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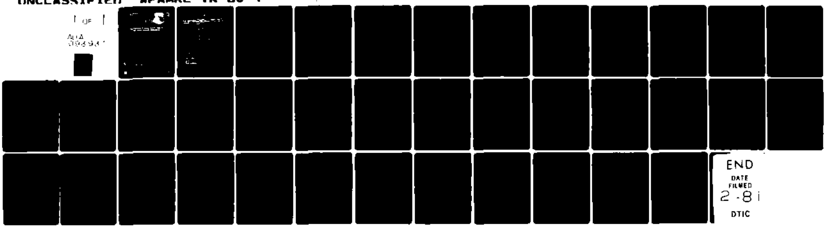

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A field study was conducted to assess the scope and severity of mission-related optical problems associated with the new F-111 Bird Impact Resistant Transparency (BIRT) windscreen. Data for this study was gathered from an 81-item questionnaire and used to scale the opinions of 33 USAFE pilots. Principal findings indicate that: 1) Distortion is perceived as the most disruptive optical factor followed in order by multiple images, haze and rainbowing. 2) The worst combination of optical defect and flight task is multiple images during night approach and landing. 3) The extent to which BIRT optical

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problems are perceived as impairing mission performance is sufficiently great to further justify research for improving windscreen optical quality. (4) Pilots with very limited amounts of BIRT flying time (20-80 hours) are less likely to perceive windscreen optical problems than a middle experience group (with 100 to 180 flying hours). This difference is attributed to a lack of exposure to the optical effects; and (5) Pilots with relatively extensive BIRT flying experience (over 200 hours) are also less prone to perceive windscreen problems than the middle experience group. This difference is attributed to the effect of a period of adjustment to the optical anomalies.

SUMMARY

The objective of this effort was to evaluate the data of a field study which addresses a variety of pilot visibility problems. All of these problems are associated with optical defects in the Bird Impact Resistant Transparency (BIRT), the windscreen currently being flown in the F-111 aircraft. A major goal of this study was to gain a more detailed and user-related understanding of the scope and severity of mission-dependent visibility problems associated with BIRT.

An 81-item questionnaire was used to survey pilot opinion about the following BIRT optical defects: distortion, multiple images, haze and rainbowing. The questions were designed to identify:

- The extent to which the BIRT optical defects are detected by pilots under specified conditions or phases of the flight mission.

- The extent to which such defects are perceived as impairing pilot performance for specified flight tasks or conditions.

- Windscreen locations where distortion or rainbowing is most noticeable.

- The hues and saturations perceived in the rainbowing color patterns.

- The variability among F-111 windscreens in terms of perceived distortion or rainbowing.

The subjects were 33 volunteer USAFE pilots stationed at Upper Heyford and Lakenheath Royal Air Force Bases in England. All were currently flying combat-ready missions in the F-111 fitted with BIRT windscreens.

The main findings of the study are summarized as follows:

1. The BIRT optical factors are ranked in the following order, both with respect to their *detectability* and their *perceived adverse effects* on mission performance, i.e., distortion, multiple imaging, haze and rainbowing.

2. The two flying tasks perceived as most susceptible to impairment from BIRT defects are approach/landing and target acquisition.

3. The combination of defect and flying task creating the most severe problem is identified as multiple images during night approach and landing.

4. Both rainbowing and distortion are most frequently perceived in the margins and center arch of the windscreen as well as the forward ⅓ area, and rarely anywhere else.

5. The dominant hue in rainbowing is red. Blue, yellow and purple are sometimes perceived, while green is almost never reported. Pilots show inconsistency with respect to the degree of saturation reported in rainbowing.

6. About 60% of the pilots find noticeable, considerable or large differences in both distortion and rainbowing patterns among F-111 BIRT windscreens.

7. On the average, the responses of 38% of the pilots show the BIRT anomalies to be perceived with a frequency between "always" and "sometimes." With the same frequency, *an average of 34% of the pilots judged these defects to impair various aspects of their mission performance*. The latter finding appears sufficiently serious to further justify the need to admonish aircraft transparency design engineers not to sacrifice good optical quality in the interest of obtaining marginal gains in aerodynamic efficiency.

8. Extent of flying time with BIRT was also analyzed as a determinant of pilot attitude. It was found that pilots with less than 100 hours fail to either notice or perceive problems with BIRT defects to the same extent as pilots with an intermediate amount of experience (100–180 hours). These differences can be largely accounted for as lack of exposure to the problem. To an even greater degree pilots with over 200 hours of BIRT flying time also perceive less of a problem with the defects than the intermediate group. (Both groups in this case, however, notice the defects to about the same degree.) This difference can be explained as an adjustment to the problem by the more experienced group.

PREFACE

This report documents an in-house study performed by the Visual Display Systems Branch, Human Engineering Division of the Aerospace Medical Research Laboratory. The authors wish to thank all the USAFE personnel stationed at Upper Heyford and Lakenheath Royal Air Force Bases in England who supported or participated in this effort. In particular we wish to acknowledge the assistance of Captain Michael P. Nishimuta of the 55th Tactical Fighter Squadron, 20th Tactical Fighter Wing, who helped to enlist and schedule the services of the experimental subjects. We also wish to thank Ms. Mary Anne Howes of the System Research Laboratories for her assistance in reducing the experimental data.

The senior author, Dr. Shelton MacLeod, died just after completion of the first draft of this report. Major Eggleston, the coauthor, completed the work for his colleague, whose scienctific acumen was respected by all.

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INTRODUCTION

Bird impact resistant transparencies (BIRT) were introduced in February 1977 in the F-111 E and F fighter aircraft for combat-ready pilots of the USAFE Tactical Fighter Squadrons stationed at Upper Heyford and Lakenheath, England. Although pilot exposure to this particular windscreen is still somewhat limited, it has now become possible to gather a substantial amount of field data to assess visibility problems associated with BIRT. At issue is the extent to which these problems interfere with the effective performance of tactical fighter missions.

Both optical analysis and subjective experience reveal four major visual defects inherent in the curved, laminated BIRT design. These optical factors have been identified and defined by Provines, Kislin, and Tredici.* An abbreviated version of their definitions is presented:

1. *Distortion*: "Light refracted . . . in various ways as it passes through an optical medium, resulting in a viewed image not being a true representation of the object." Three types of distortion evident in BIRT are lensing, displacement grading, and roll or band distortion.

2. *Haze*: "A scattering effect of light passing through an optical medium. This scatter is caused by imperfections (such as scratches) on the surface and/or effects within the medium itself. The visual effect is that of an object appearing cloudy, obscured, or less distinct from its background (reduction in contrast)."

3. *Multiple Images*: Internal interface reflection within the transparency media surfaces, which may result in one or more less intense secondary (ghost) images of a single object (usually an external light source in a dark background). Such images may appear, disappear and swirl. They are normally only visible at night.

4. *Rainbowing*: Production of colors by means of refraction through a birefringent medium. Particular patterns are dependent on stresses within the medium and are accentuated by polarized incident light (such as sky light).

Despite the fact that all of the above anomalies can be perceived by the observer and, if of sufficient magnitude, can be shown by laboratory tests to elevate thresholds of visibility, little or no data exist for establishing or prioritizing their effects as potential hazards to the flight mission. An obvious first approach for acquiring this kind of information to assess the extent and severity of the BIRT windscreen problem is a systematic survey of pilot opinion. Such data were collected during the month of October, 1978, from 33 pilots stationed at Upper Heyford and Lakenheath Royal Air Force Bases in England.

This study was designed to provide answers to the following kinds of questions:

1. Questions indicating the extent to which BIRT optical defects are detected by pilots. Some of these questions are restricted to particular phases or conditions of the flight mission (e.g., approach and landing).

2. Questions indicating the extent to which BIRT optical defects distract pilots or impair their flight performance. Again, some questions are general and some are restricted to particular phases or conditions of the mission.

3. Questions which deal with windscreen locations where a particular optical effect is most noticeable.

4. Questions dealing with the perceived hues and saturation of rainbow color patterns.

It was possible to partition the questionnaire data with respect to the number of hours flown by the pilot subjects with the new BIRT. Thus the pilot opinions could be appraised not only in a general sense (i.e., as applicable to all pilots), but also with respect to amount of specific flying experience with the BIRT windscreens.

In summary, the objective of this effort was to analyze the above kinds of survey data to gain a more detailed and user-related view about the scope and severity of mission-dependent visibility problems associated with BIRT. It is hoped that this information can also be used in the selection of optical quality specifications for aircraft windscreens which will be cost effective and yet not jeopardize aircrew safety and mission performance.

* Provines, W.F., B. Kislin and T.J. Tredici, *Optical Evaluation of F/FB-111 Field-Service Test Windshields*, SAM TR 77-19 (AD A-046 490), USAF School of Aerospace Medicine, Brooks AFB, TX.

METHOD

SUBJECTS

Detailed background data (gathered from the personal data sheet shown in Appendix A) for the 33 volunteer USAFE pilots is summarized in Table 1. All of these personnel were on active duty, and all were currently flying with F-111 (E or F) BIRT windscreens. Two held the rank of Major, the others were Captains.

The top row of Table 1 lists medians and ranges for the entire sample with respect to age, total flying hours, combat flying hours, and flying hours with the new BIRT windscreen. The data reveal wide ranges of experience in the three categories of flying. Note that only one-third of the group (11) had combat experience and that only one pilot (with 1100 hours) had over 400 hours of flying with BIRT.

Since it was logical to assume that the amount of BIRT flying experience would be the most critical background factor in affecting responses to the questionnaire, the pilots were subdivided according to this variable into three nearly equal groups. The bottom three rows of Table 1 provide a comparison of these three groups in all the background factors. Note that all groups are closely matched in terms of age. As one would expect the 10 pilots with a high amount of BIRT experience have on the average more total and combat flying hours than the other two groups, which are roughly equivalent in terms of total flying hours, but differ in combat experience. The 11 pilots with the lowest BIRT flying hours had some combat experience, but the group of 12 with intermediate BIRT flying hours had none.

QUESTIONNAIRE

The questionnaire contained 81 items and appears in the Appendix.

Three items were eliminated from the analysis. The first of these (item No. 13) called for the number of times an aerial engagement had to be broken off as a result of poor visibility through BIRT. It became apparent that the question was meaningless, since none of the pilots had ever flown combat or participated in air-intercept training while using a BIRT windscreen. The other two questions (No. 47 and No. 73) concerned the frequency of noticing haze and rainbowing with the sun at 6 o'clock. Since perception of these phenomena under this condition is a near-physical impossibility (happily verified by almost no positive responses), these items served only to verify that the subjects were responding in an attentive and logical manner and need no further analysis.

Sixty-two of the remaining 78 items required the respondent to register a degree of opinion as to whether BIRT optical defects: (a) were detectable (17 items); or (b) tended to impair mission performance (45 items). These will

TABLE 1

BACKGROUND DATA FOR 33 PILOTS TAKING THE BIRT QUESTIONNAIRE. MEDIAN AND RANGES ARE LISTED FOR EACH BACKGROUND CATEGORY FOR BOTH THE ENTIRE GROUP AND FOR THREE SUBGROUPS WITH DIFFERENT AMOUNTS OF BIRT FLYING EXPERIENCE.

Subject Groups	*Age*		*Total Flying Hours*		*Combat Flying Hours*		*BIRT Flying Hours*	
	Med.	*Range*	*Med.*	*Range*	*Med.*	*Range*	*Med.*	*Range*
Total (N = 33)	31	26-36	1900	450-4000	0	0-1000	111	20-1100
High BIRT Exper. (N = 10)	32	28-35	2055	1720-4000	190	0-900*	300	200-1100
Intermed BIRT Exper. (N = 12)	30.5	26-34	1525	450-2800	0	0	116	100-180
Low BIRT Exper. (N = 11)	29	27-36	1660	950-3000	0	0-1000**	60	20-80

* 6 pilots had combat experience
** 5 pilots had combat experience

subsequently be referred to as scaling items. The majority of the scaling items were 5-category Likert-type questions that asked the subjects to rate the frequency of detectability or impairment associated with BIRT. The remaining scaling items used a two-category (yes/no) response format to assess detectability or impairment.

All of the questions addressed optical characteristics of the BIRT windscreen. Most of these dealt with specific optical factors (distortion, multiple images, haze and rainbowing), but a number of items also addressed the general state of optical quality that might have arisen out of any combination of these factors.

The questions were presented in random order. Thus the response to each question could be formed in a relatively independent and spontaneous manner with less tendency to develop mental sets or biases than might have arisen out of a patterned progression of questions addressing a single optical variable.

PROCEDURE

Before administering the questionnaire, the examiner briefed all the pilots on its objectives, stressing its importance to the Air Force. The subjects were encouraged to provide honest evaluations and to annotate, wherever necessary, the survey forms with individual comments. Subjective (rather than optical) definitions were provided to describe all major optical phenomena associated with BIRT defects, and an attempt was made to insure that all pilots understood and agreed on the nature of each visual factor to be evaluated. (See cover letter in the Appendix.)

RESULTS

DISTINCTION BETWEEN DETECTION AND IMPAIRMENT ITEMS

The results have been separated into two sections: the analysis of those items associated with detection and those associated with perceived mission impairment. Although the latter category is obviously the more critical one, for the following reasons it was considered important to analyze BIRT phenomena independently in terms of their detectability:

1. Judgments involving the detection of a stimulus are probably less subjective, more reliable and less influenced by extraneous factors than judgments that relate the stimulus to mission performance.

2. If a visual anomaly is rarely observed under flying conditions, one can tend to ignore it as a major cause of mission impairment. (However, the mere fact that an anomaly is noticeable does not necessarily mean that it will adversely affect a flying task. The pilot may adjust to it.)

3. Finally, the conspicuity of a BIRT defect may indeed reflect its impairment potential for the flying task.

TABLE 2

COMPARISON OF BIRT OPTICAL FACTORS IN TERMS OF SCALED DETECTABILITY
(BASED ON TWELVE 5-CATEGORY ITEMS AND FIVE YES/NO ITEMS)

BIRT Optical Factor	*5-Category Items*			*2-Category Items (Yes/No)*	
	Number of Items	*Mean Response Scale Score*	*% Responses in Categories 1-3*	*Number of Items*	*% Responses Showing Detectability*
Distortion	3	3.2 (.55)	48	1	91
Multiple Images	–	—		3	65 (17)
Haze	4	3.5 (.39)	40	—	–
Rainbowing	5	3.7 (.41)	31	1	53
Totals	12	3.5 (.43)	38	5	68 (48)

NOTES: 1. Numbers in parentheses are standard deviations showing inter-item variability.
2. Means and percentages are based on responses of 33 subjects.
3. Response scale categories are: 1 Always, 2 Frequently, 3 Sometimes, 4 Occasionally, and 5 Never.

TABLE 3

DETECTABILITY OF DISTORTION OF VARIOUS FLIGHT CONDITIONS (5-CATEGORY ITEMS)

Item No.	*Flight Condition*	*Mean Response Scale Score*	*% Responses in Categories 1-3*
6	Unspecified	2.6	70
49	Gunnery range	3.5	42
62	Low level flight	3.6	33

NOTE: Response scale categories: 1 Always, 2 Frequently, 3 Sometimes, 4 Occasionally, and 5 Never.

TABLE 4

WINDSCREEN LOCATIONS WHERE RAINBOWING AND DISTORTION ARE MOST NOTICEABLE

Alternative Locations	*Item No. 61 Rainbowing*	*Item No. 30 Distortion*
	% Responses	*% Responses*
Edges & Center Arch	61	59
Forward 1/3	29	35
Around Boresight	3	0
Rear Arch	3	6
Same Everywhere	3	0

DETECTABILITY OF BIRTS OPTICAL DEFECTS

Seventeen questions were available to scale the detectability of BIRT optical factors. Each of these items refers to one of four defects (distortion, multiple images, haze or rainbowing). An analysis of responses to them is summarized in Table 2.

Two types of scores are provided in the table to show the degree of detectability for the 5-category items. One of these is the mean response scale score. The probabilities of detection that can be associated with different magnitudes of this score are (1) very high, (2) high, (3) intermediate, (4) low, and (5) very low.

The other measure is the percentage of responses occurring within categories 1-3. Collapsing across these three categories provides a single index that shows a moderate-to-high likelihood for detecting the optical factors in question.

Table 2 shows that, for either response criterion, the order of detectability is highest for distortion, intermediate for haze, and lowest for rainbowing. For both measures the haze score is about midway between the scores for the other two factors. In summary, these data show an overall mean response score of 3.5 and a relatively large percentage of pilots (38%) who have used the top three response categories. This clearly indicates that these optical problems are detectable much of the time.

Although somewhat fragmentary, the data for the two-category detection items (also shown in Table 2) are consistent with the multiple choice results in showing a very high percentage of "yes" responses (91%) for this distortion question and a considerably lower (though still sizeable) percentage (53%) for the rainbowing item. The three questions on multiple images also show this factor to be detected a relatively high percentage of the time (65%). A more detailed analysis of the detection items, organized in terms of optical factors, follows. The data summarized here provide a more precise understanding of how the perceptibility of distortion, multiple images, haze, and rainbowing depend on specific flight tasks or conditions.

Distortion

The high perceived incidence of BIRT distortion is certainly indicated by the responses to item No. 67, which simply asks if it is ever seen. Ninety-one percent of the pilots indicate "yes." More definitive answers are provided by the 5-category items (Nos. 6, 49, and 62) reviewed in Table 3, which indicate that distortion has a relatively high probability of detectability (70% responses in category 1-3) when the flight conditions are unspecified, and is still more than occasionally detectable on the gunnery range or in low-level flight.

A particular concern for distortion is the windscreen location where it is most frequently observed (Item No. 30). Rather clear answers (consistent with other empirically-derived data) to this question are provided by the data in Table 4 where 59% of the responses show the most likely area to be the edges and center arch with a sizeable percentage (35%) of responses also obtained for the forward 1/3 area. Negligible percentages are indicated for the bore-sight and rear-arch locations. There is, as one would expect, no indication that distortion is equally probable at all windscreen locations.

Another matter of interest (covered in item No. 24) concerns inter-aircraft variations of distortion patterns which reflect possible differences among windscreens with respect to this factor. Table 5 suggests significant variation since 59% of the subjects find aircraft differences to be noticeable (the modal response), considerable, or large.

Multiple Images

This is an optical defect typically produced by external sources of illumination during night missions. Table 6 (covering item No. 12) shows that this kind of aberration is most frequently reported for the flight task of night approach and landing (as indicated by 68% of the pilots). Landing lights and lights from other approaching aircraft are undoubtedly responsible for this finding.

The data from three yes/no type items (Nos. 40, 33 and 66) also show the relative detectability of multiple images under different night flight conditions. The results (see Table 7) show a considerable higher percentage of detection responses specific to approach/landing or under unspecified conditions (73–76%) than to the night air refueling situation (45%). This probably occurred because, while night flying missions are common, hence night approach and landing must be made, few of these missions involve air refueling. Therefore, it is likely that, for the refueling task, the pilots have very limited experience upon which to base judgments of multiple imaging.

Haze

Four 5-category items (Item Nos. 23, 48, 59, and 39) scale the detectability of haze under various mission conditions (see Table 8). As one might expect, this optical factor is most frequently noticed when flying into the sun (mean response = 3.1 and 67% of responses are in categories 1–3). For the other options, haze is least frequently observed with the sun at 3 or 9 o'clock and has intermediate probabilities of detection (about the same as distortion and somewhat higher than rainbowing) under conditions of low-level flight and on the gunnery range.

Rainbowing

Table 2 has already shown an overall tendency for rainbowing to rank lowest for detectability in comparison with the other optical factors. Nevertheless, it is of interest to identify those conditions where it is most or least frequently observed. Table 9 provides some answers to this question based on five items (Nos. 16, 18, 50, 57 and 9). As for haze (among the alternative conditions) rainbowing is most frequently detected when flying into the sun where its detectability is placed in category 1–3 53% of the time. For the other flight conditions (flying with the sun at 3 or 9 o'clock, gunnery range or low-level flight) the indicated frequency of observation is considerably lower.

TABLE 5

OBSERVED VARIATIONS IN DISTRIBUTION AND INTENSITY OF RAINBOWING AND DISTORTION PATTERNS AMONG F-111 BIRT WINDSCREENS

Alternative Amts. of Variation	*Item No. 7 for Rainbowing* — *% Responses*	*Item No. 24 for Distortion* — *% Responses*
Large	3	0
Considerable	17	9
Noticeable	41	50
Little	14	25
None	24	16

TABLE 7

DETECTABILITY OF MULTIPLE IMAGES FOR VARIOUS NIGHT FLIGHT CONDITIONS (YES/NO ITEMS)

Item No	*Flight Condition*	*% Detection (Yes Response)*
40	Approach/Land	76
33	Unspecified	73
66	Air Refuel	45

TABLE 6

PHASE OF NIGHT FLYING WHERE MULTIPLE IMAGES ARE MOST NOTICEABLE (ITEM NO. 12)

Alternatives	*% Responses*
Air Refuel	5
Approach Land	68
Formation Flight	8
Ground Taxi	3
Other	16

TABLE 8

DETECTABILITY OF HAZE FOR VARIOUS FLIGHT CONDITIONS (5-CATEGORY ITEMS)

Item No.	*Flight Condition*	*Mean Response Scale Score*	*% Response in Categories 1–3*
23	Flying into sun	3.1	67
48	Low level flight	3.5	36
59	Gunnery range	3.6	39
39	Fly with sun at 3 or 9 o'clock	3.9	17

NOTE Response scale categories: 1 Always, 2 Frequently, 3 Sometimes, 4 Occasionally, and 5 Never

One yes/no type question (No. 44) queries the pilot on whether rainbowing is noticed more often on a particular phase of the F-111 mission and then he is asked to list those conditins. The initial question is answered affirmatively by 53% of the subjects. Eleven phases of flight are mentioned with the following being indicated by more than one subject: high altitude flying (4 times); landing, low altitude and flight formation (3 times); and flying into the sun (twice). Oddly enough, one of the entries is dusk flying and one is night landing.

Two items on rainbowing are comparable to those addressing distortion. One of these (No. 61) deals with windscreen locations where the phenomenon is most noticeable and is covered in Table 4. Note that the same locations are selected for the two factors and that the respective percentages of response in both are nearly identical. This degree of correspondence suggests that the stress birefringence responsible for the rainbow pattern covaries with distortion. The other recurring question (question No. 7) concerns the interaircraft variations for BIRT defects. (See Table 5). Again the results for rainbowing are comparable to the distortion data with 61% of the pilots finding noticeable, considerable or large differences in distortion patterns among F-111 windscreens.

One is also curious as to the possible range of altitudes where rainbowing is most frequently noticed (Item No. 3). The data in Table 10 show a preponderance of judgments (50%) for altitudes less than 5,000 ft, although 32% of the pilots do select altitudes higher than 10,000 ft. Rather than having a physical explanation, these results may only reflect that most of the training for the pilots was carried out at low altitudes.

Two 5-category questions require the pilot to check the predominant and observable hues visible in the BIRT rainbow. Analyses of these items are shown in Table 11.

TABLE 9

DETECTABILITY OF RAINBOWING FOR VARIOUS FLIGHT CONDITIONS (5-CATEGORY ITEMS)

Item No.	*Flight Condition*	*Mean Response Scale Score*	*% Responses in Categories 1-3*
16	Flying into sun	3.0	53
18	Flying with sun at 3 or 9 o'clock	3.7	32
50	Gunnery Range	3.9	34
9	Unspecified	3.9	33
57	Low Level Flight	4.0	15

NOTE: Response scale categories: 1-Always, 2-Frequently, 3-Sometimes, 4-Occasionally, and 5-Never

TABLE 10

ALTITUDES WHERE RAINBOWING IS MOST FREQUENTLY NOTICED (ITEM NO. 13)

Alternative Choices	*% Responses*
Above 20,000 ft	19
10,000-20,000 ft	13
5,000-10,000 ft	3
Less than 5,000 ft	50
Never seen	16

TABLE 11

OBSERVED RAINBOW COLORS

Alternative Colors	*Item No. 22 Which Color Predominates?*	*Item No. 34 Which Colors Observable?*
	% Responses	*% Responses*
Red	50	34
Blue	11	18
Green	0	8
Yellow	19	14
Purple	19	18

The predominant color (Item No. 22) in the BIRT rainbow (selected by half of the pilots) is obviously red, with some slight tendencies to select purple, yellow or blue. Green is never reported. When pilots are asked to check all the rainbow colors they have observed (Item No. 34), red is again seen most often, green least often, with intermediate percentages again being shown for the remaining hues.

Another discriminable dimension for rainbowing is its degree of saturation. Two questions analyzed in Table 12, require the pilots to judge differing percentages of rainbow colors which are highly saturated (Item No. 21) or washed-out (Item No. 55). The data from question No. 21 indicates a negligible tendency to judge rainbow colors as highly saturated (70% of the responses indicate that less than 40% of rainbowing is in this category). The data for item No. 55, on the other hand, shows a bimodal tendency for pilots to check both ends of the scale; i.e., to judge either a large or small percentage of rainbow colors to be washed-out. One other relevant question (No. 42) requires the respondent to rate rainbow colors along a five-point scale for depth of saturation. The percentages of judgments along this scale (also shown in table 4) appear to be normally distributed.

The inconsistencies shown by the saturation data suggest one or both of the following explanations: (a) There is a common lack of perceptual awareness of what is meant by saturation. (It is typically confused with brightness rather than purity of color); (b) Rainbow saturation may change in a rather capricious manner depending on fluctuating optical factors that occur during flight and affect the polarization of light through the windscreen.

IMPACT OF BIRT OPTICAL DEFECTS ON MISSION PERFORMANCE

In the preceding section of this report we have dealt only with those items that show the frequency with which visual anomalies produced by BIRT are perceived. We now turn to a more serious issue; namely, the degree to which BIRT optical defects may interfere with crew safety and effective performance of the flying mission.

For the analysis of the 5-category items that indicate the degree to which BIRT optical factors impair mission performance, we have adopted the same two indices used for showing detectability. To reiterate, one is the mean response scale score, while the other is the percentage of responses falling in the first three categories (now reflecting the highest degrees of severity). Both of these measures are interpreted as before except that now degree of impairment rather than detectability is implied.

For the less numerous two-category (yes/no) items, a single index is again used; namely, the percentage of responses representing the perceived amount of impairment associated with a particular optical problem.

TABLE 12

OBSERVED RAINBOW SATURATION

Judged Percentage of Saturation	*Item No. 21 How Often Highly Saturated?*	*Item No. 55 How Often Washed Out?*	*Item No. 42 Rate Rainbow Colors for Saturation*	
Alternatives	*% Responses*	*% Responses*	*Alternatives*	*% Responses*
80-100	7	26	Deep	3
60-80	3	23	Saturated	14
40-60	20	16	Most Colors Slightly Washed Out	45
20-40	33	10	All Colors Washed Out	31
0-20	37	26	Very Faint	7

arison of Optical Factors

questions lend themselves to a rank ordering of five BIRT optical factors (distortion, multiple images, haze, owing, and transmission loss) in terms of severity of impact on mission performance. Three items call for election of the most extreme factor in terms of: (a) obstruction to visibility (No. 25); (b) which should be nated (No. 32); and (c) which is *least* objectionable (No. 1). Table 13 shows (for these items) the percentages e each factor was selected and its rank order in terms of severity. Question No. 81 requires separate ranking five factors and the mean rank for each is also shown in the table. Mean ranks representing all four questions r in the last column.

ata in Table 13 clearly indicate that transmission loss (ranked lowest in each instance) is perceived to have ast effect on mission performance. Rainbowing (varying between a rank of 3 and 5) has a relatively stable rank of 3.5 (about halfway between transmission loss and haze). The rankings for the other three factors ore variable (ranging between 1 and 4). Nevertheless, distortion, which is ranked highest on three out of questions, can clearly be considered as most disruptive to mission performance (mean rank = 1.7). The ranks for multiple imagery and haze are nearly identical and fall about halfway between distortion and owing.

receding data are corroborated by the results shown in Table 14 for 5–category items (Nos. 35, 20, 77, 8, and l of which use the same scaling terms to describe differing degrees of impact for the same five optical factors ht safety. The pilot's concern for safety engendered by multiple images, haze and distortion are shown here unusually high (62–70% of the responses are in category 1–3). These attitudes are particularly surprising w of the basic protection from catastrophic bird strikes provided by the windscreen. One might have pated more of a tendency for the pilots to play down safety concerns arising from optical flaws in a media therwise wraps them in security.

ost extensive basis for comparing BIRT optical factors is provided by the data of the 45 performance scaling ons summarized in Table 15. Looking first at the analysis of 37 five-category items one notes that:

he effects of both rainbowing and transmission loss (represented by only one item) are both judged to be latively benign. Less than a quarter of the pilots consider these factors to be a problem of some magnitude, ., in the 1–3 category range

TABLE 13

COMPARISON OF BIRT OPTICAL FACTORS IN TERMS OF SEVERITY OF THEIR EFFECTS ON MISSION PERFORMANCE (BASED ON FOUR MULTIPLE-CHOICE ITEMS)

al Factor	*Greatest Obstruction to Visibility Item No. 25*		*Which one should be Eliminated Item No. 32*		*Which One is least Objectionable Item No. 1*		*Mean Rank in order of Adverse Effects Item No. 81*	*Mean Rank* for all Four Items*
	% Responses	*Rank**	*% Responses*	*Rank**	*% Responses*	*Rank**		
ion	40	1	47	1	15	3	1.9	1.7
e Images	11	4	21	2	12	2	2.5	2.6
	26	2	18	3.5	3	1	2.75	2.3
wing	20	3	18	3.5	21	4	3.5	3.5
ission Loss	3	5	3	5	48	5	4.1	4.8

in order of severity of effect

2. Distortion is now more clearly established as the most disruptive factor. It has a relatively low mean response scale score (3.3) and can be considered a problem 56% of the time.*

3. Multiple images and haze are nearly equal for both performance indices and fall about midway between distortion and rainbowing in severity.

4. Both performance indices are nearly equal to their respective average responses levels for all nine items involving general BIRT effects (where no particular factor is specified). The mean response score is 3.8 and about one-third of the responses fall in the category 1–3 (problem) range.

More limited data from the eight yes/no items fail to support all of the trends enumerated above. For example, the relative severity of distortion and rainbowing (based on percent of responses showing impairment) is reversed. However, the percentage of response showing impairment by BIRT effects in general is again about the same as the percentage (44%) for all items. Clearly, with almost half the pilot responses indicating impairment, these data must be taken seriously.

Two major conclusions emerge from the above measures and intercomparisons regarding the impact of BIRT factors on flight performance. First, despite a few discrepancies, it seems reasonable to rank the factors in the following order according to their perceived impairment potential: (1) distortion, (2) multiple images, (3) haze, (4) rainbowing, and (5) transmission loss. Second, the overall impact of the BIRT visibility defects on mission performance appears to be a matter of significant concern, since, on the average, about one-third of the affected pilots regard them as a problem of some magnitude.

Effects of BIRT Factors on Mission Performance for Various Flight Tasks

Twenty-three of the 5-category scaling items are specifically addressed to the following flight tasks:

1. Approach/landing
2. Target acquisition
3. Air-to-air search
4. Low-level flight
5. Weapons delivery
6. Night air refueling
7. High-level flight

TABLE 14

RELATIVE IMPORTANCE OF BIRT OPTICAL FACTORS ON FLIGHT SAFETY (5-CATEGORY ITEMS)

Item No	*BIRT Optical Factor*	*Mean Response Scale Score*	*% Responses in Categories 1–3*
35	Multiple Images	2.5	70
20	Haze	2.7	68
77	Distortion	2.9	62
8	Rainbowing	3.4	49
75	Transmission Loss	4.1	22

NOTE: Response scale categories: 1. Probably affects flight safety, 2. Possibly affects flight safety, 3. Frequently annoying, 4. Distraction, and 5. Minimal impact on mission performance.

* This finding represents something of an enigma in that recent data (pilot debriefings, operational hazard reports, and deficiency reports) show rainbowing, multiple imaging and haze effects to be written up as pilot problems more frequently than distortion. A possible explanation for this discrepancy may be due to the fact that distortion is *present all of* the time and the pilot simply accepts this fact without reporting it. On the other hand, rainbowing, multiple imaging, and haze-related effects occur somewhat infrequently and therefore stand out and are generally reported. This explanation receives some support from the fact that the vast majority of crew complaints focused on distortion when field reports about the BIRT windscreen were first collected, but over a period of several months the frequency of complaints about distortion dropped precipitously to near zero.

TABLE 15

COMPARISON OF BIRT OPTICAL FACTORS IN TERMS OF THE SCALED SEVERITY OF THEIR EFFECTS ON MISSION PERFORMANCE (BASED ON THIRTY-SEVEN 5-CATEGORY ITEMS AND 8 YES/NO ITEMS)

Optical Factor	*5-Category Items*			*Yes/No Items*	
	No. of Items	*Mean Response Scale Score*	*% Responses in Categories 1-3*	*No. of Items*	*% Responses Showing Impairment*
			% SD		*% SD*
Distortion	3	3.3 (.84)	56 (26)	3	37 (26)
Multiple images	5	3.7 (.80)	40 (22)	2	
Haze	8	3.8 (.47)	35 (16)		
Rainbowing	11	4.2 (.35)	24 (12)	2	53 (27)
Transmission Loss	1	4.1	22		
General	9	3.8 (.35)	34 (14)	3	46 (25)
Totals	37	3.9 (.53)	34 (18)	8	44 (23)

NOTE: Numbers in parentheses are standard deviations showing inter-item variability.

Seventeen of these items represent specific BIRT defects (haze, rainbowing, and multiple image) while the other six deal with the general impact of BIRT windscreens.

A two-way tabulation (Table 16) portrays the effects of flight tasks vs. BIRT factors. Note, first, that the differences among column means (showing effects of BIRT factors on mission performance) is (as one would expect) consistent with the outcomes in the previous section. (Further discussion of these data seems unnecessary.)

The row totals show relationships between flight tasks and response scores across types of defects. In general, for the tasks sampled, the two perceived as being most susceptible to BIRT defects are approach and landing and target acquisition (with mean response scale scores of 3.8–3.9 and 34–35% of the responses in categories 1–3). Slightly less affected are air-to-air search and low-level flight (with mean response values of 3.9-4.0 and 30–32% responses indicative of a problem). Least affected are weapons delivery,* night air refuel and high-altitude flight where the respective response indices are about 4.2 and 18–22%. Further inspection of the table for task-defect combinations yielding highest impairment shows that the most adverse effects are produced by: (a) approach and landing with general BIRT defects; (b) approach and landing with multiple images; and (c) target acquisition with multiple images. Mean response scores for these combinations fall within the range of 3.5–3.8 scale units and the percentage of responses in category 1–3 runs from 44–48%. The least affected combinations, on the other hand, turn out to be: (a) weapons delivery with rainbowing; (b) night air refuel with unspecified BIRT defects; (c) high altitude flight with rainbowing; and (d) approach and landing with rainbowing. For these situations the mean responses range from 4.3 to 4.5 and only 11 to 24 percent of the pilots checked the first three categories.

A single multiple choice question (No. 2) requires the respondent to select from six categories the phase of flying affected most by distortion. The results are shown in Table 17. Approach and landing is clearly selected most often (49% of the time); gunnery range is next (23%); two other phases (formation flight, low-level flight) are only selected 6–14% of the time. Since neither ground taxi nor takeoff are every checked, apparently these phases are relatively impervious to distortion effects.

* Here some explanation is warranted. Weapons delivery might have been perceived as more seriously affected by windscreen factors if the pilot had not had the option of flying by a hard-to-see target, picking up necessary cues, and then making a second, successful run. One pilot, in fact, reported that he made just such a maneuver because of low target contrast due to haze. Under real combat conditions it is unlikely that the pilot could afford the luxury of a second approach.

TABLE 16

SCALED IMPAIRMENT EFFECTS ON FLIGHT PERFORMANCE FOR SPCEIFIC COMBINATIONS OF BIRT OPTICAL FACTORS AND FLIGHT TASKS (BASED ON 23 5-CATEGORY ITEMS)

FLIGHT TASK	BIRT OPTICAL FACTORS														
	General			*Haze*			*Rainbowing*			*Multiple Images*			*Totals*		
	No. Items	*MRSS**	*% Responses in Category 1-3*	*No. Items*	*MRSS**	*% Responses in Category 1-3*	*No. Items*	*MRSS**	*% Responses in Category 1-3*	*No. Items*	*MRSS**	*% Responses in Category 1-3*	*No. Items*	*MRSS**	*% Responses in Category 1-3*
Approach and Land	2	3.55	44.5	1	4.10	24.0	1	4.30	1.50	1	3.50	48.0	5	3.80 (.45)	35.2 (18.0)
Target Acquisition	2	3.85	36.0	2	3.90	33.0	1	4.05	28.5	1	3.80	44.0	7	3.91 (.15)	34.1 (9.25)
Air-to-Air Search				1	3.80	30.0	1	3.90	3[illegible]				2	3.85	32.0
Low Level Flight	1	4.10	27.0	1	3.90	39.0	1	4.20	25.0				3	4.07	30.5
Weapons Delivery				1	3.90	27.0	1	4.50	18.0				2	4.20	22.5
Night Air Refuel	1	4.40	11.0							1	4.00	26.0	2	4.20	18.5
High Altitude Flight				1	4.20	21.0	1	4.30	24.0				2	4.25	22.5
Totals	6	3.84 (.44)	34.4 (17.1)	7	3.96 (.15)	29.6 (8.0)	7	4.19 (.20)	24.7 (8.5)	3	3.77 (.25)	39.3 (11.7)	23	3.98	30.3

* MRSS Mean Response Scale Score

NOTE Numbers in parentheses are SD's showing inter item variability

TABLE 17

PHASE OF FLYING MOST AFFECTED BY DISTORTION (ITEM NO. 2)

Phases	*% Responses*
Approach/Landing	49
Gunnery Range	23
Formation Flight	14
Low Level Flight	6
Take-Off	0
Ground Taxi	0
Other	9

TABLE 18

GENERAL ADVERSE IMPACT OF BIRT WINDSCREENS ON MISSION PERFORMANCE (5-CATEGORY ITEMS)

Item No.		*68*	*29*
Question asked		How much adverse effect on mission performance?	What is % of BIRT windscreens adversely affecting mission performance?
Scale Categories	1	Monumental	100
	2	Considerable	70-100
	3	Noticeable	40-70
	4	Little	10-40
	5	None	None
Mean Response Scale Score		3.5	3.7
% Responses in Categories 1-3		52	23

Thus far we have gained an overall appreciation for the relative seriousness of alternative BIRT defects as well as the flying tasks affected by them. It is now of interest to look at some of the specific (and possibly moderating) conditions which can illuminate the general trends that have been established. Pertinent results and discussion are organized with the context of major optical factors. As these data are reviewed, one will note considerable similarity among the effects of the same antecedent conditions upon both detection and impairment measures. This parallelism is indicative of an overall positive correlation between the perceptibility of BIRT defects and the degree to which they are judged to impact flight performance or safety.

General (Unspecified) BIRT Factors

The 5-category questions (shown in table 18) deal with the frequency of adverse impact on mission performance resulting from BIRT windscreens (note the differences in category terms). The somewhat discrepant results show that 52% of the pilots select category 1-3 items for item No. 68. This is certainly a strong indication of a problem. However, only 23% of the pilots pick the first three categories for item No. 29 showing percentages of BIRT windscreens with adverse effects on mission performance.

Table 19 covers seven 5-category items which pertain to different flight tasks and conditions. All items here use the same scaling terminology. Note that night approach and landing (No. 53) is by all odds perceived the most vulnerable condition. Night air refuel* (No. 10), on the other hand, is reportedly the condition least likely to suffer (with only 11% category 1-3 responses). Conditions associated with an intermediate amount of impairment are air-to-ground target acquisition (No. 41), day approach and landing (No. 45), IMC to VMC adjustment (No. 80), unexpected movement (No. 80), unexpected movement of target (No. 28), and flying low (No. 14). See Table 19 for the precise data associated with these items.

Three yes/no items shown in Table 20 pose different kinds of questions for appraising general BIRT effects. The results show that a surprisingly high percentage of pilots (74%) can envision breaking off an aerial engagement (No. 26) because of a BIRT problem; a smaller (but still important) percentage (38%) do not feel confident about day landings (No. 4) with BIRT windscreens; and a still smaller percentage (26%) report deliberate changes in landing techniques (No. 17) due to BIRT defects.

* In view of the relative infrequency of night air refueling, this result could be an artifact of limited exposure.

TABLE 19

GENERAL EFFECTS OF BIRT OPTICAL FACTORS ON MISSION PERFORMANCE FOR VARIOUS FLIGHT TASKS OR CONDITIONS (5-CATEGORY ITEMS)

Item No.	*Flight Task or Condition*	*Mean Response Scale Score*	*% Response in Categories 1-3*
53	Night Approach/Land	3.2	59
41	Air-to-Ground Target Acquisition	3.7	36
45	Day Approach/Land	3.9	30
80	Visual Adjustment: IMC to VMC	4.0	36
28	Unexpected Movement of Target	4.0	36
14	Flying Low if Terrain Avoidance Equipment Fails	4.1	27
10	Night Air Refueling	4.4	11

NOTE: Response scale categories: 1-Always, 2-Frequently, 3-Sometimes, 4-Occasionally, and 5-Never

TABLE 20

GENERAL EFFECTS OF BIRT OPTICAL FACTORS ON MISSION PERFORMANCE FOR VARIOUS FLIGHT TASKS OR CONDITIONS (YES/NO ITEMS)

Item No.	*BIRT Effects Questioned*	*% Responses Showing Impairment*
26	Circumstances for breaking off Aerial Engagement?	74
4	Confidence about Day Landing?	38
17	Changes in Day Landing Technique?	26

Distortion

Only two 5-category scaling questions are concerned with this defect. The category terms and the response indices for these questions are shown in Table 21. Responses to item No. 54 show that 79% of the pilots rate the severity of distortion as a problem. This is a strong indication of the potency of this factor, in line with previous analyses where it tends to be rated as the most disruptive of BIRT optical factors. However, when the question concerns the effect of distortion on knowledge of aircraft position (Item No. 58) only 28% of the pilots consider this to be a problem.

Additional evidence for mission impairment by distortion is provided by two of the three yes/no category items analyzed in Table 22. Sixty-one percent of the respondents feel that mission performance would suffer with the worst BIRT distortion, and 42% say that distortion has produced temporary confusion about a target location (No. 51). However, when asked generally whether adequate mission performance exists with BIRT distortion (No. 36), 91% of the pilots say "yes."

Multiple Images

This defect is almost exclusively associated with night missions and has already been shown, for night approach and landing, to have the most adverse effect of all BIRT factors.

One of the two 5-category items (No. 70) shown in Table 23 confirms the above finding, since 48% of the pilots find multiple images to be always, frequently, or sometimes distracting during night approach and landing. However, multiple images are perceived as less of an impediment during night air refueling (No. 64) where only

26% of the subjects see this anomaly as a problem. Despite the probable limited amount of pilot exposure to the night refueling task, this result is gratifying and suggests that present levels of multiple imaging in BIRT windscreens do not constitute a severe problem for this operation.

One potentially dangerous effect of multiple images is the relative movement of secondary or ghost images causing a swirling motion of ground-based lights. This question (Item No. 19) with five categories of "how frequently observed" responses is covered in Table 24. Note that 44% of the subjects have observed these illusory motions on multiple occasions. Nevertheless, multiple imagery rarely causes a pilot to report shooting a second approach (Item No. 5) since only 12% of the pilots show multiple occurrence of this kind of flight deviation.

TABLE 21

EFFECTS OF DISTORTION ON MISSION PERFORMANCE (5-CATEGORY ITEMS)

Item No.	*54*	*58*
Question Asked	*Observed Magnitude*	*Number of Times Pilot Uncertain About Aircraft Position*
Scale Categories 1	Severe	10 times or more
2	Moderate	5-10 times
3	Medium	2-5 times
4	Light	Once
5	None	Never
Mean Response Scale Score	2.8	4.3
% Responses in Categories 1-3	79	28

TABLE 22

EFFECT OF DISTORTION ON MISSION PERFORMANCE (YES/NO QUESTIONS)

Question No.	*Question on BIRT Effects*	*% Responses Indicating Impairment*
15	Would mission performance suffer with worst BIRT distortion	61
51	Did distortion ever cause temporarily confusion about target location	42
36	Is there adequate mission performance with BIRT distortion	9

TABLE 23

DISTRACTIVE EFFECTS OF MULTIPLE IMAGES ON MISSION PERFORMANCE FOR TWO FLIGHT TASKS (5-CATEGORY ITEMS)

Item No.	*Flight Task Where Degree of Distraction Questioned*	*Mean Response Scale Score*	*% Responses in Categories 1-3*
70	Night Approach/Landing	3.5	48
64	Night Air Refueling	4.0	26

NOTE: Response scale categories are: 1-Always, 2-Frequently, 3-Sometimes, 4-Occasionally, and 5-Never

TABLE 24

NUMBER OF TIMES MULTIPLE IMAGES IMPAIRED FLIGHT PERFORMANCE (5-CATEGORY ITEMS)

Item No.	*Impairment Caused by Multiple Images*	*Mean Response Scale Score*	*% Response in Categories 1-3*
19	Ghost Images Cause Swirl of Ground-based Lights	3.8	44
5	Shoot Second Approach	4.7	12

NOTE: Response scale categories are: 1-10 times, 2-5 to 10 times, 3-2 to 5 times, 4-1 time, and 5-Never

Haze

Seven 5-category items reveal the effects (shown in Table 25) of haze on mission performance. Six items (Nos. 71, 69, 52, 72, 78 and 60) address its possible distracting effects as related to specific flight tasks. Note the relatively small variation in the mean response scores which range from 3.8 (air-to-air search) to 4.2 (high-altitude-flight). The highest percentage of responses (39%) indicative of a mission impairment is associated with low-level, while the smallest percentage (21%) is found for high-altitude flight. One item (No. 56) in the table considers the likelihood of haze causing a target to disappear and reappear through the windscreen. A relatively large percentage of pilots (42%) view this type of distraction as a problem.

Rainbowing

The data in Table 26 provide item-by-item documentation for the general finding that rainbowing is a relatively mild deterrent to the flight mission. A possible exception to this trend is its role in air-to-air search (Item No. 37), where it is judged by 34% of the pilots to pose a problem. For both low (No. 27) and high (No. 65) altitude flight it is placed in the first three scale categories about 25% of the time. Note the very low category 1-3 percent for items No. 46, No. 63, and No. 43 (weapons delivery, 18%; day approach and landing, 15%; and takeoff, 6%).

TABLE 25

DISTRACTIVE EFFECTS OF HAZE ON MISSION PERFORMANCE FOR VARIOUS FLIGHT TASKS OR CONDITIONS (5-CATEGORY ITEMS)

Item No.	*Flight Task or Condition Where Distractive Effect Questioned*	*Mean Response Scale Score*	*% Responses in Categories 1-3*
71	Air-to-Air Search	3.8	30
69	Low-Level Flight	3.9	39
52	Weapons Delivery	3.9	27
72	Air-to-Gr. Target Acquisition	4.0	24
78	Day Approach/Landing	4.1	24
60	High Altitude Flight	4.2	21
56	Cause Target to Disappear and Reappear	3.8	42

NOTE: Response scale categories are: 1-Always, 2-Frequently, 3-Sometimes, 4-Occasionally, and 5-Never

TABLE 26

EFFECTS OF RAINBOWING ON MISSION PERFORMANCE FOR VARIOUS FLIGHT TASKS OR CONDITIONS (5-CATEGORY ITEMS)

Item No.	*Flight Task Distracted by Rainbowing*	*Mean Response Scale Score*	*% Responses in Categories 1-3*
37	Air-to-Air Search	3.9	34
11	Air-to-Ground Target Acquisition	4.1	19
27	Low Level Flight	4.2	25
65	High Altitude Flight	4.3	24
63	Day Approach/Landing	4.3	15
46	Weapons Delivery	4.5	18
43	Take-off	4.7	6

NOTE: Response scale categories are 1 Always, 2 Frequently, 3 Sometimes, 4 Occasionally and 5 Never

Other effects of rainbowing are summarized in Table 27. (Here a slightly different set of 5-category descriptions has been used.) One matter of concern is indicated by item No. 76, where 38% of the subjects view rainbowing as a problem (similar to haze) in causing objects to disappear and reappear. A somewhat lower percentage (22%) see it as creating an unsafe situation (item No. 79), and a smaller proportion yet (18%) indicate that it would be likely to cause a change in a run-in heading or flight path.

One of the two yes/no-type items addressing rainbow effects on performance (No. 31) provides the strongest single indication that this factor may be a problem. As shown in Table 28, 72% of the pilots see rainbowing as a possible deterrent to performance of an assigned mission. The other item (No. 74) provides additional credence to its distracting effect (acknowledged by 34% of the pilots) in causing targets to disappear.

A summarizing comment which appears justified in reviewing the specific effects of BIRT optical factors on mission performance would be as follows: Under adverse conditions these anomalies cause a large proportion (usually one-third and in some cases over half) of the pilots to experience distraction, uncertainty, disorientation, temporary loss of targets, and a general feeling of concern about successful mission performance. Although the likelihood of such indications to result in overt accident or mission failure remains unclear, one would be ill-advised to ignore these kinds of danger signals. The data of this study therefore lend support to the implementation of cost-effective programs to reduce BIRT visibility problems through windscreen redesign or improved acceptance standards. On the positive side, the survey also shows a relatively small reported real incidence of mission disruption, mission failure or flight deviation directly attributable to BIRT visibility defects.

Another general conclusion is that both the detectability and mission impairment criteria for BIRT failures appear to be positively correlated, both with respect to the kind of defect as well as the phases of flight mission affected. Therefore, since conspicuity of a BIRT defect and its judged impairment potential tend to correspond, the relative detectability of a BIRT factor may well provide a valid indication of its adverse impact on mission performance.

EFFECT OF FLYING EXPERIENCE ON PILOT REACTIONS TO BIRT OPTICAL DEFECTS

Of all the background factors listed for the subjects (see Table 1) the one which obviously seemed most relevant to pilot opinion on the new BIRT windscreens was the accrued number of hours flying with them. It is certainly

TABLE 27

EFFECTS OF RAINBOWING ON MISSION PERFORMANCE (5-CATEGORY ITEMS)

Item No.	*Did Rainbowing Ever:*	*Mean Response Scale Score*	*% Responses in Categories 1-3*
76	Cause Object to Disappear and then Reappear	4.0	38
79	Create an Unsafe Situation	4.2	22
38	Cause a Change of Flight Path	4.5	18

TABLE 28

EFFECTS OF RAINBOWING ON MISSION PERFORMANCE (YES/NO ITEMS)

Item No.	*Question on Rainbowing Effects*	*% Responses Indicating Impairment*
31	Is there any situation where it degrades performance?	72
74	Did target ever disappear into rainbow area?	34

logical to assume that the kinds of familiarization and adaptation which develop with continuing exposure to BIRT would affect or change pilot reaction to them.

To test this assumption the responses to all 62 questions (both 5- and 2-category) which scale the effects of BIRT optical factors, either with regard to their perceptibility or to their impact on flight performance, were analyzed separately for the following three (nearly equal) groups of pilot subjects:

1. A group of 11 pilots with a relatively low amount of flying experience with BIRT (20–80 hr)—to be referred to as the L-group.

2. A group of 12 pilots with an intermediate amount of such experience (100–180 hr)—to be referred to as the M-group.

3. A group of 10 pilots with a high amount of BIRT experience (200–1100 hr)—to be referred to as the H-group.

An analysis of 17 items showing the scaled detectability of four BIRT factors (haze, distortion, multiple images, and rainbowing) for the three experience groups is provided in Table 29. The data in the left section of the table are for 5-category items and are expressed according to the previously defined detectability indices: (1) mean response scale score; and (2) percentage of responses in categories 1–3. Within the right section of the table are the data for the 2-category (yes/no) items which are expressed as percentage of responses indicating detectability.

Inspection of the totals (bottom row) shows considerably lower detectability scores (with respect to all three response indices) for the L-group as compared with the M-group. With the exception of one entry (the yes/no item for distortion) the data in all the cells of the table confirm this finding.

Table 30 provides statistical confirmation of this tendency. The first column of the table shows the total number of comparisons of detection items between the L-group and M-group while the second column shows the number of times greater detectability was demonstrated for the M-group. These data show that an overwhelming preponderance (15 out of 17) of these comparisons (which holds for all 4 BIRT factors) indicate greater detectability for the M-group. A chi-square of 17 shows this result to be significant beyond a .001 p level. Repetition of the same detectability comparison for the H- and M-group yields a different result. Although the H- and M-group differences between the three response indices shown in Table 29 appear (with a number of exceptions) to indicate slightly greater detection by the M-group, chi-square for the 9 out of 17 instances of this tendency is insignificant (see Table 31). One therefore must conclude that there is no difference between the H- and M-groups in their ability to detect BIRT optical defects.

TABLE 29

MEASURES OF DETECTABILITY OF BIRT OPTICAL FACTORS FOR THREE GROUPS OF PILOTS WITH DIFFERENT AMOUNTS OF EXPERIENCE FLYING WITH BIRT WINDSCREENS (H-GRP HAS 200-1100 FLYING HOURS: M-GRP HAS 100-180 FLYING HOURS: AND L-GRP HAS 20-80 FLYING HOURS)

Optical Factor	*Five-Category Items*							*Yes/No Items*			
	Mean Response Scale Score				*% Responses in Category 1-3*			*% Responses Showing Detectability*			
	No. Items	*H-Grp*	*M-Grp*	*L-Grp*	*H-Grp*	*M-Grp*	*L-Grp*	*No. Items*	*H-Grp*	*M-Grp*	*L-Grp*
Haze	4	3.8	3.2	3.5	28	48	42				
Distortion	3	3.4	2.7	3.3	40	56	48	1	100	83	91
Multiple Image								3	78	72	42
Rainbowing	5	3.4	3.6	4.1	42	35	18	1	56	67	36
Totals	2	3.6	3.3	3.7	37	44	34	5	78	73	51

TABLE 30

INTERCOMPARISONS BETWEEN DETECTABILITY SCORES OF PILOTS WITH 20-80 HOURS (L-GRP) AND PILOTS WITH 100-180 HOURS (M-GRP) OF BIRT FLYING EXPERIENCE. DATA BEING COMPARED ARE M-GRP AND L-GRP SCORES TO 17 QUESTIONNAIRE ITEMS WHICH SCALE THE DETECTABILITY OF BIRT OPTICAL FACTORS. ENTRIES SHOW THE NUMBER OF TIMES THAT AN M-GRP SCORE INDICATES GREATER DETECTABILITY THAN AN L-GRP SCORE.

Optical Factor	*No. Items Compared*	*No. M-Grp scores showing greater detectability than L-Grp scores*
Haze	4	4
Distortion	4	3
Multiple Images	3	3
Rainbowing	6	5
Total	17	15*

* $X^2 = 17, P < .001$

TABLE 31

INTERCOMPARISONS BETWEEN DETECTABILITY SCORES OF PILOTS WITH OVER 200 HOURS (H-GRP) AND PILOTS WITH 100-180 HOURS (M-GRP) OF BIRT FLYING EXPERIENCE. DATA BEING COMPARED ARE M-GRP AND H-GRP TO 17 QUESTIONNAIRE ITEMS WHICH SCALE THE DETECTABILITY OF BIRT OPTICAL FACTORS ENTRIES SHOW NUMBER OF TIMES THAT THE M-GRP SCORE INDICATES GREATER DETECTABILITY THAN THE H-GRP SCORE.

Optical Factor	*No. Items Compared*	*No. of times M-Grp scores showing greater detectability than H-Grp scores*
Haze	4	3
Distortion	4	3
Multiple Images	3	0
Rainbowing	6	3
Total	17	9*

* $X^2 = .06, P = .8$

The same type of analysis was similarly applied to the 45 items which scale perceived BIRT effects on mission performance. Table 32 provides a breakdown of these items showing response indices for the three experience groups. The only difference between Table 29 and this table is that these scores reflect degree of mission impairment rather than their detectability. Note also that the items now represent five specific optical factors in addition to general effects of BIRT.

The totals for the M-group in Table 32 show somewhat greater indications of BIRT impairment than those for the L-group with respect to all performance indices (mean response scale scores, percentages of responses in category 1-3, and percentage of responses to yes/no items showing impairment). Although these differences are relatively small they appear to be representative of similar differences for all of the BIRT optical factors. A test of significance is provided in Table 33. Here we see that, out of a total of 45 item comparisons, in 28 instances M-group responses are more indicative of mission impairment than L-group responses. A chi-square value of 2.7 shows this indication to be significant at the .10 probability level. Hence we can conclude (with a fair amount of confidence) that the M-group feels its mission to be more impaired by BIRT defects than the L-group.

The remaining comparison for perceived mission impairment by BIRT is between the H- and M-groups. Inspection of totals for the response indices shown in Table 32 shows considerably larger differences (e.g. a total difference of 13% responses in categories 1–3) which indicates greater impairment felt by the M-group. With only one exception (transmission loss) this kind of difference is maintained in the table entries for all optical factors. Table 34 provides another frequency tabulation on the number of times that an M-group score showed more mission-impairment than an L-group score. The total count shows 35 such indications out of 45 intergroup comparisons. Chi-square for this contingency is 13.9 which is highly significant ($p<.001$).

TABLE 32

MEASURES OF MISSION PERFORMANCE IMPAIRMENT FOR THREE GROUPS OF PILOTS WITH DIFFERENT AMOUNTS OF EXPERIENCE FLYING WITH BIRT WINDSCREENS (H-GRP HAS 200–1100 FLYING HOURS; M-GRP HAS 100–180 FLYING HOURS; AND L-GRP HAS 20–80 FLYING HOURS)

Optical Factor	*Five-Category Items*							*Yes/No Items*			
		Mean Response Scale Score			*% Responses in Categories 1–3*				*% Responses Showing Performance Impairment*		
	No. Items	*H-Grp*	*M-Grp*	*L-Grp*	*H-Grp*	*M-Grp*	*L-Grp*	*No. Items*	*H-Grp*	*M-Grp*	*L-Grp*
General	9	4.2	3.6	3.8	23	41	38	3	32	63	42
Haze	8	4.0	3.6	3.9	24	44	34				
Distortion	3	3.7	3.2	3.1	42	62	63	3	27	39	40
Multiple Image	5	3.7	3.5	3.9	34	46	40				
Transmission Loss	1	4.2	4.4	3.7	10	17	40				
Rainbowing	11	4.3	4.1	4.2	22	25	24	2	50	58	50
Totals	37	4.1	3.7	3.9	26	39	36	8	35	53	46

TABLE 33

INTERCOMPARISONS BETWEEN PERFORMANCE IMPAIRMENT SCORES OF PILOTS WITH 20–80 HOURS (L-GRP) AND PILOTS WITH 100–180 HOURS (M-GRP) OF BIRT FLYING EXPERIENCE. DATA BEING COMPARED ARE M- AND L-GRP SCORES TO 45 QUESTIONS WHICH SCALE THE EFFECTS OF BIRT OPTICAL FACTORS ON MISSION PERFORMANCE. ENTRIES SHOW THE NUMBER OF TIMES THAT AN M-GRP SCORE REFLECTS MORE OF A MISSION PROBLEM (I.E. SHOWS GREATER PERFORMANCE IMPAIRMENT) THAN AN L-GRP SCORE.

BIRT Optical Factor	*No. Items Compared*	*No. of times M-Grp Score Shows a greater problem than L-Grp*
General	12	8
Haze	8	7
Distortion	6	2
Multiple Images	5	4
Transmission Loss	1	0
Rainbowing	13	7
Total	45	28*

* $X^2 = 2.7, P = .10$

TABLE 34

INTERCOMPARISONS BETWEEN PERFORMANCE IMPAIRMENT SCORES OF PILOTS WITH OVER 200 HOURS (H-GRP) AND PILOTS WITH 180 HOURS (M-GRP) OF BIRT FLYING EXPERIENCE. DATA BEING COMPARED ARE M- AND H-GRP SCORES TO 45 QUESTIONNAIRE ITEMS WHICH SCALE THE IMPACT OF BIRT OPTICAL FACTORS ON MISSION PERFORMANCE. ENTRIES SHOW THE NUMBER OF TIMES THAT AN M-GRP SCORE REFLECTS MORE OF A MISSION PROBLEM (I.E. SHOWS GREATER PERFORMANCE IMPAIRMENT) THAN AN H-GRP SCORE.

BIRT Optical Factor	*No. Items Compared*	*No. times M-Grp score reflects a greater problem than H-Grp score*
General	12	12
Haze	8	7
Distortion	6	4
Multiple Images	5	4
Transmission Loss	1	0
Rainbowing	13	8
Total	45	35*

* X^2 = 13.9, P<.001

These results show the importance of experience in shaping and changing pilot responses to the optical defects in BIRT windscreens. The pilots with very few BIRT flying hours have such limited experience with these anomalies that they report relatively few detections. The fact is they have not had sufficient opportunity to see all the optical manifestations under the conditions where they are likely to show up. One simply cannot report seeing a phenomenon that has yet to occur. For the same reason, pilots with limited experience find relatively few flying problems with BIRT. What one has not *yet observed (e.g. multiple images at night)* cannot constitute a problem.

It can be further argued that the group of pilots with intermediate BIRTexperience has encountered the optical defects under a sufficient variety of conditions to have both perceived and been distracted by them to a greater extent than very unexperienced pilots. Hence both detection and performance impairment scores of the M-group are higher than those of the L-group.

Finally, it is reasonable to suppose that with sufficient experience, pilots looking through BIRT windscreens continue to observe the aberrations, but have somehow learned to adjust to them. To this extent then they pose a less serious problem for mission performance. These assumptions are borne out by the fact that members of the H-group and M-group show the same likelihood of detecting the BIRT phenomena, but the H-group finds them to be less of an impediment to the flying mission. Apparently, they have at least partially learned to cope with BIRT visibility problems.

SOME FINAL COMMENTS

A few final comments are in order to highlight the findings of this field study and place them in reasonable perspective.

1. Our readers are reminded that all of the data in this study represent pilot *opinions* about what they see and how well they fly rather than direct measures of visual or mission *performance*. One can usually assume that subjective and objective measures are reasonably well correlated, but important exceptions to this assumption can occur. It would therefore be desirable to carry out some experimental flights with BIRT windscreens under controlled simulated mission conditions where pilot performance can be measured and related to optical factors (e.g. simulated bombing runs). To the extent that this kind of hard data are collectible, it can provide a valuable alternative or supplement to pilot opinion research.

2. The severity of BIRT optical problems, indicated by the survey, is already diminishing. Since the earlier prototypes, the visual quality of BIRT windscreens coming from the manufacturers has been showing continuous improvement (especially with regard to measurable amounts of distortion). Though we can by no means assume that all significant visibility problems have been solved, one can at least regard them with a greater degree of optimism. To effectively demonstrate that the improved optical quality is in fact "paying off," *we need to run additional comparative field studies with the new windscreens.*

3. On the negative side, a word of warning is in order for BIRT defects that produce haze. Haze is a time-dependent problem that gets significantly worse with the age of the windscreen. Given the continuous abrasive effects of maintenance and the flight environment, unacceptable levels of haze will eventually be reached. Care should be taken to replace windscreens well before the time they can be considered to be haze-defective.

4. A final and most important point is that nothing in this report is intended to cause *undo* alarm about the optical problems that have been identified and assessed. There is no reason to believe that the kinds of danger-signals indicated in this report should require windscreens to be immediately replaced or missions to be terminated. The *primary protection from lethal impact offered* by BIRT still has to be considered ahead of visibility problems, as long as the latter do not seriously jeopardize the mission. At the same time we cannot conclude that visibility problems are to be glossed over or ignored. Throughout this field study there are many indications that BIRT windscreens are subjectively unacceptable to the pilots. This finding is particularly difficult to ignore since pilots are known to be highly confident individuals, unlikely to minimize the severity of potential hazards. Even though a condition of unacceptability need not imply probable overt accident or mission failure, it is almost certain to be accompanied by the lowering of pilot or crew-member morale and some proneness toward mission inefficiency. We would therefore continue to demand the aircraft crew station design engineer to design for good transparency optical quality, while still meeting reasonable structural, aerodynamic, and other design parameters in the development of aircraft windscreens and canopies.

APPENDIX

F-111 BIRT WINDSCREEN SURVEY

PERSONAL DATA

1. Date ______________________
2. Name (Last, First, MI) ______________________
3. Rank ______________________
4. Organization ______________________
5. Duty Phone ______________________
6. Aeronautical Rating ______________________
7. Total Flying Time ______________________
8. Combat Time ______________________
9. List the aircraft flown and approximate number of hours in each:

10. Aircraft Currently Flying ______________________

11. Approximate flying time with BIRT windscreens

12. Age ______________________

13. Vision (Circle one): Corrected Uncorrected

F-111E BIRT WINDSCREEN SURVEY

1. Of all the optical problems of the BIRT windscreen, *which one* do you find to be the *least* objectionable? (A) transmission loss (B) distortion (C) rainbowing (D) haze (E) multiple imaging

2. During what phase of flying do you feel distortion causes the greatest problem? (A) approach and landing (B) takeoff (C) gunnery range work (D) low level flying (E) ground taxi (F) formation flying (G) other __________

3. At what range of altitudes is rainbowing most frequently noticed? (A) above 20,000 feet (B) 10,000-20,000 feet (C) 5,000-10,000 (D) below 5,000 feet (E) rainbowing has never been seen

4. Considering the optical quality of the BIRT windscreen, do you feel as confident landing the aircraft with this windscreen? (A) yes (B) no

5. How many times have you had to shoot a second approach due to any uncertainty caused by multiple imaging? (A) 10 or more times (B) 5-10 times (C) 2-5 times (D) 1 time (E) none

6. How often have you noticed distortion in the BIRT windscreens? (A) always (B) frequently (C) sometimes (D) occasionally (E) never

7. How would you characterize the variations in the *rainbow pattern* and intensity across the F-111 fleet outfitted with BIRT windscreens? (A) large differences between aircraft (B) considerable differences between aircraft (C) noticeable differences between aircraft (D) little difference between aircraft (E) essentially no difference between aircraft.

8. How would you characterize the importance of the rainbowing problem? (A) probably affects safety of flight (B) possibly affects safety of flight (C) frequently annoying (D) distracting (E) minimal impact on mission performance

9. Approximately how often have you noticed rainbowing in the BIRT windscreen? (A) more than 80% of the time (B) 60-80% of the time (C) 40-60% of the time (D) 20-40% (D) 0-20%

10. Have you encountered any difficulty during *night* aerial refueling that you believe is attributable to the visual quality of the BIRT windscreen? (A) always (B) frequently (C) sometimes (D) occasionally (E) never

11. About how often has rainbowing been *distracting* during air-to-ground target acquisition? (A) always (B) frequently (C) sometimes (D) occasionally (E) rarely or never

12. Under what conditions is multiple imaging most noticeable? (A) night air refueling (B) night approach and landing (C) night formation flying (D) night taxi (E) other __________

13. How often have you had to break off an aerial engagement due to poor *visibility caused* by the BIRT windscreen? (A) 10 or more times (B) 5-10 times (C) 2-4 times (D) 1 time (E) never

14. If your TA equipment fials, would you fly as low with the BIRT windscreen as with the previous glass version for the F-111? (A) definitely (B) probably (C) possibly, but not sure (D) never (E) unlikely

15. Would mission performance suffer if you were flying the aircraft with the worst BIRT windscreen (distortion) that you have every flown? (A) yes (B) no (C) cannot say

16. How often have you noticed rainbowing when flying into the sun? (A) always (B) frequently (C) often (D) occasionally (E) never

17. Have you noticed any changes in the way you land the aircraft during day approach and landing with the BIRT windscreen? (a) yes (B) no

18. How often have you noticed rainbowing when flying with the sun at the 3 or 9 o'clock position? (A) always (B) frequently (C) often (D) occasionally (E) never

19. With regard to multiple imaging during night flying, how often have you noticed a relative movement of a secondary or ghost image with respect to the true image, causing a swirling motion of ground based lights? (A) 10 or more times (B) 5-10 times (C) 2-5 times (D) 1 time (E) never

20. How would you characterize the importance of haze? (A) probably affects safety of flight (B) possibly affects safety of flight (C) frequently annoying (D) distracting (E) minimal impact on mission performance

21. What percent of the rainbowing appears to be made up of highly saturated colors? (A) 100-80% (B) 60-80% (C) 40-60% (D) 20-40% (E) 0-20%

22. Based on your experience what is the most predominant color in the rainbow pattern? (A) red (B) blue (C) green (D) yellow (E) purple

23. How often have you noticed haze when flying into the sun? (A) always (B) frequently (C) often (D) occasionally (E) never

24. How would you characterize the variations in the distortion severity and pattern across the F-111 fleet outfitted with BIRT windscreens? (A) large differences between aircraft (B) considerable differences between aircraft (C) noticeable differences between aircraft (D) little differences between aircraft (E) essentially no differences between aircraft

25. Considering visibility through the BIRT windscreens, what do you believe is the greatest obstruction to out-of-cockpit viewing? (A) distortion (B) rainbowing (C) haze (D) multiple imaging (E) reduced light transmission

26. Do you envision any circumstances which might lead you to break off an aerial engagement due to poor visibility caused by the BIRT windscreen? (A) yes (B) no

27. About how often has rainbowing been *distracting* during low level flying? (A) always (B) frequently (C) sometimes (D) occasionally (E) rarely or never

28. Have you noticed sudden, unexpected movement of moving targets or other aircraft when flying with the BIRT windscreens? (A) frequently (B) sometimes (C) occasionally (D) once (E) never

29. Approximately how many of the BIRT windscreens that you have flown with do you think might adversely *affect mission performance*? (A) 100% (B) 70-100% (C) 40-70% (D) 10-40% (E) 0%

30. Is rainbowing most severe ____________? (A) around the edges and the center arch of the windscreen (B) in the forward 1/3 (C) around the boresight (D) near the rear arch (E) about the same everywhere

31. In your opinion, is there *any* situation you believe rainbowing might degrade your ability to perform an assigned mission? (A) yes (B) no

32. If the windscreen manufacturer could *eliminate only one* of the optical problems of the BIRT windscreen, which one would you like to see eliminated? (A) rainbowing (B) multiple imaging (C) haze (D) distortion (E) transmission loss

33. Have you ever noticed multiple images with the BIRT windscreen? (A) yes (B) no

34. What colors do you normally observe in the rainbow pattern? (circle each color) (A) red (B) blue (C) green (D) yellow (E) purple (F) others ____________

35. How would you characterize the importance of multiple imaging? (A) probably safety of flight (B) possibly affects safety of flight (C) frequently annoying (D) distracting (E) minimal impact on mission performance

36. Do you feel that you can adequately perform your mission given the distortion found in BIRT windscreens (A) yes (B) no

37. About how often has rainbowing been distracting during air-to-air search? (A) always (B) frequently (C) sometimes (D) occasionally (E) rarely or never

38. Have you ever changed a run-in heading or altered the flight path to avoid having rainbowing in a particular region of the windscreen? (A) frequently (B) sometimes (C) occasionally (D) once (E) never

39. How often have you noticed haze when flying with the sun at the 3 or 9 o'clock position? (A) always (B) frequently (C) often (D) occasionally (E) never

40. Have you ever seen multiple imaging during approach and landing? (A) yes (B) no

41. Have you encountered any difficulty during air-to-ground target acquisition that you believe is attributable to the visual quality of the BIRT windscreen? (A) always (B) frequently (C) sometimes (D) occasionally (E) never

42. How would you rate the rainbowing for saturation, or color intensity? (A) vivid, deep colors (B) saturated colors (C) most colors slightly washed out (D) all colors washed out (E) very faint colors

43. About how often has rainbowing been *distracting* during takeoff? (A) always (B) frequently (C) sometimes (D) occasionally (E) rarely or never

44. Have you noticed rainbowing more frequently during one particular mission or phase of flying than another? (A) yes (B) no If yes, identify the mission

45. Have you encountered any difficulty during day approach and landing that you believe is attributable to the visual quality of the BIRT windscreen? (A) always (B) frequently (C) sometimes (D) occasionally (E) never

46. About how often has rainbowing been *distracting* during weapon delivery? (A) always (B) frequently (C) sometimes (D) occasionally (E) rarely or never

47. How often have you noticed haze when flying with the sun at 6 o'clock? (A) always (B) frequently (C) often (D) occasionally (E) never

48. Have you noticed haze during low level flight? (A) always (B) frequently (C) sometimes (D) occasionally (E) never

49. How often have you noticed distortion while on the gunnery range? (A) always (B) frequently (C) sometimes (D) occasionally (E) never

50. How often have you seen rainbowing while on the gunnery range? (A) always (B) frequently (C) sometimes (D) occasionally (E) never

51. Have you ever been temporarily confused about target location due to distortion (A) yes (B) no

52. About how often has haze been *distracting* during weapon delivery? (A) always (B) frequently (C) sometimes (D) occasionally (E) rarely or never

53. Have you encountered any difficulty during *night* approach and landing that you believe is attributable to the visual quality of the BIRT windscreen? (A) always (B) frequently (C) sometimes (D) occasionally (E) never

54. If you were to rate the magnitude of distortion typically observed in F-111 BIRT windscreens, what would your rating be? (A) severe (B) moderate (C) mild (D) light (E) none

55. What percent of the rainbowing appears to be made up of washed out colors? (A) 100-80% (B) 60-80% (C) 40-60% (D) 20-40% (E) 0-20%

56. Have you ever noticed an object or some aspect of the scene briefly disappear in the haze and then reappear again? (A) frequently (B) sometimes (C) occasionally (D) once (E) never

57. Have you noticed rainbowing during low level flight? (A) always (B) frequently (C) sometimes (D) occasionally (E) never

58. Have you ever felt temporarily uncertain about your aircraft position with respect to the ground due to BIRT windscreen distortion? (A) 1-10 or more times (B) 5-10 times (C) 2-5 times (D) 1 time (E) never

59. How often have you seen haze while on the gunnery range? (A) always (B) frequently (C) sometimes (D) occasionally (E) never

60. About how often has haze been *distracting* during high altitude flying? (A) always (B) frequently (C) sometimes (D) occasionally (E) rarely or never

61. In which portion of the windscreen is distortion most noticeable? (A) around the margins and center arch (B) forward ⅓ (C) boresight area (D) rear arch (E) almost everywhere

62. Have you noticed distortion during low level flight? (A) always (B) frequently (C) sometimes (D) occasionally (E) never

63. About how often has rainbowing been *distracting* during approach and landing? (A) always (B) frequently (C) sometimes (D) occasionally (E) rarely or never

64. About how often do you find multiple imaging distracting during night aerial refueling? (A) always (B) frequently (C) sometimes (D) occasionally (E) never or rarely

64. About how often has rainbowing been *distracting* during high altitude flying? (A) always (B) frequently (C) sometimes (D) occasionally (E) rarely or never

66. Have you ever seen multiple imaging during night air refueling (A) yes (B) no

67. Have you ever seen distortion in *any* of the BIRT windscreens? (A) yes (B) no

68. What adverse impact do you believe the optical quality of the BIRT windscreens that you have seen would have on mission performance? (A) monumental (B) considerable (C) noticeable (D) little (E) none

69. About how often has haze been *distracting* during low level flying? (A) always (B) frequently (C) sometimes (D) occasionally (E) never or rarely

70. About how often do you find multiple imaging distracting during approach and landing? (A) always (B) frequently (C) sometimes (D) occasionally (E) never or rarely

71. About how often has haze been *distracting* during air-to-air search? (A) always (B) frequently (C) sometimes (D) occasionally (E) rarely or never

72. About how often has haze been *distracting* during air-to-ground target acquisition? (A) always (B) frequently (C) sometimes (D) occasionally (E) rarely or never

73. How often have you noticed rainbowing when flying with the sun at 6 o'clock? (A) always (B) frequently (C) often (D) occasionally (E) never

74. When a target or visually acquired object is first seen and then enters into the rainbow area, has it ever disappeared? (A) yes (B) no

75. How would you characterize the importance of transmission loss? (A) probably affects safety of flight (B) possibly affects safety of flight (C) frequently annoying (D) distracting (E) minimal impact on vision performance

76. Have you ever noticed an object or some aspect of the scene briefly disappear in the rainbowing and then reappear again? (A) frequently (B) sometimes (C) occasionally (D) once (E) never

77. How would you characterize the importance of distortion? (A) probably affects safety of flight (B) possibly affects safety of flight (C) frequently annoying (D) distracting (E) minimal impact on mission performance

78. About how often has haze been *distracting* during approach and landing? (A) always (B) frequently (C) sometimes (D) occasionally (E) rarely or never

79. In your opinion, has rainbowing ever created an unsafe situation, even momentarily? (A) 5 or more times (B) 3-5 times (C) 2 times (D) once (E) never

80. When transitioning from IMC to VMC, during approach and landing and at other times, does it take any longer for you to become visually adjusted to the *out-of-cockpit* scene with the BIRT windscreen (A) always (B) frequently (C) sometimes (D) occasionally (E) not aware of an increase adjustment time

81. Considering the impact on flight safety and mission performance, please rank the relative importance of the below listed optical/visual problems. Assign the #1 to the *most severe* problems. #2 to the next, and so on

Distortion	Haze	Multiple Imaging
Rainbowing	Transmission loss	

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