NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Washington, D.C. 20594

March 11, 2020

Video Study

NTSB Case Number:
DCA18MM028

A. ACCIDENT

Location:	Branson, Missouri
Date:	July 19, 2018
Time:	7:08 PM CDT
Vessel:	Stretch Duck 7 (SD7)

B. AUTHOR

Dan T. Horak
NTSB

C. ACCIDENT SUMMARY

On Thursday, July 19, 2018, about 7:08 p.m. central daylight time, the amphibious passenger vessel *Stretch Duck 7 (SD7)*, owned and operated by Ride the Ducks Branson, sank in Table Rock Lake, near Branson, Missouri. Local area forecasts for the time of the accident included thunderstorm warnings and data indicated winds of over 70 mph were encountered by a nearby vessel. The *Stretch Duck 7* was carrying 31 persons: 29 passengers and two crewmembers. The vessel sank in approximately 15 feet of water and came to rest on the lake floor at a depth of 70 feet. Seventeen persons died, including one crewmember.

D. DETAILS OF INVESTIGATION

The main purpose of this study was estimating the locations and speed of vessel SD7 along its path from the lake entry ramp to the location where it sank. Two videos were used in the analysis. The first video was recorded by a rear-facing camera mounted on vessel SD54 (‘SD54 video’). The video had 704x480 resolution and frame rate of 25 fps. SD54 entered the lake shortly before SD7 and made it successfully to the lake exit ramp. The second video was recorded by a person on board the docked Showboat

Branson Belle using a hand-held smartphone (‘Showboat video’). The video had 1920x1080 resolution and frame rate of 30 fps.

Camera Calibration

The analysis of this accident required mathematical models of the optics of the two cameras. The mathematical model of camera optics requires seven parameters in the most general case. Three are the X, Y and Z camera location coordinates. Three are the yaw, pitch and roll camera orientation angles, and the seventh parameter is the camera horizontal field of view angle (HFOV). The estimation of these parameters is based on references that are visible both in video frames and in aerial views of the area.

SD54 Camera Calibration

The rear-facing camera on SD54 was to be used for estimating the locations of SD7 when both were afloat on the lake and moving. The calibration of the camera required some man-made structures that could be used as calibration references. Therefore, calibration was performed when the vessel was parked, before it entered the lake. Camera model location parameters X, Y and Z and the yaw, pitch and roll angles of the camera when the Stretch Duck is parked only apply at the parked location. The camera was fixed to SD54 and these six camera parameters were varying as SD54 was moving on the lake and its orientation angles were fluctuating due to the stormy waters. Therefore, the only calibrated camera parameter useful for video analysis was the HFOV.

The estimation was based on references that were visible both in video frames and in aerial images. The cameras on SD54 and on SD7 were identical so that the SD7 right-side camera video, which recorded the best calibration references, could be used for calibration of the HFOV parameter of all the cameras. Figure 1 shows a frame from the right-side camera on SD7 when it was parked in front of the Ride the Ducks terminal building. The image in Figure 1 has severe barrel distortion caused by the wide-angle camera lens. This distortion was mathematically corrected before estimating the HFOV of the camera.

Figure 1 shows curbs, lane lines, power line poles, power lines, Denny’s restaurant, Hotel Grand Victorian and other details that were used as camera model calibration references. Figure 2 shows an aerial view of the same location with the references from Figure 1 visible.

A computer program that simulates camera optics was then used to project the references seen in the aerial view onto a frame from the video in an iterative process in which the seven parameters were varied so as to align the projected references with their images. When the projected references were aligned optimally with their images in the frame, values of the seven camera model parameters were their optimal estimates. At that point, the model of the camera optics was calibrated. During the calibration, estimation of HFOV required that X, Y, Z, yaw, pitch and roll angles also be estimated. However, these six parameters only applied when the Stretch Duck was parked at the calibration location and they had no use once it moved from that location.

Figure 1. Video Frame Used for Calibration of the Right-Side SD7 Camera

Figure 2. Aerial Image Used for Calibration of the Right-Side SD7 Camera

Showboat Camera Calibration

The second video was recorded with a smartphone hand-held by a passenger on board the docked Showboat Branson Belle. The camera location was approximately constant, but its yaw and pitch orientation angles were constantly changing as the passenger was following the moving SD54 and SD7. There were large and fast yaw and pitch angle changes as the passenger was switching the camera orientation between SD54 and SD7. The video showed that the camera zoom setting was changed during the recording and all the useful information was recorded after this change. Consequently, estimating the HFOV could not be performed by calibrating a different identical camera because the HFOV was not at the default setting. Once the zoom function is used, HFOV has an unknown smaller value than its default maximum.

Calibration of the HFOV of the Showboat camera was hindered by the lack of measurable references. The only reference that could be used for calibration was the outline of the terrain across the lake, located 5000 feet or father from the camera. To make calibration possible, a topographic map of the terrain across the lake was constructed based on USGS elevation data and is shown in Figure 3. The color scale used to display elevation is shown on the right. The darkest blue color corresponds to the elevation of the water in the lake. The Showboat camera location coordinates were set at (0,0), as marked in the figure. Three local elevation peaks could be identified on the map and are marked P1, P2 and P3.

As the camera was looking in the direction of the peaks, the outline of the terrain between P1 and P3 that was recorded by the camera was proportional to the highest pitch angle along a line of sight from the camera to the terrain in a yaw direction. The yaw angle from the camera to the terrain was defined to be zero when the camera pointed west, and it was positive when the yaw angle was deviating clockwise from west. Along each yaw direction, there was a pitch angle from the camera to the terrain for each distance from the camera. The largest pitch angle along that yaw direction determined the outline of the terrain as recorded by the camera. Figure 4 shows a plot of the largest pitch angle vs. the yaw angle from the camera. The three peaks in Figure 4 correspond to the three peaks in Figure 3.

Note that the elevation differences of the terrain across the lake are small. For example, as can be seen in Figure 3, the elevation in between peaks P1 and P2 is only about 50 feet lower than the elevation of the peaks.

Figure 5 shows the upper half of a frame from the Showboat video. It displays terrain peak P2 and also shows SD7. Because the video was recorded in the evening and during a storm, only the outline of the terrain across the lake can be seen. This is the reason for using the pitch angle to terrain, shown in Figure 4, for correlating Showboat video frames with the terrain elevation data during the camera calibration process and during SD7 location estimation described below.

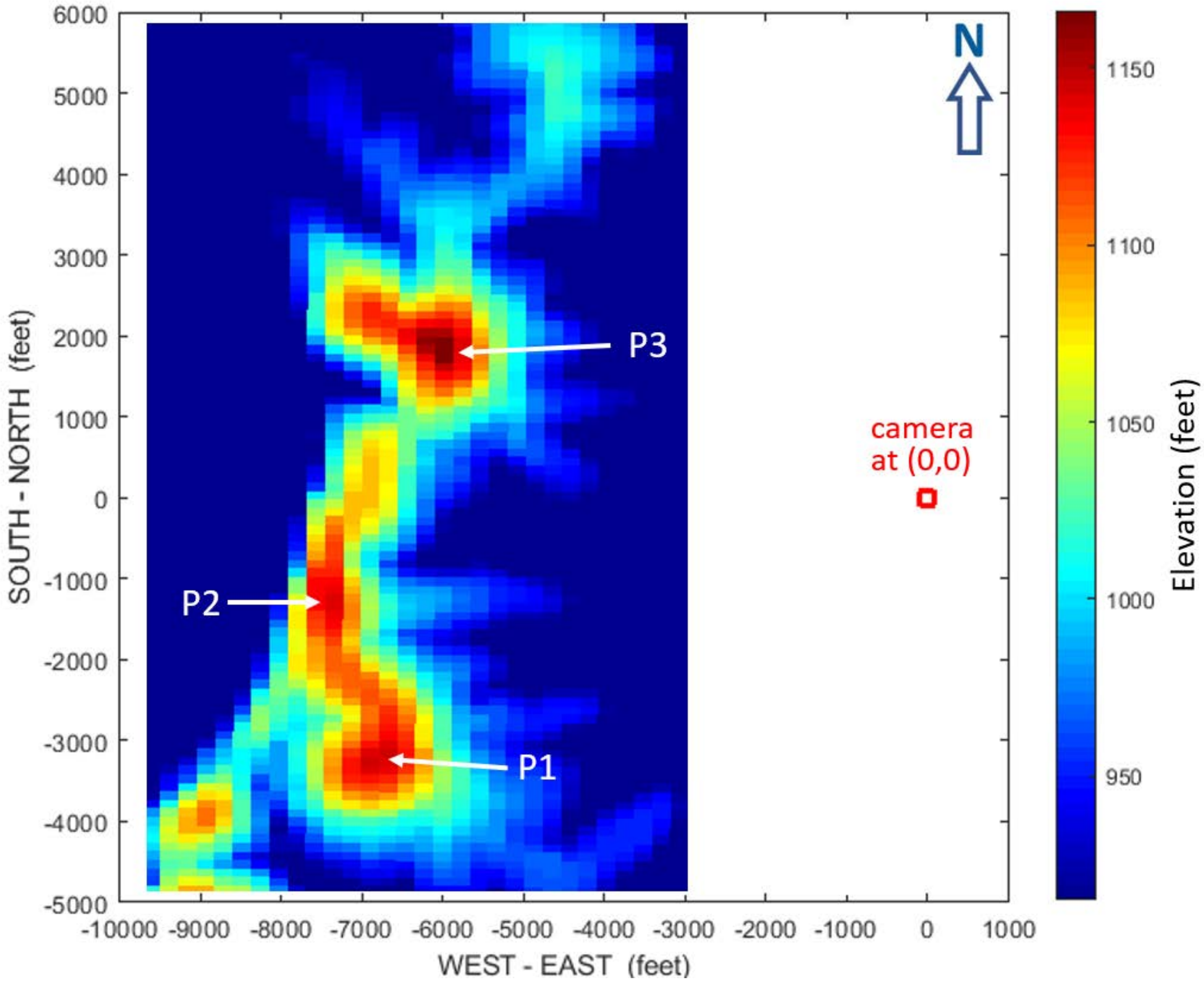

Figure 3. Topographic Map of the Terrain across the Lake from the Showboat

After the zoom of the Showboat camera was changed from its default setting, the HFOV of the camera became too narrow to show more than one peak at a time. This complicated the HFOV calibration process because the yaw angle difference between two peaks seen in Figure 4 could not be correlated with the distance, measured in pixels, between two peaks in a video frame. It was because there were no video frames that showed two peaks.

Therefore, the calibration process had to use peaks as well as the minimum elevation locations in between the peaks and the overall shape of the terrain as shown in Figure 4 during the process. The calibration process consisted of mapping the terrain shape from Figure 4 onto video frames such as the one shown in Figure 5. The camera model parameters were then varied until the terrain shape from Figure 4 optimally matched the terrain seen in a video frame. At that time the parameter values used by the mapping algorithm were the optimal estimates of these parameters.

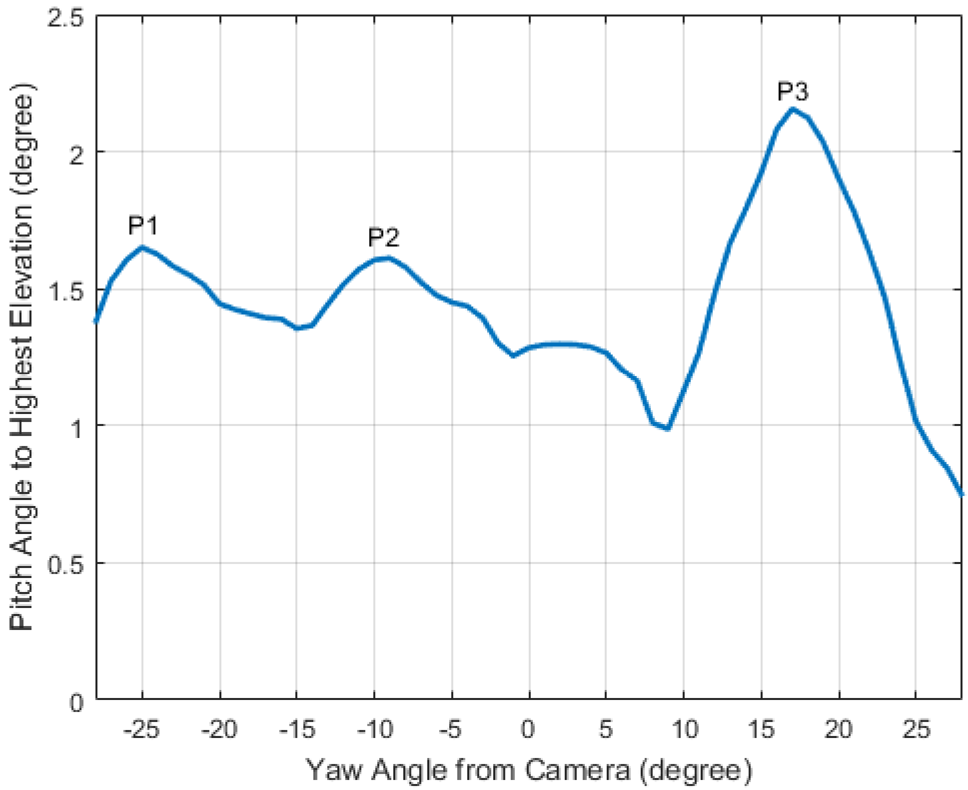

Figure 4. Pitch Angle from Camera to Terrain vs. Yaw Angle from the Camera

The calibration process resulted in estimates of HFOV, yaw, pitch and roll angles of the camera. Camera location coordinates X, Y and Z were known to be on the docked Showboat. The estimated yaw, pitch and roll angles only applied to the times when the video frames used for calibration were recorded and had no further use in the analysis. Their estimation was necessary to allow estimation of the HFOV. During estimation of the locations of SD7 based on the Showboat video, these angles were different because the hand-held camera was changing orientation as the video was being recorded.

Estimation of SD7 Locations Based on the SD54 Video

Figure 6 is an aerial view of the accident area with marked locations relevant to the analysis, including the three peaks, P1, P2 and P3, mentioned above and the docked Showboat Branson Belle. It also shows the ramps where the Stretch Ducks enter and exit the lake.

Figure 7 shows a map of the specific lake area where SD7 and SD54 passed during the analyzed time period. The solid yellow line is the path of SD54 which entered the lake through the entry ramp and successfully made it to the exit ramp. Its path is known accurately because a Brigade MDR-408-1000 mobile digital recorder installed on SD54 recorded its GPS-based locations and GPS-based time in addition to recording videos from four cameras installed on the vessel. The hard drive in the Brigade recorder installed on SD7 was damaged in the accident and, consequently, there were no SD7 GPS-based location data available. However, an SD card in the SD7 recorder did save the time-stamped videos from the four SD7 cameras.

Figure 5. Upper Half of a Frame from the Showboat Video Showing P2 and SD7

Stretch Duck SD54 entered the lake at 06:53:42. Stretch Duck SD7 entered the lake at 06:55:37, 115 seconds after SD54 entered. The SD54 rear-facing camera recorded SD7 from the time it entered the lake. Between time 06:57:01 and time 06:59:28, the image of SD7 in the video was sufficiently clear to allow estimation of SD7 locations. Figure 8 shows SD7 in a video frame recorded at time 06:58:58. Note the barrel distortion caused by the wide-angle camera lens, as was the case during camera calibration (see Figure 1). The distortion was mathematically corrected before analyzing the video frame.

Figure 6. Aerial View of the Accident Area

The estimation of the locations of SD7 based on the SD54 video used the calibrated mathematical model of the SD54 camera. A wireframe model of the Stretch Duck was constructed and superimposed on a frame from the SD54 video. The location of the SD54 camera was known from GPS data. The yaw orientation of the SD54 camera was estimated based on the images of the Showboat, the island and the entry ramp visible in the video frames. The camera model then moved and rotated the SD7 wireframe model until it optimally matched the image of SD7 in the video frame. At that time, the location and orientation angles of the wireframe model were the optimal estimates of the location and orientation angles of SD7 at the time the analyzed SD54 video frame was recorded.

This analysis step was performed four times, resulting in four SD7 location estimates. They are marked by the white circles in Figure 7. The four locations are numbered 1 through 4 and the times when SD7 was at these locations, known from the GPS-based time stamps on the SD54 video frames, are shown next to the point numbers. The dotted yellow lines connect points 1 through 4 with points on the path of SD54. These are the SD54 path locations where SD54 was when the corresponding SD7 locations were estimated.

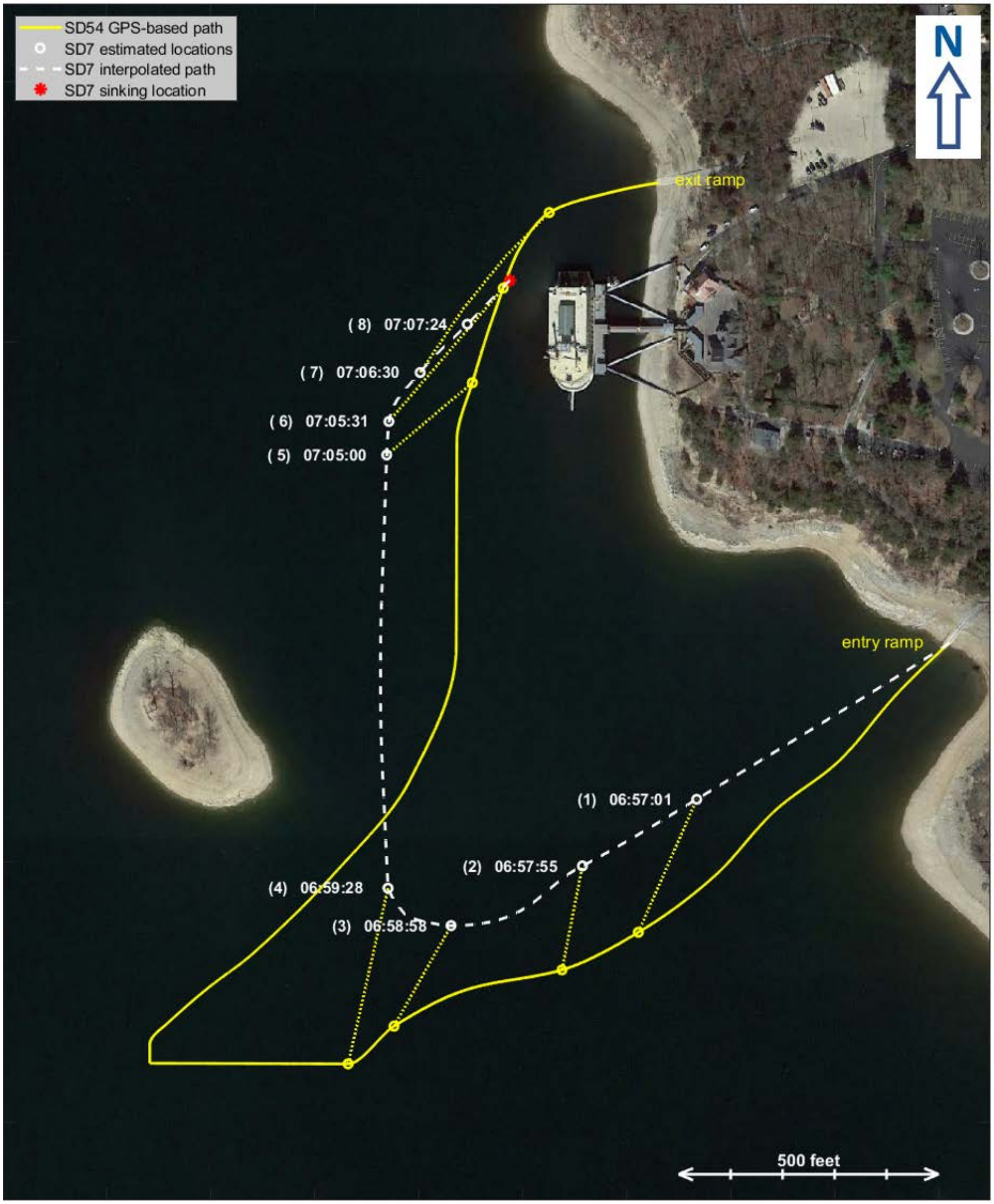

Figure 7. Aerial View of the Accident Area with Marked SD54 and SD7 Paths

Estimation of SD7 Locations Based on the Showboat Video

The estimation of the locations of SD7 based on the Showboat video used the calibrated mathematical model of the Showboat camera. Terrain information shown in Figure 4 was first used for estimating the yaw orientation of the camera for each analyzed video frame, as it was done during the calibration of the camera model. The location of the Showboat camera was known to be on the Showboat. The same wireframe model of the Stretch Duck that was used above for analyzing the SD54 video was then superimposed on frames from the Showboat video. The camera model then moved and rotated the wireframe model until it optimally matched the image of SD7 in a video frame. At that time, the location and orientation angles of the wireframe model were the optimal estimates of the location and orientation angles of SD7 at the time that Showboat video frame was recorded.

Figure 8. Frame from the SD54 Video Showing SD7 at Time 06:58:58

Four SD7 locations were estimated based on the Showboat video. They are marked by the white circles numbered 5 through 8 in Figure 7. The times corresponding to points 1 through 4 in the figure were based on the GPS-based time stamps on the SD54 video frames. The Showboat video frames did not have time stamps but its frame rate was known to be 30 fps. Showboat video frames that displayed SD7, SD54 or both were used for correlating the frame times in the Showboat video with the GPS time stamps of the SD54 video. The estimated accuracy of this time alignment was ±5 seconds. This time alignment made it possible to assign accurate GPS times to the four SD7 locations that were based on the Showboat video. These times, corresponding to points 5 through 8, are displayed in Figure 7.

The dotted yellow lines in Figure 7 that originate at points 5, 6 and 7 connect these points with the locations on the path of SD54 where SD54 was at the times when SD7 was at 5, 6 and 7. When SD7 was at location point 8, SD54 was already out of the lake.

Figure 9. Locations and Speeds of SD54 and SD7 along their Paths

Analysis of SD7 and SD54 Paths and Speeds

Since the path of SD54 was known accurately, it was possible to estimate its speed accurately based on its GPS-based locations along the path. Only eight locations, corresponding to eight GPS times, could be estimated along the SD7 path and are shown in Figure 7. Therefore, interpolation was used to estimate more SD7 locations along its path, from the entry ramp to its sinking location. Figure 9 shows the GPS-based locations of SD54 and the estimated SD7 locations along their paths in one minute intervals. Each path point is labeled with the time at that location and with a speed estimate at that time.

Figure 9 shows that until time 6:59:00, both boats moved southwest at about 3 mph. SD54 turned north, toward the exit ramp, at about time 7:01:00. It was already increasing its speed when it turned. Its speed peaked at 4.6 mph at time 7:03:00.

SD7 started turning north, toward the exit ramp, at about time 6:59:00. Its average speed decreased to about 1.7 mph after the turn. Consequently, while it turned north about two seconds before SD54 did, at time 7:04:00 SD54 was already ahead of it on its way toward the exit ramp because it moved faster. When SD7 sank, at about 7:08:00, SD54 was already out of the lake.

There is no direct information in the two analyzed videos to explain why the speed of SD7 was so much lower than the speed of SD54. One possible reason is the path SD7 took toward the exit ramp. As can be seen in Figure 9, SD7 path was almost 200 feet west of the path of SD54 and, therefore, farther away from the shore. It is possible that winds, waves and currents caused by the storm were stronger farther from the shore and slowed SD7 as it attempted to reach the exit ramp.

Wave Height Estimation

The Showboat video was used for estimating the wave height on the lake. The video lasted 5 minutes. SD7 was visible in the video for about 2.9 minutes and SD54 was visible for about 1.6 minutes. Wave height had to be estimated using the dimensions of the vessels as a distance reference. Consequently, only waves near the vessels could be analyzed. Furthermore, a wave had to be located between a vessel and the Showboat and sufficiently far from a vessel toward the Showboat so that the wave height was not affected by interaction with the vessel. Consequently, the wave height analysis that follows was limited by time and by location and not representative of the overall conditions on the lake.

Figure 10 illustrates the wave height estimation method. A video frame was selected where a vessel and two wave crests were visible. A line, shown in yellow in the figure, was drawn that was tangential to both crests. The distance H from the yellow line to the throw between the crests, measured perpendicularly to the yellow line, was considered an estimate of the wave height. Figure 10 shows SD7 and the highest wave that was observed in the Showboat video. The estimated wave height H was 3.5 feet.

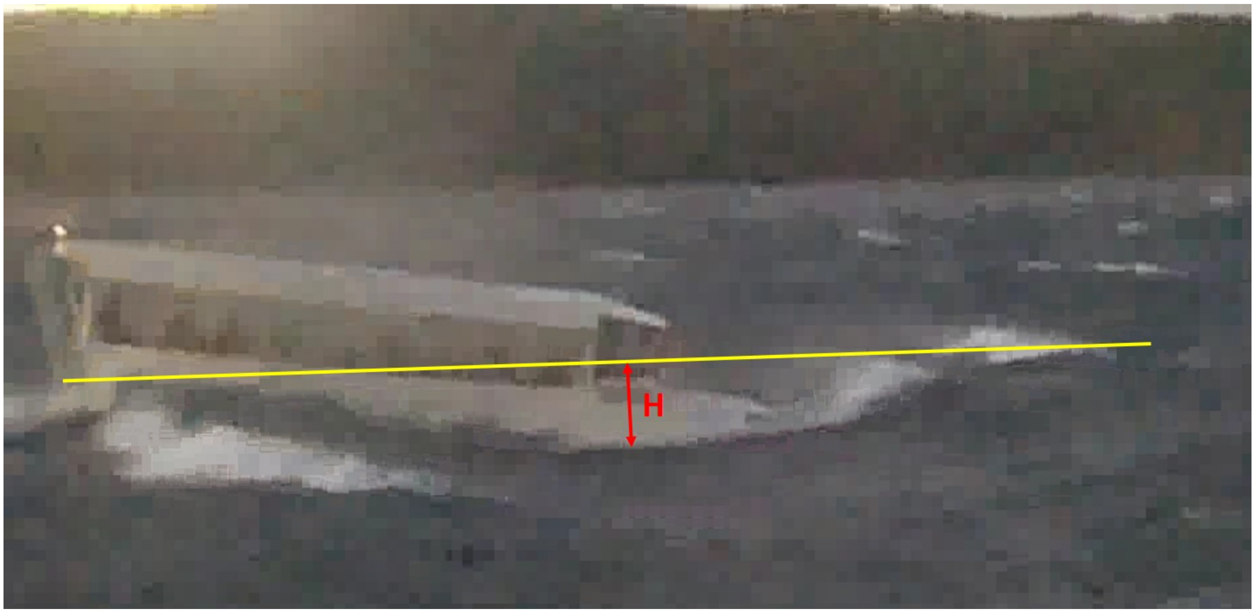

Figure 10. Wave Height Estimation

The video frame in Figure 10 and other frames show waves with wavelength of about 40 feet, a length that is close to the 33-foot length of the vessel. This resulted in large pitch motions of the vessels, as large as 6º at times. The estimated frequency of the pitch motion of the vessels was about 0.4 cycles/second. The large pitch angles resulted in the bow of the vessel going occasionally under water when a wave was approaching a vessel oriented with a bow-down pitch angle, as seen in Figure 10.

Vessel SD7, seen in Figure 10, was moving forward at about 1.6 mph. The waves were approaching the bow of the vessel (moving right to left in the figure) at the speed of about 10 mph at that time, slowing the forward motion of the vessel.

E. CONCLUSIONS

Videos recorded by two cameras were used for estimating the locations of a moving Stretch Duck amphibious passenger vessel that sank on a lake during a storm. The analysis resulted in accurate specification of the path of the vessel and in accurate speed estimates along the path. The height of waves on the lake was also estimated.