

# Scaling the Aircrew Risk-Taking Behavior in Aviation Accidents: The Moderating Role of Phase of Flight

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**Abstract.** This study linked aircrew risk-taking behavior to aviation loss, and in this relationship it examined the moderating role of phase-of-flight. First, it developed a measurement model in view of prior accident causation theories and findings of 715 general aviation accidents in Pakistan over a period spanning 2000–2014. Later, it espoused this model for hypotheses testing using original data from 224 randomly chosen accidents and assessed the model through structural path analysis. Results indicated a positive relationship between aircrew risk-taking behavior and aviation loss, and significant moderating role of phase-of-flight.

**Keywords:** Accident · Risk-taking · Aircrew · Flight · Injury · Aviation-loss

## 1 Introduction

Why do we have accidents? This query has concerned aviation safety managers for a longtime. Numerous accident causation theories have evolved to explain their occurrence. Starting with “Heinrich’s domino theory”, the first scientific approach to accident causation in 1920s, several other theories were coined e.g. Human Factors Theory, Accident/Incident Theory, Epidemiological Theory, Systems Theory and Behavior Theory. They were all founded on the ontological position that accidents are “caused”, they do not “happen” by chance. Nevertheless, risk-taking is fundamental to every theory of accident causation. While all such theory have merits in explaining aircraft accident per se, none offers empirical measures for estimating aircrew risk-taking behavior (ARTB) and its influence on aviation loss (AL) in accidents.

Aviation history is full of mishaps. Since the advent, when first aircraft crashed after few moments it took off in Kitty Hawk, there is a long trail of mishaps. Many of these accidents were avoidable particularly the more frequent ones. A large number of studies focused on analyzing multi-year accident data have been published e.g., [1, 2]. Notably, these efforts have widely focused on risk as a decision variable but tended to neglect its interaction [3]. In fact, very little is known about how the phase-of-flight, might have affected the ARTB in ensuing AL during accidents.

This study attempted to model the influence of ARTB on AL. Specifically, it addressed two queries: (a) what determines the amount of ARTB and its resulting AL in an accident? And (b) what influence does phase-of-flight have on relationship

between ARTB and AL? The answers to these queries addressed in this study may contribute to the existing body of knowledge advance the present empirical research on risk and aviation safety.

## 2 Theory and Model Development

In line with the prior researchers [e.g., 4–6] this study approached accident causation through metaphysical presumption of determinism i.e. events (accidents) does not happen by subjective chance, all events have causes, and whatever event (accident) occurs can be connected to other events by general laws [7]. The trade-offs between theory development in social sciences and applying it for developing methods in ergonomics and human factors was dealt with by the work of prior researchers [8]. In developing the method for risk assessment and narrowing the gap of research and practice, simplicity and generality was given more importance than accuracy [9]. A concise outline of the accident causation theories provided foundation for model development.

### 2.1 Accident Causation Theories

Numerous theories have been developed to describe accident etiology. Starting with industrial safety axioms of Heinrich [4], to the “Domino theory” of Bird [5] and human errors “Swiss cheese model” of Reason [6], have been consistently embraced in aviation scholarship [10]. ‘Domino Theory’ radically traced the root cause of all mishaps to malfunctions in organizational control. Admittedly, the most significant one has been the narrative of latent and active failures described by Reason [6], in his “Swiss cheese model” of accident causation. It described four stages of crew failure, and suggested that each one triggers the next: (a) organizational influence leading to instance of; (b) unsafe supervision that sets; (c) precondition for; (d) unsafe act of aircrew. Mostly aircraft accident investigations have focused on the last level i.e. the unsafe act. Reason’s study changed the course of accident investigation but it lacked necessary details for its application in real world scenario [10]. Unfolding the Reason’s design into practical application, Shappell and Wiegmann [11, 12], developed “Human Factors Analysis and Classification System” (HFACS), which is widely being used today for accident investigations. Reason alleged that in complex system, a mishap is the result of unpredictable combinations of organizational and human factors [13].

### 2.2 Aircrew Risk Taking Behavior

Risk is the probability of mishap and severity of expected loss including damage of property and injury to people that may result from exposure to hazards [14]. Investigations discovered that accidents generally result from wrong decision of aircrew in the face of risky situation [15]. Wiegmann and Shappell [16] argued that aircrafts are

reliable, but humans progressively play significant causal role in aircraft accidents. Aircrew has unfitting cockpit culture [17], and suffers from plan-continuation error, whereby they continue with their flight plan despite clear indications in the cockpit, instructions from air traffic controller and dicey weather [18]. Risky attitudes lead to accidents [19]. Mishaps do not occur in isolation, rather it is a chain of events that usually culminate into aircrew risk-taking and unsafe act. Drawing on HFACS, the findings of 715 aircraft accidents investigations in Pakistan over the period spanning 2000–2014 illustrated certain perennial causal factors (hazards) across accidents: (a) Material failure; (b) Bird hit; (c) Weather; (d) Technical failure; (e) Training hazard; (f) Foreign object damage or FOD; (g) Maintenance error; (h) Human error: and (i) Pilot error. The study found that these factors (hazards) pervasively played primary, secondary and (or) contributory role in accident causation. Accepting the avoidable hazards (risk) determine the risk-taking behavior (RTB) of aircrew in an accident. Hence, the ARTB can be measured as:

$$\text{ARTB} = [\text{Risk}] \times [\text{Avoidability}]$$

$$\text{or ARTB} = [\text{Causal Factors}] \times [\text{Avoidability}]$$

$$\text{or ARTB} = [\text{Primary} + \text{Secondary} + \text{Contributory factor}] \times [\text{Avoidable/Unavoidable}]$$

The operational definition of ARTB is provided in Fig. 1.

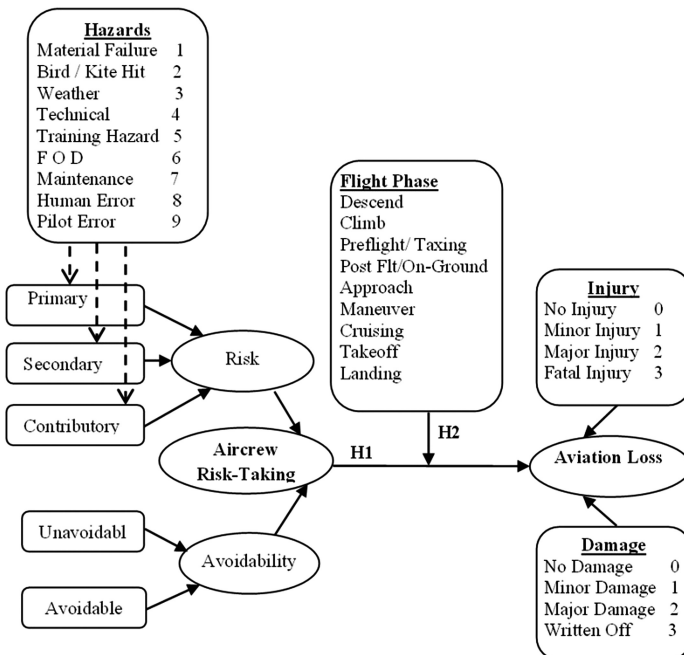


Fig. 1. The ARTBAL model and study hypotheses

### 2.3 Aviation Loss

Accident can be minor or major, depending upon its resulting loss, which is determined by severity of injuries and extent of damage. The study measured aviation loss of an accident by adding up aircrew injuries and material damage. Previously, several probabilistic models have been proposed for investigating the injury severity that based on various characteristics, allocate occupant in various injury severity segment [20]. In the present study injuries were scaled in a continuum on the basis of their severity (from less to more severe), and classified in four categories: (a) No injury- when there is no injury to aircrew, or the injury is so minor that it does not require medical treatment resulting in absence from normal duty for more than one day; (b) Minor injury: Injury that require proper medical treatment resulting in aircrew absence from duty up to one week; (c) Serious injury: Injury which require medical treatment resulting in aircrew absence more than one week, and may involve trauma to some internal organ, extensive laceration, bone fracture, burn involving more than 5 % of the body and any other condition declared serious by medical authorities; and (d) Fatal injury: Injury which results in the death of occupant. The operational definition of aviation loss is depicted in Fig. 1.

Damage to aircraft was also scaled in a continuum (from less to more severe) in four categories: (a) No damage: when there was no recordable damage and the aircraft landed safely or aircraft could be made airworthy by installing a component out of the shelf within the organization; (b) Minor Damage: Aircraft could be made airworthy by replacing minor component that got damaged or malfunctioned with the help of resources inside the country or abroad; (c) Major Damage: Aircraft could be made airworthy by replacing major damaged or malfunctioned component with the help of resources inside the country or abroad and (d) Aircraft written off (Hull Loss): Aircraft completely destroyed or damaged, and had no further value except for possible salvage of some parts. Hence, aviation loss in a particular accident was computed as:

$$\text{Aviation Loss} = \text{Injury} + \text{Damage.}$$

The study assumed that more ARTB may result in more accidents and hence, more AL. Therefore, it was hypothesized that:

H1: Risk taking behavior of aircrew is directly related to aviation loss.

### 2.4 Phase of Flight

After flight planning, fueling, crew scheduling and pre-flight inspection, an orchestrated sequence (phases) are followed by every flight. This study, in congruence with [21], classified these flight activities into nine phases as shown in Fig. 1. It comprised taxiing out to the runway, takeoff, climb to a pre designated flying altitude; cruising to destination, descend to a particular altitude and calls downwind or finals for landing. After a safe landing, the aircraft is taxied back to the tarmac for parking and a post flight inspection is carried out. Various studies [e.g., 2], disclosed significant involvement of phases-of-flight in accidents. General aviation statistics revealed that majority of these mishaps occurred during landings (24.1 %) and takeoffs (23.4 %).

Also, 3.5 % accidents occur during preflight and taxing, 3.3 % during climb, 15.7 % while cruising, 2.6 % at descent, 13 % while maneuver, 9.7 % at approach and 4.7 % after landing or post flight [21]. Also, [22] found a significant positive effect of psychological function of driving (and presumably, flying) on risk taking behavior. Keeping statistics of prior accidents in view, the study assumed that certain phases such as landing, takeoff etc. have a psychological effect and provide aircrew with more chances to err and take risk, hence, it was hypothesized that:

H2: The phase-of-flight strengthens the relationship between aircrew risk-taking behavior and aviation loss.

### 3 Method

The study collected data of 715 general aviation accidents investigations in Pakistan over the fifteen years 2000–2014 for model development in view of HFACS. The model was espoused as precursor for hypotheses testing using data from 224 randomly chosen accidents. The sample satisfied the representativeness and adequacy criteria for parametric tests [23–25]. It also fulfilled the sample-size requirement for modeling crash severity proposed by Ye and Lord [20]. The aircrew and accident profile is provided (Tables 1 and 2). The variables were mean centered to reduce multicollinearity issues [37], and two hypotheses were tested at  $\alpha = .05$  significance level using hierarchical multiple regression analysis (Fig. 1). The moderation significance was tested through coefficient's t and F test [26].

**Table 1.** Accidents profile

Risk				Aircrew Total Flight Hours			
<i>Causal Factors</i>	<i>Freq</i>	<i>%</i>	<i>C%</i>	<i>Experience</i>	<i>Freq</i>	<i>%</i>	<i>C%</i>
Bird hit / Kite Hit	18	8.0	8.0	Up to 1000	43	19.2	19.2
Material Failure	83	37.0	45.0	1000- 2000	45	20.1	39.3
Weather	13	5.8	50.8	2000- 3000	47	21.0	60.3
Technical Failure	11	4.9	55.7	3000 - 4000	47	21.0	81.3
Training Hazard	19	8.5	64.2	5000- 6000	34	15.2	96.4
FOD	15	6.7	70.9	6000 +	8	3.6	100
Maintenance Error	8	3.6	74.5	Total	224	100	
Human Error	20	9.0	86.5				
Pilot Error	37	16.5	100				
Total	224	100					

*Not.* FW - Fixed Wing Aircraft; HEL - Helicopter; C% - Cumulative Percentage

**Table 2.** Accidents profile

Damage To Aircraft				Crew Injuries			
<i>Extant</i>	<i>Freq</i>	<i>%</i>	<i>C%</i>	<i>Type</i>	<i>Freq</i>	<i>%</i>	<i>C%</i>
No Damage	19	8.5	8.5	No Injury	169	75.4	75.4
Minor Damage	160	71.4	79.9	Minor Injuries	22	9.8	84.3
Major Damage	27	12.1	92.0	Major Injuries	16	7.1	91.4
Written off	18	8.0	100.0	Fatal	17	7.6	100.0
Total	224	100.0		Total	224	100.0	

*Not.* C% - Cumulative Percentage

### 3.1 Independent Variable

Aircrew risk-taking behavior (ARTB) was computed by multiplying risk and avoidability. The “Risk” was scaled in nine categories of hazards in a continuum from lesser to more severe depending upon the degree to which they can be avoided by the aircrew. The ranking (provided in Fig. 1) was based on concordance between 18 raters (comprising pilots of varying aircraft type and experience, flying instructors, a flight surgeon, and an aviation psychologist). They rank ordered these factors in a linear continuum from least avoidable to easily avoidable risk, and their ranking consistency was assessed through Kendall’s W coefficient (Kendall W = 0.8792, chi-squared = 126.5981, df = 8, p < 0.0001), which indicated a strong degree of agreement [27]. For example, they agreed that avoiding a stray bullet or a small bird becomes very difficult (though a good lookout is always advisable in low level visual meteorological condition-VMC flying); hence, it was assigned the least score.

In case of engine failure, aircrew can land safely if landing ground is available and they follow a standard procedure of emergency landing i.e. “SFO”(simulated flameout) for FW and “Autorotation” for helicopters [28]. Similarly, FOD can be avoided if various procedures in civil aviation and FOD drills in military aviation are religiously followed i.e. if tarmac, taxi-links, holding areas and runway are scanned on weekly basis for debris, loose pebbles and other hazardous material, and their record is maintained. Hence, they are in the middle of the continuum. But, pilot-error depicts aircrew negligence [11, 29]. It represents hazards that could have been avoided easily by adhering to standard procedures, and therefore, it was assigned the maximum score. However, “Avoidability” was scaled nominally i.e. Unavoidable = 1, avoidable = 2.

### 3.2 Dependent Variable

In a particular accident, AL was computed by adding up severity of injuries and extant of damages. They were scaled using the Fisher’s exact test [30], and injury severity (i.e., 0 = No Injury; 1 = Minor Injury; 3 = Serious Injury; and 4 = Fatal Injury), and extant of damage (i.e., 0 = No Damage; 1 = Minor Damage; 3 = Major Damage; and 4 = Aircraft Written off or Hull Loss) was employed.

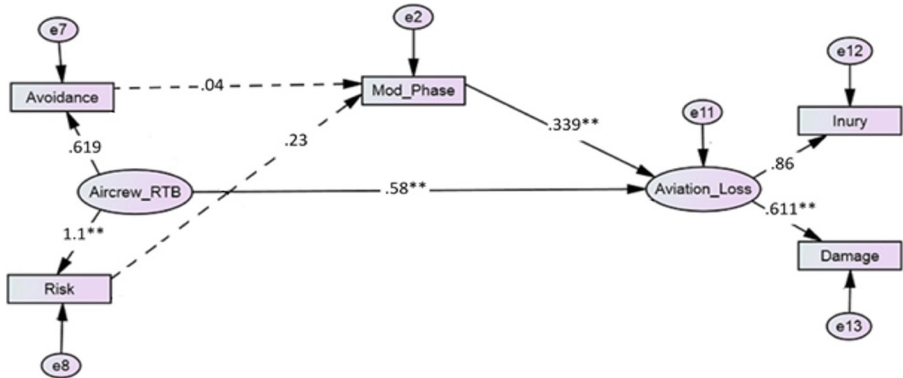


Fig. 2. Latent structure of the ARTBAL model with moderating variables

### 3.3 Moderating Variable

In line with FAA [21], accident statistics, the phase-of-flight was classified into nine categories in a continuum from less to most probable as: Descend, Climb, Preflight/Taxing, Post Flight/On-Ground, Approach, Maneuver, Cruising, Takeoff and Landing.

### 3.4 Model Fit

The ARTBAL model along with the moderating variables was evaluated through structural path analysis with renowned model-fit indices. The standard criteria were: Chi-squared/df  $\leq 5$  [31], goodness-of-fit index GFI  $\geq .90$  [32], comparative fit index CFI  $\geq .90$  [33], normed fit index NFI  $\geq 0.8$  and root-mean-square-error of approximation RMSEA  $\leq .10$ , through a confidence interval CI of 90 % [34].

The path model (as shown in Fig. 2) converged without iterations and agreeable indices were attained. Since the model had lesser degree of freedom, therefore the absolute fit index with fitted covariance matrix (Chi-squared/df) at 0.05 thresholds was 5.2, and the RMSEA was .105. While these two values were slightly above the upper threshold [31, 34], researchers argued that accidents' data with independent residuals, higher kurtosis values, and small degree of freedom, usually generate inflated Chi-squared values, but the comparative model fit indices are not affected much [35, 36]. Hence, all comparative fit indices of ARTBAL model were well within agreed limits. For example, variance accounted for through anticipated population covariance, the GFI was .941 [23]. Likewise, the NFI .925 indicated that based on the Chi-squared the ARTBAL model enhanced the fit by 92.5 % relative to null model. And, ensuring the least effect of sample size, the CFI of .935 was found. With these parameters, Chi-squared (11, N = 224) = 57.6,  $p > .05$ ; RMSEA = .105 with 90 % CI {.079, .132}; and CFI = .935, the model provided a reasonable good fit to the data.

### 4 Results

Descriptive statistics of study variables are provided in Table 3. While every observation corresponded to a particular accidents situation with higher independent residuals [35], the descriptive statistics exhibited a kurtotic and skewed distribution. The overall mean values of risk-taking were comparatively higher, and so do its standard deviation. Table 3 also elucidates the significant positive correlation of aircrew risk-taking with aviation loss ( $r = .567$ ;  $p < 0.01$ ), and with the phase-of-flight ( $r = .251$ ;  $p < 0.01$ ).

**Table 3.** Means, Standard Deviation and correlations of study Variables

Variables	Mean	S.D.	1	2	3	4	5	6	7	8
1. Aircraft type	3.66	2.331								
2. Phase of flight	5.03	4.174	-.010							
3. Loss	.05	.383	-.010	-.021						
4. Damage	.99	.507	.001	.023	.526**					
5. Experience (Hours)	2.86	1.629	.161*	-.252**	.140	.082				
6. Risk	4.228	5.864	-.042	.287**	.480**	.490**	.045			
7. Risk taking	7.212	11.92	-.050	.251**	.487**	.511**	.053	.988**		
8. Aviation loss	1.052	.8573	-.002	.001	.854**	.876**	.128	.551**	.567**	
9. Avoidability	1.25	.458	-.150*	.256**	.228**	.334**	-.054	.721**	.767**	.320**

Note. \*  $p \leq .05$ . \*\*  $p \leq .01$ . (2-Tailed).

Hypotheses were tested systematically while controlling for the effect of previous exogenous and moderating variable in hierarchical regression analysis. Hypothesis 1 proposed the main effect of ARTB. The model accounted for 34.3 % explained variance in AL ( $F3, 220 = 32.02, R^2 = .343, p < .001$ ), and a positive correlation between ARTB and AL was found ( $R = .586, \beta = .044, t = 9.80, p < .01$ ). These results duly supported Hypothesis 1 stating that ARTB is directly related to AL. The addition of moderator “phase-of-flight” in the model demonstrated a significant F change from ( $F3, 220 = 32.02, p < .001$ ) to ( $F4, 219 = 34.75, p < .01$ ). Moderator phase-of-flight significantly enhanced the positive relationship between ARTB and AL, and increased the explained variance in AL by 5.1 % ( $\Delta R^2 = .051, \beta = .048, t = 10.80, p > .01$ ). These results sufficiently supported Hypothesis 2 asserting that the phase-of-flight strengthens the positive relationship between ARTB and AL. The results of all three hypotheses are provided in Table 4.

**Table 4.** Hierarchical regression analysis

Hypotheses	R	R <sup>2</sup>	SE	Change statistics			Coefficients		Decision
				$\Delta R^2$	$\Delta F$	$df_{1-2}$	B	t	
H1	.586	.343	.70	.343**	32.02	3-220	.044	9.801	Supported
H2	.628	.394	.67	.051**	15.39	4-219	.048	10.809	Supported

Note. \*\*  $p \leq .01$ . (2-Tailed),



To probe further, the interaction patterns were plotted through significant change in the slope and intercept of the regression line in accordance with Aiken and West [37], approach as shown in Fig. 3.

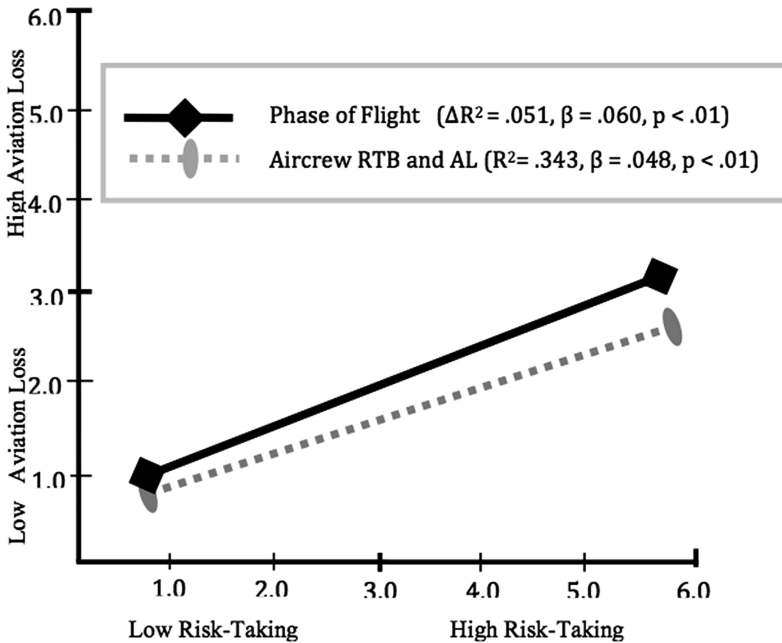


Fig. 3. Interaction Effect depicted through change in the slope and intercept of Regression

## 5 Discussion

Present study developed a practical model for scaling the ARTB and AL, and analyzed the aircrew behavioral aspect towards risk-taking that led to AL. Results demonstrated a positive relationship between RTB and AL ( $R = .586$ ,  $p < .001$ ), and significant moderation effect of phase-of-flight in this relationship. It supported the assertion of Moller and Gregersen [22], regarding a positive psychological function of driving (and presumably, flying) on risk taking behavior. Moreover, accident profile (Table 1) indicated that maximum accidents (25.4 %) occurred during the landing phase, which is slightly higher than accident rate (24.1 %) provided by FAA [21]. Also, phase-of-flight significantly augmented the relationship between RTB and AL by 5.1 % ( $\Delta R^2 = .051$ ,  $p < .01$ ). These results supported the earlier viewpoint that majority of accidents occurred during the critical stage of flight (such as landing) owing to aircrew improper decisions [15]. Present results, though, are in slight variation to the findings of Shaoa et al. [2], who found that maximum accidents in Taiwan occurred during takeoff instead of landing phase. Similarly, it was also noticed that bulk of accidents occurred during a flight phases that demand superior handling (e.g., landings and takeoffs). This finding presumes that alongside ARTB, presence of skill-based

errors cannot be ruled out. These findings strengthen the need for enhancing aircrew personal-skills through risk management coaching programs aimed at transforming risk perception and attitudes towards risky flying, and designing aviation infrastructure according to pilot's risk perception [38].

### **5.1 Implications**

The value of understanding ARTB as a function of phase-of-flight is obvious in that it will facilitate informed decisions for managing the risk. Nonetheless, there is a wider benefit to aviation managers in identifying aircrew limitations in different phases of flight, and designing effective training interventions to reduce RTB [19]. Results suggested that "material failure" has been the primary causal factor in 37.0 % accidents. This finding has direct implications to the strategies concerning quality assurance, aircraft aging, maintenance and procurement of spares. While mishap results from unpredictable combinations of human factors and organizational fiasco [10, 13], the study observed that all major and fatal accidents were attributed to pilot error only, and organizational factors remained subtle [39]. It is recommended that accident investigators need to uncover organizational factors that are repeatedly overlooked or undisclosed [4, 40].

### **5.2 Limitations and Future Directions**

With the present results in hand, study in ARTB should take into consideration few important perspectives in future. First, having an accident says little about the severity of that accident until the "Rate" and "Severity" is discretely measured. Nevertheless, larger aircraft with more numbers of passengers resulted in multiple major and fatal injuries, and in many accidents damages were more expensive to be fixed. If these variables are measured precisely, the present results can be replicated with greater confidence in future studies. Second, more experienced pilots are less likely to be involved in air accident than less experienced pilots [1]. More flight experience also provides aircrew with more chances to err. Hence, future study in ARTB should also take aircrew flight experience in consideration. And last, as do others [e.g., 35], this study also recognized the inbuilt limitation of frequentist approach in dealing with aircraft accidents data, and recommends trying a Bayesian approach in future study.

### **5.3 Conclusion**

In conclusion, this study presented a practical model for measuring aircrew risk-taking behavior and aviation loss, and provided empirical evidence that they are directly related in general aviation accidents. The relationship gets stronger when aircrew faces diverse situations in varying phases of flight. Numerous factors limit the generalization of these findings. Nevertheless, the results are noteworthy in their own domain and warrants *ex-ante* measures for measuring potential risks associated with every phase of flight. If it were assumed that aircrew is driven by complacency and obsolescence, the cause of their risk-taking propensity at different phases of flight would clearly be more essential and justifiable for further study.

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