Reliability of Aircraft Altitude Estimates by Ground Observers

Euegene W. Benson

Western Michigan University

Follow this and additional works at: https://scholarworks.wmich.edu/masters_theses

Part of the Aviation Commons

Recommended Citation

https://scholarworks.wmich.edu/masters_theses/3538

This Masters Thesis-Open Access is brought to you for free and open access by the Graduate College at ScholarWorks at WMU. It has been accepted for inclusion in Master's Theses by an authorized administrator of ScholarWorks at WMU. For more information, please contact maira.bundza@wmich.edu.
RELIABILITY OF AIRCRAFT ALTITUDE
ESTIMATES BY GROUND OBSERVERS.

by

Eugene W. Benson

A thesis presented to the
Faculty of the School of Graduate
Studies in partial fulfillment
of the
Degree of Master of Arts

Western Michigan University
Kalamazoo, Michigan
August 1964
ACKNOWLEDGMENTS

The investigator wishes to thank the many members of the Michigan Air National Guard of Battle Creek, Michigan who participated in this study. This project could not have been completed without the splendid cooperation and support they provided. Especially helpful were Major Howard C. Strand, Major Richard Rann, Captain Kenneth Stick, Sergeants Robert J. Grycska, Frank A. Leach and Paul McArthur.

The investigator wishes to express his sincere appreciation to his instructors -- Dr. E. J. Asher, Dr. Frank Fatzinger, Dr. Stanley Kuffel and Dr. George G. Mallinson -- for their assistance, advice and encouragement.

Others who deserve special mention for their active support of this project are Dr. T. E. Cotterman, Mr. Milton E. Wood and Mrs. Helen Lehman of the Behavioral Sciences Laboratory, Wright-Patterson Air Force Base, Ohio.

Eugene W. Benson
<table>
<thead>
<tr>
<th>TABLE OF CONTENTS</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>THE PROBLEM AND ITS BACKGROUND</td>
<td>1</td>
</tr>
<tr>
<td>THE PRELIMINARY INVESTIGATION</td>
<td>3</td>
</tr>
<tr>
<td>Introduction</td>
<td>3</td>
</tr>
<tr>
<td>Method</td>
<td>4</td>
</tr>
<tr>
<td>Results</td>
<td>7</td>
</tr>
<tr>
<td>Discussion</td>
<td>11</td>
</tr>
<tr>
<td>THE RELATIONSHIP OF ANGLE OF ELEVATION WITH ALTITUDE ESTIMATION</td>
<td>13</td>
</tr>
<tr>
<td>Introduction</td>
<td>13</td>
</tr>
<tr>
<td>Method</td>
<td>14</td>
</tr>
<tr>
<td>Results</td>
<td>19</td>
</tr>
<tr>
<td>Discussion</td>
<td>23</td>
</tr>
<tr>
<td>SUMMARY</td>
<td>25</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>27</td>
</tr>
</tbody>
</table>
Occasionally it is extremely important to obtain an accurate estimate by a ground observer of an aircraft's altitude. Many of the incidents requiring altitude estimates occur at or near centers of flying activity such as commercial airports or military bases. Investigations of accidents or instances of flying violations, for example, commonly produce a wide variation in altitude judgments from witnesses.

Altitude judgment has not been widely investigated. Conclusions from experimental studies reported by Applied Psychology Corporation (1963) indicate an estimate of a target's altitude by an observer must be accompanied by some estimate of its range. These studies were basically concerned with range and altitude judgments and their role in mid-air collision prevention. Most of the data are related to estimates by pilot-observers who were in flight at the time of the observations. Ground-to-air judgments of altitude by the pilots were shown to be less accurate than the air-to-air estimates. In general, a poor performance in altitude judgment was found in all studies.

A further review of the literature reveals that conventional experiments have been limited to some form of laboratory distance-size estimating tests. Most of these experiments discuss relatively short distances of 30 feet or less; many are limited to inches. They seem to be only vaguely related to estimating distances or altitude through the atmosphere. Distance and altitude judgments through the atmosphere present problems not easily simulated in the laboratory.
A preliminary investigation was made by the experimenter to determine the relationship between an individual’s accuracy in judging aircraft altitude and the extent to which his occupation is related to flying. It was felt by the experimenter that flying experience would affect accuracy in altitude judgment. This is based on general knowledge that experience is a major factor in perceptual judgment. In addition, the preliminary study attempted to identify some of the factors influencing the individual judgments.

The design of the experiment of main concern in this report was based upon the results of the earlier study. A specific factor of altitude judgment was investigated in this second experiment -- the relationship between angle of elevation and the accuracy of altitude estimation. One of the studies dealing with short distances (Hermans, 1954) discussed the relationship between elevation change and perceived size. The angle of elevation was found to influence the perceived size of an object.

The Battle Creek Air National Guard Base of Battle Creek, Michigan was chosen as the site of the experiments. The commander, flight operations officer, pilots and many other men of the unit cooperated to provide direct support for the investigations. Additional approval and cooperation were required and received from local officials of the Federal Aviation Administration (FAA).
The preliminary investigation

The purpose of this experiment is to determine the accuracy with which a ground observer can judge the altitude of an aircraft in flight, and to determine the effect on an individual's flying experience on the judgment accuracy. Since there are very little data available concerning this particular problem, another purpose of this study is to try to identify and define other factors which might influence accuracy in altitude judgment.
Method

Aircraft employed in the investigation were RB-57 jet bombers assigned to the Air National Guard. This aircraft has a wing span of 64 feet and is 65.5 feet in length. The height of the plane is 14.8 feet (Gallery of USAF Weapons, 1962). Pilots were assigned various altitude levels at which to fly over three different ground positions. The positions were at different distances and directions from the single point of observation where all subjects were stationed. Table 1 shows the conditions for each of the experimental flights.

A random assignment for the sequence of flights was employed. "Angle of Elevation" in Table 1 refers to the approximate size of the angle formed by two lines diverging from the observation point to the aircraft being observed and to the predetermined ground position directly below the aircraft.

Only one flight was scheduled at the 150 ft. level over Position 1. Safety restrictions prohibited the 150 ft. flights over Positions 2 and 3. A dwindling fuel supply prevented one pilot from flying three assigned passes, and one 4500 ft. pass was obscured by a patch of clouds. This accounts for the blank spaces in Table 1. Weather conditions and a lack of time prevented a rescheduling of flights.

A total of fifteen men served in the experiment as subjects in three groups of five men each. Group "A" subjects all had extensive flying experience. It consisted of two pilots, two navigators, and one flight engineer. All five subjects in Group "B" were experienced
### Table 1

**Experimental Flight Conditions:**

**Flight Sequence and Angle of Elevation**

<table>
<thead>
<tr>
<th>Assigned Altitude</th>
<th>Position 1</th>
<th>Position 2</th>
<th>Position 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>11,080' South</td>
<td>5,600' West</td>
<td>1,000' Southeast</td>
</tr>
<tr>
<td>Sequence</td>
<td>Angle</td>
<td>Sequence</td>
<td>Angle</td>
</tr>
<tr>
<td>4500'</td>
<td>8</td>
<td>22°</td>
<td>*</td>
</tr>
<tr>
<td>3500'</td>
<td>1</td>
<td>18°</td>
<td>*</td>
</tr>
<tr>
<td>2500'</td>
<td>6</td>
<td>13°</td>
<td>10</td>
</tr>
<tr>
<td>1500'</td>
<td>7</td>
<td>8°</td>
<td>2</td>
</tr>
<tr>
<td>500'</td>
<td>12</td>
<td>3°</td>
<td>5</td>
</tr>
<tr>
<td>150'</td>
<td>11</td>
<td>1°</td>
<td></td>
</tr>
</tbody>
</table>

* Weather conditions and procedural difficulties prevented flights at these levels.
flight line mechanics who did not ordinarily participate in aerial flights as part of their duties. Subjects of Group "C" were members of the Air National Guard, as were all subjects, but their duties were less associated with flying activities than were those of subjects in Groups "A" and "B". Group "C" consisted of two clerks, two cooks, and one medical technician. None of Group "C" had extensive flying experience. All subjects had normal vision.

The subjects were instructed to record the altitude estimate (in feet) as each aircraft pass was made. The nature of the experiment was explained and the investigator asked subjects not to reveal their responses to others or discuss the experiment after it began. A mobile radio unit in contact with the pilots relayed information to the investigator as to which aircraft was beginning its passes. The investigator could then direct the subjects' attention to the area where the plane would fly. For Position 1, the pilots flew either an east to west or a west to east heading, maintaining the assigned altitude for one mile on each side of the point or position directly south of the observation point. The subjects were told to record their estimates for the altitude at this position directly south of the observation point. Similar procedures applied for flights over Positions 2 and 3. Over Position 2, pilots flew either a north to south or a south to north heading. Headings of either northeast to southwest or southwest to northeast were flown over Position 3. Airspeed was between 250 and 300 miles per hour for each pass.
Results

The subjects' responses were scored by determining the difference between the estimate and the actual aircraft altitude. It was also noted whether each incorrect estimate was above or below the correct altitude. The "average error" per estimate or observation over all twelve observations for each group is as follows: (1) Group "A" -- 709 feet, (2) Group "B" -- 1331 feet, and (3) Group "C" -- 1748 feet.

Figure 1 shows results of the six observations of flights over Position 1 in terms of group average error. The results of Position 2 observations are presented in Figure 2. Figure 3 shows the results of the flight estimates for Position 3.

There was no consistent direction in error as an underestimation or as an overestimation of altitude for either Group "A" or Group "B", or for individual subjects of these groups. Most individual subjects of Group "C", however, showed tendencies to be either consistently high or consistently low in all their estimates.
AIRCRAFT ALTITUDE AND ANGLE OF ELEVATION FOR EACH FLIGHT

Figure 1. Average Error of Estimates for Each Group for Flights Over Position 1.
Figure 2. Average Error of Estimates for Each Group for Flights Over Position 2.
Figure 3. Average Error of Estimates for Each Group for Flights Over Position 3.
Discussion

A reasonable assumption would be that total error in estimate will increase as altitude increases. A 500 ft. judgment error for an observation of an aircraft at 5000 feet in altitude is within 10% of the correct response, but a 500 ft. error for a 1000 ft. flight is 50% off the correct response.

Figure 1, a graph showing results of Position 1 flights, illustrates two inconsistent points. The first and most noticeable is the error peak for 2500 feet followed by the decline in error at 3500 feet. A possible explanation will be discussed later. The second point worthy of mention is the response accuracy of Group "C" subjects for the 1500 ft. observation. No reason other than chance is offered to account for this inconsistency.

Noteworthy in Figure 2, again, is the error peak at 1500 feet. This seems to dispute the contention expressed earlier that errors should increase as altitude increases. The error peak in Figure 2 is at 1500 feet while in Figure 1 the peak is at 2500 feet. A possible explanation could be the effect of the angle of elevation. The angles corresponding to the two error peaks are just two degrees apart. The particular aircraft used in this experiment is quite large overall, but with a height of only 114.8 feet, it presents a very slim silhouette when viewed from the low angles of elevation. At the 3, 5, and 8 degree angles, there is the obvious advantage of using relative distance above terrain as a cue for altitude judgment. Perhaps the appar-
ent increase in total area of the aircraft which can be seen at 18 or 20 degrees over that viewed at 14 degrees is enough to influence the accuracy in altitude estimates.

Figure 3 shows the greatest differences in response errors for the three groups. Position 3 was the closest to the observers. Familiarity with aircraft landing and takeoff patterns by Group "A" subjects probably influenced these estimations in their favor.

The results generally indicate that flying experience is related to accuracy of altitude estimation. This is not surprising. The sample size was small, but representative of distinct occupational groupings within the organization.

Procedural difficulties were encountered as in most preliminary studies. For example: The use of several aircraft of the same type for the test was not an efficient method. One pilot ran low on fuel while waiting for his turn to make his assigned passes.

This study has shown that experience related to flying influences the accuracy of altitude judgment. There is a strong indication that the angle of elevation at which the observation is made also influences the judgment.
THE RELATIONSHIP OF ANGLE OF ELEVATION WITH ALTITUDE ESTIMATES

An interpretation of the results of the preliminary study suggested a similar experiment using angle of elevation as an equating comparison measurement. Based on these preliminary findings, a specific hypothesis was made by the investigator.

Hypothesis

The percentage of error in estimating altitude by ground observers will tend to be larger for flights near 15 degrees of elevation than for flights at other angles.
Method

The site for conducting this test was the same used for the first study. An RB-57 jet bomber assigned to the Air National Guard was used in this study also. In this case, however, only one pilot was employed to make all the flights to be observed. This procedure allowed closer coordination between the investigator and the pilot through the mobile radio facilities, compared to procedural difficulties encountered in the preliminary study in which several aircraft were used.

The pilot flew over three assigned ground positions located at different distances and directions from the single point of observation where all subjects were stationed. The aircraft was flown over these positions at altitude levels which were systematically varied so flights could be viewed at equivalent angles. The flight conditions are described in Table 2.

A random assignment for the sequence of flights was employed. "Angle of Elevation" in Table 2 refers to the approximate size of the angle formed by two lines diverging from the observation point to the aircraft being observed and to the predetermined ground position directly below the aircraft.

The discrepancy between the approximate angle of elevation presented in Table 2 and the exact angle is very slight. The following procedure was used to assign the altitude level for each flight: (1) The exact desired altitude to produce a particular angle of elevation
Table 2
Experimental Flight Conditions:
Flight Sequence and Altitude

<table>
<thead>
<tr>
<th>Angle of Elevation</th>
<th>Position 1</th>
<th>Position 2</th>
<th>Position 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Position 1</td>
<td>Position 2</td>
<td>Position 3</td>
</tr>
<tr>
<td></td>
<td>Sequence</td>
<td>Altitude</td>
<td>Sequence</td>
</tr>
<tr>
<td>5°</td>
<td>10</td>
<td>1,008'</td>
<td>12</td>
</tr>
<tr>
<td>15°</td>
<td>2</td>
<td>3,008'</td>
<td>4</td>
</tr>
<tr>
<td>30°</td>
<td>11*</td>
<td>6,408'</td>
<td>7</td>
</tr>
<tr>
<td>60°</td>
<td>5*</td>
<td>19,158'</td>
<td>6*</td>
</tr>
</tbody>
</table>

* No observations were recorded for these flights which were obscured by clouds.
was calculated to the nearest foot. (2) The elevation of the field above sea level (942 feet) was added to the desired altitude. (The aircraft's altimeter registers feet above sea level.) (3) This figure was rounded to the nearest 50-foot interval for the pilot's convenience in reading the altimeter and maintaining the altitude throughout the flight. (4) To obtain the actual altitude above the ground which is presented in Table 2, field elevation was subtracted from the altimeter reading. An illustration of this procedure using the fourth flight of the sequence is presented as an example:

\[ \begin{align*}
1512 \text{ feet} & \quad \text{(Altitude of aircraft necessary to produce a 15° angle of elevation over Position 2)} \\
+942 \text{ feet} & \quad \text{(Field elevation above sea level)} \\
2454 \text{ feet} & \quad \text{(Altimeter reading necessary to produce a 15° angle)} \\
2450 \text{ feet} & \quad \text{(Actual altimeter reading for flight)} \\
-942 & \quad \text{(Actual altitude above Position 2)} \\
\end{align*} \]

Subtracting 942 from the altimeter reading of each flight accounts for all altitude levels in Table 2 ending with the digit "8".

As occurred in the preliminary study, weather conditions interfered with observation of certain flights. A solid cover of clouds at about 5,000 feet in altitude appeared shortly after the experiment began. Nine of the twelve flights in the experimental design were visible to the observers.

A total of 18 subjects served in the experimental and control conditions for the purpose of this investigation. The subjects were members of the Air National Guard and were chosen on the basis of availability. A division of subjects into stratified groupings based on experience, as was done in the preliminary study, was not consi-
dered to be necessary for this test. The responses from subjects of all three groups in the first study were indicative of a general pattern of error in altitude judgment—experience being a factor only in magnitude of error.

The military positions held by the subjects are summarized: Seven were aircraft mechanics, there were two pilots, two flight engineers, two aircraft inspectors, one navigator, one clerk, one accountant, one roads and grounds specialist, and one educational specialist. The subjects' range of age was from 21 to 49 years; the average age was 35 years.

The subjects assembled at the observation point and were given the following information and instructions:

"This is an experiment in which you are requested to make some estimates of aircraft altitude. Each of you has been given a folder with a numbered paper on which to record your estimates.

I'd like your names on the papers, only for the purpose of establishing the amount of experience you have with the aircraft. Individual names will not be used in any report. The individual responses will not be disclosed.

I'd rather not discuss now, too much of the nature of the experiment, at least until after the results today. However, I'll send a copy of the final report to Sergeant McArthur when the results are analysed. He can circulate this among those of you who might be interested in the results.

Please make each estimate in feet and record this in your folder without revealing to anyone else, and please don't discuss any of your judgments with anyone until we have completed this test today."

The investigator was in radio contact with the pilot and directed the subjects' attention to the area of each experimental flight. For
Position 1 the pilot flew either an east to west or a west to east heading, maintaining the assigned altitude for one mile on each side of the point or position directly south of the observation point. The subjects were told to record their estimates for the altitude at this position directly south of the observation point. Similar procedures applied for flights over Positions 2 and 3. Over Position 2, the pilot flew either a north to south or a south to north heading. Headings of either northeast to southwest or southwest to northeast were flown over Position 3. Airspeed was between 250 and 300 miles per hour for each pass.
Results

The scoring system used was the subject's error, in feet, divided by the correct altitude of the particular flight. This score multiplied by 100 yields the "percentage of error".

All subjects' responses in terms of percentage of error, plotted on a frequency graph, produces an approximately normal curve with a slightly positive skewness. An analysis of variance was performed to detect differences in subjects' responses to the various flights. The procedure suggested by Winer (1962) for experiments having repeated measures on the same elements was followed. Subjects who, for various reasons, did not make responses to all of the nine experimental flights were eliminated from consideration for the purpose of this analysis. Four subjects were in this category.

The *F* statistic in Table 3 shows a significant difference exists between means; but Figure 4, which shows the group's percentage of error for each flight, is an obvious indication that the stated hypothesis must be rejected. The flights viewed at angles of 15 degrees did generally produce greater judgment error than the flights observed at the other elevation angles. Flight 9 produced a significantly greater percentage of error, but Flights 2 and 4 which were also observed at the 15 degree angle of elevation did not.

There were no absolutely correct responses in this test. This investigator noted the "round number tendency" on the part of the subjects' responses as described by Gibson and Bergman (1954). Sub-
Table 3

Analysis of Variance

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Subjects</td>
<td>24,728.51</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within Subjects</td>
<td>76,213.08</td>
<td>112</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flights</td>
<td>21,612.59</td>
<td>8</td>
<td>2701.57</td>
<td>5.15**</td>
</tr>
<tr>
<td>Residual</td>
<td>54,600.49</td>
<td>104</td>
<td>525.00</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>100,941.59</td>
<td>125</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**F .99 (8,60) = 2.82**
Figure 4. Percentage of Error for Observers' Altitude Judgments.
jects were free to use any number, but of course some number cate-
gories were preferred over others. All subjects showed a tendency to
use numbers ending in "0".

There was an obviously significant direction to the error of
estimation for this group of subjects. Almost all of the subjects
were consistently low in their estimates. Of a total of 147 responses
by the group, 25 were "high" and 122 estimates were "low".
Discussion

The pattern of error evident from the preliminary investigation, which suggested that flights viewed at angles approximate to 15 degrees would produce greater error in altitude judgment, did not appear in the results of this study. The hypothesis of effective angle of elevation was not supported.

There is no apparent logical explanation for the wide deviation in percentage of error for Flight 9 observations. The relatively low altitude of this flight coupled with the fact that subjects showed a tendency to respond in "round numbers" appears as a temptingly reasonable explanation for the high percentage of error. However, it is not supported by the data. One other flight (Flight 3) was flown at approximately half the altitude of Flight 9, yet produced a rather low error percentage in responses.

Nearly all sets of responses in this study were quite accurate in comparison to the estimates of the preliminary study. One possible explanation for this discrepancy is the difference in weather conditions affecting visibility. The sky was "broken cloudy", but "bright" for the first experiment. A solid cover of clouds at about 5,000 feet in altitude was evident throughout most of the second experiment. This factor was not considered to be serious at the time the data were collected.

The consistent pattern of "low" estimates made by the subjects of this experiment could possibly be the most important result of
the study. Perhaps conditions similar to those experienced at that
time, such as weather, consistently influence judgments in this manner.

One problem which confronts units of the Air Force and Air Na-
tional Guard is the high frequency of complaints from the citizenry
concerning low-altitude flights. Quite often a report will be received
that "a jet came by just 50 feet above my house," when the altimeter
reading and radar tracking devices show the aircraft to be well above
the minimum levels set by regulation.

Additional experiments would be necessary to support the inves-
tigator's opinion that weather conditions could affect the accuracy
of altitude judgment by ground observers.

Factors which should be investigated in the future are: The
influence of aircraft size on altitude judgment, the effect of a
completely "clear" sky on judgment, and further experiments concern-
ing effects of various weather conditions.

The possibility remains that angle of elevation could be an influ-
encing factor in altitude judgment under certain circumstances. Even
though this study did not prove a definite relationship exists, the
angle of elevation at which an aircraft is viewed should be considered
as one of the possibly influential factors in altitude estimation.
SUMMARY

These investigations were conducted in an attempt to obtain information concerning the ability of ground observers to judge the altitude of aircraft in flight. There are frequent instances which require the testimony of witnesses in this regard. Aircraft accident investigations, for example, have produced a wide variation in altitude judgment by different witnesses to the same occurrence.

The studies have attempted to answer the following questions:

1. How accurately can an individual on the ground judge the altitude of an aircraft in flight?  
2. Does the individual’s flying experience affect his accuracy?  
3. What factors influence altitude judgment?, and subsequently,  
4. Is the angle of elevation at which the individual observes the aircraft influential to the judgment accuracy?

Both of the studies used the RB-57 jet bomber as the experimental aircraft. The aircraft, participating pilots, and subjects were assigned to the Air National Guard base at which the tests were conducted.

In the first or preliminary study, the subjects were arranged in occupationally oriented stratified groupings. The results of this study were a clear indication that experience related to flying is a positive influence on judgment accuracy.

The results of this preliminary study also supported the need for an investigation of the effects of angle of elevation on altitude
judgment. This was the purpose of the second experiment. On the basis of the preliminary findings, the investigator hypothesized that flights viewed at angles of about 15 degrees would produce a higher percentage of error in altitude judgment than would flights viewed at different angles.

The design of the second study was quite similar to that of the first. Certain procedural improvements were incorporated into the design of the second experiment.

A statistical analysis of the results of the second study did not support the investigator's hypothesis.

The second study did produce interesting and possibly important results concerning direction of error. The errors in altitude judgment were predominantly errors of underestimation. There was no apparent trend in either direction for the preliminary study.

The investigator presents an opinion that the difference in weather conditions could account for inconsistent findings from the two studies. The investigator also expresses the opinion that many complaints by private citizens of "dangerously low flights" or "buzzing" might be based on faulty judgments due partly to weather conditions, lack of experience or other possible factors.
REFERENCES


