Unit 1 Cooling Tower Fan Stack Replacement to Increase Cooling Tower Performance

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ABSTRACT

Unit 1 Cooling Tower (CT) fan stack was designed with height of 6 feet and had relatively straight vertical panels which didn't produce significant velocity recovery. In other hand, due to Wayang Windu Geothermal Plant is located in the mountain; the CT is exposed to swirling and shifting winds. These types of winds can force down the exiting plume (hot air) from the CT and drawn back into the CT which increases the entering wet bulb temperature. This phenomenon is called recirculation. The increasing of wet bulb temperature will impact to decreasing of CT performance.

Star Energy Geothermal Wayang Windu Ltd. conducted an engineering study and recommended that CT performance can be improved by replacing the existing fan stack with higher fan stack (10 feet tall) which has a flared velocity recovery design. This new design fan stack will convert some of the wasted velocity pressure energy at the top of fan stack into useful work at the plane of the fan; therefore fan efficiency will be increased. By improving fan efficiency, additional motor power can be made available to further increase the air drawn through CT; thus, overall CT performance can be improved. In addition, this new design also reduces the effect of recirculation.

The fan stack replacement work was completed in Dec 2011. CT performance test reveals data of decreasing of approach temperature as much as 1.44^{o}C, an increasing of range temperature as much as 1.92^{o}C, and increasing of CT effectiveness as much as 71.43% (from 66.26%). The impact is equivalent with generation improvement of 1.44 MW.

1. INTRODUCTION

Wayang Windu Geothermal Power Plant Unit 1, which has a capacity of 110 MWe, was the largest single cylinder turbine in the world when it was commissioned in May 2000. Electricity from the Power Plant is supplied to PLN (Indonesia's state electricity company).

1.1 Process Overview

The separated main steam containing some non-condensable gases is supplied from two 36" steam lines to a 48" header after any liquid droplets are removed from the steam through the steam scrubbers. The design steam supply conditions are 10.6 bars absolute at 182°C and flow of 211 kg/second.

The turbo generator is supplied from the steam header via a 44 inch line through steam strainers, steam turbine main stop valves and steam flow control valves. To control the output of the turbo generator, the turbine governor operates the steam flow control valves.

The FUJI 110 MW steam turbine is directly coupled to the FUJI two-pole 137.5 MVA 13.8 kV generator. The steam turbine is a single casing, double-flow, reaction type with eight stages in each flow. The generator is three phase 50Hz air cooled with forced air cooling using water.

The generator electrical output is supplied to the PLN grid via a generator transformer that increases the voltage to 150kV. An additional connection to the generator output is used to supply the power station electrical plant through a 13.8 kV to 6.3 kV unit transformer. A circuit breaker and an earthing switch is installed between the generator and transformer. The generator can be synchronized to the PLN grid using low voltage or the high voltage circuit breakers.

After doing the work in the turbine, the steam is exhausted to a direct contact spray type condenser mounted beneath the turbine. Cooling water delivered from the cooling tower through the condenser spray nozzles is used to condense the steam through direct contact. The condenser cooling water and condensed turbine exhaust steam collects in the condenser hotwell as condensate. Two 50% duty hotwell pumps remove condensate from the hotwell and deliver it to the cooling tower.

In the cooling tower, heat is removed from the condensate by the air flowing through the tower. The cooling tower is a counter flow type forced draught type with motor driven fans to provide the forced draught.

The loss of cooling water that is carried away in the water vapor plume of the cooling tower is not enough to counter the additional condensed steam. A cooling tower level control system is used to remove excess condensate to the Steam Above Ground System (SAGS) condensate re-injection system.

Non condensable gases are collected and removed from the condenser by the gas removal system. The gas removal system is a hybrid system using steam ejectors and liquid ring vacuum pumps to remove non-condensable gases and deliver them to the cooling tower. The steam supply to gas removal system is from the main steam header by a 10" supply line separate to the turbo generator supply. The non-condensable gases are discharged to the cooling tower beneath the fans and are carried away in the thermal plume of the cooling tower.

An auxiliary cooling water system supplied from the cooling tower basin outlet pipe is used for cooling turbine lube oil, generator air coolers and the gas removal system inter and after condensers. Two 100% duty auxiliary cooling water pumps are installed for circulation of the auxiliary cooling water.

The plant compressed air systems use three rotary screw compressors to supply two general air receivers that supply the instrument air and utility air supplies. Instrument air is supplied via heat less air dryers and filters to control valves and other instruments that require clean dry air. Utility air is supplied via an auto shut off valve that will close if instrument air pressure falls.

Plant fire protections systems include automatic and manual sprinklers, fire hydrants and portable fire extinguishers. Fire detection is by heat sensors and smoke sensors. A diesel and electric fire are installed to supply sprinkle and hydrant systems.

Plant electrical systems use 6.3 kV supplies for major auxiliary plant supplies and 6.3kV/380 V transformers to supply general auxiliary equipment. An 1100 kW emergency generator supplies the 380 V systems. DC systems of 125V and 230V use batteries and battery chargers for essential supplies. Essential no-break AC equipment such as the DCS plant control systems are supplied by a UPS that uses rectifiers, batteries and inverters.

The plant is controlled from a central control room adjacent to the turbine hall. A distributed control system is used for all start, stop, and on line operations and monitoring. Automatic turbine start, synchronizing, loading, shut down are achieved by use of the plant control systems. Automatic control of critical and important process conditions such as the SAGS power station interface steam pressure is included in the distributed control system functions. Remote switching of electrical equipment and automated sequential starting and stopping of major auxiliaries is another feature available to the operators in the control room.

1.2 Unit 1 Cooling Tower Fan Stack Issue

Unit 1 CT fan stack was designed with height of 6 feet only and had relatively straight vertical panels which didn't produce significant velocity recovery. In other hand, due to Wayang Windu Geothermal Plant is located in the mountain; the CT is exposed to swirling and shifting winds. These types of winds can force down the exiting plume (hot air) from the CT and drawn back into the CT which increases the entering wet bulb temperature. This phenomenon is called recirculation. The increasing of wet bulb temperature will impact to decreasing of CT performance. Figure 1 shows recirculation effect in Unit 1 CT.

	
Minor Plume Recirculation	**Major Plume Recirculation**

Figure 1: Recirculation Effect in Unit 1 Cooling Tower

2. ENGINERING STUDY

Design of a cooling tower requires a unity of many engineering disciplines. Mechanical engineering, chemical engineering, and civil engineering disciplines contribute a big portion in CT design. In this project, SEGWWL engineers conducted engineering study based on available design data, simulation and experimental method. The aim is the new design fan stack will produce significant velocity recovery to convert some of the wasted velocity pressure energy at the top of fan stack into useful work at the plane of the fan; therefore fan efficiency will be increased. By improving fan efficiency, additional motor power can be made available to further increase the air drawn through CT; thus, overall CT performance can be improved. In addition, this new design also reduces the effect of recirculation with its higher fan stack design.

Engineering study scopes were as follow:

- Study of Unit 1 CT design
- Fan blade performance simulation

- CT structure strength analysis
- Air flow measurement before and after fan stack replacement
- Thermal imaging monitoring

2.1 Study of Unit 1 CT Design

Study of CT design is to know cooling system design parameter and data which were used in the design. It will also help the designer to do some simulations if some parameters are changed or added to system. Therefore, it gives advantages for flow simulation subject.

For this project, SEGWWL engineers focused study on calculation and simulation of CT fan and structure design because the design and load of the new fan stack shall affect the air flow performance and allowable design load of CT structure.

2.2 Fan Blade performance simulation

There are many data can be obtained from fan blade performance simulation as follow:

- Air flow
- Thrust load
- Motor capacity required
- Fan blade load
- Blade noise level, etc .

Thrust load data is a main input data required for CT structure strength analysis along with weight of new fan stack. The sample of fan blade performance simulation was shown in Attachment – 1.

2.3 CT structure strength analysis

CT structure strength analysis was conducted to assure CT structure is strong enough to withstand load produced while CT in operation. The flow chart to conduct CT structure strength analysis is shown in Attachment - 2.

2.4 Air flow measurement before and after fan stack replacement

Air flow measurement before and after fan stack replacement was conducted to know the improvement of CT performance. The result data was also compared to simulation data for further study.

2.5 Thermal Imaging Monitoring

Monitoring by using thermal imaging was conducted to know the change of water outlet temperature after new fan stack installed. The monitoring data is used to confirm the improvement of CT performance.

3. RESULT AND DISCUSSION

Modeling and simulation of existing CT design provided a technical explanation about the weakness of existing design and recommendation how to increase the CT air flow to improve CT performance. Therefore, SEGWWL engineers have good guidance to study design of a new fan stack. The modeling of existing CT fan stack and blades is shown in Figure 2.

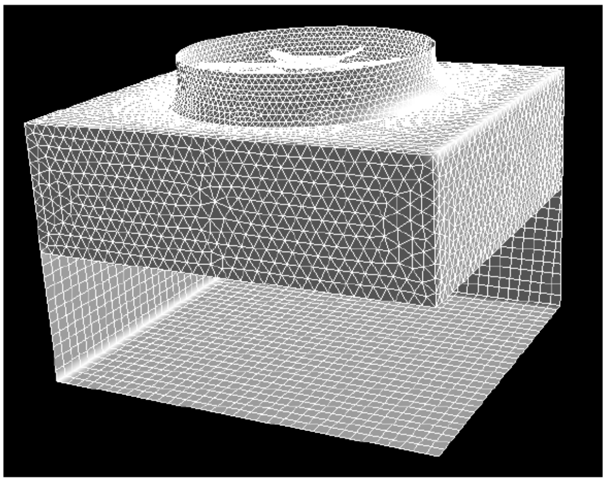


Figure 2: Numerical Modeling of Unit 1 Cooling Tower

As stated earlier, the conceptual design required for a new fan stack is:

- Fan efficiency will be improved by converting some of the velocity pressure at the fan to static pressure to increase air flow.
- By improving the fan efficiency, additional motor power can be made available to further increase the air draft through the cooling tower, thus, overall cooling tower performance will be improved

Based on these criteria, SEGWWL's CT consultant proposed a new design of fan stack and provided simulation to calculate how much improvement of air flow can be obtained. As shown in Attachment -1, fan blade simulation was conducted to see the improvement of air flow by changing the fan blade pitch angle while considering the existing motor power.

The proposed design of new fan stack is 10 feet height with inclined vertical panel design. This design will provide velocity recovery to improve CT air flow. The new fan stack design is shown in Attachment - 3.

Economical analysis review was conducted prior to moving to next process to know how much benefit can be obtained from this project. Table 1 shows economical analysis of fan stack replacement project.

Table 1: Economical Analysis of Unit 1 Fan Stack Replacement Project

No	Description	Qty	Unit	Unit rate (USD)	Total (USD)
Project Work Cost					
1	Fan Stack Replacement	1	lot	132,000.00	132,000.00
Total					**132,000.00**
Planned Generation Reduction cost					
2	Fan Stack Replacement work	60	days	1,980.00	118,800.00
Total					**118,800.00**
Total Cost					**250,800.00**

No	Description	Qty	Unit	Unit rate (USD)	Total (USD)
Profit from generation improvement (assume ~ 1.5 MWe obtained)					
1	Production Revenue	1.5	MWe	1,320.00	1,980.00
Total Profit/ day					**1,980.00**
Total days required for break even (days)					**126.67**
Total days required for break even (months)					**4.22**

To assure the new fan stack can be supported safely by existing CT wooden structure, CT structure strength analysis was conducted by using SAP program. As shown in Attachment – 2, there are several steps required to conduct structure analysis using SAP program. The modeling of CT structure is shown in Figure 3.

After modeling of CT structure, loading simulation was conducted. In this case, there are several loading simulation conducted as follow:

1. D
2. D + L
3. D + (W or 0.7E)
4. D + 0.75(W or 0.7E) + 0.75L
5. 0.6 D + W
6. 0.6 D + 0.7 E

Whereas: D = dead load, L = live load, W = wind load, and E = earthquake load

From this simulation, there are some reinforcement works for CT structure required in order to provide safe operation of CT. Attachment - 4 shows a drawing sample of reinforcement wood position that should be conducted.

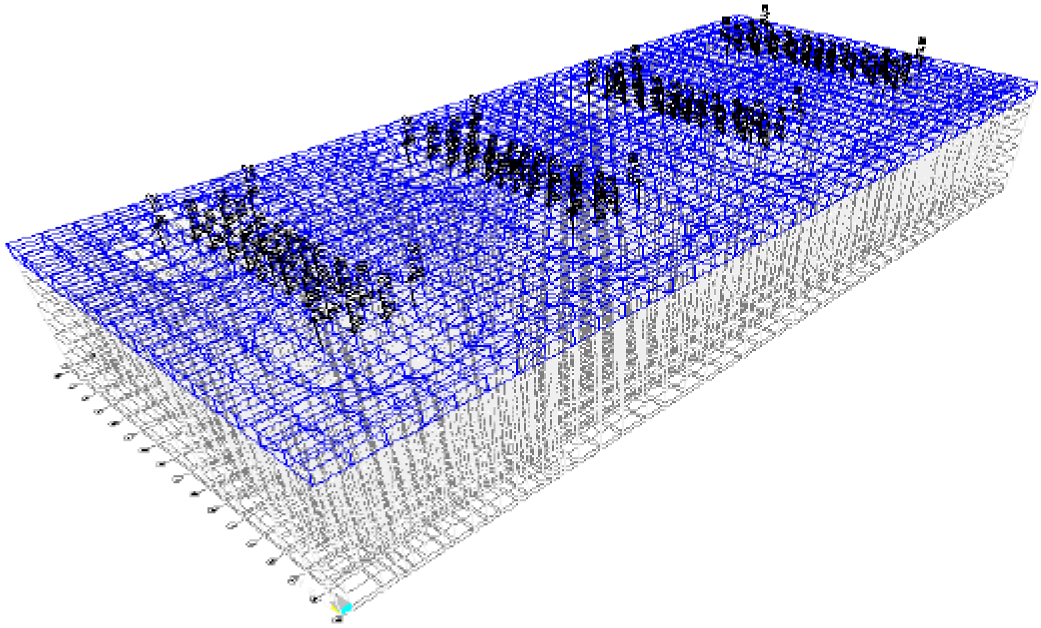
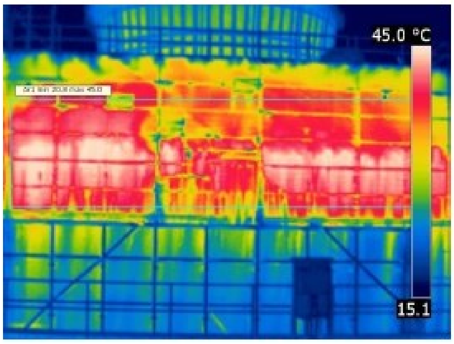


Figure 3: Modeling of Unit 1 CT Structure

After the new fan stacks were installed, instead of air flow measurement, thermal imaging monitoring was also conducted. As shown in Figure 4, significant improve of heat recovery from new fan stack was revealed in comparison of condition before and after fan stack replacement. This data confirms the improvement of CT performance.

Thermal Imaging Monitoring



Unit 1 Cooling Tower	Before Modification (average temp. °C)		After Modification (average temp. °C)	
	Fan stack	CT Side (water falls)	Fan stack	CT Side (water falls)
Cell-A	25.5	28.9	29.8	24.2
Cell-B	25.4	27.9	29.0	27.3
Cell-C	24.4	29.0	28.9	27.0
Cell-D	N/A	N/A	30.8	23.5
Cell-E	25.1	29.8	28.1	22.3
Cell-F	27.1	29.1	29.1	25.7
Cell-G	25.1	29.2	28.2	27.0
Cell-H	N/A	N/A	31.1	25.2

Figure 4: Thermal Imaging Monitoring of Unit 1 CT Fan Stack

The fan stack replacement work was completed in Dec 2011. Figure 5 shows pictures of fan stack replacement project. CT performance test reveals data of decreasing of approach temperature as much as 1.44^{o}C, an increasing of range temperature as much as 1.92°C, and increasing of CT effectiveness as much as 71.43% (from 66.26%). The impact is equivalent with generation improvement of 1.44 MW.

Figure 5: Pictures of Fan Stack Replacement Project

3. ACKNOWLEDGEMENT

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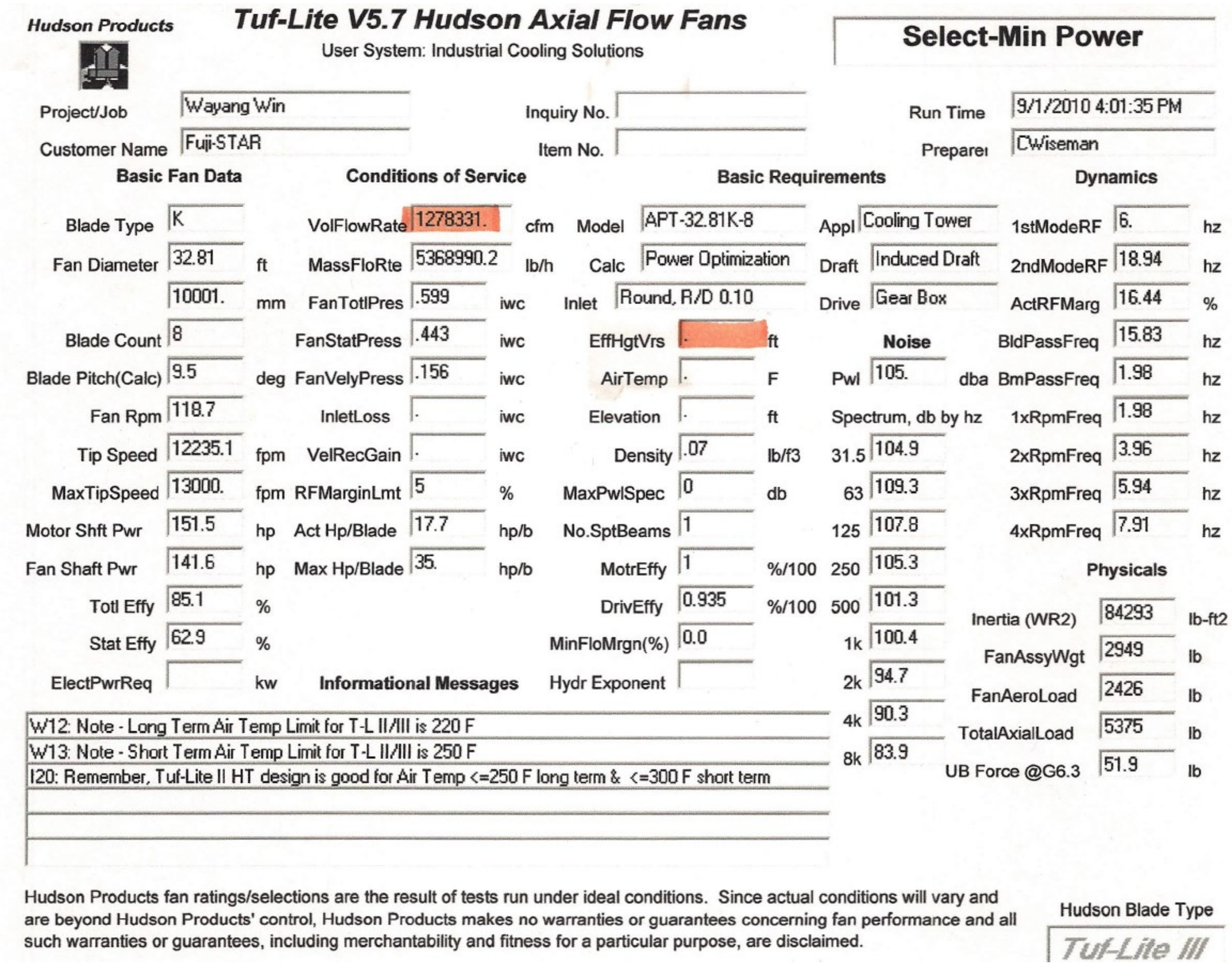
Amarillo Gearbox Model 1712 Specification

CTI Standard ATC-105 Acceptance Test Code for Water Cooling Tower

Attachment 1: Fan Blade Simulation by using Tuf-Lite V5.7 Software



Hudson Products — **Tuf-Lite V5.7 Hudson Axial Flow Fans**

User System: Industrial Cooling Solutions

Select-Min Power

Project/Job	Wayang Win	Inquiry No.		Run Time	9/1/2010 4:01:35 PM
Customer Name	Fuji-STAR	Item No.		Preparer	CWiseman

Basic Fan Data

Blade Type	K	
Fan Diameter	32.81	ft
	10001.	mm
Blade Count	8	
Blade Pitch(Calc)	9.5	deg
Fan Rpm	118.7	
Tip Speed	12235.1	fpm
MaxTipSpeed	13000.	fpm
Motor Shft Pwr	151.5	hp
Fan Shaft Pwr	141.6	hp
Totl Effy	85.1	%
Stat Effy	62.9	%
ElectPwrReq		kw

Conditions of Service

VolFlowRate	1278331.	cfm
MassFloRte	5368990.2	lb/h
FanTotlPres	.599	iwc
FanStatPress	.443	iwc
FanVelyPress	.156	iwc
InletLoss	.	iwc
VelRecGain	.	iwc
RFMarginLmt	5	%
Act Hp/Blade	17.7	hp/b
Max Hp/Blade	35.	hp/b

Basic Requirements

Model	APT-32.81K-8	
Calc	Power Optimization	
Inlet	Round, R/D 0.10	
EffHgtVrs	.	ft
AirTemp	.	F
Elevation	.	ft
Density	.07	lb/f3
MaxPwlSpec	0	db
No.SptBeams	1	
MotrEffy	1	%/100
DrivEffy	0.935	%/100
MinFloMrgn(%)	0.0	
Hydr Exponent		

Appl	Cooling Tower
Draft	Induced Draft
Drive	Gear Box

Noise

Pwl	105.	dba

Spectrum, db by hz

31.5	104.9
63	109.3
125	107.8
250	105.3
500	101.3
1k	100.4
2k	94.7
4k	90.3
8k	83.9

Dynamics

1stModeRF	6.	hz
2ndModeRF	18.94	hz
ActRFMarg	16.44	%
BldPassFreq	15.83	hz
BmPassFreq	1.98	hz
1xRpmFreq	1.98	hz
2xRpmFreq	3.96	hz
3xRpmFreq	5.94	hz
4xRpmFreq	7.91	hz

Physicals

Inertia (WR2)	84293	lb-ft2
FanAssyWgt	2949	lb
FanAeroLoad	2426	lb
TotalAxialLoad	5375	lb
UB Force @G6.3	51.9	lb

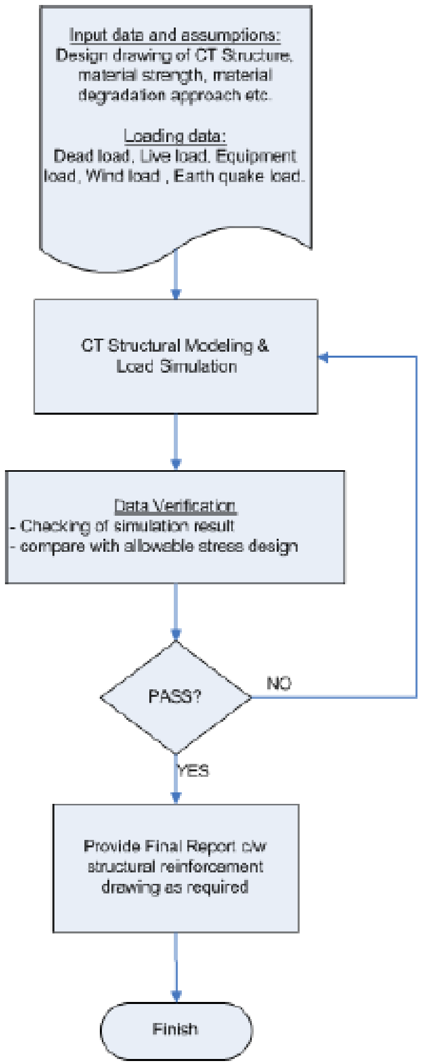
Informational Messages

W12: Note - Long Term Air Temp Limit for T-L II/III is 220 F
W13: Note - Short Term Air Temp Limit for T-L II/III is 250 F
I20: Remember, Tuf-Lite II HT design is good for Air Temp <=250 F long term & <=300 F short term

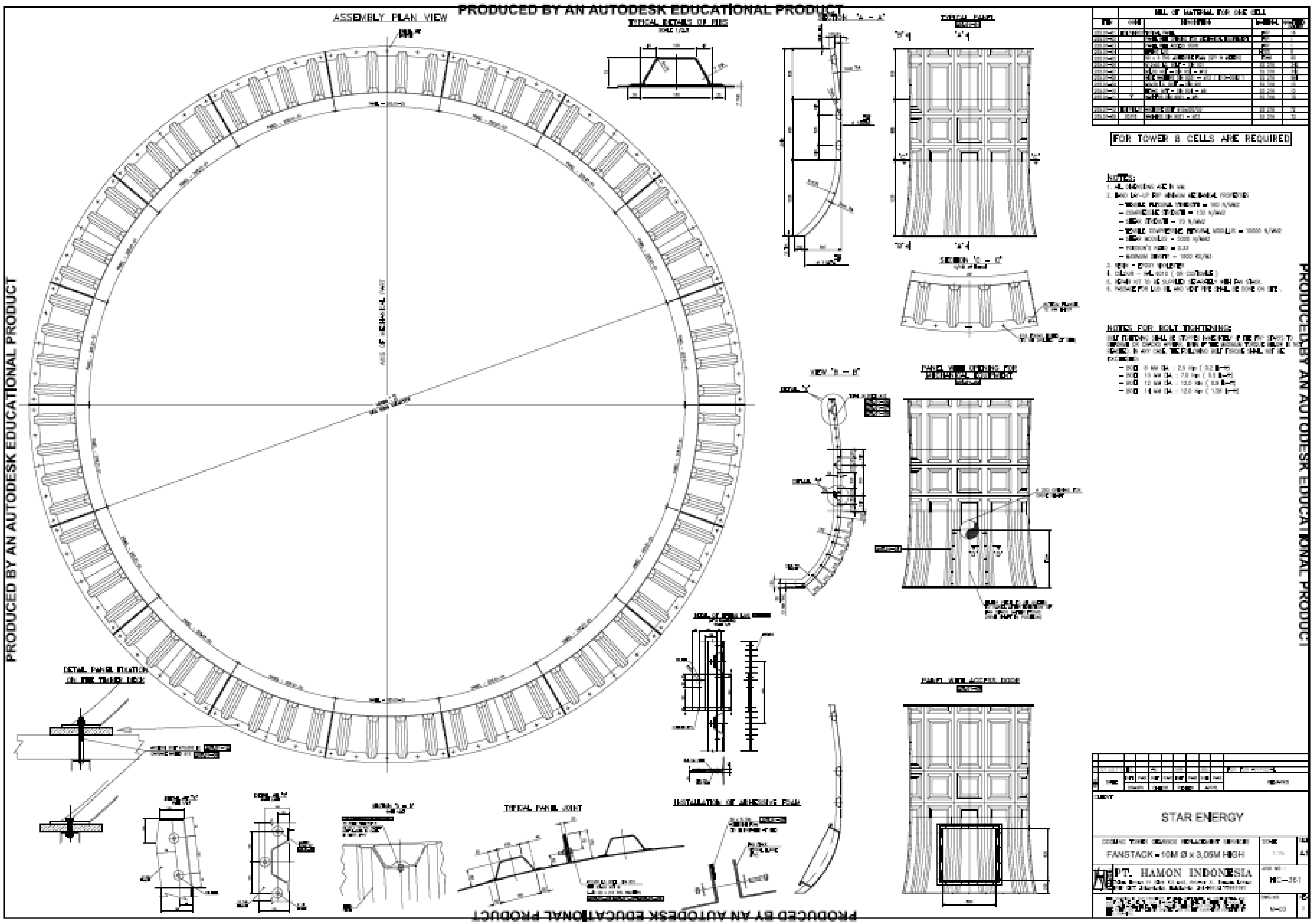
Hudson Products fan ratings/selections are the result of tests run under ideal conditions. Since actual conditions will vary and are beyond Hudson Products' control, Hudson Products makes no warranties or guarantees concerning fan performance and all such warranties or guarantees, including merchantability and fitness for a particular purpose, are disclaimed.

Hudson Blade Type: Tuf-Lite III

Attachment 2: Flow Chart of Unit 1 CT Structure Strength Analysis Verification



Attachment 3: Sectional Drawing of Unit 1 CT Fan Stack



Attachment 4: Wood Reinforcement Point of Unit 1 CT Structure