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## PROJECT ADMINISTRATION DATA SHEET

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Fort Worth Division

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## RESTRICTIONS

See Attached N/A Supplemental Information Sheet for Additional Requirements.

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Date 6/24/88

Project No. G-42-626 School/Lab Psychology

Includes Subproject No.(s) ~~A-4873~~

Project Director(s) G. M. Corso GTRC/GIT

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Title Deceptive Camouflage Development Study

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- [ ] None
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# F-16 Camouflage Development Study

## Final Report

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Prepared for General Dynamics under P.O. #1129584

December 1987

## Abstract

The focus of this research project was the development of a procedure by which various alternative camouflage schemes could be developed, and once developed, evaluated. Our approach was to delineate principles of camouflage, for concealment and for deception. Once these principles were uncovered, various combinations of independent variables, each developed from a particular principle were then used in the development of three related deception camouflage patterns. In Experiment 1 these patterns were evaluated in terms of time to judge direction of an aircraft and accuracy of this judgment. In Experiment 2 the time to identify the presence of camouflage was measured. In both experiments evaluation was in terms of a worse-case scenario with the best camouflage pattern resulting in the poorest performance, i.e. slowest response time and poorest accuracy, as well as highest response variability.

# Introduction

Camouflage literally means to disguise (Webster's, 1958). With concealment camouflage the intent is to hide an object and thereby make it more difficult for a human observer to detect it. This is the same whether the object is stationary or moving. The influence of camouflage is determined by measuring the probability of detection of a target as well as the time it took to detect the target. In contrast with deception camouflage the intent is to alter the perception of a target, in such a way that key attributes of the target are distorted. With a moving target, such a as an aircraft in flight, the intent of deception camouflage is to distort perception of the path of movement (i.e. the flight path). Changing relevant characteristics of the target object may impede an observer's prediction of the flight path.

## Concealment camouflage

The use of concealment camouflage by humans on a formal basis began with the work of Bush and Thayer (1902) who adapted a scheme for painting ships to make them less visible. This reduction in visibility was accomplished by painting the ship with a color that appeared to be the same as the color of the ocean when viewed from a distance. However, there appears to be no information concerning how the colors were matched or how performance was actually reduced a function of this color matching technique. Such techniques as these were widely used in World War I, particularly in the war at sea (Luckiesh, 1965, pp. 210-247).

Most concealment techniques were copied from observations from naturalistic situations (Bruce & Green, 1985, pp. 112-116; O'Neill, 1986; Rock, 1975, p.278; 1984). Among these techniques are:

1. Countershading. This technique is concerned with altering the quantity of light being reflected from an object. Generally, for objects on land illumination comes from above. Thus, the underside of an object appears darker than the top side. To reduce this difference, the topside of an object can be painted in a darker shade while the underside of an object can be painted in a lighter shade. For aircraft, this would suggest that a lighter shade be used on the underside while the topside be a darker shade. This technique would tend to decrease the probability of detection by reducing the shading difference found on the object.

2. Blending. This technique is concerned with the wavelength characteristics of light and the reflective and absorption properties of the target. Objects tend to absorb certain wavelengths of light and reflect others. Absorption and reflection of different wavelengths by the target as compared to the background give rise to the perception of form. To reduce this perception of form, the object can be painted with a paint that has the same wavelength composition of the background in which it will be concealed. For aircraft, when viewed from above, the distribution of wavelengths of the paint on the aircraft should approximate the distribution of wavelengths of the background in which it would be observed.

3. Disruption. Edges and contours distinguish an object from its background. They also can be found on the surface of an object where they can give rise to the perception of different surface sections on a target. Disruption techniques attempt to break up the perception of edges and contours regardless of where they are located. Several different approaches involved in the technique of disruption involve the use of shading and coloring.

One approach is to alter the edges of an object by changing shades and/or colors located on edges that are near the background to reflect the spectral composition of the background. Then a paint of a different spectral composition could be used for the to generate illusionary edge locations, thereby resulting in the misperception of various structural characteristics of the object.

Another approach is to alter the edges and contours found on the object by altering the spectral composition of the paint so that the edges and or contours within the object are reduced or hidden.

A third approach is to alter the edges and contours found on the object by altering the spectral composition of the paint on different surfaces so that when viewed from different positions, various surface areas blend into one another. For example, the tail of an aircraft could be painted such that when viewed from an angle that is both behind and slightly above, the tail would blend into the fuselage of the aircraft.

4. Mimicking. This technique involves the application of the characteristics of a high probability object to conceal a low probability object. The characteristics that could be used include mimicking color, shape, size, and/or perceived function. For example a bomber could be redesigned to take on the physical characteristics of a fighter and be concealed in a group of fighter aircraft.

5. Symmetry reduction. This technique involves the idea that man-made objects may be symmetrical and as such are more readily identified as figure than asymmetrical objects. Figures appear closer than ground, show more brightness contrast, are more "thing-like" (i.e. seem to have a shape), and are usually seen as more meaningful than ground (Coren, Porac & Ward, 1984, p. 346). Aircraft, due to aerodynamic constraints, tend to be symmetric and as such may be more detectable. A reduction in the appearance of symmetry through surface markings may reduce detectability.

Principles of concealment camouflage

Concealment, from a psychological point of view is measured by the length of time it takes to detect an object and the probability of detection. From the psychological literature we know that these two dependent measures may vary with each other. That is, objects with a low probability of detection will also result in a longer response latency. Furthermore, variables which make an object less detectable are the same as those variables which make an object more detectable. It is the values of these variables which are important. The techniques of concealment camouflage discussed above may be considered to result from variables which can be summarized by the following set of principles:

1. Principle of attensity. The principle of attensity refers to the attention getting properties of a stimulus (Teichner, Christ & Corso, 1977). To the extent that the previous techniques reduce contrast, reduce edges and in general reduce the perception of figure produced by the target against a uniform background, the less attensive it will be, and consequently, the harder it will be to detect the target.

2. Principle of similarity. This principle is a special case of the principle of attensity. The principle of similarity refers to the target when compared to other discrete items in the immediate surround. To the extent that the target looks like other items it will be harder to detect.

3. Principle of form and function. The principle of form and function suggests that an association between the form of the object and its function has been learned. For example wing-like structures appearing on any object imply that the object can fly. To the extent that the association between form and function has not been learned, the detection of a target will be reduced. Furthermore, if old forms are given to new functions, those forms will be harder to detect in the presence of old forms associated with old function. Whether or not new forms given old functions will be harder to detect is a matter of experimental determination although it is known that novel stimuli are easier to detect.

4. The principle of uncertainty. The principle of uncertainty refers to the number of items within which the target item is presented. The greater the number of total items, the longer it will take to find the target.

These four principles appear to be involved in concealment camouflage, regardless of whether the aircraft is stationary or moving. Movement, relative or absolute, will enhance the probability of detection (Regan & Beverly, 1984), if it increases the attensive aspect of the aircraft. For example, if there is a detectable difference in movement between the target aircraft and the background, and the aircraft is already detectable, the addition of movement will increase that detectability. If there are other aircraft present, and the target aircraft is among those other aircraft, its movement will only be a cue to detectability if that movement is different from the other aircraft.

## Deception Camouflage

The intent of deception camouflage for moving aricraft is to alter the perception of a target that has been detected such that the relevant characteristics which result in a prediction of the flight path are distorted. With such a distortion, the prediction of the flight path is either delayed, incorrect or both.

We are proposing the following principles, not as fact built on years of research but as working hypotheses. For this reason principles of deception camouflage are presented before techniques based on them rather than following the order presented for concealment camouflage where principles were derived based on previously utilized techniques. The techniques that incorporate these principles will be presented in the next section of this report.

1. Principle of location uncertainty. Surface structures, such as a the air scoop, flaps and canopy on a target resolve uncertainty concerning the aircraft's attitude and therefore the flight path. The greater the number of locations of one surface structure the greater the uncertainty and the poorer the prediction of the flight path. For example, if the aircraft has two canopies, each located at a different location on the aircraft, the prediction of the flight path should be delayed, or incorrect.

2. Principle of size/shape constancy. There is a difference between the retinal size and shape of a target and its resulting perception. To the extent that judgments of size and shape of a target do not accord with the retinal size and shape of that target, there should be a decrease in ones ability to predict the flight path.

3. Principle of gaze preference. Humans appear to attend to the centroid of configuration and the centroid of motion. To the extent that these two centroids can be distorted the ability to predict the flight path should be reduced. Such an approach was first suggested by Ronson (1942) and further refined by Ferris (1980).

4. Principle of visual scanning. The visual system is attracted by edges and corners. Once these characteristics are detected, they result in eye movements to the interior of the target. The termination of eye movements appears to be located at the centroid of mass and/or the centroid of motion (O'Neill, 1986). By altering the direction of eye movements so that the termination points are not at the actual centroids, the prediction of the flight path should be delayed or incorrect.

5. Principle of relative movement. Absolute movement of a target is rarely seen (Johansson, 1973; 1975; 1985). The perception is of common motions within a target. To the extent that motion within an object can be distorted, a reduction in flight path predictability should occur.

6. Principle of function. Functions may be associated with shapes. Once a target is detected, its shape may provide information about its dynamic characteristics. Therefore, altering the shape of a target may provide for a reduction in flight path predictability.

<u>Techniques for the application of deception camouflage</u>

Based on the previous principles, the typical scenario for predicting the flight path of an aircraft may be as follows:

An aircraft is detected. Its shape is determined. The eyes are attracted to the outside edges and move to the centroids. Both the determined shape of the object and its corresponding centroids give rise to the predicted flight path. Periodic checking reaffirms this prediction.

1. Detection limiting. Obviously, if the aircraft is not detected neither will its flight path. Any of the principles listed under concealment camouflage should also assist in deception.

2. Multiple locations. The incorporation of multiple locations for a common structure, such as multiple canopies, or the illusion of multiple canopies (Ferris, 1978) should retard the determination of a flight path. Other such structures could include multiple tails, more than two wings, additional air scoops ( one forward, one rear). Increases in uncertainty regarding these structures, should contribute to an increase in the latency and/or accuracy of predicting the flight path.

3. Shape alteration. Directional information can be obtained through the slant of the wings and the cylindrical shape of the fuselage. Any aircraft that is lacking all or parts of these information providing structures should result in a reduction in the ability to predict the flight path.

4. Edge addition. The visual system is attuned to edges and corners. Perception of edges results from differences between an aircraft and its background. Therefore, increasing the number of edges should result in more information being processed, and therefore a greater increase in the latency to predict the flight path.

5. Centroid disruption. The gaze pattern starts from the edges of the object and terminates at the centroids of the form. Additional cues should disrupt the perception of the location of these centroids. As a result a discrepancy between the perceived centroid and the actual centroid may occur. This discrepancy would result in an increase in the latency to predict the flight path and a decrease in the accuracy of that prediction.

Potential Deceptive Camouflage Patterns

O'Neill and Scott (1986) evaluated several possible new camouflage patterns for tanks with the objective of drawing a gunner's eyes away from the centroids:

1. An Angles pattern - based on the tendency for the gaze to wander to the interior of a vertex.

2. A Stripes pattern - based on the notion of lateral inhibition.

3. A Grassfire pattern - configured to break up symmetry features rather than boundaries.

The dependent measure was shot dispersion, so that the greater the dispersion, the better the pattern. The results showed that for experienced gunners, early in the session, the angles pattern was best. However, as more rounds were fired, a slightly greater dispersion of shots occurred when the Stripes pattern was employed than when other patterns were used. Furthermore, a greater dispersion of shots occurred when any of the new patterns was used than occurred when the Standard U.S. Army Forest Green Pattern was used.

Based on the previous principles of camouflage, the proposed techniques, and an investigation by O'Neill and Scott (1986) three camouflage patterns were developed and are presented in Figures 1A-1C.

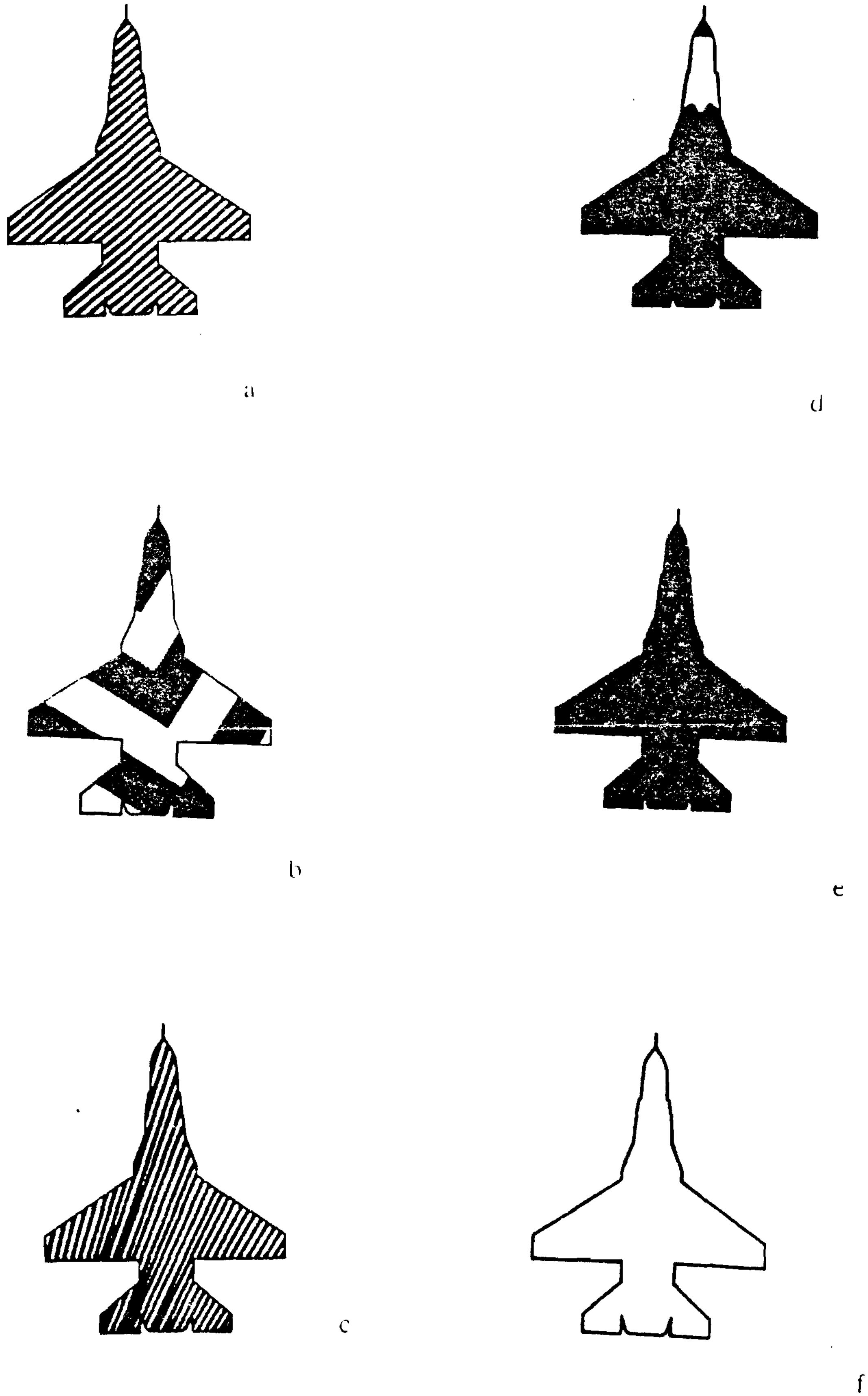



Figure 1. Representative patterns used in Experiment 1.

Figure 1A presents a parallel line pattern. The intent of this pattern was to increase the number of edges required for processing. This pattern is based on the Principle of Visual Scanning.

Figure 1B presents an angle pattern. The intent of this pattern was to increase the number of edges required for processing, to disrupt real contours, and to produce illusionary contours. This pattern is based on the Principle of Gaze Preference.

Figure 1C presents a converging pattern. The intent of this pattern was to increase the number of edges, to disrupt real contours, produce illusionary contours, and to produce illusionary centroids. This pattern is based on the Principles of Gaze Preference and Visual Scanning.

All three patterns were high contrast, black on white gratings. Gratings of .35 c/d, 3.5 c/d and 14.2 c/d were used for each pattern. In addition, four orientations of the pattern on the aircraft were used: plus and minus 30 degrees and plus and minus 50 degrees, from a line drawn on the aircraft from the nose to the tail.

## Experiment 1

### Subjects, stimuli and apparatus

For the initial assessment technique, a worst-case scenario was developed. Worst-case in this context refers to large visual angles, static testing, discrete responses, large angles of movement, and large response steps. The task of the subject was to press a response key to designate the direction that the aircraft was heading. Each group of subjects saw a random presentation of 10 blocks of 70 slides each. The 70 slides were all possible combinations of three spatial frequencies (.35, 3.5 and 14.2 cycles per degree), four orientations of the pattern on the aircraft (-50, -30, 30, and 50 degrees from mid-line) and five orientations of the aircraft (-50, -30, 0, 30, and 50 degrees). Plus there were five slides of the standard F-16 camouflage pattern (Figure 1D) , one slide for each aircraft orientation, and five filled silhouettes (Figure 1E), one for each aircraft orientation. These combinations resulted in a total of 70 slides per block, with ten replications of each block. Therefore each subject was presented with a total of 700 slides comprised of one new camouflage pattern, the standard F-16 pattern, and the silhouette.

Forty-five right-handed males volunteered for the experiment in exchange for extra credit in introductory psychology classes. Two subjects withdrew prior to completing the experiment and the data of seven others were incomplete due to equipment failure. The remaining 36 subjects were distributed equally among the three camouflage group conditions.

Slides of the aircraft were back-projected on a screen by a Kodak random access projector controlled by an IBM PC through a LabMaster board manufactured by Scientific Solutions. Stimulus duration was controlled by a Gerbrands shutter. A 1.5 neutral density filter, placed between the projector and the shutter, reduced the brightness of the projected image.

The response panel consisted of a home key, and seven response keys arranged in a semicircle above the home key. Each response key was an equal distance from the home key, about 12 cm. On each response key was an arrow pointing in the direction that indicated the possible heading of the aircraft. Except for the two extreme keys, which displayed arrows that pointed further to the right or left than any of the actual aircraft orientations, the remaining five keys corresponded with the five actual aircraft orientations.

Procedure

Immediately after reporting for the experiment the subject was seated at the response panel and the experimenter read the following instructions:

> "This study is financed by a grant from General Dynamics and is a fairly simple experiment from which you can expect no adverse effects and from which you can withdraw at any time without penalty.
>
> In this experiment you will be trying to determine the direction in which airplanes are pointed. Each airplane will be flashed briefly on the screen in front of you, and you will make your response by pressing a button on the panel in front of you. To start a trial you will have to hold down the bottom unmarked button with you right index finger for at least one second. After holding this button down for at least one second, a picture of an airplane will be flashed on the screen. After you have determined the plane's direction, press the button with the arrow that points in the direction that you think the aircraft is pointed. For example, if the plane is pointed in this direction (the experimenter indicates the vertical direction) you would press this button (the experimenter indicates the button corresponding to the vertical direction). Please use the index finger of your right hand to press all buttons and respond as quickly and as accurately as you can.
>
> You will have a few practice trials to be sure that you understand what to do. Do you have any questions?"

After his questions were answered the subject signed an informed consent form. The experimenter then continued with the instructions saying, "Now I'll show you what the slides look like". The experimenter displayed two to three slides for a few seconds. After the initial viewing, the experimenter continued:

> "Are you ready for a few practice trials? In the actual experiment there will be 25 minutes of slides followed by a short rest period, then 25 more minutes of slides. In the practice session there will be only about one-half minute of each"

The subject then was presented with six practice trials, a short pause, and another six practice trials. After this practice period the subject was then reminded to use his index finger to press all buttons and to respond as quickly and as accurately as possible.

The subject sat about 75 cm from the projection screen. There was no chin rest or other restraining device to maintain the 75 cm distance. The planes subtended a visual angle of 10.8 degrees. An F-16 at a distance of 253 feet would subtend such a visual angle. Each slide was presented for 100 ms.

## Results and Discussion

Response latencies.

Response latencies were determined for each of 70 conditions by calculating the median of the 10 responses to each condition. Latencies were of three types - lift-off, terminal, and decision. Data of each of these types was subjected to an analysis of variance. Two separate analyses were conducted for each type. In the first analysis each of the 70 conditions was considered as a separate within-subject stimulus. In the second analysis, the standard camouflage pattern and the silhouette pattern were removed from the analysis. Bacause of aberrant responding, data from three subjects were excluded from all analyses.

Lift-off latency. Lift-off latency was the time from the opening of the shutter to the subject's release of the home key. Lift-off latencies are presented in Table 1. This measure can be thought of as the amount of time to detect the aircraft, so one would not expect to find differences in lift-off latency as a function of the camouflage patterns. As can be seen in Table 1, median lift-off latencies were similar across the three different types of camouflage patterns. The analysis of variance showed no significant difference between the three camouflage patterns. However, there does appear to be a much larger standard deviation associated with the convergent pattern than with any of the other patterns, suggesting less consistent responding associated with this pattern.

Terminal Latencies. Terminal response latency was the time from the opening of the shutter to the subject's key press designating the direction in which the aircraft was headed. Terminal latencies are thought to be composed of detection time, decision time and movement time associated with a particular response-stimulus combination. As can be seen in Table 1, and as supported by the analysis of variance, $F(2,30) = 1.90$, $p.=.17$, the convergent pattern appears to result in a much longer terminal response latency, as well as a larger standard deviation. In addition, spatial frequency was significant, $F(2,60) = 3.31$, $p.=.04$. However, the magnitude of this effect was quite small.

Decision latency. Terminal response latency can be considered to contain latencies associated with detection time, decision time, and movement time. By subtracting the lift-off latency from the terminal response latency, the difference can be considered to be an estimate of the amount of time required to make a decision. In this case the decision concerns the direction of the aircraft. Median decision latencies for each subject were subjected to an analysis of variance. A significant difference between the three patterns was observed, $F(2,30) = 2.67$, $p.=09$. Furthermore, a significant difference between the experimental striped patterns and the two control conditions was also significant, $F(1,30) = 3.33$, $p. = .08$). Once again the convergent pattern resulted in the longest latencies and the highest standard deviation. The values for these latencies are also reported in Table 1.

Number Correct.

The mean number correct for each of the three patterns is also shown in Table 1. No significant differences in the mean number of correct responses as a function of the type of camouflage pattern were observed. The number of correct responses was in the 70 to 80 percent range, suggesting no problem with a ceiling effect. Furthermore, there appeared to be no difference between the standard deviations associated with the three patterns. These results imply that the differences observed in the latency data are not the result of a speed-accuracy trade-off.

Table 1. Lift-off, terminal response, decision latencies and number correct for the deception camouflage patterns. All latencies are in ms; standard deviations are in parentheses.

| Pattern Type | Lift-off Latency | Terminal Latency | Decision Latency | Number Correct |
|---|---|---|---|---|
| Convergent | 535 (223) | 1081 (519) | 546 (379) | 7.7 |
| Parallel | 461 (99) | 869 (164) | 409 (136) | 7.8 |
| Angles | 505 (71) | 828 (133) | 324 (104) | 8.0 |

Discussion.

Taken as a whole these results indicate that the convergent camouflage pattern was superior to the other patterns and that differences were not apparent in detection processes as measured by lift-off latencies which could be attributed to the orientation of the aircraft or the spatial frequency. This latter finding was somewhat surprising, in light of the number of studies showing a relationship between spatial frequency and detection time. On the other hand, there are an equally large number of studies showing that sensory variables have no effect on choice reaction time, the type of response measures obtained within this investigation. This would suggest that decisions regarding direction may not be influenced by some variables that influence detection.

# Experiment 2

In Experiment 1, The type of pattern and not spatial frequency determined performance as defined by latency. The poorest performance being associated with a convergent line pattern. The second experiment was conducted for three reasons: (1) to replicate the previous finding showing support for the poor performance given the convergent line pattern; (2) to use a different dependent measure, in the hope that insight could be gained regarding the changes in performance as a function of the type of camouflage pattern; (3) to investigate the possibility that spatial frequency would have some influence on detection performance that was not revealed in the first experiment.

## Subjects and Apparatus

Eighteen right-handed males participated in the experiment. Data from three of these participants were excluded due to equipment failure. The remaining 15 participants were distributed randomly among three groups with the restricition that each group contain an equal number of subjects.

The stimuli were the same as those used in the first experiment with two exceptions. First, all aircraft pointing in the vertical direction were eliminated, and second, an empty line drawing (Figure 1F) was added. As a result of these changes, the total number of slides within one block was reduced to 60, for a total of 600 slides.

Two changes were introduced to the apparatus. First a Heath audio generator was used to generate a 60 ms, 1000 Hz warning tone, and second, the response panel used in the first experiment was replaced with a response panel containing two telegraph keys.

## Procedure

Each subject was read the following set of instructions:

> "This study is financed by a grant from General Dynamics and is a fairly simple experiment from which you can expect no adverse effects and from which you can withdraw at any timewithout penalty.
>
> In this experiment you will be trying to determine the type of pattern drawn on pictures of airplanes. Each airplane will be flashed briefly on the screen in front of you, and you will make your response by pressing one of the two keys in front of you. Here are the kinds of patterns that you will see drawn on the planes (the subject was shown Figure 2. One kind of pattern is

made up of stripes, and the other kind is made up of a more solid pattern. What I want you to do is press the left key if you see a pattern made up of stripes and the right key if the pattern is not made up of stripes. Please keep your left index finger on the left key and your right index finger on the right key so that you can respond as quickly as possible. Do not hold the keys part way down while waiting for the picture to appear.

To help you get ready to respond to each picture, a warning tone will be sounded . Immediately after the tone the picture will appear very briefly on the screen in front of you. The time interval between the warning tone and the picture will vary slightly from trial to trial, so you will not be able to anticipate exactly when the picture will be flashed, but when you do see the picture respond as quickly and as accurately as you can"

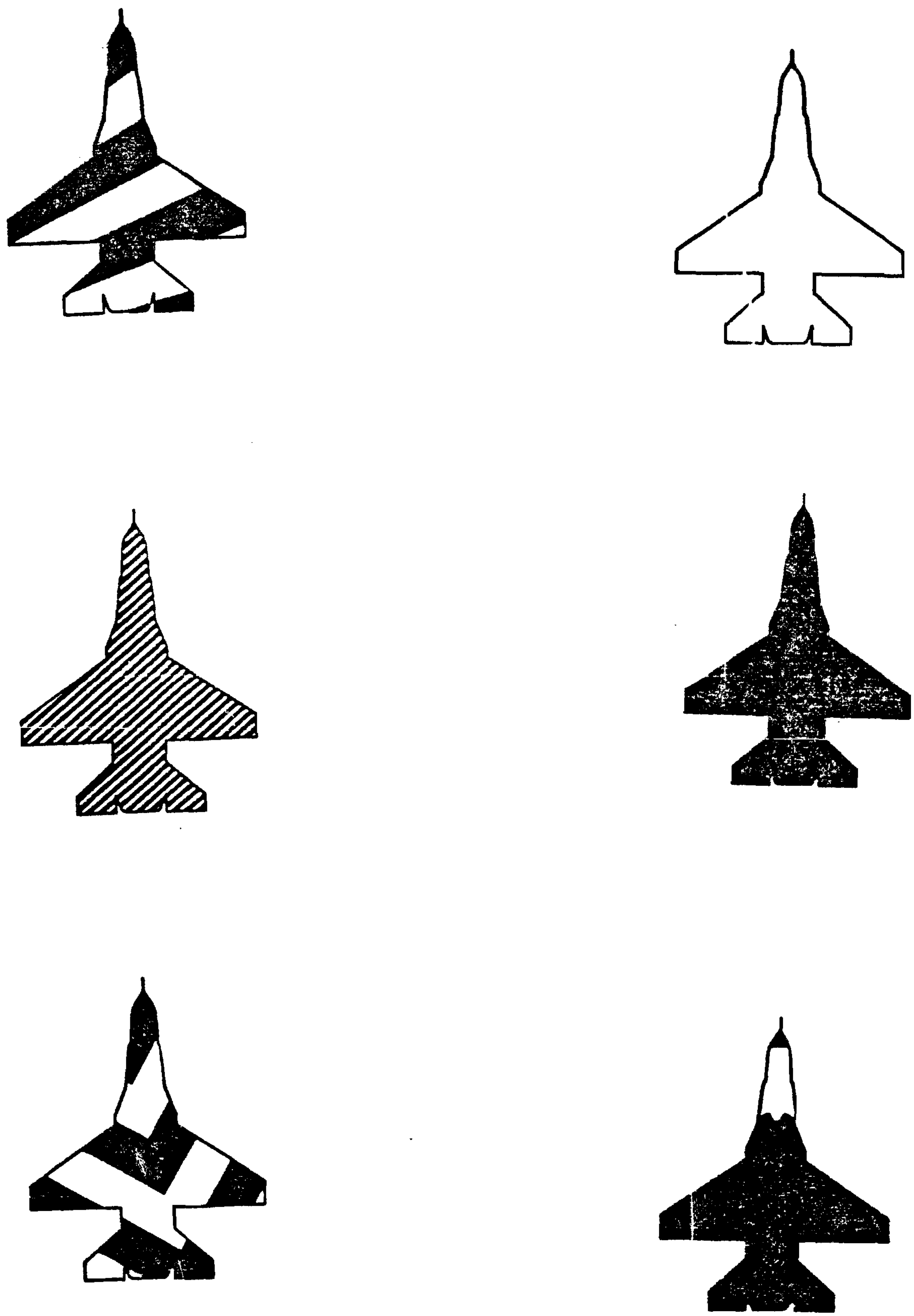


Figure 2. Representative patterns used in Experiment 2.

After asking questions and reading and signing an informed consent form, each subject was presented with 12 practice trials. As in the first experiment, the order of slides was randomized within blocks, with different random orders across the 10 blocks. A short rest period occurred half way through the session. The duration of the session was 50 minutes. For each trial, a 1000 Hz warning tone of 60 ms signaled the onset of a slide. The warning interval varied randomly and assumed values of 0 to 1500 ms, in 300 ms steps.

## Results and Discussion

Latency.
For each subject a median response latency for the four orientation of patterns, the three spatial frequencies and the four orientation of aircraft for the striped camouflage pattern was computed. These medians were subjected to a split-plot analysis of variance where the type of striped pattern was the between-subject variable. This analysis showed a significant main effect of spatial frequency, $F(2,24) = 34.38$, $p < .01$, and a significant interaction between the type of pattern, spatial frequency and pattern orientation. A closer inspection of this interaction showed no systematic effects of pattern orientation. The relationship between spatial frequency, latency and the three camouflage patterns is presented in Figure 3. While not significantly different, the convergent pattern across all spatial frequencies tended to result in poorer performance, a result also found in the first experiment.

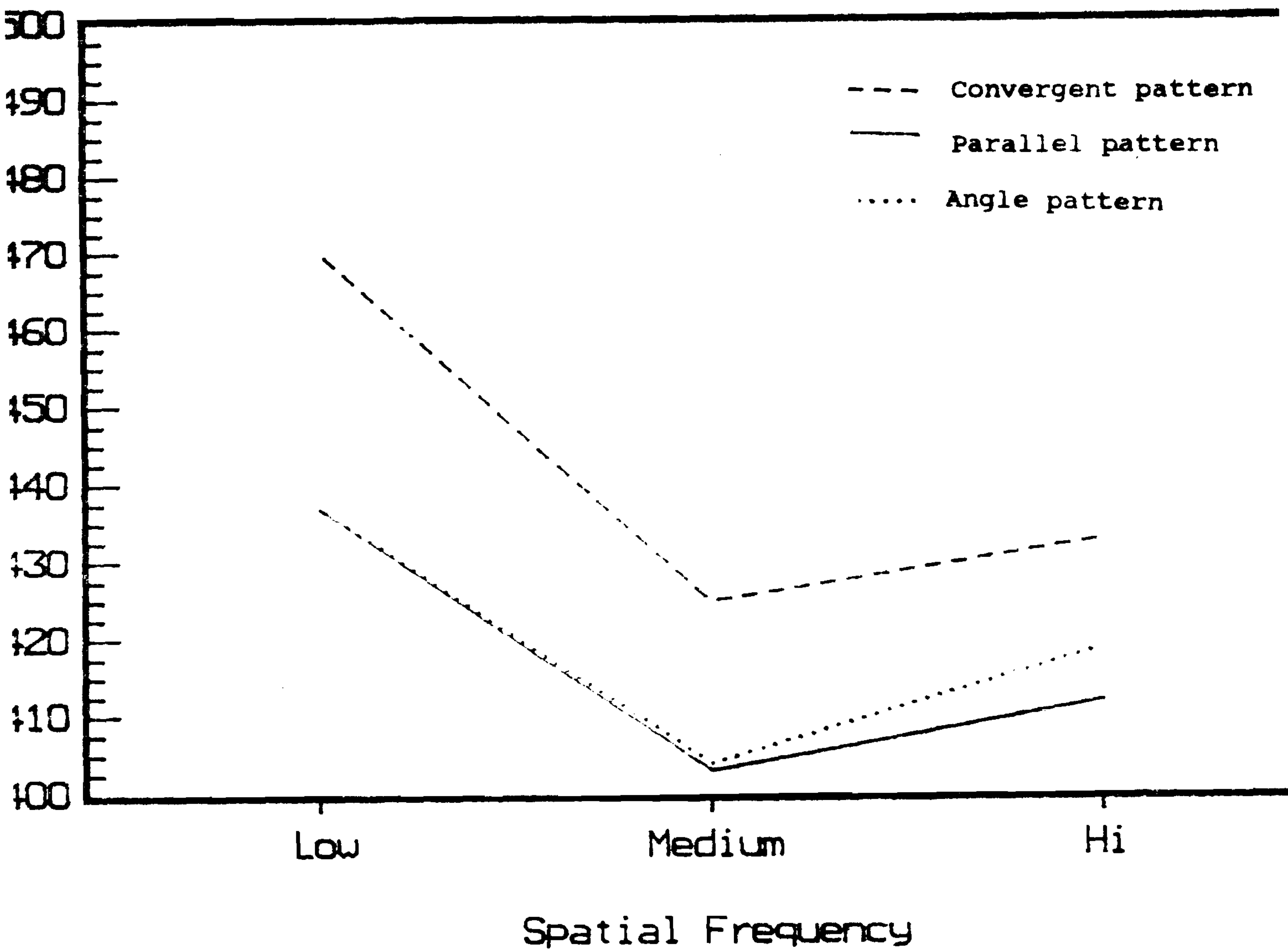



Figure 3. The observed relation between spatial frequency and latency with pattern type as the parameter.

Signal detection analysis.
In light of the findings from this experiment and those of the first experiment, a signal detection analysis was conducted. The intent of this analysis was to determine if results from the different camouflage patterns could be attributed to the discriminability of the target (d'), to the subjects response criterion (Beta), or both. A signal was defined as the striped aircraft, while a noise stimulus was defined as a non-striped aircraft. A hit was defined as a yes response when the striped aircraft was presented, while a false alarm was defined as a yes response when the non-striped aircraft was presented. For each subject, the probability of a hit and the probability of a false alarm was calculated. The discriminability of a target (d') is then defined as the normal deviate associated with the probability of a (1-hit) plus the normal deviate associated with a false alarm. The resulting d's were subjected to a one-way analysis of variance. No significant differences between the patterns were observed. The mean values of d' are presented in Table 2.

In a similar fashion, Beta was calculated. Beta is the ratio of the ordinate associated with the probability of 1-hit over the ordinate associated with the probability of a false alarm. Since Betas are not normally distributed, no analyses were conducted on these values. They are presented in Table 2. It appears from a visual inspection of the Betas and d's that the results associated with the convergent camouflage pattern is consistent with the earlier findings. That is, the influence of this pattern is on Beta or response criterion and not on the discriminability of the pattern.

Table 2. The signal detection measures of d′ and Beta for each of the striped camouflage patterns.

| Pattern | d′ | Beta |
|---|---|---|
| Convergent | 4.1 | .53 |
| Parallel | 3.9 | .17 |
| Angles | 3.3 | .16 |

## General Discussion

Given the consistent, albiet statistically weak, findings from the two experiments, it appears that the convergent camouflage pattern is superior to the other patterns developed. It also appears to be superior to the camouflage pattern currently employed on the F-16. The new patterns have been applied to the three F-16 models provided by General Dynamics, the photos of which are presented at the end of this report. It would appear that the superior effects observed for the convergent pattern arose from the principles developed earlier in this report. The convergent pattern provided more that just an increase in the number of edges, it produced illusionary edges and contours. The illusionary effects contributed to the misperception of direction and resulted in increases in decision time and terminal response latency. Furthermore, large increase in the standard deviations were also observed. Both of these effects appear to result from the need for an increase in information pertaining to the pattern.

### Proposed Investigations

In this investigation we have developed principles of deception camouflage based on the slim evidence provided by the literature. From these principles three camouflage patterns were developed, with each pattern taking into consideration one or more of the principles. Moreover, a worst-case scenario was used to assess these patterns. Further investigations could proceed along two intertwining routes.

The first would be concerned with the development of additional patterns based on the principles. Since the convergent pattern involved a larger combination of the principles than either of the other two patterns, on a post hoc basis one would expect it to result in the poorest performance. Further combinations and weighting of additional principles when applied to the pattern development process might result in even worse performance. Those principles that contributed nothing could be eliminated. Additional principles might be uncovered and further refinement of the existing principles could be undertaken.

The second would be concerned with the development of testing procedures. Within the confines of the current investigation, aircraft motion was not introduced. Various degrees of motion, from both the stimulus point of view and the response point of view should be introduced into the assessment process. Motion could be from very small movements to free-flight. Small movements could be produced by mounting model aircraft, painted with the proposed camouflage patterns, on an arm attached to stepping motors and then asking subjects about the attitude and/or the heading of the aircraft. Comparisons between aircraft with different camouflage patterns that are at the same attitude and/or heading could be performed. With the introduction of eye-movement measurements, it would be possible to determine where the observer is looking. This information would be useful in substantiating the effectiveness in distrupting the gaze pattern.

Further increases in movement could be produced by suspending the aircraft from strings wound on pullies attached to motors which are mobile. The motors would then move in the horizontal direction, resulting in changes in the horizontal location of the aircraft. Changes in the length of string would result in changes in the altitude and attitude of the aircraft. Speed of movement of the aircraft could be induced by altering the rate of change of movement of the motors and changes in the rate of retraction or extention of the string. Given this type of situation, judgments concerning the flight path of aircraft, each or which is painted with different camouflage patterns, could be performed. Such judgments could be concerned with perceived differences in distance, attitude, altitude, and/or heading. In addition to judgments concerning these attributes other types of performance measures could be used to assessed the camouflage patterns. For example, the speed and accuracy of aiming a video camera at the target could provide information regarding the effectiveness of the camouflage pattern. Again, the use of eye-movement recording systems would be beneficial in assess the effectiveness of the camoulfage patterns in distrupting the gaze patterns.

Increase in movement would result from the use of radio controlled models painted with alternative camouflage patterns. Once again judgments concerning attitude, altitude, heading, and/or distance could be performed as well as the aimimg performance described earlier.

The final test would involve actual aircraft each of which would be painted with different patterns. The speed and accuracy of aiming the gun camera could be used to assess the effectiveness of the pattern. Such a procedure could also provide information regarding where the pilot is looking.

While the additional factors that could be introduced could go on forever, the following research ideas are being proposed as a continuation of this project.

First, a complete evaluation of the deception principles needs to be accomplished. Such an evaluation would involve basic research into the most salient variables that contribute to deception and the values of those variables which might contribute to deception. For example, the three values of spatial frequency used in this investigation were selected from basic research that suggested those values as being representative of low, medium and high spatial frequencies. However, when the values of spatial frequency are combined with a convergent line pattern, the spatial frequency is no longer constant over the aircraft. Other ways of combining spatial frequency and angle of line could have been, and probably should have been, generated. But there appear to be no studies that have simultaneously manipulated both of these variables.

Second, patterns based on a systematic combination of the variables contained within the principles need to be developed. It would appear that the combination of two variables that are contained within two different principles should result in poorer performance than one variable, and yet, information of this type does not exist. Furthermore, if the combination of two principles reduces performance, is there a limit beyond which the addition of more variables results in no further declines in performance.

Third, a systematic evaluation of the camouflage patterns in situations where the aircraft is moving needs to be performed. A continuum of movement from static to dynamic, needs to be employed. Moreover, not only does movement need to be manipulated, but the direction of that movement also needs to be investigated. While in the static situation one type of pattern may result in the poorest performance, a change to a dynamic aircraft environment may negate the influence of some variables. Such an assessment, as mentioned earlier would utilize speed of decision and accuracy of decision, but should also incorporate eye-movement data.

The investigation was a starting point that has resulted in a deeper understanding of the nature of deception camouflage. However, if this endeavor is going to be of greater value additional research is needed.

References

Bruce, V. & Green, P. (1985). Visual perception: Physiology, psychology and ecology. Hillsdale, N. J.: Lawrence Erlbaum Associates.

Bush, G. & Thayer, A. H. (1902). Process of Treating the Outsides of Ships &c., for making Them Less Visible. Letters Patent No. 715,013, dated December 2, 1902. United States Patent Office.

Coren, S. & Porac, C. & Ward, L. M. (1984) Sensation and perception. 2nd ed. Orlando: Academic Press.

Ferris, C. K. (1978). Camouflaged Aircraft, Surface Vessel or Vehicle or the Like. United States Patent 4,089,491. May 16, 1978. United States Patent Office.

Ferris, C. F. (1980). Camouflaged and Deceptive Distorted Vehicle and Method of Assembling Such Vehicles. United States Patent 4,212,440. July 15, 1980. United States Patent Office.

Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. Perception and Psychophysics, 14, 201-211.

Johamsson, G. (1975). Visual motion perception. Scientific American, 232, 76-89.

Johansson, G. (1985). Vector analysis and process combinations in motion perception: A reply to Wallach, Becklen, and Nitzberg. Journal of Experimental Psychology: Human Perception and Performance, 11, 367-371.

Luskiesh, M. (1922, 1965). Visual illusions: Their causes, characteristics and applications. Originally published by Van Nostrand, 1922. Republished New York: Dover, 1965.

O'Neill, T. R. (1986). What the gunner's eye tells the gunner's brain. I: The nature of visual camouflage. HSL Report 86-1. Human Sciences Laboratory, Department of Behavioral Sciences and Leadership. West Point, New York: United States Military Academy.

O'Neill, T. R. & Scott, B. D. (1986). What the gunner's eye tells the gunner's brain. II: Dazzle camouflage and tracking performance. HSL Report 86-3. Human Sciences Laboratory, Department of Behavioral Sciences and Leadership. West Point, New York: United State Military Academy.

Regan, D. & Beverley, K. I. (1984). Figure-ground segregation by motion contrast and by luminance contrast. Journal of the Optical Society of America, 1(5), 433-442.

Robson, A. D. (1942) Camouflage. United States Patent 2,292,848. August 11, 1942. United State Patent Office.

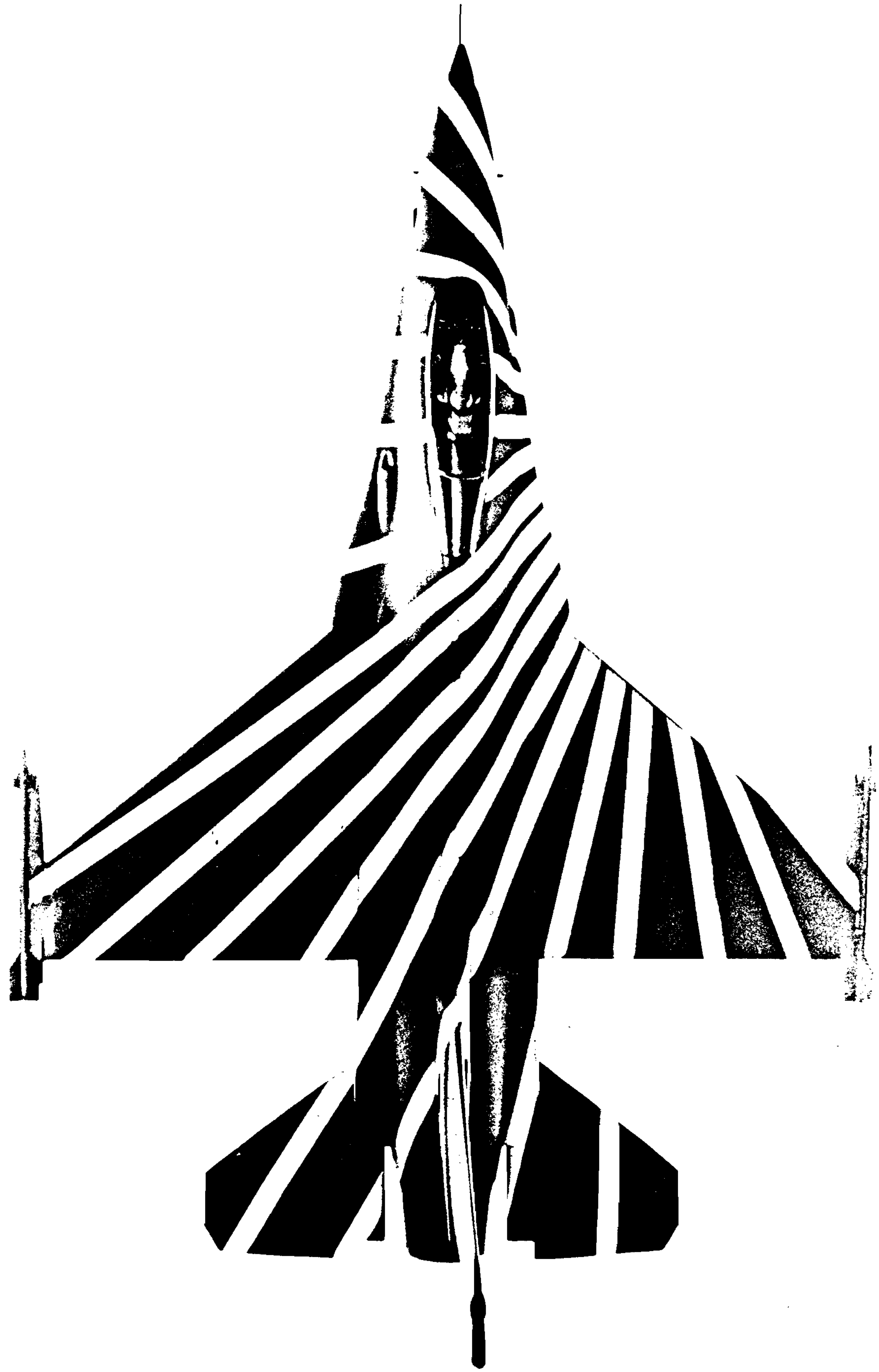
Rock, I. (1975). An introduction to perception. New York: Macmillan.

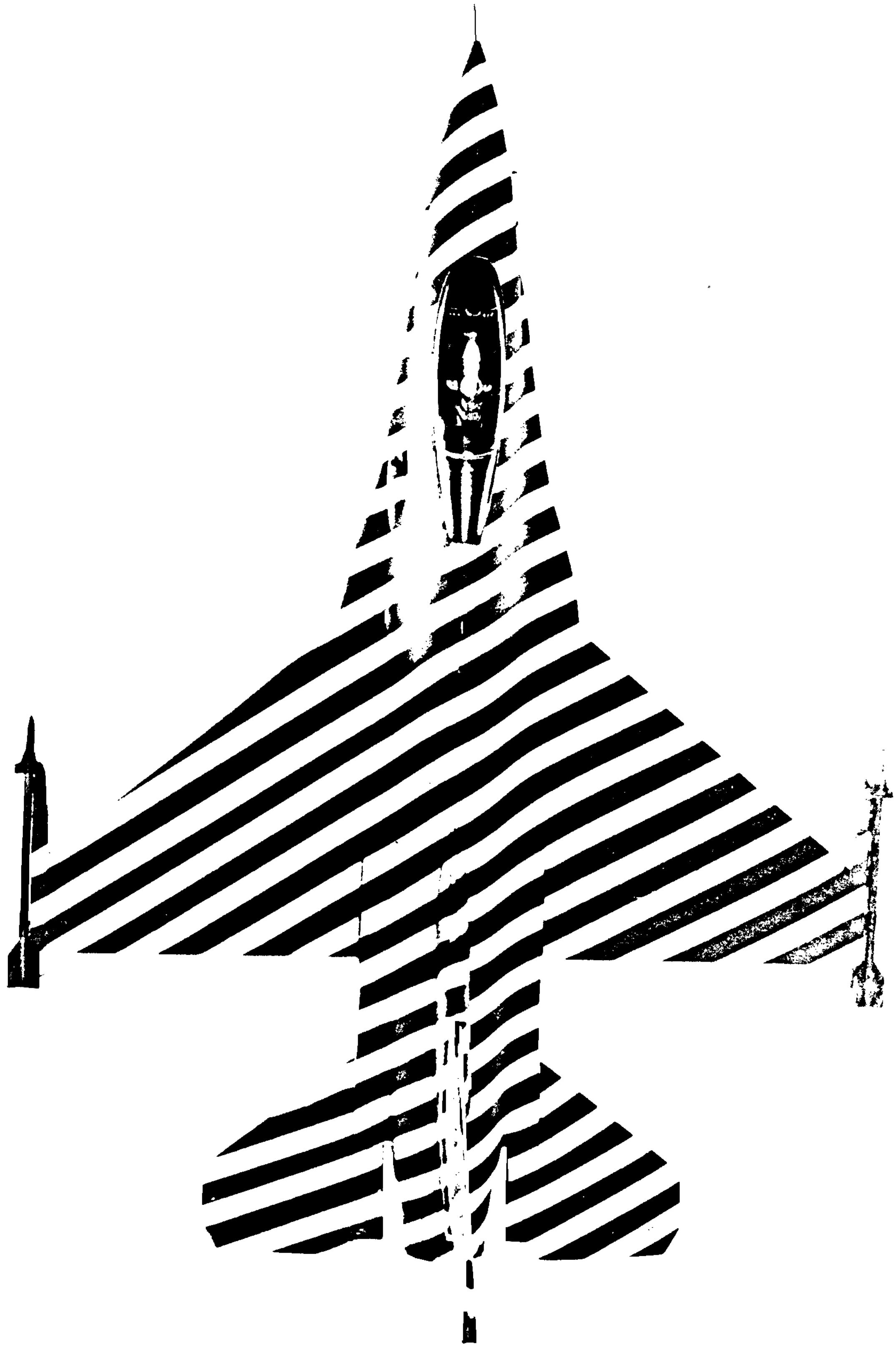
Rock, I. (1984). Perception. New York: Scientific American Books.

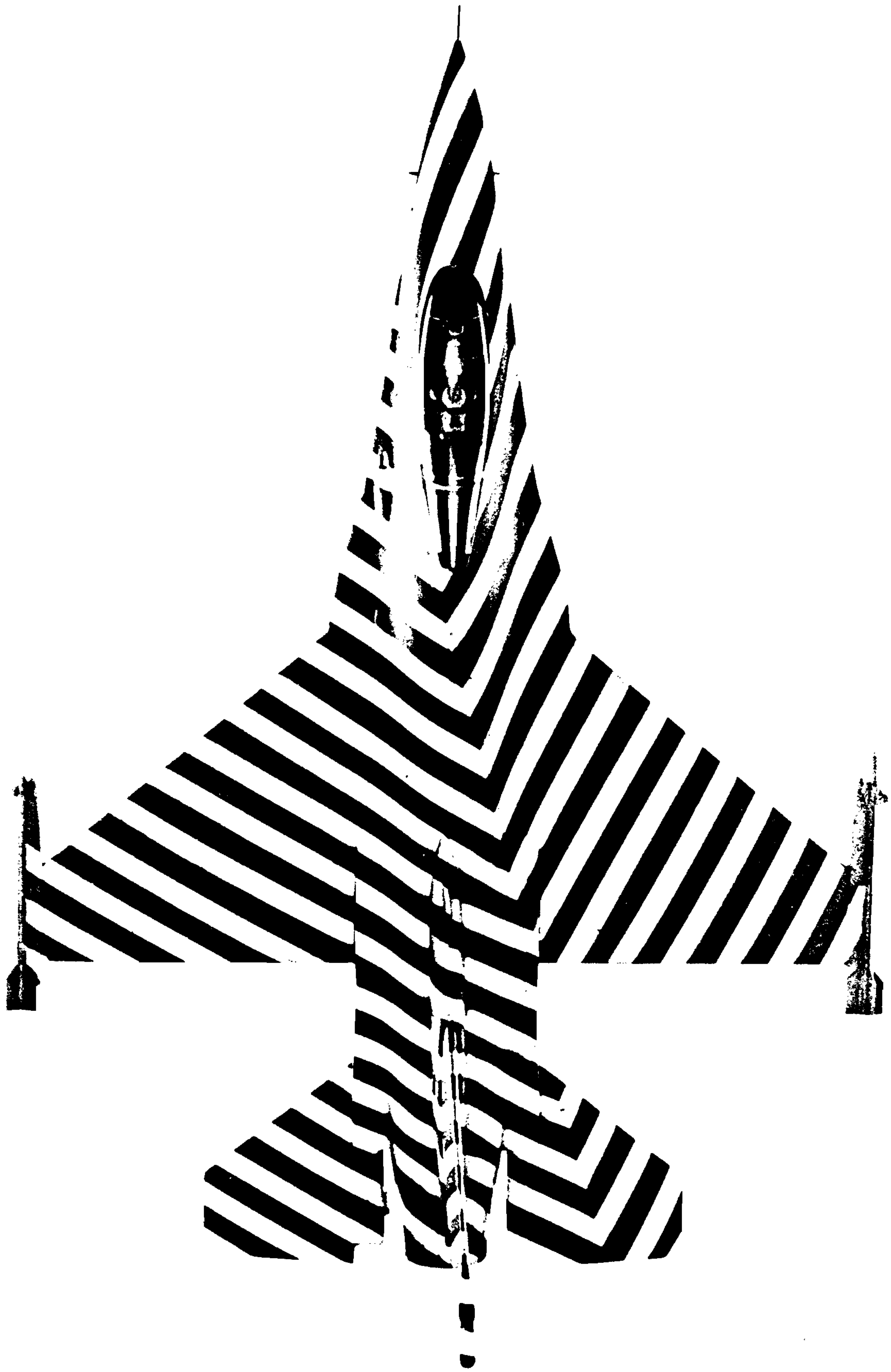
Teichner, W. H., Christ, R. E. & Corso, G. M. (1977). Color research for visual displays. New Mexico State University, Las Cruces, New Mexico.

Webster's New Collegiate dictionary (1958). Springfield, Mass.: Merrian.

PLATES 1-3







# F-16 Camouflage Development Study
# Final Report Addendum

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**Abstract**

This report details the results from three experiments which investigated attitude deception camouflage patterns. The deceptive patterns investigated were the convergent pattern, the angles pattern, the parallel pattern (Corso, Payne, Rose, & Folds, 1988) and the standard F-16 camouflage pattern. The major difference between the three experiments was the view of the aircraft. In the first experiment, a rear view of the aircraft was used, with the aircraft at a 10 degree pitch (nose up). The independent variables were camouflage patterns and changes in yaw. The results indicated significant differences between the camouflage patterns. In the second experiment, the aircraft was orientated at 270 degrees pitch angle and 0 degrees roll. The independent variables were the camouflage pattern and changes in yaw. The analysis of data revealed significant differences between the patterns In the third experiment, the view of the aircraft was from the front. The independent variables were the camouflage patterns, the axis manipulated and the degrees of rotation about that axis. For one group changes in yaw occurred, for the second group changes in pitch occurred while for the third group, changes in roll occurred. For each axis, the changes were in one degree steps, with a maximum of plus or minus five degrees. The analysis of the data revealed significant differences between the axis manipulated as well as significant camouflage pattern differences.

## Introduction

Previous experiments conducted in our laboratory have suggested that the perceived attitude of a line drawing of an aircraft can be altered through the use of camouflage patterns (Corso, Payne, Rose & Folds, 1988). The intent of the experiments reported in this document were two-fold. First, the prior experiments used outline drawings of F-16 aircraft, a partial replication of the previous experiments using slides of model F-16 aircraft would permit us to evaluate the influence of different types of representations of aircraft on the perception of aircraft attitude. Second, the previous experiments were restricted in the view of the aircraft presented to the subjects. In the following experiments different views of the aircraft, as well as the independent manipulation of pitch, roll and yaw were investigated.

## General Method

### Apparatus & Stimuli

In order to assess the camouflage patterns proposed in Corso, Payne, Folds and Rose (1988), four 1/40 scale models were painted in various camouflage patterns. The standard (F-16A 78002, 388th TFW) camouflage pattern was painted on one model so as to compare the results obtained with the proposed camouflage to those of traditional camouflage. The remaining models were painted to generate parallel, convergent, and angle camouflage schemes using light (FS 36622) and dark (FS 36118) grays. The lines painted with light gray were 1/4 of an inch wide. For the angles and the parallel patterns the dark gray lines were also 1/4 of an inch wide. For the convergent pattern, the dark areas were one inch wide for the largest separation and 1/8 of an inch wide for the smallest separation. These models were then photographed against gray backgrounds to generate the stimuli used in the experiment. The actual deceptive camouflage patterns used were presented in Corso, Payne, Folds and Rose (1988) in Plates 1-3. Those plates are reproduced as Figures 1-3.

The models were photographed while they were hung from a specially modified tripod mounted to a room ceiling. This facilitated the changing of pitch, roll, or yaw as needed in one degree increments while minimizing the possibility of external visual cues. All photographs were taken with daylight-balanced photofloods using daylight balanced film, thus insuring minimal color shifts in the final photographs. The final photographs were projected by a Dukane Pro-100 random access slide projector onto a rear projection screen. The projected slides of the models had a wingspan of 1.75 inches on the screen when the pitch, roll and yaw angles

Figure 1. The parallel camouflage pattern

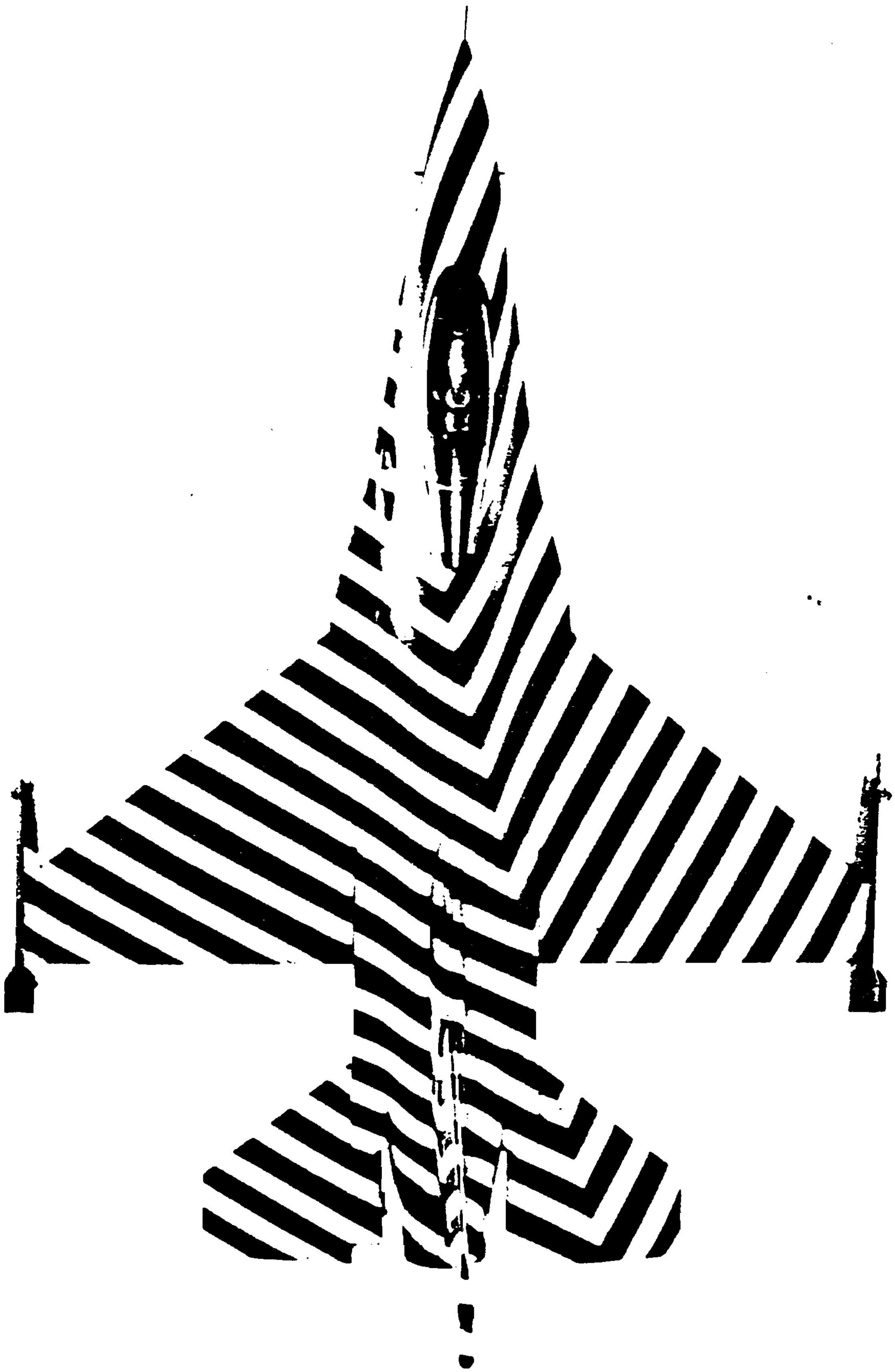

Figure 2. The angles camouflage pattern.

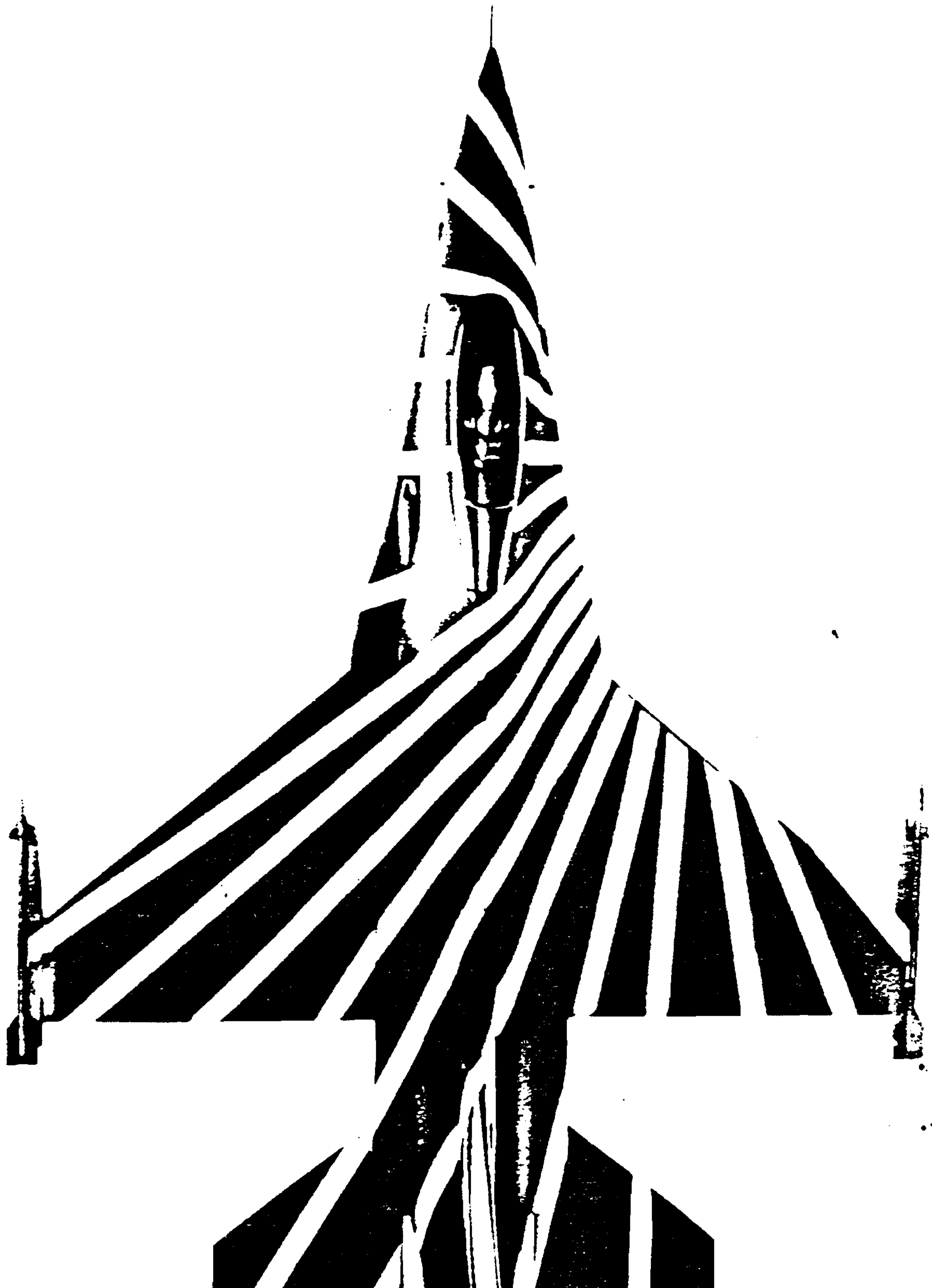

Figure 3. The convergent camouflage pattern.

assumed values of 0 degrees. As changes in pitch, roll and yaw occurred the projected length and wingspan were reduced. The projected aircraft size simulated the appearance of an F-16 aircraft when viewed from approximately three-quarters to one mile away. The actual visual angle of the aircraft as seen by a particular subject depended in part on where in the laboratory that subject was sitting. Approximate visual angles may be calculated using the dimensions presented in Figure 4.

The overall luminance values of the aircraft and their backgrounds differed depending on the condition being viewed. For Experiments 1 and 2, the background had a luminance value of 1.4 foot-lamberts and the aircraft had average luminance values of 0.8 foot-lamberts resulting in a contrast ratio of 75% (Grether & Baker, 1972). For Experiment-3, the background had a luminance value of 1.1 foot-lamberts, while the aircraft had a luminance value of 1.7 foot-lamberts. This results in a contrast ratio of -54.5%. The luminance values were all measured using a standard photographic exposure meter, and converted to foot-lamberts as per Coren & Miller (1973).

An IBM PC computer equipped with two LabTender laboratory interface cards controlled the experiment. This equipment provided an independently controllable millisecond timer for each subject as well as digital input/output capabilities to control and monitor events external to the computer. This system allowed relatively automated data collection as software could be used run the experiment and synchronize the use of all the required equipment, including a Dukane PRO-100 random access slide projector, a Lafayette Instrument 43011/16 shutter, and eight two-button subject response panels.

**Subjects**

A total of 50 male and female undergraduate students participated in the experiment. All subjects were right-handed and had 20/20 corrected or uncorrected vision. Of these subjects, nine were excluded from the analyses due to equipment failure, or failure of the subjects to follow directions. Of the remaining 41 subjects, 11 participated in Experiment-1, six participated in Experiment-2, and 24 participated in Experiment-3. The subjects in Experiment-3 were placed into one of three groups; nine in group 1 where yaw angle manipulated, eight in group 2, where roll angle was manipulated, and seven in group 3 where pitch angle was manipulated. Subjects were given credit for their participation which could be used for extra-credit in their psychology class. In addition, a $5.00 bonus was offered for the best performance in each condition.

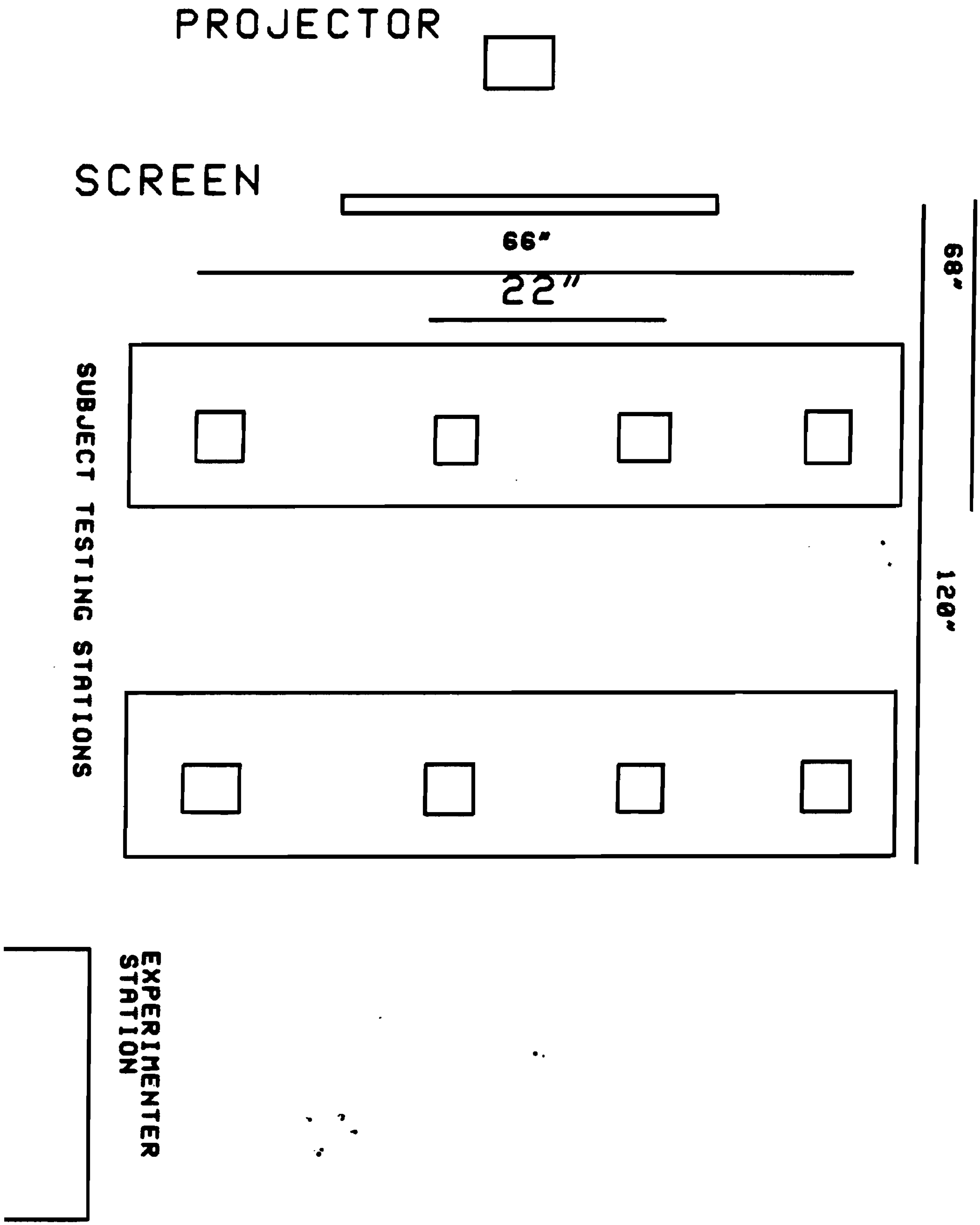


Figure 4. The subject testing room.

**Procedure**

Subjects were brought into the testing-room, shown in Figure 4, and had the task explained to them in general terms. Between one and eight subjects might be run in a given session depending on how many had volunteered. The subjects were told that they would have to decide if the aircraft shown on the projection screen was oriented in a particular direction. If it was, they were to use the right index-finger to push the key labelled yes as quickly and accurately as possible. If the aircraft was not oriented in the specific orientation, they were to push the key labelled no. The "YES" and "NO" labels associated with each response key were counterbalanced between subject stations. Between trials, subjects were instructed to rest their finger on a red spot between and below the response keys. In the event subjects were not sure which aircraft had been presented, they were told to make their best guess.

Four aircraft (one aircraft for each camouflage pattern), in the target orientation were then presented to the subjects. Each aircraft was presented for two seconds. At this point the task instructions were summarized, and then ten practice trials were given. Target and non-target slides were presented with equal probability and were selected randomly. However, for the practice trials only the most extreme, i.e. four or five degree rotations were used for the non-target slides. A trial lasted approximately ten seconds, during which time the projector advanced to the selected slide, after a random pause (1-3 seconds) the shutter would open for 50 milliseconds, and the subjects then had three seconds in which to respond. In the event that the slide for a given trial was the same as that of the preceding trial, the projector motor was momentarily activated in order to generate an auditory cue that the slide had changed. At the conclusion of the practice trials subjects were given the opportunity to ask questions, and the instructions would be repeated as necessary.

Each subject in all three experiments received 400 trials arranged in five blocks of 80 trials. Within each block there were an equal number trials for each camouflage pattern (10 trials per pattern for the target trials and 1 trial for each pattern for the non-target trials at each angle), as well as an equal number of target and non-target trials. In addition, there were an equal number of presentations of each angle rotation for each of the non-target slides. Each trial proceeded as in the practice trials. After each block of trials, subjects were given a short break before continuing. Each of the three experiments required approximately an hour and a half of subject participation.

## Experiment 1

In this experiment, the primary concerns were, (1) the effect of manipulation of yaw when the aircraft was viewed from the rear, and (2) the effect of the type of camouflage pattern on the perception of attitude. There were four camouflage patterns; the standard pattern, the convergent pattern, the parallel pattern and the angles pattern. The pitch and roll angles were held constant at 10 and 0 degrees respectively. Yaw angle assumed values from +5 to -5 degrees in 1 degree steps. The subject's task was to make a decision regarding aircraft orientation. If the aircraft was orientated at 0 degrees yaw angle, 0 degree roll angle and 10 degrees pitch angle, the response key labelled yes was to be depressed otherwise the response key labelled no was to be depressed. The subjects were shown four slides of each aircraft camouflaged with one of the four patterns at the target position of 0 degrees yaw, 0 degrees roll and 10 degrees pitch. Additionally, they were given 10 practice trials. Upon completion of the practice trials, five blocks of 80 trials were presented to the subjects.

### Results

The data obtained from the subjects were separated into hits and correct rejections. A response was defined as a hit if a yes response was given to the orientation of the aircraft that matched the orientation specified during the instructions. In this experiment that orientation was 0 degrees yaw, 0 degrees roll and 10 degrees pitch. A correct rejection was defined as a no response given to an aircraft that was not at that position. There were a total of 50 target trials, where the aircraft orientation matched the specified orientation, and 50 non-target trials. Within the non-target trials, the aircraft assumed yaw angle values of +5 degrees to -5 in 1 degree steps. Consequently, there were five trials for each non-target position. Separate data analyses were conducted on the hits, hit reaction times and correct rejections. Due to the limited number of non-target trials for each yaw angle, there were trials where no correct rejections occurred. Consequently, correct rejection latencies were not subjected to an analysis.

**Hits.** The number of hits for each subject as a function of each camouflage pattern was subjected to an analysis of variance. This analysis revealed significant effects for camouflage pattern, $F(3,30) = 5.70$, $p.<.01$. The greatest number of hits resulted from the standard pattern, 37 out of a maximum of 50, with 33 for the convergent pattern, and 27 for both the parallel and angles pattern.

**Hit reaction time.** The mean hit latencies for each subject as a function of each camouflage pattern was subjected to an analysis of variance. A significant effect for pattern was observed, $F(3,30) = 3.01$, $p < .05$. The standard pattern resulted in the fastest response time, 987ms, followed by the convergent pattern at 1002 ms, the parallel pattern at 1077 ms and the angles pattern at 1116 ms.

**Correct rejections.** The number of correct rejections for each subject at each yaw angle for each camouflage pattern was subjected to an analysis of variance. Significant differences for camouflage pattern were observed, $F(3,30) = 5.30$, $p < .01$, as was the yaw angle, $F(9,90) = 3.89$, $p < .01$ and the pattern by angle orientation ,$F(27,270) = 1.95$, $p < .01$. While there was a significant interaction, both the consistency and the magnitude of that interaction appear rather meaningless. The largest number of correct rejections was for the angles pattern, with 26 out of a maximum of 50, followed by the standard pattern with 24 correct rejections, the convergent pattern with 21 correct rejections, and the parallel pattern which produced 19 correct rejections.

### Discussion

These results suggest that the poorest pattern for both hits and hit reaction time was the standard camouflage pattern. While the best of the patterns as measured by hits and hit response time was the angles pattern. The qualitative statements of best and poorest refer to the patterns' deceptive ability, where the best deceptive pattern resulted in the poorest performance. When viewed in terms of the correct rejection data, the poorest pattern was the angles pattern while the best pattern was the parallel pattern. Given that performance resulting from the angles pattern differed as a function of the type of trial, target or non-target, it would appear that either the parallel or the convergent pattern should receive additional consideration.

## Experiment 2

In this experiment the primary concern was the yaw angle and the camouflage pattern. Once again, the four patterns selected for evaluation were those proposed by Corso, Payne, Folds and Rose. The top of the aircraft was viewed. The aircraft was at a pitch angle of 270 degrees (nose up), and 0 degrees roll. Yaw angle assumed values from -5 to 5 degrees in 1 degree steps. This condition was a partial replication of the earlier studies from Corso, Payne, Folds and Rose (1988).

### Results

As in Experiment-1 a response was classified as either being a hit or a correct rejection. A response was classified as a hit if it occurred to an aircraft that was at 270 degrees pitch angle, 0 degrees roll angle and 0 degrees yaw angle.

**Hits.** The number of hits as a function of each camouflage pattern was subjected to an analysis of variance. A difference between the patterns, $F(3,15) = 2.40$, $p.<.1$ was observed. The number of hits being greatest for the standard pattern, 39 out of a maximum of 50, followed by 30 hits for the angles and convergent patterns and 28 hits for the parallel pattern.

**Hit response time.** The response times associated with each hit for the camouflage patterns were subjected to an analysis of variance. This analysis showed a significant effect for camouflage pattern, $F(3,15) = 5.38$, $p.<.01$. The standard patterns resulted in the fastest response time, 829 ms followed by the convergent pattern, 860 ms, the parallel pattern, 948 ms and the angles pattern, 952 ms.

**Correct rejections.** The correct rejections were subjected to an analysis of variance. No significant differences were observed.

**Discussion**

Both the number of hits and the hit reaction times seem to suggest that the best deceptive pattern when the aircraft is orientated at 270 degrees pitch angle, is the angles pattern. These results seem to conflict with the results from the earlier investigations (Corso, Payne, Folds & Rose, 1988) where the best deceptive pattern for an aircraft with the same orientation was the convergent pattern. However, it must be remembered that the earlier investigations used line drawings while this investigation used slides of model aircraft. Furthermore, the earlier investigations found no significant differences in the number of correct responses. The latency data reported in this study may have been different given a lack of differences in the number of hits. Lastly, the earlier investigations reported on data that resulted from collapsing target and non-target trials.

## Experiment 3

The intent of the third experiment was to investigate a front view of the aircraft and the four previously described camouflage patterns. Pitch, roll and yaw angles were manipulated independently. Two of these angles were held constant while the other angle assumed values from +5 degrees to -5 degrees in 1 degree steps. A subject was placed into one of three groups. For group-1, yaw angle was manipulated, while pitch and roll angles were held constant at 0 degrees. Roll angle assumed values from -5 to +5 degrees in 1 degree steps. For group 2, pitch and yaw angles were held constant at 0 degrees, while roll angle assumed values from -5 to +5 degrees in 1 degree steps. For group 3, roll and yaw angles were held constant at 0 degrees, while pitch angle assumed values from -5 to +5 degrees in 1 degree steps.

**Results**

Three different dependent variables, hits, hit response time and correct rejections were subjected to three separate split-plot analyses. The between-subject variable was the angle (pitch, roll or yaw) manipulated, while the within-subject variables were the camouflage patterns9 and, for the correct rejections, the angle of change.

**Hits.** An analysis of variance of the hit responses revealed a significant effect due to the camouflage pattern, $F(3,63) = 10.14$, $p.<.01$. The greatest number of hits occurred with the standard pattern, 37 out of a maximum of 50, followed by the parallel pattern, 34 hits, the angles pattern, 32 hits and the convergent pattern with 28 hits. No other significant main effects or interaction were observed.

**Hit Reaction Time.** The only significant effect revealed by the analysis was due to the camouflage pattern, $F(3,63) = 3.52$, $p.<.02$. The fastest response time resulted from the standard pattern, 1037 ms, followed by the parallel pattern, the convergent pattern and the angles pattern with response times of 1064, 1112, and 1123 respectively.

**Correct rejections.** The analysis of correct rejections revealed significant main effects for axis of manipulation $F(2,21) = 3.98$, $p.<.05$, and for camouflage pattern, $F(3,63) = 6.38$, $p.<.01$. Additionally, significant interactions between pattern and angle, $F(27, 567) = 3.53$, $p.<.01$ and between pattern, angle and axis, $F(54, 567)= 1.73$, $p.<.01$ were observed. The practical significance of these interactions in somewhat doubtful given the large number of degrees of freedom. The largest number of correct rejections was observed when roll was the axis manipulated, with yaw resulting in the fewest number of correct rejections. The corresponding number of correct rejections, out of a maximum of 5, were 2.9, 2.2 and 1.83 for roll, pitch and yaw respectively. The number of correct rejections were 24, 20, 21 and 27 out of 50 for the standard pattern, the parallel pattern, the convergent pattern and the angles pattern, respectively.

**Discussion**

When the aircraft is viewed from the front the best deception pattern is either the convergent pattern or the parallel pattern. The number of hits, correct rejections and the hit response time for these two patterns resulted in greater deception than the standard pattern. While the angles pattern resulted in the slowest response time, it also resulted in the greatest number of correct rejections thereby eliminating this pattern from consideration.

## General Discussion

While comparisons of the findings from this series of experiments with those from Corso, Payne, Folds and Rose (1988) would seem to be appropriate the differences between the aircraft stimuli would negate the meaningfulness of the comparisons. For example, the size of the aircraft in the current series of experiments was much smaller that in the earlier Corso, et al studies. As a result, the visual angles are different as are the spatial frequencies associated with the patterns. Likewise luminance and contrast values were different between the two series of experiments. Nevertheless, even given these differences the general finding associated with the two series of experiments appears to hold, that is, camouflage patterns can be designed which will result in attitude deception.

Within this series of experiments, it appears that the view of the aircraft does not interact with the camouflage pattern. Consequently, as a methodological note, different views of the aircraft, for symmetrical camouflage patterns, may not need to be manipulated. It does appear that the best performance results from the condition where the greatest amount of surface area of the aircraft is exposed. For the current series of experiments this was an aircraft orientated at either 10 degrees pitch or 270 degrees pitch.

With respect to the best deceptive camouflage pattern, of those patterns tested, either the parallel pattern or the convergent pattern appears to result in fewer hits, slower response times, and greater number of correct rejections when compared against the standard camouflage pattern. However, in some cases, the magnitude of the effects appears to be small.

## References


Coren, S. and Miller, J. (1983). The use of exposure meters as photometers. Behavioral Research Methods and Instrumentation, 5, 357-360.

Corso, G.M., Payne, M.C., Folds, D.J. and Rose, P. (1988). F-16 Camouflage Development Study, Final Report. School of Psychology, Georgia Institute of Technology, Atlanta, Ga.

Grether, W. F and Baker, C. A. (1972) Visual presentation of information. In: Van Cott, H. P. and Kinkade, R. G. Human Engineering Guide to Equipment Design, U. S. Government Printing Office, Washington D. C., 41-122.