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ACKNOWLEDGEMENTS

This year's publication of the University Aviation Association *Proceedings* marks the sixth year that papers of scholarly inquiry have been presented to the membership of the association in this manner. As a vehicle for aviation educators and those interested in sharing the results of their research with the profession, the *Proceedings* is the sole such effort in collegiate aviation education.

The referee process used in evaluating manuscript submissions is a rigorous procedure. Every submission is blind reviewed by as many as five peers and never less than three. This year for the first time, the reviewers were asked to provide authors with comments about their manuscripts.

Congratulations are in order. A great deal of thanks goes to the authors who prepared manuscripts for submission this year; such scholarly effort requires countless hours of writing and rewriting. In addition, the referee process would be impossible without the time given by numerous reviewers. The Publications Committee wishes to thank these individuals for the time they devoted to this all important process.

There are a few but somewhat significant changes in the *Proceedings* this year. Authors were asked to provide their final manuscript on a computer disk so that the final copy of the *Proceedings* could be prepared using the same editing, format, and printer.

My sincerest thanks to all who had a part in the preparation of this University Aviation Association *Proceedings*.

Henry R. Lehrer, Ph.D.
Publications Committee Chairperson

OPTIMIZED ENGINE OUT PROCEDURES
FOR MULTI ENGINE AIRPLANES

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Abstract

This investigation examined hazards associated with asymmetric thrust, engine out flying in twin engine airplanes at low speeds and low altitudes. National Transportation Safety Board (NTSB) data provided a measure of the comparative risks posed by control and performance inadequacies.

Pilot training literature, as well as both pilot and instructor levels of awareness, indicated considerable misunderstanding of relevant aerodynamic principles. Virtually total emphasis has been devoted to directional control, which represents but one-third of the hazard. Regardless of circumstances, five degrees of bank is commonly believed to be the best available procedure for engine out flight.

Mathematical analysis has been used to show that the optimum performance bank angle depends on several factors. In marginal rate of climb scenarios, the optimum bank is much smaller than five degrees. Wind tunnel experiments validated the analytical work and suggested substantially improved climb performance was achievable, with adequate control, by flying at zero sideslip.

Flight tests in three light twin airplane models verified that angle of bank strongly influences rate of climb. Best climb resulted at the small angles of bank corresponding to zero sideslip. Increasing bank to five degrees degraded climb performance approximately 75-90 feet per minute from optimum. This penalty was equivalent to a weight addition of up to nine percent or a density altitude increase of as much as 1900 feet.

Pilot Operator Handbook predicted rate of climb was achieved only at zero sideslip.

Engine-out training techniques incorporating correct aerodynamic principles have been recommended. Similarly, appropriate revisions to The Federal Aviation Administration (FAA) Flight Training Handbook (FAA, 1980) and other training references are proffered.

"A false notion which is clear and precise will always have more power in the world than a true principle which is obscure or involved" (anonymous).

Introduction

Since the advent of twin-engine airplanes, the rhetorical question has been asked whether that second engine makes the plane twice as safe or twice as dangerous? The answer depends on the pilot's knowledge and training. The more complex plane demands more decisions and provides less margin for error, particularly during engine-out emergencies.

The literature and airplane mishap records suggest potential for significant improvement. Unpublished National Transportation Safety Board (NTSB) data for light twin accidents between March 1984 and October 1986 was examined. It indicated that an annual average of 33 accidents occurred in the initial climb (between liftoff and power reduction) phase of engine-out flight. Evaluating accident narratives, the investigator rejected approximately 70% which appeared due to weather, fuel mismanagement, other gross judgement or technique deficiencies, or which otherwise defied classification. The remaining 23 (nine per year) could be attributed to: (a) loss of directional control, (b) stall, or (c) inadequate climb performance. The resulting distribution of causal factors for these three is contained in Table 1.

Table 1

Light Twin Engine-out Initial Climb Accident Factors

CAUSE	Accidents (%)	Fatal/Serious Injury (%)
Loss of Direct. Cont.	30%	35%
Stall/Spin	26%	38%
Inadequate Climb Perf.	43%	25%

A review was conducted of pilot-oriented literature relating to handling engine-out emergencies. It indicated that certain dubious concepts are widespread in the pilot training and certification process. Extensive written questioning of pilots proved such to be the case. Virtually all engine-out training emphasis is focused on directional control, whereas inability to maintain altitude and/or airspeed causes two-thirds of the accidents and injuries.

Aviation educators and organizations such as the University Aviation Association may consider it appropriate to assert a leadership role in clarifying questions related to engine-out flying. It is in hope of correcting certain common misconceptions that this treatise is aimed.

Significance

The following analysis deals with optimum management of the engine-out situation in conventional, wing-mounted, twin-engine airplane wherein yaw from asymmetrical thrust can be substantial. Extension to three or four engine airplanes would be straightforward.

Analysis of forces and moments

FIGURE 1: RIGHT ENGINE INOPERATIVE
(wings level, ball centered)

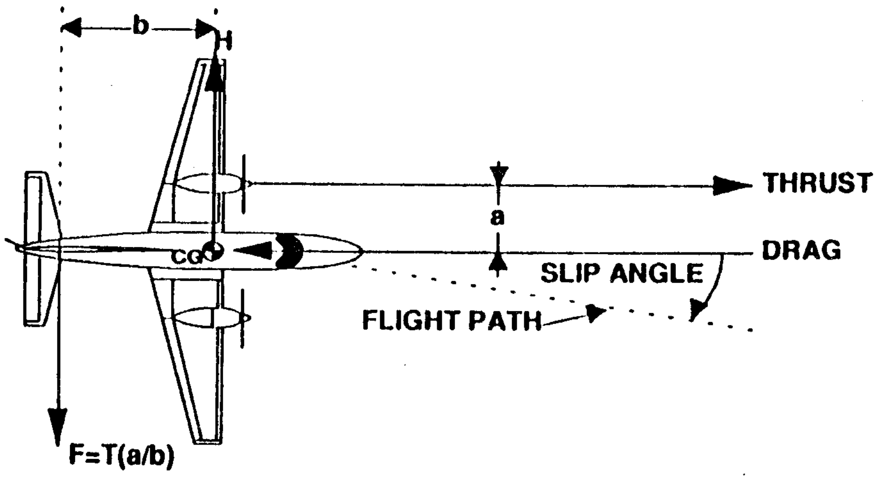

Figure 1 depicts the asymmetric, engine out flight conditions resulting from a failed (right) engine. The airplane is assumed configured for climb, with propeller feathered. Clockwise yaw due to the engine thrust T offset by distance a is neutralized by (left) rudder deflection. The drag D is assumed to equal T and act through the center of gravity (CG). To counteract yaw due to asymmetric thrust, the lateral tail force F must equal T(a/b), where b is the longitudinal distance between the CG and tail's aerodynamic center. Acting through the vertical tail's aerodynamic center, it produces a counter clockwise moment equal to T(a). The plane must sideslip (to the right) such that a horizontal fuselage lift force H, equal and opposite to F and assumed to act through the CG, is established.

Level, equilibrium flight at zero angle of bank would then prevail. The balance ball would be centered, and all would appear tidy from the cockpit. In fact, until approximately 1980, many pilots were trained to fly, engine-out, in just this manner.

Disadvantages of the sideslip are twofold, since "sideways" flight inevitably:

1. increases drag, and
2. decreases the tail fin's angle of attack, thereby adding a weathervaning tendency which compounds the yaw from asymmetric thrust.

Both climb performance and directional control are degraded by sideslip toward the inoperative engine. Current literature seems unanimous on that point.

Since the plane is slipping with wings level, can one bank the opposite direction (toward the operative engine) to alleviate both the disadvantages cited? As will be proven, the answer is yes, but only up to a point. Furthermore, one must become familiar with the governing laws of physics.

The optimum amount of bank angle, into the operative engine, is the key question. It is central to how multi-engine emergency training is conducted and how unquestioning multi-engine pilots inculcate their emergency procedures. Unfortunately, evidence suggests much of that training is incomplete or incorrect. Various items of evidence will be examined to evaluate the current state of pilot training and opinion on this subject, together with speculation as to the confusion's root cause.

Questionnaire results

The following written question, among several others, was administered to all multi-engine rated pilots at a Certified Flight Instructor (CFI) refresher seminar and at a Federal Aviation Administration (FAA) safety seminar.

"With regard to engine-out flying, select the following statement you consider most correct.

a. Best climb performance and directional control are achieved at zero bank angle.

b. Best climb performance results from the bank producing zero sideslip. Additional bank improves directional control but hurts performance.

c. Best directional control results from the bank producing zero sideslip. Additional bank improves performance but hurts directional control.

d. The bank angle producing zero sideslip results both in best performance and directional control.

e. A five degree bank gives the best performance and directional control.

f. A bank angle of more than five degrees gives best performance and directional control.

g. None of the above statements is correct".

Only 26% of an experienced, representative cross section of 54 multi-engine pilots (including just 22% of the multi-engine instructors) answered correctly. Significantly, 78% of the wrong responses were choice "e". The investigator termed this phenomenon the Five Degree Forever (FDF) Syndrome, and it will be analyzed carefully. As will be proven, five degrees of bank provides neither best performance nor best directional control.

Literature Review

In his pioneering work, Berven (1980) focused on the influence of bank on the relationship between an airplane's published and actual minimum control speed (Vmc). He pointed out that Federal Aviation Regulation 23.149a defines the precise conditions under which the manufacturer must determine Vmc, and permits the applicant an angle of bank of not more than five degrees. Since greater bank yields a lower, more favorable Vmc, the clear intent of the Regulation is to impose standardization, limit the permissable bank, and preclude publication of unrealistic Vmc values.

Berven emphasized that the actual Vmc may dangerously exceed the nominal value under some scenarios, and that this fact must be understood by multi-engine pilots. Among his most important recommendations to the FAA were that emphasis should be placed both on teaching pilots the importance of banking at least 5° into the good engine immediately after an engine failure, and the correct technique for flying at zero sideslip to maximize engine-out performance and insure optimum stall characteristics.

All evidence suggests that the 5° bank recommendation has received far more emphasis than has the necessity to assume zero sideslip for optimum performance. Furthermore, the relationship between the two is not well understood by the multi engine pilot and instructor communities.

The current FAA Flight Training Handbook (1980) incorporated part of Berven's recommendations, but failed to clarify the relationship between optimum performance and control. On the contrary, there appears the following assertion:

"Banking at least 5° into the good engine ensures that the airplane will be controllable at any speed above the certificated Vmc, that the airplane will be in a minimum drag configuration for best climb performance, and that the stall characteristics will not be degraded. Engine-out flight with the ball centered is never correct...The magnitude of these effects will vary from airplane to airplane, but the principles are applicable in all cases"(p.237). It appears that this assertion, combined with the 5° bank limit of FAR 23.149a, represents the origin of the FDF Syndrome.

Kershner (1985) discussed engine-out flying technique. He recommended "...also to establish the 10° bank into the good engine..."(p.187), for the purpose of establishing a slip to ensure directional control. Subsequently he warned that "asymmetrical flight such as sideslip greatly increases drag and hurts climb performance"(p.187). However, only the most astute reader is likely to synthesize this guidance correctly to determine the optimum bank appropriate for a particular phase of any emergency.

Kershner's suggested training with a yaw string installed has much merit. However, the instructions to "...set up a bank about one ball width into the operating engine and keep the yaw string centered with the rudder" (p.187) deserve clarification.

A contemporary treatise by Newton (1987) has much to recommend it, and represents a comprehensive explanation of engine-out aerodynamics. It too explained the advantages of training with a yaw string. In handling the emergency, Newton logically emphasized first control, then performance. For control,the recommendation was to "...bank the airplane at least (not at most) five degrees into the good engine" (p.74). In subsequently discussing climb, no mention was made of reducing the bank to improve climb performance. The reader surely must assume the intent was to maintain at least 5°.

Cessna T303 Crusader Handbook (1981) stated "Establish bank--5° toward operating engine. Trim tabs--adjust to maintain 5°..."(p.3-6). The Piper PA 44 Seminole Handbook (1978) stated "Trim the aircraft as required and maintain a 3° to 5° bank toward the operating engine. The ball will be 1/2 to 3/4 out for minimum drag"(p.3-12). By contrast, the Beech Baron 58 Handbook (1979) emergency procedures are silent on the subject of engine out bank angle.

Analytical Estimates of Optimum Performance Bank

Pilot answers to the questionnaire confirmed the pervasiveness of the FDF Syndrome. The training literature, originating with the FAA, is persistent in promoting the impression that the optimum bank angle is five degrees universally.

Given the variety of configurations and apparent relationship between performance and control, it appeared illogical that 5°, or any single angle of bank, could optimize every situation in every airplane. Therefore, an attempt was made to estimate mathematically that bank angle corresponding to zero slip, minimum drag, and best climb performance. Readers possessing more faith than mathematical curiosity are invited to move ahead to the resulting Equations 1 and 2.

FIGURE 2: ZERO SIDESLIP FLIGHT (right engine failed)

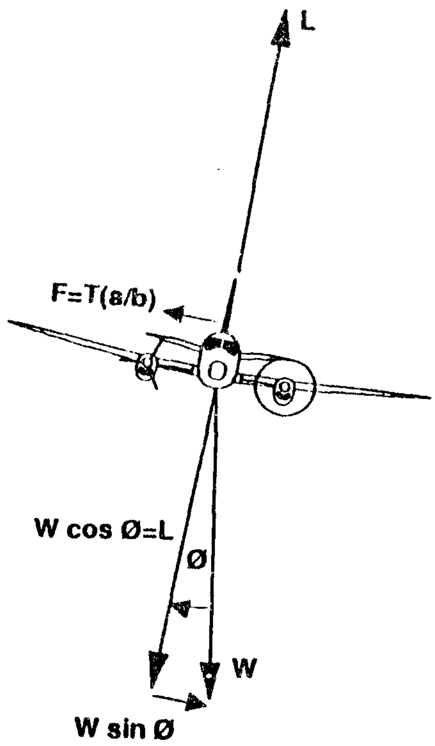

Figure 2 represents a force diagram for (right) engine-out flight in a condition of equilibrium and zero slip. The plane is banked left at angle O such that the lateral tail force F is just neutralized by the lateral component of weight, W sin O. The sidewise fuselage force H vanishes at zero slip.

From Figures 1 and 2, the tail force, F=T(a/b)=W sin O, or:

$$O=\text{Sin}^{-1}[(T/W)(a/b)] \qquad \textbf{Equation 1}$$

As an item of peripheral interest, the reader is invited to contrast the relationship between weight and lift in normal (symmetrical), level turning flight, with the same relationship in engine-out, non-turning flight. In the former case, the forces are unbalanced and L=W/cosO>W. In the latter case (Figure 2), the forces are balanced and L=W cos O<W. This paradox is explained by the vertical tail's "lift" component (W $\sin^2$O) opposite to weight. The wing's lift requirement, and induced drag, actually are reduced slightly by virtue of the bank.

Equation 1 established that the zero slip bank angle depends on design geometry (a and b) as well as the thrust to weight ratio. Due to asymmetric disk loading in propeller airplanes, the actual value of distance a depends on which engine is operating, and is greatest with critical engine operations. Distance b varies slightly with CG position. Engineering estimates of the a/b ratio for representative twin-engine airplanes (assuming symmetric disk loading) are contained in Table 2.

From Equation 1, it is important to observe that the thrust to weight ratio (T/W) and required bank angle will be greatest under conditions of low density altitude and minimum weight. It is under precisely these conditions that performance will be most

Table 2

Twin-Engine Airplane a/b ratios

AIRPLANE	a/b ratio
Cessna Crusader (T 303)	.41
Piper Seminole (PA 44)	.46
Beech Baron 58	.38
Embraer Bandeirante	.35
Boeing 737-200	.39
Lockheed S-3 Viking	.38
Grumman S-2 Tracker	.41
AVERAGE	**.40**

robust, with maximum tolerance for imprecision. On the contrary, low T/W, marginal climb performance conditions concurrently:

1. present the greatest hazard, and
2. require the minimum bank angle.

An airplane can maintain equilibrium climb only when thrust exceeds drag. The critical, limiting case will be examined wherein thrust just equals drag at zero rate of climb. Lift is assumed equal to weight.

Equation 1 may be modified, using the above assumptions that: L=W and T=D. For the small bank angles involved, the sine of the bank angle and the angle (in radians) are considered equal. Rearranging Equation 1, and equating 1 radian to 57.3 degrees, the following results:

$$\Theta=57.3[(a/b)/(L/D)] \qquad \textbf{Equation 2}$$

The important parameter, L/D, may be estimated with comparative ease. Always numerically equal to the airplane's glide ratio, its peak value, (L/D)max, equals best glide ratio and also frequently is tabulated (eg, Lan and Roskam, 1980). Representative values of (L/D)max are listed in Table 3.

Table 3

Typical Airplane (L/D)max Values

AIRPLANE	(L/D)max	REFERENCE
Cessna 172 (Windmilling)	9.1	POH
Cessna Crusader (Feathered)	12.1	POH
Beech Baron (Feathered)	12.2	POH
DC-3	14.1	Lan & Ros.
Gulfstream II	15.2	Lan & Ros.
Jet Transports	16.4-19.4	Lan & Ros.

Range of Optimum Performance Bank Angles

The question of how much bank is best for performance can now be answered in the form of an expected range. Limiting values of bank angle from Equation 2 were estimated using typical a/b and L/D values tabulated above. Since it is unlikely an engine-out airplane will fly precisely at its (L/D)max value, it was assumed L/D=.9(L/D)max.

From Table 2, $.35<(a/b)<.46$. From Table 3 (modified), $10.9<(L/D)<17.5$. Substituting into Equation 2, the optimum performance bank angle can be expected to range between approximately:

$57.3(.35/17.5)=1.1^\circ$ and $57.3(.46/10.9)=2.4^\circ$

Despite the approximations implicit in this analytical model, two important conclusions are clear:

1. In every case the optimum bank is likely to be much less than 5°, and
2. The less the performance margin, the smaller the optimum performance angle of bank.

Simulated Engine-out Wind Tunnel Experiments

A Lockheed S-3A "Viking" model of 12" span was tested in a low speed (100 fps) wind tunnel. The objective was to estimate the sideslip angle resulting from engine-out, wings level flight, and to study the relationship between slip angle and drag.

Given the a/b ratio of .38 (Table 2), it was found that a slip angle of 2.0° corresponded to H/D=0.38. With wings level and 2.0° slip angle, the parasite drag was 1.14 times its zero slip value, under conditions of approximately zero lift and induced drag. Hence, zero slip flight should reduce parasite drag by (1.00-1.00/1.14)100=12.6% . Assuming conditions of flight were near (L/D)max, where parasite drag equals half of total drag, zero slip total drag should be reduced about 6.1% compared to wings level.

Substituting a/b=.38 and (L/D)=17x0.9 into Equation 2, the zero slip bank angle was estimated to be 1.4°. Assuming a linear relation between bank angle, slip angle and drag, banking 2.8° would produce a 2.0° slip into the live engine and produce drag equal to the wings level value. Banking the additional 2.2° to 5° should increase drag about (2.2/1.4)6.1=9.6% above the minimum, zero slip value for the S-3A.

Subsequently, wind tunnel tests were conducted using a 16" span Cessna Crusader (T303) model. Results were qualitatively similar to those described above, and also correlated with actual flight test data. Significant wind tunnel equipment upgrades are programmed in the near future, with the potential for substantially improved experimental precision.

The S-3A wind tunnel experiment and attendant assumptions yielded encouraging but imprecise data. Nevertheless, the promise of significant drag reduction, compared to that corresponding to the 5° bank, was tantalizing. It was noted that a given percentage change in drag was equivalent to either a thrust or weight change of like magnitude - under the most critical flight conditions.

Flight Test Experiments

The analytical model and wind tunnel experiments promised improved performance, with adequate control, at zero slip. Subsequently, flight tests were conducted in three airplanes, the Cessna Crusader, Piper Seminole, and Beech Baron. Test data confirmed the analytical and wind tunnel results.

A yaw string about three feet long was attached to the nose, where it could be seen clearly in order to establish zero slip flight. An effective precision bank indicator was fabricated by combining a common protractor, plumb bob, and bubble level. Mounted beneath the glare shield, the device allowed bank angle measurements to 1/2 degree precision or better. All experiments were conducted in smooth air.

Rates of climb, as a function of bank angle, were determined by measuring altitude change over two or three minute intervals at steady V_Y. Constant power settings and base altitudes were utilized. Weight variations, with fuel consumed, were accounted for and results reduced to a common time/weight. Approximately 1/3 of the Crusader data was gathered at zero thrust, simulated engine-out conditions. The remainder, as well as all the Seminole and Baron data, were taken with a propeller feathered. Except for the Baron, the airplanes have counter-rotating propellers, hence no critical engine. Various bank angles, up to 7°-10° were evaluated. Rate of climb predictions in the POH were carefully compared to observed values for the Crusader.

A summary of the experimental data is contained in Table 4. In Figure 3 the data are plotted using a least squares, linear regression.

Table 4

Summary of Engine-out Flight Test Results

FACTOR	UNITS	CESSNA CRUSADER	PIPER SEMINOLE	BEECH BARON 58
		(BASIC CHARACTERISTICS)		
Max T.O. Wt	lbs	5150	3800	5400
Mid Test Wt	lbs	4930	3400	5050
Base D.A.	feet	3450	3350	5070
Vmc (POH)	KIAS	65	56	81 *
Vlof	KIAS	77	70	86
Vyse	KIAS	96	88	100
Zero Slip Bank (Equation 2 Est.)	Deg	2.2	2.4	2.0
		(FLIGHT TEST MEASUREMENTS)		*
Zero Slip Bank	Deg	1.5	2.1	2.7
Ball Defl (Z.S.)	-	.3	.4	.7
Max Bank Angle	Deg	10	7	8.5
Zero Rudder Bank	Deg	8	N.O.	7.5
ROC Chg($0^{o}$to ZS)	FPM	+42	+62	+105
ROC Chg(ZS to 5^{o})	FPM	-91	-92	-76
ROC Penalty	Ft/Min-Deg	-26	-32	-33
Corr. Coefficient	-	-.957	-.943	-.945
		(EQUIVALENCY CALCULATIONS {Zero Slip to 5^{o}})		*
Weight Penalty	lbs	398	305	296
Weight Penalty	%	8.1	9.0	5.9
D.A. Penalty	feet	1850	1900	1170
Temp. Penalty	^{o}C	15	16	10

* Left (critical) propeller feathered

FIGURE 3: RATE OF CLIMB VS ANGLE OF BANK

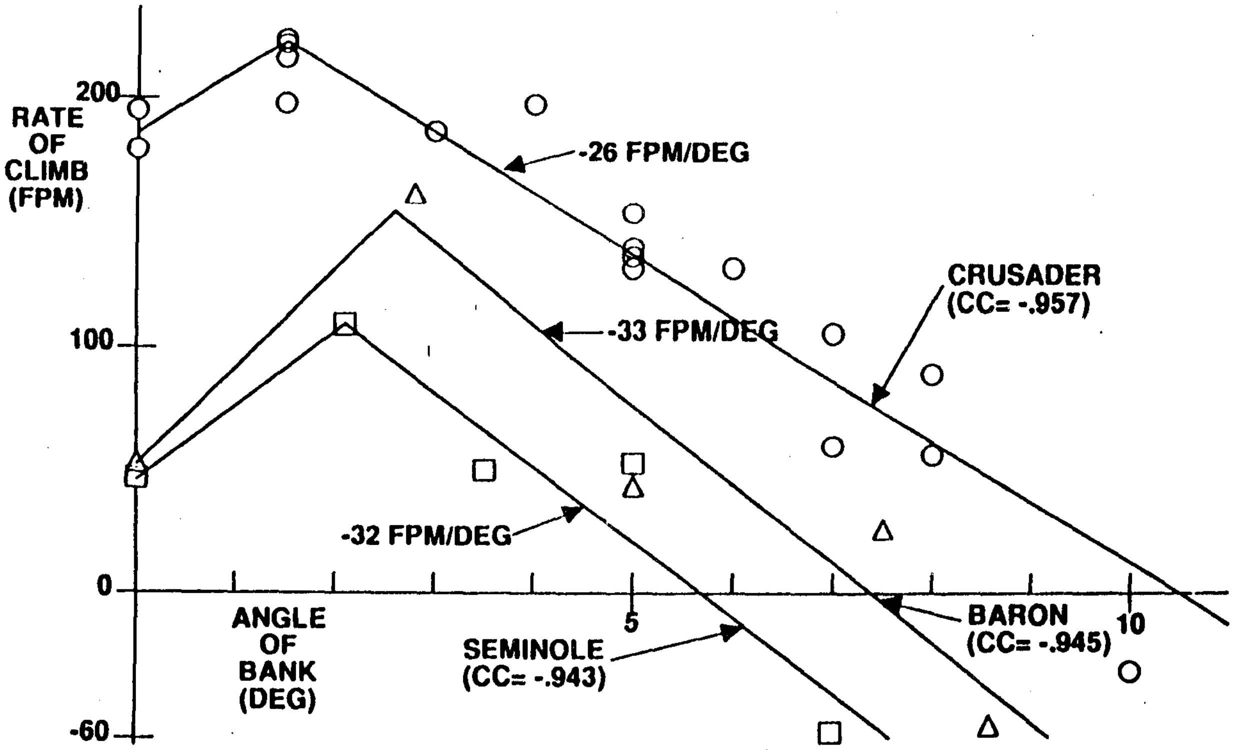

Table 4 and Figure 3 show flight test results. Zero slip bank angles and ball deflections proved significantly less than described in common references, such as those cited previously.

For the Crusader and Seminole, the actual zero slip bank angles were slightly lower than estimated using Equation 2. The reverse applied to the Baron's critical engine. The differences are probably explained by asymmetric disk loading ("P factor"). In critical engine operations, dimension "a" and resulting yaw is increased, while for other propeller airplanes (including counter rotating), it is reduced. For jets this factor would not apply.

High correlation coefficients lend credibility to the experimental flight techniques and the assumed linear relation between bank and drag. The sharp loss of climb performance, as bank exceeded the zero slip (ZS) value, was the most significant finding. Rate of climb degraded 26-33 feet per minute (FPM) per degree of bank in excess of the ZS value. The penalty for 5° bank ranged up to more than 90 FPM from optimum.

The bottom of Table 4 contains equivalency results derived from the respective POH. In comparing ZS and 5° bank performance, the effective penalty was equated to as much an a 9% weight or 1900 foot density altitude increase, except for the critical engine case. Since the latter required a larger ZS bank angle, the use of 5° imposed a somewhat reduced handicap.

Conclusions

Current multi-engine pilot education and training is handicapped by persistent misunderstandings concerning engine-out flying hazards and techniques to minimize them. In the low speed, low altitude engine-out environment, there exists three lethal hazards of comparable severity. These are loss of directional control, loss of climb performance, and loss of flying speed. Combined, they result in an annual average of 9 accidents and 10 fatal or serious injuries. Yet directional control receives virtually total emphasis in classroom and cockpit training, with insufficient regard to its influence on the ability to maintain altitude and/or flying speed.

Objective questioning of rated multi engine pilots and instructors proved that the relationships between control and performance are seldom understood. This apparently stems from the FAA Flight Training Handbook, as well as from other standard sources.

Analytical methods showed that the optimum performance angle of bank is neither 5° nor any other single value, but rather one dependent on the airplane, its weight, density altitude, and other minor factors. In marginal performance situations, when tolerance for error is least, it is at the minimum and far less than 5°.

Wind tunnel tests, although of limited scope, validated the theoretical model. Results suggested impressive performance gains, with adequate directional control, were available to the knowledgeable pilot.

Wind tunnel results suggested logical extension to actual test flights. Tests in three different airplanes yielded results consistent with the theory, the wind tunnel experiments, and each other.

Plotting rate of climb versus bank for each airplane produced "roof top" curves, with apex corresponding to optimum performance under zero slip (ZS) conditions. Banking beyond ZS incurred a substantial performance penalty in return for slightly reduced rudder pressure.

The experiments provided insight into critical engine operations and the design advantage of counter rotating propellers. Directional control was no problem for the Crusader and Seminole, as the 30+ knots between Vmc and Vyse (Table 4) suggests. However, with full rudder, the Baron (critical engine operation) would not hold heading, at Vyse, with the slightest bank toward the inoperative left engine. Also, 8.5° right bank required full aileron.

Bank beyond ZS produced a slip toward the operating engine, increased rudder authority, and reduced rudder pressure. It was interesting to observe that zero rudder deflection was adequate to hold heading at 7.5° of bank in the Baron and 8° in the Crusader-at a very large performance penalty. Any greater bank required cross controlling with "top" rudder.

A yaw string of about 3' length was extremely sensitive, deflecting approximately 2" for each degree of bank. One ball width deflection, corresponding to 4-6° of bank, corresponded to approximately a 10" deflection.

At zero slip, the Crusader engine out rate of climb differed only an average of about 10 FPM from POH predictions. Figure 3 indicates that performance would have been substantially inferior to predictions at the 5° bank recommended by that POH. However, the POH fails to alert the pilot to this anomaly.

In summary, between zero bank and zero slip, both control and performance improved with bank. However, once the bank angle for zero slip was exceeded, performance deteriorated rapidly. Equivalent weight increase (or thrust decrease) handicaps of some

6-9% resulted from the popular 5° bank, and rate of climb was degraded by 76-92 FPM.

In addition to offering optimum performance, flight at zero sideslip may confer another safety benefit. Although beyond the scope of these experiments, the writer believes Berven (1980) was correct in asserting that zero slip flight also provides insurance against premature, and possibly asymmetrical, stall and violent roll characteristics.

The Flight Training Handbook and other references cited deserve timely revision. Replacement instructions are recommended as follows:

> As soon as directional control is established and the airplane configured for climb, reduce the bank angle to that producing zero slip and best performance. (In the absence of specific guidance for zero slip, a bank of 2° or 1/2 ball deflection is suggested).

Engine-out instruction should be conducted regularly with a yaw string installed. Heavy weight, marginal power, minimum performance, worst case T/W conditions should be emphasized. Rather than adding weight, this can be accomplished simply by power reduction on the operating engine until best climb rate is barely positive.

In this manner, marginal T/W ratio simulation may be accomplished realistically and dramatically on any training flight. Concurrently, the optimum performance, zero slip bank angle and ball position can be determined readily for any model (and engine, if appropriate). The advantage of determining zero slip ball deflection is that it can be reproduced readily under any lighting or visibility conditions, as well as in turning flight.

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A FIRST PROFESSIONAL DEGREE FOR THE AVIATION INDUSTRY: RECOMMENDATIONS FOR RESEARCH AND PRACTICE

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Introduction

The deregulation of the airline industry precipitated a number of aviation industry changes:

> In the fall of 1978, Congress deregulated commercial aviation, arguing that the airlines had matured and no longer required the protection offered by regulation . . . The effects of deregulation were felt almost immediately. Airlines, testing their new freedoms, increased fares on some routes and decreased them on others. They entered numerous new markets and withdrew from a number of smaller, low-density markets. New carriers filed for certification and new marketing strategies evolved as the airlines' managements attempted to structure their route networks for survival in the new, highly competitive environment. (Federal Aviation Administration, 1987, p. 3)

These changes, in turn, created or enhanced several aviation industry-wide problems:

> The evolution of the industry to date has had a significant impact on Federal Aviation Administration (FAA) workload and facility planning. The rapid development of connecting hub airports and an increased airline emphasis on schedule frequency to attract and control traffic have made airport capacity problems a major challenge for the FAA. (Federal Aviation Administration, 1987, p. 3)

These problems have, in turn, called attention to the need for improvement in the preparation of aviation industry professionals to be better able to lead the aviation industry into a new and different era. For example, at least three domestic U.S. airlines have developed "ab initio" pilot preparation programs through various universities and community colleges. Also, the Federal Aviation Administration has developed both an "Airway Science Curriculum" and a "Cooperative Education Program in Air Traffic Control" in conjunction with the nation's leading aviation-oriented colleges and universities. But, where is the "common thread" for these programs? Should universities simply be satisfied with renewed industry interest in universities during an impending crisis? Is there a need for a "forst professional degree" (or set of degrees) for the aviation industry?

Definitions

The following definitions will be used in this study:

1. Aviation Industry. The aviation industry refers to that area of the economy devoted to the manufacture, operation and regulation aircraft. It includes such segments as aerospace manufacturing, airlines, general aviation, and government (other than the military). In 1985 the aviation industry employed over two million people (NewMyer, 1985, p. 36).

2. First Professional Degree. According to George H. Brown: "A first professional degree is one that signifies completion of the academic requirements for beginning practice in a given profession" (Brown, undated, p. 1). Academic requirements for the aviation industry are stated in the University Aviation Association's College Aviation Accreditation Guidelines.

3. A Profession. Webster's Third New International Dictionary defines this term as follows:

> A calling requiring specialized knowledge and often long and intensive preparation including instruction in skills and methods as well as in the scientific, historical or scholarly principles underlying such skills and methods, maintaining by force of organization or concerted opinion high standards of achievement and conduct and committing its members to continued study and to a kind of work which has for its

> prime purpose the rendering of a public service. (Webster, 1971, p. 1811)

4. The University Aviation Association (UAA). The Association includes 201 members (in 1986) who identify closely with the aviation industry. Among the aims and objectives of the UAA are these topics:

> To furnish a national vehicle for the dissemination of information relative to aviation among institutions of higher education and governmental and industrial organizations in the aerospace field.

To facilitate the interchange of information among institutions that offer aviation programs that are non-engineering oriented; for example, Business Technology, Transportation, and Education. (UAA, 1976, p. 2)

The Concept of the Professional and First Professional Degree

The evolution of the concept of "professional degrees" began with an important debate about the meaning of the term "professional." Abraham Flexner, in his historic evaluation of medical schools and their degree offerings in 1915, presented six criteria which define a profession:

> ...they involve essentially intellectual operations with large individual responsibility; they derive their raw material from science and learning; this material they work up to a practical and definite end; they possess an educationally communicable technique; they tend to self-organization; they are becoming increasingly altruistic in motivation. (Houle, 1980, p. 22)

The Council on Postsecondary Accreditation (COPA) and The Council of Graduate Schools (CGS) in the United States has distinguished between research-oriented and practice-oriented (professional) graduate degree programs. The primary objective of the professional graduate degree ". . . is to train graduate students through the Master's or Doctor's level in preparation for professional practice directed mainly toward the application or transmission of existing knowledge . . ." (COPA and CGS, 1978, p. 2).

According to Spurr, however, the professional versus research argument is not as crucial as <u>which degree</u> serves as the first professional degree.

> In some professions, the bachelorship identifies the first professional degree . . . . The major patterns of undergraduate-graduate articulation involving the professional master's degree include: (1) An undergraduate program in a profession followed by a master's program in the same profession. In this instance, the baccalaureate is the first professional degree. (2) An undergraduate program in the liberal arts followed by a master's program in a profession. In this case the master's is the first professional degree. (3) An undergraduate program in a profession followed by a master's program designed to remedy the student's undergraduate deficiencies in basic science or the arts. (4) A professional field requiring five or six years of study from university matriculation to the first professional degree, which may be either at the bachelor's or the master's level. (Spurr, 1970, pp. 50 & 75)

Spurr's argument is that the "professional master's degree" can readily serve as the "First Professional Degree," depending upon .pa the status of the field and the sequence of education followed by the student.

In summary, the first professional degree is the minimum degree necessary to enter a profession, an industry segment or a particular kind of occupation in an industry. Most important of all there has been no published discussion of the first professional degree as it applies to the aviation industry.

Research Procedure and Sample

This is a descriptive study in that it attempts to determine the view of a specific group of people (aviation educators) about the structure, content and need for non-engineering master's degrees in aviation. The study includes a literature search, collection of data through mailed questionnaires, analysis of replies and conceptualization of the results.

The second source of information used in this study is questionnaire responses from aviation educators concerning their perceptions of non-engineering master's degrees in aviation. The 1986 membership list of the University Aviation Association (UAA) includes 201 names of people who are involved in collegiate aviation programs. It is assumed that members of this group are knowledgeable about both the aviation industry and aviation education.

The questionnaire was developed to correspond to the research questions prepared for this study. The questionnaire was "piloted" with a panel of experts which included aviation educators at the local, state and national level. The analyses provided by this panel were focused on the format and clarity of the questionnaire. Based on suggestions by the panel, the questionnaire was refined. An initial mailing was made in early August 1987. A second mailing was made in September to those who had not responded.

Response Rate

The 1986 individual membership list of the University Aviation Association includes 201 names. Each was mailed a questionnaire in August, 1986. A second mailing occurred in September, 1986 to the 90 members who had not responded to the first mailing.

A total of 141 responses (70.3 percent) was received, of which 125 (62.2 percent) were usable. The non-usable responses were mostly from people who were retired or were no longer related to the aviation field. These people wrote on the questionnaire that they were uncomfortable completing the survey instrument because of their lack of current contact with the aviation field.

Within the 125 "usable responses" the number of respondents answering the various questions on the survey instrument ranged from a low of 108 to a high of 125.

First Professional Degree

As noted earlier, "a first professional degree is one that signifies completion of the academic requirements for beginning practice in a given profession" (Brown). When asked what their first professional degrees were, the respondents gave 54 separate responses at the bachelor's and master's degree level (see Table 1).

Table 1

Array of Degree Titles of the First Professional Degrees Held by Respondents

Title of First Degree	Frequency
BA Govt	1
BME Aero	1
Business Admin	1
Adult Ed	1
Education	1
AV Maintain	1
MBA/A Erav	1
BS Pol Sc	1
BS Chem	1
BS Ba	1
BA Transport	1
MT Hood Comm Col	1
BS Mech Eng	3
BS Maths	1
BS Psycho	2
Chem Sc	1
BS Agriculture	1
BS Agronomy	1
BS Naval Eng	1
BS Second Ed	1
Business	1
BS IE	1
MPA	1
BS Ind Arts	1
BA Chem	1
BAS	1
Aero Astro Eng	1
BA Aero Sp	1
BAPsycho	1
BS Ind Eng	2
BA Ed	2
MS	1
Bach Aero Sc	1
BBA Personnel Ad	1
BA Physics	2
BS Zoology	1
MA Foreign Affair	1
BS Elec Eng	2
MS Acct	1
BBA	1
BS Mil Studies	1
Bach History	1

Table 1 (continued)

Title of First Degree	Frequency
BA Econ Hist	1
BA Econ	1
BS Av Eng Tech	1
BS Aero Tech	1
BSEE	1
BS Mil Sc	2
M Ed	1
BS Aeronautics	2
BA Mata Hist	1
BS ME	1
BS Aircraft Eng	1
BS Health Ed	1
MA Sociology	1
BS Aero Eng	3
Ed	1
No Degree	1
BA History	2
BA Economics	1
BS Polit Sci	1
BS Av Tech	2
BS	5
Just Academic De	1
B Ed	1
BS Music Ed	1
BS Math	1
BA	6
BS Bio Sc	1
AB	1
Bs Ed	6
Bach Music	1
Bach Arts	1
AAS Av	1
BS Av Mgt	2
BS Bus Adm	5
TOTAL	108

Leading the responses were business and education bachelor's degrees with six responses each. Other responses were as widely varying as chemistry, zoology, sociology, economic history, and military studies. Since the average age of the respondents is 50.4 years, these responses reflect entry of a substantial number of people into the aviation industry at least two decades ago (late 1950's through 1960's). And, since many people in the response group entered aviation through the military (see Table 2), the responses are likely to reflect the minimum degree necessary to enter the military. The wide disparity in responses shows that there was no commonly identifiable "first professional degree" for entry into the aviation industry. As noted in Table 2, close to half of the respondents entered the aviation industry by way of the military (55 respondents or 44 percent). Since aviation education is the area of emphasis of the University Aviation Association, it is not surprising that the second largest number of respondents, 27 (or 21.6 percent) showed aviation education as their "first position". General aviation - which usually means employment as a flight instructor - was the third largest "first position" segment at 21 responses (16.8 percent). General aviation flight instruction is a typical point of entry for many people coming into the aviation industry. When asked whether their first professional degree adequately prepared them for their first position in the aviation industry, 69 (57.0 percent) replied in the negative (see Table 3). In analyzing the

"First Professional Degrees" held by the "No" respondents, the vast majority of these degrees were baccalaureate degrees in non-

Table 2

Distribution of Respondents by Their First Position in the Aviation Industry (By Industry Segment)

Aviation Industry Segment	Number	Percent
Manufacturing	7	5.6
Airline	8	6.4
General Aviation	21	16.8
Government	6	4.8
Military	55	44.0
Aviation Education	27	21.6
	124	100.0

Table 3

DISTRIBUTION OF RESPONSES TO THE QUESTIONS: DID YOUR FIRST PROFESSIONAL DEGREE ADEQUATELY PREPARE YOU FOR YOUR FIRST POSITION IN THE AVIATION INDUSTRY? AND WHAT WAS MISSING IN YOUR FIRST PROFESSIONAL DEGREE?

	Number	Percent
Yes	52	43.0
No	69	57.0
	121	100.0

Items Missing:	Number	Percent
Aviation Content	46	59.0
Work Experience/Internship	6	7.7
Other Answers*	26	33.3
	78	100.0

*The other answer category reflects a broad range of essay answers, including:

(1) I got my first degree after my first position.
(2) I had a position in secondary education before entering aviation.
(3) Not applicable.
(4) CFI-pilot.
(5) Earned degree after military pilot training (several said something similar to #5).

aviation fields. Four of the "No" respondents held aviation related baccalaureate degrees. A total of 46 respondents stated that aviation content was missing from their first professional degree, while 6 respondents mentioned the lack of relevant work experience/internship.

When asked whether a non-engineering master's degree in aviation would have been helpful in gaining their first entry-level job in the aviation industry (see Table 4), 77 respondents

Table 4

Distribution of Responses to the Following: "Given My First Entry-level Job in the Aviation Industry, I Feel That A Non-engineering Aviation Master's Would Have Been Just As Helpful In Gaining Employment as My Firts Professional Degree."

	Number	Percent
Strongly Agree	34	27.8
Agree	43	35.2
Neutral	28	23.0
Disagree	9	7.4
Strongly Disagree	8	6.6
	122	100.0

(63.0 percent) either strongly agreed or agreed. Only 17 (or 14.0 percent) either strongly disagreed or disagreed. The non-engineering master's degree also has credibility with a majority of the respondents as a "First Professional Degree" with their respective aviation industry segments. A total of 98 respondents strongly agreed or agreed that the non-engineering master's degree in aviation could serve in the capacity of "first professional degree" in their industry segment (see Table 5).

Table 5

Distribution of Responses to the Following: "I Feel That A Non-engineering Aviation Master's Degree Would Satisfy Entry-Level Employment Criteria For **My Segment** of the Aviation Industry?"

	Number	Percent
Strongly Agree	36	29.0
Agree	62	50.0
Neutral	11	8.9
Disagree	6	4.8
Strongly Disagree	9	7.3
	124	100.0

In summary, a clear majority of respondents (79 percent) favored non-engineering master's degrees in aviation as a first professional degree for the aviation industry. The majority of respondents also felt that their own first professional degree did not prepare them well for their first aviation industry job.

Conclusions

The following conclusions are drawn from this research:

1. The respondents showed no commonly identifiable "First Professional Degree" for the aviation industry. Furthermore, over half of the respondents stated that their first professional degree did not prepare them for their

first position in the aviation industry.

2. The respondents first positions in aviation were largely in the military, aviation education or were general aviation-related.

3. Aviation content was the primary item missing from the respondents' first professional degree.

4. Sixty-three percent of respondents strongly agreed or agreed that a person should be able to get into the aviation field with a non-engineering aviation master's degree.

5. Seventy-nine percent of respondents strongly agreed or agreed that the non-engineering master's in aviation would satisfy entry-level employment criteria in their segment of aviation.

Based on these conclusions, the following recommendations are made:

Recommendations for Research

1. The results of this study point to a lack of a "first professional degree" for this group of respondents (average age of 50.3 years) from the aviation industry. Further research needs to be done to broaden the research base on this point so that a clear understanding of first professional degrees for the aviation industry can be achieved. For example, can an industry-wide "first professional degree" be created or will such a degree have to vary in level and content, depending upon industry segment or professional job content?

2. Regarding the aviation industry's needs for a first professional degree, further research needs to be done to parallel to this study, including a broader range of aviation industry practitioners as respondents.

3. Research needs to be done by someone from outside the aviation industry in the subject areas of industry wide professional entry and development requirements. People outside the industry will not have a built-in "pro-aviation" bias which might affect the results of the study.

Recommendations for Practice

1. The UAA should clearly define its mission in the non-engineering aviation fields. It is recommended that the UAA develop a mission statement regarding its role in the definition of first professional degrees, data collection, and accreditation of non-engineering aviation degree programs.

2. The UAA should create a "task force" (including external reviewers) to update its College Aviation Accreditation Guidelines in the area of "graduate aviation programs." The following task force goals appear appropriate based on the survey results:

    A. Provide further study of the "First Professional Degree" needs of each aviation industry segment. Replicate this survey where needed and enhance the portion of the instrument related to first professional degree. The appropriate role of the non-engineering master's in aviation should be studied by major and by industry segment.

B. Based on "A", a set of professional academic standards should be created by industry segment and by degree content. A core aviation program should be identified for each segment.

3. Using Stephen Spurr's paradigm, a standard professional curriculum, or set of first professional degrees, needs to be established for the aviation industry. There are several major patterns for the development of a first professional degree. Yet, the aviation industry has not yet defined its own unique pattern for non-engineering fields. This needs to be done to provide a more organized, less haphazard way of preparing aviation industry professionals.

4. The University Aviation Association needs to tackle the larger issue of Accreditation through extensive contacts with the aviation industry. By establishing the standard professional curriculum as recommended in item 3 above, the UAA can take an important substantive step in the direction of becoming an accreditation body. With the years of experience since the creation of the College Aviation Accreditation Guidelines, and with the UAA's experience with the Airway Science Curriculum Committee, since 1982 it appears to be a good time for UAA to explore its role in accrediting non-engineering aviation curricula, but only if the aviation industry is actively involved in the effort.

After all, it is their need for personnel that UAA member schools are, in fact, attempting to meet.

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FOUNDATIONS

OF

COCKPIT RESOURCE MANAGEMENT (CRM) TRAINING

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Abstract

Objectives: To provide an analysis of the foundations of cockpit resource management (CRM) for the scientific, academic, and aviation training communities through a review of CRM history, literature, and research.

Scope: This study provides a summary of what cockpit resource management (CRM) is, what its originare are, a review of contemporary research in its various components, and recommendations for selection and training to meet the objectives of improved cockpit management. It contains views on crew member skills, roles, behaviors and available resources commonly included in the analysis of CRM.

Findings: Out of the review of literature and survey activities related to this study, a descriptive analysis of CRM was constructed. This included a history of CRM development, a summary of CRM research, and an account of CRM training issues. Lack of institutional priority and absence of governmental support for funding the production of CRM training media are cited as the most important areas of concern.

Introduction

Among the reported causes of civil jet transport accidents and incidents are many factors which relate to ineffective management of available resources by the flight crew (Lauber, 1980, p. 3). Murphy (1980, p. 298) classified resource management as "the application of specialized skills to achieve a crew organization and process that effectively utilizes available resources in attaining system objectives." Lauber (1985) further refined the definition of cockpit resource management (CRM) as the utilization of all resources - information, equipment, and people - to achieve safe and efficient flight operations.

National Aeronautics and Space Administration (NASA) undertook a review of jet transport accidents occurring between 1968 and 1976 and identified sixty-two accidents which were related to improper resource management. Other such accidents have been subsequently identified. Common factors in many of these accidents involved: preoccupation with minor mechanical problems, failure to delegate tasks and assign responsibilities, failure to set task priorities, inadequate monitoring, and failure to utilize available data (Lauber, 1980, pp. 5-7). In addition to reviewing the transport accident record, a search of the Aviation Safety Reporting System (ASRS) database was conducted. The search, which covered jet transport operations only, recovered 670 incident reports that were relevant to the issue of resource management.

Resource management skills related to accidents and incidents factors cover a broad spectrum. Murphy (1980, p. 304) identified several classifications under which such skills could be placed. Among others, these classifications include: communications, leadership, planning, problem solving, and decision making. The relationship of resource management to elements of human factors research has been shown (KLM, 1980). Suggestions have been made to further identify resource management concepts as a first step in prescribing appropriate training procedures (Crump, 1980, p. 157). Cooper & White (1980) and the Flight Safety Foundation (FSF) (1985) developed lists of twenty such concepts to deal with the judgement and decision-making aspects of CRM (Figure 1).

Resource management training remains a focal point of NASA, Federal Aviation Administration (FAA), and airline interest at this time. As recently as 1986 (Orlady & Foushee, 1987), answers were being actively sought for the questions of CRM concept identification and appropriate training strategies. Although solutions other than training, such as "increasing awareness" or"setting rules" have been examined as adjuncts to training, they are not considered adequate within themselves (Lauber, 1980, p.10). In addition to the content of any CRM training curriculum developed, the sequence and format of its presentation may be important. There are also valid arguments for selection processes which emphasize acquiring resource management training prior to employment (Crump, 1980, p. 157), as well as continued

Essential CRM Skills

Listening
Assertiveness
Ability to deal with conflict
Problem-solving
Problem definition
Establishing priorities
Open mindedness
Personality awareness
Managing distractions
Fatigue management and recognition
Judgment and decision-making
Workload assessment
Managing division of attention
Stress management
Advising and critiquing
Knowledge of interdepartmental relationships
Consideration for crew
Fairness to crew
Consideration of all alternatives
Setting task priorities
Comunication of plans
Anticipation, awareness, and analysis of situation
Appreciation of captain's responsibilities
Awareness of crew's tasks
Ability to delegate
Willingness to teach or share experience
Ability to instill confidence
Professionalism
Confidence
Command presence—style—integrity
Communication of intent

Figure 1

(Adapted from Cooper et. al. 1980 and FSF, 1985)

CRM emphasis in the upgrade and recurrent training programs which span a pilot's career (Frink in Cooper, White, and Lauber, 1980, p. 188).

The Need for Cockpit Resource Management Training

As modern aircraft become more dependent upon technological advances to cope with the increasing demands of flight, managerial tasks require a higher percentage of each crew member's time. Monitoring the proper functioning of complex electronic and mechanical components overshadows the fundamental skills which were required to fly aircraft of lesser sophistication (Frink, 1980, p. 149). In addition to the increasing complexity of equipment, the flight environment is constantly making heavier demands on the crew. More traffic shares the airspace, and aircraft are operated under ever-lowering minimums of ceiling and visibility. Night flying, with its related fatigue, has been increased to meet public demand and to achieve higher rates of aircraft utilization (Glines, 1974, pp. 7-8). These demands must be balanced through nontechnical training in resource management as a supplement to existing technical training programs (KLM, 1980).

There was a time in aviation history when complexity was minimal. Aircraft had a simplicity which was actually inappropriate to the task (Solberg, 1979, p. 130). Aviation pioneers compensated for this deficit with high levels of individual skill (LeMay & Kantor, 1965, p. 495). Eventually, pilots who entered the air transport industry had to face operational requirements which often exceeded their individual performance limits. The two-man crew became necessary. Later, crews of up to five were needed to perform the combined functions of systems operation, navigation, and communication (Holland & Smith, 1971, p. 188). With the advances in avionics and flight automation achieved during the past twenty years, the current crew complement standard has been reduced.

Contemporary requirements for the jet transport crew member have advanced from purely psychomotor skills used in a simple application, to highly cognitive and affective skills used in a very complex, team-oriented application. Unfortunately, training has not fully recognized this changing emphasis. Basic flying ability is necessary, but these skills alone are not enough. Restrictions imposed on crew certification have emphasized individual performance and minimized the task sharing and managerial aspects of flying. As a result, the airline industry continues to witness reinforcement of the "macho pilot" stereotype who insists on demonstrating his individual ability when the other resources are available to reduce his workload (Foushee, 1980). This individualized approach to performance has also been referred to as the inappropriate "captain-does-it-all" concept cited by American Airlines (1980). Changes in training programs are necessary to emphasize group processes in complex task management.

Several attempts have been made to point out the problems and training needs related to CRM (Lauber, 1980, pp. 3-11). A

NASA resource management workshop was convened in 1979 to examine the issue in depth. Studies to identify elements of CRM have been requested by the industry, the International Air Transportation Association (IATA), and the Air Line Pilots Association (ALPA) (Cooper et al. 1980). Since that time, many papers, symposia and workshops have evolved concerning CRM issues (Lauber, 1987, p. 9). Standards for determining what concepts are essential to CRM and what training strategies to employ are still in the formative stage. When these elements are identified,more appropriate training can be developed, and improvements increw performance should result.

This study was designed to provide an overview of the CRM issue and to provide and analyze CRM research within the scientific communities. The remaining sections include the implications of CRM and contemporary CRM research activities.

The Implications of Cockpit Resource Management

If the goals of safety and crew effectiveness in scheduled airline operations are to be met, airline training programs must focus on those deficiencies which have contributed the most to accidents, incidents, and violations within the industry. When analyzing causal factors related to these events, pilot error is frequently seen as a technical deficiency in knowledge or psychomotor skills. In reality, an examination of airline accident statistics has yielded an alarming number of primary and contributing factors which relate to ineffective crew coordination (NTSB, 1976); (Lauber, 1980, pp. 5-7). The array of skills, abilities, and characteristics needed by airline captains to deal effectively with their crew and to utilize the human and material elements of their flight environment has been categorized by the term cockpit resource management (Lauber, 1980, pp. 3-4); (Murphy, 1980, p. 298). These have been consolidated in Figure 2.

Murphy (p. 305) depicts a graphic representation of available resources in a systems context, Figure 3, and an integration of resource management skills into a systems context, Figure 4.

One of the most important aspects of research in cockpit resource management is to identify and define its components (Crump, 1980, p. 157). Only when these components are examined individually can their priority and relative importance to airline operations be determined (Cooper & White, 1980). In studying each facet of the resource management function, concepts can be developed to enhance the resource management abilities among airline crews. Once identified, resource management concepts can be evaluated for appropriate methods and training strategies (Houston, 1980, p. 162). The attainment of some of these CRM objectives, however, might be assured more effectively through the employment selection process, which would identify pre-employment skills in CRM. Allward (1967, p. 157) described a systematic approach to enhancing flight safety by emphasizing the importance of pilot education as well as training. Since

Classification of Identified Cockpit Resource Management Problems into Skill, Role, and Resources Categories

SKILLS	RESOURCES
Social and Communications	**Human**
Strained social relations	Individual differences in knowledge, proficiency, experience, motivation, stress reaction.
Assertiveness	**Material**
Nonverification of communications	**Facility**
Withholding communications	Availability
Unnecessary communications	Adequacy
Assumptions about message	Human engineering
Assumptions about meaning	**Equipment Availability**
Assumptions about other's understanding	Access
Planning, Problem Solving, & Decision-making	Adequacy
Inadequate planning	Human engineering
Information retrieval	Automatic vs. manual
Quality and timeliness of information	**Textual Information**
Credibility of information	Availability
Problem-solving strategies	Access
Staying ahead of the problem (crises prevention)	Adequacy
Decision under stress	Human engineering
Group think (false hypothesis)	**Environmental Information**
	Availability
	Adequacy
Leadership and Management	**ROLE**
Delegation of authority	Definition and understanding (pilot-copilot)
Erosion of authority	Command responsibility of Captain when First Officer is flying
Captain's trust-doubt dilemma	
Lack of decisive command	Responsibility of First Officer when Captain deviates from safe or legal practices
Discipline and leadership in applying regulations	
Casualness in cockpit	
Crew Coordination	Reduced command options
Time structuring, priorities	

NOTE: Adapted from Lauber (1980) and Murphy (1980) education in related skills prior to employment could lead to better crew capabilities in some areas of resource management, an improved selection process based on an appropriate educational background could eventually increase the ability of flight crews in this regard (Crump, 1980, p. 157).

According to Redding and Ogilvie (1984, p. 45), the flight crew

> ...can never be machines. They carry with them feelings, attitudes, beliefs, and values which provide them with individual personality. They also carry with them sets of values derived from their cultures. This cultural level of difference, although it is assumed not to operate in affecting professional behaviors of flying crew, may, in fact, be operating unconsciously and in ways which are difficult to perceive.

If deficiencies in resource management among crew members now employed are to be corrected, a further analysis of their training needs must be undertaken. Some of these training needs fall into the category of social and communications skills (Murphy, 1980, pp. 303-304). The ability to maintain effective coordination with others is essential in the small group environment of the flight crew (White, 1980, p. 174).

A research effort was begun at NASA's Ames Research Center in 1973 to develop a human-factors-in-aviation safety program (Lauber, 1980, p. 3). In an extensive interview program, NASA was advised by airline captains that nontechnical training in leadership, crew coordination, communications, and command was needed. Bruggink (1976) has stated, "No adult with average reasoning powers can claim ignorance of the fact that emotions,

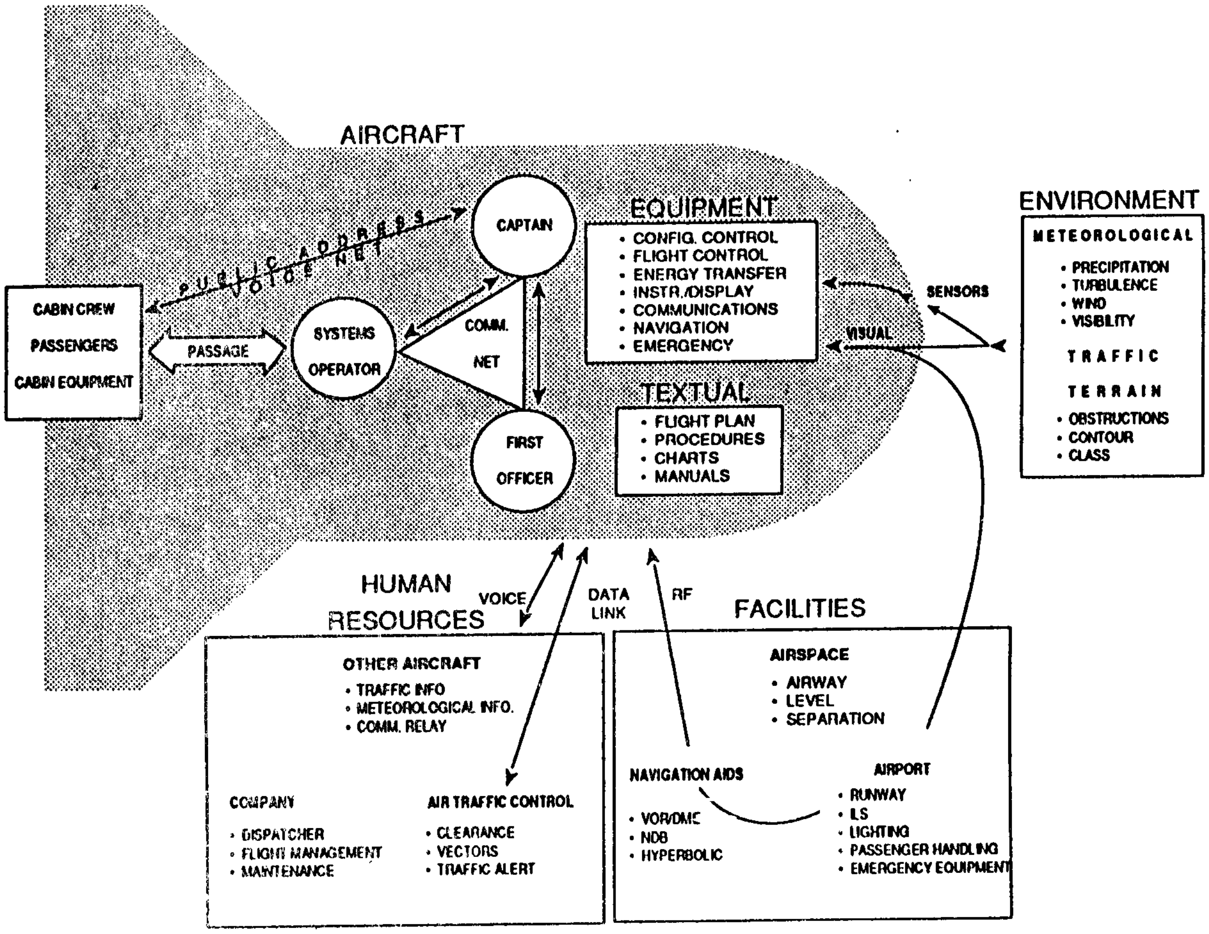

Figure 3

Systems Diagram--Categorization of Resources
(Adapted from Murphy, 1980, p. 305)

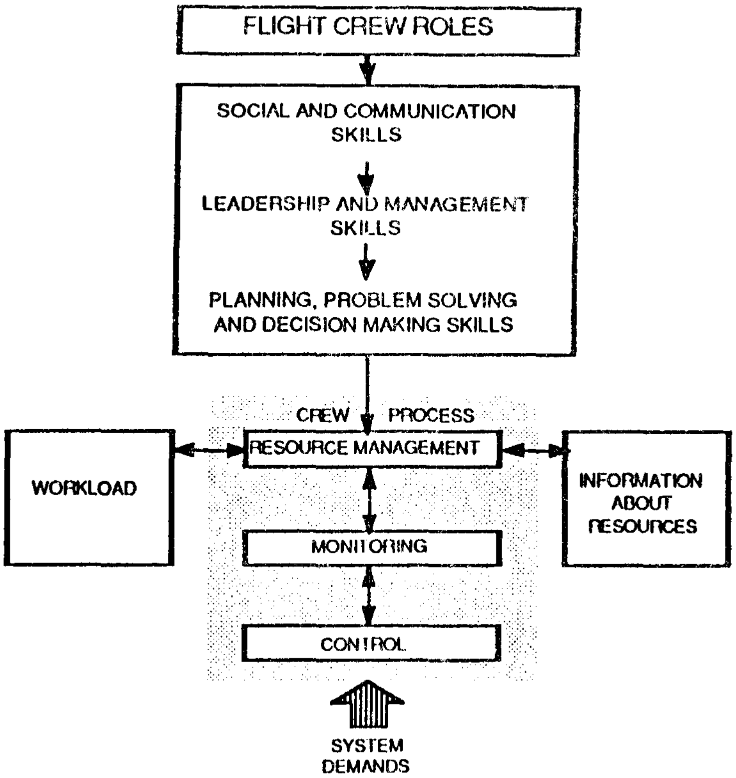

Figure 4

Resource Management Skills in a System Context
(Adapted from Murphy, 1980, p. 305)

distractions, fatigue, and a variety of other stresses affect the reliability of his performance." Gradually, a recognition of these behavioral and interpersonal elements of resource management began to take form.

In 1979, a NASA/Industry Workshop was held to focus additional attention on the resource management issue (Cooper et al., 1980). Among the seventy in attendance were representatives of the major airline training departments, NASA, and other interested agencies. Two papers were read which brought unique psychological theories to bear on the resource management issue.

Helmreich (1980, p. 17) stated that personality and situational factors intersect to determine crew responses and that assessment under full crew and mission conditions provides the most valuable performance data. Bolman (1980, p. 32) postulated that the pilot's theory of his situation often differs from reality in complex situations, and alertness to this difference is often critical to safe flight. Other papers from within the industry were presented, and a series of working group meetings convened to discuss and report on training concepts for resource management. Conference members ended the meeting with a call for additional research and a request for NASA to coordinate efforts to identify training requirements in resource management (Billings, 1980, pp. 201-202).

Research in Cockpit Resource Management

Jensen (1985, p. 12) addressed the problem of having university academic disciplines on one side of the research issue and the operational pilot and his support system on the other side. Through the influence of the first four symposia held by the Association of Aviation Psychologists, there have been opportunities to modify the extremes of each of these groups to achieve more practical and systematic inputs by all. This is a clear demonstration of how academia and industry can work together to identify and solve problems in the field of aviation.

In looking toward those research issues that relate to CRM training, Foushee and Helmreich (n.d., pp. 35-37) are concerned about the impact of mandated standards. If cockpit resource management training is required by Federal Aviation Regulations (FAR) at some future time and this requirement encompasses evaluation, it will be essential to maintain a sharp distinction between training and the evaluation process. In addition to the operational reasons for maintaining this separation, they feel that future research on all important aspects of cockpit resource management training will be jeopardized if it is conducted in an evaluative environment.

There are few opportunities to conduct formal CRM research based on full mission simulation or Line Oriented Flight Training (LOFT), except within the training facilities of the air carrier industry. One exception to this is the simulator facility and computer complex opened in 1985 by NASA at the Ames Research Center. The facility contains both state-of-the art and advanced concept simulators. This allows the determination of flight crew behavior in both the environments of present day technology and in that envisioned for the future (Merrifield, 1985). The major areas of interest to be pursued by Ames scientists while using this new facility are work load management, decision-making, communications, and problem-solving.

The Requirements for CRM Research

The history of research in "small group" studies indicates that the complexity of the aviation environment introduces variables which can never be fully treated, given the limitations of pure academic research. This type of research is considered to be important, and is still being attempted in spite of these limitations. In reviewing early CRM research, Murphy (1977, p. 4) concluded that suggested causal factors in crew effectiveness "have not been well-defined through systematic study or research, and proposed solutions have not been validated. Such definition and validation studies are strongly recommended." In his review of research findings and strategies related to crew coordination and performance, Murphy noted some difficulty in establishing which crew factors are responsible for ineffective crew performance. Some of those factors include role relationships, lack of decisive command, and social adjustment.

Strauch (1985, pp. 139-140) also cites the need for additional research and training program development for CRM. He points out the importance of considering the intervening variables which interact with CRM behavior.

In the recommendations of the cockpit resource management committee of the AOPA/FSF symposium, Jensen (1985, p. A50) proposed scientific studies using control groups to compare the communications and management styles of those pilots who have had CRM training with those who have not.

In discussing the existence of research evidence on any change of crew coordination patterns resulting from CRM training, Helmreich and Wilhelm (1987, pp. 440-446) answer with an unequivocal "no." They state simply that data meeting the requirements of scientific rigor and rules of evidence are lacking.

Topics for CRM Research

In addition to generalized research in the behavioral disciplines and in human factors, the aviation community has seen the necessity for more specialized research in specific areas related to cockpit resource management. These include areas of CRM skill, CRM characteristics, and CRM processes. A discussion of behavioral research outside these specific areas is beyond the scope of this study.

A brief overview of important research categories will be covered including research accomplished and, in some cases, research which has been called for. Research on personality and attitudes, communications/role/coordination, human factors/workload, and needs analysis is reviewed.

Needs analyses. Kaufman (1983, p. 54) refers to "need" as the gap between current results and desired results. When used in this context, the gap refers to the difference between "what is" and "what should be" in a training program. Need exists at different levels. One level relates to the identification of training objectives and goals. Another level involves the process or method of training to obtain these desired goals.

A needs analysis study of the Air Canada line pilots was accomplished in 1984 and 1985 by Westerlund (1985, p. 236). A significant portion of this report was devoted to a discussion of command, leadership, and cockpit resource management training. This statistically based study attempted to identify the managerial, interpersonal, developmental, and appropriate technical training needs of pilots in Air Canada. The results of this survey indicated that 96 percent of responding line pilots agreed that effective crew concepts are essential to operational success. The pilots accused airlines of continuing to focus on achievement of individual pilot proficiency while paying relatively little attention to fostering skills and coordinated action among crew members. One of their statements was (p. 235), "A collection of qualified individual pilots does not guarantee an effective team in the cockpit."

One of the most interesting responses quoted by Westerlund from his research dealt with the very essence of the CRM problem (p. 256):

> The best captains are the most well-liked because the rest of the crew works hard to please him and feels bad if they make a mistake... The biggest liability is the captain with a personality problem because, no matter how good he is, he polarizes the crew socially. There is no training in this area. Personalities are hard to change and there is no hard direction in this area from hiring time on. They train a captain to rattle off checks and drills like a machine, but they don't teach him how to command. Command is the artful skill of reading a man's personality and tiptoeing through his social land mines so that, in the end, he accepts you and hopefully likes you. Then, he will give you his best.

Additional insights concerning CRM training design should be explored. By pursuing a more formal "needs analysis" procedure, each airline could define important objectives while allowing a range of CRM concepts and training strategies to be assessed.

Personality and attitude. Helmreich (1984, p. 583) draws major distinctions between personality traits and attitudes with respect to cockpit resource management ability. As a corollary to his research, he developed a "management attitudes" questionnaire which revealed a number of significant differences in attitudes about flight deck management. In this study, crew position was used as his dependent variable. He concluded that the observed variability in CRM attitudes stems from basic differences in belief rather than in ambiguities of interpretation. This divergence in attitudes about cockpit management indicates that there are many experienced pilots who are either unaware or unconvinced of current findings regarding effective flight deck management (pp. 588-589). Data suggests that these attitudes toward CRM are, in fact, independent of personality traits. This supports the conclusion that training in cockpit resource management may improve these attitudes and subsequently improve observable performance in line operations. Since personality traits are so resistant to change, it was considered important by Helmreich that the dimension of attitude change for cockpit resource management should be exploited. By enhancing CRM attitudes, he feels it is possible to compensate for adverse personality characteristics which frequently persist in the exercise of cockpit resource management.

The element of personality may play a much larger role as a determining factor in flight deck behavior than has been realized. Helmreich (1987) reveals in his recent research that any observable change in personality as a result of training in cockpit resource management may be illusory. He states (p. 16):

> After the honeymoon effect of the training task is over, the facade of cooperativeness and eagerness may crumble, revealing hostility and arrogant insensitivity. Prior studies on this have been faulty in that they examine those

personality traits and their effect on performance during training, rather than in application at some later time.

Pre-employment attitude and personality characteristics important to pilot selection were also discussed by Beach (1980, p. 170). The airline pilot applicant should bring more to the airline than his flying experience.

1. He should have effective interpersonal communication skill.
2. He should be a team player.
3. He should be a good follower as well as a good leader.
4. He should operate cooperatively within the system.
5. He should have a stable personality.
6. He should be flexible [and] adaptable.
7. He should have proper motivation.

These characteristics may be measurable using existing instruments described in the psychological literature. If none can be found, they should be developed. Beach emphasized, however, that the final selection process for airline pilots cannot be accomplished simply by testing. The selection process should be influenced heavily by in-depth interviews conducted by carefully selected line crew managers. The importance of "selecting in" the proper personality and related interpersonal attributes, prior to hiring, emphasizes the need for further CRM research to determine the most effective and predictive selection processes. Longitudinal studies on recently hired pilots now being conducted by American Airlines may provide a partial resolution to these needs (American Airlines, n.d.).

Research by Gerathewohl (1978) also emphasizes the importance of personality. In his research (p. 48), he states that personality was the most ambiguous characteristic of the factors he studied. It consisted of "confidence level, self-discipline, apprehension, mood, conscientiousness, security, risk-taking, rigidity, adaptability, motivation ... and interpersonal relations." With respect to impact of personality in the work place, he states, "In work that requires continuous close cooperation with other crew members, interpersonal relationships probably contribute more to success or failure than minor deviations from acceptable performance in an individual's task."

Chidester agrees that in the personality factors that contribute to qualities of leadership and suitability for captaincy, formalized training appears to have a minimal effect. Since these are important issues for cockpit resource management, he stresses that pilot selection based on personality attributes may be necessary to achieve the desired cockpit resource management training results (1987, p. 478). An appropriate resolution to this problem, in his view, is to combine training and selection processes to serve as complementary approaches.

<u>Communications, role, and crew coordination</u>. In examining the research related to cockpit resource management, Murphy (1977, p. 4) considers that crew coordination is an important but little understood factor in commercial aircrew performance. Citing typical examples of pilot/copilot role relationships, he noted that lack of decisive command and strained social relations were typical problems. He stressed that causal factors in crew

effectiveness and command deterioration have not been well defined through systematic studies, nor have any proposed solutions been validated.

Bolman (1980, p. 32) agrees with this deficiency. He states, "There is a need to understand the dynamics of the role system, how to create an effective and mutually understood set of role relationships, and how to modify those relationships quickly, without creating confusion, overlaps, and gaps." To accomplish this, the "10 Commandments of Good Crew Coordination" (American Airlines, 1978, p. 12) can be put to good use. These are:

1. Think people!
2. Set the tone!
3. Solicit information!
4. Use other crew member's experience!
5. Don't be shy!
6. Be persistent!
7. Remember who's in command!
8. Be tactful!
9. Reinforce good coordination!
10. Don't shirk your responsibility!

American Airlines (Ehman, 1980) also established a well-recognized set of principles for CRM. These include:

1. Appropriate delegation of tasks and assignments of responsibilities.
2. Establishment of a logical order of priorities.
3. Continuous monitoring and cross checking of essential instruments and systems.
4. Careful assessment of problems and avoidance of preoccupation with minor ones.
5. Utilization of all available data to conduct an operation.
6. Clear communication among crew members of all intentions.
7. Assurance of sound leadership by the pilot in command.

Judgment and Decision-Making. Norman and Edmunds (1980) indicate that the relationship of judgment to decision-making is considered to be essential to cockpit resource management training. Components of this process are problem recognition, information gathering, and information integration. Diehl and Buch (1986, p. 9) illustrate a decision-making process in Figure 5. In determining an appropriate course of action, prompt

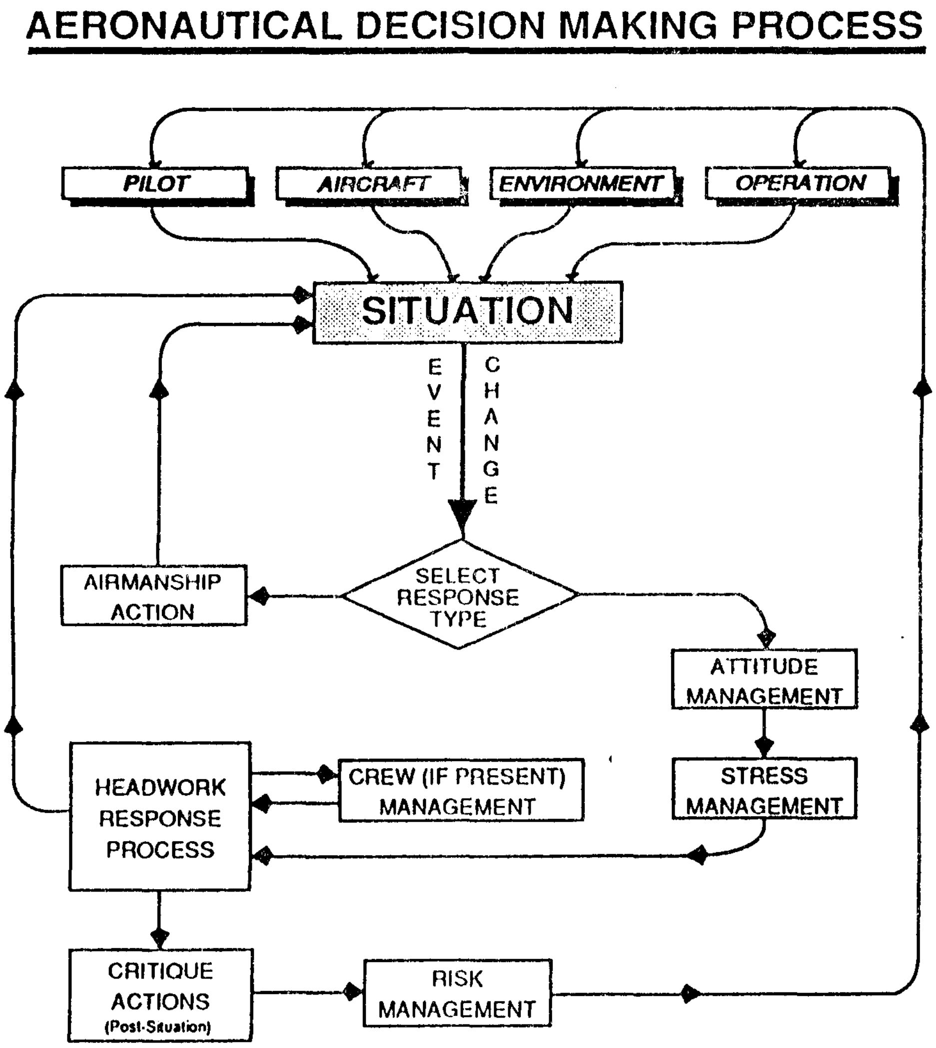

Figure 5
(Adapted from Diehl and Buch, 1986, p.9)

analysis of an appropriate number of alternative courses must be accomplished and compared for relative effectiveness. A best course of action must then be derived for the present situation, given the information, resources, and time available to the pilot. The action may be airmanship (psychomotor) or headwork (cognitive/ affective). Attitude, stress, and teamwork are brought to bear during headwork responses. During the implementation of this derived course of action, a feedback loop consisting of additional information or a change in information, allows the reevaluation of current conditions, risk assessment, and a concomitant change in the decision making process. Each course of action determined through this means requires constant monitoring during the progress toward the desired goal.

Human factors and workload. Barnhard et al. (1975, p. 13) described a method of study for human factors in aircraft operations. This research was accomplished prior to the full development of the cockpit resource management concept. As a result, in the initial illustration of the information processing algorithm, cockpit resource management was not graphically addressed. In a modification of their model, the elements of interpersonal relationship and crew coordination have been added. After adapting the model to accommodate this resource management philosophy, one can follow the segmented portion of Figure 6 to convey the essential CRM elements of such an adaptation.

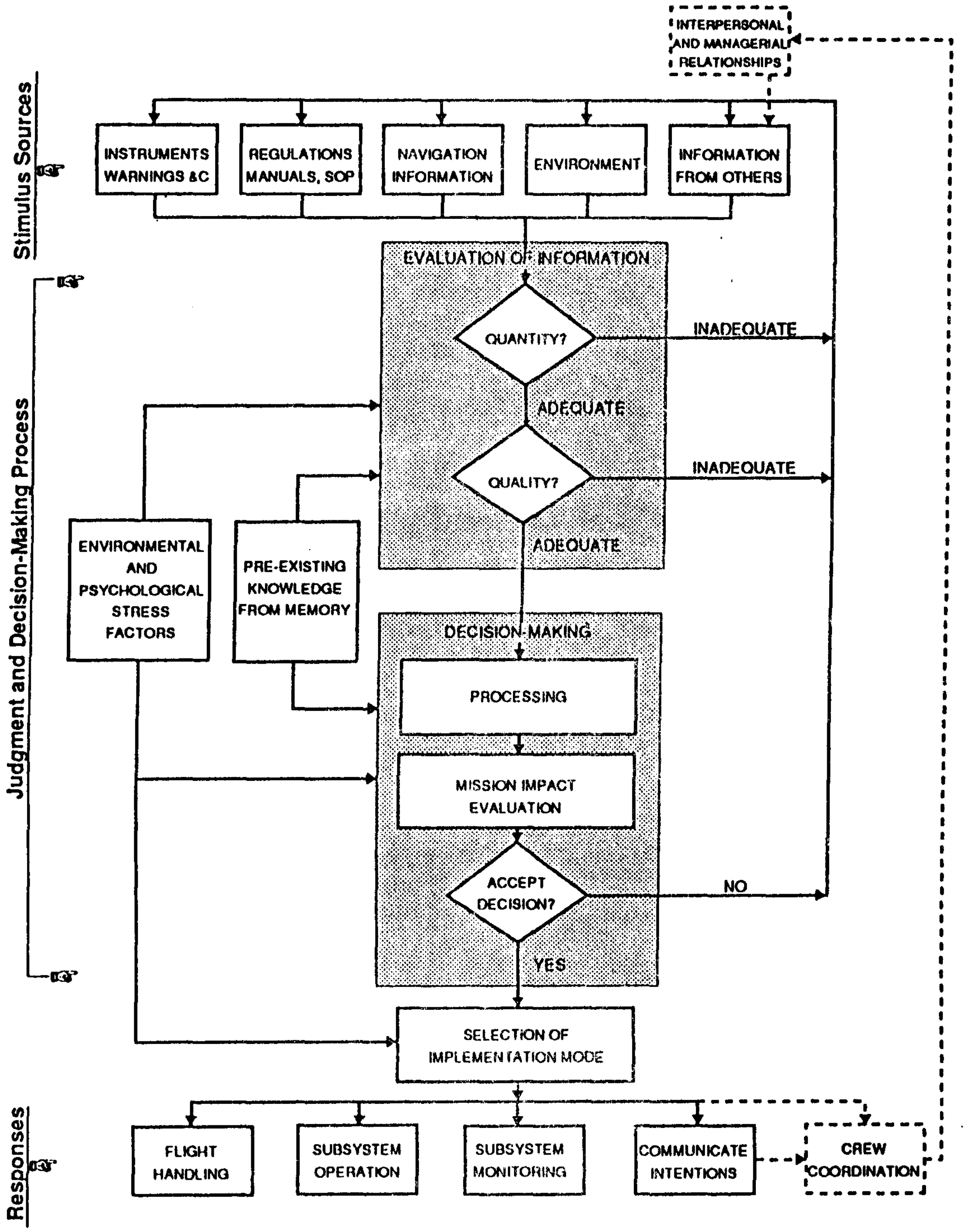

Figure 6

Processing Model for Cockpit Behavior and Resource Management (Adapted from Barnhart et al., 1975, p. 73)

Wiener (1985, p. i) discussed the results of a two-year study to determine the factors affecting the transition of airline pilots from traditional to highly automated aircraft. Implications of cockpit resource management insufficiency were found in some of the difficulties that pilots had in adapting to the new systems. The general view of pilots toward cockpit automation was favorable, but some findings reported a degree of skill loss through automation. He concluded (p. 91) that concern for psychological disenchantment among professional pilots as a result of these technology advances was unwarranted.

In partial contrast to Wiener's findings, Curry (1985) described the results of a questionnaire on pilot attitudes toward new technology cockpits. An important element of cockpit resource management emerged (p. 29) concerning distractions encountered during high levels of cognitive activity. When abnormal or unexpected functions of the automated systems were encountered requiring intervention by the crew, that need frequently went unnoticed in the two-man cockpit. In that environment, the frequency of high cognitive activity and workload curtailed the normal amount of cross-checking. In such a situation, the immediate need for pilot intervention can easily go unnoticed.

Problems of this nature are frequently encountered during the departure and arrival segments of a flight. Typical of the high cognitive level of the distractor task would be the simultaneous requirements for programming the flight management computer while the other pilot is responding to radio communications. If unselected mode changes or inappropriate responses occur in the flight management system, inordinate exposure to unwanted and hazardous modes of flight can be encountered.

There is no way to avoid the additional stress and monitoring workload related to the contingency operations of automated systems. The element of risk attributable to this additional subjective workload in the two-man crew may not have been given its appropriate level of importance by the MacLucas committee on crew complement in new technology aircraft (President's Task Force, 1981). In reaching their conclusions concerning the safety and efficacy of the two-man cockpit, the committee chose to disregard a 1964 jet transport cockpit study by the Civil Aeronautics Board (CAB). In that study (President's Task Force, 1981, Appendix E), the CAB concluded that the minimum flight crew manning determination should be based on aircraft operational complexity and the resulting workload. A major contributing factor to the tragic 1987 Northwest MD-80 crash could be the McLucas Committee's failure to observe that CAB conclusion. The development of effective CRM training may help to alleviate the consequences of that committee's ruling against the three-man crew.

Summary

In studying 28,000 reports submitted by pilots and air traffic controllers to the ASRS program during a four-year period, Billings and Cheaney (1981) discovered numerous problems in the transfer of information which subsequently degraded flight safety. Items contributing to these deficiencies were distraction, failure to monitor, complacency, high workload, and ambiguous procedures, all of which can respond to improvements in cockpit resource management. In spite of the recognition that many crew error accidents are avoidable, little effort has been devoted to determining what factors are involved in human error, or what CRM training concepts could be effectively applied. Shaw states (IATA, 1981, p. 1):

> A lack of knowledge [exists] about the [human factors] discipline, including its goals, methods, techniques, needs, timing, training, applications,...[CRM] skills and knowledge are only vaguely understood. The objectives... are a fundamental understanding of human factors for airline personnel and prompt organizational actions to produce training and informational programs which help to develop that awareness.

In reviewing the history of cockpit resource management as it has emerged from the fields of aviation safety and human factors, some successes and some failures have been noted. Additional research has been called for, but very little CRM research has been accomplished. Requests for support have been frequently made, but responses to those requests have been slow to materialize. CRM has been discussed at great length in a wide range of settings over an inordinate length of time. Philosophically, most participants in these dialogues have maintained a favorable and sympathetic point of view toward the resolution of the CRM problem. There are, as in all issues, some elements of dissension. The economics of CRM training program development, instructor manning, and crew manpower requirements make the CRM issue difficult to resolve. Non-standardization of CRM objectives, lack of a CRM media pool, and other training priorities within the airline industry have contributed to this difficulty. Only recently (Jensen, 1987) has the FAA directed specific attention to CRM training issues. Many questions remain on training methods and effectiveness. With the proper ingredients of cooperation and support between all individuals and agencies affected by this issue, a more rapid and favorable resolution to program development in cockpit resource management and its subsequent adoption into the aviation system may yet be achieved.

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