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# FLIGHT TEST OF AN ALTITUDE - CODED AIRCRAFT LIGHT

PROJECT NO. 110-512R

prepared for

FEDERAL AVIATION AGENCY  
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE

This report has been approved for general distribution.  
by

APPLIED PSYCHOLOGY CORPORATION

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MARCH 1963

TECHNICAL REPORT NO. 16

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FLIGHT TEST OF  
AN ALTITUDE-CODED AIRCRAFT LIGHT

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For

Federal Aviation Agency  
Systems Research and Development Service  
Washington 25, D. C.

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#### ABSTRACT

Light signals which code the altitude at which an aircraft is flying have been suggested as a more positive visual mid-air collision prevention aid than any other type of information that can be presented by aircraft light systems. These flight tests were designed to determine pilots' judgments of the altitude and maneuvers of an aircraft equipped with a beacon light signalling the aircraft's altitude in a dot-dash code, compared to the same light flashing a fixed-frequency uncoded signal.

Results indicate that pilots were more than twice as accurate in estimating altitude and almost four times as accurate in judging maneuvers when the light was coded. When some tolerance is allowed in the estimates on the uncoded light, accuracy of altitude estimates becomes more comparable for the two light types. Allowing as a correct maneuver judgment the detection of a maneuver (even though the precise altitudes are not correct) more than doubles the frequency of correct maneuver responses for the uncoded light. However, the accuracy is still considerably less than that of the correct responses for the coded light, which was not allowed this tolerance.

These tests demonstrate in a limited situation the feasibility of an altitude-coded light in providing altitude and maneuver information that pilots can use in evaluating collision threats.

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The investigators express their appreciation and thanks to the many persons who contributed to this study. Particular thanks are due to the pilots who served as observers and to those who patiently flew the restricted patterns; to Eugene E. Pazera, FAA Project Manager; and to Philip R. Marshall, also of SRDS, who conducted the tests.

## SUMMARY OF THE PROJECT

More than 85% of all mid-air collisions have occurred during VFR operations. Since in all likelihood a substantial majority of flights will continue to take place under Visual Flight Rules for some years to come, the Federal Aviation Agency in July, 1959, established a program calling for comprehensive research into visual aids for preventing mid-air collisions.

The principal areas being investigated by the contractor, the Applied Psychology Corporation, are paints, exterior light systems, smoke and vapor trails, optical devices, training procedures, and determination of those items of information needed by pilots for making reliable avoidance-maneuver decisions.

The approach consists of a progression from laboratory work, through field tests, to flight testing. Experimental studies have been conducted to derive those quantitative data regarded as prerequisite to efficient and practical field tests. The field tests have then been designed to assess promising devices and techniques through ground-based observations; as such, they served as economical screenings prior to flight tests.

In-flight evaluations have been reserved for final testing of proposed solutions and for investigating operational problems.

Technical Reports have been, and will be, issued as statements of particular experiments or analytic studies; Summary Reports will be issued as summarizations of all work done in the various broad areas of investigation (e.g., paints, exterior light systems).

The present report is Technical Report No. 16. Other reports, both published and planned for publication, are listed below:

### Technical Reports

- |       |   |
|-------|---|
| No. 1 | Analysis of the Usefulness of Coded Information in Visual Collision Avoidance |
| No. 2 | Comparative Conspicuity of Several Aircraft Exterior Paint Patterns           |
| No. 3 | Aircraft Flight-Attitude Information as Indicated by Exterior Paint Patterns  |

- No. 4            Field Study of Threshold Ranges for Aircraft Detection and Color Identification
- No. 5            Pilot Judgments of Simulated Collisions and Near Misses: A Comparison of Performance With Uncoded and Two-Tone Coded Models
- No. 6, 9, & 14      Effects of Backscattered Light on Target Light Detectability in a Ground Test Environment<sup>1</sup>
- No. 7            Outdoor Test Range Evaluation of Aircraft Paint Patterns
- No. 8            Flight Simulator Tests of Altitude-Coded Lights
- No. 10 & 11        Pilot Judgments of Aircraft Range and Relative Altitude: Ground-to-Air and Air-to-Air Observations
- No. 12           Distance Estimation of Frequency-Coded and Uniformly Flashing Lights<sup>2</sup>
- No. 13           Conspicuity of Selected Signal Lights Against City-Light Backgrounds<sup>3</sup>
- No. 15           Altitude Evasion in Visual Collision Avoidance<sup>4</sup>

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<sup>1</sup>    These three Technical Reports have been combined and replace the previously listed reports. The title of the combined reports has been modified from that previously listed.

<sup>2</sup>    This title replaces the previously listed "Evaluation of the Conspicuity of Aircraft Smoke Trails: A. Ground-to-Air Observations" which will not be published.

<sup>3</sup>    This title replaces the previously listed "Evaluation of the Conspicuity of Aircraft Smoke Trails: B. Air-to-Air Observations" which will not be published.

<sup>4</sup>    Title changed from that listed in previously published reports.

Summary Reports

The Role of Paint in Mid-Air Collision Prevention

The Role of Range and Altitude Judgment in Mid-Air Collision Prevention

The Role of Visible Trails in Mid-Air Collision Prevention<sup>1</sup>

The Role of Exterior Lights in Mid-Air Collision Prevention

The Role of Optical Devices in Mid-Air Collision Prevention

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<sup>1</sup> Title modified from that listed in previously published reports.

TECHNICAL REPORT NO. 16

FLIGHT TEST OF AN ALTITUDE-CODED AIRCRAFT LIGHT

Background

During visual flight operations, the lights of a sighted aircraft provide the pilot with information which he can use in an effort to determine whether a collision course exists. Some of this information is specifically coded into the light system. All systems in use, for example, provide coded azimuthal sector information. Other information, not specifically coded into the system, such as movement of the observed aircraft against its background, or in the observer's frame of reference, may also be used in analyzing collision potential. It has been shown, however, that all the information presently available is often subject to a considerable degree of uncertainty (Applied Psychology Corporation, 1961; Calvert, 1958).

Several types of information, in addition to azimuthal sector, may be coded into a navigation light system. Analysis has suggested that of all of these, information about altitude seems to offer the greatest hope of substantial improvement in the pilot's ability to determine the existence of a collision situation, and to take effective evasive action (Applied Psychology Corporation, 1961).

In instrument flight, altitude separation (combined with horizontal separation) has been the predominant reliance for avoiding collision. The VFR pilot, although using a prescribed system of altitude separation, has no reliable method for determining the relative altitudes of aircraft he observes near him. Anticipated wide-scale usage of altitude transponders (such as GAT and SLATE) will provide altitude information to ground controllers, but pilots will have to rely on other methods to determine relative altitude of proximate aircraft.<sup>1</sup>

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<sup>1</sup> For examples of pilot ability to determine range and relative altitude of other aircraft, and discussions of the applications of this information, see Technical Reports 10/11 and 15, and Summary Reports 2 and 4 of the present series (Applied Psychology Corporation, 1962b; 1962c; 1963; 1962d).

A flight-simulator test of pilot ability to use coded light signals to determine relative altitude demonstrated the feasibility of such a system (Applied Psychology Corporation, 1962a). Pilots were better able to determine whether another aircraft was above, level with, or below them, and its direction of flight (up, down, or level) when the other aircraft presented Morse code signals than when it presented uncoded fixed-frequency flashes. However, this ability has not been examined when the observer is in an operational environment, that is, on a relatively unstable base, viewing the target aircraft against real backgrounds.<sup>1</sup>

### Purpose

These flight tests were designed to determine the comparative effectiveness of an altitude-coded light and an uncoded flashing light in providing relative altitude and maneuver information for avoiding collision during nighttime visual flight. It was expected that the altitude-coded light, if detected and its code identified, would provide effective relative altitude information about the target aircraft, including changes of altitude. In contrast, it was expected that the same beacon light flashing steadily, without coding, would provide considerably less accurate altitude and maneuver information. Only one experimental coded light was fabricated; multiple-target tests were hence not included in these tests.

### Equipment and Procedures

#### Summary of Experimental Plan

An experimental beacon, mounted atop a Twin-Beech (C-45) target aircraft<sup>2</sup> at the normal anti-collision light position, presented in random sequence both

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<sup>1</sup> For discussions of an operational concept for the use of altitude-coded aircraft lights, possible techniques for installation, selection of altitude cycles, and problems to be overcome, see Technical Report 15 and Summary Report 4 of the present series (Applied Psychology Corporation, 1962c; 1962d).

<sup>2</sup> The target aircraft carried conventional navigation lights as well.

uncoded and altitude-coded flashing light signals. The altitude coding consisted of five Morse code signals, each representing a 500-foot level of altitude. The target aircraft flew a designated pattern which provided a variety of altitudes, ranges, and relative bearings. Observers viewed the light signals from the co-pilot's seat of an Aero-Commander flying a holding pattern. Each problem consisted of estimating the altitude of the target aircraft at the beginning and at the end of one-minute viewings of the light. Estimates were scored for accuracy of altitude judgment and accuracy of maneuver judgment.

### Experimental Flashing Beacon

The experimental beacon shown in Fig. 1 consisted of a 28-volt, 150-watt quartz iodine lamp (Trade No. 1959) mounted inside a cylindrical clear-glass Fresnel lens. Flashing was achieved by a shutter consisting of a cylindrical sleeve mounted inside the Fresnel lens, which when closed (during the "off" periods) reduced the beacon's intensity to about 50 candles (see Fig. 2). This shutter was actuated by a standard flasher-coder (shown in Fig. 1) which allowed selection either of a conventional forty-per-minute flash rate, or of one of the five repeating Morse code signals. During the tests the beacon intensity seen by the observer varied according to the target aspect and relative altitude, but was never less than 1000 candles except when a vertical stabilizer briefly obscured the light.

The code signals each consisted of three elements previously found to be rapidly and accurately identifiable (Applied Psychology Corporation, 1960). Dashes were one second long; dots and off periods between elements were .4 second.

### Observers

Three experienced pilots served as observers. All had passed their periodic physical examination, and were currently qualified.

### Flight Patterns

The basic flight pattern is shown in Fig. 3. During each test session the target aircraft made eight circuits of approximately 18 minutes each. Each circuit of the oval observer pattern required four minutes. This combination of circuit times provided nine different target positions (problems) during each two circuits of the

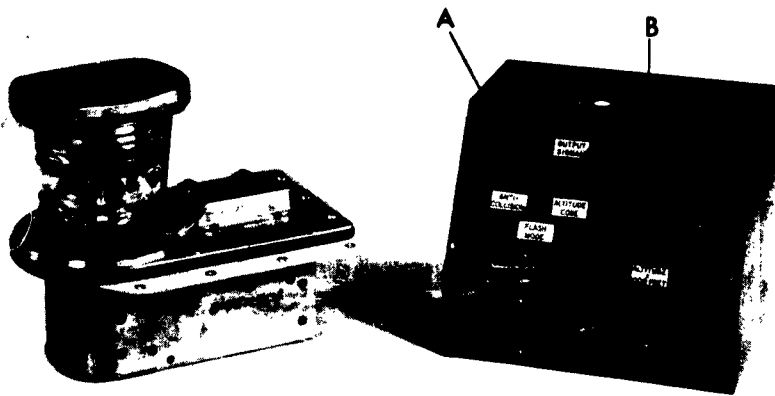


Fig. 1. Experimental altitude-coded beacon (left) and flasher-coder control box (right). Flash mode switch (A) controls beacon so as to display altitude codes or uncoded flashes. Pointer (B) controls altitude code to be presented.

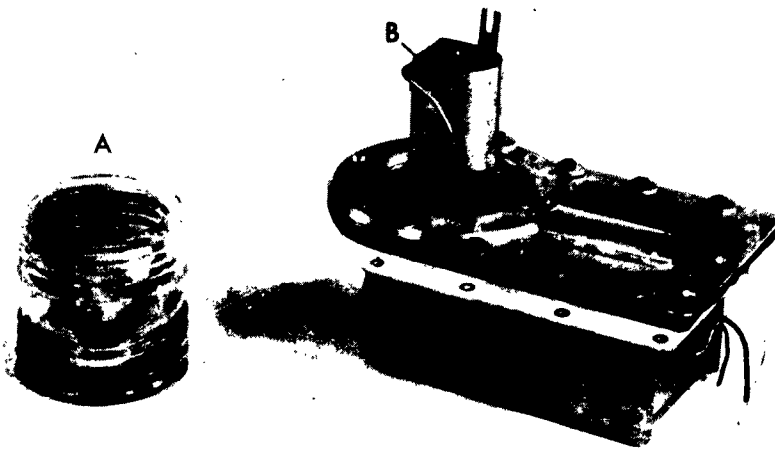
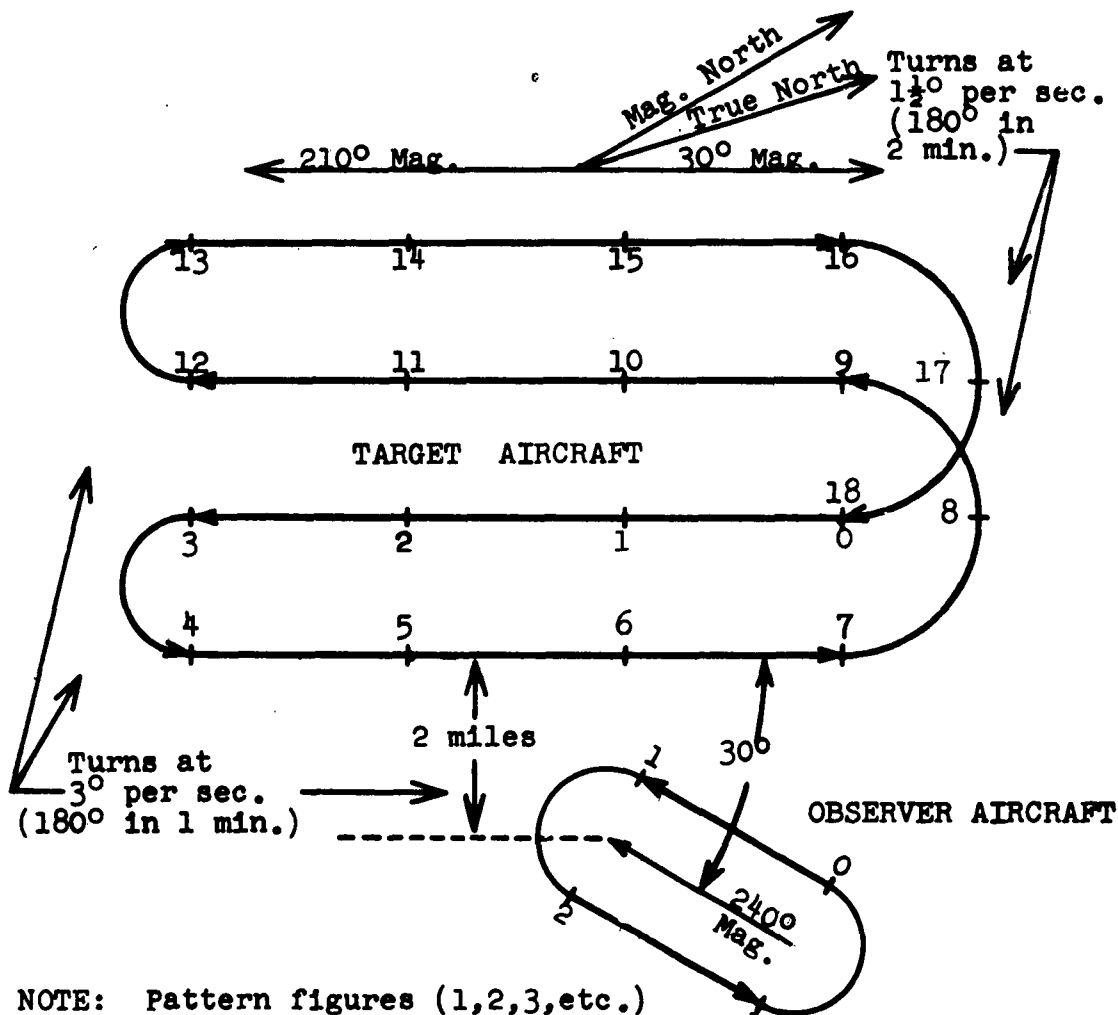


Fig. 2. Experimental altitude-coded beacon with Fresnel lens (A) removed, and shutter (B) in "up" or "off" position.



NOTE: Pattern figures (1,2,3,etc.) indicate minutes after beginning of test session. Add 18 min. to figures for each succeeding circuit of target pattern, 4 min. for each circuit of the observer pattern.

SCALE: 0.5 in. = 1 mi.  
 AIRSPEED: 140 knots

Fig. 3. Flight pattern for observations of altitude-coded light.

target pattern. Flight patterns were flown in an area west of Ocean City, N. J. Target and observer aircraft were monitored and directed by radar facilities at the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, N. J.

### Test Sessions

Observers were tested individually in sessions lasting about two-and-a-half hours. During each session there were 36 different problems, given at approximately four-minute intervals. These were split into two schedules (Plan X and Plan Y), each of which included nine altitude-coded and nine uncoded problems. Wherever in the target aircraft flight pattern Plan X had a coded problem, Plan Y had an uncoded problem, and vice-versa. Thus, during a session, the observer saw 18 pairs of coded and uncoded problems, each pair under nearly identical conditions of relative altitude and range. Table I shows the characteristics of problems during each test session.

### Use of Altitude-Coded Groups

The five Morse code letters were assigned to altitudes as shown in Table II. Each code actually represented a 500-foot band or layer of altitude centered on the altitudes shown in Table II. Using 500-foot segments, each cycle of the five codes covered 2500 feet of altitude. The first cycle began at sea level, the next at 2500 feet, then 5000 feet, etc. A mnemonic device, shown in Table II, was suggested to help observers remember the Morse code letters and their order. When during climbs and descents the aircraft passed through the 250- and 750-foot levels of each 1000 feet of altitude, an experimenter riding in the target aircraft changed altitude code signals.

Eight target altitudes ranged from 1500 feet below the observer to 2000 feet above him. Thus, the observer saw the flash code for "U" in the cycle below him as well as in his own cycle, and he saw the flash code for "W" and "D" of the cycle above him as well as in his own cycle. To present full altitude cycles both above and below the observer would have resulted in unacceptably long test sessions. An optimum altitude cycle depth must be determined through more extensive experiments.

### Training of Observers

Observers were provided with material explaining the purpose of the test, the methods and codes to be

Table I  
 Schedule and Characteristics of Problems  
 for Each Test Session

Problem No.	Target Pattern Position <sup>a</sup>	Target True Altitude (Feet) <sup>b</sup>	Code Plan		Target Relative Altitude (Feet) <sup>b</sup>	Approx. Target Range (Miles) <sup>b</sup>
			X	Y		
Plan X	Plan Y		(Prob. 1-18)	(Prob. 19-36)		
1	19	0 to 1	3500	NO CODE	Same	4 to 3
2	20	4 to 5	3500 to 4000	NO CODE	Same to +500	7½ to 3
3	21	8 to 9	4500	NO CODE	+1000	4½ to 5
4	22	12 to 13	5500	NO CODE	+2000	9 to 8
5	23	16 to 17	5000	NO CODE	+1500	7 to 5½
6	24	2 to 3	4500 to 4000	NO CODE	+1000 to +500	6 to 6
7	25	6 to 7	3000 to 2500	NO CODE	-500 to -1000	3½ to 2½
8	26	10 to 11	2500 to 3000	NO CODE	-1000 to -500	6 to 5
9	27	14 to 15	4000 to 4500	NO CODE	+500 to +1000	8½ to 6
10	28	0 to 1	4000 to 3500	NO CODE	+500 to Same	4 to 3
11	29	4 to 5	3500 to 3000	NO CODE	Same to -500	7½ to 3
12	30	8 to 9	2500	NO CODE	-1000	4½ to 5
13	31	12 to 13	2000	NO CODE	-1500	9 to 8
14	32	16 to 17	3000	NO CODE	-500	7 to 5½
15	33	2 to 3	3000 to 3500	NO CODE	-500 to Same	6 to 6
16	34	6 to 7	4000	NO CODE	+500	3½ to 2½
17	35	10 to 11	4000	NO CODE	+500	6 to 5
18	36	14 to 15	5000 to 4500	NO CODE	+1500 to +1000	8½ to 6

<sup>a</sup> See Fig. 3 for position relative to observer.

<sup>b</sup> Where two figures are reported, the first indicates the position of the target at the beginning, the second at the end of the one-minute viewing period.

**Table II**  
**Altitude Code Signals and Cycles**

Cycle	Target Altitude <sup>a</sup>	Code Letter	Mnemonic Device <sup>b</sup>
	7000	U (---)	<u>U</u> p
3rd	6500	G (---)	<u>G</u> oing
Cycle	6000	K (---)	<u>K</u> eeP
	5500	D (---)	<u>D</u> oubtful
	5000	W (---)	<u>W</u> hen
	4500	U (---)	<u>U</u> p
2nd	4000	G (---)	<u>G</u> oing
Cycle	3500	K (---)	<u>K</u> eeP
	3000	D (---)	<u>D</u> oubtful
	2500	W (---)	<u>W</u> hen
	2000	U (---)	<u>U</u> p
1st	1500	G (---)	<u>G</u> oing
Cycle	1000	K (---)	<u>K</u> eeP
	500	D (---)	<u>D</u> oubtful
	Sea Level	W (---)	<u>W</u> hen

<sup>a</sup> Each code was displayed through a 500-foot band of altitude centered on the altitudes shown. For example, the letter "U" in the second cycle was displayed at any time the aircraft was between 4250 feet and 4750 feet.

<sup>b</sup> This column is to be read in ascending order.

used, instructions for recording data, and probable target bearings for each problem.

Even though the observers were allowed to use this material during the tests, they were asked, in the interest of simplifying the night operations, to memorize the altitude codes. They were not told (a) the nature of the target pattern, (b) the upper and lower altitude limits used, (c) the fact that the coded flight levels during the first half of an observer's test session were the same as the uncoded levels during the second half of the session, and (d) the near and far limits of target range during the tests.

### Recording Results

Observers were asked to view the target throughout the one-minute problem interval. At the end of each problem, the observer aircraft turned away from the target, and the observer recorded four items of observed or estimated information on a simple form. The target altitudes at the beginning (first 30 seconds) and at the end (last 30 seconds) of each one-minute problem interval were to be recorded to the nearest 500 feet of altitude. Similarly, the target ranges at the beginning and end of each problem (first and last sighting) were to be recorded to the nearest one-half mile.<sup>1</sup> Subsequently entered on the observer's record form were the actual altitudes scheduled in the test plan, and the actual ranges, as recorded by NAFEC radar at the time of each problem.

### Control Procedures

In addition to radio direction and monitoring from the NAFEC radar control room, target and observer aircraft received other advisories designed to facilitate problem flow. For example, observers were told at the start of each problem the "clock" direction in which to look for the target. Timing was not started until the observer had the target in sight. If a problem maneuver was scheduled, it also commenced at this time. Some irregularity of pattern times was thus caused by adjustments of observer and target pattern legs. Observers were also advised when to expect the twin vertical stabilizers on the target aircraft to obscure the target light. As noted above, NAFEC radar recorded the range of the target twice during each problem.

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<sup>a</sup> These range estimates were not taken for use in the present study.

During the first two test sessions the observer aircraft maintained the schedule altitude of 3500 feet, and the target aircraft followed the altitude schedule shown in Table I. A layer of haze during the third session required a 2000-foot increase in all altitudes, with corresponding adjustments in altitude codes.

### Results

The three test sessions yielded 216 altitude estimates and 108 judgments of maneuver. Two problems in which haze precluded obtaining observations were retained in the tabulation as incorrect judgments. One of these was a coded problem, the other an uncoded problem.

#### Altitude Estimates

Table III shows that more than twice as many estimates of altitude were "correct" for the coded as for the uncoded light. A "correct" estimate of altitude is one reflecting the 500-foot band of altitude of the target at the beginning or at the end of each problem.

Since an estimate within one altitude band above or below the correct altitude band may be considered satisfactory for situations in which the light provides no information about altitude, this tolerance was allowed in tabulating the data for the uncoded light. This tolerance was not allowed the altitude-coded light, which was designed to give relatively precise information about altitude. In these circumstances, accuracy of altitude estimates for the two light types is more comparable (85% accuracy for the coded light, 76% for the uncoded).

Sixteen of the 108 problems using the altitude-coded light were missed. Possible explanations for this include: (a) the light was not seen; (b) the light was seen, but not correctly interpreted; (c) the code was not seen correctly; and (d) the observers may not have been thoroughly familiar with the code. Two of the sixteen were missed because the light was not seen at all, in haze at seven miles range. Two other mistakes were cases of misinterpreting the altitude code cycle. One target at 3.75 miles was estimated to be 2500 feet higher than actual (one cycle too high) and a target at 11.50 miles was estimated to be 2500 feet lower than it was actually (one cycle too low).

The remaining 12 errors may have a variety of causes. It is possible that haze may have contributed to four

Table III  
Accuracy of Altitude Estimates (%)  
With Coded and Uncoded Lights

Observer	Altitude-Coded	Target Light	
		Uncoded	
		Exact Estimate <sup>a</sup>	With 500 ft. Tolerance <sup>b</sup>
1	81	36	69
2	92	33	86
3	83	39	72
TOTAL	85	36	76

<sup>a</sup> These are estimates which identified correctly the 500-foot band of altitude in which the target was flying.

<sup>b</sup> These figures include the exact estimates and those in the 500-foot bands above or below the correct one.

mistakes made when the target was between 8.50 and 10.50 miles away, but it is unlikely that this was a factor in eight mistakes made when the target was between 3.50 and 6.75 miles away.

Observers were familiar with the codes and cycles, and correctly read the codes in a ground test prior to their test flight. However, reading codes in light flashes was not a normal task for them, and they may have sometimes confused the codes during the flights. Six of the 12 unexplained errors were made by the first observer, who had less time than the others to become proficient in interpreting the codes.

It is unlikely that the mistakes were caused by a lack of time for observing each code. In level flight problems, the observer had 60 seconds to view the code; in climb/descent problems, he had 30 seconds to view each code. Yet fewer mistakes were made on the climb/descent problems (five errors) than on the level flight problems (seven errors).

It seems probable that with better atmospheric conditions and more intensive training of observers, accuracy of altitude estimates using the coded light could be improved beyond the already high accuracy found in this study.

#### Maneuver Judgments

Observers made no judgments of maneuver as such. They estimated altitude only, but they did so at the beginning and at the end of a one-minute observing period. If both altitudes were estimated correctly, the problem was scored as a correct judgment of maneuver.

Table IV shows that judgments with the altitude-coded light were considerably better than those with the uncoded light. The superiority of the altitude-coded light obtained even when the uncoded light was allowed the tolerance of being scored correct when only level flight, climb, or descent had been recognized and the altitude had not been correctly estimated.

With the altitude-coded light, all three observers were able to recognize maneuver on the climb/descent problems as well as or better than on the level flight problems. With the uncoded light, observers did less well on the climb/descent problems than on the level flight problems, in practically every instance.

Table IV  
Accuracy of Maneuver Judgments (%)  
With Coded and Uncoded Lights

Maneuver	Observer	Target Light		
		Altitude-Coded	Uncoded	
			Exact Judgment <sup>a</sup>	With Tolerance <sup>b</sup>
Level Flight	1	67	22	56
	2	78	11	44
	3	67	44	56
	TOTAL	70	26	52
Climb or Descent	1	78	11	78
	2	89	0	33
	3	67	22	22
	TOTAL	78	11	44
GRAND TOTAL		74	19	48

<sup>a</sup> These are judgments which identified correctly the 500-foot band of altitude in which the target was flying at both the beginning and end of the one-minute problem.

<sup>b</sup> Level, climbing, or descending flight judged as such, but with erroneous altitude estimates in addition to the exact judgments.

### Summary and Conclusions

Three pilot observers made estimates of the altitude of an experimental aircraft light which flashed codes indicating altitude and also flashed a fixed-frequency uncoded pattern. The estimates were also used to determine accuracy in judging the target's maneuver.

Altitude estimates of the altitude-coded light were more than twice as accurate as those for the uncoded light. Altitude estimating performance on the two light types becomes comparable only when the estimates on the uncoded light are allowed some tolerance. When no tolerance was allowed for the uncoded light, aircraft maneuvers (level, climbing, or descending flight) was recognized almost four times as well with the altitude-coded light.

This study corroborates and extends the findings of the previous flight-simulator study of altitude coding (Applied Psychology Corporation, 1962a). The results suggest (for the limited situation studied) the utility of an altitude-coded light system in providing altitude and maneuver information that pilots can readily use in evaluating collision threats.

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