Pilot Operating Characteristics Analysis of Long Landing Based on Flight QAR Data

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Abstract. Long landing events make up the largest percentage of all exceedance incidents and multiply the risk of runway excursions in landing phase. For the aim of exploring operating factors causing long landing, this study examined the pilot operating characteristics of long landing events by the methods of variance analysis, regression modeling and flare operation analysis based on flight QAR data. Finally it concluded that flare is the most critical operation in landing, which determining the touchdown distance by two key factors of flare time and flare height. Both of the control column and throttle operation plays an important role in the flare process. Pilots' faster pulling up columns and softer throttle closing is probably helpful for a successful flare. In addition, pilots need to control the aircraft to an appropriate groundspeed and descent rate before descending to the flare initial point. The conclusions are expected to be applied into practice to prevent the happening of long landing events.

Keywords: Pilot Operating Characteristics, long landing, QAR data, safety.

1 Introduction

Final approach and landing is the most important flight phase because a pilot needs to deal with more operations, decision-making, and workloads than other phases [1-4]. Accident statistics have also indicated that approach and landing was the most dangerous phase of flight, which accounted for only 4% of exposure time but resulted in over one-third of all commercial jet accidents. In particular, the landing phase alone accounted for 22% of total fatal accidents occurring between 2001 to 2010, despite the fact that the landing phase accounts for just 1% of average flight time [5].

A long landing event, which is one case of undershooting, is defined as an aircraft's contact with the runway over the normal touchdown area. A NLR (National Aerospace Laboratory of Netherlands) study has revealed that if the landing was long, the landing overrun accident risk was 55 times greater than when it was not long [6]. Referring to Iceberg Theory and Heinrich Accident Triangle [7], a runway excursion

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accident is the smallest visible part of ice above the surface of water, while long landing events are he large invisible part of ice beneath the surface of water which is always omitted. Statistics also showed that long landing events regularly accounted for the largest part of exceedance events [8]. Therefore, long landing events are expected to attract more concern from aviation carriers and researchers.

The long landing event is generally monitored by using Quick Access Recorder (QAR) data in most commercial air carriers, but these data are also confidential for them. Meanwhile, there are few aviation administrators whom enforced their airlines to install QAR equipment on every transport jet. Therefore, QAR data were difficult and rarely utilized into research. Civil Aviation Administration of China (CAAC) has implemented the program of Flight Operations Quality Assurance (FOQA) since 1997, with all commercial airplanes of Chinese airlines obliged to install QAR or similar equipment. The practice has proved that QAR data were helpful for improving flight safety management and quality control.

In this study, we use QAR data to analyze long landing events and try to find the differences of pilot operating characteristics between normal landing and long landing. Meanwhile, the critical operation variables leading to long landing are expected to be analyzed.

2 Methods

2.1 QAR data

The QAR data in this study were collected from three commercial aircrafts (Boeing 737-800) of a local airlines. The data covered all normal and exceedance flights of these three aircrafts from the 1st of April to the 30th of May in 2012. First, 293 flight samples were selected and relevant QAR data files were downloaded from QAR ground station of airlines. The original data is a CSV (Comma Separated Value) file with thousands of rows and columns. Therefore, VBA (Visual Basic for Applications) programing functions in Microsoft Excel was applied and 19 columns of original QAR data of every file were refined as following. Finally we also compiled the VBA program to calculate 19 parameter variables and touchdown distance of each flight sample.

These parameter variables covered all flight and operational parameters in the critical visual and manual landing stages from the height of autopilot-disconnected to touchdown. Generally the threshold of identifying normal and long landing was set as 2600 feet for this aircraft type by the airlines. Based on this threshold, 293 cases of QAR data were divided into two groups with 119 cases of normal landing (Group 1) and the other one was 174 cases of long landing (Group 2). QAR data of 119 normal landing events and 174 long landing events were regarded as two groups of independent samples. The mean and standard deviation of touchdown distance of these two groups respectively was 2248.88±247.27 (Group 1) and 3082.62±357.64 (Group 2).

Table 1. Selection of parameters

Classification of parameters	Parameter name of QAR data	Explanations
Height	RADIO HEIGHT LRRA	Radio height
Speed	GROUND SPEED	Groundspeed
	VERT SPD CMD	Descent rate
	AIR SPD	Airspeed
Operation	SELTD TRA FILTERED	Throttle resolver angle
	CONTRL COLUMN POSN	Control column position
	CONTRL COLUMN FORCE	Control column force
	CONTRL WHEEL FORCE	Control wheel force
	CONTRL WHEEL POSN	Control wheel position
	FLAP HANDLE POSN	Flap handle position
	SPD BRAKE HANDLE POSN	Speed brake handle position
	RUDD PEDAL POSN	Rudd pedal position
Attitude	CAP DISP PITCH ATT	Pitch angle
	CAP DISP ROLL ATT	Roll angle
Configuration	FLAP	Flap
	AILERON POSN	Aileron
	ELEV POSN	Elevator
	RUDD POSN	Rudder
Acceleration	VERT ACCEL	Vertical acceleration

2.2 Variable Selection and Flare Operation

Currently most of commercial aircrafts have an advanced autopilot system and even an automatic landing system, so that the main task of the human pilot during most of flight time is monitoring instrument panels and checking the aircraft states for any abnormality. However, during take-off and final landing (below 60 *m*), the automatic system is rarely used and the aircraft is still operated by pilot. Especially, the final landing control is known as the most difficult maneuvers for airline pilots in normal operation. Pilots are required to control groundspeed and descent rate in a quick and few seconds depending on visual and other situational information. Among that a characteristic and critical maneuver is called flare, which involves lifting of the nose to both land the aircraft on the main gear first and decrease the sink rate and vertical load at the landing. Flare operation would make large influences on final landing performance including touchdown distance and also is one of the most skilled operation in flight [9-12]. Therefore, the pilot operation below 200 feet, especially the flare operation was selected as the main subject for analysis.

2.3 Statistical Methods

Before data analyzing, the final landing track of two groups of flight samples was depicted based on their height average at every time scale before touchdown. The height change and difference between two groups would be found from the figure of track.

These parameters regarding with flare operation were the main variables to examine. Firstly, they were classified into four categories of height and time, operation parameter, configuration and attitudes and flight performance parameters. There were 20 variables included in the four categories in total. It needs to explain that the variable of *Flare Time* means the total time from flare initial point to touch down point. In addition, the flare operation initial point in this study is higher than definition in most of flight manuals where it is always defined as 30 feet. This is because any slight pulling up of control column could be recorded by Quick Access Recorder, and it leads that the time and height of flare is earlier than theoretical value. Secondly, the normal distribution test was carried on. Then for the aim of difference analysis, one way ANOVA was used to examine variables which were subjected to normal distribution and non-parameter K-W test for other ones. Thirdly, in order to further analyze the correlations between touchdown distance and the 20 variables related with flare operation, a multiple linear regression model was developed. Considering the probable collinearity between independent variables, the stepwise regression method was used for eliminating and the stepping criteria were based on probability of F ($F \leq 0.05$ for entering and $F \geq 0.10$ for removal). Meanwhile, the effectiveness of the model was analyzed.

For further observing dynamic change of flight variables in final landing phase and their differences between two groups, the altitude of 200 to 0 feet was divided into four flight levels (200-150-100-50-0 feet) and selected 20 variables were measured in every level. The multivariate analysis process of general linear model was introduced to compare the differences in the two groups. Especially, the variable *Control Column* and *Throttle Resolver Angle* was analyzed in detail and presented in this paper.

3 Results and Discussions

3.1 Analysis of Final Landing Track

Scaling with the time before aircraft touchdown and the height mean of each group, the final track of two kinds of landing is as showing as Figure 1. The first second on horizontal axis is touchdown point.

As seen in Figure 1, following points are easily to be found.

(1) The average height of normal landing is higher than long landing at each same second before touchdown.
(2) The height change of two groups was basically linear before flare operation initial point, and their slope was also basically the same.
(3) There is no significant difference between the flare initial height of two groups, which are both around 50 feet. The height change shows difference after flare operation.
(4) The most remarkable difference is the time of flare starting and also the flare operation time, the normal landing is around 8 seconds and long landing is around 10 seconds.

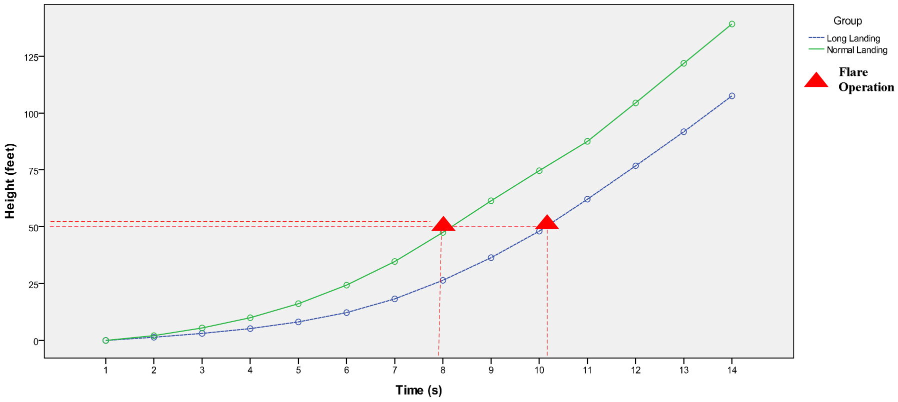

Fig. 1. Final track of normal and long landing

3.2 Data Analysis of Flare Operation Point

3.2.1 Results of Difference Analysis

The results of difference analysis on variables at flare point are as showing as Table 2.

Table 2. Difference analysis on variables of flare point

Parameter Categories	Variable Names	Group	N	Mean±SD	*p* (K-S)	*p* (ANOVA/K-W)
Height and Time	Flare Height	1	119	52.076±21.975	0.044	0.351
		2	174	50.787±25.005	0.000	
	Flare Time	1	119	7.891±2.102	0.002	0.000
		2	174	10.684±2.589	0.003	
Operation Parameters	Throttle Resolver Angle	1	119	49.570±1.926	0.996	0.052
		2	174	49.062±2.355	0.132	
	Control Column	1	119	1.004±0.773	0.144	0.818
		2	174	1.023±0.667	0.108	
	Column Force	1	119	2.072±0.942	0.284	0.419
		2	174	2.164±0.978	0.270	
	Control Wheel	1	119	0.461±8.938	0.894	0.330
		2	174	-0.628±9.674	0.207	
	Wheel Force	1	119	-0.017±0.424	0.423	0.139
		2	174	0.055±0.466	0.012	
	Flap Handle Position	1	119	31.597±3.678	0.000	0.008
		2	174	30.632±2.441	0.000	
	Speed Brake Position	1	119	2.949±0.822	0.000	0.286
		2	174	2.843±0.912	0.000	
	Rudder Pedal	1	119	0.563±0.250	0.000	0.564
		2	174	0.579±0.142	0.041	

Table 2. (*Continued*)

Configurations and Attitudes	Elevator	1	119	2.492±0.938	0.110	0.547
		2	174	2.431±0.794	0.060	
	Aileron	1	119	1.504±1.864	0.713	0.307
		2	174	1.267±2.006	0.527	
	Flap	1	119	31.597±3.678	0.000	0.008
		2	174	30.632±2.441	0.000	
	Rudder	1	119	-0.160±0.605	0.858	0.189
		2	174	-0.248±0.528	0.996	
	Pitch Angle	1	119	1.464±0.653	0.683	0.596
		2	174	1.421±0.704	0.229	
	Roll Angle	1	119	-0.345±1.221	0.628	0.074
		2	174	-0.091±1.173	0.097	
Flight Performance	Air Speed	1	119	148.462±4.871	0.429	0.000
		2	174	150.575±4.402	0.407	
	Groundspeed	1	119	146.277±7.453	0.834	0.000
		2	174	152.080±7.375	0.842	
	Descent Rate	1	119	-813.849±148.094	0.007	0.131
		2	174	-825.448±142.712	0.065	
	Vertical Acceleration	1	119	1.047±0.037	0.273	0.005
		2	174	1.061±0.040	0.167	

As seeing from Table 2, seven variables show the difference at the significant level of 0.05, which are *Throttle Resolver Angle, Flap Handle Position, Flap, Air Speed, Groundspeed, Vertical Acceleration* and *Flare Time*. However, there are only *Air Speed, Groundspeed, Flare Time* represented the significant difference at the level of 0.001. This point means that the major difference of two groups is reflected on longitudinal speed including airspeed and groundspeed. In fact, the three variables of *Throttle Resolver Angle, Flap Handle Position, Flap* would make direct effect on longitudinal speed. Meanwhile, we can find that most of operation variables such as *Control Column* and *Control Wheel* do not represent a significant difference at flare point. It is probably because that most of operation are a consequent movement, their differences exist in a time period or a stage, not at a point. Therefore the difference analysis based on flight height change was also carried on in coming steps.

3.2.2 Multiple Linear Regression Model

The results of stepwise linear regression shows that five significant predictors are included in the final regression model, which are *Flare Time, Flare Height, Groundspeed, Descent Rate, Vertical Acceleration*.

The R square of the final model achieves 0.974, which indicates that the relatively good fitness of this linear model ($F(5,287) = 1074.868$, $p < 0.001$). The linear regression model is expressed as the following equation:

$$TD = -1823.106 + 235.295x_1 - 18.940x_2 + 19.111x_3 + 0.204x_4 + 566.668x_5 \quad (1)$$

Table 3. Coefficients of model

No.	Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
	(Constant)	-1823.106	239.156		-7.623	0.000		
x_1	Flare Time	235.295	3.606	1.255	65.257	0.000	0.478	2.094
x_2	Flare Height	-18.940	0.442	-0.869	-42.863	0.000	0.430	2.328
x_3	Groundspeed	19.111	0.909	0.292	21.019	0.000	0.914	1.094
x_5	Descent Rate	0.204	0.053	0.057	3.863	0.000	0.813	1.231
x_5	Vertical Acceleration	566.668	204.316	0.043	2.773	0.006	0.735	1.361

The standardized regression model, which could present this correlation directly, is introduced and written as following equation:

$$Z_{TD} = 1.255Z_{x_1} - 0.869Z_{x_2} + 0.292Z_{x_3} + 0.057Z_{x_4} + 0.043Z_{x_5} \quad (2)$$

In Table 3, all of the coefficients are highly statistically significant ($p < 0.01$). The variable x_1 (*Flare Time*) carries the biggest one (1.255) and had the greatest impact on touchdown distance. This point is consistent with the results of difference analyses. It should point out that the variable x_2 (*Flare Height*) also carried a great contribution on touchdown distance, despite of there is no significant difference between normal and long landing groups.

The Durbin-Watson test shows that there are no autocorrelations existing among predictors (Durbin-Watson = 1.884). All VIF coefficients of these five predictors are less than three which meant that collinearity level of independent variables is acceptable. A P-P plot demonstrates that the regression standardized residual is basically subjected to a normal distribution. It means that the normality assumption of regression is not violated.

3.3 Flight Operation Analysis of 200-0 Feet

According to the landing description in flight manual, both groundspeed and descent rate are the two most critical flight parameters which human pilots should monitor and the most important operation actions are finished by control column and throttle. The difference of 20 variables from 200 feet to touchdown were analyzed by using repeated measure and one way ANOVA. Due to length limitation, here only the results of groundspeed, descent rate, control column and throttle are presented.

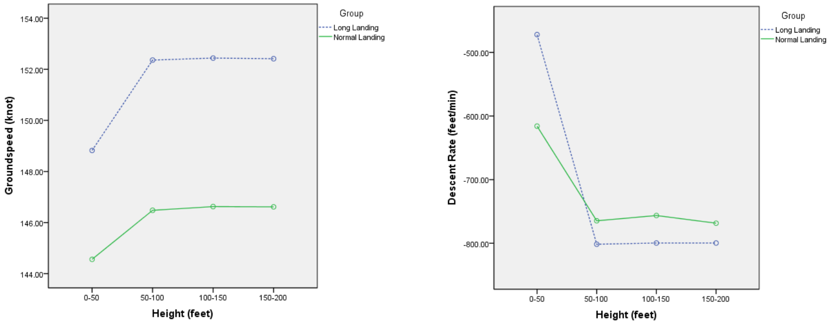

Fig. 2. Difference analysis of groundspeed and descent rate

As shown in Figure 2, the significant difference of variable *Groundspeed* is existing in the whole stage of 200-0 feet ($F(1,291) = 37.265$, $p < 0.001$), the groundspeed of long landing group is higher than normal group. The results of repeated measure ANOVA showed that the group effect of variable *Descent rate* is not significant ($F(1,291) = 1.802$, $p = 0.18$). However, the results of one way ANOVA on each stage showed that the difference is significant. The descent rate of long landing is bigger than normal group before 50 feet which is also the flare initial point, but it changes a lot after past 50 feet and makes a more significant difference between groups ($F(1,291) = 234.373$, $p < 0.001$).

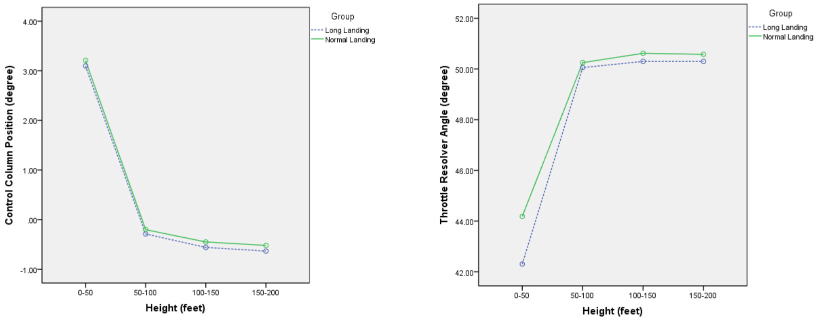

Fig. 3. Difference analysis of control column and throttle resolver angle

In Figure 3, the control column and throttle change greatly after passing 50 feet (flare operation initial point). There is no difference between control column of two groups ($F(1, 291) = 2.771$, $p = 0.097$) . The column change degrees and trend of two flights both are keeping the same. However we need to note that the time of operating column is definitely different, which means that the speed of pulling column is significant different. The normal landing group is faster than long landing group (7.9 seconds for normal landing and 10.7 seconds for long landing). There is also no difference found for throttle operation before 50 feet, the main difference is reflected after flare starting when pilot begins to decrease thrust. The result of one way ANOVA is $F(1, 291) = 46.351$, $p < 0.001$. The throttle change of normal group is smaller than long landing group, which means that the throttle of normal operation is closed more steady and softly.

4 Conclusions

Long landing is one kind of unsafe incident which could increase the risk of runway excursions. It occurs frequently and sometimes lead to runway excursion accidents. Though many studies regarding runway excursion have been conducted, most of them have been based on accident investigations, models, or experiments rather than real flight data. Because real flight data was hard to be obtained from air operators. Basing on flight QAR data, this study provides a new way to analyze long landing and its operating characteristics. The main works are concluded as following.

- Flare is the most critical operation in final landing, which would make great influences on touchdown distance through the factors of flare operation time and height.
- Flare time is the most significant different variable between normal landing and long landing, where the variable mean is 7.9 seconds for normal landing and 10.6 for long landing.
- The control column and throttle operation below 50 feet represents a difference between groups and plays a great role on flare together. Pilots' faster pulling up columns and softer throttle reduction maybe helpful for a better flare and landing.
- Pilot is suggested to monitor and control aircraft to an appropriate longitudinal and vertical speed when entering into a manual operation phase in landing. Groundspeed and descent rate are always the two crucial parameters guiding to a good landing performance.

In future work, a more qualitative model is expected to be developed for explaining how control column and throttle operation contributes to touchdown distance and other landing performance.

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