The Design and Recreation of a 17th Century Taiwanese Junk: A Preliminary Report

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Abstract
A 17th century trading junk sailing from Taiwan to Nagasaki, Japan was recorded with other junks and Dutch ships by Japanese painters. The City Government of Tainan, the ancient capital of Taiwan before late 19th century, decided to make a replica of this 30m long ship, named Taiwanese Junk, to promote the spirits of sailing and historical tourism. The design and recreation of this ship has been undergoing for several years based on the Japanese painting as well as knowledge of typical sea-going Chinese junks from several previous studies and model making. Modern naval architecture design and computational tools and ship model tests were also used for performance prediction in the design and construction process. To follow present regulation of ships, the design and equipments of Taiwanese Junk has to be modified slightly and thus brought a long and fierce debate between historians and naval architects involved. She is now under construction in Tainan and scheduled to be launched near the end of 2009. This article discusses the methods, debates, design, and problems encountered during the processes of planning, design, experiments, construction and demonstration-in-work.

Keywords: junk, recreation, Taiwan, replica

1 Introduction
1.1 Background, review and motivation
There are several typical types of traditional Chinese junks. According to the shape of middle section, they can be divided in to two major categories: Fu (Fu-Jian) style and Sha (sand) style. Worcester (1971) recorded many types of junks and sampans in early 20th century China and their equipments and tools, as well as their construction process. However, there was quite limited scientific understanding of the performance of junks, such that deeper and broader discussion on the voyages and trade in the past using ships’ performance couldn’t be possible.

Few Chinese engineering scholars conducted studies on Chinese junks using modern naval architecture knowledge recently. My colleagues and I also use computational tools to investigate and compare hydrostatic and hydrodynamic performance of various types of junks (Chen & Hsu, 2002; Hsu & Chen, 2002; Chen, 2003; Tseng & Chen, 2006). Our important findings include that (1) some empirical formulas developed from Western ships is invalid for junks; (2) the comparisons validate the qualitative descriptions in ancient Chinese warfare books; (3) ancient Chinese books’ record contained some mistakes of numbers and words and they can be found and easily corrected by 3D model making or computer model simulation; and (4) this computational (and simulation) approach is a simple, quick, and effective method to preliminarily evaluate the performance of junks. But our studies lacks of verification from experiments so far.

Japanese scholars in naval architecture also started to study junk-like Ryukuan Tribute Ship (Yagi et al., 2008) after many studies of traditional Japanese ships. Similarly, Korean engineering scholars also studied a couple of junks sunk in Korean water (Choi & Yuck, 2005; Choi, 2006). We hope that researches using this approach will lead to a more
complete understanding of performance of junks in the near future after accumulating many case studies, no matter by which countries.

There exist some replicas of Chinese junks: *Lu Mei Mao* in Zhejiang, China, several years ago; *Princess Taiping* sailed to San Francisco from Taiwan in 2008, but was hit by a large container ship and sunk in the return trip just offshore of Taiwan earlier in this (2009) year. But we found it is still necessary and worthy to make another replica. The reason is that there was no scientific design and records of traditional shipbuilding methodologies of junks in these past cases. In addition to detail records of voyages, we have no other evidence. Meanwhile, the voyage logs and other records of *Princess Taiping* were also lost at sea during the accident. Considering the benefits from tourists, Tainan City Government decided to make a replica of Taiwanese junk to make its maritime historical park more completed.

### 1.2 Historical background

In the late Ming dynasty, Cheng Chi-Lung established his maritime trade empire in East Asia in about 1628 till 1646 when he surrendered to the emperor of Ching dynasty. He was the king of the sea before he surrendered. This maritime trade empire was successfully succeeded by his son Cheng, Cheng-Kung, also known as *Koxinga*, after 1661 when *Koxinga* expelled Dutch from Tainan and made Tainan as his base. Their trade routes was extended to Japan (Nagasaki), China, and Southeastern Asia. Note that Koxinga’s mother was Japanese and he was born near Nagasaki.

Japan only traded with Chinese and Dutch at Nagasaki then. It is fortunate that Japanese draw foreign merchant ships arriving at Nagasaki. A complete copy, *Paintings of Chinese Junks*, was collected in Matsura Historical Museum at Hirado City near Nagasaki. Another possible copy was collected by National Gallery of Victoria at Melbourne, Australia. According to Japanese scholars’ study (Yamagata, 2005), *Paintings of Chinese Junks* was edited in 1715 when Japanese Government started to limit the export of copper to China. The purpose of making copies of the painting of Chinese junks was to make officials easier to check where the ships were from. Therefore these paintings have detail description of sizes of each parts and flags. The shapes of ships look near a “normal look” by naked eyes, unlike those pictures in ancient Chinese warfare books. Hence, this *Paintings of Chinese Junks* provided a very valuable source of the present study. Taiwanese Junk (Fig.1-1) was one of 11 junks painted. This Taiwanese Junk had elegant curve of hull and a simple bamboo cover near the stern. Others include junks from Nanjing, Ningpo, Amoy, Canton, Siam, and other places. These numerous places show that trade was quite international.

One may question the date of painting of these junks. According to the flags shown in these picture, a clear Chinese character *Ye* (mandarin), *ia* (Fujian dialet), or *ga* (as in Koxinga), meaning a noble male, was on the flag (Fig.1-2). Because nobody else dared to claim himself another Ye at that time, the ships must be under Koxinga’s control, either his own ships or had his permission to trade. Thus, it is also the evidence that the paintings were accomplished before 1683 when Ching dynasty defeated Koxinga’s grandson and obtained Tainan. The related locations of these places are shown in Fig. 1-3.
Fig. 1-1 Taiwanese Junk in *Paintings of Chinese Junks*

Fig. 1-2 The flags show the mark of Koxinga

Fig. 1-3 The locations of Taiwan and Nagasaki.
2 Preparation Research

2.1 Background

In the past, only Tseng (2003) and Yamagata (2005) studied Taiwanese Junk. Their lines are similar except near the bow. Tseng also made a 1/10 model for National Taiwan History Museum. All the following works in Taiwan based on Tseng’s version (Fig.2-1). Tainan City Government started the project even before the fund for construction was obtained. First, they initiated a preliminary study on the project. This preliminary study was conducted by a team of scholars at National Cheng Kung University during years of 2006 and 2007. The team members include scholars in history, naval architecture, public policy, and management. The feasibility in engineering, tourism benefits, detail historical background, and political benefits were all studied. My research in this period consists of preliminary performance evaluation and simple equipment arrangement design for their engineering contract purpose. The following summarizes some important results of this research.

Fig. 2-1 Tseng’s design of Taiwanese Junks (2003)
2.2 Methodologies

The methods and tools used for performance evaluation are typical ones in modern naval architecture practice, including (1) computer-aided design software, Tribon®, (2) flow simulation software, Shipflow®, and (3) a home-made FORTRAN code for nonlinear stability simulation. The performance analyzed includes hydrostatic performance, static stability, resistance estimation, nonlinear dynamic stability, and pressure on the hull. Some results were also compared with other typical types of junks. The detail is as follows.

The hull shape was reconstructed using computer-aided design software Tribon® to make the hull form smooth and ready for further computation. This hull form was then used to compute hydrostatic performance by Tribon® and to establish grids for flow simulation as shown in Fig. 2-2. This grid will be used by Shipflow® to simulate the flow field around the ship at various speeds in order to obtain the resistance-speed relation and pressure distribution on hull. Shipflow® uses potential flow-viscous flow coupled simulation method to increase the speed of simulation. Table 2-1 shows main specification and parameters of Taiwanese Junk and typical Fu Chuan, Sha Chuan, Zhanzuo Chuan (Battle Flag Ship) compared. Table 2-2 shows the estimation of weight and centers of gravity. It is accomplished according to the general arrangement.

Table 2-1 Main Specification and Parameters of Typical Fu Chuan, Sha Chuan, Zhanzuo Chuan and Taiwanese Junk compared

<table>
<thead>
<tr>
<th>Items</th>
<th>Fu Chuan (Fu ship)</th>
<th>Sha Chuan (sand ship)</th>
<th>Zhanzuo Chuan (Battle Flag Ship)</th>
<th>Taiwanese Junk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length overall, L (m)</td>
<td>30.120</td>
<td>30.120</td>
<td>30.120</td>
<td>30.00</td>
</tr>
<tr>
<td>Waterline length, Lw (m)</td>
<td>24.867</td>
<td>22</td>
<td>26.926</td>
<td>22.70</td>
</tr>
<tr>
<td>Beam, B (m)</td>
<td>7.414</td>
<td>6.620</td>
<td>7.790</td>
<td>6.70</td>
</tr>
<tr>
<td>Draught, T (m)</td>
<td>2.802</td>
<td>1.600</td>
<td>1.558</td>
<td>2.00</td>
</tr>
<tr>
<td>Moulded Depth, D (m)</td>
<td>3.502</td>
<td>2.500</td>
<td>2.856</td>
<td>2.20</td>
</tr>
<tr>
<td>Freeboard (m)</td>
<td>0.70</td>
<td>0.90</td>
<td>1.30</td>
<td>0.25</td>
</tr>
<tr>
<td>Lw/B</td>
<td>3.354</td>
<td>3.323</td>
<td>3.456</td>
<td>3.38</td>
</tr>
<tr>
<td>B/T</td>
<td>2.646</td>
<td>4.137</td>
<td>5.000</td>
<td>3.35</td>
</tr>
<tr>
<td>LW/T</td>
<td>8.875</td>
<td>13.750</td>
<td>17.282</td>
<td>11.35</td>
</tr>
<tr>
<td>Block Coefficient, C_B</td>
<td>0.341</td>
<td>0.549</td>
<td>0.501</td>
<td>0.417</td>
</tr>
<tr>
<td>Water plane Coeff., C_WP</td>
<td>0.658</td>
<td>0.694</td>
<td>0.714</td>
<td>0.697</td>
</tr>
<tr>
<td>Midsection Coeff., C_M</td>
<td>0.653</td>
<td>0.756</td>
<td>0.756</td>
<td>0.63</td>
</tr>
<tr>
<td>Prismatic Coefficient, C_p</td>
<td>0.523</td>
<td>0.727</td>
<td>0.663</td>
<td>0.661</td>
</tr>
<tr>
<td>Wetted Surface Area, S (m²)</td>
<td>188</td>
<td>144</td>
<td>181</td>
<td>161.89</td>
</tr>
<tr>
<td>Displacement (ton)</td>
<td>180.62</td>
<td>131.21</td>
<td>166.96</td>
<td>147.39</td>
</tr>
<tr>
<td>Rolling Period, Tn (sec)</td>
<td>2.84</td>
<td>2.85</td>
<td>2.67</td>
<td>4.08</td>
</tr>
<tr>
<td>GM0 (m)</td>
<td>1.968</td>
<td>0.746</td>
<td>2.427</td>
<td>2.088</td>
</tr>
</tbody>
</table>
On the evaluation of nonlinear dynamic stability, we use a FORTRAN code to simulate a ship’s rolling motions under wave and wind impacts. It is a good indicator to relative safety and seaworthness. The method is the same as we used for previous studied on junks, using a fourth order Runge-Kutta algorithm to solve a nonlinear rolling motion equation which considers a 16 continuous sine waves and constant side wind. (Soliman & Thompson, 1991):

\[ \ddot{\theta} + b \dot{\theta} + c_1 \theta + c_2 \theta \dot{\theta} + c_3 \dot{\theta}^3 + c_4 \dot{\theta}^5 + c_5 \theta^5 = \frac{F_4}{I_{44}} \sin \omega_e t + \frac{W_4}{I_{44}} \]

where \( \theta \) is rolling angle; \( \dot{\theta} \) is the angular velocity; \( \ddot{\theta} \) is the angular acceleration; \( b \) is damping coefficient; and \( c_1, c_2, c_3, c_4, c_5 \) are righting moment coefficients obtained from righting moment curves which is part of hydrostatic performance. \( I_{44} \) is rolling inertia with added inertia; \( F_4 \) is wave moment; \( W_4 \) is wind moment; \( \omega_e \) is wave frequency; and \( t \) is time.

Other detail can be seen in previous studies (Chen and Hsu, 2002; Chen, 2003). The simulation results (whether the ships will capsize) of different initial conditions (\( \theta \) and \( \dot{\theta} \) values) were then plotted in an x-y plot to show the size of the “safety basin” and its evolution with increasing wind and waves.

### 2.3 Results

First, the righting arm curve (Fig. 2-3) shows that Taiwanese Junk has its largest righting capability at 25° of heeling angle, and its stability disappear at 68°. These numbers, according to modern stability theories and experience, are not bad for a seagoing ship. If the maximum righting capability takes place at a smaller angle, a ship may have problem in large rolling motion which is not unusual in severe weather conditions.

Second, estimated effective power (needed to propel the ship) at various speeds is shown in Fig. 2-4. The power required at 9 knots is about 150ps. This number, together with the efficiency of devices, is useful to estimate the power of propulsion system. It can also provide a condition for the study of Chinese sail-rig system since it has to provide the

<table>
<thead>
<tr>
<th>Items</th>
<th>Weight (tones)</th>
<th>Longitudinal Center of Gravity (m)</th>
<th>Vertical Center of Gravity (m)</th>
<th>Longitudinal moment (t-m)</th>
<th>Vertical moment (t-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hull under deck</td>
<td>98.15</td>
<td>0.860</td>
<td>1.600</td>
<td>84.4</td>
<td>157.0</td>
</tr>
<tr>
<td>Fore Mast</td>
<td>1.70</td>
<td>-10.000</td>
<td>7.500</td>
<td>-17.0</td>
<td>12.8</td>
</tr>
<tr>
<td>Fore sail</td>
<td>0.45</td>
<td>-9.500</td>
<td>12.000</td>
<td>-4.3</td>
<td>5.4</td>
</tr>
<tr>
<td>Main mast</td>
<td>3.09</td>
<td>-1.400</td>
<td>10.000</td>
<td>-4.3</td>
<td>30.9</td>
</tr>
<tr>
<td>Main sail</td>
<td>1.00</td>
<td>1.500</td>
<td>15.000</td>
<td>1.5</td>
<td>15.0</td>
</tr>
<tr>
<td>Main Outfits</td>
<td>6.00</td>
<td>-1.500</td>
<td>3.300</td>
<td>-9.0</td>
<td>19.8</td>
</tr>
<tr>
<td>Stern Equipments</td>
<td>2.50</td>
<td>12.000</td>
<td>7.500</td>
<td>30.0</td>
<td>18.8</td>
</tr>
<tr>
<td>Subtotal</td>
<td>112.89</td>
<td>0.720</td>
<td>2.300</td>
<td>81.30</td>
<td>259.66</td>
</tr>
<tr>
<td>Loading</td>
<td>34.50</td>
<td>-0.300</td>
<td>1.250</td>
<td>-10.4</td>
<td>43.1</td>
</tr>
<tr>
<td>Total</td>
<td>147.39</td>
<td>0.4814</td>
<td>2.0543</td>
<td>70.95</td>
<td>302.79</td>
</tr>
</tbody>
</table>
propulsion power. For the replication work, this is necessary for estimating the power of engines, if they want to install propeller system as a secondary propulsion system. In that case, general speaking, the brake power needed for a diesel engine is roughly 300ps for a maximum speed of 9 knots, and only 75ps for 6 knots.

Third, the pressure distribution on hull and wave generated by Taiwanese Junk at 4 to 9 knots simulated by Shipflow ® are shown in Fig.2-5 (Hsu et al., 2009). With the increasing of speed, the pressure at bow and midsection increases. And the concentration of pressure on the bow is very obvious. That implies the structure strength at bow need special attention. The wave patterns at various speeds also show interesting results. At low speed (<6 knots), the increase of speed would not cause much change on wave generated. This means that the increase of resistance mainly come from frictional force. But when the speed increase to near 9 knots, wave making resistance starts to become clear as the wave pattern is clear and wave height increases significantly. This phenomenon was also observed from non-dimensional resistance coefficient – Froude number figure (not shown here), providing more evidence of the emergence of wave making resistance at about 7 to 9
knots. This may be a significant finding for the cruising speed of traditional junks. Usually, it was estimated that junks sail between 6 and 8 knots in good conditions. It should be noted that this simulation result shall be checked by a ship model test in a towing tank. We hope it can be done soon if there is any research grant.

![Fig. 2-5 Pressure distribution and wave generated at 4 to 9 knots (top to bottom) simulated by Shipflow ® (Bow on right hand side)](image-url)
Finally, the safety evaluation by the simulation of nonlinear rolling motion in waves is shown in Fig. 2-6. The “safety basins” (white region in each small box) of various types of junks under different wind-wave conditions are shown. With the increase of wind-wave forces, the safety basins shrink and are “eroded”. It is seen that Fu Chuan, Fishing Boat (a kind of Fu Chuang) and Zhanzuo Chuan (a hybrid or middle type between Fu Chuan and Sha Chuan) have better seaworthiness, because their safety basin disappear gradually. On the other hand, Sha Chuan capsizes quickly in larger wind wave conditions. Taiwanese junks have a different shape of safety basin and appear a highly chaotic behavior when the safety basin is gradually eroded in worse conditions. So its safety basin appears more obvious fractal feature than the others in middle conditions. These “grey” safety basins also means the ship can not sustain a consecutive 16 waves of that large amplitude, but may have better chances than other types of junks if encountering less large waves, because its grey region is larger than Fu Chuan and Zhanzuo Chuan’s white region at the same conditions (20% to 60% of average January wind-wave condition in Taiwan Straight).

<table>
<thead>
<tr>
<th>Type</th>
<th>Taiwanese Junk</th>
<th>Fu Chuan</th>
<th>Sha Chuan</th>
<th>Fishing Boat</th>
<th>Zhanzuo Chuan (Battle Flag Ship)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
<td><img src="image5" alt="Image" /></td>
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<td>10%</td>
<td><img src="image6" alt="Image" /></td>
<td><img src="image7" alt="Image" /></td>
<td><img src="image8" alt="Image" /></td>
<td><img src="image9" alt="Image" /></td>
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<tr>
<td>20%</td>
<td><img src="image11" alt="Image" /></td>
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<tr>
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<tr>
<td>40%</td>
<td><img src="image21" alt="Image" /></td>
<td><img src="image22" alt="Image" /></td>
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<td><img src="image24" alt="Image" /></td>
<td><img src="image25" alt="Image" /></td>
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<tr>
<td>50%</td>
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<td><img src="image27" alt="Image" /></td>
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<tr>
<td>70%</td>
<td><img src="image36" alt="Image" /></td>
<td><img src="image37" alt="Image" /></td>
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<td><img src="image39" alt="Image" /></td>
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<tr>
<td>80%</td>
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<tr>
<td>90%</td>
<td><img src="image46" alt="Image" /></td>
<td><img src="image47" alt="Image" /></td>
<td><img src="image48" alt="Image" /></td>
<td><img src="image49" alt="Image" /></td>
<td><img src="image50" alt="Image" /></td>
</tr>
<tr>
<td>100%</td>
<td><img src="image51" alt="Image" /></td>
<td><img src="image52" alt="Image" /></td>
<td><img src="image53" alt="Image" /></td>
<td><img src="image54" alt="Image" /></td>
<td><img src="image55" alt="Image" /></td>
</tr>
</tbody>
</table>

Fig. 2-6 The evolution of safety basins in increasing wind-wave conditions of various types of junks.

2.4 Model making and Test

The original designer of the replica of Taiwanese Junk is Mr. Tseng, Shu-Ming, who is also a good and experienced model maker. His works of various types of Chinese junks were collected in three large museums in Taiwan, National Museum of Nature Science,
National Museum of Taiwan History, and the largest maritime museum in Taiwan, Evergreen Maritime Museum. He is considered the best junk model maker in Taiwan, China, and Hong Kong. The reason is that he studied the ship very carefully and he can also draw lines like engineers. He built several models of Taiwanese junks of difference scale. One of them was equipped with remote controlled rudder to be tested in a pond. The building process is seen in Fig. 2-7. The sailing test was conducted in a pond in Keelung, as seen in Fig. 2-8.

![Fig. 2-7 Taiwanese Junk’s model under construction (left) and completed (right)
(Photo: Mr. Tseng, Shu-Ming)](image)

![Fig. 2-8 Model test: under preparation (left) and sail by wind (right)
(Photo: Mr. Tseng, Shu-Ming)](image)

### 3 Administration of Replication

With the above study and other evaluation of benefits and risks, Tainan City Government had confidence and decided to build a replica of the 17th Century Taiwanese Junk (unnamed yet). The only problem is required money. After many failed lobbies, it is luck to obtain the budget needed from Taiwan’s central government at the end of 2007 as well as the end of the preliminary study. Hence, the practical construction needed to be well planed.

During the first half of year 2008, Tainan City Government, as the owner of the
replica, took our advise to invite United Ship Design and Development Center (USDDC), a half government owned non-profit organization, to join the work playing a key role as the final designer and superintendent of the construction of this replica. This turned out to be a key step because it brought both positive and negative influence on this project, as illustrated later. USDDC has many experiences on modern merchant ships, boats, yachts, military vessels, and fishing ships. The engineers at USDDC are familiar with modern ships and related regulations, but lack of knowledge of ancient ships and culture sensitivity of this ship. However, understanding the potential huge difference between the ancient junk and modern regulation, they accepted this job after some consideration with a condition requiring that they will put safety first in the design process.

Tainan City Government then used USDDC to represent it to make the construction design and prepare the technical paper work for choosing a proper builder. On the other hand, the government officials also know that both USDDC and the City Government do not have sufficient knowledge about the ancient ships. So, they still invite the NCKU team members, professional tourism planners and other naval architects to form a “Technical Advisory Group” (TAG) to “supervise” and to advise the work of USDDC and the City Government (Fig.3-1).

The official paper work for tender was announced in August, 2008 in order to sign a contractor to build the replica by the end of that year. Before its release to the public, the TAG team was not informed and did not review the contents prepared by USDDC. Even though some TAG team members, including myself, found some technical contents may jeopardize the historical correctness and valuable chances of experimental archaeology, it was too late to correct the document. This administrative mistake generated frictions between some core TAG members and USDDC project manager later. This was probably avoidable if our preliminary research included a visit to European replicas, as I suggested then, to learn the experience of management and regulation of replicas. But the traveling budget of preliminary research was quite limited such that only some members visited China.

![Fig. 3-1 The Organization Structure of the Construction Work of Taiwanese Junk.](image)

In September, 2009, the contractor was decided. Dragon (Song-Lin) Boat Building Ltd, at Anping, Tainan got Tainan City Government’s contract of NTDS79 million (about US$2.4 million) to build the replica of Taiwanese Junk and a necessarily temporary shipyard. This company was chosen because of its experience of wooden fishing boat (though long time ago), location, financial condition, and proper size. The general manager of this company even invited an 80+ years old and retired technician back to lead the work because he is the only alive one in that area having experience of building a wooden boat.
three decades ago. The project manager and superintendent sent by USDDC is Mr. Chen, Lin-Fu who will play a key role in the whole building process. The shipyard was on a planned wharf of Anping fishing harbor and next to the Lin Muo-Niang Park. Lin Muo-Niang is the name of Chinese Goddess who protects seamen. The replication project was schedule to begin in January and finish in December of 2009.

4 Replication Design

USDDC’s project manager, Mr. Chen, Lin-Fu, re-designed the “replica” of Taiwanese Junk based on our previous design for two reasons. The first one is that he put safety as the first priority because the Mayor wants the “replica” sail to Japan in her first voyage. The second reason is that the design must pass the present regulation for the same voyage reason. A hidden third reason was also important: he changed the material of structures and hull and the sizes of some structure for safety consideration, and thus increases the weight very much such that the freeboard and the shape under the original waterline must be changed to increase the total displacement and safety! (Fig.4-1)

![Fig. 4-1 The mid section plot of redesigned Taiwanese junk The freeboard is increased to 1.0m. The inner keel is also clearly seen. (Source: Chen, L.-F.)](image)

In particular, there are four major differences of this “replica” and the ancient Taiwanese Junks, all in the name of safety and regulation. The first one is the hull shape and freeboard as described in the above. The second one is the materials used. The material for the keel is beech from southeastern Asia and its density is larger than water! Mr. Chen, Lin-Fu’s reason is that its strength and hardness is the best among all available woods. Other important parts like the frames and hull plates are Formosa Acacia (Acacia confusa) and Shorea; both are common materials for wooden fishing boats in Taiwan. But in Ching dynasty, junks built or repaired in Fujian and Taiwan never used beech for keel because it is not available then. Moreover, the plates and frames were made in pine, camphor and Taiwania (Taiwania cryptomerioides). The reason to use those woods in 17~19 centuries is
that they were easily available in Fujian and Taiwan and the life cycle for most junks were short (less than 10 years) then.

The third difference is the addition of “inner keel” on top of the main keel in order to strengthen the keel and also to fix the ribs on the keel (Fig. 4-1). This structure design was quite typical for wooden fishing boats in Taiwan in 20th century, but never seen on Chinese junks. The ribs and other structure were also thicker. The reason to make this change is again for the safety reason. Of course, this also increases the weight of hull and decrease the loading capability such that the draught and lines need some correction.

The fourth difference is the use of modern metal rivets to joint structures. Traditional junks used mortise and tenon joints and special nails, instead. There are several types of nail specially made for junks. One of them is similar to rivet, but much thinner, and the way to use it is to bend one part after it passes through the timber. The above major differences between Taiwanese junk to my best knowledge and its 2009 “replica” is summarized in Table 4-1. Other changes are more tolerable, such as a pair of small powered propellers, higher bulwarks and safety equipments as seen in the general arrangement (Fig. 4-2). The change of bulwarks was also controversial because it also changes the outlook and makes the use differently. Mr. Chen L.-F. insisted that the change for regulation and safety is necessary.

The whole attitude and thought of Mr. Chen Lin-Fu is like that this ship’s safety and seaworthiness is the highest priority, and only the outlook is important to the replication work. This is, of course, totally not acceptable to historians and archaeologists. Moreover, due to lack of experience of wooden ships for three decades, Taiwan's engineers, officers, and surveyors probably have too little confidence to put a wooden boat on unknown risk. Thus, they tend to increase the safety standard of this ship as high as modern ships, and forgot the limited use and timing of use of this “replica”. Therefore, a long and fierce debate and even quarrels are unavoidable between historians and engineers.

Table 4-1 Comparison of Taiwanese Junk and its 2009 “replica”

<table>
<thead>
<tr>
<th>Item</th>
<th>Taiwanese Junk to my best knowledge</th>
<th>The “replica”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draught</td>
<td>2.0m</td>
<td>2.0m</td>
</tr>
<tr>
<td>Freeboard</td>
<td>0.25m</td>
<td>1.0m</td>
</tr>
<tr>
<td>Rudder shape</td>
<td>Slight Curvy</td>
<td>? (Not decided!)</td>
</tr>
<tr>
<td>Materials</td>
<td>Pine, Camphor, Taiwania</td>
<td>Formosa Acacia, Shorea, Beech</td>
</tr>
<tr>
<td>Structure</td>
<td>No inner keel.</td>
<td>Add one inner keel.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All thicker.</td>
</tr>
<tr>
<td>Tools for connection</td>
<td>Mortise and tenon joints and special nails.</td>
<td>Rivets and few mortise and tenon joints.</td>
</tr>
<tr>
<td>Construction Procedure</td>
<td>Bulkheads and frames are made part by part simultaneously, as described by Worcester.</td>
<td>Whole piece of frames made outside and assembled first, then the bulkheads.</td>
</tr>
</tbody>
</table>
5 Controversies and Debate

Arguments, debate, and even quarrels between engineers and historians began before the redesign and lasted till the point of no return. Before signing the contract with Song-Lin Shipbuilding Co., members in TAG already knew USDDC’s idea and plan of redesigning the “replica”. The first “technical group meeting” was convened by the City Government right after the contract-singing ceremony on the same day and same place, The Shrine of Koxinga. This “technical group” is formed by the following persons:

1. Representatives of Dragon Boat Building Ltd.: Mr. Lin San-Ching, the CEO.
2. Representative of USDDC: Mr. Chen Lin-Fu, Project manager.
3. Representatives of TAG:
   i. Prof. Chen Hsin-Hsiung, historian;
   ii. Prof. Chen Jeng-Horng, naval architect;
   iii. Mr. Tseng Shu-Ming, the original designer and historian;
4. Outside consultants:
   i. Prof. Chang Buo-Chao, naval architect;
   ii. Prof. Lu Hsueh-Hsin, naval architect;
   iii. Prof. Chen Hong-Jong, naval architect;
5. Representatives of City Government: 2~3 officers in charge.

During the first and following “technical group” meetings, historians and engineers (representatives of USDDC and the shipbuilding company) have severe conflicts on the changes of materials, shapes, and construction methods. Historians insisted that the correctness of material to be used, the shape of hull, and the way it is constructed are all very important and the spirit of the whole replication work. On the other hand, engineers insisted that it is important not only to obey the regulation for a ship-to-sail, but also to increase the safety and life of this ship to average modern standard, i.e. much higher than
that of the ancient Taiwanese junk. I, as a bridge to both sides, tried to minimize their gap, although I prefer the historians’ idea considering the importance of the needs of experimental archaeology (Mathieu, 2002). I hoped that this ship may have a sea trial test like "Naniwa-muru" (Nomoto et al., 2000) in Japan. However, it is not easy to convince my engineering colleagues, while more naval architects were invited into this technical meeting.

Fig. 5-1 A quarrel between a history professor and USDDC project manager in a technical meeting on Mar. 3, 2009 at Tainan City Government.

The results of these series of debates made some TAG members very disappointed. The construction and material preparation was kept going without any delay. Finally, two TAG members, historian Prof. Chen, Hsin-Hsiung and Mr. Tseng, Shu-Ming both resigned from the TAG and technical meeting, and never attend any ceremony or related meeting again, as a gesture of protest. I stayed in the TAG and technical meeting to observe and record the progress of this “replication”, and keep engineers away from doing or even proposing any further change, because they did try to add more modern equipments on the ship for better hospitality for the crew.

6 Construction Process
6.1 Construction Procedure

The construction site is chosen to be on a planned wharf in Anping Harbor near a huge statue of Lin Mou-Niang (Fig. 6-1). Anping is the first area in Taiwan to enter international world during the 17th century. Dutch built Zeelandia Castle over ten years (1624-1634) and used Anping as an important international trade hub (1624-1661). Eternal Golden Castle was build as the first Western style castle equipped with English Armstrong canons in Taiwan in late Ching dynasty. With such rich historical context, the present site was chosen to build the “replica” of Taiwanese Junk. It was empty (Fig.6-2) and needed preparation by building a simple shipyard, as seen in Fig. 6-3.

The first stage of construction is to prepare the materials. The timber was moved into a neighbor shipyard’s plant (the original Dragon Boat Building Ltd.) for cutting by modern electrical saws and other tools, as seen in Fig. 6-4 ~ Fig. 6- 6. Then these wood parts were moved to the shipyard for the “replica” by stackers as seen in Fig. 6-7.

The keel was made by beech (a.k.a. Batu). It is 10.3m (L) x 0.45m (H) x 0.35 (W) and weight about 2 tons. Hence its density is larger than 1.2kg/m³, as mentioned in the above. The special structure of stern and bow needs special structure connected to the keel by mortise and tenon joints (Fig.6-8). But notice that metal rivets were heavily used. The bow keel which will support two extended bow beams was connected to the keel in the keel laying ceremony (Fig.6-9) using crane, and rivets (Fig.6-10). The holes drilled for rivets were easily seen on both sides (Fig. 6-11) such that even reporters who did not know much
about ships and this case asked me “Was there any rivet in the 17th century for shipbuilding?”

Fig. 6-1 The location of the construction site (N 22.9919°, E120.1567°).

Fig.6-2 The construction site at Anping before construction (8-29-2008)

Fig.6-3 The construction site before keel is laid (left). Notice the rail for launch is prepared (right). (2-13-2009)
Fig. 6-4 The timber arrived at ship yard. (Photo: Chen L.-F.)

Fig. 6-5 The cutting of timber by modern machines. (Photo: Chen L.-F.)

Fig. 6-6 finished keel, inner keel, and bottom plates. (Photo: Chen L.-F.)

Fig. 6-7 The keel was transported by a small stacker. (Photo: Chen L.-F.)

Fig. 6-8 The keel before laying ceremony. The connection is clearly seen (right) (2-13-2009)

Fig. 6-9 Keel laying ceremony (left) and performance just before laid (right) (2-15-2009)
Then, the ribs and other parts were cut and assembled after lofting work (Fig. 6-12). Lofting, of course, is a procedure in modern or western shipbuilding process, because the shape of structure is cut according to design drawing that is not a process in traditional Chinese junk. Traditionally, junks were made by rules of thumb or simple guidelines with draft drawing. Woods were cut by electrical saws (Fig. 6-13). Ribs were made from pieces of parts and completed by rivets (Fig. 6-14, 6-15, 6-16), just as they were connected and erected on the keel (Fig. 6-17). Ribs were assembled on the keel from the bow, and then the inner keel covered them from top (Fig. 6-18).
Fig. 6-14 Rivets were used to assemble parts and structures. (3-3-2009)

Fig. 6-15 Assembled rib. (3-3-2009)

Fig. 6-16 Completed ribs waiting for assembling. (3-3-2009)

Fig. 6-17 Supports of ribs were assembled before the ribs on the keel. (3-3-2009)

Fig. 6-18 The process of assembling ribs and the inner keel. (4-9-2009)
The bottom planks were the next part to be assembled (Fig. 6-19). They were the first part of planks to be assembled after ribs and inner keel were completed, even before the bulkheads because they were needed when installing the bulkheads. This is corrected in both traditional junk building process and the modern wooden ships. Then, the side planks were also assembled on ribs and longitudinal structures from bottom (Fig. 6-20) still by rivets because the thickness of planks is enough after redesign. The rivet holes were filled in a traditional way by using fibers and sticky materials (Fig. 6-21). To this step, the main structure was completed and they can be seen in Fig.6-22. The stern plate was also assembled as seen in Fig. 6-23.
6.2 Controversy

The construction process also contains many differences from traditional junk building methods. The workers use modern electrical tools, such as table saws, electrical hammer, and a sky crane, in the preparation of material. The procedure was also modified. Traditionally, a junk’s bulkheads and ribs are made part by part simultaneously, as described by Worcester. So their heights increase simultaneously. But the present construction method is to make whole pieces of ribs outside the hull and be assembled first, then the bulkheads. So it is basically the modern way of building a ship. Since a crane is available, it made this modern method possible, and also increases the speed of construction.

6.3 Education and Tourism

The construction is also open to students and tourists. At beginning, it was only open to those who book a schedule in advance. Now, it is open to general public without appointment during regular office hours. About 200 volunteer guides who had culture guiding experience were trained in August, 2009. Before they can serve the visitors, USDDC’s project manager, Mr. Chen Lin-Fu, also guided the visitors, as seen in Fig 6-24 and 6-25. He also asked the technicians to made a sample assembled plank for explanation and display (Fig.6-26).

6.4 Record and Promotion

Tainan City Government, experienced with cultural tourism and promotion, also actively cooperated with National Geography Channel to make a documentary film. So the
producer, the photographer and a translator came to shipyard whenever there was a
ceremony or important work to be finished. They also interviewed related professionals
and the shipbuilding company (Fig.6-27). A ten minute advertisement sample in Chinese is
already available. The complete version is scheduled to be shown on TV in November,
2010. Other records by archiving documents, pictures, and video films have been done
since the beginning of the reconstruction.

Fig. 6-27 Producer, photographer, and translator from National Geography Channel shot
for a documentary film. (5-6-2009)

7 Summary
7.1 Research findings
For the replication of 17th century Taiwanese junk, the preliminary study has
completed the following:
(1) The basic hull shape and structure design according to a reliable Japanese painting with
major dimensions and other documents about traditional Fu-style junk.
(2) Taiwanese junk’s performance was studied using direct computation and computer
simulation. We found that:
i. Her resistance is similar to typical yachts of same size.
ii. Her seaworthiness is not bad, but not as good as typical Fu style junks.
iii. Her bow’s pressure is much larger than other parts of the hull.
(3) It is evident again that modern naval architecture tools can and did help the
understanding of ancient ships’ performance, and the design, verification, and
preparation work for a replica.
(4) The future research needs to conduct model experiments for resistance and sail
performance to verify the analysis and simulation based on some assumptions.

7.2 Construction
Among the categories for various levels of replication of ancient ships suggested by
Fenwick (1993), the present Taiwanese Junk under construction (unnamed) is not a
“replica” or “reconstruction” due to changes of materials and methods. If we ignore the increase of draught and a small change in midship hull shape, this work is only a “reproduction”. Nevertheless, it is the first one in Taiwan and the most serious replication and documented work for Chinese junks so far.

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Reference


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