat to go out of control. In the ocean, swells can give significant impact on ship's control, so the skipper must be careful. In other words, sailing is a skill in itself and, to be effective, the crew must be both proficient and willing - there is often a considerable amount of hard work involved in the setting up of appropriate sails, particularly on large vessels.

Objectives

Since energy cost is a main concern in the development of any industry, increased fuel oil price in the world market has extremely retarded the growth of many Thai industries including fisheries. Given the world fuel oil situation, wind energy, therefore, is an alternative energy, which is abundant and renewable. However, wind energy could only be used as an auxiliary energy because of its fluctuation and inconsistency. Thus, with the advantages of wind energy as well as some limitations, this study targets to use an auxiliary sail in fishing boats in order to save on fuel by about 10% in fishing operations of medium-size fishing boats and by 50-90% for the small fishing boats.

Wind Statistics in Southeast Asia

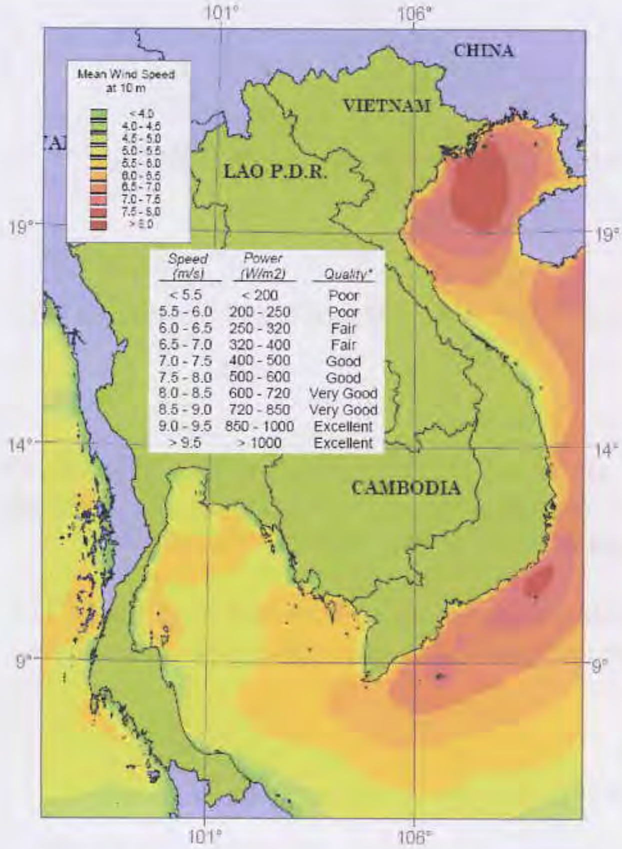


Figure 2 MesoMap of Ocean Wind Speed in Southeast Asian Region

Some considerations on wind statistics in the South China Sea and in the Gulf of Thailand is shown in the Meso Map (Figure 2).

Mean wind speeds in most parts of Thailand are rather modest, ranging (at 10 m height above the ground level) from around 2.0 m/s in the northern part of the country up to 4.0 m/s at some locations on the coast. Some coastal areas of Vietnam experience mean annual wind speeds of up to 8.0-10.0 m/s. Moreover, the average wind speed along the Thai and Cambodia coast and in the Gulf of Thailand is about 4.0-6.0 m/s a poor range of wind resource velocity. Along the coast of Vietnam however, wind power has been abundant, and the wind speed velocity ranges from fair to good at 5.5 to over 8.0 m/s, respectively. Thus, the coast of Vietnam has more proficient wind power than in the Gulf of Thailand, which makes it sufficient to apply auxiliary sail on fishing their boats.

Theory of air flow

Determination of mass flow of air through an area (**A**) is illustrated in Figure 3. From the continuity equation in fluid mechanics, the mass flow rate as a function of air density (ρ) and air velocity (assumed uniform) (**U**) is computed using formula (1) below:

$$\frac{dm}{dt} = \rho A U \qquad (1)$$

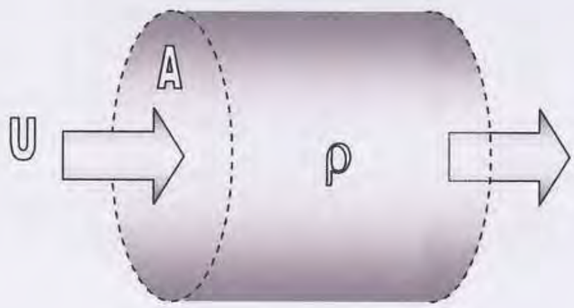


Figure. 3 Air flow through an area

The Kinetic energy (**KE**) of an object with total mass (**m**) and velocity (**U**) is given in formula (2).

$$KE = \frac{1}{2} * m * U^2 \qquad (2)$$

The power of the flow expressed as kinetic energy per unit time is given in formula (3).

$$Power = \frac{KE}{t} = \frac{1}{2}\frac{m}{t}U^2 = \frac{1}{2}\rho A U^3 \qquad (3)$$

The wind power per unit area (**P/A**) or wind power density is computed based on formula (4).

$$\frac{P}{A} = \frac{1}{2}\rho U^3 \qquad (4)$$

During standard conditions, the density of air is 1.225 kg/m^3. The power of wind is proportional to the cross section area swept and the cube of wind velocity. In practical conditions, maximum conversion energy is about 45-60 % giving the ideal wind energy.

From formula (3), the wind flow power is calculated by varying the area and wind speed. The results are shown in Table 1 and Table 2. In the computation of the wind power, losses during the flow through an area are not considered.

Table 1. Calculated results of wind power (watts) at varying wind speeds and sail areas

Sail Area (m^2)	Wind speed, m/s (km/h)									
	1 (3.6)	2 (7.2)	3 (10.8)	4 (14.4)	5 (18.0)	6 (21.6)	7 (25.2)	8 (28.8)	9 (32.4)	10 (36.0)
20	12	98	331	784	1,531	2,646	4,202	6,272	8,930	12,250
30	18	147	496	1,176	2,297	3,969	6,303	9,408	13,395	18,375
36	22	176	595	1,411	2,756	4,763	7,563	11,290	16,074	22,050
40	25	196	662	1,568	3,063	5,292	8,404	12,544	17,861	24,500
60	37	294	992	2,352	4,594	7,938	12,605	18,816	26,791	36,750
80	49	392	1,323	3,136	6,125	10,584	16,807	25,088	35,721	49,000
100	61	490	1,654	3,920	7,656	13,230	21,009	31,360	44,651	61,250

Table 2. Calculated results of wind power (Hp) at varying wind speeds and sail areas

Sail Area (m^2)	Wind Speed, m/s (km/h)									
	1(3.6)	2 (7.2)	3 (10.8)	4 (14.4)	5 (18.0)	6 (21.6)	7 (25.2)	8 (28.8)	9 (32.4)	10 (36.0)
20	0.016	0.131	0.443	1.051	2.053	3.547	5.632	8.408	11.971	16.421
36	0.030	0.236	0.798	1.892	3.695	6.384	10.138	15.134	21.548	29.558
40	0.033	0.263	0.887	2.102	4.105	7.094	11.265	16.815	23.942	32.842
60	0.049	0.394	1.330	3.153	6.158	10.641	16.897	25.223	35.913	49.263
80	0.066	0.525	1.773	4.204	8.210	14.188	22.529	33.630	47.883	65.684
100	0.082	0.657	2.217	5.255	10.263	17.735	28.162	42.038	59.854	82.105

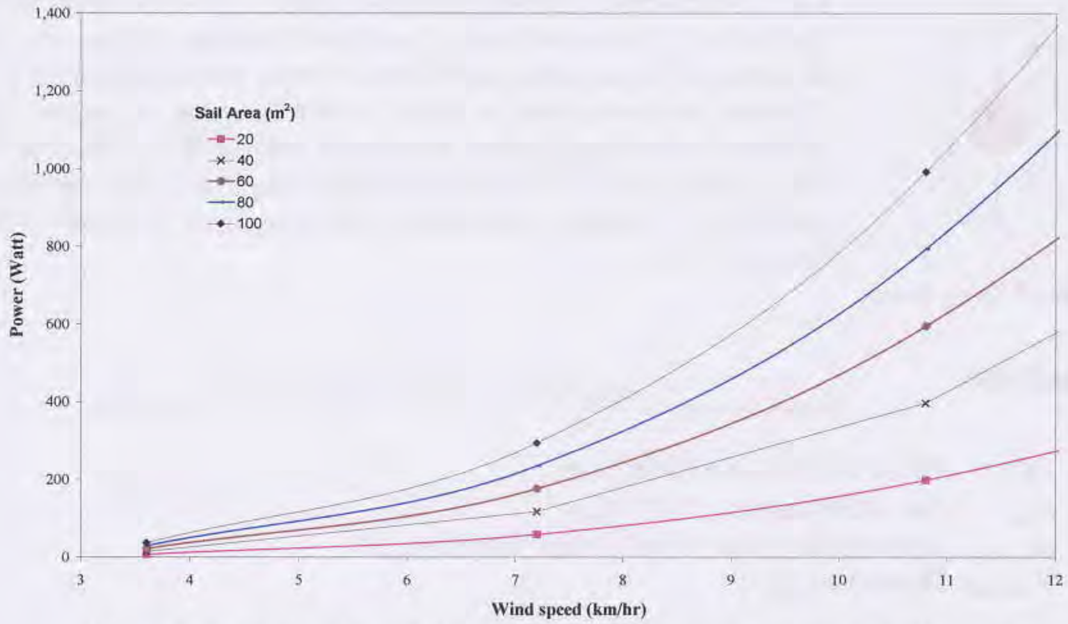


Figure 4. Relationship of the calculated wind power against wind speed

Wind power is proportional to wind speed, speed^3, and sail area. As the wind speed and sail area increase, the propulsion power also rises up sharply. The bigger is the sail area, the more wind power is extracted. Thus, for sailing at high speed, the boat must be installed with wide sail area with out exceed limit causing lose of its stability while sailing.

Calculation of Boat Speed

Small-scale Fishing Boat (Long Tail Fishing Boat)

The displacement of small-scale fishing boat is about 2 tons. Assuming the applied sail has an area of 36 m^2, considering on initial conditions, the sailboat will not move. At 5 m/s wind speed, the maximum sail speed is about 5 m/s (9.72 knots). The calculated wind power as shown in Table 1 and Table 2 is 2,756 watts and correspondingly, 3.695 Hp. The average propulsion force over the surface area of the sail can be calculated using the formula below:

$$WindForce = \frac{WindPower}{WindSpeed} = \frac{2{,}756}{5} = 551.2N$$

When a boat is sailing with the water current, drag force and hull resistance are two significant factors resisting the propulsion power. When the direction of a boat is opposite with the water current, the boat tends to move in the less speed. The effects of water current on speed must therefore, be included in the calculation of the boat's speed. Drag is a force that resists the movement of a solid object through a fluid (a liquid or gas). Drag is made up of: friction forces, which act in a direction parallel to the object's surface (primarily along its sides, as friction forces at the front and back cancel themselves out) and pressure forces, which act in a direction perpendicular to the object's surface (primarily at the front and back, as pressure forces at the sides cancel themselves out).

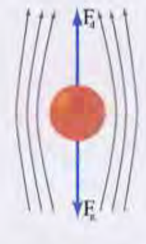


Figure 5 Drag force

For a solid object moving through a fluid or gas, the drag is the sum of all the aerodynamic or hydrodynamic forces in the direction of the external fluid flow. (Forces perpendicular to this direction are considered as lifts). It therefore acts to oppose the motion of the object, and in a powered vehicle it is overcome by thrust. Drag force on the boat is higher when no water current is considered. A simple calculation of the drag force is given by the formula below:

Long tail boat:

$$DragForce = \frac{C_d \rho_{sea} A V_{boat}^2}{2} = \frac{0.54 \times 1.225 \times 2 \times 5^2}{2} = 16.54N$$

Where **C_d** : Block coefficient of boat shape

ρ_{sea} : Sea water density, 1.225 kg.m^{-3}

A : Cross section area of hull under water line, m^2

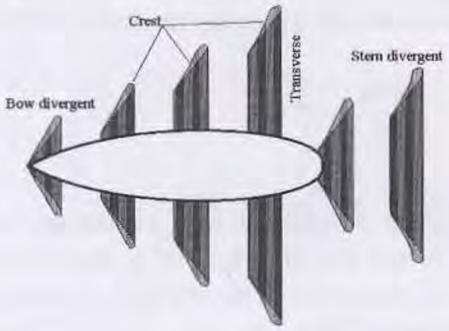
$V_{current}$: Boat speed, m/s

MV Plalung:

$$DragForce = \frac{C_d \rho_{sea} A V_{boat}^2}{2} = \frac{0.54 \times 1.225 \times 8 \times 5^2}{2} = 66.15N$$

Resistance forces affecting the hull velocity include the skin friction resistance of the hull, Eddy-making resistance, wave-making resistance, air resistance. In practice, air resistance is minimal accounting for only a few percent of the total resistance, usually less than 5%. However, in faster ships the speed could be created more resistance on the ship hall. Eddy-making resistance is quite small and in a well-designed hull, it is negligible, and quite often combined with wave-making resistance. Wave-making resistance is extremely important as it increases dramatically with speed. This is the power that the ship expends making all those nice foamy waves, etc.

Wave-making resistance: When a body moves through a fluid it displaces that fluid and the displacement takes energy to that effect. The calculation of the amount of resistance, that a wave-making cause is fraught with difficulty. It is determined by using towing tank observations or complex modeling programs run on fast computers.



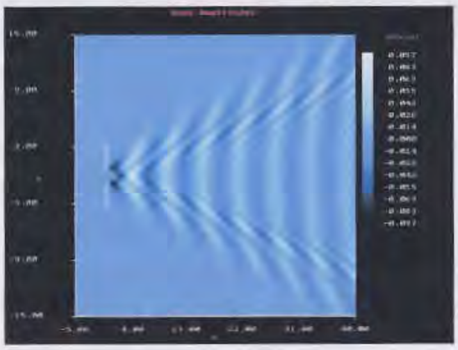


Figure 6. Wave-making resistance

Froude (1967) stated that frictional resistance is dependent on the following four factors: area of the surface, type of surface, length of surface, and density of fluid.

Froude (1967) derived the following formula that allows a close approximation of the frictional resistance:

$$R_f = FSV^{1.825}$$

Where $\mathbf{R_f}$ = frictional resistance in Newton

F = a constant dependent on length

S = wetted surface area in square meters

V = speed of ship in meters per second

The values for F in seawater are:

Length in meters	**F**	**Length in meters**	**F**
5	1.736	120	1.421
10	1.604	140	1.415
20	1.515	160	1.410
40	1.464	180	1.404
60	1.457	200	1.399
80	1.437	250	1.389
100	1.428	300	1.386

To derive the wetted area Taylor's formula $S = C\sqrt{\Delta L}$ was used.

Where: **S** = moulded wetted surface area in square meters

C = constant which differs with form but is usually between 2.56 and 2.59

Δ= displacement in tons

L = mean immersed length in meters but usually taken as waterline length

The wetted surface areas of two sample fishing boats are shown below:

Long tail boat: $S = 2.58\ (2*10)^{0.5} = 11.54\ m^2$

M.V. Plalung: $S = 2.58\ (27*16.45)^{0.5} = 54.37\ m^2$

The results of the total water resistance are presented in Figure 7.

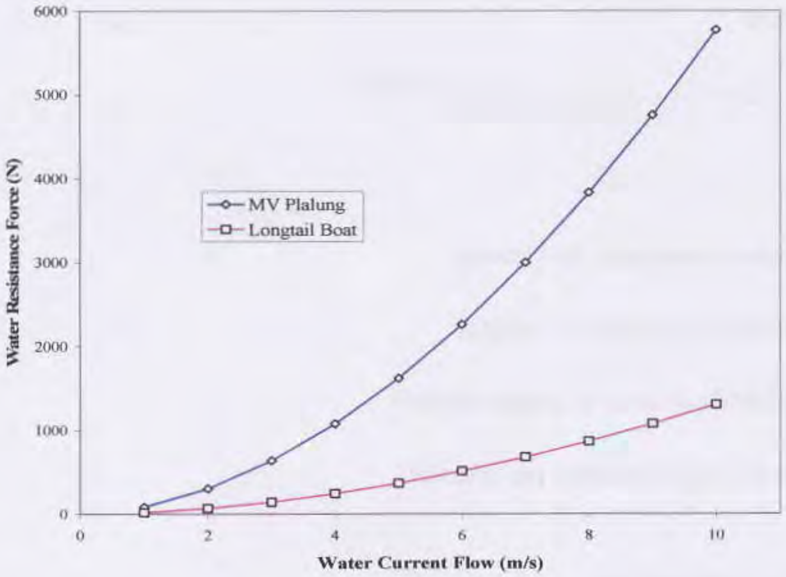


Figure 7. Total water resistance over hull of M.V. Plalung and Long tail boat

Frictional resistance is that part of the resistance created by the effect of the hull "rubbing" against the fluid it is moving through. At 5 m/s wind speed, the total resistance of M.V. Plalung and Long tail Boat are 1,199.4 N and 365.70 N, respectively.

Sail Characteristics

There are various shapes of sails installed on small- and medium-scale fishing boats. For example, fishermen in Myanmar use a straight sheet as sail (Figure 8 left) to propel their boats without engine. This characteristic of the sail has a local and traditional design, although this is still trial, the sail has been acceptable in attaining propulsion power.

The other style also in Figure 8 (right) is a western design called spinnaker. This kind of sail is being modified and is being adapted for small- and medium-scale fishing boats in the SEAFDEC study. The difference of these two styles is in their extraction efficiency for wind power. The differential pressure on the spinnaker over the straight sheet is 6 Pa, [(101,347-101,315)-(101,340-101,314)] referred on the flow line in Figure 10 and Figure. 11, or about 20% more, because the stream of air on the surface of the spinnaker has longer transmission period of force than straight sheet.

Figure 8. Characteristics of sail (Dim.: mm.): Small fishing boat (left), Western sail boat (Right)

Spinnaker Styles

Although some older symmetric spinnakers are constructed crosscut, the most modern chutes now being used is the radial or tri-radial spinnakers (Figure 9). Since the spinnaker is attached to the boat at three corners, all the stress radiates into the sail at these points. With the tri-radial, the stress is along the seams instead of across the sail, making the sail stronger and minimizing stretch and distortion.

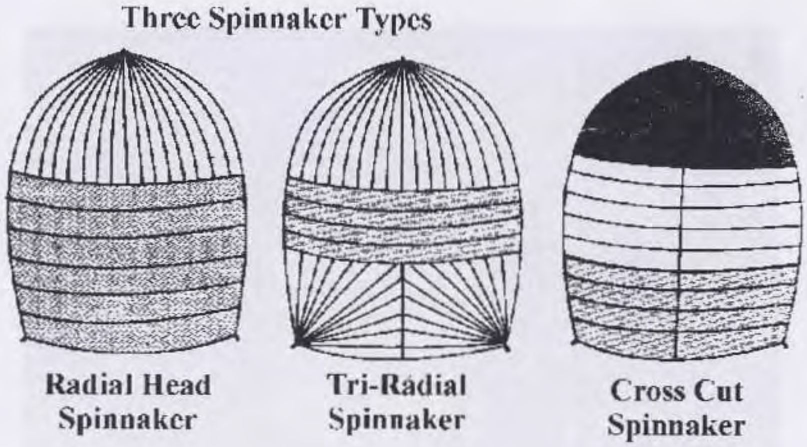


Figure 9. Three types of spinnaker

Radial head spinnakers are normally used for running because they are cut very full at the shoulders. Tri-radial spinnakers on the other hand, are better for reaching since they stretch less and are cut flatter.

Flow Line of Wind on Sail Shapes

The suitable shapes of sail designs are simulated using 5 m/s wind speed for propulsion analysis by finite element method. The results are shown in Figure 10 below.

Shape I: Straight Sheet

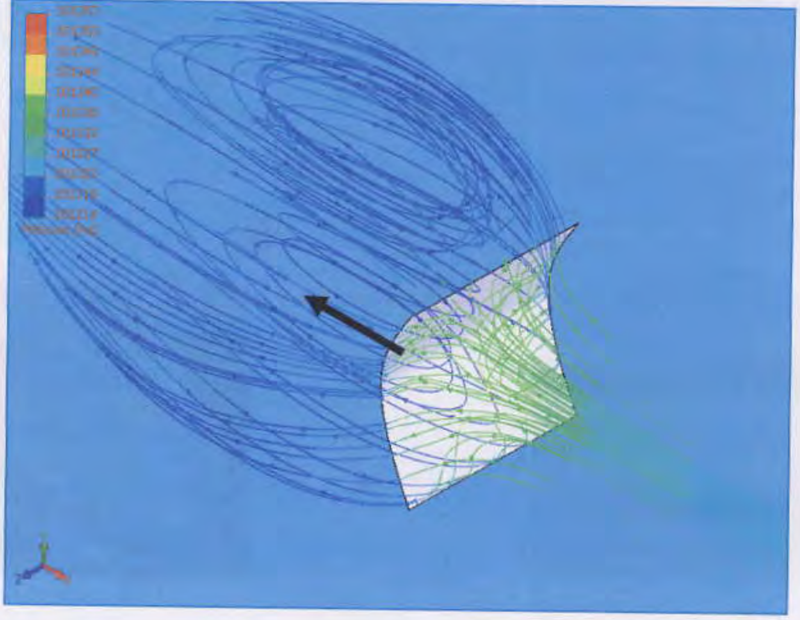


Figure 10. Effect of wind pressure on sail (36 m^2) designed for Long tail boat

The thrust produced by shape I is calculated using the formula below:

$$Thrust = \Delta P \times A = (101{,}340 - 101{,}314)(36) = (26)(36) = 936N$$

Where ΔP is differential pressure (Pa: N/m^2)

A is projection area of the sail (m^2)

Shape II: Spinnaker

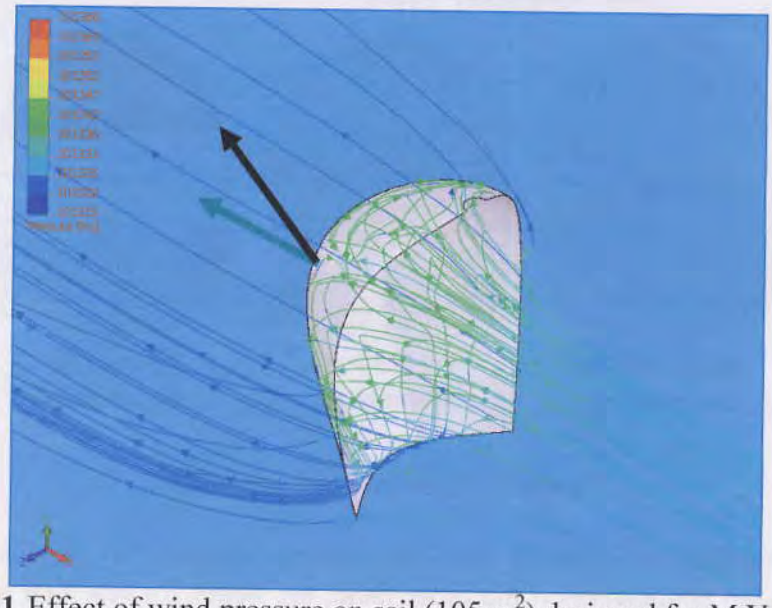


Figure 11. Effect of wind pressure on sail (105 m^2) designed for M.V. Plalung

The flow vector lines substitute 5 m/s wind vector of airflow pressing along the sail surface. The different colors of the lines mean different pressures of wind along the flow trajectory. Most of the flow lines, green, are on the upper part. The occurring thrust force vector of the air pressure pulls the sail upward resulting in the front deck also being pulled up, conveniently providing directional control of the navigator.

The thrust produced by shape II is calculated using the formula:

$$Thrust = \Delta P \times A = (101{,}347 - 101{,}315)(105) = (32)(105) = 3{,}360N$$

The speeding period of a boat from stop until 5 m/s is converted using the second law of Newton indicated as: $\sum F = ma$

Where **F**: force, N

m: mass, kg

a: acceleration, m/s^2 = v/t

v: ship speed, m/s

Long tail boat:

Wind Force	= total water resistance + ma
936	= 366 + 2,000 x (5 / t)
t	= 17 sec.

M.V. Plalung:

Wind Force	= total water resistance + ma
3,360	= 1,199.4 + 27,000 x (5 / t)
t	= 62.48 sec. (1 min 2.5 sec.)

In the wind force equation, boat weight is the most significant parameter directly effecting the variation of the speeding period. Lighter weight boat enhances faster boat speed. Thus, the use of lightweight but with high sufficient strength material for the hull in small-scale fishing boats is recommended. Modern high-speed boats are fabricated using fiberglass and aluminum alloy as standard materials because these materials have acceptable mechanical properties, but could also incur high material costs.

Similarity Test of Sail with the M.V. Plalung as model

Using Similarity Analysis, three similarities, i.e. Geometric, Kinematic, and Dynamic were calculated and tested to observe ship model stability and propulsion force while there is wind flow, in a wind tunnel. The definitions and calculation of these similarities are presented below:

Geometric similarity: All linear dimensions of the model and prototype must be proportional, with the same angles and shapes to achieve geometrical similarity. Photographs from all angles must be indistinguishable as regards their different positions. Furthermore, the model must be aligned with the flow at the same angles in order that the flows over the prototype could be considered geometrically similar. Geometrical similarity is necessary but may be insufficient for modeling a prototype flow. Geometric similarity exists between the model and prototype if the ratio of all corresponding dimensions in the model and prototype are equal:

Length ratio: $$L_r = \frac{L_{prototype}}{L_{model}} = \frac{30}{1} = 30$$

where L_r is the scale factor for length.

Kinematic similarity: The similarity of flows requires not only the same length scale ratios of the geometric similarity, but also the same time scale ratios in order that identical velocity scale ratios are achieved. This similarity exists between the model and prototype as shown below:

Velocity ratio: $V_r = \frac{L_r}{T_r}$

$$L_r = \frac{L_p}{L_m} \qquad T_r = (L_r)^{\frac{1}{2}} = (\frac{L_p}{L_m})^{\frac{1}{2}}$$

Dynamic similarity: The similarity includes not only geometrical (length scale ratio) and kinematics (time scale ratio) similarities, but also force scale similarity. This means that all the relevant force ratios such as the Reynolds number (inertial/viscous), Froude number (inertial/buoyancy), Rossby (inertial/Coriolis), Euler number (pressure/inertial), Weber number (inertial/surface tension), etc. that are relevant must be equal. Dynamic similarity exists between geometrically and kinematically similar systems if the ratios of all forces in the model and prototype are the same.

Force ratio: $$F_r = \frac{F_r}{F_m} = \frac{M_p a_p}{M_m a_m} = (\frac{\rho_p L_p^3}{\rho_m L_m^3})(\frac{L_p}{L_m})(\frac{t_p}{t_m})^{-2}$$

$$\frac{\rho_p}{\rho_m} = 1 \qquad \frac{L_p}{L_m} = L_r \qquad t_r = (L_r)^{\frac{1}{2}} = \frac{t_p}{t_m}$$

$$\frac{F_p}{F_m} = \left(\frac{1}{1}\right)\left(L_r^3\right)\left(\frac{L_r}{\left(\left(L_r^{\frac{1}{2}}\right)\right)^2}\right) = L_r^3$$

$$F_p = F_m\left(L_r^3\right) = F_m\left(30^3\right) = 27{,}000 F_m$$

An experiment was set up using as model the M.V. Plalung scaled down by 1:30 and using the strain gauge in measuring propulsive thrust. The physical values of the model, 1 kg in weight, 53 cm in length, and 13.3 cm in width, were modified.

The thrusts of three equivalent wind speeds of 10, 20 and 30 knots, were measured by the strain gauge, as follows:

Equivalent wind speed	30 knot	tension force	75	gram
	20 knot	tension force	50	gram
	10 knot	tension force	25	gram

Conversion forces were calculated using the formula:

Wind speed of 30 knots $\quad F_{prototype} = F_{model} \times (30^3)$
$= 75\ g_f \times 27{,}000$
$= 2{,}025$ N

Wind speed of 20 knots $\quad F_{prototype} = F_{model} \times (30^3)$
$= 50\ g_f \times 27{,}000$
$= 1{,}350$ N

Wind speed of 10 knots $\quad F_{prototype} = F_{model} \times (30^3)$
$= 25\ g_f \times 27{,}000$
$= 675$ N

Speed period of the prototype from standstill until 5 m/s (9.8 knots) including total resistance on the surface of the hull is calculated by:

$$F - f = ma = \frac{m(V-u)}{t}$$

Case I: wind speed 30 knots (55.56 km/hr) $t_{30knot} = \dfrac{27{,}000kg(5m/s)}{2{,}025N} = 67 \quad Sec.$

Case II: wind speed 20 knots (37.04 km/hr) $t_{20knot} = \dfrac{27{,}000kg(5m/s)}{1{,}350N} = 1 \quad Min. \quad 40 \quad Sec.$

Case III: wind speed 10 knots (18.52 km/hr) $t_{10knot} = \dfrac{27{,}000kg(5m/s)}{675N} = 3 \quad Min. \quad 20 \quad Sec.$

From the similarity results, the equivalent period of 10 knots wind speed is quite long, 3 min. and 20 sec., which might be ineffective for medium-scale fishing boats. With wind speed of 20-30 knots, the speed period of the fishing boat may be acceptable because it is one-half of the speeding period of wind speed at 10 knots. Since the main target of this project is to save on the cost of fuel consumption, the sail could be an important component in propelling the boats.

Structural Design of Sails

An additional sail installed on the M.V. Plalung, a 27 gross-tonnage medium-sized fishing boat, was designed for flexible utilization (Figure 12). The mast can be laid down when the boat is not operated. The installed area is the fore mast of the M.V. Plalung. A couple of channel steel is used to support the column of the sail mast. The rigidity of the sail mast structure is fixed by stretching cross-slings at the top end of the sail mast and the other ends on the hull. A sheave at the top of the sail mast (not shown in the Figure 12) for rolling the top end of sail upward and downward is made from aluminum alloy, which is light weight with high corrosive resistance.

Figure 12. Right and front view of additional sail on M.V. Plalung

In Figure 13, laying down and up the mast without stretching the sling is demonstrated. By stretching either front/back or left/right, the sling on the mast fixes and transfers wind power onto the deck of the boat. The strength and corrosive resistance of the sling must be considered in choosing the right materials. Polyethylene rope is an unsuitable material for tensing the mast because it has a flexible property, which can stretch while sailing.

Figure 13. Side view of the M.V. Plalung with an auxiliary sail structure: laying down mast (left), setting up mast (right)

Both sides of the spinnaker pole can be slid outward or inward the main guide as shown in Figure 14 (left). The full length of the pole is used for adjusting the sail angle when changing wind direction. When the sail is unused, the pole will be slid in and locked on the intermediate link.

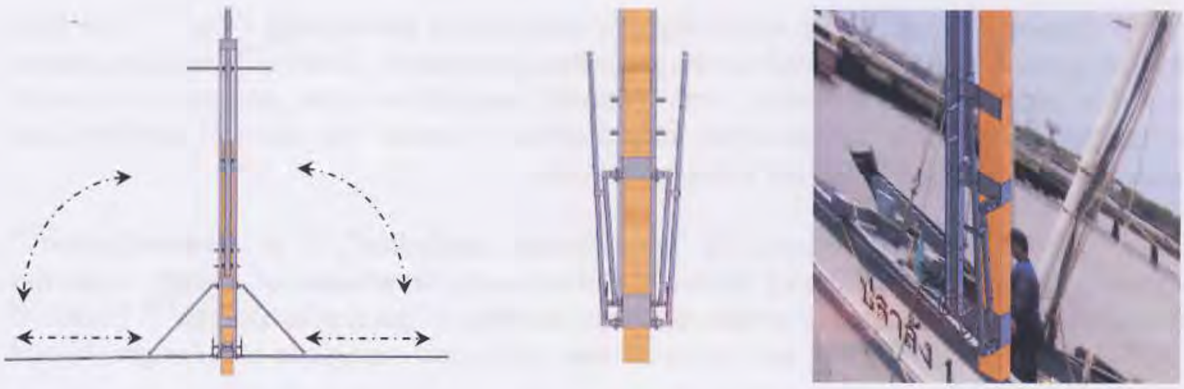


Figure 14. Spinnaker pole: Operation feature (left), cease-operation feature (middle), isometric view of spinnaker pole (right)

Adjustment of the angle of the spinnaker poles is illustrated in Figure 15. The angle range is about 30 degrees at both the forward and backward bases in neutral position. The poles must be in opposite positions when sailing. However, the sail angle can be controlled by releasing and tensing the rope tied on the sail and passing the end of the pole.

Figure 15. Isometric view of a side of spinnaker pole: Adjustable horizontal pole angle for directional control of sail

Sail materials and required properties of sailcloth

Fabric make-up and lay-up has been created for sailcloth. The list of fabrics includes Vectran™ and Certran™, PBO and PEN. In woven fabrics like Dacron and Nylon™, the important components are the yarn, the weave, and the finish. In laminated fabric, the yarn, film, adhesive, and the amount of pressure brought about to bear on the fabric during lamination are factors that hold the fabric all together. The most important component is still the yarn. Since it is in the yarn where development and changes usually occurs, it was deemed necessary to look at available yarns and their distinctive features, as shown below.

Vectran™: The length of the tow had to remain constant, and the fiber had to withstand adverse conditions. Vectran™ is shown to be an ideal fiber for sailcloth, until its creators exposed it to the sun and found that sunlight was its greatest enemy. The two important properties of ideal sailcloth are their relative stretch characteristics and their softness.

Durable Dupont Dacron™ and Allied-Signal's (now called Honeywell) Pentex™ are both Polyester yarns but at opposite ends of the performance spectrum. Dacron™ was a benchmark in the 50s because of its durability, with relatively inexpensive price, and easier to use in making the sails. There was however, one drawback because the material stretches and stretchy fabric could distort the sail's shape over time.

Pentex™ or PEN is an acronym for "polyethylene napthalate". It is a super-Dacron™ combining all the great qualities of Dacron™ without major drawbacks, i.e. stretch. It also has two and a half times modulus or stretch resistance than that of the regular Dacron™. Pentex™ is best used in laminated form, and has been used with equal success in one-design jibs and mega-yacht mainsails.

Spectra™ (made by Honeywell), Dyneema™ (made in Holland by Dutch company DSM), and Certran™ (made in the US by Hoechst Celanese) fabrics are almost akin groups, made of polyethylene. They have excellent sunlight durability, flexing or chafe and stretch resistance. Their initial stretch resistance is high however, over time they start to creep permanently. This distortion is not good for the sail's shape. With their slippery texture, they are difficult to laminate and the fibers melt at a relatively low temperature.

The recognizable Kevlar, belonging to Aramid family of synthetic fibers, is the most successful fiber available for sail making purposes. It has become a standard material used for sail on racing boats. However, Kevlar has also its own drawbacks that can not comply with the two major factors adversely affecting the sail material during sailing days, i.e. sunlight (UV effect) and flutter. One of the most effective ways to protect threads from UV is by filming the yarns with UV inhibitors.

The most common film used in sailcloth is Mylar™, which is extruded from polyester and comes in different thickness, depending on its application. The film allows the fibers to be laid out in a multitude of directions where they can be most effective. The problem with Mylar™ is the opposite of polyester, because in its original form, polyester stretches. Once extruded into film, Mylar™ shrinks, distorting the shape of the sail. Sailcloth makers still rely on the film to aid them in minimizing off-thread line stretch and in protecting delicate yarns from sunlight and abrasion, as well as for cushion flexing.

Expected Results

Calculation of Fuel Savings

An auxiliary sail has been designed for small- and medium-scale fishing boats that are widely used in the Southeast Asian region. The sail can have 100% propulsion force substituting engine power for small-scale fishing boats and at least 10 % for the medium-scale boats. A condition was set up for calculating the savings on fuel. The results are shown in Table 3 and Table 4 for small-scale and medium-scale boats, respectively.

Table 3. Small Scale-Fishing Boat**

Calculation of Boat Acceleration Period at 5 m/s wind speed	
Boat Displacement (tonnage)	2
Sail Projection Area (m^2)	36
Wind Power (Watts) at 5 m/s (9.7 knot)	2,756
Wind force (N) [wind power/wind speed]	551.2

Drag Force=$C_d r_{sea} AV^2/2$	16.54
Speeding Period (s)	9.24

Fuel Saving Calculation

Horse power (Ps)	10.5
Specific Fuel Consumption (g/Ps-Hr)	180
Fuel Consumption (l/hr)	2.52
Fuel Consumption (l/day)*	5.04
Fuel Consumption (l/yr)	1,814
Fuel cost (Baht/yr) (23.29 b/l)	42,257
Approximate Cost of Additional Sail Construction (Baht)	5,000

* Operation period: 2 hours a day

** Agricultural Diesel Engine on Small-scale Fishing Boat: YANMAR Model TF 105-L(H) 10.5 Ps 180 g/Ps-Hr

Note: The calculated results on Table 3 show that a small-scale fishing boat with 36 m^2 sail area operating at 5 m/s wind speed, obtains a propulsion power of 2,756 watts. Speeding period of the boat is 9.24 seconds including the effect of water resistance, which is 16.54 N. Assuming that a fishing operation period is about 2 hours per day, the computed fuel saving rate shows that the boat can reduce its fuel consumption rate at 5.04 l/day or 1,814 l/year. Thus, the income of a fisherman will be enhanced by 42,257 Thai Baht/year. The approximate breakeven point in installing an additional sail on fishing boat is about one and a half months.

Table 4. Medium-Scale Fishing Boat***

Calculation of Boat Acceleration Period at 5 m/s wind speed	
Ship Displacement (tonnage)	30
Sail Projection Area (m^2)	100
Wind Power (Watts) at 5 m/s (9.7 knot)	7,656
Wind force (N) [wind power/wind speed]	1531.2
Drag Force=$C_d r_{sea} AV^2/2$	99.225
Speeding Period (s)	104.75

Fuel Saving Calculation

Horse power (Ps)	200
Fuel Consumption (l/hr)	39.00
Fuel Consumption (l/day)*	78.00
Fuel Consumption (l/yr)	28080.00
Fuel cost (baht/yr) (23.29 b/l)	653,983.20
Approximate Cost of Additional Sail Construction (Baht)	50,000

* Operation period: 2 hours a day

***Diesel Engine of the M.V.Plalung 1: HINO Model K13D-A11644, 200 Hp and 39 l/hr fuel consumption

Note: For medium fishing boat (Table 4), the sail area is 100 m^2. When the boat sails at 5 m/s wind speed, the power generated is 7,656 watts. The ship's period speed is about 104 seconds including water resistance. Fuel consumption rate of the engine in a medium fishing boat is 39 l/hour. Since fishing operation is two hours/day, the auxiliary sail contributes to the reduced fuel consumption rate of 78 l/day or 28,080 l/year, which is equivalent to a reduction of the total budget for fishing operations by 653,983 Thai Baht. Since the construction cost of an auxiliary sail is about 50,000 Baht, a return period for this installation is one month. In practical operations however, the sail could save fuel consumption at the rate of 10% so that the rate of return may be prolonged by nine months.

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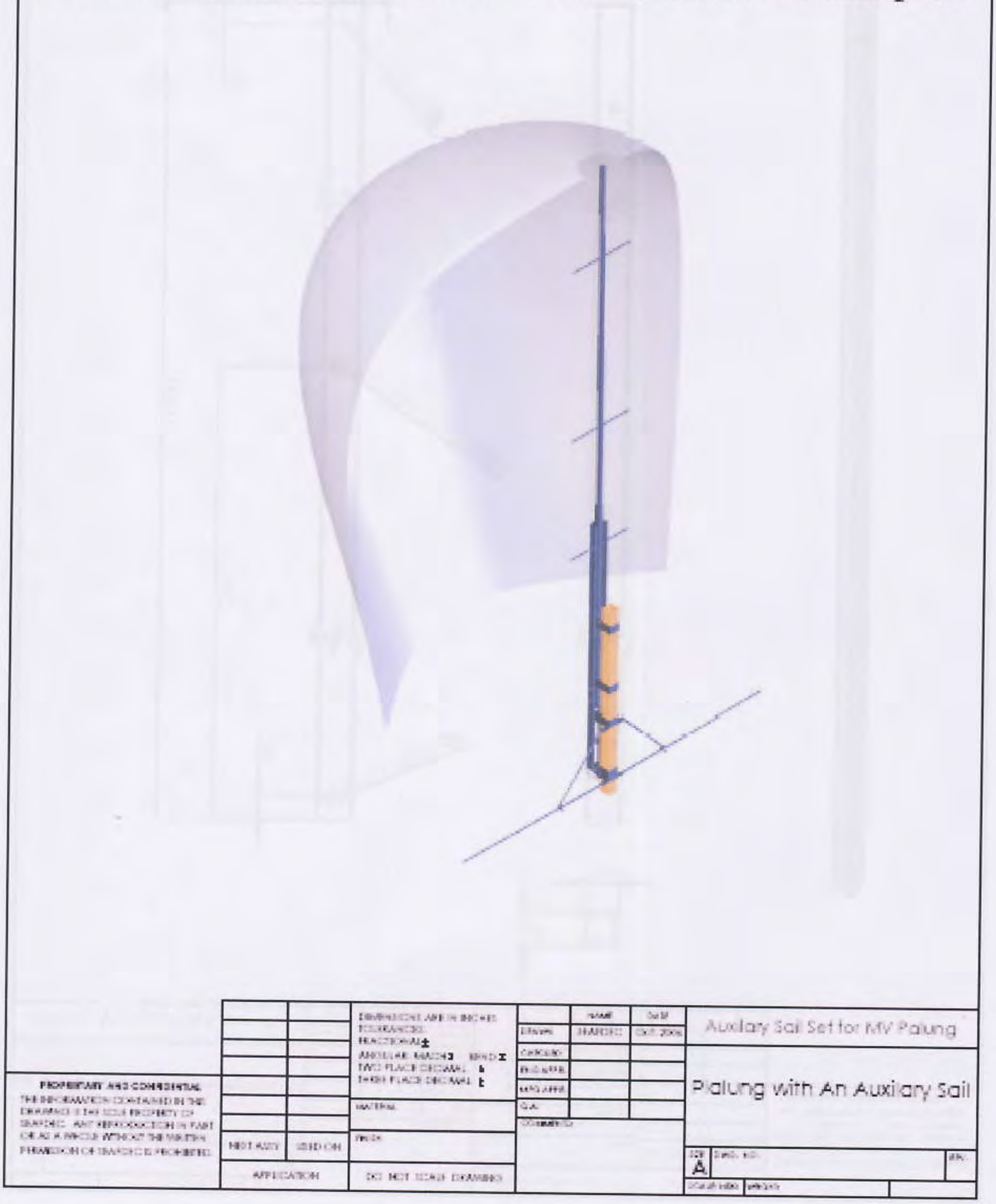
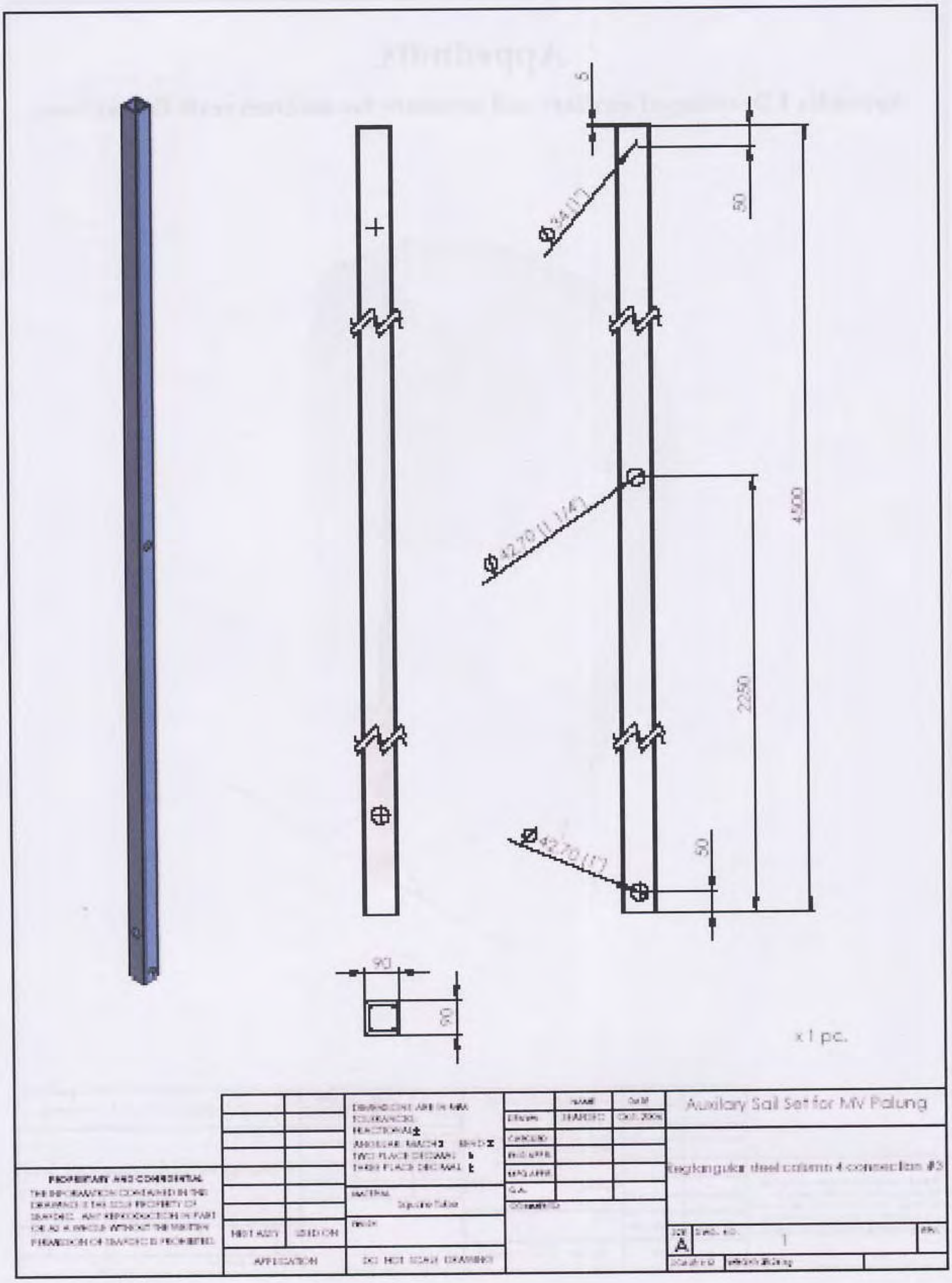
Appendix

Appedndix

Appendix I Drawingsof auxilary sail structure for medium scale fishing boat





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90
x 1 pc.
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DATE
CHECKED
APPLICATION
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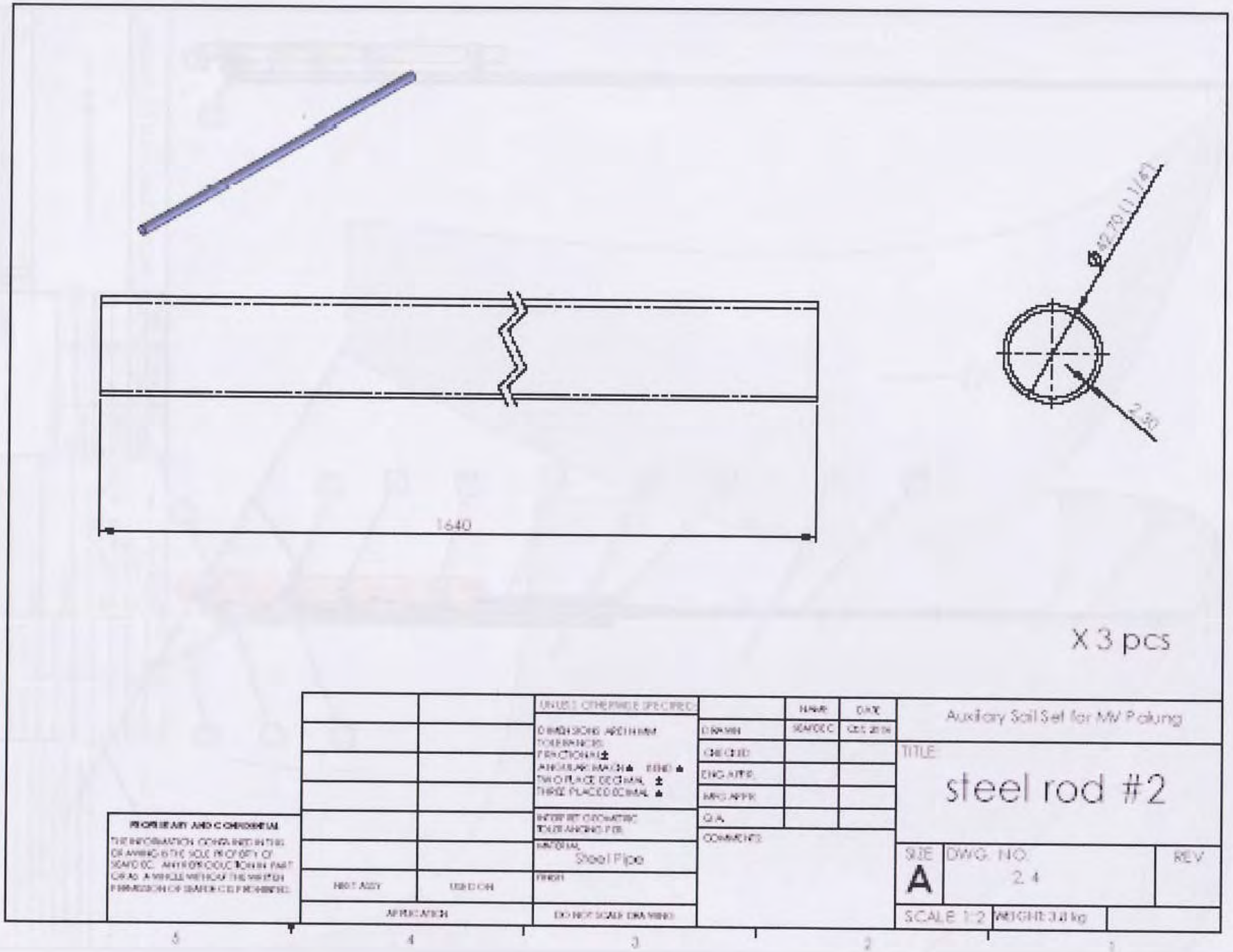
A
1



Ø42.70 (1 1/4")
2.30
1640
X 3 pcs
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NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
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REV
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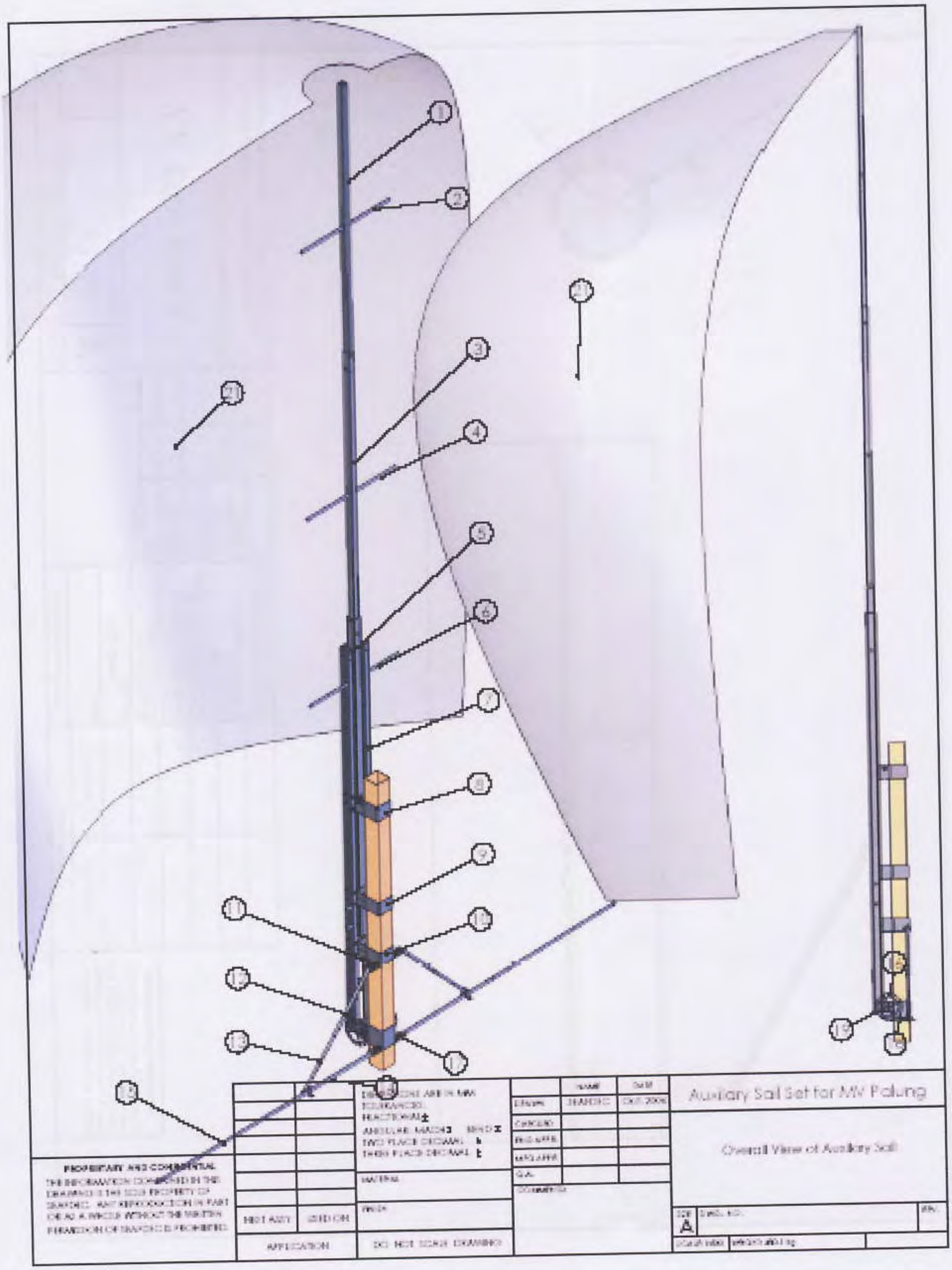
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL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Overall View of Auxiliary Sail
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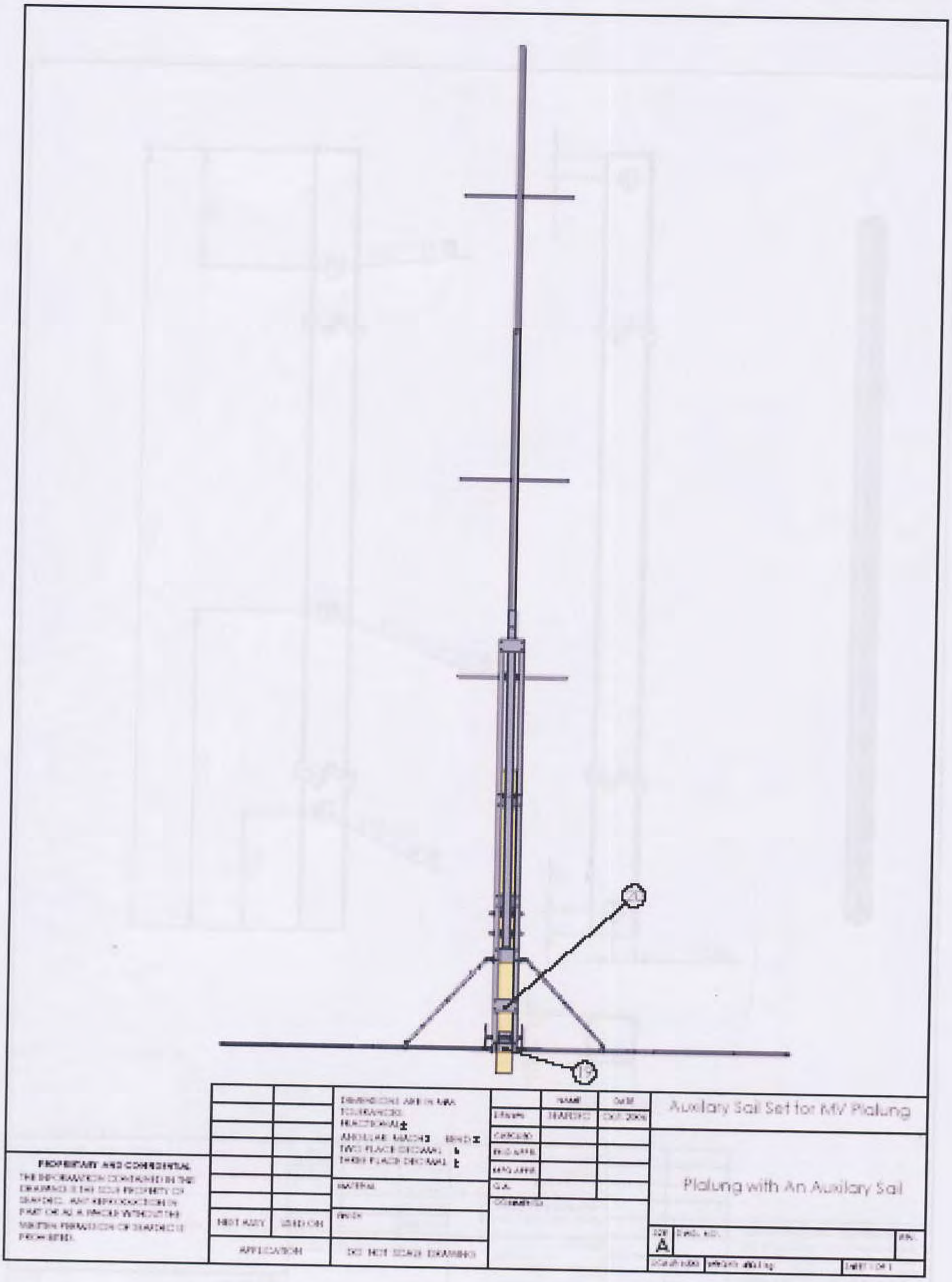
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Plalung with An Auxilary Sail
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NAME
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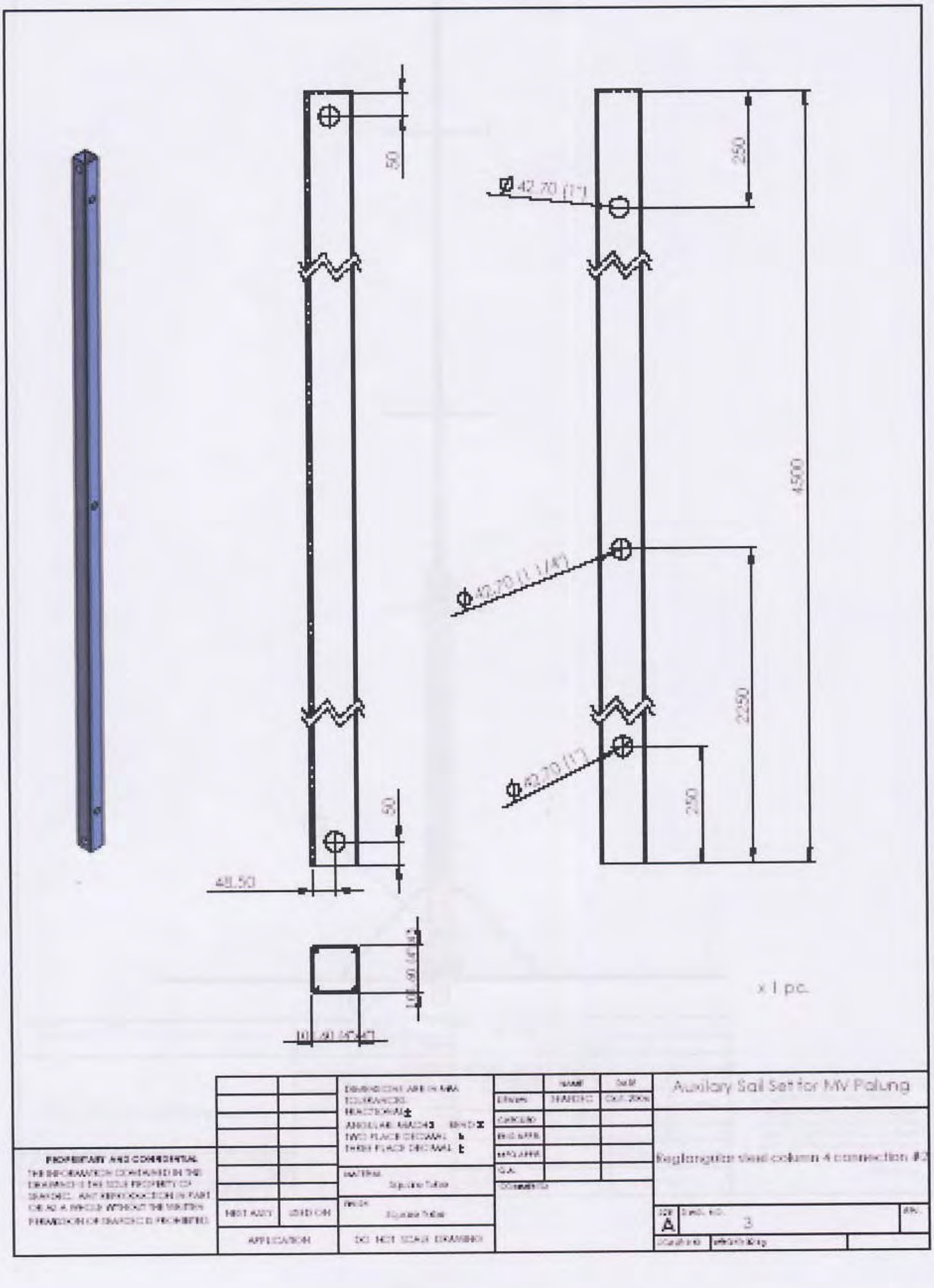
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250
4500
2250
250
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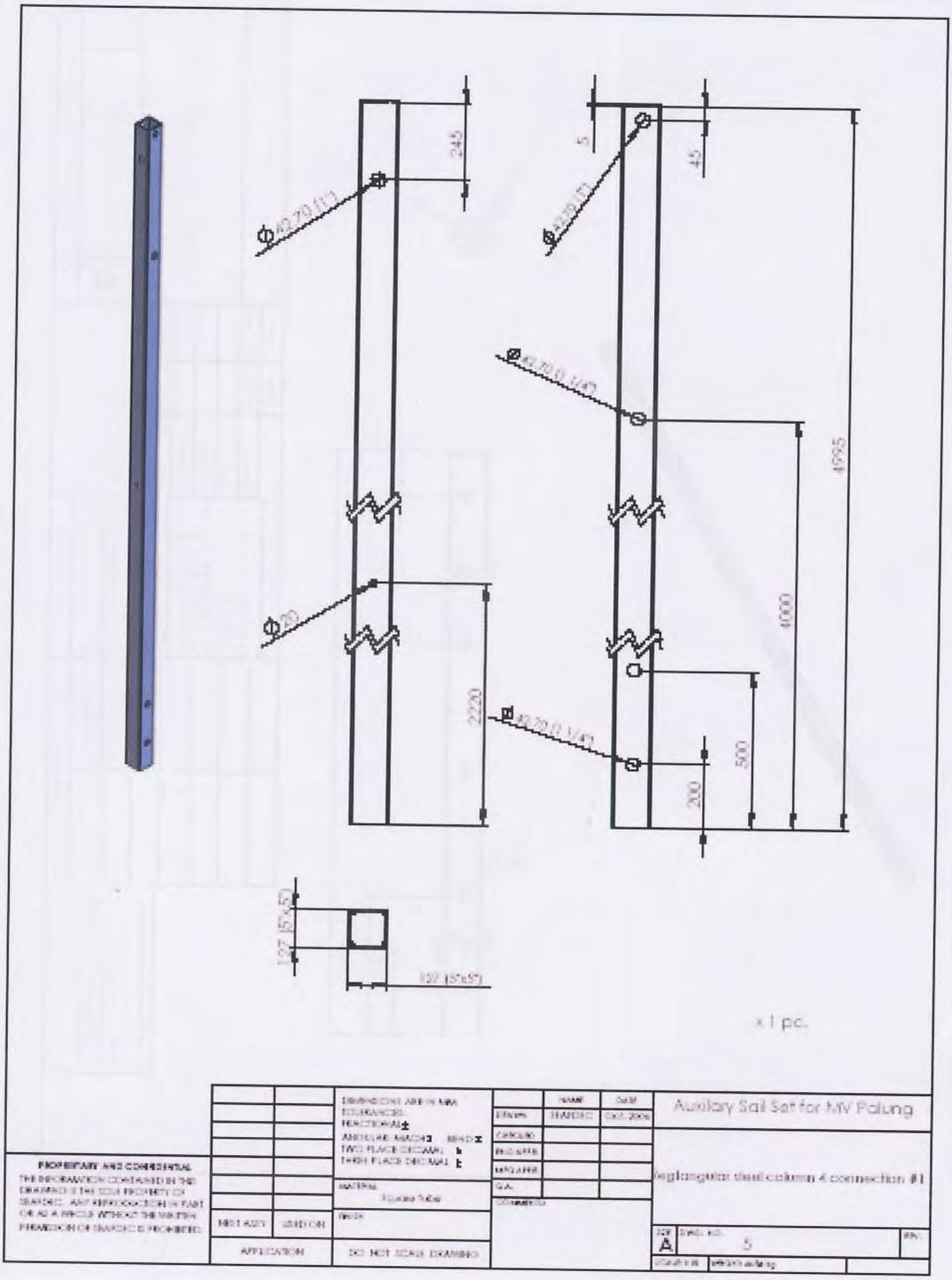
3



245
5
45
4995
4000
500
200
2220
Ф20
127 (5"x5")
x 1 pc.
Auxilary Sail Set for MV Palung
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
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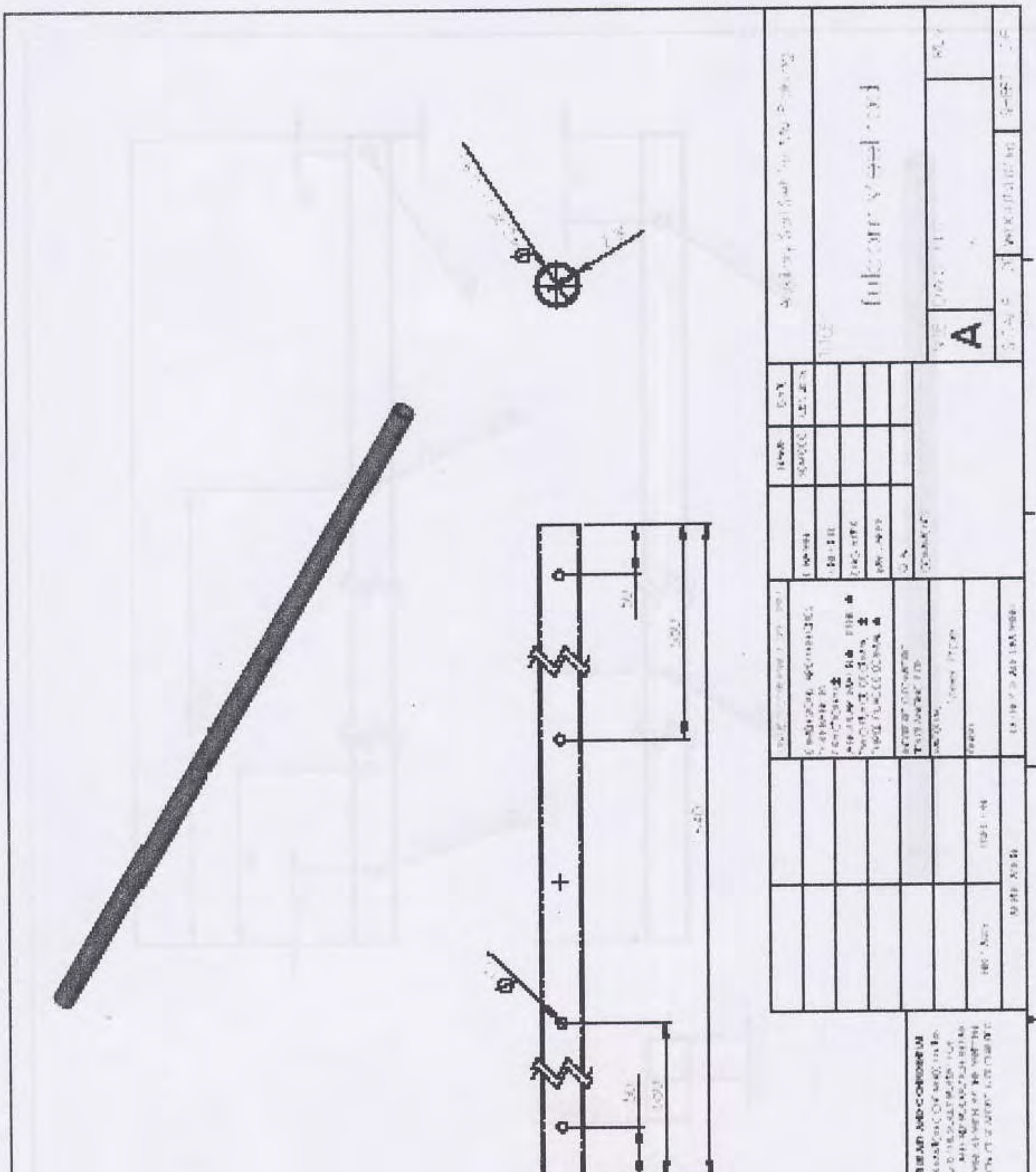
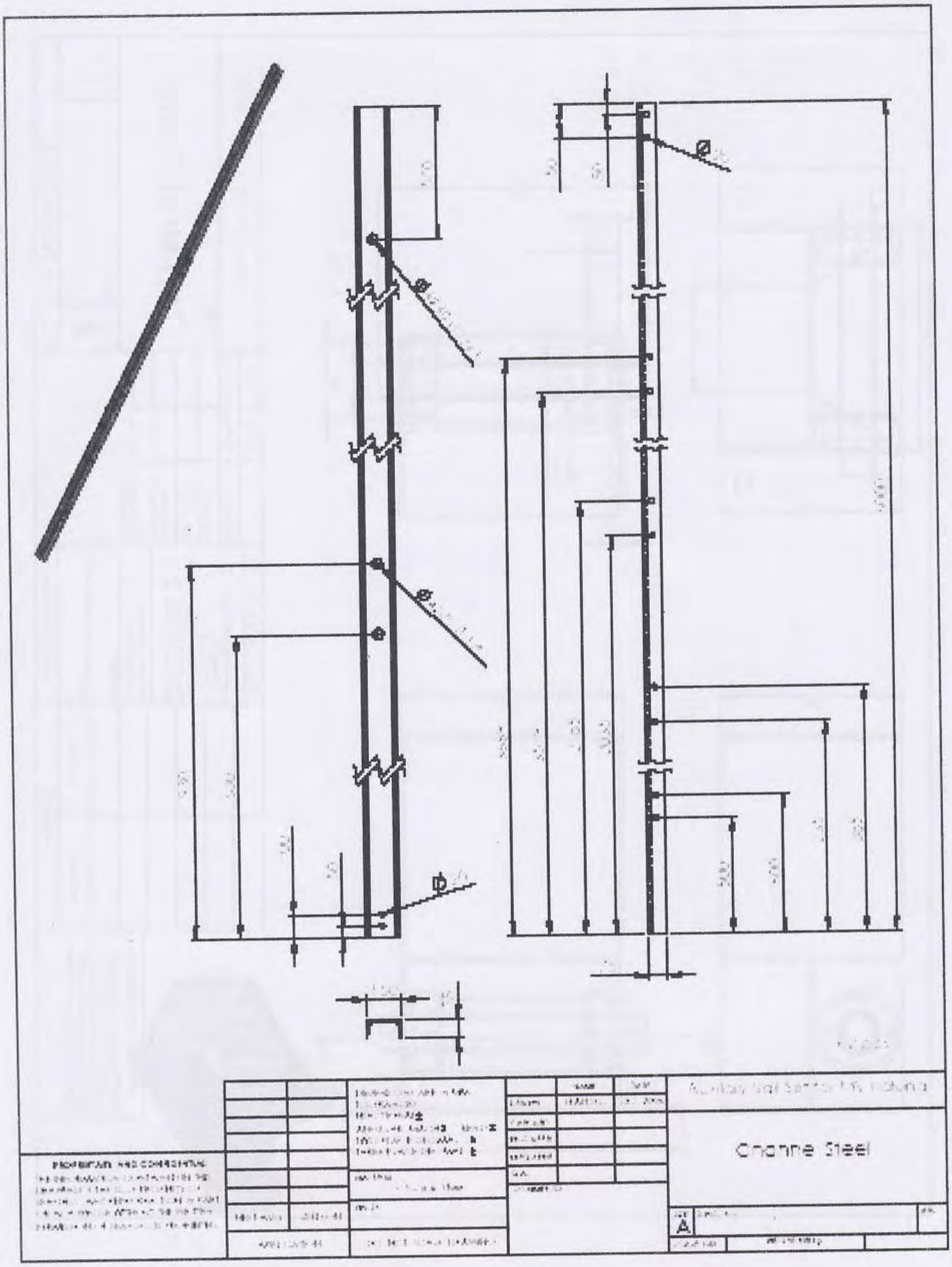
A
5




Channe Steel
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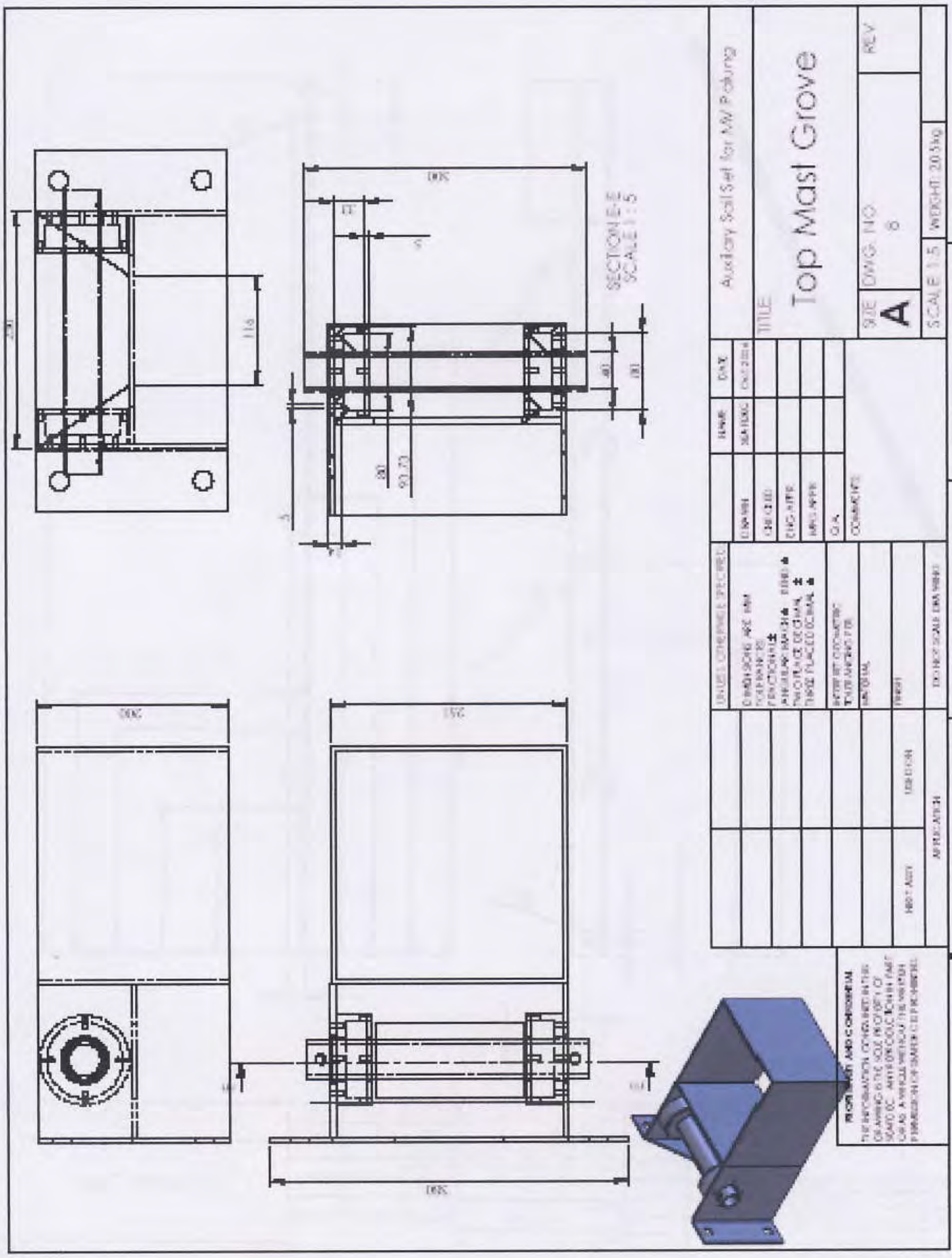
PROPRIETARY AND CONFIDENTIAL



SECTION E-E
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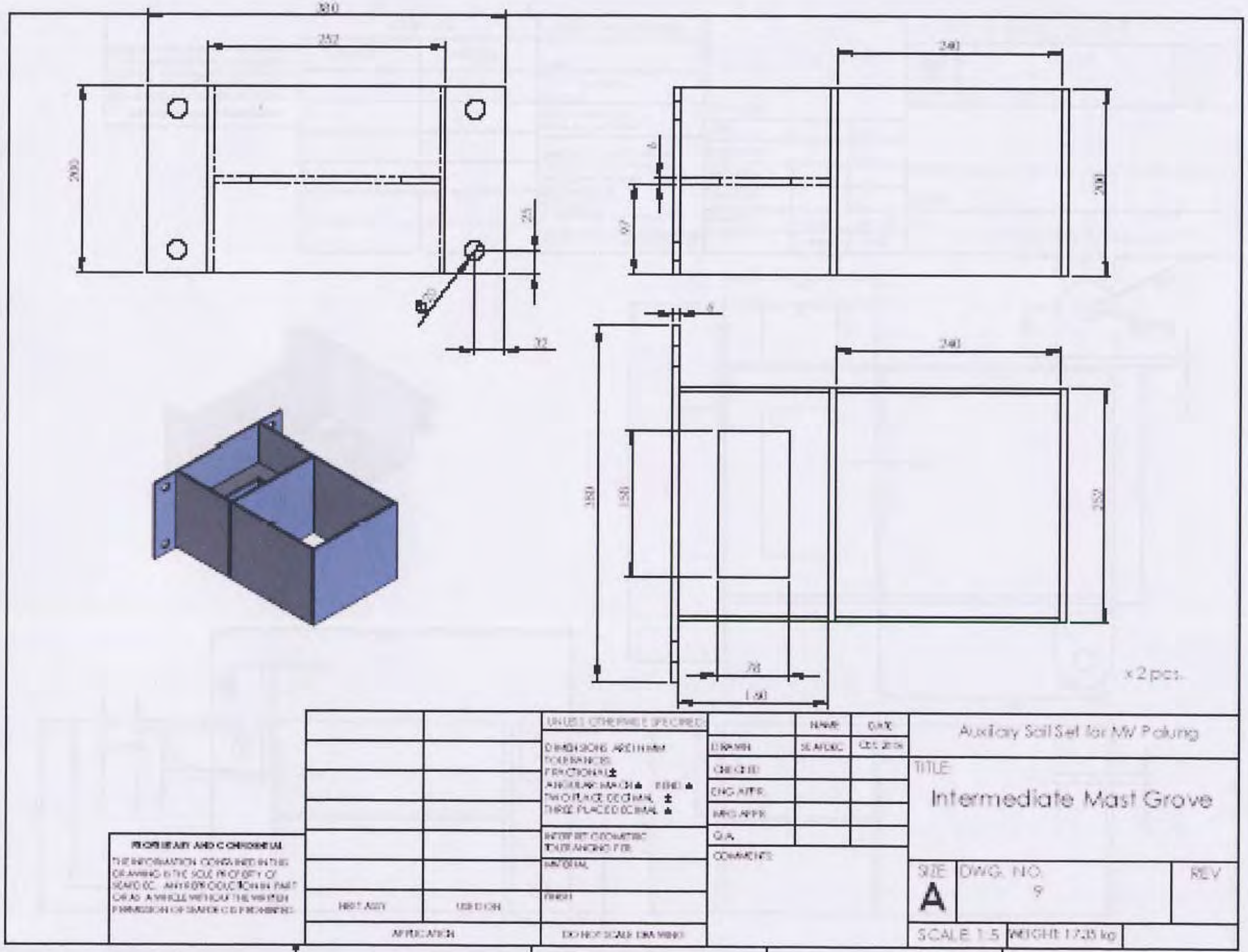

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NAME
DATE
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CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
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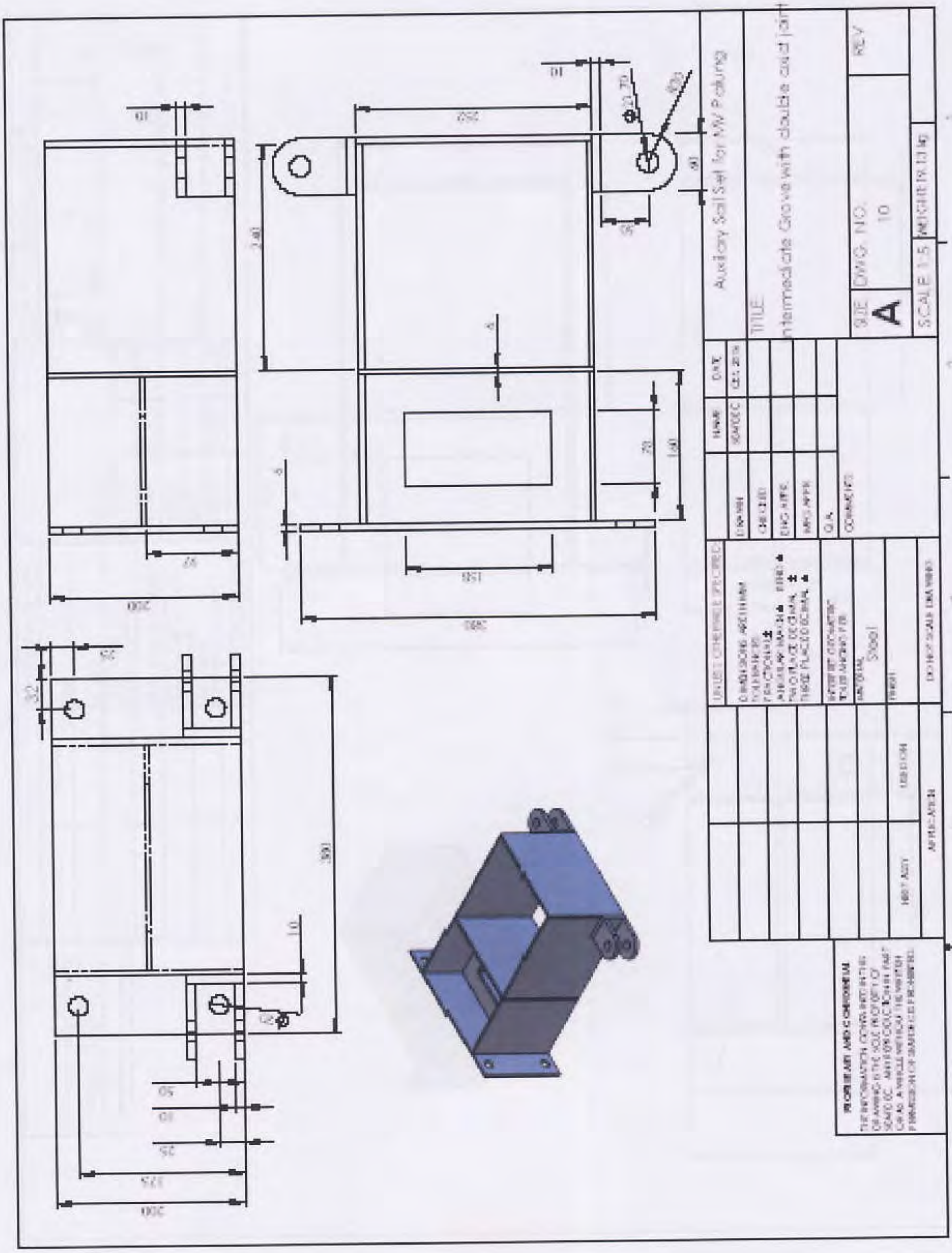
WEIGHT 17.35 kg



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REV
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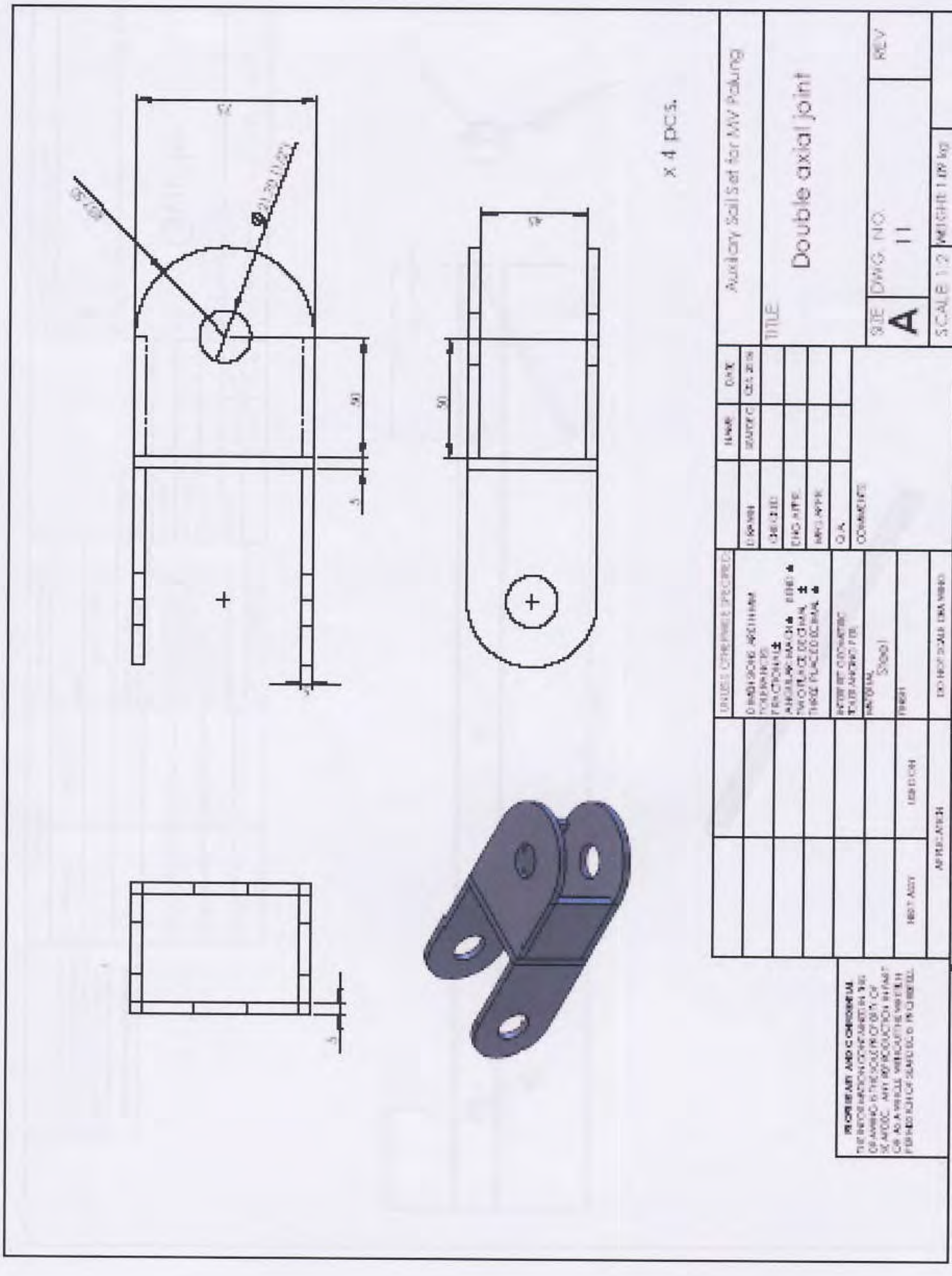
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CHECKED
ENG APPR.
MFG APPR.
Q.A.
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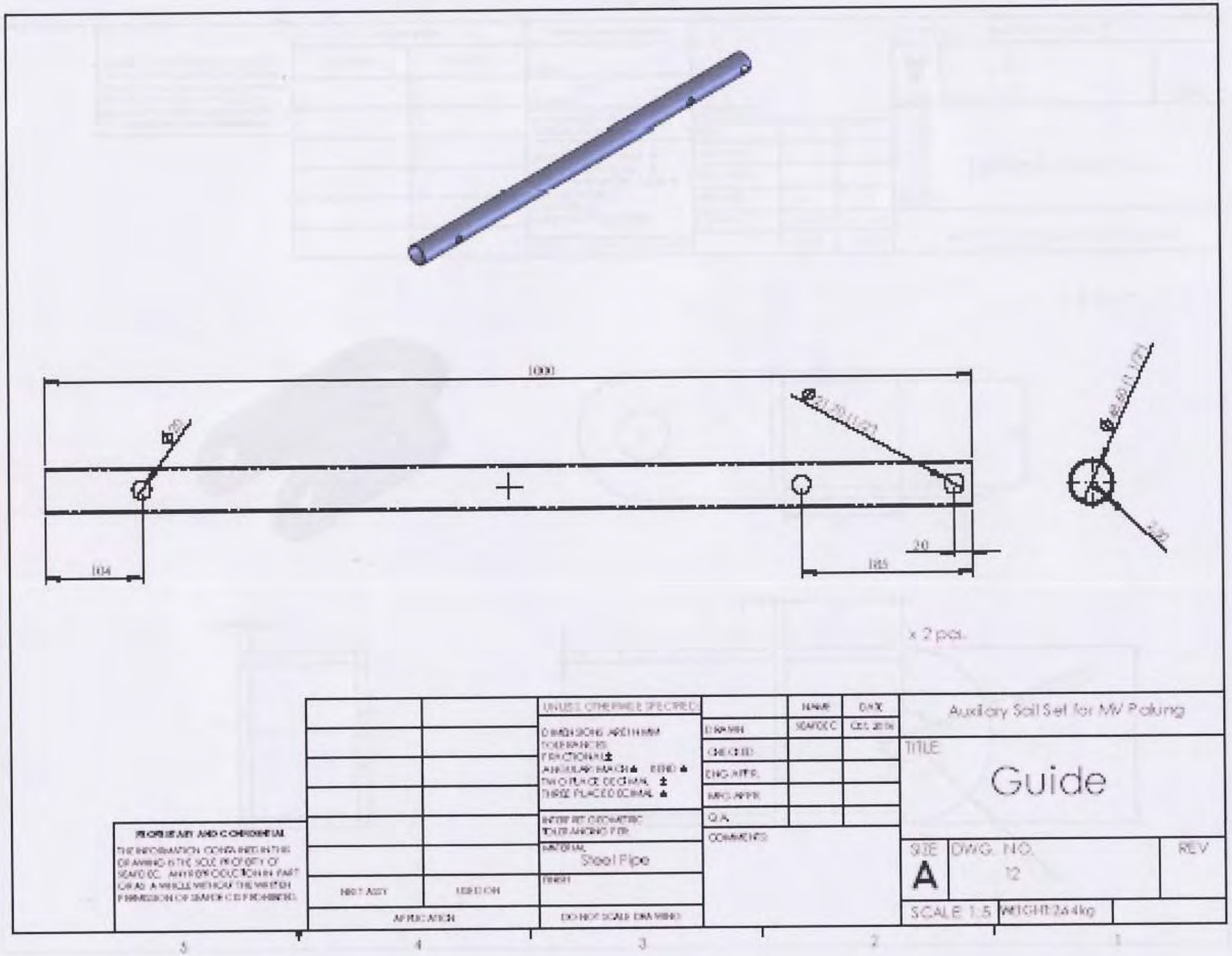

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185
20
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NAME
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MFG APPR.
Q.A.
COMMENTS
MATERIAL
Steel Pipe
FINISH
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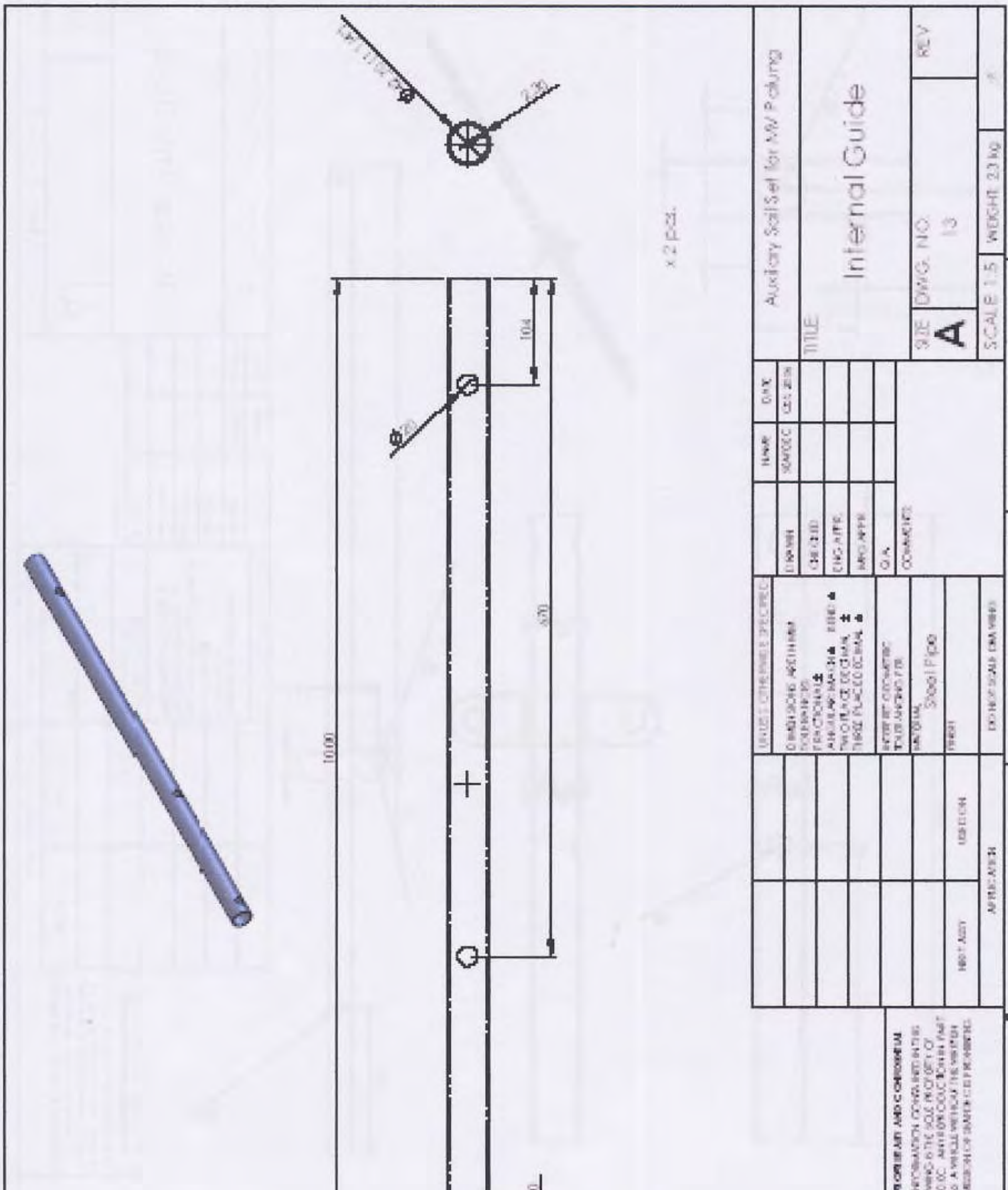

Auxiliary Soil Set for MV Palung
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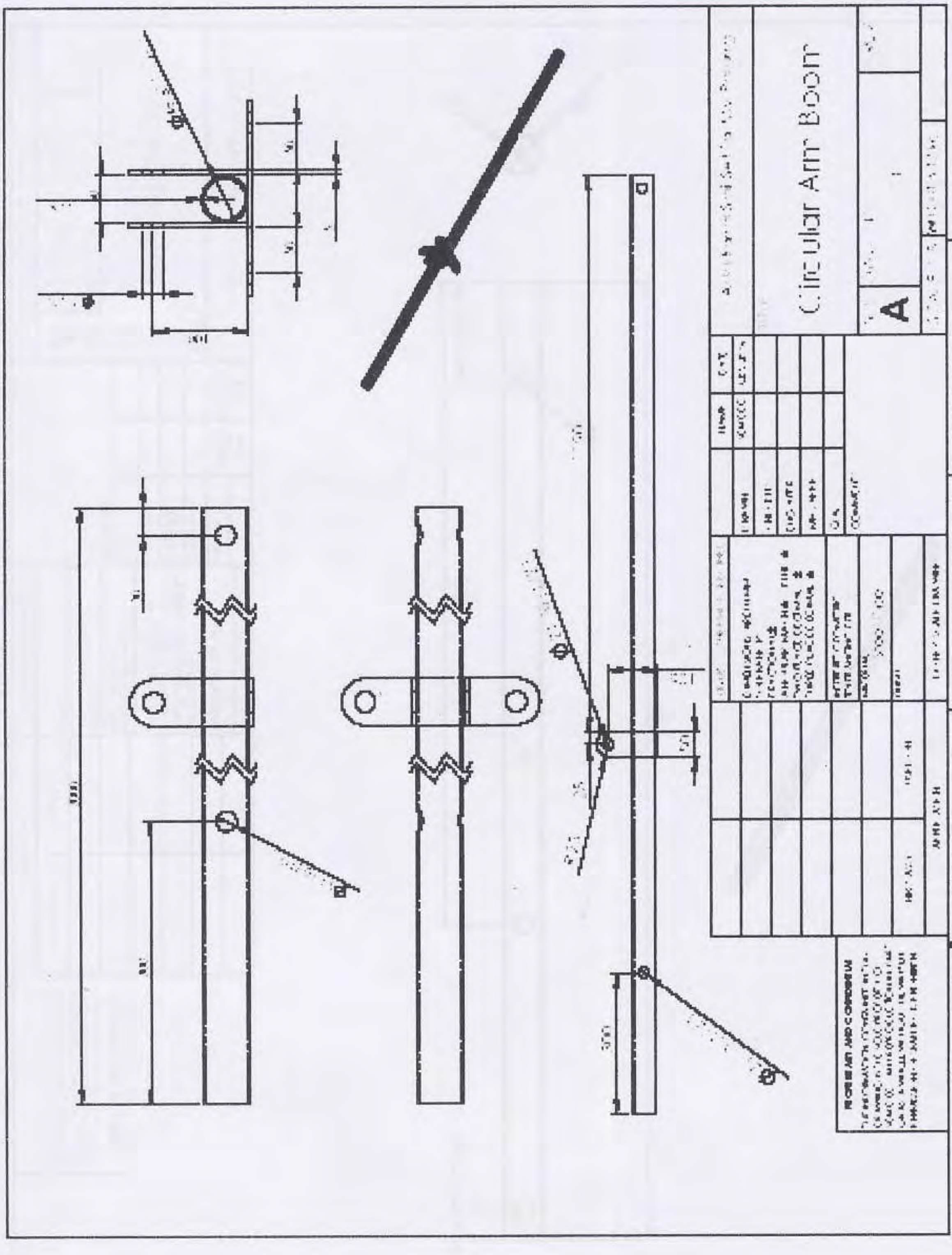
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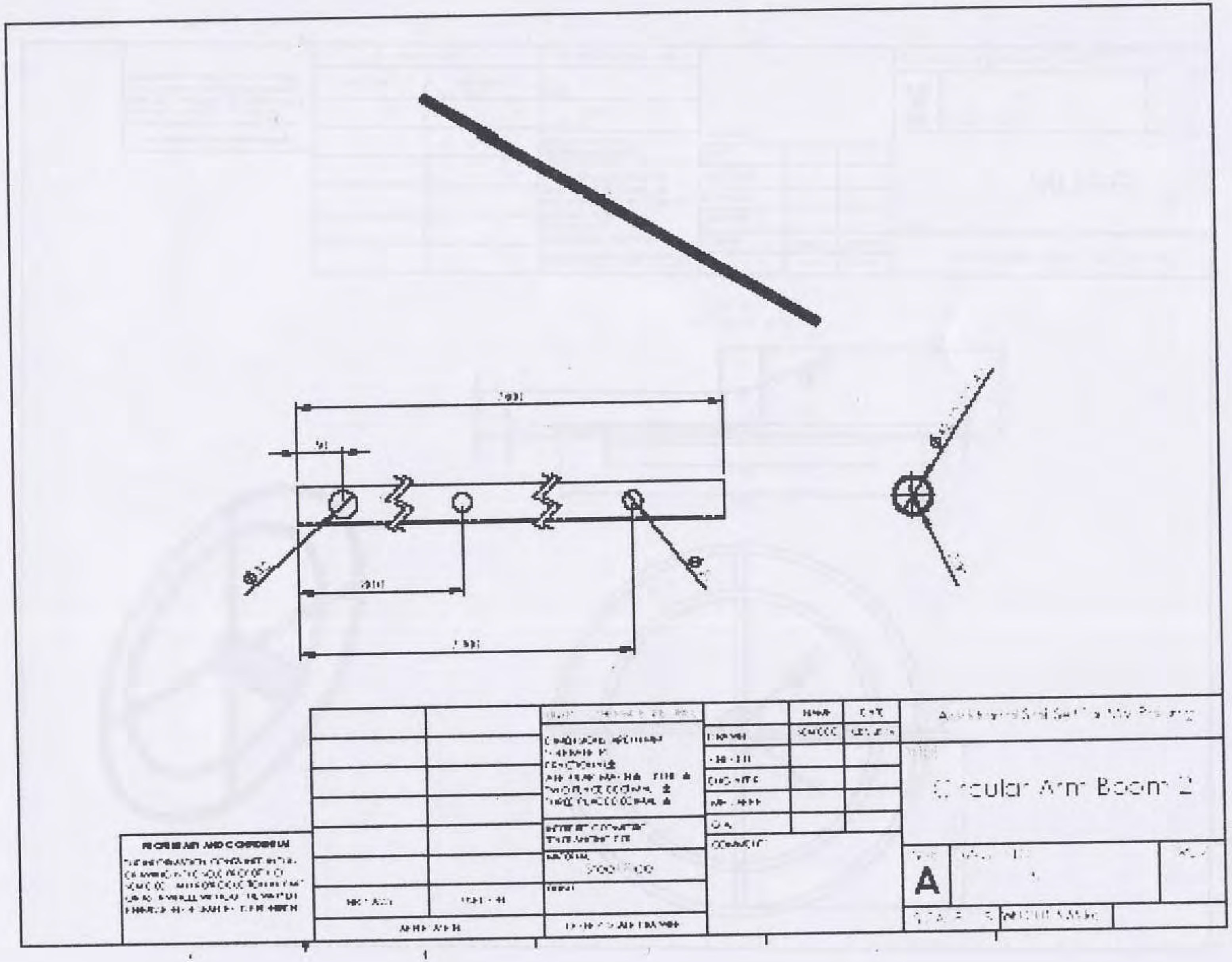
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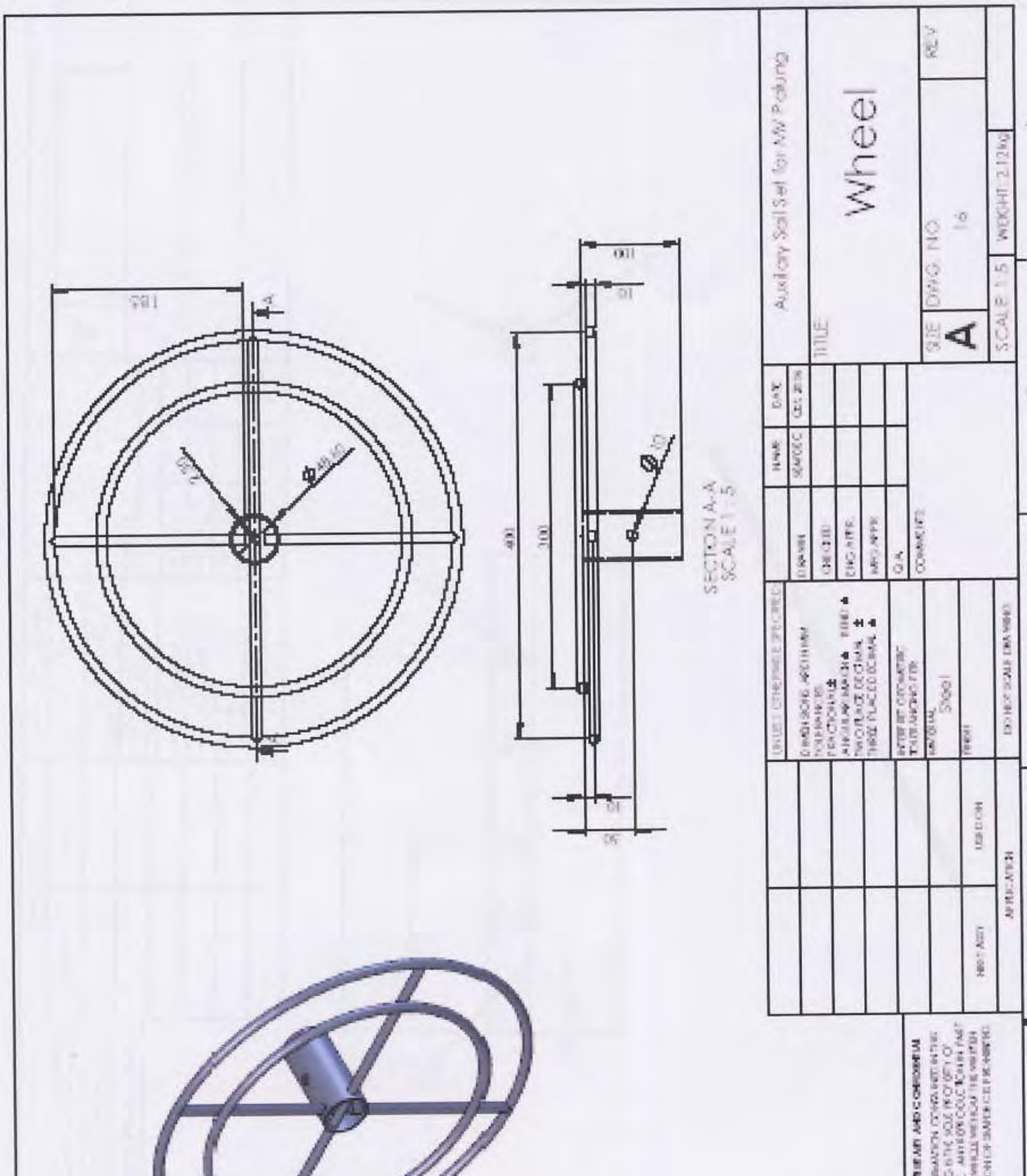
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ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
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MATERIAL
Steel
FINISH
DO NOT SCALE DRAWING
NAME
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DRAWN
SEAFDEC
CHECKED
ENG APPR.
MFG APPR.
Q.A.
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SIZE
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DWG. NO.
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2
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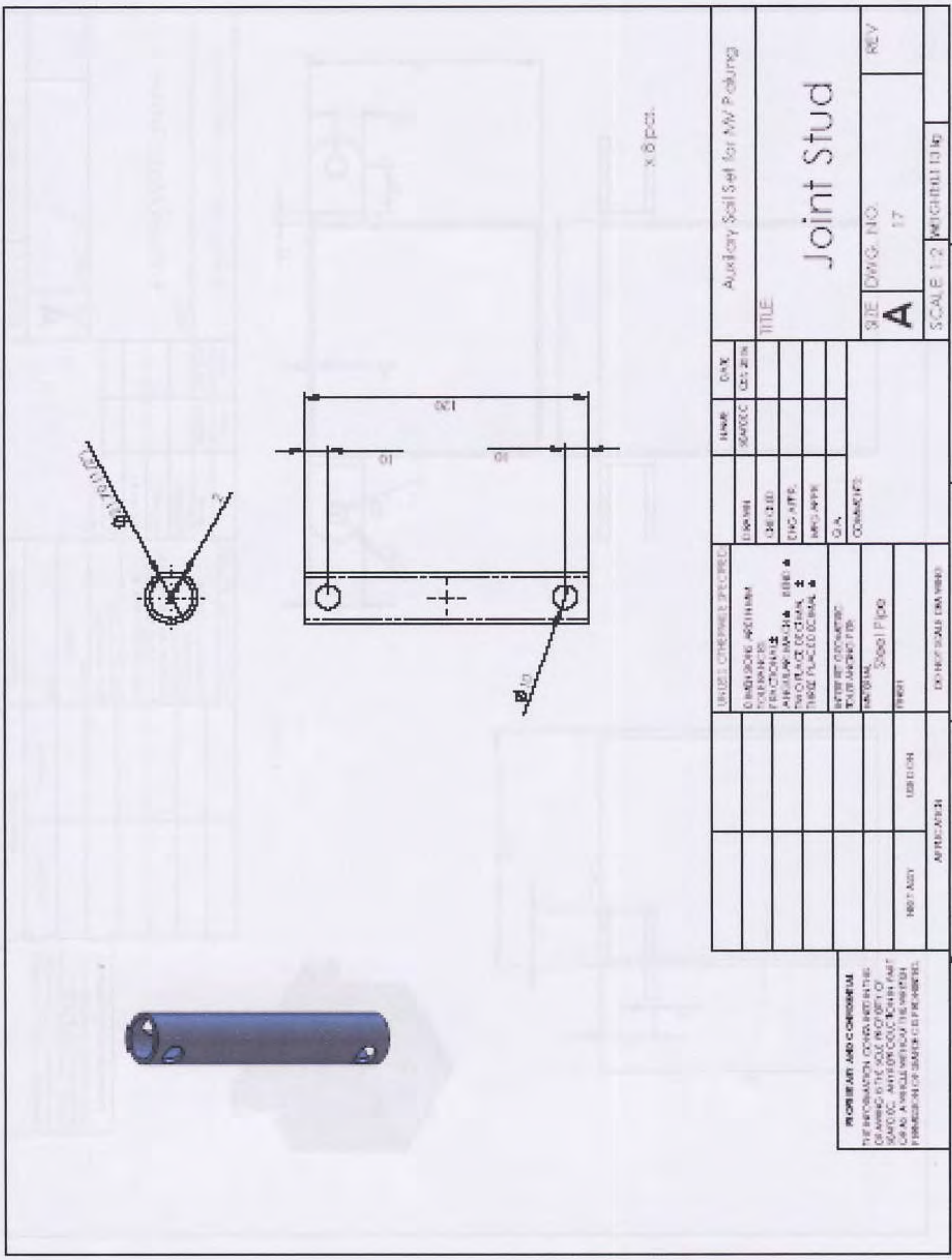
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CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
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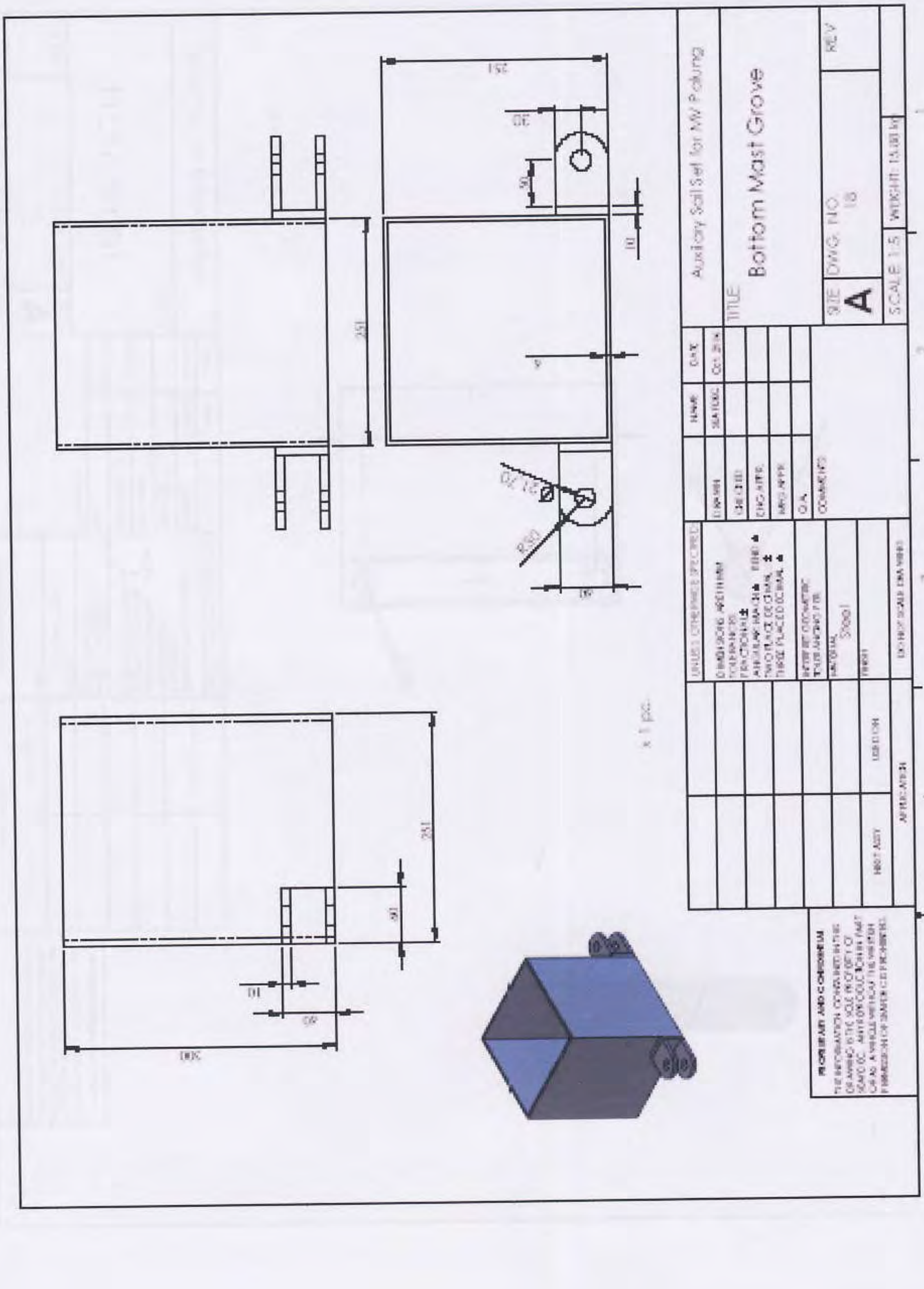
PROPRIETARY AND CONFIDENTIAL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ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
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Steel
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APPLICATION
PROPRIETARY AND CONFIDENTIAL
NAME
DATE
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CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
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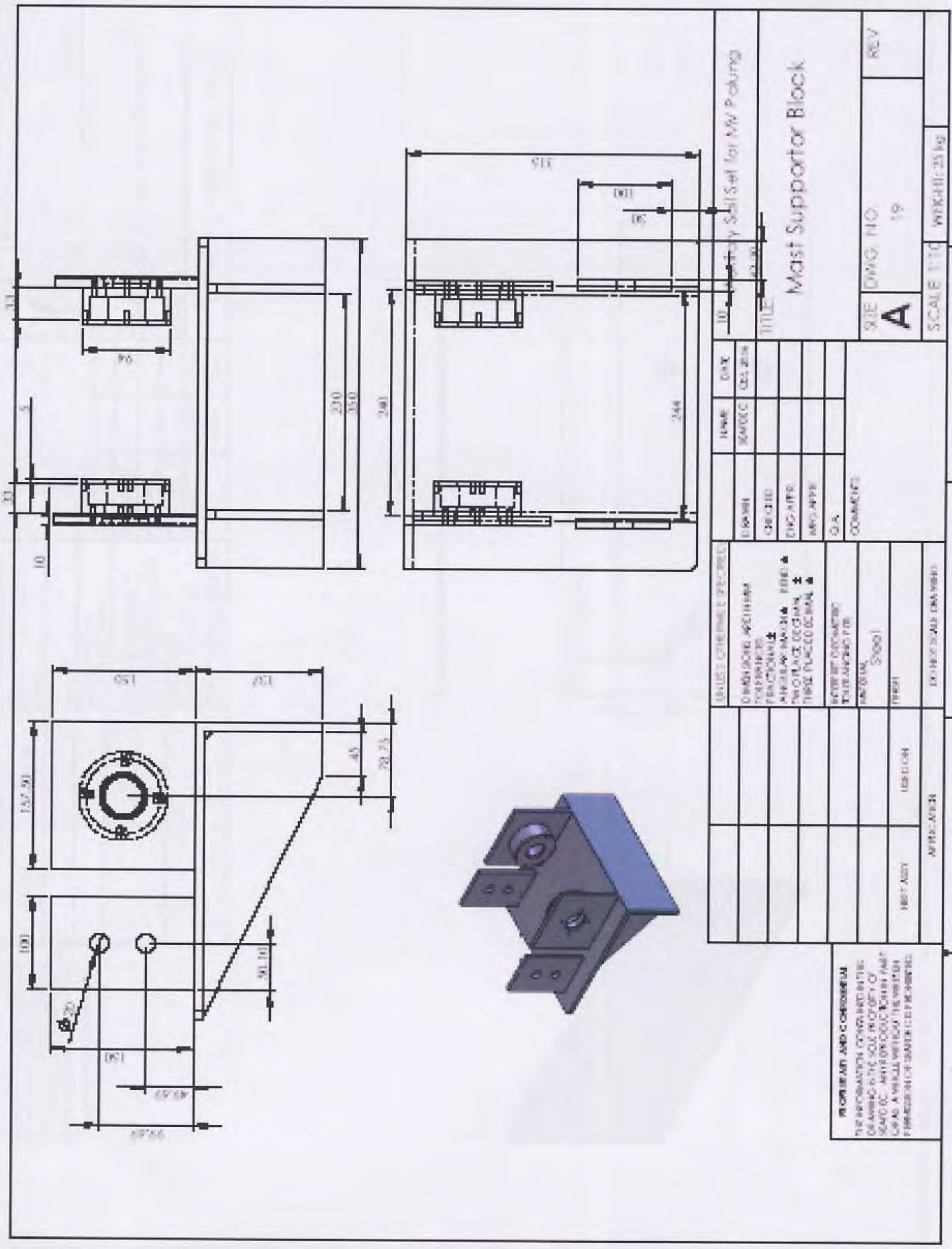
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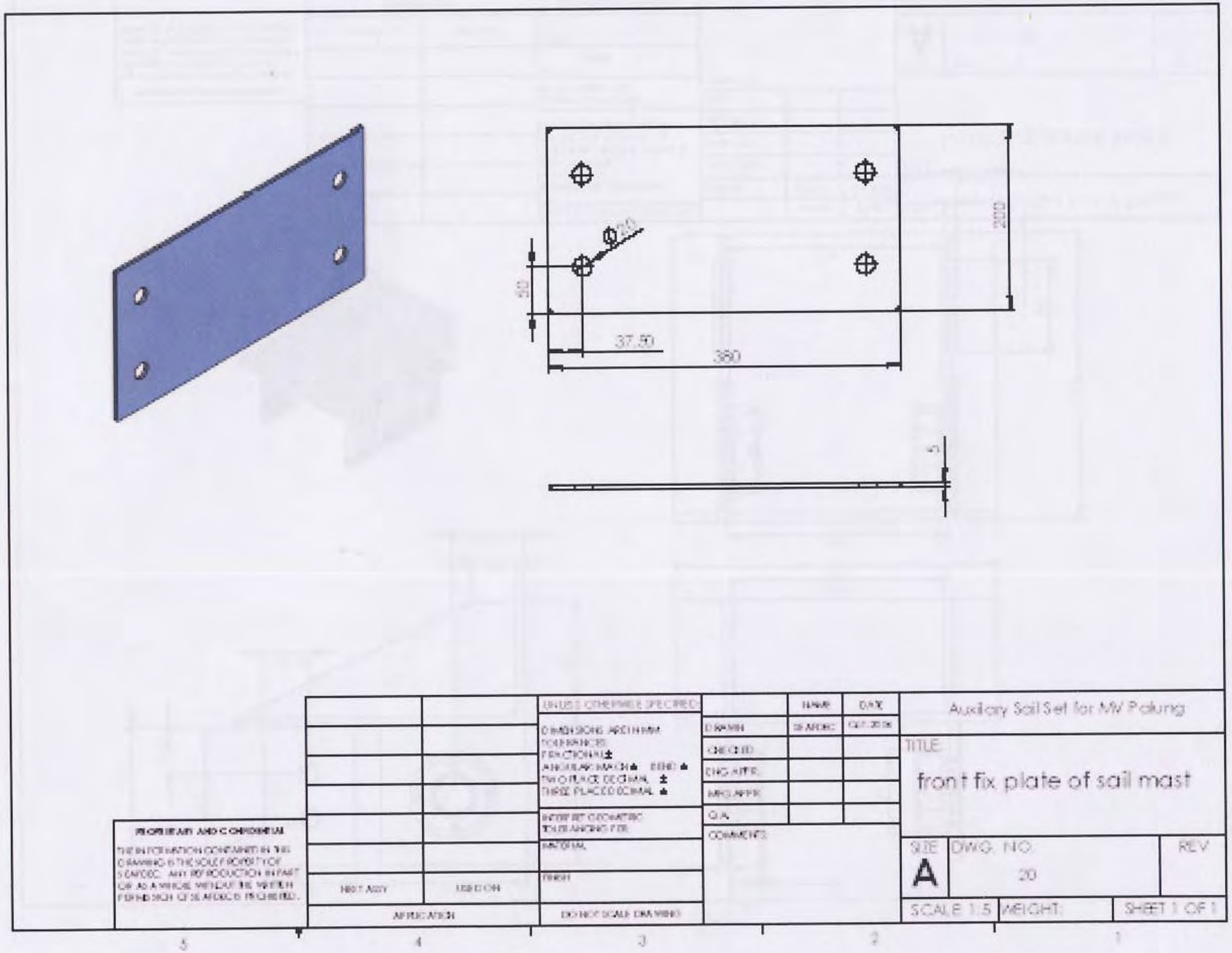
REV
MATERIAL
Steel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380
200
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UNLESS OTHERWISE SPECIFIED
NAME
DATE
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CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
Auxiliary Sail Set for MV Palung
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front fix plate of sail mast
SIZE
DWG. NO.
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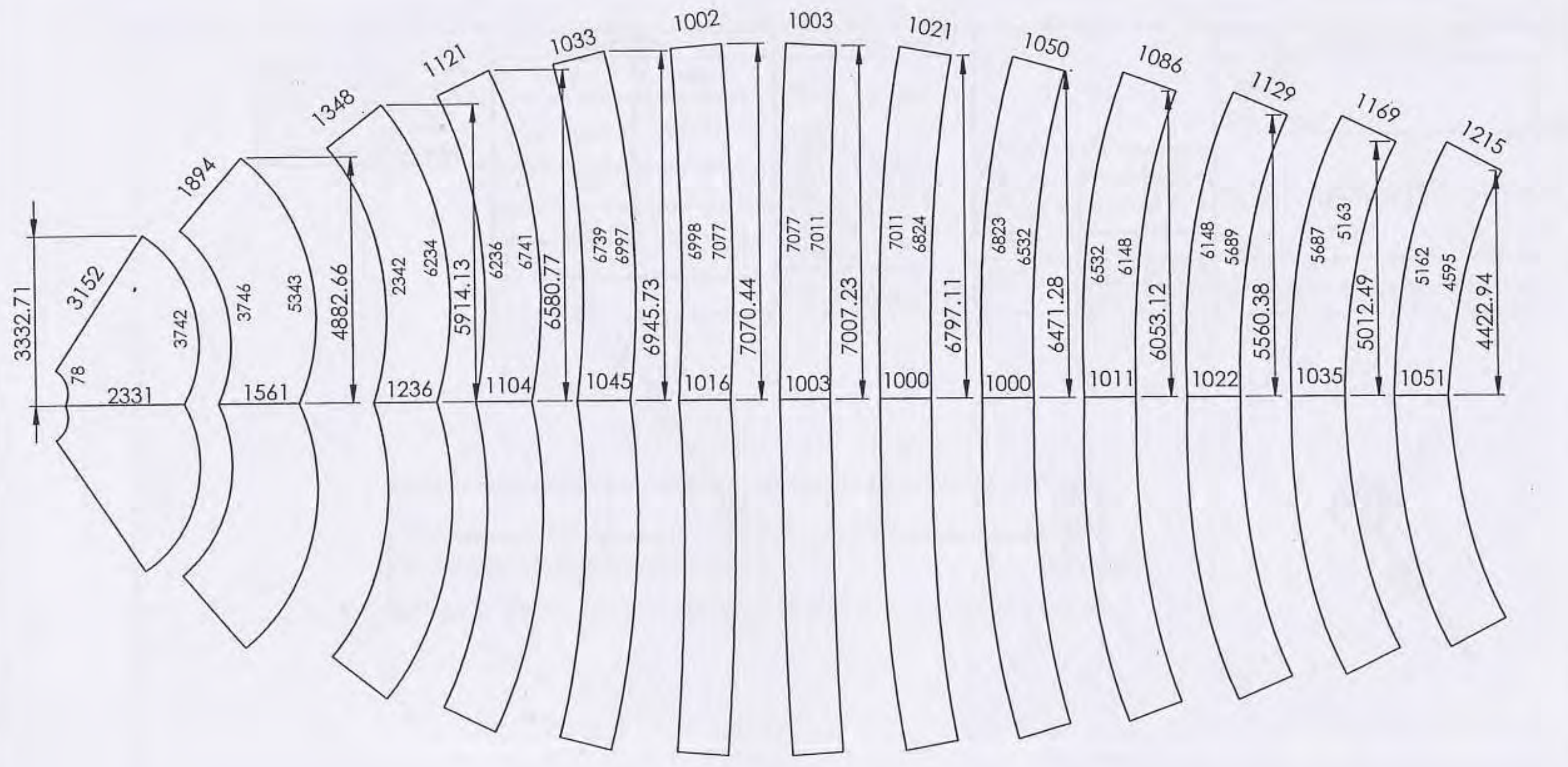
REV
A
SCALE 1:5
WEIGHT:
SHEET 1 OF 1



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	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

Auxilary Sail Set for MV Palung

TITLE:

Projection of Sail

SIZE A | DWG. NO. 21 | REV

SCALE: 1:110 | WEIGHT:

PROPRIETARY AND CONFIDENTIAL

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NEXT ASSY | USED ON

APPLICATION

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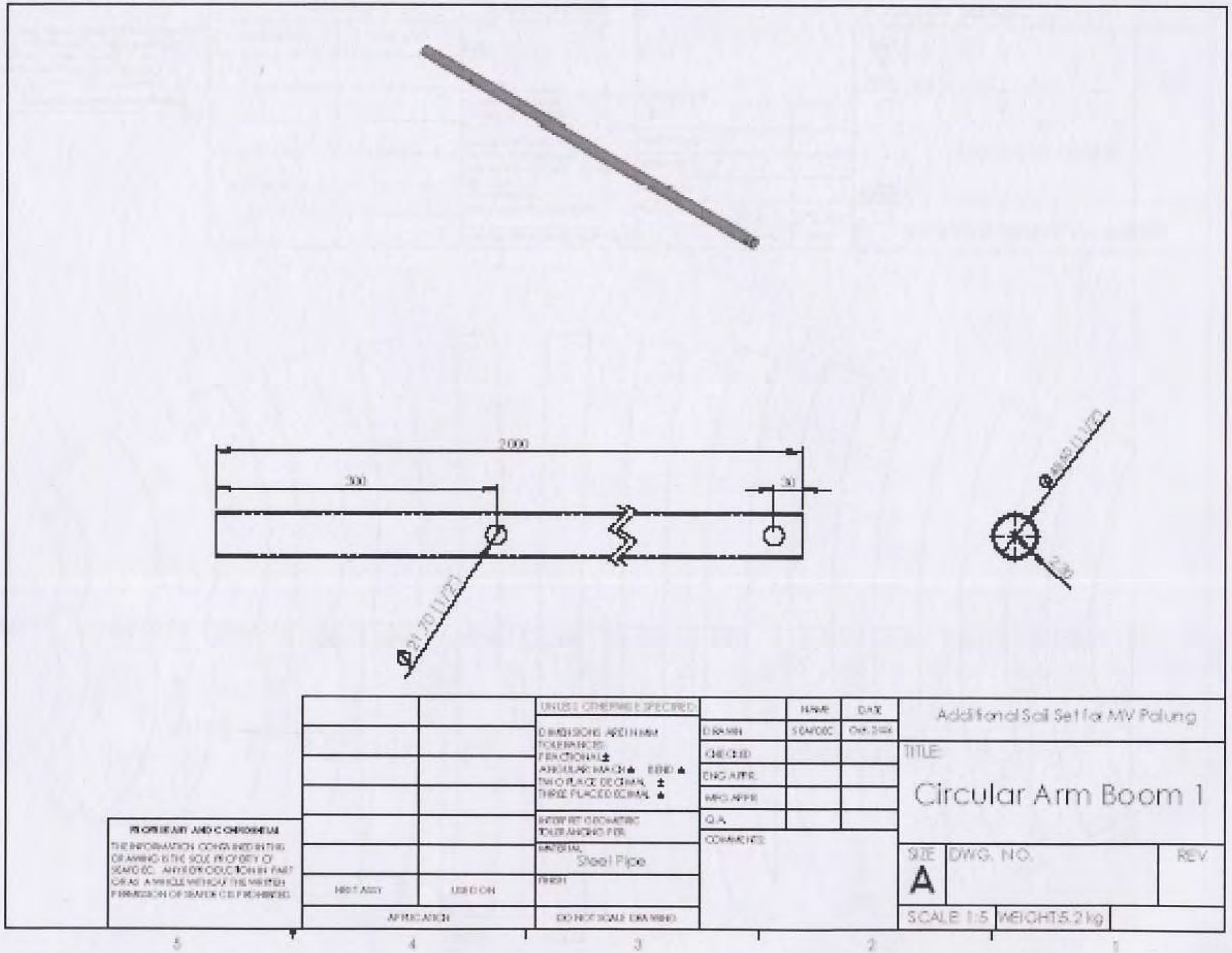
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Additional Sail Set for MV Palung
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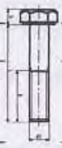
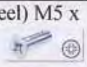
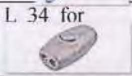
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
Steel Pipe
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
SIZE
A
DWG. NO.
REV
SCALE 1:5
WEIGHT:5.2 kg
5
4
3
2
1

Appendix II. Materials of Sail Structure and Estimated Cost

No.	Item	Quantity	Unit	Price/unit (Baht)	Total (Baht)
1.	square tube 90x90x3.2 □	1	Pcs.	1500	1500
2.	square tube 4"x4"x3.2 □	2	Pcs.	1375	2750
3.	square tube 5"x5"x3.2 □	1	Pcs.	1900	1900
4.	pipe □ 42.7 (1 ¼") thickness 2.3 mm	3	Pcs.	558	1674
5.	pipe □ 48.6 (1 ½") thickness 2.3 mm	1	Pcs.	670	670
6.	Steel rod□ 20 mm	1	Pcs.	200	200
7.	Steel rod□ 10 mm	1	Pcs.	110	110
8.	Steel sheet thickness 6 mm. (4'x8')	1	set	3920	1960
9.	Steel Sheet thickness 10 mm. (4'x8')	1	set	4500	4500
10.	Steel Sheet □ 80 mm. thickness 10 มม.	6	sheet	200	1200
11.	Steel sheet thickness 6 mm. width 50 mm. length 6 m.	1	sheet	305	305
12.	Channel steel 150 x 75 x 75 mm	2	Pcs.	2700	5400
13.	Nut □ 20 mm. Length 200 mm. + spring washer+ washer + Stainless screw 	25	set	22	550
14.	Nut □ 20 mm. Length 100 mm. + spring washer + washer+ Stainless screw 	10	set	22	220
15.	Nut □ 10 x 100 mm. Stainless steel	20	Pcs.	20	400
16.	stainless steel pin 3 mm.	100	Pcs.	1	100
17.	Philips cross recessed flat head machine screws (Stainless Steel) M5 x 8 mm 	50	set		100
18.	Forged straining screws 6 mm. 	20	Pcs.	20	400
19.	Wire rope shackles Size 4 for wire dia. 4-4,5 b2~ 14 L 34 for screws-ø M6 mm 	30	Pcs.	20	600
20.	sling □ 4 mm.	60	M	9	540
21.	Sling ring	100	Pcs.	5	500
22.	Aluminum Sheave 	2	Pcs.	300	600
23.	Polyethylene cloth width 2 m. Length 160 yr.	1.33	row	50 (160 yd)	8000
24.	Eye ring □ 30 มม. With eye ring puncher				300
25.	yarn length 400 m.				500
26.	Polyethylene rope □ 10 mm. length 100 m.	1	row	924	924
27.	Coating color (TOA)	2	Box	270	540
28.	Plastic color (white)	1	Box	500	500
29.	Thinner AAA	1	gallon	480	480
30.	Color brush	2	Pcs.	20	40
31.	ใบเลื่อย ecrip เบอร์ 2	3	Pcs.	150	450
32.	ใบเลื่อย ecrip เบอร์ 2 (เล็ก)	3	Pcs.	30	90
33.	bearing 40 x 80 x 23 	4	Pcs.	200	800
34.	Tap M5	1	set	200	200

39,003

Appendix III. Fuel cost estimation of small scale fishing boat in Thailand

Thai small-scale fishing boats, i.e. long tail boats use engine directly as propulsion primover through a propeller. Calculation of fuel consumption rate of this type of boats was made using the formula:

$$F = \frac{f(g/Ps-hr)\times Ps}{SpedificGravity(g/l)\times 1000}(l/hr)$$

Where **F**: Fuel consumption rate (l/hr)
f: Specific fuel consumption (g/Ps-hr)

Typically, a diesel engine installed on small local fishing boat is a YANMAR agricultural diesel engine. The engine TF 105-L(H) has 10.5 Ps at 180 g/Ps-Hr specific fuel consumption. Thus, the fuel consumption rate of a small fishing boat per operational day is:

$$\begin{aligned} F &= \frac{180(g/Ps-hr)\times 10.5}{0.83(g/l)\times 1000}(l/hr) \\ &= 2.277 \quad l/hr-boat \end{aligned}$$

Assuming that the sailing period of a fishing boat is approximately two hours a day. The fuel consumption of diesel engine on the small-scale fishing boat gives

$$\begin{aligned} F &= 2.277\times 2(hr/day) \quad l/hr-boat \\ &= 4.557 \quad l/day-boat \\ &= 136.62 \quad l/month-boat \\ &= 1639.44 \quad l/year-boat \end{aligned}$$

Statistics show that the number of Thai long-tail boats used in fisheries until the year 2000 (Fisheries Department and National Statistical Office of Thailand) was 43,240 boats or 74.5% of the total of small fishing boats. Using the formula below, the overall fuel saved is:

$$\begin{aligned} F &= 1639.44\times 43{,}240(boat) \quad l/year-boat \\ &= 70{,}889{,}385.6 \quad l/year \end{aligned}$$

Recently, the price of diesel fuel is about 23.29 Baht/liter (as of 10 September 2005). From the computations, the fisheries sector could attain savings on fuel cost as follows:

$$\begin{aligned} F &= 70{,}889{,}385.6\times 23.29(Baht/l) \quad l/year \\ &= 1{,}651{,}013{,}790.62 \quad Baht/year \end{aligned}$$

The amount saved (1,651,013,790.62 Baht/year) is quite a large amount for the fishery economic sector that has been dependent on fuel. Considering that the use of sailboat is an old knowledge and technology, the savings on operational costs is very attractive. Although the computations were made using Thailand's fishery sector as model, the other countries in the region could start considering again the use of auxiliary sails in their fishing boats.

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