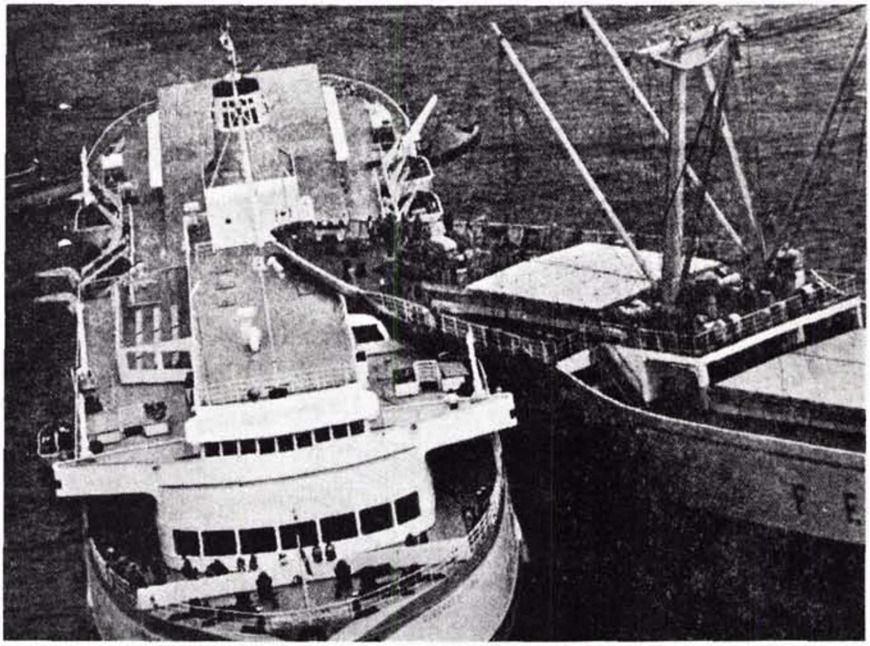

FRONTISPIECE. Photograph showing the impact of the freighter *Sergey Yesenin* and the ferry *Queen of Victoria*.

DR. A. J. BRANDENBERGER
Laval University
Quebec, Canada

Ship Collision Cases

Amateur movie frames were used in determining ships' positions with an accuracy of ±20 m and speeds to ±0.5 mph.

(*Abstract on page 36*)

INTRODUCTION

THE RANGE OF application of photogrammetry is nearly unlimited, and every year this potential method is used to perform the necessary measurements for projects and problems for which in the past conventional surveying and measuring techniques were applied. Evidently in recent years the potentiality of photogrammetry to solve surveying and measuring problems has been further emphasized by its superiority in solving four-dimensional measuring problems, i.e., for problems in which not only the three dimensions X, Y, and Z are involved but also their variability as a function of the time t (there are many problems in science and technology which require frequently repeated measurements as the dimensions to be measured are not time invariant). Such applications are particularly frequent in the field of the so-called nontopographic photogrammetry.

In the following sections are included two specific examples which clearly illustrate the multitude of applications of photogrammetry and which at the same time were subjects of research projects performed in our department.

THE CASE "SHIP COLLISION TRANSATLANTIC-HERMES"

Many applications of photogrammetric methods exist for measuring displacements of objects as a function of time. One spectacular example was the measurement of the displacement by aero-photogrammetric

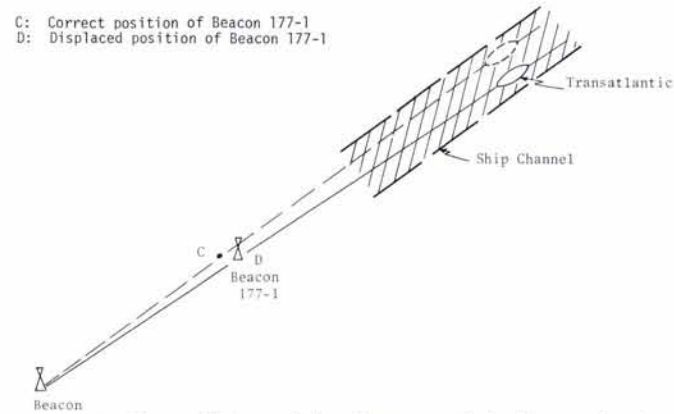

FIG. 1. Ship collision of the *Hermes* and the *Transatlantic*.

ABSTRACT: *The recording and mapping of traffic accident situations using standard equipment of terrestrial photogrammetry is a well known procedure. It is not so well known that in certain cases also aerial photogrammetry can or has to be used; or that the necessary measurements have to be done on movie pictures. In this case the problems can become quite complex. This is evident from the photogrammetric analysis of two ship collision cases which are discussed in this paper (Ship collision TRANSATLANTIC-HERMES in the St. Lawrence River and collision between the Russian freighter SERGEY YESENIN and the B. C. ferry QUEEN OF VICTORIA near Vancouver).*

methods of a navigation beacon due to ice pressure in connection with the ship collision between the German freighter *Transatlantic* and the Dutch freighter *Hermes* which occurred in April 1965 in the Lake St-Peter portion of the St. Lawrence River. As a consequence of this collision the German freighter sank and the respective insurance company claimed a damage compensation of \$5 million payable by the Canadian Government. This claim was based on the following justification: An investigation revealed that the mount of one navigation beacon (Ship Channel Point 177-1, Pointe du Lac Ranges) was oblique and that a displacement of the concrete pier carrying the beacon must have occurred probably due to ice pressure (see Figure 1).

From this assumption it was concluded that the freighter *Transatlantic* could have entered the ship channel on the wrong side due to a navigation error (alignment error) caused by the displacement of Beacon 177-1. The problem was to determine whether a displacement of Beacon 177-1 took place and, if so, whether the displacement was of such a magnitude as to explain the fact that the German freighter sailed on the wrong side of the ship channel, and also to determine when the displacement of Beacon 177-1 took place or whether this displacement was a gradual one as a function of time.

The position of Beacon 177-1 was determined in 1938 by the Canadian Hydrographic Office; since then, no further geodetic determination of the beacon's position was undertaken. However, aerial photographs were available of August 1959 taken from 18,000 ft flying height and of September and October 1964 taken from 8,000 ft and 18,200 ft respectively. On these photographs the pier carrying Beacon 177-1 was identifiable. Consequently, Canadian Aero Service Ltd., Ottawa, was asked to determine photogrammetrically the position of Beacon 177-1 for the years 1959 and 1964. For absolute reliability, an independent second position determination of the beacon was requested from Aero-Photo Ltd., Quebec, and General Photogrammetric Services Ltd., Ottawa, which companies entrusted verification of their work to our department.

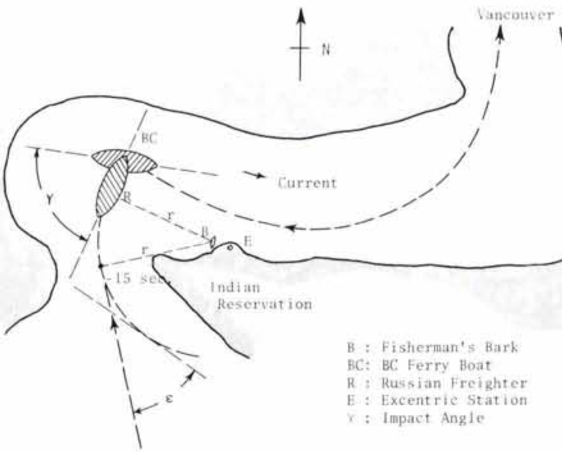

FIG. 2. Sketch of the collision of the *Sergey Yesenin* and the *Queen of Victoria*.

A total of eight ground controls points identifiable on the photographs were supplied by the Federal Department of Energy, Mines and Resources. The models in question were oriented at the Wild Autographs A7 and A8, and the instrument coordinates of all points in question were recorded on the coordinate printers. Data processing (coordinate transformation and adjustment) produced the following final results and conclusions:

- The photogrammetrically measured movement of Beacon 177-1 between 1938 and 1959 was 12.5 ft ± 3.0 ft along an azimuth of 90°;
- The photogrammetrically measured movement of Beacon 177-1 between 1959 and 1964 was 15.5 ft ± 3.2 ft along an azimuth of 102°;
- The total measured movement from 1938 to 1964 was 28.0 ft ± 1.01 ft

The error in position resulting from the two sets of observations from the 1959 photography is larger than what is normally experienced using this type of photogrammetric procedure. This is because of the nonoptimum location of the available control points which caused a rather narrow base to be used for the location of the beacon.

Our observations indicated definitely that Beacon 177-1 had moved between 25 and 30 ft since 1938. Our observations also indicated that this movement had been gradual over the period 1938–1964 with a smaller movement occurring before 1959 and a larger movement after 1959. These data were used as evidence material for the Supreme Court procedures.

THE CASE "SHIP COLLISION SERGEY YESENIN/QUEEN OF VICTORIA"

Another spectacular application of photogrammetry was the photoanalysis required for the collision between the 20,000-ton Russian freighter *Sergey Yesenin* and the 10,000-ton B. C. Ferry Boat *Queen of Victoria*, which occurred in August 1970 near Vancouver, and caused the death of three persons and a million dollars damage to both ships (the Russian freighter penetrated the ferry boat up to its center line). Figure 2 is a sketch map of the accident situation.

For the Court procedure it was desirable to reconstruct the path of both ships before the collision, to determine the exact position of the impact, to reconstruct the path of both ships locked together after the collision, and to determine the speed of both ships before and after the collision by considering also the current in the channel. For this purpose 8-frames-per-second 8-mm amateur movie pictures were available taken by a fisherman from his bark *B* before, at, and after the collision. Among other experts our department had been requested to solve this rather difficult problem.

The first clue to solve this problem was the fact that the Russian freighter sailed in a circle around the bark *B* starting 15 seconds before the impact. This was evidenced by the fact that the center starboard and port Samsons on the movie frames were in coincidence during this time period (see Figures 3 and 4).

The next thing we did was to identify horizon points H_1, H_2, H_3 (tops of fir trees) located on the vertical extensions through the midpoints of Samsons S_1, S_2, S_3. Then we decided that we had to turn angles from the position of Bark B (which would be located to an accuracy of about 1 to 2 m) to the horizon points H_1, H_2, H_3 for at least one movie frame.

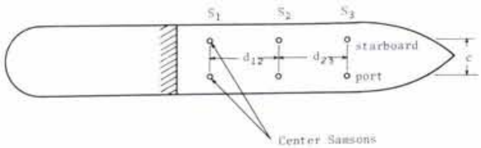

FIG. 3. Top view of the freighter *Sergey Yesenin.*

This caused some difficulty as the water depth at B exceeded considerably the height of our theodolite tripod. Fortunately we found an excentric station E on land near B from which the horizontal directions to Points H_1, H_2, and H_3 could be measured. These directions were then centered to Station B.

Now we had right triangles BH_1H_2 and BH_1H_3 with additional angles α_{12}, α_{13} and (provided by the Captain of the Russian freighter) known distances S_1S_2, and S_1S_3, respectively, (see Figure 5) which allowed us determine the radius r of the Russian freighter's circular path during the last 15 seconds before impact. In addition to this we determined by means of a magnetic compass the azimuth of lines BH. Thus, we were able to plot the freighter's circular path during the last 15 seconds before the collision including the impact point on an enlarged hydrographic chart by plotting on the same chart Station B and azimuth lines BH_1.

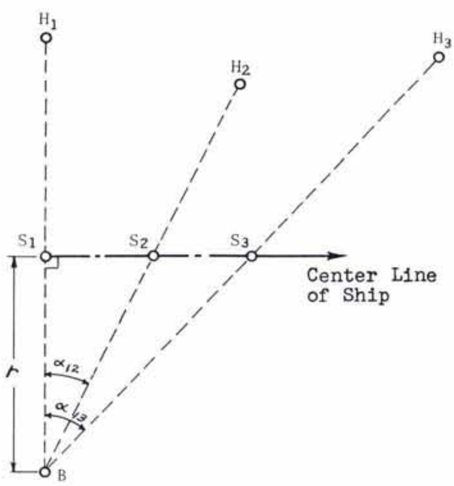

FIG. 4. Position of the *Sergey Yesenin* on the movie frames during the last 15 seconds before the impact.

The reconstruction of the path of the Russian freighter before Point 15 sec. was somewhat more difficult, and was achieved by determining for each movie frame before Point 15 sec. (see Figure 2) the angle ϵ between the respective course heading and the tangent to the circle with Radius r. The angle ϵ was obtained from the known distance c (see Figure 3) and from the distance a (see Figure 4) measured on the movie frame in question (for the photo scale, the value of the previous movie frame was taken by an integrative procedure until the respective frame for Point 15 sec. for which frame the photo scale could be determined by comparing Distances d on the movie frame with the true values).

The reconstruction of the path of the Ferry *Queen of Victoria* up to the point of impact was accomplished by an integrative process backward from the point of impact by comparing known dimensions of the ferry on the movie frames with the true values and taking into consideration the inclination angle of the ferry's center line with the site line from Station B.

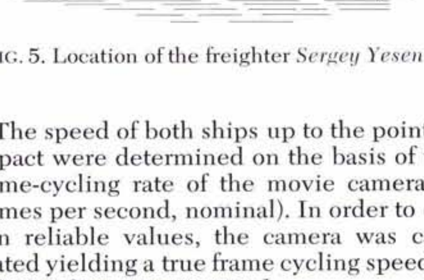

FIG. 5. Location of the freighter *Sergey Yesenin.*

The speed of both ships up to the point of impact were determined on the basis of the frame-cycling rate of the movie camera (8 frames per second, nominal). In order to obtain reliable values, the camera was calibrated yielding a true frame cycling speed of only 6.8 frames per second.

Finally, we were requested to determine the path and speed of both ships locked together after the collision. This was done by using similar procedures as described before. In connection with this phase also the impact angle γ between the center lines of both ships was determined. It could be assumed that this angle remained invariant (see Figure 2 and the Frontispiece) during the displacement of both ships (after collision). Due to the heavier weight of the freighter and the channel's current, both ships locked together moved in an easterly direction.

In evaluating the accuracy achieved in this particular project, one needs to take into consideration the low quality of the available movie pictures. We estimate that we achieved an overall positional accuracy in the order of 20 m and an accuracy for the speeds of the ships of approximately 0.5 mile/hour (standard errors) These accuracies were considered as sufficient in answering the question whether one of the ships or both sailed on the wrong side of the channel.

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