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AN ANALYSIS OF FLIGHT DATA FROM AIRCRAFT LANDINGS WITH AND WITHOUT THE AID OF A PAINTED DIAMOND ON THE SAME RUNWAY

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INTRODUCTION

The National Aeronautics and Space Administration Dryden Flight Research Center has been investigating the possible merits of a large single diamond painted on a runway to provide glideslope information. A flight test experiment was conducted to determine the usefulness of such a diamond as a visual aid for general aviation.

The objectives of the experiment were to determine the influence of the diamond on the pilots' ability to intercept and track the diamond projected glideslope, and to determine the influence on the pilots' touchdown performance.

For these objectives, pilots were selected from two groups: research and general aviation. Also, three different weight categories of aircraft were selected to be representative of general aviation.

The objective of this report is to present results from statistical analyses of flight data obtained from the experiment. The analyses were performed to delineate the significant effects due to the diamond after accounting for the effects of different pilots and their interactions with the diamond. Such analyses were performed separately on each aircraft and pilot group combinations.

The flight data and statistical analyses are appended to this report. The details of the experiment, analyses and discussions are part of the main report.

SYMBOLS AND NOTATIONS

◆, ⧫̸ :	Diamond painted on runway, No diamond.
RES, GEN, EXP:	Research, General Aviation, Experienced Pilot
GSI, FPEA, TD:	Glideslope Intercept, Flight Path Elevation Angle, Touchdown Distance
SI, PA:	Straight-In, Pattern Approach
LWA, MWA, TEA:	Light Weight, Medium Weight, Twin Engine Aircraft
ANOVA:	Analysis of Variance
SSS, MS, F:	Sum of Squares, Mean Square, F Statistic
*, **:	95%, 99% Significance
X, Y, Z:	Binary (1, 0) random variables
S.D., S.E.:	Standard Deviation, Standard Error
SS:	Sample Size

EXPERIMENT AND DATA

The Experiment

The experiment at the NASA Dryden Flight Research Center was conducted to investigate the usefulness of a single painted diamond on a runway as a visual aid in safe landing of aircraft. Three general aviation aircraft [Light Weight Aircraft (LWA), Medium Weight Aircraft (MWA), Twin Engine Aircraft (TEA)], three research pilots (RES) and four general aviation pilots (GEN) participated in this experiment. One pilot (EXP) who had in-depth experience with the diamond also flew, but his data were used only for comparison between the pilots. The pilots made straight-in (SI) and pattern (PA) approaches for the runway landings. The data obtained from ninety SI and ninety PA landings were analyzed by methods of analysis of variance (ANOVA) which separates out the variability accounted for by diamond (◆), and no diamond (◆̸) landings, different pilots, and pilot ◆,◆̸ interactions.

The flight data for approach and landing consisted of three variables: glide-slope intercepts (GSI), flight path elevation angles (FPEA) and touchdown distances (TD) from the runway threshold. To minimize any learning effects, SI and PA approaches were randomized in the experiment. All landings were made on the same runway, first without the painted diamond, and later with the diamond. This runway was 1828.8 meters (6,000 feet) long, level and without any obstructions or visual cues, except the normal runway markings. Use of the same runway thus delineates the fact that the only difference was the use of visual cues due to the diamond. The entire experiment was conducted under similar weather and visibility conditions.

The white painted diamond on the black asphalt runway provided a high quality of contrast when viewed from the air. The diamond was designed and so placed that it appeared as a square to the pilots when they were 402.3 meters (1/4 mile) from the runway threshold and on a 5 degree slope to the diamond. The 5 degree slope for the diamond design was selected by an examination of data obtained from flights prior to this experiment.

A manually operated tracking device, placed close to the runway was used to obtain elevation angles which were recorded on magnetic tape. The aircraft were tracked during the entire final approach until touchdown. The records on magnetic tapes were reduced to obtain GSI and FPEA data. Markers placed at 15.2 meter (50-foot) intervals alongside of the runway aided in measuring TD distances.

On each flight a safety pilot accompanied the pilot. The safety pilot handled communications, recorded pilot comments, and took photographs of the diamond when the pilot remarked that he was on the 5 degree glideslope. These qualitative data were not analyzed in this report.

The Quantitative Data

The continuous records of elevation angles on magnetic tape were sampled at one-half second intervals for PA and one second intervals for SI approaches. The elevation angle at the instant the pilot remarked that he was on the 5 degree glideslope was defined as GSI. The entire history of the sampled data from the moment the pilot remarked that he was on glideslope until touchdown was processed by regression analysis (Ref. 1) to compute the representative flight path. The elevation angle computed from this flight path was defined as FPEA. GSI data are pertinent to the perception of the diamond, whereas FPEA are pertinent to the utilization of that perception. Touchdown data needs no reduction, and are pertinent to the end result of the diamond perception and its utilization.

These data are shown in Appendix A, which has two sections. Section A-1 shows data for SI approaches and section A-2 shows the data for PA approaches. This report deals with the data presented in this appendix and are referred to as flight data.

ANALYSIS OF FLIGHT DATA

The statistical analysis of flight data was performed on three variables: GSI, FPEA and TD. These variables were initially analyzed separately. Later, their joint relationship was investigated. The data on each variable were analyzed separately for each combination of aircraft and pilot group for SI and PA approaches.

These analyses were performed by the method of analysis of variance (ANOVA) (Ref. 2). The linear model for which ANOVA is appropriate was considered proper for these data. The linear model

$$x_{ijk} = x_{...} + x_{i..} + x_{.j.} + x_{ij.} + (x_{ijk} - x_{...} - x_{i..} - x_{.j.} - x_{ij.})$$

assumes that each observed data, either GSI or FPEA or TD denoted by x_{ijk} is the sum of an average value $x_{...}$, an effect of ◆ or ⧣ treatment denoted by $x_{i..}$ (i=1 for ◆, i=2 for ⧣), an effect due to pilot denoted by $x_{.j.}$ (j=1,2,3,4 for j-th pilot), an effect due to differential interaction between ◆, ⧣ treatment and j-th pilot denoted by $x_{ij.}$, and lastly, an effect due to randomness denoted by x_{ijk} minus the sum of $x_{...}$, $x_{i..}$, $x_{.j.}$, and $x_{ij.}$.

Randomness is an essential part of experimentation, and sometimes is referred to as uncontrolled variation, because nothing is exactly repeatable in nature. The measure of randomness is standard error (S.E.). The smaller the S.E., the smaller is the uncontrolled variation in the flight data.

Treatment (◆, ⧫̸) effect represents a shift from a general average purely due to treatment. Pilot effect, in a similar way, represents the shift from the general average purely due to pilot. The interaction between treatment and pilot is the shift from the average value which is in addition to the shifts due to treatments and pilots separately. The importance or significance of the magnitude of various shifts can only be measured in terms of standard error units. If S.E. is large, then a shift of large magnitude is of little importance. Thus wherever the effects are 95% or 99% significant it means that these effects are much larger than the S.E. of the experiment. The over-all objective of the present analysis was to determine if shifts due to the diamond, no diamond treatments were significant.

Straight-In Approaches

The results of ANOVA and summary of results for each aircraft and pilot combination are presented in Appendix B-1. ANOVA shows the sources of variation, their degrees of freedom (df), their sum of squares (SSS), the associated mean squares sum (MS) and statistic F to test which of the sources are significant on the S.E. scale. The sources which are significant are marked by * for 95% significance, and ** for 99% significance. The summary shows the estimates of shifts for treatment and pilot combinations. S.E. for each analysis are shown at the bottom of the ANOVA tables.

There are fifteen ANOVA and summary tables. The significance of ◆, ϕ effect and pilot (◆, ϕ) interaction from these fifteen tables are shown in table I. The last column of this table shows the S.E. obtained from each analysis. Note that treatment (◆, ϕ) effects are significant in all cases except for touchdown (TD) distances for research pilots in twin engine aircraft, and general aviation pilots in medium weight aircraft.

Table I. Summary of ANOVA for Straight-In Approaches

DATA VARIABLE	PILOT GROUP	AIRCRAFT TYPE	◆, ϕ EFFECT	PILOT (◆, ϕ) INTERACTION	STANDARD ERROR
GLIDESLOPE INTERCEPT	RES	LWA	**	**	0.32
		MWA	**		0.36
(GSI)		TEA	**	**	0.34
	GEN	LWA	**	**	0.60
Degrees		MWA	*	*	0.73
FLIGHTPATH ELEVATION ANGLE (FPEA)	RES	LWA	**	**	0.50
		MWA	**		0.29
		TEA			0.21
	GEN	LWA	**	**	0.58
Degrees		MWA	**		0.53
TOUCHDOWN DISTANCE	RES	LWA	**	*	35.7 (117)
		MWA	**		36.6 (120)
(TD)		TEA			58.5 (192)
Meters (Feet)	GEN	LWA	*	**	59.1 (194)
		MWA		**	57.9 (190)

It was stated earlier that if any effect is significant, the magnitude of the effect needs to be measured in respective S.E. units. By itself, an estimate of shift due to any effect does not contain all the information; for this reason S.E. of each experiment was shown in Table I. In Table II the magnitudes of shifts due to ◆,◆̸ effects are shown. These values are from the fifteen tables given in Appendix B-1. Note that the painted diamond induces a downward shift on GSI and FPEA. For touchdown distances for research pilots, the shifts are mixed, but for general aviation pilots, the painted diamond again induced a downward shift.

Table II. ◆,◆̸ Effect on Flight Data for Straight-In Approaches

DATA VARIABLE	PILOT GROUP	AIRCRAFT TYPE	◆,◆̸ EFFECT ◆ AVG	◆̸ AVG	◆ − ◆̸ DIFF
GLIDESLOPE INTERCEPT	RES	LWA	3.3	5.1	-1.8
		MWA	3.3	5.1	-1.8
(GSI)		TEA	3.0	4.3	-1.3
	GEN	LWA	3.9	5.8	-1.9
Degrees		MWA	3.8	4.9	-1.1
FLIGHTPATH ELEVATION	RES	LWA	2.9	4.8	-1.9
ANGLE		MWA	2.8	3.8	-1.0
(FPEA)		TEA	3.2	3.6	-0.4
	GEN	LWA	3.3	5.9	-2.6
Degrees		MWA	2.8	4.5	-1.7
TOUCHDOWN DISTANCE	RES	LWA	206.3 (677)	202.1 (663)	-56.7 (-186)
		MWA	285.6 (937)	219.2 (719)	66.4 (218)
(TD)		TEA	281.9 (925)	242.0 (794)	39.9 (131)
	GEN	LWA	213.4 (700)	271.9 (892)	-58.5 (-192)
Meters(Feet)		MWA	228.6 (750)	276.8 (908)	-48.2 (-158)

Pattern Approaches

The results of ANOVA and summary of results for PA are presented in Appendix B-2. ANOVA shows the sources of variation, their df, SSS, MS and F statistics. The F statistics are labeled by * if effect is significant at 95% level, and ** if significant at 99% level. Table III shows the significances of ◆, ≠ effects and pilot (◆, ≠) interaction obtained from the analyses. The last column of this table shows the S.E. of each analysis. The results show that the painted diamond did effect the research pilots and not the general aviation pilots.

Table III. Summary of ANOVA for Pattern Approaches

DATA VARIABLE	PILOT GROUP	AIRCRAFT TYPE	◆, ≠ EFFECT	PILOT (◆, ≠) INTERACTION	STANDARD ERROR
FLIGHTPATH ELEVATION ANGLE (FPEA)	RES	LWA	**		0.62
		MWA	**	**	0.21
		TEA	**	**	0.25
	GEN	LWA	**		1.57
Degrees		MWA			1.14
TOUCHDOWN DISTANCE (TD)	RES	LWA			59.1 (194)
		MWA	**	**	32.6 (107)
		TEA		*	43.0 (141)
	GEN	LWA			127.0 (416)
Meters(Feet)		MWA			96.6 (317)

Table IV shows the magnitude of ◆ and ≠ effects. The ◆ induced a downward effect on FPEA, but the results on touchdown data are mixed.

Table IV. ◆, ◆̸ Effect on Flight Data for Pattern Approaches

DATA VARIABLE	PILOT GROUP	AIRCRAFT TYPE	◆,◆̸ EFFECT		
			◆ AVG	◆̸ AVG	◆-◆̸ DIFF
FLIGHTPATH	RES	LWA	2.7	3.9	-1.2
ELEVATION		MWA	2.6	3.7	-1.1
ANGLE		TEA	2.7	3.4	-0.7
(FPEA)					
	GEN	LWA	4.3	6.1	-1.8
Degrees		MWA	4.5	5.1	-0.6
TOUCHDOWN	RES	LWA	192.3 (631)	190.5 (625)	1.8 (6)
DISTANCE		MWA	253.6 (832)	205.7 (675)	47.9 (157)
		TEA	206.7 (678)	201.2 (660)	5.5 (18)
(TD)					
	GEN	LWA	242.3 (795)	309.4 (1015)	-67.1 (-220)
Meters(Feet)		MWA	251.5 (825)	266.7 (875)	-15.2 (-50)

Interrelationship Between Variables (GSI, FPEA, TD)

As indicated earlier GSI is pertinent information on ◆ perception, FPEA pertinent to the utilization of this information, and TD pertinent to the end result of perception and utilization. There is some commonality among the three recorded variables; none of the variables replaces the information contained in the other, yet there is some overlap. Thus it is important to investigate their interrelationship.

The interrelationship between these variables was investigated by two methods. First by defining binary random variables X from GSI, Y from FPEA, Z from TD and then determining if any pair of X, Y, Z or all three jointly, are independent variables. Let X=1 if the difference of GSI averages for ◆ and ◆̸ is negative, and X=0 if the difference is positive. Similarly, Y and Z are 1 or 0 if the difference of averages for FPEA or TD is negative or positive. If the hypothesis of independence is true then it is expected that the chance of either X, Y or Z being 1 or 0 is each equal to 1/2. Under this hypothesis of independence, the chances of observed data were calculated and are shown in Appendix C. If these chances are very small, then the hypothesis of independence is hard to accept. If these chances are less than 5%, then the hypothesis is rejected and indicated by *. The summary of all these results is shown in Table V. The results show that for SI approaches the binary variables X, Y and Z are not independent. Thus GSI, FPEA and TD are interrelated.

Table V. Significance of Independence Hypothesis of Variables GSI (X), FPEA (Y) and TD (Z) for ◆-⧫ Effect Data

APPROACH	PILOT GROUP	AIRCRAFT	INDEPENDENCE OF			
			(X,Y)	(X,Z)	(Y,Z)	(X, Y, Z)
SI	RES	LWA	*			*
		MWA	*	*	*	*
		TEA	*			*
	GEN	LWA	*		*	*
		MWA	*			*
PA	RES	LWA				
		MWA				
		TEA				
	GEN	LWA			*	
		MWA				

The interrelationship between variables was also investigated by correlation methods. The correlation, besides investigating independence, also gives a value of a correlation coefficient. The assumptions, however, in the calculation of the correlation coefficients are more restricted. Therefore, the dependence of X, Y, Z calculated earlier is not exactly equivalent to the values of correlation coefficients. The correlation coefficients are always calculated on normalized variables, i.e., subtract the average and divide by S.D., thus various shifts due to treatments are subtracted, and normalized GSI, FPEA and TD are purely reflective of the true relationship between variables not affected by various effects. Correlation coefficients were, however, calculated for ◆ and ◆̸ data and also for all data as shown in Appendix C. The results of Appendix C are reproduced in Table VI.

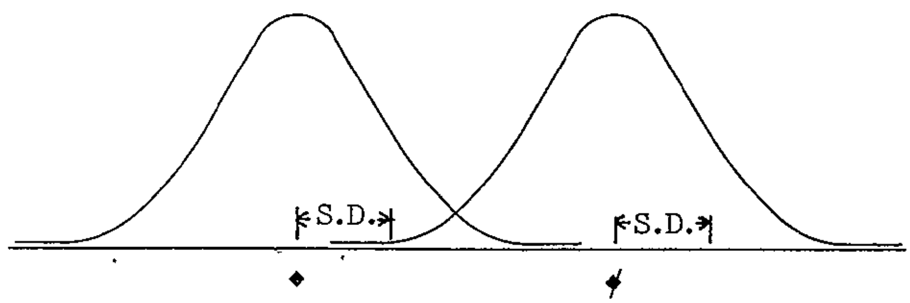
Table VI. Correlations Between Variables (GSI, FPEA, TD)

AIRCRAFT	APPROACH	CORRELATION BETWEEN VARIABLES	PILOT GROUP (SAMPLE SIZE)	
			RESEARCH	GENERAL AVIATION
		(GSI, FPEA)	.8656 (18)**	.8411 (24)**
	SI	(GSI, TD)	.4135 (18)*	-.2171 (24)
LWA		(FPEA, TD)	.4481 (18)*	.4963 (24)**
	PA	(FPEA, TD)	.3425 (18)	.7638 (24)**
MWA	SI	(GSI, FPEA)	.8027 (18)**	.4982 (12)*
		(GSI, TD)	-.2200 (18)	-.6155 (12)*
		(FPEA, TD)	.0288 (18)	.2468 (12)
	PA	(FPEA, TD)	.3692 (18)	-.6730 (12)**
TEA	SI	(GSI, FPEA)	.4161 (18)*	
		(GSI, TD)	-.0200 (18)	
		(FPEA, TD)	.4810 (18)*	
	PA	(FPEA, TD)	.7531 (18)**	

DISCUSSION OF RESULTS

The results of analyses presented in previous sections are now discussed in reference to the question, what are the effects of the painted diamond on the recorded flight data? How and why the diamond caused these effects may be discussed and speculated, but cannot be considered here simply because flight data do not pertain to these aspects. Appropriate remarks, however, will be made on the nature of these aspects.

The linear model used in analyses of flight data was considered appropriate in light of the following observation: If a pilot makes landings with and without a painted diamond on the same runway under identical conditions, and if no learning is involved, then it is expected that any recorded data will show similar distributions, only differing in their centers of location shown graphically below.



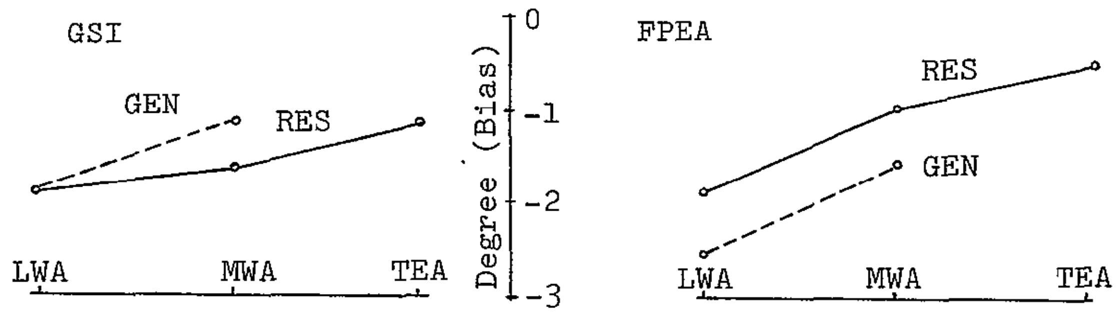
The standard deviations of the two distributions will most likely be the same because a pilot's proficiency in landing remained the same. S.D. is a measure of random variation around the shifted average values. Thus, for data obtained from landings made by equally proficient pilots, the S.D. of the data must remain the same after accounting for all the shifts of average values. This is the main assumption of a linear model.

The S.E. of analyses measures the proficiency of pilots. Proficiency may depend on the pilot's experience and the aircraft flown, thus it is proper to separately analyze data for the two groups of pilots and three types of aircraft. Smaller S.E.s may reflect a higher proficiency pilot group. The

S.E. columns in Tables I and III show that in all cases the RES group has smaller S.E.s than the GEN group. Further, the S.E.s in SI approaches are lower than S.E.s in PA approaches, indicating that all pilots were more proficient in SI approaches than in PA approaches. Also, as expected the data indicate that the RES group, in every case, is more proficient than the GEN group of pilots. The different aircraft, however, do not appear to markedly affect the proficiency of pilots.

The effect of ◆ and ⧫̸ conditions will thus be discussed in terms of their relative shifts of averages which are summarized in Tables II and IV. The difference between ◆ and ⧫̸ estimates of center of the distributions may be called bias. The last column of the tables shows that the diamond produces a negative bias on GSI and FPEA for SI and PA approaches for RES and GEN groups of pilots. The biases are significant in all cases except for the GEN group of pilots in pattern approaches. This group failed to achieve significance because the S.E. is close to 1.44°, indicating that in PA approaches the GEN group has extremely low landing proficiency. All these results thus establish that the diamond, which was painted to project a 5 degree slope, somehow is perceived and utilized by RES pilots as projecting a glideslope between 2.6° and 3.9°, and for GEN pilots, a glideslope between 2.8° to 4.4°. It may thus be concluded that a painted diamond on a runway does induce a downward bias on GSI and FPEA, the amount of bias depending on the projected glideslope and the consistency of information utilized by pilots.

Further examination of the results from GSI and FPEA data relates to the effect of the different aircraft on these downward biases induced by the diamond. The summary of data presented in Table II is shown graphically below. These graphs have been prepared on average values of GSI and FPEA.



Diamond data bias due to different aircraft.

The figure shows that the amount of bias decreases with the increase in the weight class of aircraft. This holds for both RES and GEN groups of pilots. This suggests that an appropriately painted diamond would be most useful in light weight aircraft category used in general aviation.

The effect of the painted diamond on touchdown distances is more pronounced on LWA and MWA aircraft where the differences achieved significance. The differences in TEA data are not significant, and this is without any marked difference in S.E.s, that is, the proficiency of pilots. Thus, for LWA and MWA, diamond has an influence, but the direction of influence may be either negative (-) or positive (+). It is to be remarked here that with the diamond painted on the runway pilots have a sense of aim point, whereas in the absence of any aim point, the distances from the runway threshold are indicative of a pilot's perference for various aim points. This observation may be the basis of non-agreement in the direction (–, +) of bias in the TD data.

Further, the distribution of the touchdown points without the diamond has a wider range than the touchdown points with the diamond. Since the pilot's proficiency remains unchanged, the wider range of touchdown points again is indicative of each pilot's preference for various aim points when there is no diamond on the runway.

The interaction between pilots and (◆, ◆̸) shown in Tables I and III needs careful interpretation. Interaction in analysis refers to that portion of shifts in an average which is over and above the shifts assignable to the treatment (◆, ◆̸) and pilot differences. In other words, the difference in shifts of an average may be due to either ◆ and ◆̸ alone, or due to the pilots' different landing techniques alone, or due to different landing techniques used by the same pilot when landing with or without the diamond on the runway. If none of the pilots change the technique of landing, then there is no interaction. In contrast, even if a single pilot changes the landing techniques in the experiment, the interaction is likely to be present. With this in mind, it is not unexpected that interaction may be most pronounced in LWA aircraft. Indeed, this is the situation as shown by significances in Table I for SI approaches. On PA approaches, the situation is reversed. It may be remarked that the final leg of the approach is much shorter in PA approaches than in SI approaches and the pilots have less time and opportunity to react to diamond information as compared to SI approaches.

The interrelationship between GSI, FPEA and TD flight variables studied by the above two methods shows that each contains partial information on the other and that the variables are interrelated. The amount of linear relationship, as measured by the square of the correlation coefficient shown in Table VI indicates that for RES pilots overlap information between GSI and FPEA is about 64% for SI approaches in LWA and MWA types of aircraft. In TEA aircraft, the overlap drops to 16%. For pattern approaches, the overlap for flight variables in LWA and MWA is about 10%. However, for TEA aircraft this overlap rises to 50%. For GEN pilots the overlap of information between the three variables varies between 5% and 70%. Thus, each variable contains some, but not all of the information contained in the other variables. Therefore, all variables should be considered for analysis.

CONCLUSIONS

An experiment at NASA Dryden Flight Research Center was conducted to investigate the usefulness of a painted diamond on a runway as a visual aid to perform safe landings of aircraft. Flight data on glideslope intercepts, flight path elevation angles, and touchdown distances were collected in this experiment and analyzed for this report.

It is concluded that an appropriately painted diamond on a runway has the potential of providing glideslope information for the light weight class of general aviation aircraft for all classes of pilots. This conclusion holds irrespective of the differences in landing techniques used by the pilots.

The painted diamond induces a downward bias on all flight data except the touchdown distances. The amount of bias depends on the projected glideslope and the consistency of information utilized by the pilots. The bias decreases with the increase in weight of the aircraft. The conclusions hold irrespective of the differences in landing techniques used by the pilots.

The proficiency of pilots, as measured by standard errors, shows that all pilots are more proficient performing straight-in rather than pattern approaches, and research pilots are more proficient than general aviation pilots. This conclusion holds irrespective of the aircraft flown.

The study of interrelationship between flight variables shows that each variable contains some, but not all, of the information contained in the other variables. Therefore, all variables should be considered for analysis. This conclusion holds irrespective of bias introduced by pilots and diamond, no-diamond combinations.

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APPENDIX A. DATA FROM EXPERIMENT [a]

a. To convert the touchdown distance data from the English units of measure to the International System of Units, multiply distance in feet by 0.3048 to obtain meters.

Table A. Number of Landings in each Category of Experiment.

AIRCRAFT	PILOT GROUP	◆ FLIGHTS		◆̸ FLIGHTS	
		SI	PA	SI	PA
LWA	RES	9	9	9	9
	EXP	3	3	3	3
	GEN	12	12	12	12
MWA	RES	9	9	9	9
	EXP	3	3	3	3
	GEN	6	6	6	6
TEA	RES	9	9	9	9
	EXP	3	3	3	3

Table A-1a. Landing data for Light Weight Aircraft (LWA) in SI.

PILOT		LANDING	◆ FLIGHT			⧫ FLIGHT		
CODE	GROUP	#	GSI deg	FPEA deg	TD ft	GSI deg	FPEA deg	TD ft
A	RES	1	3.5	4.1	711	3.2	3.3	695
		2	3.4	3.4	649	3.8	3.9	1000
		3	3.4	3.4	634	3.6	3.8	775
B	RES	1	3.4	2.4	294	5.8	5.9	900
		2	3.2	2.2	310	5.6	5.0	800
		3	2.8	2.0	490	5.8	5.4	840
C	RES	1	3.6	2.8	1150	6.0	6.5	760
		2	3.3	2.8	850	6.8	4.7	1006
		3	2.9	3.2	1000	5.8	5.0	995
D	EXP	1	5.8	5.6	1150	3.4	4.2	910
		2	5.6	5.3	900	6.0	5.3	1090
		3	5.4	4.9	1040	5.2	4.3	840
E	GEN	1	4.0	2.9	390	3.3	2.2	300
		2	4.0	3.5	775	3.8	4.4	700
		3	4.0	3.2	835	3.6	3.9	525
F	GEN	1	4.0	3.3	425	5.6	7.5	1050
		2	4.0	4.2	775	6.2	6.6	1400
		3	4.4	3.8	625	5.2	6.0	1150
G	GEN	1	4.0	3.3	486	9.4	6.7	400
		2	3.7	3.0	600	7.5	7.1	450
		3	3.9	3.0	670	6.6	6.1	625
H	GEN	1	3.7	3.3	980	5.5	6.7	1270
		2	3.1	3.1	725	6.6	6.5	1150
		3	3.3	2.3	1108	6.0	7.3	1680

Table A-1b. Landing Data for Medium Weight Aircraft (MWA) in SI

PILOT		LANDING	◆ FLIGHT			◆̸ FLIGHT		
CODE	GROUP	#	GSI deg	FPEA deg	TD ft	GSI deg	FPEA deg	TD ft
A	RES	1	3.0	2.9	820	4.7	3.2	535
		2	3.6	3.5	900	4.8	2.7	615
		3	3.5	3.3	1110	5.0	3.6	520
B	RES	1	3.4	2.8	800	4.6	4.1	575
		2	3.5	2.6	700	5.2	3.7	530
		3	3.1	2.5	800	4.8	3.6	550
C	RES	1	2.8	2.8	1100	5.0	4.5	905
		2	3.4	2.6	1000	5.2	4.4	940
		3	3.3	2.4	1200	6.2	4.7	1300
D	EXP	1	5.7	4.9	1400	5.4	4.4	800
		2	5.2	4.9	1230	5.5	4.3	1500
		3	5.6	5.3	1000	5.3	4.3	900
E	GEN	1	3.4	2.7	1100	4.4	5.1	1900
		2	3.6	2.9	800	2.7	4.3	1400
		3	3.2		600	3.2		1450
G	GEN	1	3.5	2.7	600	5.4	3.8	275
		2	4.6	2.9	725	6.5	3.6	200
		3	4.4	2.9	675	7.4	5.1	225

Table A-1c. Landing Data for Twin Engine Aircraft (TEA) in SI.

PILOT CODE	PILOT GROUP	LANDING #	◆ FLIGHT GSI deg	◆ FLIGHT FPEA deg	◆ FLIGHT TD ft	⚡ FLIGHT GSI deg	⚡ FLIGHT FPEA deg	⚡ FLIGHT TD ft
A	RES	1	3.2	3.0	950	3.9	3.0	600
		2	3.2	3.0	700	4.4	3.1	500
		3	3.1	3.2	875	4.6	3.3	500
B	RES	1	2.6	3.2	775	3.8	3.7	800
		2	2.3	3.3	1100	3.8	3.5	550
		3	2.3	3.4	500	4.8	3.2	650
C	RES	1	3.1	3.0	1025	4.8	4.1	850
		2	3.8	3.0	1200	4.6	4.5	1400
		3	3.4	3.6	1200	4.2	4.3	1300
D	EXP	1	5.0	4.8	1200	5.0	3.5	550
		2	5.0	4.6	940	5.7	4.2	525
		3	5.2	4.5	1190	6.0	3.9	690

Table A-1d. Summary of Elevation Angles for LWA in SI

PILOT		LANDING	♦ FLIGHT					♦̸ FLIGHT				
CODE	GROUP	#	SS	b_0	b_1	b_2	SE	SS	b_0	b_1	b_2	SE
A	RES	1	70	4.120	-.012		.283					
		2	75	3.416	-.006		.043					
		3	67	3.441	-.010		.048					
B	RES	1	52	3.553	-.022		.120	36	5.804	.004		.069
		2	57	3.278	-.018		.093	54	5.812	-.015		.166
		3	58	2.932	-.015		.075	52	5.904	-.010		.174
C	RES	1	72	3.744	-.014		.133	56	5.938	.009		.088
		2	86	3.087	-.003		.098	49	7.414	-.055		.248
		3	89	2.858	.004		.128	31	5.681	-.021		.088
D	EXP	1	51	5.864	-.006		.048	53	2.811	.175	-.0004	.271
		2	52	5.872	-.011		.104	49	5.968	.075	-.0028	.072
		3	56	5.621	-.014		.128	59	5.230	.024	-.0018	.083
E	GEN	1	64	4.071	-.019		.087	70	3.143	-.013		.168
		2	69	4.186	-.011		.134	72	3.796	.009		.086
		3	68	4.105	-.013		.081	70	3.772	.002		.098
F	GEN	1	58	4.333	-.017		.261	43	6.000	.036		.149
		2	47	4.281	.001		.225	36	6.175	.106	-.0030	.126
		3						38	4.792	.174	-.0037	.202
G	GEN	1	88	3.772	-.005		.192	49	9.751	-.061		.185
		2	89	3.843	-.010		.083	56	7.438	-.006		.154
		3	82	3.986	-.013		.090	53	6.358	.049	-.0010	.133
H	GEN	1	43	3.755	-.010		.073	58	5.962	.012		.159
		2	60	3.017	.026	-.0004	.046	37	6.716	.072	.0018	.062
		3	55	3.484	-.013		.105	54	6.430	.016		.151

Table A-1e. Summary of Elevation Angles for MWA in SI

PILOT		LANDING	◆ FLIGHT					⧫ FLIGHT				
CODE	GROUP	#	SS	b_0	b_1	b_2	SE	SS	b_0	b_1	b_2	SE
A	RES	1		2.841	.021	-.0003	.060	61	5.037	-.029		.148
		2	59	3.699	-.003		.074	61	4.980	-.038		.081
		3	45	3.434	-.004		.059	65	5.260	-.027		.167
B	RES	1	52	3.598	-.015		.194	55	4.411	.058	-.001	.108
		2	51	3.696	-.022		.077	54	4.894	.059	-.002	.097
		3	55	3.261	-.013		.099	61	4.573	.052	-.001	.100
C	RES	1	66	2.878	-.002		.066	47	5.111	-.012		.151
		2	54	3.561	-.018		.056	52	5.248	-.016		.119
		3	73	3.243	-.011		.051	60	6.523	-.030		.270
D	EXP	1	44	6.052	-.026		.477	49	5.555	-.024		.088
		2	35	5.496	-.017		.094	41	5.627	-.033		.137
		3	39	5.525	-.005		.096	50	5.300	-.019		.092
E	GEN	1	44	3.390	-.016		.052	30	4.136	.031		.083
		2	50	3.322	-.008		.100	49	2.550	.030		.103
		3										
G	GEN	1	43	3.710	-.024		.110	53	5.801	-.038		.298
		2	58	4.569	.019	-.0008	.058	54	6.457	-.053		.112
		3	63	4.610	-.027		.090	65	8.111	-.046		.320

Table A-1f. Summary of Elevation Angles for TEA in SI

PILOT CODE	PILOT GROUP	LANDING #	◆ FLIGHT SS	b_0	b_1	b_2	SE	⧫ FLIGHT SS	b_0	b_1	b_2	SE
A	RES	1	33	3.256	-.008		.051	64	4.044	-.016		.110
		2	35	3.263	-.007		.037	64	4.570	-.022		.123
		3	33	3.143	.003		.032	57	4.973	-.029		.175
B	RES	1	54	2.724	-.018		.088	44	4.120	-.010		.157
		2	53	2.477	-.018		.097	39	4.002	-.012		.129
		3	59	2.358	-.019		.115	46	3.785	-.012		.110
C	RES	1	54	3.883	-.017		.105	60	4.511	-.008		.136
		2	53	3.889	-.017		.079	67	4.700	-.005		.110
		3	59	3.178	.006		.124	73	4.069	.009		.095
D	EXP	1	43	5.585	-.018		.205	14	5.145	-.114		.032
		2	36	5.279	-.018		.090	34	6.174	-.058		.243
		3	36	5.774	-.036		.155	35	6.306	-.068		.146

Table A-2a. Landing Data for Light Weight Aircraft LWA in PA

PILOT CODE	PILOT GROUP	LANDING #	◆ FLIGHT FPEA deg	◆ FLIGHT TD ft	◆̸ FLIGHT FPEA deg	◆̸ FLIGHT TD ft
A	RES	1	2.6	608	2.5	650
		2	2.6	523	2.7	59
		3	2.7	607	3.0	730
B	RES	1	2.8	240	4.6	410
		2	2.3	180	3.8	200
		3	2.3	225	3.9	520
C	RES	1	3.1	1143	4.1	1300
		2	3.1	1080	4.3	840
		3	3.2	1070	6.6	910
D	EXP	1	4.8	1100	4.8	835
		2	5.6	1300	5.0	1060
		3		1080	5.5	880
E	GEN	1	2.1	650	4.2	350
		2	4.8	770	6.3	975
		3	5.8	830	7.0	1200
F	GEN	1	2.9	480	4.0	675
		2	8.1	1600	4.9	950
		3	3.7	615	4.1	275
G	GEN	1	2.9	525		2000
		2	4.7	650	8.0	1050
		3	4.3	590	5.3	350
H	GEN	1	2.6	945	7.5	1450
		2	5.1	890	8.5	1500
		3	4.2	1000	7.1	1400

Table A-2b. Landing Data for Medium Weight Aircraft (MWA) in PA

PILOT CODE	PILOT GROUP	LANDING #	◆ FLIGHT FPEA deg	◆ FLIGHT TD ft	⧫ FLIGHT FPEA deg	⧫ FLIGHT TD ft
A	RES	1	2.8	680	2.7	580
		2	3.0	1070	3.0	500
		3	3.0	1010	3.1	500
B	RES	1	2.0	500	3.6	620
		2	2.0	450	3.6	600
		3	1.7	400	3.3	600
C	RES	1	2.8	1200	4.4	800
		2	3.0	1000	4.8	890
		3	2.9	1175	5.2	980
D	EXP	1	5.8	1160	5.4	1000
		2	5.5	1210	5.0	1200
		3	5.2	1080	4.2	950
E	GEN	1	4.2	1200		2000
		2	4.0	800	4.3	900
		3	3.6	950	3.4	1200
G	GEN	1	5.0	650	5.1	175
		2	4.9	700	6.0	425
		3	5.2	650	7.4	550

Table A-2c. Landing Data for Twin Engine Aircraft (TEA) in PA.

PILOT		LANDING	◆ FLIGHT		⧫ FLIGHT	
CODE	GROUP	#	FPEA deg	TD ft	FPEA deg	TD ft
A	RES	1	2.5	550	2.8	400
		2	2.6	750	3.0	400
		3	3.0	850	3.0	350
B	RES	1	1.4	475	3.3	500
		2	1.3	300	3.4	720
		3	1.5	400	2.7	575
C	RES	1	3.7	900	4.3	800
		2	3.7	875	4.5	900
		3	4.3	1000	4.2	1300
D	EXP	1	4.7	1150	4.6	675
		2	4.3	1000	4.4	725
		3	4.8	1020	4.7	650

Table A-2d. Summary of Elevation Angles for LWA in PA

PILOT		LANDING	◆ FLIGHT					✓ FLIGHT				
CODE	GROUP	#	SS	b_0	b_1	b_2	SE	SS	b_0	b_1	b_2	SE
A	RES	1	31	3.355	-.027		.058	41	4.340	-.046		.058
		2	31	3.774	-.039		.081	18	3.500	-.047		.033
		3	28	3.669	-.036		.058	45	5.322	-.054		.068
B	RES	1	17	3.690	-.085		.062	38	5.911	-.034		.158
		2	21	3.996	-.081		.053	43	6.046	-.054		.194
		3	20	4.591	-.112		.076	25	5.346	-.058		.104
C	RES	1	50	3.652	-.011		.129	30	5.075	-.034		.061
		2	89	2.858	.004		.128	34	5.427	-.032		.077
		3	53	3.066	.004	-.0001	.066	39	7.138	-.017		.146
D	EXP	1	26	5.263	-.018		.042	15	5.243	-.035		.045
		2	26	6.139	-.020		.064	16	5.863	-.070		.050
		3						16	6.315	-.065		.161
E	GEN	1	34	3.947	-.048		.070	27	5.720	-.059		.069
		2	25	5.333	-.024		.051	24	7.075	-.034		.072
		3	31	6.407	-.022		.141	25	7.703	-.028		.074
F	GEN	1	32	4.347	-.046		.133	19	4.274	.013		.073
		2	31	6.827	.042		.144	33	6.027	.032		.132
		3	27	3.582	.054	-.0018	.068	28	4.754	.019		.080
G	GEN	1	37	4.343	-.038		.074					
		2	27	6.483	-.069		.048	19	8.975	-.056		.108
		3	23	6.248	-.084		.075	30	7.257	-.069		.067
H	GEN	1	16	3.915	-.010		.054	30	7.422	-.027	.0010	.055
		2	15	5.334	-.017		.040	28	7.816	.026		.103
		3	17	4.601	-.033		.085	26	7.674	-.021		.045

Table A-2e. Summary of Elevation Angles for MWA in PA

PILOT		LANDING	◆ FLIGHT					◆̸ FLIGHT				
CODE	GROUP	#	SS	b_0	b_1	b_2	SE	SS	b_0	b_1	b_2	SE
A	RES	1	23	4.598	-.083		.067	40	4.369	-.043		.079
		2	26	4.452	-.058		.122	28	5.028	-.077		.061
		3	28	4.948	-.069		.119	33	5.462	-.075		.075
B	RES	1	26	3.109	-.046		.044	27	5.407	-.070		.065
		2	24	2.969	-.043		.043	30	5.306	-.059		.058
		3	21	2.849	-.060		.051	35	4.916	-.048		.095
C	RES	1	46	3.953	-.025		.091	28	5.552	-.041		.133
		2	39	3.787	-.022		.081	46	5.713	-.016		.083
		3	46	3.652	-.017		.141	33	5.884	-.021		.083
D	EXP	1	31	6.682	-.031		.041	17	6.249	-.055		.105
		2	29	6.448	-.033		.144	17	6.223	-.078		.056
		3	29	6.714	-.054		.083	16	5.195	-.077		.067
E	GEN	1	30	4.295	-.041		.053					
		2	32	6.263	-.075		.161	17	4.108	.012		.091
		3	28	5.540	-.073		.128	17	3.506	-.023	.0010	.041
G	GEN	1	21	5.757	-.040		.073	36	7.410	-.067		.073
		2	25	6.305	-.057		.120	41	8.263	-.055		.122
		3	17	6.165	-.061		.072	37	9.062	-.046		.112

Table A-2f. Summary of Elevation Angles for TEA in PA

PILOT		LANDING	◆ FLIGHT					◆̸ FLIGHT				
CODE	GROUP	#	SS	b_0	b_1	b_2	SE	SS	b_0	b_1	b_2	SE
A	RES	1	17	2.763	−.018		.041	16	3.728	−.065		.062
		2	17	3.173	−.038		.051	29	4.671	−.060		.057
		3	17	3.888	−.056		.063	25	4.481	−.062		.049
B	RES	1	17	2.307	−.056		.056	43	4.175	−.021		.092
		2	17	2.373	−.067		.044	39	3.987	−.017		.049
		3	16	2.748	−.081		.046	35	3.704	−.028		.065
C	RES	1	29	4.865	−.042		.095	25	4.769	−.020		.131
		2	24	4.358	−.027		.061	48	5.977	−.032		.076
		3	22	4.968	−.034		.053	55	5.535	−.052		.063
D	EXP	1	31	5.767	−.037		.087	19	5.432	−.052		.094
		2	27	5.267	−.035		.062	21	6.364	−.096		.049
		3	30	6.116	−.046		.142	19	5.479	−.044		.054

APPENDIX B. ANOVA FOR APPROACHES[a]

Section B-1. ANOVA for Straight-In (SI) approaches

Section B-2. ANOVA for Pattern (PA) Approaches

a. To convert the SSS or MS data from the English units of measure to the International System of Units, multiply either by 0.0929. To convert TD data, multiply distance in feet by 0.3048 to obtain meters.

Table B-1a. GSI Data Analysis of Variance (ANOVA) and Summary for SI Approaches for RES Pilots

ANOVA — SUMMARY

LIGHT WEIGHT AIRCRAFT

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	15.87	158.7	158.7**
PILOTS	2	5.11	2.56	25.6**
PILOT (◆, ◆̸) INTERACTION	2	7.17	3.59	35.9**
RANDOM	12	1.24	0.10	

S.E. = 0.32 degree

PILOT	◆ deg	◆̸ deg	◆ − ◆̸ deg
A	3.4	3.5	-0.1
B	3.1	5.7	-2.6
C	3.3	6.2	-2.9
AVG.	3.3	5.1	-1.8

MEDIUM WEIGHT AIRCRAFT

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	14.05	14.05	108.08**
PILOTS	2	0.19	0.10	0.77
PILOT (◆, ◆̸) INTERACTION	2	0.66	0.33	2.54
RANDOM	12	1.54	0.13	

S.E. = 0.36 degree

PILOT	◆ deg	◆̸ deg	◆ − ◆̸ deg
A	3.4	4.8	-1.4
B	3.3	4.9	-1.6
C	3.2	5.5	-2.3
AVG	3.3	5.1	-1.8

TWIN ENGINE AIRCRAFT

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	7.87	7.87	65.58**
PILOTS	2	1.59	0.80	6.67**
PILOT (◆, ◆̸) INTERACTION	2	0.38	0.19	1.58
RANDOM	12	1.42	0.12	

S.E. = 0.34 degree

PILOT	◆ deg	◆̸ deg	◆ − ◆̸ deg
A	3.2	4.3	-1.1
B	2.4	4.1	-1.7
C	3.4	4.5	-1.1
AVG	3.0	4.3	-1.3

Table B-1b. GSI Data Analysis of Variance (ANOVA) and Summary for SI Approaches for GEN Pilots

A N O V A — S U M M A R Y

LIGHT WEIGHT AIRCRAFT

SOURCE OF VARIATION	df	SSS	MS	f
(◆ , ◆̸)	1	22.43	22.43	63.29**
PILOTS	3	12.91	4.31	12.16**
PILOT (◆, ◆̸) INTERACTION	3	15.65	5.22	14.79**
RANDOM	16	5.67	0.35	

S.E. = 0.60 degrees

PILOT	◆ deg	◆̸ deg	◆ - ◆̸ deg
E	4.0	3.6	0.4
F	4.1	5.7	-1.6
G	3.9	7.8	-3.9
H	3.4	6.0	-2.6
AVG	3.9	5.8	-1.9

MEDIUM WEIGHT AIRCRAFT

SOURCE OF VARIATION	df	SSS	MS	f
(◆ , ◆̸)	1	3.97	3.97	7.39*
PILOTS	1	10.64	10.64	19.80**
PILOT (◆, ◆̸) INTERACTION	1	3.74	3.74	6.96*
RANDOM	8	4.30	0.54	

S.E. = 0.73 degree

PILOT	◆ deg	◆̸ deg	◆ - ◆̸ deg
E	3.3	3.4	-0.1
G	4.2	6.4	-2.2
AVG	3.8	4.9	-1.1

Table B-1c. FPEA Data Analysis of Variance (ANOVA) and Summary for SI Approaches for RES Pilots

ANOVA — SUMMARY

LIGHT WEIGHT AIRCRAFT

ANOVA

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	16.44	16.44	65.76**
PILOTS	2	0.83	0.42	1.68
PILOT (◆, ◆̸) INTERACTION	2	8.37	4.19	16.76**
RANDOM	12	2.99	0.25	

S.E. = 0.50 degree

SUMMARY

PILOT	◆ deg	◆̸ deg	◆ − ◆̸ deg
A	3.6	3.7	-0.1
B	2.2	5.4	-3.2
C	2.9	5.4	-2.5
AVG	2.9	4.8	-1.9

MEDIUM WEIGHT AIRCRAFT

ANOVA

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	4.60	4.60	9.39**
PILOTS	2	0.47	0.24	0.49
PILOT (◆, ◆̸) INTERACTION	2	3.05	1.53	3.12
RANDOM	12	0.98	0.08	

S.E. = 0.29 degree

SUMMARY

PILOT	◆ deg	◆̸ deg	◆ − ◆̸ deg
A	3.2	3.2	0.0
B	2.6	3.8	-1.2
C	2.6	4.5	-1.9
AVG	2.8	3.8	-1.0

TWIN ENGINE AIRCRAFT

ANOVA

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	0.89	0.89	0.89
PILOTS	2	1.27	0.64	0.64
PILOT (◆, ◆̸) INTERACTION	2	0.98	0.49	0.49
RANDOM	12	0.54	0.54	0.05

S.E. = 0.21 degree

SUMMARY

PILOT	◆ deg	◆̸ deg	◆ − ◆̸ deg
A	3.0	3.1	-0.1
B	3.3	3.5	-0.2
C	3.2	4.3	-1.1
AVG	3.2	3.6	-0.4

Table B-1d. FPEA Data Analysis of Variance (ANOVA) and Summary for SI Approaches for GEN Pilots

A N O V A — S U M M A R Y

LIGHT WEIGHT AIRCRAFT

ANOVA

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	42.78	42.78	125.36**
PILOTS	3	12.86	4.29	12.57**
PILOT (◆, ◆̸) INTERACTION	3	11.28	3.76	11.06**
RANDOM	16	5.46	0.34	

S.E. = 0.58 degrees

SUMMARY

PILOT	◆ deg	◆̸ deg	◆ - ◆̸ deg
E	3.2	3.5	-0.3
F	3.8	6.7	-2.9
G	3.1	6.6	-3.5
H	2.9	6.8	-3.9
AVG	3.3	5.9	-2.6

MEDIUM WEIGHT AIRCRAFT

ANOVA

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	6.11	6.11	21.69**
PILOTS	1	0.16	0.16	0.57
PILOT (◆, ◆̸) INTERACTION	1	0.17	0.17	0.60
RANDOM	6	1.69	0.28	

S.E. = 0.53 degree

SUMMARY

PILOT	◆ deg	◆̸ deg	◆ - ◆̸ deg
E	2.8	4.7	-1.9
G	2.8	4.2	-1.4
AVG	2.8	4.5	-1.7

Table B-1e. TD Data Analysis of Variance (ANOVA) and Summary for SI Approaches for RES Pilots

A N O V A — S U M M A R Y

LIGHT WEIGHT AIRCRAFT

SOURCE OF VARIATION	df	SSS	MS	F
(◆ , ◆̸)	1	157361	157361	11.46**
PILOTS	2	383069	191535	13.95**
PILOT (◆ , ◆̸) INTERACTION	2	239330	119665	8.61*
RANDOM	12	164805	13734	

S.E. = 117 feet

PILOT	◆ ft	◆̸ ft	◆ - ◆̸ ft
A	665	823	-158
B	365	847	-482
C	1000	920	80
AVG	677	863	-186

MEDIUM WEIGHT AIRCRAFT

SOURCE OF VARIATION	df	SSS	MS	F
(◆ , ◆̸)	1	213422	213422	14.78**
PILOTS	2	571119	285560	19.77**
PILOT (◆, ◆̸) INTERACTION	2	84266	42133	2.92
RANDOM	12	173304	14442	

S.E. = 120 feet

PILOT	◆ ft	◆̸ ft	◆ - ◆̸ ft
A	943	557	386
B	767	552	215
C	1100	1048	52
AVG	937	719	218

TWIN ENGINE AIRCRAFT

SOURCE OF VARIATION	df	SSS	MS	F
(◆ , ◆̸)	1	76701	76701	2.07
PILOTS	2	830278	415139	11.21
PILOT (◆ , ◆̸) INTERACTION	2	91481	45741	1.21
RANDOM	12	444214	37018	

S.E. = 192 feet

PILOT	◆ ft	◆̸ ft	◆ - ◆̸ ft
A	842	533	309
B	792	666	126
C	1142	1183	-41
AVG	925	794	131

Table B-1f. TD Data Analysis of Variance (ANOVA) and Summary for SI Approaches for GEN Pilots

ANOVA — SUMMARY

LIGHT WEIGHT AIRCRAFT

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	221568	221568	5.91*
PILOTS	3	1489995	496665	13.26**
PILOT (◆, ◆̸) INTERACTION	3	630362	210121	5.61**
RANDOM	16	599366	37460	

S.E. = 194 feet

PILOT	◆ ft	◆̸ ft	◆ – ◆̸ ft
E	667	508	159
F	608	1200	-592
G	585	492	93
H	938	1366	-428
AVG	700	892	-192

MEDIUM WEIGHT AIRCRAFT

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	75208	75208	2.08
PILOTS	1	1725208	1725208	47.73**
PILOT (◆, ◆̸) INTERACTION	1	1050208	1050208	29.06**
RANDOM	8	289167	36145	

S.E. = 190 feet

PILOT	◆ ft	◆̸ ft	◆ – ◆̸ ft
E	833	1583	-750
G	667	233	434
AVG	750	908	-158

Table B-2a. FPEA Data Analysis of Variance (ANOVA) and Summary for PA Approaches for RES Pilots

A N O V A — S U M M A R Y

LIGHT WEIGHT AIRCRAFT

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	6.48	6.48	17.05**
PILOTS	2	5.77	2.89	7.61**
PILOT (◆, ◆̸) INTERACTION	2	2.75	1.38	3.63
RANDOM	12	4.56	0.38	

S.E. = 0.62 degree

PILOT	◆ deg	◆̸ deg	◆ - ◆̸ deg
A	2.6	2.7	-0.1
B	2.5	4.1	-1.6
C	3.1	5.0	-1.9
AVG	2.7	3.9	-1.2

MEDIUM WEIGHT AIRCRAFT

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	6.13	6.13	153.25**
PILOTS	2	4.43	2.22	55.50**
PILOT (◆, ◆̸) INTERACTION	2	3.17	1.59	39.75**
RANDOM	12	0.53	0.04	

S.E. = 0.21 degree

PILOT	◆ deg	◆̸ deg	◆ - ◆̸ deg
A	2.9	2.9	0
B	1.9	3.5	-1.6
C	2.9	4.8	-1.9
AVG	2.6	3.7	-1.1

TWIN ENGINE AIRCRAFT

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	2.88	2.88	48.00**
PILOTS	2	10.83	5.42	90.33**
PILOT (◆, ◆̸) INTERACTION	2	2.00	1.00	16.67**
RANDOM	12	0.75	0.06	

S.E. = 0.25 degree

PILOT	◆ deg	◆̸ deg	◆ - ◆̸ deg
A	2.7	2.9	-0.2
B	1.4	3.1	-1.7
C	3.9	4.3	-0.4
AVG	2.7	3.4	-0.7

Table B-2b. FPEA Data Analysis of Variance (ANOVA) and Summary for PA Approaches for GEN Pilots

ANOVA

SUMMARY

LIGHT WEIGHT AIRCRAFT

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	24.00	24.00	9.72**
PILOTS	3	5.39	1.80	0.73
PILOT (◆, ◆̸) INTERACTION	3	16.91	5.64	2.28
RANDOM	16	39.59	2.47	

S.E. = 1.57 degrees

PILOT	◆ deg	◆̸ deg	◆ - ◆̸ deg
E	4.2	5.8	-1.6
F	4.9	4.3	0.6
G	4.0	6.7	-2.7
H	4.0	7.7	-3.7
AVG	4.3	6.1	-1.8

MEDIUM WEIGHT AIRCRAFT

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	3.41	3.41	2.63
PILOTS	1	4.08	4.08	3.15
PILOT (◆, ◆̸) INTERACTION	1	0.02	0.02	0.02
RANDOM	8	10.37	1.30	

S.E. = 1.14 degrees

PILOT	◆ deg	◆̸ deg	◆ - ◆̸ deg
E	3.9	3.9	0.0
G	5.0	6.2	-1.2
AVG	4.5	5.1	-0.6

Table B-2c. TD Data Analysis of Variance (ANOVA) and Summary for PA Approaches for RES Pilots

A N O V A — S U M M A R Y

LIGHT WEIGHT AIRCRAFT

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	181	181	
PILOTS	2	182532	912661	24.17**
PILOT (◆, ◆̸) INTERACTION	2	64873	32437	0.86
RANDOM	12	453110	37759	

S.E. = 194 feet

PILOT	◆ ft	◆̸ ft	◆-◆̸ ft
A	579	480	99
B	215	377	-162
C	1098	1017	81
AVG	631	625	6

MEDIUM WEIGHT AIRCRAFT

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	111235	111235	9.67**
PILOTS	2	696753	348377	30.28**
PILOT (◆, ◆̸) INTERACTION	2	240094	120047	10.43**
RANDOM	12	138075	11506	

S.E. = 107 feet

PILOT	◆ ft	◆̸ ft	◆-◆̸ ft
A	920	527	393
B	450	607	-157
C	1125	890	235
AVG	832	675	157

TWIN ENGINE AIRCRAFT

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	1335	1335	
PILOTS	2	783475	391738	19.72**
PILOT (◆, ◆̸) INTERACTION	2	237005	118503	5.97*
RANDOM	12	238348	19862	

S.E. = 141 feet

PILOT	◆ ft	◆̸ ft	◆-◆̸ ft
A	717	383	334
B	392	598	-206
C	925	1000	-75
AVG	678	660	18

Table B-2d. TD Data Analysis of Variance (ANOVA) and Summary for PA Approaches for GEN Pilots

ANOVA / SUMMARY

LIGHT WEIGHT AIRCRAFT

ANOVA

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	288204	288204	1.66
PILOTS	3	712750	237583	1.37
PILOT (◆, ◆̸) INTERACTION	3	657813	219271	1.26
RANDOM	16	2773283	173330	

S.E. = 416 feet

SUMMARY

PILOT	◆ ft	◆̸ ft	◆-◆̸ ft
E	750	842	-92
F	898	633	265
G	588	1133	-545
H	945	1450	-505
AVG	795	1015	-220

MEDIUM WEIGHT AIRCRAFT

ANOVA

SOURCE OF VARIATION	df	SSS	MS	F
(◆, ◆̸)	1	7500	7500	
PILOTS	1	1267500	1267500	12.63**
PILOT (◆, ◆̸) INTERACTION	1	333333	333333	3.32
RANDOM	8	802917	100365	

S.E. = 317 feet

SUMMARY

PILOT	◆ ft	◆̸ ft	◆-◆̸ ft
E	983	1367	-384
G	667	383	284
AVG	825	875	-50

APPENDIX C. INTERRELATIONSHIP BETWEEN VARIABLES

Table C-1. The frequency of landing for joint events and their probability under hypothesis of independence. Straight-in approaches.

Table C-2. The frequency of landing for joint events and their probability under hypothesis of independence. Pattern approaches.

Table C-3. Correlations between landing variables for straight-in and pattern approaches.

Table C-1. The frequency of landing for joint events and their probability under hypothesis of independence. Straight-in approaches.

EVENT[a]				AIRCRAFT AND PILOT GROUP				
				LWA		MWA		TEA
X	Y	Z		RES	GEN	RES	GEN	RES
0	0			1	1			
0	1							
1	0					1		1
1	1			8	11	8	5	8
			TOTAL	9	12	9	5	9
			PROBABILITY	.000	.000	.000	.000	.000
0		0		1	3			
0		1						
1		0		2	3	8	3	5
1		1		6	6	1	3	4
			TOTAL	9	12	9	6	9
			PROBABILITY	.001	.001	.000	.005	.001
	0	0		1	1	1		
	0	1						1
	1	0		2	5	7	3	5
	1	1		6	6	1	2	3
			TOTAL	9	12	9	5	9
			PROBABILITY	.001	.000	.000	.010	.002
0	0	0		1	1			
0	0	1						
0	1	0			2			
0	1	1						
1	0	0				1		
1	0	1						1
1	1	0		2	3	7	3	5
1	1	1		6	6	1	2	3
			TOTAL	9	12	9	5	9
			PROBABILITY	.000	.000	.000	.000	.000

a. X = 1 or 0 for GSI; Y = 1 or 0 for FPEA; Z = 1 or 0 for TD.
The difference (♦-ϕ)< 0 indicates 1, difference (♦-ϕ)> 0 indicates 0.

Table C-2. The frequency of landings for joint events (Y, Z) and their probability under hypothesis of independence. Pattern approaches.

EVENT[a]			AIRCRAFT AND PILOT GROUP				
			LWA		MWA		TEA
Y	Z		RES	GEN	RES	GEN	RES
0	0			1	1		
0	1		1			1	
1	0		3	3	5	3	5
1	1		5	7	3	1	2
		TOTAL	9	11	9	5	7
		PROBABILITY	.002	.000	.002	.020	.001

[a] Y = 1 or 0 for FPEA; Z = 1 or 0 for TD.
The difference (◆−φ̸) < 0 indicates 1; difference (◆−φ̸) > 0 indicates 0

Table C-3. Correlations between landing variables for straight-in and pattern approaches

LIGHT WEIGHT AIRCRAFT

PILOT GROUP	SAMPLE SIZE	FLIGHT LANDINGS	STRAIGHT-IN APPROACHES (GSI, FPEA)	(GSI, TD)	(FPEA, TD)	PATTERN APPROACHES (FPEA, TD)
RES	9	◆	.4619	.1718	.4191	.8886**
	9	◆̸	.7861**	.4157	.0701	.3822
	18	All	.8656**	.4135*	.4481*	.3425
GEN	12	◆	.5992*	-.4707	-.1960	.7450**
	12	◆̸	.7289**	.0237	.5623*	.8555**
	24	All	.8411**	-.2171	.4963**	.7638**

MEDIUM WEIGHT AIRCRAFT

PILOT GROUP	SAMPLE SIZE	FLIGHT LANDINGS	STRAIGHT-IN APPROACHES (GSI, FPEA)	(GSI, TD)	(FPEA, TD)	PATTERN APPROACHES (FPEA, TD)
RES	9	◆	.3608	-.1367	.0388	.1907
	9	◆̸	.5959*	.8399**	.7481*	.9602**
	18	All	.8027**	-.2200	.0288	.3692
GEN	6	◆	.7378*	-.1484	-.3308	-.6829
	6	◆̸	.0151	-.8065*	.4910	-.6291
	12	All	.4982*	-.6155*	.2468	-.6730**

TWIN ENGINE AIRCRAFT

PILOT GROUP	SAMPLE SIZE	FLIGHT LANDINGS	STRAIGHT-IN APPROACHES (GSI, FPEA)	(GSI, TD)	(FPEA, TD)	PATTERN APPROACHES (FPEA, TD)
RES	9	◆	-.3574	.5539	.0184	.9595**
	9	◆̸	.1896	.1490	.9140**	.8039**
	18	All	.4161*	-.0200	.4810*	.7531**

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15 Supplementary Notes

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16 Abstract

An experiment at NASA Dryden Flight Research Center was conducted to investigate the usefulness of a painted diamond on a runway as a visual aid to perform safe landings of aircraft. Flight data on glideslope intercepts, flight path elevation angles, and touchdown distances collected in this experiment were analyzed.

Research and general aviation pilots participated in the experiment with both groups flying straight-in and pattern approaches Flight data were statistically analyzed for significant effects due to diamond and no diamond approaches and landings. Pilot proficiency was measured by standard error in the flight data.

The results show that an appropriately painted diamond has the potential of providing glideslope information for the light weight class of general aviation aircraft for all classes of pilots. This conclusion holds irrespective of the differences in landing techniques used by the pilots.

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