4 Model Calibration

Introduction

Model calibration adjusted parameters in the physical model until the physical model and the ISWS prototype data agreed. The following three areas are suspected of causing differences between the model and prototype:

a. The physical model needs adjustment because the boundary layer along the vessel and along the channel perimeter grows faster in the physical model than in the prototype. This phenomenon occurs in all physical navigation models operated according to the previously presented Froudian scaling criteria. By using equal Froude numbers in a navigation model that is smaller than the prototype, the Reynolds number will be smaller in the model than in the prototype. The smaller Reynolds number in the model results in a faster growing boundary layer that causes the tow's effective size to be larger than in the prototype. To quantify the boundary layer effects, the displacement thickness is computed. This thickness indicates the distance by which the external streamlines are shifted owing to the formation of the boundary layer. Using the Prandtl-Schlichting skin friction equation for a smooth flat plate at zero incidence (Schlichting 1968) and computing the displacement thickness results in the following derived equation

$$\delta_l = \frac{0.292L}{[\text{Log}(R_L)]^{2.58}} \qquad (4)$$

where

δ_l = displacement thickness

L = plate length, set equal to the total barge length herein

R_L = plate Reynolds number defined as VL/ν

V = free stream velocity set equal to vessel speed relative to the water and determined from $V = V_s + V_r + V_a$

V_s = vessel speed relative to the ground

V_r = average return velocity from Schijf

V_a = ambient velocity, positive for upbound, negative for downbound

n = kinematic viscosity of water

In an unpublished study, a 1:37.5-scale navigation effects model was adjusted by reducing the draft of the barges to account for the dissimilarity of boundary layer. This comparison between model and prototype was approximate because the channel shape was a rough representation. Vessel length was 304.8 m. The required draft correction D_C is shown in the following tabulation.

River	Vessel Speed m/sec	Return Velocity m/sec	D_c m	δ_{1m} m	d_{1p} m	d_{1m} - d_{1p} m	$D_c/d_{1m} - d_{1p}$
Ohio	3.30	0.10	0.46	0.70	0.31	0.39	1.18
Illinois	2.77	0.19	0.69	0.72	00.31	0.41	1.68

d_{1p} = prototype displacement thickness
d_{1m} = model displacement thickness *37.5

Model and prototype temperatures were 10 and 20 °C, respectively. In this tabulation all the dissimilarities between boundary layer on the vessel and the channel perimeter have been lumped into conditions on the vessel. The draft correction can be computed from

$$D_C = C(d_{1m} - d_{1p}) \tag{5}$$

$$d_e = d_a + D_C \tag{6}$$

where C is a coefficient that must be determined experimentally. Adding D_C to the actual model draft d_a results in effective draft d_e of barges. The Ohio and Illinois River results in the tabulation show a value of C of 1.18 and 1.68. These values will be compared to the Kampsville experiments in the draft correction section below.

b. When the physical model is started from rest, flume length limitations dictate a faster acceleration than in the prototype. The acceleration for the physical model is shown in Figure 18. The tow in conjunction with the towing carriage becomes a wave generator that creates a wave in front of the tow. This wave is not as significant in the prototype because of the slower prototype acceleration and also tow motion in the prototype is initiated much farther from the measurement point. The “wavemaker” in the prototype (the barges) generally is powered by about a 3,728-kW (5,000-hp) towboat whereas the towing carriage in the model has a scaled power of up to 111,855 kW (150,000 hp). Stated differently, the inertia of the vessel and the water in front of the vessel is significant compared to the power of the prototype tow and the resulting acceleration is low. These inertial forces in the model are insignificant compared to the power of the carriage.

c. The physical model flume length prohibits velocity/wave measurements for a significant time after tow passage because the startup wave generated by the tow bounces off the flume end wall and returns to the experiment section. Once this happens, the physical model data are not valid. Wave suppression devices are not effective for the long-period wave and are difficult to employ when flowing water is part of the experiment flume.

The verification process will show that the physical model reproduces the most significant tow displacement effects—the maximum return velocity and drawdown.

Verification

The Kampsville verification compared maximum return velocity and drawdown for three tow events and developed rules for adjusting the model that resulted in agreement between model and prototype. These rules were then applied to three different tow events to determine the level of agreement between model and prototype. All six tows were three barges wide, loaded to 2.74 m, and either four or five barges long. The tows for developing the adjustment rules were the *William C. Norman* (trip 1), *Jack D. Wofford* (trip 2), and *Olmstead* (trip 2). The *Jack D. Wofford* and *Olmstead* were nearly identical in all respects. The ambient depth-averaged velocity distribution in the physical model for the *William C. Norman* conditions is shown in Figure 19. The three tows used to research the rules and to determine the level of agreement between model and prototype were the *Rambler, Charles Lehman,* and *Mr. Lawrence* (Oct 15) and were from trip 1 at Kampsville. For each of the six prototype tows, five replicate runs of the physical model were conducted. At each probe, the five replicate runs were analyzed for maximum (or minimum) velocity alongside the tow, maximum drawdown, and the ambient velocity or water level before the tow effects arrived at the measurement location. These values were analyzed for outliers using the Chauvenet criterion given in Coleman and Steele (1989). This criterion specifies that all points should be retained that fall within a band around the mean that corresponds to a probability of 1-1/(2N) using Gaussian probabilities. For the five replicate experiments in Kampsville, Chauvenet's criterion specifies that data were discarded only if they departed from the mean by more than $1.65S_x$ where S_x is the standard deviation of the sample of five points. All remaining experiments were averaged for comparison with the prototype data. The ambient velocities were averaged as were the maximum (or minimum) velocities alongside the tow for each probe. The difference between these two averages defined the maximum return velocity that represented the physical model for each probe. The same technique was used for drawdown.

The initial experiment series was conducted with all physical model parameters scaled to the previously presented Froudian criteria, which require geometric similarity between model and prototype. Results comparing maximum return velocity and drawdown for the *William C. Norman*, *Olmstead*, and *Jack D. Wofford* are shown in Table 7. It is quite clear that the physical model over estimates return velocity and drawdown when using geometric scaling and the Froude criteria. This was the expected result based on the boundary layer concerns presented previously. The next series of experiments was conducted with reduced model barge draft to offset the greater boundary layer growth in the physical model. Also of concern at this stage was the startup wave, which was not present in the prototype data. Efforts were directed at reducing the magnitude of the startup wave because of concern that the presence of the startup wave might affect the return velocity and drawdown. Various model accelerations were tried with no significant impact, probably because the limited model length prevented significant reduction of the acceleration. The best agreement of return velocity and drawdown with the least startup wave was found with a 2.28-m draft on all barges except that the bow of the lead barge was drafted 1.14 m. This change in draft on the lead barge had no apparent impact on the return velocity but minimized the amplitude of the startup wave. Results for the *William C. Norman, Olmstead,* and *Jack D. Wofford* are presented in Tables 8 and 9. This same draft correction was used to simulate the *Rambler, Charles Lehman,* and *Mr. Lawrence* which were not used to develop the draft correction. Results are shown in Tables 10, 11, and 12, respectively.

To compare the model and prototype, the most consistent data were expected at meters farthest from the channel perimeter. Meters close to the perimeter (998 and 1001) could easily be affected by local channel bottom irregularities and by differences between boundary layer growth in the model and prototype. Scatter plots of meters 332, 642, 999, 1000, 040, and 071 are shown in Figures 20 and 21 for the three rule development tows and the three tows used to research the rules, respectively. Lateral distribution of return velocity in both model and prototype is shown in Figures 22-26 for each tow. Actual and filtered time-histories for the *William C. Norman* physical model data using the corrected draft are shown in Figures 27-33.

Draft Correction

In order to obtain an effective draft of 2.74 m, the actual draft was adjusted by the draft correction. The draft correction used for the six Kampsville verification experiments was 2.74 m - 2.28 m = 0.46 m and is compared in Table 13 to the difference in displacement thickness for the six tows used in the verification process. The six verification experiments yielded an average C for Equation 5 of 1.72, which is close to the value determined in the previous experiments for the Illinois River. A draft correction coefficient C of 1.72 from the Kampsville experiments will be used to compute D_C (Equation 5) and effective draft d_e (Equation 6) in the Kampsville experiments and will be compared to subsequent experiments using the Clark's Ferry reach on the Mississippi River.

These results showed that the physical model is limited in the minimum draft that can be simulated in the model. Unloaded model barges draft about 0.6 m. With a draft correction of approximately 0.46 m for five long barges, the minimum draft that can be researched in the physical model is about 1.06 m at the 1:25 scale.

One-Barge-Wide Verification Experiments

After completion of the production experiments described in the next chapter, two attempts were made at comparing the physical model to prototype data from loaded, one-barge-wide tows. The first experiments were run with the *Luke Burton* from trip 1. Bhowmik, Soong, and Xia (1993) show this is a one-wide by three-long "mixed" tow. Experiments were conducted with three 10.7-m by 59.5-m barges end to end (Table 14). Model values were about 60 percent of prototype values. The average return velocity from the Schijf equation was 0.115 m/sec and yielded an average ratio of physical model return velocity to Schijf return velocity of 1.18, consistent with previous results. Further examination of the prototype experiments showed that the mixed tow was actually a mixed chemical tow of unspecified length. The difference in widths made this comparison invalid. The unknown size of the prototype prevented further comparisons with this prototype tow.

The second one-barge-wide experiments were run with the *Dixie Express* from trip 2. Based on conversations with the company owning the *Dixie Express,* this tow consisted of two asphalt barges 15.9 m wide by 76.2 m and 83.8 m long for a total length of 160.0 m. Two model barges 13.3 m wide by 74.4 m long were placed end to end for a total length of 148.8 m. To offset the lesser model beam width, the model barges were drafted to an equivalent draft of (15.9*2.74)/13.3 = 3.28 m. To account for boundary layer differences, an actual model draft of 2.93 m was used and was based on a value of C in Equation 5 of 1.72. Model results are shown in Table 15. The average of the four prototype return velocities divided by the Schijf average return velocity is 1.19, which is consistent with previous results. The average of the four physical model experiments divided by the Schijf average return velocity was 0.63, which is different from all previous results and from the subsequent production experiments. It is possible that offsetting the lesser beam width with increased draft had some effect on these results, but the low ratio of physical model return velocity/Schijf suggests a problem with the physical model data. The need to proceed with the subsequent Clark’s Ferry site prevented additional experiments to resolve this problem.