difference between the two groups did occur but it disappeared again by the end of the exercise.

In the urban area problem, the experimental group was told that a defecting municipal official had reported that unfriendly forces had placed military units in all hospitals in the area, and were using these hospitals as centers for political activity. He had also reported that this area was known for its many hospitals and that unfriendly forces had been using their control of these medical facilities to impose their will on the populace. In this exercise, both the experimental and control groups were required to search for all hospitals. In addition, both groups were required to search for all concentrations of 10 or more revetted buildings appearing in the photography. No suggestive information was given to either group as to the presence of revetted buildings however.

Analysis of the data—numbers of hospitals reported by the two groups—showed a significantly greater number of PI's in the experimental group reporting hospitals than in the control group for all time periods. No difference was found between the two groups in reporting revetted buildings.

To summarize these results, a *sustained* effect, due to the introduction of intelligence information, was found in only one case, that of hospitals. It is of interest to note that of all the objects used to test the effect of introducing intelligence information, hospitals are the most ambiguous and therefore, for the PI, are the most difficult to check. In some cases the intelligence information was effective in the initial time periods, and in others not at all effective.

In general, the data indicate that under some conditions the introduction of intelligence information has an effect on the PI performance, and that this effect is related to certain other variables of the photo interpretation situation. The variables hypothesized include such things as ambiguity of the object as noted in the case of hospitals, the effect of time as seen in the cases of tanks and vehicles, and object related factors. These variables will be investigated in future research as well as the general area of expectancy using experienced PI's.

Some methods which are now under study and which may compensate for the introduction of erroneous intelligence information, include such things as use of independent interpretations, peer and supervisor checks on interpretations, use of indications of confidence by the PI in his interpretation, and other somewhat similar devices. Other analyses which have been made of these data show that PI's are significantly more confident of their responses when they make a right response than when they make a wrong response. In other research which has been conducted it has been found that it is possible to substantially increase the proportion of right information, by pooling independent interpretations and by using items on which PI's agree.

### Reference

Solley, C. M. and Murphy, G. *Development of the Perceptual World*. New York: Basic Books, Inc., 1960.

# *Investigation of the Church Method for Orientation of a Single Aerial Photograph**

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(*Abstract is on next page*)

## Introduction

The Church Method is used to compute the tilt, swing, azimuth and exposure station coordinates for a single aerial photograph. The Alwac III-E computer program, which is currently being utilized for solution, was written by Charles W. Hanson, Broadview Research Corporation. The Church Method utilizes three or more ground-control points and determines the solution by an

* Publication in this Journal has been cleared by the Department of Defense.

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iterative process using the direction cosine method. Three sets of data are required for inputs into the program. These are the photographic coordinates of three or more photo-identifiable ground points (as measured by a precise micron comparator), the ground coordinates of the same three points (as computed on any cartesion coordinate system), and the approximate exposure station coordinates.

Since several sources of error were to be investigated, a set of fictitious photographic and ground-control data was computed to be used as inputs for the tests. This was accomplished using 20°, 35°, 45°, 60° and 70° tilts and a constant swing and azimuth of 180° and 360° respectively. The focal-length was 153 millimeters and the flying height was 18,000 meters. The tests were then begun, utilizing errors due to poor ground-control, poor photo-image coordinates, erroneous focal-length, film and lens distortion, etc.

ABSTRACT: *This paper describes the investigations of the Church Method for orientation of single oblique aerial photographs, as conducted by the 544th Reconnaissance Technical Group. The purpose of the project was to analyze various results due to introduced errors, and to determine any limitations which may exist in the method.*

## DISCUSSION AND RESULTS

The first two questions to be answered involved accuracy of ground control; the accuracy of ground control required to provide a correct solution to within 10 seconds of tilt, and the maximum error allowable prior to receiving an overflow from the computer. A very extensive program was prepared in order to attempt to answer these questions, since it is a known fact that ground-control will not always be accurate, depending on the area of interest, the charts, maps, and other geodetic information available, and the scale of the photography. Approximately 70 examples were run, deviating the ground-control from 20 to 5,000 meters, varying from 3 to 8 points, and utilizing all tilts mentioned in "Introduction." Reviewing all results it was noted that where 500 meter errors were introduced the errors in tilt averaged approximately 0°30′ and never more than 1°00′. Where 1,000 meter errors were introduced the resulting tilt error ranged from only 0°03′ to 1°35′. An estimate of 1°00′ could be assumed as an average error. Where more than 1,000 meter error was introduced the resulting tilt error ranged from 0°15′ to almost 4°, depending on several possible variations in point selection. The variations in results when utilizing 1,000 meter errors were so great that it seems reasonable to say that none of these results were reliable.

No computer overflows occurred due to severe ground-control variation. All overflows were caused by a poor selection of points, a selection which would cause an indeterminate solution in the computer. This indeterminate solution occurs when the projection of the exposure station falls on a circle or cylinder ("cylinder of confusion") defined by the three ground-control points.

The effect of misidentification or poor estimate of the exposure station was next considered. From 5,000 to 25,000 meter errors were introduced with interesting results. The average error in tilt was only 0°03′ up to 20,000 meters, with overflow occurring at 25,000 meters. It was safe to assume that up to 15,000 or even 20,000 meter errors can be tolerated in approximating the exposure station, assuming that the "cylinder of confusion" is not violated. This is equivalent to a radius of between 13 and 17 miles from the true exposure station.

Next, the effect of erroneous vertical control was studied. Inputs used all tilts and varied from 50 meters to 5,000 meters in differing amounts on the points. All tilts were very accurate, the only error being in the $Z$ value (altitude of aircraft) of the exposure station. In all cases the final error in $Z$ was equal to the variation introduced in the vertical ground-control.

The maximum allowable error in photo coordinates and the effect of film shrinkage were covered by the same test since film shrinkage warps the photo coordinates. A shrinkage of 0.4 per cent across the film and 0.3 per cent along the film giving a differential contraction of 0.1 per cent, was used for this test. The photo coordinates were then modified to this indicated film shrinkage. This error amounted to 0.300 millimeters, far more than would be encountered in photo measurement. The errors in tilt averaged only 0°18′. This would indicate that film distortion does not affect tilt determination appreciably.

The next test was to determine the effect of a mismatched ground coordinate and photo coordinate system; i.e., the ground coordinates with positive $X$ to the left and the photo coordinates with positive $X$ to the right. As was expected the only change was in the final azimuth, 180 degrees opposite from the azimuth where the coordinate systems were matched. The tilts remained the same, as did the swing. This test was conducted to verify the fact that the positive $y$ photo axis should always be toward the horizon on an oblique photograph. This means that in a flight traveling north, the positive $y$ axis of the right oblique would be east, and the positive $y$ axis of the left oblique would be west, 180° opposite; the only difference appears in the azimuth, with the tilt and swing remaining the same for both obliques.

Tests were then conducted to determine the effects of an erroneous focal length. A two millimeter error would be an extreme case where the calibrated focal-length was unknown. This discrepancy was fed into the data and the maximum error in tilt was only 0°28′, the average of ten examples being 0°8′.

Three other extensive tests were also run. These involved tests where no error was introduced, the effect of weak triangle selections, and the effect of multiple errors introduced simultaneously. The first test runs, involving no error, were performed to check the accuracy of the fictitious data; the error in the results believed to be due to round-off in the original ground coordinate computations amounted to less than 00°04′. Further tests revealed a larger error when 35° tilt examples were used.

Investigation of 35° tilt examples led to a complete study of the relationships of the nadir-point to the ground-control. From this study it became evident that between tilts of 30° and 45° the nadir-point fell in such a position as to cause many possible "circles of confusion." This investigation was deemed

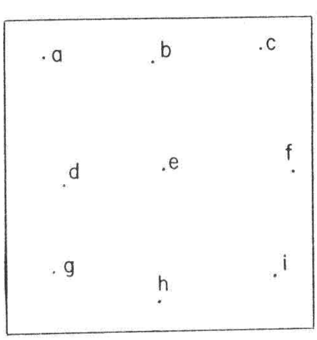


FIG. 1. Location of fictitious points on 9″×9″ aerial photograph. (Same points used for all tests.)

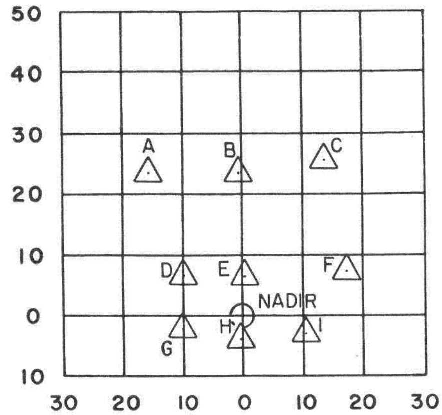


FIG. 2. Relationship of points on ground to the nadir point when 20° tilt exists in the photograph (in thousands of meters).

practical since many split-vertical and trimetrogon camera configurations utilize obliques within this vertical range of tilt. As a result, graphs were prepared which illustrate the relationships of the points selected for this project with the nadir-point for 20°, 35°, 45°, 60° and 70° tilts. Note Figures 1 through 6. These graphs are very useful in selection of points, since one can visually evaluate the best areas to obtain a strong triangle or network of triangles, and at the same time prevent selection of points which would cause an overflow due to the "circle of confusion" or the 4:1 ratio.

A word is necessary at this point as to the definition of a strong triangle and a 4:1 ratio.

The errors in tilt determination caused either by errors in photo measurements or errors in ground-control is inversely proportional to the area of the control triangle. In

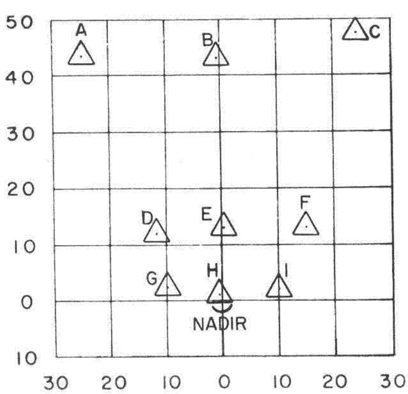


FIG. 3. Relationship of points on ground to the nadir point when 35° tilt exists in the photograph (in thousands of meters).

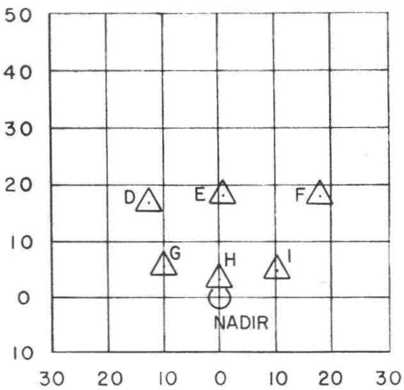


FIG. 4. Relationship of points on ground to the nadir point when 45° tilt exists in the photograph (in thousands of meters). Points A, B and C cannot be used since they fall beyond the 4:1 limit.

what is considered a strong control triangle, the three angles will be approximately the same, that is, almost an equilateral triangle.[1] This type of triangle will obviously have more area than one in which the three angles are widely dissimilar.

The other consideration in point selection is the 4:1 ratio factor. The straight line distance between the exposure station and the farthest ground point selected should not exceed four times the distance from the exposure station to the nearest ground point selected. If this 4:1 ratio is exceeded the computer will automatically overflow. It should be noted that the 4:1 ratio is only applicable to this particular computer program.

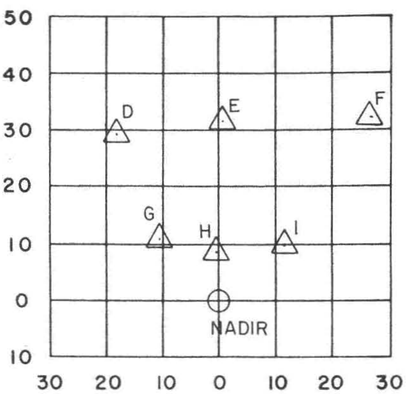


FIG. 5. Relationship of points on ground to the nadir point when 60° tilt exists in the photograph (in thousands of meters). Points A, B and C cannot be used since they ran beyond the 4:1 limit.

The tests for weak triangles further proved that a strong triangle is essential for accurate results. Although most results using weak triangles were good, it was impossible to predict which examples would give a result and which would cause an overflow in the computer. Approximately thirty per cent of these examples resulted in an overflow.

When several sets of errors were introduced simultaneously, the resulting errors could almost be predicted based upon point location. Most errors were less than 0°30′ in tilt when strong triangles or triangle networks were used. The largest error occurred with a good triangle network, but the introduced errors were extreme, i.e., 3 millimeters in focal-length, 1 millimeter in photo coordinates, 500 meters in ground-control, and 200 meters in vertical-control.

## CONCLUSIONS

Analyzing the project as a whole, one general conclusion can be reached. The selection of ground points must be such as to minimize the chance for a "circle of confusion" and at the same time emphasize the chance for the strongest triangle or network of triangles possible.

The accuracy of ground-control required to provide a correct solution to within 10 seconds of tilt cannot be ascertained. The reason for this is that a 20 meter error in only one point can cause up to 0°4′ error in tilt. An almost perfect set of data could cause more

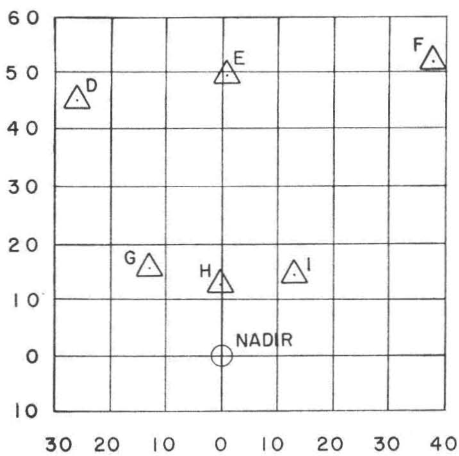


FIG. 6. Relationship of points on ground to the nadir point when 70° tilt exists in the photograph (in thousands of meters). Points A, B and C cannot be used since they fall beyond the 4:1 limit.

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[1] "The Accuracy of Space Resection and Tilt Determination," Frederick J. Doyle, Mapping & Charting Research Laboratory, Tech. Paper No. 211.

than a 10 second error in tilt, due only to the mechanics of the mathematics. From the results it can then be concluded that in no case may an accuracy of better than 30 seconds be expected. In order to provide a correct solution to within 30 seconds of tilt, the accuracy of the ground-control should be 500 meters or better. Also, to provide a correct solution to within one degree of tilt, the accuracy of the ground-control should be 1,000 meters or better. Any control less accurate than 1,000 meters would cause an error in tilt up to 5 degrees.

It now becomes evident that if ground-control is scaled from a chart on which positions are in error by more than 1,000 meters the resulting tilt could be considered excessive for reliable orientations. In reviewing procedures from past SAC rectification projects, it was found that the charts used for scaling control (AMS 1:50,000 and 1:250,000) were of poor reliability. Recent projects within this same area of interest indicate that the reliability of the charts, maps, and control is very poor, with possibly greater than 1,000 meters error in some areas. After this initial error is determined, additional errors are introduced in point identification and in operator measurement, which could cause further discrepancies from the true photo orientation. Therefore, ground-control information is very important if a satisfactory result is expected. It is recommended that if geodetic information on the selected points is not available—and in most cases the information will not be available in certain areas of interest—then an evaluation of the accuracy of the chart must be conducted prior to point scaling.

All other introduced errors caused little effect on the true orientation. Estimation of the approximate exposure station need be accurate only to 15,000 meters. Vertical-control errors affect only the true flying height of the aircraft but yield good results in tilt. Minor operator errors in comparator measurements have little effect, as do film distortion errors amounting to a differential contraction of 0.1 per cent. Mismatched coordinate systems are not a problem if flight orientations are properly evaluated before computation. Erroneous focal-length error is also negligible if the error is not over 2 or 3 millimeters.

In examples other than fictitious it is possible that any combination of errors could exist, and probably do exist. However, it is believed that if all errors in focal-length, photo measurement, and film distortion can be kept to a minimum, then the only problem is in ground-control reliability. If the ground-control is reliable to the desired accuracy, then the rest of the job is mechanical. That is, it is then the technician's job to assure that the 4:1 ratio is not violated and that a strong triangle network of ground points is selected. If all conditions are satisfied as mentioned, then the photo orientation can be considered reliable.

In conclusion, reference is made to Wright Air Development Center Technical Report 56–7 which states the following: "in terms of accuracy the analytical computation methods such as the direction cosine method (Church Method) are superior to other analytical tilt determination methods because they are mathematically correct, and the personal equation has been almost completely eliminated."

# IMPORTANT NOTICE

If you have not yet read page 695, I urge that you do it now. Then make definite plans for MARCH 11-17, 1962.

THE EDITOR