THE APPLICATION OF CYCLOIDAL PROPELLERS TO THE WESTERN RIVERS TOWBOAT INDUSTRY

Fred Y. Martin, Associate Member

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THE UNIVERSITY OF MICHIGAN

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COLLEGE OF ENGINEERING
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TO THE
WESTERN RIVERS TOWBOAT INDUSTRY

by
Fred Y. Martin

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ABSTRACT

An investigation is made to determine the applicability of the vertical axis or cycloidal propeller to the western rivers towboat of the United States. Because of a scarcity of data, both resistance and self-propelled model studies were conducted at The University of Michigan naval tank. The model data in collaboration with a historical survey of cycloidal propeller applications enables the development of a number of conclusions concerning the employment of these propulsive devices in the towboat industry.
INTRODUCTION

Although the Voith-Schneider cycloidal propeller has enjoyed a high degree of acceptance on the rivers and inland waters of Europe, Asia and Africa, this propulsive method (not limited to the Voith-Schneider design) has received only limited recognition in this country. The general tendency is for designers, builders, owners and operators to discount the merits of this propulsive device—outstanding capabilities in maneuverability, control and backing, all of which are essential for safe towboat operation—by belaboring such characteristics as efficiency, reliability and initial cost.

The latter two reasons, which are usually given, are relatively easy to state quantitatively, while the efficiency of a towboat equipped with cycloidal propellers is much more evasive.

Hence, a student research project was undertaken in the Department of Naval Architecture and Marine Engineering, The University of Michigan, to investigate the propulsive characteristics of cycloidal propellers when applied to river towboats. The research program, spread over two semesters,
was divided into three parts. The first being the development of a towboat hull form hydrodynamically suitable for the propeller application, the development of a tow configuration and the acquisition of model cycloidal propellers. The second phase of the program was devoted to the resistance and self-propelled model test of the towboat only in water depths corresponding to 12 feet, 26 feet and deep water. And finally, the resistance and self-propelled model test of the towboat and barge train was conducted in deep water, concluding the test program.

THE PROPELLER

History and Development

The vertical axis propeller derives its name from its generally accepted position of installation, that is, with its blades projecting vertically downward from the bottom of the ship. Because this propulsive device is not constrained to be mounted in the vertical position only, the more descriptive term cycloidal propeller will be used. The term cycloidal propeller is very apt because it describes the motion of each blade of the propeller as the ship advances.
Historically, the principle of the cycloidal propeller for ship propulsion appears to have been originated by Robert Hooke in the second half of the seventeenth century. Somewhat later, about 1870, a device consisting of a wholly submerged horizontal feathering paddle wheel was proposed by Moody and Fowler and installed on the U.S. torpedo boat Alarm. This propeller was a decided success in its ability to maneuver a vessel, but it proved uneconomical in power consumed as compared to a screw propeller. After a lapse of nearly 50 years, the principle was "rediscovered" almost simultaneously and independently by Dr. F. K. Kirsten in the United States and Mr. E. Schneider in Austria. The two propellers, though alike in principle, are dissimilar in mode of operation. Both permit a change of thrust direction without changing the direction of rotation of the propeller; however, in addition, the Schneider propeller permits the magnitude of the thrust to be varied for a constant rpm.

The Schneider propeller, further developed and refined in collaboration with the J. M. Voith Company of Germany, has enjoyed great success in Europe and throughout the rest of the world. At present, approximately 2000 of the Voith-Schneider propellers have been delivered. Meanwhile, in the United States, the Boeing Company, working with Dr. Kirsten,
perfected the Kirsten-designed propeller. However, because of the lack of thrust variation capability or perhaps due to differences in geographical and economic conditions, the Kirsten-Boeing propeller has been used only in very limited cases in the United States.

At the close of World War II, the capture of several of the German R-class minesweeping craft provided a stimulus for the United States' interest in the cycloidal propeller. Both the Navy and the Army ran test programs on the captured ships. The results of the test programs are that both branches now have or have had in operation ships propelled by cycloidal propellers. Of great interest to this study is the river towboat designed and built by the Dravo Corporation for the U.S. Army Transportation Research and Engineering Command.\textsuperscript{5-8} This particular ship, the LTI-2194, was equipped with twin sinusoidal propellers, which differ from cycloidal propellers only in the motion of the blades.

Concept of Operation

The concept of the cycloidal propeller is based upon the effect of a blade or foil moving in a circle about a
fixed center which at the same time is translating along a straight path. Hence, the motion so described is precisely that of a point on a circle rolling on a flat surface. Basic mathematics books would define the locus of such a moving point as a cycloidal curve. Depending on the location of the point relative to the rolling circle, three types of cycloidal curves are possible, the curtate, common and prolate. Figure 1 illustrates these three types of cycloidal curves.

If a specific oscillatory motion is imposed upon the blades of a cycloidal propeller as the propeller rotates and translates, the path so described by the blades can be made to follow the locus of a cycloidal curve. Hence, the three types of cycloidal curves gives a convenient way of categorizing cycloidal propellers. The curtate cycloidal (below Pi or low-pitch type) is the one commonly used and will be briefly discussed.*

The character of the curtate cycloid, that is the size of the loop and the distance between loops, is a function of the propeller pitch and propeller slip. As pitch increases the loop decreases from a complete circle at zero pitch to a cusp at Pi pitch. As slip increases, the loop for a given pitch will increase. Figure 3 illustrates in diagrammatic form the relative positions of the blades of a 4-bladed propeller. When the propeller is at rest, the four blades will assume the positions indicated on the propeller diagram. As the propeller

*Figure numbers within the quotation have been changed to correspond to the figures in this paper.
Figure 1

1. **Curate Cycloid**
   - Path of rolling circle: $< \pi D$

2. **Cusp or Common Cycloid**
   - Path of rolling circle: $\pi D$

3. **Prolate Cycloid**
   - Path of rolling circle: $> \pi D$
\( \theta = \text{ANGLE OF ROTATION} \)
\( \beta = \text{ANGLE OF BLADE OSCILLATION RELATIVE TO THE TANGENT OF THE ORBIT CIRCLE} \)
\( E = \text{ECCENTRICITY OF THE LINKAGE - A MEASURE OF PITCH FOR ZERO SLIP CONDITION} \)
\( N = \text{STEERING POINT FOR ZERO SLIP CONDITION} \)

**Figure 2**

**Line of Max. \( \beta \) Points**

- \( 0^\circ \)
- \( 60^\circ \)
- \( 90^\circ \)
- \( 240^\circ \)
- \( 300^\circ \)
- \( 360^\circ \)

- Pitch Ratio
  - \( 4\pi \)
  - \( \pi \)
  - \( 6 \)
  - \( .8 \)
  - \( 1.0\pi \)

**Notes:**
- \( \theta \) and \( \beta \) are angular measurements.
- The diagram illustrates the relationship between \( \theta \) and \( \beta \) for various pitch ratios.
- The figure includes a scale for measuring \( \beta \) in degrees.
- The eccentricity \( E \) and steering point \( N \) are critical for understanding the dynamics of the linkage.
$V_p = \text{VELOCITY OF ROTATION (PERIPHERAL)}$

$V_r = \text{RESULTANT VELOCITY}$

$V_t = \text{TRANSLATION VELOCITY}$

$F_t = \text{THRUST FORCE}$

$F_s = \text{SIDE FORCE}$

$F_n = \text{NORMAL FORCE}$
rotates, the blades will oscillate with a variable velocity. The linkage is such that each blade will assume the same attitude at a given point in the circle as the preceding blade did when it had reached that same point in the circle. If one blade "A" is followed around the circle, it will occupy successively the positions of the other three blades B, C, D. If the path of "A" is traced as the propeller rotates and translates with velocity V, it will be found that the blade successively occupies the position and attitude shown as $A_1$, $A_2$, $A_3$, $A_4$.

For given angles of propeller rotation $\theta$ these attitudes describe each blade of the unit as a whole or the attitude of one blade as it moves along the cycloid path.

In the below Pi or low-pitch propeller, the blade oscillates about the tangent to the orbit circle. The lower diagram of Figure 2 illustrates the angular relationship between blade position in orbit and blade attitude relative to the orbit circle. It is, in effect, a blade motion curve. As pitch increases from zero to Pi, the curve becomes progressively larger and is characterized by the sharp peak and steep gradient in the region of $\theta = 180^\circ$. As indicated by this gradient, a practical limit is reached due to the high accelerations experienced near Pi pitch.

The flow associated with an oscillating blade system such as the cycloidal propeller is very complex and has not been completely analyzed to date. In order to gain a general understanding of the operation of the propeller, a grossly simplified model will be used ignoring induced velocity effects and vortex generation.

Referring to the velocity diagram Figure 3, the combination of the velocity of rotation $V_r$ and translation $V_t$, both constant values, and the angle $\theta$ which is a variable gives a resultant $V_r$ which is variable both in magnitude and direction. The resultant velocity having an angle of attack to the blade develops a lift force $F_n$ normal to the chord.
which can then be resolved into a thrust component $F_t$ and a side force component $F_s$. By symmetry the side forces in the forward half of the propeller are equal and opposite to the side forces in the after half of the propeller, thus cancel out. The thrust forces vary in magnitude for each blade position but all have the same sign, therefore the total thrust is a summation of all the blade thrust forces. As the pitch is changed (length of ON) the blade attitude ($\beta$ angle) changes, thus changing the angle of attack and therefore the lift force. At zero pitch, all blade chords are tangent to the circle and no resultant thrust is generated. For constant RPM, thrust varies directly with pitch, thus giving ship speed control without change in RPM.

Steering is accomplished by moving point N in Figure 3 around the center O, ON remaining constant. This rotates each blade an amount sufficient to maintain a right angle between the blade chord and steering center ray. The angular displacement of the whole blade system causes an equivalent angular displacement of the thrust forces. This gives steering capability through a full 360°.

The below Pi or low-pitch propeller described above is the most prevalent one in actual use. The Voith Schneider propeller is based on this concept as well as the majority of American designs. It should be pointed out, however, that most of the propellers built depart slightly from the true cycloid motion for various practical reasons.

The Model Propellers

The two model propellers and the associated torque dynamometers used in the model test were borrowed through the auspices of Mr. Gabor F. Dobay of the Hydrodynamics Laboratory of the Naval Ship Research and Development Center,
Department of the Navy, Carderock, Maryland. These model propellers are of the Voith-Schneider type and have the following characteristics:

<table>
<thead>
<tr>
<th></th>
<th>STBD</th>
<th>PORT</th>
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<tbody>
<tr>
<td>Orbital Diameter (inches)</td>
<td>6.300</td>
<td>6.300</td>
</tr>
<tr>
<td>Number of Blades</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Pitch Ratio*</td>
<td>0.609 &amp; 0.819</td>
<td>0.609 &amp; 0.819</td>
</tr>
<tr>
<td>Blade Length (inches)</td>
<td>4.095</td>
<td>4.095</td>
</tr>
<tr>
<td>Rotation (Ahead thrust-viewed from above)</td>
<td>Clockwise</td>
<td>Counter Clockwise</td>
</tr>
</tbody>
</table>

Although actual open-water characteristic curves were not determined experimentally for the model propellers, curves for the pitch ratios tested were developed from data given in References 10-12. According to correspondence with Mr. Dobay, the open-water characteristics presented in Reference 10 are applicable for the 6.300-inch orbit diameter propeller if the parameters of blade number, pitch ratio and blade motion are consistent. Also, small Reynolds number effects might be expected when using the data from a larger propeller. For the present test, the parameters of blade

*0.609 = Pitch ratio used for heavy loaded condition of towboat pushing barges
0.819 Pitch ratio used for condition of towboat alone
FIGURE 4 OPEN WATER PROPELLER CHARACTERISTICS FOR THE MODEL PROPELLERS.
To be used when a very high-powered, the largest commercially available cycloidal propeller was chosen for the prototype ship, this being the Voith-Schneider size 125 unit. This propeller is capable of absorbing about 2500 shaft horsepower; hence, an installation of this size would have been out of scale. Having some experience with the propeller, the model would use the cycloidal propeller in a size similar to the real one.

**FIGURE 6** THE MODEL CYCLOIDAL PROPELLER UNITS TESTED.
number, pitch ratio and blade motion were duplicated and the small Reynold's effects were ignored. Figures 4 and 5 give the open-water characteristics and blade-motion curves for the model propellers. Figure 6 portrays two photographic views of a model cycloidal propeller used in the test program.

The Ship Propellers

To be consistent with the trend that modern towboats must be very high-powered, the largest commercially available cycloidal propeller was chosen for the prototype ship, this being the Voith-Schneider size 32E unit. This propeller is capable of absorbing about 2100 shaft horsepower; hence, an installation of two such units would be competitive in horsepower.

Having selected the prototype propeller and being constrained to the 6.300-inch orbit diameter model propeller, the model scale ratio was fixed at 20.

The characteristics of the size 32E Voith-Schneider propeller is as follows:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
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<tbody>
<tr>
<td>Orbital Diameter (feet)</td>
<td>10.50</td>
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<tr>
<td>Number of Blades</td>
<td>5</td>
</tr>
<tr>
<td>Pitch Ratio</td>
<td>Variable</td>
</tr>
<tr>
<td>Blade Length (feet)</td>
<td>6.54</td>
</tr>
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</table>
It is an unfortunate circumstance that the model tests were compelled to be conducted with six-bladed cycloidal propellers when the prototype units only come with five blades. However, in the extrapolation process, the number of blades will have little influence, for the primary result will be horsepower absorbed.

TOWBOAT AND BARGES

Towboat

The basic hull characteristics for the towboat were developed, using data compiled from a survey of many existing towboats. The table included in the Appendix is a compilation of the data extracted and is included for the convenience of the reader.

Having selected the hull ratio parameters of L/B, B/T and B-L/10, and giving due consideration to the extremely delicate weight distribution problem caused by the concentrated weight of the propellers' extreme aft location, a length of 150'-0" was selected for the parent ship. The resulting ship dimensions are tabulated in Figure 7. To develop the underwater form of the towboat, the hydrodynamic influences con-
SHIP AND MODEL DATA
for
TWIN CYCLOIDAL PROP TOWBOAT

U. OF MICH. MODEL NO 1168
SCALE RATIO: 20
APPENDAGES: NONE

**DIMENSIONS**

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<thead>
<tr>
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<th>SHIP</th>
<th>MODEL</th>
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<tr>
<td>LENGTH (OVERALL) FT.</td>
<td>155.83</td>
<td>7.792</td>
</tr>
<tr>
<td>LENGTH (LWL) FT.</td>
<td>150.00</td>
<td>7.500</td>
</tr>
<tr>
<td>LENGTH (LBP) FT.</td>
<td>150.00</td>
<td>7.500</td>
</tr>
<tr>
<td>BEAM (Bx) FT.</td>
<td>42.00</td>
<td>2.200</td>
</tr>
<tr>
<td>DRAFT (T) FT.</td>
<td>8.00</td>
<td>0.400</td>
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<tr>
<td>DISPL. IN S. TONS, F.W.</td>
<td>961.7</td>
<td>0.11998</td>
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<tr>
<td>WETTED SURF. SQ. FT.</td>
<td>7001.3</td>
<td>17.504</td>
</tr>
<tr>
<td>LCB AFT OF F.P. FT.</td>
<td>69.10</td>
<td>3.455</td>
</tr>
</tbody>
</table>

**SHIP LWL COEFFICIENTS**

| CB | 0.612 |
| CM | 0.949 |
| Cp | 0.645 |
| Δ/(.01L)^3 | 284.95 |

| L/B | 3.57 |
| L/B | 3.57 |
| L/B | 3.57 |
| L/B | 3.57 |
| L/B | 3.57 |

**SECTIONAL AREA DISTRIBUTION**

FIGURE 7
TWIN CYCLOIDAL PROP TOWBOAT

FIGURE 8
tributing to maximum efficiency of the cycloidal propellers had to be considered. According to Voith-Schneider\textsuperscript{14} transom immersion, propeller coverage and slope of buttocks entering into the propeller proximity greatly influence the resulting efficiency. Reference 15 gives a quantitative grasp of the desired propeller immersion and coverage. Although the test referred to in Reference 15 is for a different hull configuration, the results are indicative of the desired hull-propeller relationship and are worthy of reproduction. These were:\textsuperscript{15}

a. A maximum of 5 degrees slope to the buttocks within one propeller diameter of the hull forward of the propeller orbit circle.

b. Reduction of the buttock slope to as near zero as possible at the transom.

c. A minimum stern overhang of at least one diameter aft of the propeller orbit circle.

d. A maximum of 1-foot transom immersion in the full load condition.

Of the four guidelines suggested, three were complied with precisely, while the fourth, transom immersion, was increased slightly at the centerline to allow an increased draft at the sides. It was feared that at bollard conditions in extremely shallow water, air drawing might be experienced at the sides of the ship. Figure 8 shows the final lines of the towboat.
With the scale ratio being set by the propeller selection, the model dimensions are fixed also. Figure 7 gives the model characteristics as well as the final form coefficients and sectional area distribution.

**Barges**

The barge train selected as a tow for the cycloidal-propeller towboat is not one to exemplify the powering characteristics of any towboat. The integrated oil tow, while generally having lower and more predictable resistance characteristics, has the distinction of being a contract carrier. That is, its cargo and trade route are established, generally as longer distance carriers requiring the maximum in efficiency. Nevertheless, the configuration was used, for the more idealized hull form was the easiest to reproduce for the model test. The principal characteristics of the lead and box barges are given for both the ship and model in Figures 9 and 10, while the lines are given in Figure 11. The raked ends of the lead barges were designed for high-speed rakes, based on discussions with Mr. William H. Barton, Jr. of the Nashville Bridge Company and Mr. Donald P. Courtsal of the Dravo Corporation. It is assumed that the resistance characteristics of the total barge train are sufficiently low so that the most realistic evaluation of the cycloidal propulsion system might be made.
SHIP AND MODEL DATA

for

LEAD BARGE, FULLY INTEGRATED OIL TOW

for

TWIN CYCLOIDAL PROP TOWBOAT

U. OF MICH. MODEL NO 1169A, B, C & D
SCALE RATIO: 20
APPENDAGES: NONE

DIMENSIONS

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<td>LENGTH (OVERALL) FT.</td>
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<td>LENGTH (LWL) FT.</td>
<td>256.80</td>
<td>12.840</td>
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<tr>
<td>LENGTH (LBP) FT.</td>
<td>265.00</td>
<td>13.250</td>
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<tr>
<td>BEAM (Bx) FT.</td>
<td>52.00</td>
<td>2.600</td>
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<tr>
<td>DRAFT (T) FT.</td>
<td>9.00</td>
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<td>DISPL. IN S. TONS, F.W.</td>
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<td>0.43385</td>
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<tr>
<td>LCB AFT OF F.P. FT.</td>
<td>145.62</td>
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SHIP LWL COEFFICIENTS

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<tbody>
<tr>
<td>CB</td>
<td>0.926</td>
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<tr>
<td>CM</td>
<td>0.997</td>
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<tr>
<td>CP</td>
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<td>(\alpha/(\text{OIL})^3)</td>
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<p>| | |</p>
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<tr>
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<tbody>
<tr>
<td>L/B</td>
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</tr>
<tr>
<td>B/T</td>
<td>5.78</td>
</tr>
<tr>
<td>B - L/10</td>
<td>25.5</td>
</tr>
<tr>
<td>(V^{2/3})</td>
<td>2313.0</td>
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SHIP AND MODEL DATA
for
BOX BARGE, FULLY INTEGRATED OIL TOW
for
TWIN CYCLOIDAL PROP TOWBOAT

U. OF MICH. MODEL NO 1169E,F,G & H
SCALE RATIO: 20
APPENDAGES: NONE

DIMENSIONS

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<thead>
<tr>
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<th>MODEL</th>
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<tbody>
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<td>14.083</td>
</tr>
<tr>
<td>LENGTH (LWL) FT.</td>
<td>281.66</td>
<td>14.083</td>
</tr>
<tr>
<td>LENGTH (LBP) FT.</td>
<td>281.66</td>
<td>14.083</td>
</tr>
<tr>
<td>BEAM (Bx) FT.</td>
<td>52.00</td>
<td>2.600</td>
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<tr>
<td>DRAFT (T) FT.</td>
<td>9.00</td>
<td>0.450</td>
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<td>DISPL. IN S. TONS, F.W.</td>
<td>4101.3</td>
<td>0.51288</td>
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<td>LCB AFT OF F.P. FT.</td>
<td>140.83</td>
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SHIP LWL COEFFICIENTS

<p>| | |</p>
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<tbody>
<tr>
<td>CB</td>
<td>0.997</td>
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<tr>
<td>CM</td>
<td>0.997</td>
</tr>
<tr>
<td>CP</td>
<td>1.000</td>
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<tr>
<td>∆/(OIL)^3</td>
<td>183.55</td>
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<th></th>
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<tbody>
<tr>
<td>L/B</td>
<td>5.42</td>
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<tr>
<td>B/T</td>
<td>5.78</td>
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<tr>
<td>B - L/10</td>
<td>23.8</td>
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<tr>
<td>√2/3</td>
<td>2585.2</td>
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</table>

FIGURE 10
BOX BARGE - INTEGRATED OIL TOW

HALF BREADTH PLAN - BOX END

HALF BREADTH PLAN - RAKE END

LEAD BARGE - INTEGRATED OIL TOW

FIGURE 11
MODEL TEST

The model testing program was established to produce enough useful information about this particular towboat design so that conclusions might be drawn regarding the effectiveness of the propulsion devices. The original testing program as proposed to the Ship Hydrodynamics Laboratory of the Department of Naval Architecture and Marine Engineering required the following:

(1) Resistance Test

(a) Towboat at design displacement thru speed range 3-15 miles per hour.

(b) Towboat at design displacement pushing a two consisting of eight jumbo oil barges (approx. 1000' x 104' full size) at design draft of 9'-0" thru speed range 3-10 miles per hour. The barges will be arranged in a double string, each string four barges long.

(2) Self-Propelled Test

(a) Towboat at design displacement thru speed range 3-15 miles per hour. Also, include bollard pull test in both ahead and astern directions.

(b) Towboat design displacement pushing a tow consisting of eight jumbo oil barges (approx. 1000' x 104' full size) at design draft of 9'-0" thru speed range 3-10 miles per hour. The barges will be arranged in a double string, each string four barges long. Also, include bollard pull test in both ahead and astern directions.

(3) If time permits, vary barge draft to light displacement and repeat test. Also, measure athwartship thrust for zero speed condition.

Of the tests proposed, all were completed except for light barge displacement condition, athwartship thrust and astern bollard condition. In addition to those required, the towboat was tested, both for bare-hull resistance and self-propelled characteristics in three
RESISTANCE AND SELF-PROPELLED TEST

The University of Michigan models no. 1168 and 1169A thru H were constructed of wood to a linear ratio of 1:20. As mentioned previously, figures 7 and 8 delineate the basic hull characteristics and lines for the towboat model and ship, while figures 9-11 describe the characteristics of the barge train. The full-scale predictions herein reported are for the ship operating in smooth freshwater at 59°F. The water depths correspond to 12 feet, 26 feet and deep water. All extrapolations are based on the ATTC line using a surface correlation allowance of 0.0004. A 0.027-inch diameter trip wire, located approximately at station 2, placing it one inch above the baseline, was used for turbulence stimulation on the towboat. A 0.018-inch diameter trip wire located in the same approximate vertical position as described for the towboat was used for turbulence stimulation on the barges.

Bare hull resistance tests were conducted with the towboat at even keel displacement equivalent to 961.7 short tons of fresh water at full scale.

Due to shallow water effects, it was not possible to run the full speed range desired in the two shallow water conditions. It became apparent that unusual resistance characteristics developed near the critical speeds based on depth. Figure 23 shows some of the resulting wave patterns where the towboat was run at a depth...
Froude number of one. Hence, in both shallow water conditions the maximum speeds were restricted to approximately seven-tenths of the critical speed based on depth.

Prior to conducting powering tests with model 1168, tests were run to make sure that the propulsion steering angles were such that maximum bollard thrusts were developed by the propellers. This involved the physical rotation of the model propellers in their housings to such a position that maximum thrust recordings were developed. The powering tests were conducted at a displacement equivalent to that of the resistance test, and only through a similar speed range for each water depth.

The resistance test for the towboat and barge train was run only in deep water because the length of the shallow water facility was not great enough to allow equilibrium conditions to be established. Again, as for the powering test with the towboat, the maximum thrust was ascertained by physically rotating the propellers in their housings. The results of all of the model tests are presented in figures 12 thru 20.

It should be noted that shaft horsepower predictions were obtained by using model test values of net torque, rpm and suitable constants. It is not possible to include propeller thrust effects for it is physically impossible to make a thrust measurement when the propeller is rigidly attached to the model hull.

Figures 21-26 show the overall configuration and close-ups of the models under test.
TWIN CYCLOIDAL PROP
TOWBOAT

U. of Mich. Model N° 1168
Propellers - VOITH
Propeller Pitch - 0.819 pi
Water Depth - 12 Feet

May 1969

FIGURE 12
TWIN CYCLOIDAL PROP TOWBOAT

U. of Mich. Model No. 1168
Propellers - VOITH
Propeller Pitch - 0.819 pi
Water Depth - 12 Feet

May 1969

SHAFT HORSEPOWER IN THOUSANDS
FIGURE 13
TWIN CYCLOIDAL PROP TOWBOAT

U. of Mich. Model № 1168
Propellers - VOITH
Propeller Pitch - 0.819 pi
Water Depth - 26 Feet

May 1969

FIGURE 14
TWIN CYCLOIDAL PROP TOWBOAT

U. of Mich. Model № 1168
Propellers - VOITH
Propeller Pitch - 0.819 π
Water Depth - 26 Feet

May 1969

SHFT HORSEPOWER IN THOUSANDS

0 1 2 3 4 5 6 7 8 9 10

0 10 20 30 40 50 60 70 80

0 40 80 120

FIGURE 15
TWIN CYCLOIDAL PROP TOWBOAT

U. of Mich. Model No 1168
Propellers - VOITH
Propeller Pitch - 0.819 pi
Water Depth - DEEP

May 1969

SHIP SPEED - MPH

FIGURE 16
TWIN CYCLOIDAL PROP TOWBOAT

U. of Mich. Model No. 1168
Propellers - VOITH
Propeller Pitch - 0.819 \pi
Water Depth - DEEP

May 1969

FIGURE 17
TWIN CYCLOIDAL PROP TOWBOAT
WITH INTEGRATED OIL TOW

U. of Mich. Model N° 1168
and Models N° 1169A thru H
Propellers - VOITH
Propeller Pitch - 0.609 pi
Water Depth - DEEP

May 1969

FIGURE 18
TWIN CYCLOIDAL PROP TOWBOAT
WITH INTEGRATED OIL TOW

U. of Mich. Model No. 1168
and Models No. 1169A thru H
Propellers - VOITH
Propeller Pitch - 0.609 pi
Water Depth - DEEP
May 1969

FIGURE 19
TWIN CYCLOIDAL PROP TOWBOAT
WITH INTEGRATED OIL TOW
U. of Mich. Model N\textsuperscript{\textdegree} 1168
and Models N\textsuperscript{\textdegree} 1169A thru H
Propellers - VOITH
Propeller Pitch - 0.609 pi
Water Depth - DEEP

May 1969

FIGURE 20
FIGURE 21  MODEL 1168 RESISTANCE TESTS AT VARIOUS WATER DEPTHS AT OR NEAR THE MAXIMUM SPEED FOR EACH DEPTH.
FIGURE 22  MODEL 1168 RESISTANCE TESTS AT VARIOUS WATER DEPTHS AT OR NEAR THE MAXIMUM SPEED FOR EACH DEPTH.
FIGURE 23  CHARACTERISTIC WAVE FORMATIONS AT CRITICAL DEPTH FROUDE NUMBERS.
FIGURE 24  MODEL 1168 IN THE OUTFITTING SHOP SHOWING SELF-PROPULSION TEST APPARATUS ARRANGEMENT.
FIGURE 25  SELF-PROPELSD TEST
APPARATUS AS ASSEMBLED UNDER THE
TOWING CARRIAGE AND THE TOTAL
BARGE TRAIN.
FIGURE 26    MODEL 1168 IN SELF-PROPELLED CONDITION.
CONCLUSIONS

The fundamental propulsive efficiency (EHP\textdiv;SHP) of the cycloidal propeller-hull system is apparently low compared to that of ordinary towboat arrangements with conventional propellers in the Kort nozzles and rudders. Although the findings are quantitatively inconclusive, the indications are that cycloidal propeller systems are perhaps only half as efficient as conventional systems.

There are of course, important secondary benefits of the cycloidal propeller system: the hull form is easier to build, the rudders and steering engines are eliminated, and a bigger percentage of the available thrust area can be used. The principal benefit, however, is in the high degree of maneuverability afforded by cycloidal propellers. Whether these advantages can overcome the inherently low propulsive efficiency cannot be established without comprehensive economic studies. Obviously the ideal application of cycloidal propellers would be in services requiring extreme maneuverability. Small towboats used to assemble flotillas or to provide short delivery service would seem the best places to start.
ACKNOWLEDGMENTS

This paper was written under extreme pressures of time and required the utmost cooperation from all-too-many people. Their numbers are so great that I can name here only those who gave 200 percent efforts.

Miss Mary Schnell did most of the editing (which was badly needed) and most of the typing. Her work was done voluntarily and at a time that seriously inhibited her social life.

Arthur Reed, Leighton Pike, Arthur Twichell and Miss Jennifer Brand contributed much willing assistance in preparing the models for testing, in carrying out the test in the model basin, and in analyzing the results.

John MacKrell also helped in the testing program. Moreover, he dedicated many long hours in preparing the illustrations for this paper.

Gabor F. Dobay of the Naval Ship Research and Development Center was instrumental in making the model cycloidal propellers available to us.

Miss Irene Kendrovics of the University's Copy Center deserves credit for setting a new world's record in duplicating and binding 150 copies of the paper at the last possible moment.

Prof. Horst Nowacki directed the research project and gave much time and patience to improving its technical content.

Prof. Harry Benford deserves mention for his efficiency in holding the blowtorch to all concerned. My own blistered bottom attests to his devotion.
REFERENCES


13. Personal Correspondence from Gabor Dobay, 22 April 1969.


APPENDIX
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A COMPIlATION OF RIVER TOWBOAT DATA