4 Model Calibration

Introduction

In the model calibration, parameters in the physical model were adjusted until agreement was reached between the physical model and the ISWS prototype return velocity data from trip 2. The following four 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 equating the Froude number in a navigation model that is smaller than the prototype, the Reynolds number will be smaller in the model than in the prototype. The lesser Reynolds number in the model results in a faster growing boundary layer that causes the tow's effective size to be larger than the prototype. To quantify the boundary layer effects, the displacement thickness is computed, which 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

$$\delta_1 = \frac{0.292L}{[Log\,(R_L)]^{2.58}} \quad (4)$$

where

δ_1 = 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 the 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)

ν = 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In an unpublished study, a 1:37.5 scale navigation effects model was adjusted by reducing the draft of the barges to account for the dissimilarity of boundary layer.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 Table 7. Model and prototype temperatures were 10 and 20 °C, respectively. In Table 7 all the dissimilarity between the boundary layer on the vessel and the channel perimeter have been lumped into conditions on the vessel. The draft correction can be computed from

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

where C is the experimentally determined draft correction coefficient, δ_{1m} is the displacement thickness in the model scaled to its prototype equivalent, and δ_{1p} is the displacement thickness in the prototype. The effective draft becomes

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

where d_e is the effective draft and d_a is the actual draft. The Ohio and Illinois River results in Table 7 show C values of 1.18 and 1.68, respectively. The previous study on Kampsville on the Illinois River (Maynord and Martin 1997) resulted in an average C of 1.72 based on six tow events. These values will be compared to the required C for the Clark's Ferry experiments.

b. The second model/prototype source of scale effects results from flume length considerations. When starting the physical model from rest, flume length limitations dictate a faster acceleration than in the prototype. The acceleration for the physical model is shown in Figure 12. 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 is initiated much farther from the measurement point. The "wave-maker" in the prototype (the barges) generally is powered by about a 3,730-kW (5,000-hp) towboat whereas the towing carriage in the model has a scaled power of up to 112,000 kW (150,000 hp). Stated differently, the inertia of the vessel and the water in front of the vessel are significant compared to the power of the prototype tow and the resulting acceleration is low. The inertial forces in the model are small 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 endwall and returns to the experimental section. Once this happens, the physical model data are not valid. Wave suppression devices are not effective for the long-period waves set up by vessel startup and are difficult to employ when flowing water is part of the experimental flume.

d. The fourth area involves the unknown parameters from the prototype data such as the alignment (skew) of the tow, variations in the prototype cross section, and effects of the shape, particularly the bow, of the prototype barges. Uncertainties in both model and prototype measurements of speed, draft, tow position, etc., all contribute to differences between model and prototype.

The calibration process will show that the physical model reproduces the most significant tow displacement effects, the maximum return velocity. As stated earlier, the calibration will be based on the low-flow trip 2 tows because of the difficulty of extracting tow effects from the higher ambient velocities of trip 1. Since trip 2 prototype data did not have a recording wave gauge, calibration will be based on comparisons with return velocity only.

Verification

The Clark's Ferry verification process compared maximum return velocity for the tow events and developed rules for adjusting the model that resulted in agreement between model and prototype. All five tows from trip 2 were three barges wide, loaded to 2.74 m, and either four or five barges long. The ambient depth-averaged velocity distribution in the physical model for the trip 2 Pool 546.0 conditions is shown in Figure 13. For each of the 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 draw-down, 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/(2*N*) using Gaussian probabilities (where *N* is the number of experiments). For the five replicate experiments in Clark's Ferry, Chauvenet's criterion specifies that data were discarded only if they departed from the mean by more that $1.65S_x$ 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 initial experiments were conducted with all physical model parameters scaled to the previously presented Froudian criteria, which requires geometric similarity between model and prototype. Results comparing maximum return velocity for the *Kevin Michael*, *Kathy Ellen*, *Deborah Valentine*, *Cooperative Ambassador*, and *Conti-Nan(1)* are shown in Table 8. The physical model overestimates return velocity for most velocity meters when using geometric scaling and the Froude criteria. This was the expected result based on the boundary layer concerns presented above. 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 was found with a 2.13-m draft on all barges. Results for the *Kevin Michael*, *Kathy Ellen*, and *Deborah Valentine* are presented in Tables 9, 10, and 11. This same draft correction was used to simulate the *Cooperative Ambassador* and *Conti-Nan(1)*. Results are shown in Tables 12 and 13.

Plots of prototype return velocity versus physical model return velocity are shown in Figures 14 and 15 for the 2.74- and 2.13-m drafts, respectively. Filtered time histories for the *Coop Ambassador* prototype and physical model data using the corrected draft are shown in Figures 16 to 25. Both prototype and model data demonstrate the difficulty in extracting changes caused by the tow from ambient fluctuations.

Draft Correction

In order to obtain an effective draft of 2.74 m, the actual draft is adjusted by the draft correction. The draft correction used for the five *Trip 2* calibration/verification experiments was 2.74 m - 2.13 m = 0.61 m and is compared in Table 14 to the difference in displacement thickness for the tows used in the verification process. Omitting the *Kevin Michael*, which was the only four-barge-long tow, the verification experiments yield an average C for Equation 2 of 1.82, which is similar to the value determined in both previous experiments for the Illinois River (shown on Table 7 and in Maynord and Martin (1997)). A draft correction coefficient C of 1.72 will be used to compute D_C (Equation 5) and effective draft d_e (Equation 6) in the Clark's Ferry experiments.

These results show that the actual physical model draft along with the draft correction can be used to simulate the typical 2.74-m draft of loaded barges. However, the effective draft of an unloaded barge (about 0.6 m) cannot be obtained in the physical model. With a draft correction of approximately 0.61 m for five-barge-long tows, the minimum effective draft that can be obtained in the physical model is about 1.21 m at the 1:30 scale used herein.