Pilot Evaluation of Proposed Go-Around Criteria for Transport Category Aircraft

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The primary objective of this study was to capture pilot feedback and decision-making with regard to proposed, hypothetical, go-around criteria that were developed based on previous research. A secondary objective was to assess crews' awareness of the aircraft state on approach. An experiment was conducted using B737-800 and A330-200 Level D full-flight simulators, in which pilots flew multiple approaches that were on the borderline of the proposed go-around criteria at 300 ft. Pilots were instructed that they could either execute a go-around or land the airplane on each run, forcing a decision for the borderline cases at 300 ft. Pilots were instructed to go around if the aircraft was outside of the go-around criteria at 300 ft or if either pilot was uncomfortable with the approach. The results revealed: 1) the most important factors that drove go-around decision making during the experiment were airspeed and localizer deviation, 2) whereas the objective data suggests that the 300-ft gate is viable, many pilots were uncomfortable with the gate; perhaps more emphasis on checking the stability at 1000 ft and 500 ft, which would make more pilots comfortable with the 300-ft go-around gate, 3) allowing for momentary deviations should be considered, and 4) the acceptability of the criteria is highly dependent on each pilot's risk tolerance. Overall, the proposed criteria performed well, and most pilots would find the criteria acceptable with some minor adjustments.

Nomenclature

h	height above ground, ft
$\dot{h}$	rate of descent, ft/min, ft/s
n_r	number of runs, %
n_z	load factor, –
V_{ref}	reference airspeed, kts
V_{target}	target airspeed, kts
x	longitudinal distance, ft
y	lateral distance, ft
α	angle of attack, deg
θ	pitch angle, deg

Abbreviations

AGL	above ground level
CAST	Commercial Aviation Safety Team
FAA	Federal Aviation Administration
FSF	Flight Safety Foundation
GS	glideslope
HITL	human-in-the-loop
IATA	International Air Transport Association
ILS	instrument landing system
IMC	instrument meteorological conditions
LOC	localizer
PAPI	precision approach path indicator
PFD	primary flight display
RCC	runway condition code
RWY	runway
SFO	San Francisco International Airport
TAWS	terrain avoidance warning system
VMC	visual meteorological conditions

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The findings and conclusions in this paper are those of the author(s) and do not necessarily represent the views of the FAA.

I. Introduction

Stabilized approach criteria for transport category aircraft has fallen under scrutiny because of low compliance with established policies. Most airlines have defined stabilized approach criteria, as shown in Table 1, at specified altitudes (or gates). Typically, the airline procedures state that if pilots determine the approach is unstable, they should conduct a go-around. However, the collective industry performance of complying with go-around policies is extremely poor, and only approximately 3% of unstable approaches result in a go-around.[1]

Studies by industry safety groups have suggested that the go-around noncompliance rate could be a significant safety hazard given that approach and landing are the most common phases of flight for aviation accidents, accounting annually for approximately 65% of all accidents.[2] A Flight Safety Foundation (FSF) study of 16 years of runway excursions found that 83% of them could have been avoided by a decision to go around; thus, 54% of all accidents could potentially be avoided by conducting a go-around.[1]

Table 1. Typical stabilized approach criteria.

	Parameter	Threshold
1	Stabilization height	1,000 ft IMC, 500 ft VMC
2	Localizer deviation	± 1/2-1 dot
3	Glideslope deviation	± 1 dot
4	V_{ref} deviation	V_{ref}-5 – V_{ref}+(10-20) kts
5	Rate of descent	1,000 ft/min
6	Power on approach	Above idle
		Appropriate with airspeed,
		approach, and condition
7	Aircraft configuration	Flaps in landing conf.
		Landing gear deployed
		Spoilers armed
8	Bank angle	Wings level 300-500 ft
		Less than 25 deg

Improving the go-around compliance rate holds significant potential in reducing approach and landing accidents; consequently, organizations such as the Commercial Aviation Safety Team (CAST), the International Air Transport Association (IATA), and the FSF have investigated the root causes of go-around noncompliance and have made recommendations for improving compliance rates.[3] Studies by these organizations have revealed many reasons for noncompliance by flight crews related to pilot judgment and company policies, including little-to-no consequence for not following the policies, lack of management awareness of the compliance rate, and pilot fatigue and situation awareness. However, one of the bigger factors is that pilots see the current stabilized approach criteria as too complex or restrictive for the operational environment.

Establishing an industry standard for missed approach criteria is challenging because of the large number of variables that influence approach and landing risk, such as aircraft state, human factors, and environmental conditions. Additionally, the criteria must be able to mitigate the approach and landing risk without being so restrictive that they cannot be realistically implemented in today's operational environment. Recently, several airlines and safety organizations, including the FSF, have established revised stabilized approach criteria based on their approach and landing risk assessments. One example of revised criteria is the guidelines published by the FSF in a 2017 report. The guidelines suggest that the go-around decision height can be lowered to 300 ft above ground level (AGL), while the 500-ft or 1000-ft gates that are used by most airlines today could be classified as stabilized approach gates where the stability of the approach should be checked but the approach can continue if deviations from the criteria can be corrected by the 300-ft gate.[1]

In addition to studies conducted by IATA and the FSF, the FAA has established a research program to evaluate current stabilized approach criteria guidance such as Advisory Circular 91-79A.[4] The overarching goal of this research is to validate recommendations from organizations such as the FSF and to determine the feasibility of developing universal, simplified go-around criteria. To address these challenges, a comprehensive research plan was developed, surveys were conducted, risk models were developed, and human-in-the-loop (HITL) flight-simulation experiments were performed. The first phase of HITL experiments was conducted during the fall of 2017, which investigated the likelihood of an abnormal landing under various approach states encompassing current stabilized approach criteria.[5] Additionally, it assessed the pilots' perception of landing risk of these approach states by removing the go-around decision-making process. The experiment was executed using a sufficiently large pilot pool and three Level D full-flight simulators to compare results among both narrow-body and wide-body aircraft as well as among the Boeing and Airbus platforms. The data collected from the experiment provided insight into which approach parameters had the strongest effect on touchdown performance and into the feasibility of using a 300-ft go-around gate.

The second phase of HITL experiments was conducted during the fall of 2018 to validate the findings and conclusions of the the 2017 study. The experiment was conducted in two parts with the following objectives: 1) investigate the effect of environmental conditions on touchdown performance under varying approach states, and 2) evaluate a proposed set of go-around criteria developed based on the results of the first phase of HITL experiments as well as FSF recommendations. This paper will detail the methodology, experiment execution, and results for the second objective of the phase II HITL study.

This paper is structured as follows: an overview of the research methodology is provided in Section II, the experiment setup is described in Section III, results are presented in Section IV, a discussion is provided in Section V, and this is followed by conclusions in Section VI.

II. Research Methodology

The primary objective of this part of the phase II HITL study was to capture pilot feedback and decision-making with regards to proposed, hypothetical go-around criteria that were developed based on FSF recommendations and the results of the phase I HITL study. Key findings from the phase I study used to develop the criteria include:

1. Equivalent approach states at 300 ft and 500 ft have similar effects on touchdown performance.
2. An unstable approach state at 100 ft AGL significantly degraded touchdown performance compared to unstable approach states at 300-ft or 500-ft; thus a 100-ft go-around gate was deemed too low.
3. V_{ref} deviation and localizer deviation at the starting approach gate had the strongest influence on perceived risk.
4. A reference speed deviation of +20 kts often results in idle thrust usage during the approach.

Because no statistically significant difference in touchdown performance was found between a starting gate of 300 ft and 500 ft, the FSF recommendation for a go-around gate of 300 ft was adopted in the proposed criteria. In this study, a distinction was made between a go-around gate and a stabilized approach gate. The go-around gate is a final, absolute check, such that if the aircraft is outside of the criteria at that gate, a go-around shall be performed. In accordance with the FSF recommendations, the criteria should also be checked at the 1000-ft and 500-ft stabilized gates. If the aircraft is outside of the criteria at these gates, the pilot monitoring should verbalize any deviations, and the pilot flying should take the appropriate actions to correct the deviations.

The parameters for the proposed go-around criteria are listed in Table 2. An airspeed deviation of +10 kts was selected to be consistent with the FSF recommendations and because the phase I study showed little difference in touchdown performance and risk assessments between V_{ref} + 0 and V_{ref} + 10 kts. Glideslope and localizer deviations of less than 1 dot where selected based on established criteria. Lastly, rather than specifying a rate of descent limit, a criterion of no terrain avoidance warning system (TAWS) alert activation was used. This approach was taken for numerous reasons. First, the phase I study showed that the rate of descent at the different gate heights had little-to-no effect on touchdown performance. Second, pilots in the phase I study were easily able to arrest any initial high rate of descent quickly. Finally, the TAWS is specifically designed to mitigate controlled flight into terrain risk and should alert the pilot of an unsafe descent rate or vertical flight path.

Table 2. Proposed go-around approach criteria.

Criteria at 300 ft		
1	Airspeed	Within 0/+10 of target
2	Glideslope deviation	Less than 1 dot
3	Localizer deviation	Less than 1 dot
4	Rate of Descent	No TAWS activation

To evaluate the acceptability of the proposed criteria, a HITL simulation experiment was developed. The primary objective of the experiment was to collect objective and subjective data on the crew's decision-making with regards to the criteria and the pilot's assessment of the acceptability of the criteria. To this end, pilots in the study flew multiple approaches that were on the borderline of the go-around criteria at 300 ft. Pilots were instructed that they could either execute a go-around or land the airplane on each run, forcing a decision for the borderline cases at 300 ft. The pilots were told to execute a go-around if either 1) the aircraft was outside the go-around criteria at 300 ft or 2) either pilot was uncomfortable with the approach; otherwise, they could land.

A secondary objective of the study was to assess the crew's awareness of the aircraft state on approach. To combine the primary and secondary objectives, each approach began stable at 1000 ft; then, the aircraft was forced unstable between 500 and 300 ft. The idea was for the aircraft to be unstable below 500 ft, but to give the pilots a reasonable chance of reestablishing a stable approach by 300 ft. Using this method has a few objectives: 1) assess the ability of the pilots to detect the instabilities, 2) evaluate the pilots' acceptance of making corrections below 500 ft down to the 300-ft go-around gate, and 3) evaluate the pilots' acceptance of executing the go-around at the 300-ft gate.

The instabilities were generated using a special simulator code below 500 ft. Three types of instabilities were developed - high airspeed, localizer deviation to the right, and glideslope deviation forcing the aircraft above the glideslope. A rate of descent deviation was not included because the high-on-glideslope condition would force a high rate of descent to recapture the glideslope. The initiation and severity of the instabilities were selected such that the aircraft would become unstable below 500 ft, but could be feasibly re-stabilized by the 300-ft gate. The initiation height and methods for generating the instabilities are summarized in Table 3. The initiation heights and methods were selected using subject matter expert input and were fine-tuned through hundreds of trials by a type-rated pilot and the experiment designers. An example aircraft trajectory with lateral instability is shown in Fig. 1.

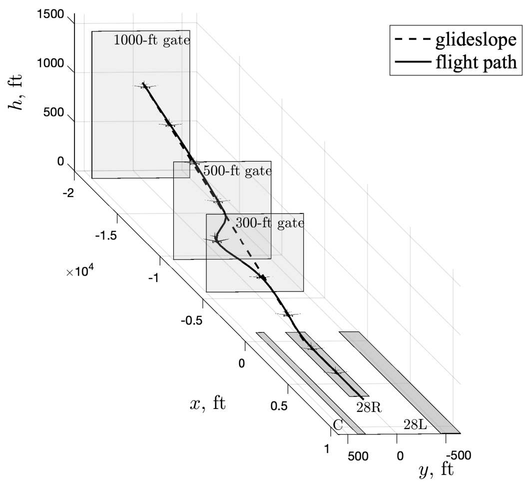

Figure 1. Mean B737 trajectory with lateral instability.

Task: approach and landing with possible go-around to SFO RWY 28R

Initial Condition: trimmed and stable on GS and LOC at 1,000 ft

Configuration: gear down, flaps full landing, speed brakes retracted

Weight: maximum landing weight

Ceiling/visibility: ceiling and visibility unlimited

Wind: 100/10 **Turbulence:** moderate **Gusts:** none

Runway: short and wet, medium braking action, RCC 3/3/3

Traffic: no traffic or departing traffic on RWY 28L (depending on run)

Procedure:

1 Recover from a possible unstable approach to SFO RWY 28R (full recovery might not be possible)

2 Apply go-around criteria and (a) continue to land on RWY 28R or (b) go-around

3a Flare and touchdown meeting, or as close to, desired touchdown criteria as possible

3b Execute the go-around

4a Task evaluation ends after the aircraft is fully stopped on the runway

4b Task evaluation ends when reaching the missed-approach altitude of 2,000 ft

Desired performance: When continuing to land:

1. Longitudinal touchdown: 1,000 –2,000 ft from threshold
2. Lateral touchdown: centerline between main wing gear
3. Sink rate at touchdown: $\leq$6 ft/s
4. Bring the aircraft to a full stop as quickly as possible

Figure 2. Experiment flight card.

During each run, the crew had to decide whether to go around or land. If the crew chose to perform a go-around, then the pilots were instructed to follow their company's go-around procedure and climb towards 3000 ft. The simulation would be terminated at 2000 ft so that the scenario was not unnecessarily prolonged. If the crew chose to land, they were instructed to land the aircraft meeting the prescribed touchdown performance criteria and then bring the aircraft to a full stop on the runway as quickly as possible by using reverse thrust and maximum manual braking. The flight card for the approach and landing or go-around with the touchdown performance criteria is provided in Fig. 2. The touchdown criteria are illustrated in Fig. 3.

III. Experiment Setup

The methodology described in the previous section was carried out using a full factorial experiment design that was conducted over 4 one-hour sessions per crew in Level D Boeing 737-800 and Airbus 330-200 simulators. In this

Table 3. Induced Instabilities.

Parameter	Target Deviation	Initiation Height (ft AGL)	Method
Airspeed deviation	V_{ref} + 20	450	wind shift to 45 KTS headwind, 5-second duration
Localizer deviation	1 dot	500	Boeing: 36 knot crosswind for 5 seconds; Airbus: lateral shift 1 dot
Glideslope deviation	1 dot	360	altitude freeze for 2 seconds

section, the development of the test matrix, the apparatus, participant selection, experiment procedures, and dependent measures will be discussed.

III.A. Test matrix and Controlled Variables

The primary independent variables were the induced instabilities provided in Table 3. Each of the primary independent variables had two possible settings: stable or unstable. Stable meant that an instability was not forced in the scenario. Unstable meant that the simulator code to produce an instability was executed in accordance with the methods described in Table 3. In addition, a traffic condition was included as an independent variable. The traffic condition was a binary variable (on or off) that determined whether a Boeing 747 aircraft was taking off from the parallel runway during the approach. The purpose of this was to determine whether traffic in close proximity of the aircraft factored into the pilot's go-around decision-making process. Using the described variables (Table 4), a test matrix was generated using a full factorial design with two repetitions per independent variable combination. This resulted in 16 experimental conditions and 32 data-collection runs per pilot.

Table 4. Independent variable settings.

Speed	Glideslope	Localizer	Traffic
Stable/Unstable	Stable/Unstable	Stable/Unstable	on/off

The fixed variables in the experiment included the starting state of the aircraft, the runway length and condition, and the environmental parameters. The initial conditions for each run are provided in Table 5.

III.B. Apparatus

The experiment was carried out using the B737-800 and the A330-200 Level D full-flight simulators located at the FAA Mike Monroney Aeronautical Center in Oklahoma City (Figs. 4 and 5). Testing both aircraft types provided the ability to evaluate the criteria among both narrow-body and wide-body aircraft, and among the Boeing and Airbus platforms.

Table 5. Initial Conditions.

Parameter	Setting
Radio altitude	1000 ft
Glideslope deviation	0 dots
Localizer deviation	0 dots
Sink rate	900 ft/min
Visibility	Unlimited
Wind	10 knot tailwind
Runway length	7500 ft
Runway condition	Wet RCC 3/3/3

Both simulators were from the same manufacturer and used in their standard configurations. Differences between simulators existed because of the different years of initial operation and the different aircraft types simulated. Care was taken to make all basic aircraft and environmental settings as similar as possible between simulators. For example, cockpit radio-altitude and warning call-outs, turbulence intensity, and runway and radio-navigation-aid geometries were equalized to provide pilots with similar basic cues across simulators. Motion cues were provided in each simulator using the standard motion logic settings. The B737 simulator has a hydraulic hexapod motion system, and the A330 simulator uses an electric hexapod motion system.

All approaches and landings were flown without any automation engaged. Autopilots, autothrottles, autobrakes, and flight directors were turned off. The primary flight display (PFD) depicted conventional localizer and glideslope

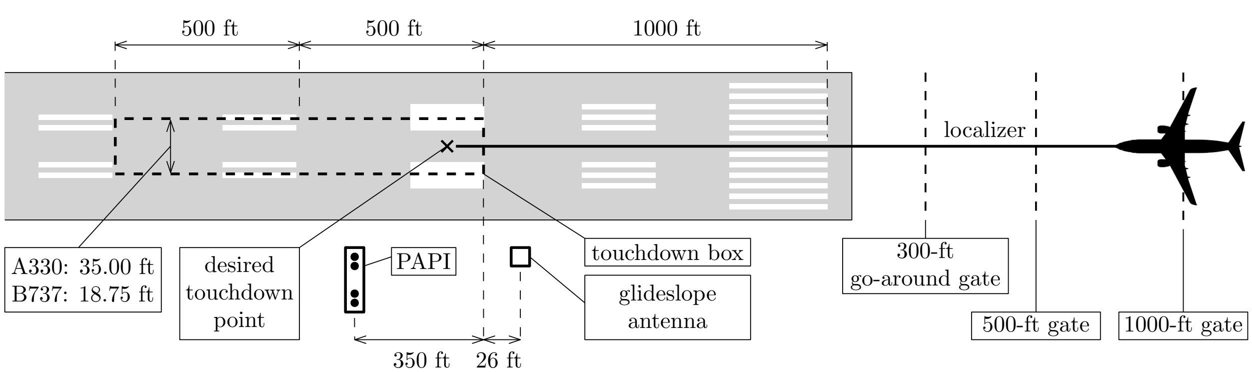

Figure 3. Touchdown zone definition.

Figure 4. B737-800 simulator.

Figure 5. A330-200 simulator.

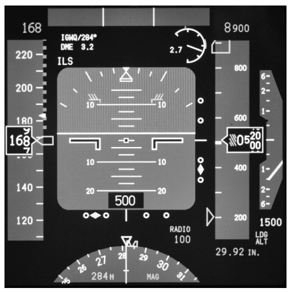

Figure 6. B737-800 PFD.

Figure 7. Out-the-window view.

error indicators. Fig. 6 shows the PFD in the B737-800 simulator. The corresponding out-the-window visual is provided in Fig. 7. Note that in this condition, the aircraft is approximately lined up with the taxiway to the right of runway (RWY) 28R at San Francisco International Airport (SFO).

Pilots used tablets to fill out questionnaires after each run. These tablets were mounted on the left and right sides of the simulator cabs for the captain and first officer, respectively, for easy access.

III.C. Participants

Six crews comprised of a captain and a first officer from the same airline participated in each simulator, resulting in a total of 12 crews, or 24 pilots, for the entire experiment. All A330 and B737 pilots were current and qualified as captain or first officer in a Part 121 carrier. All pilots gave written consent for their participation and received compensation.

III.D. Procedures

Each crew participated in two studies scheduled on two consecutive days. (This paper discusses the study conducted on the second day.) On the first day, crews received an extensive pre-experiment briefing, explaining the schedule, task, conditions, and procedures of the test. Crews were told that the experiment investigated the effects of different approach parameters on landing performance and were given no specifics about the true nature of the experiment. After the briefing, pilots provided their informed consent and filled out a pre-simulation questionnaire. This questionnaire gathered demographic data and information on their airline's current stable approach criteria, and asked about their satisfaction with those criteria. The day 1 experiment began after a simulator safety briefing.

During day 1, each pilot flew a total of 92 approaches and landings to a shortened version of SFO 28R (7,500 ft in the simulator compared to 11,870 ft in reality).[6] For this part of the experiment, the pilots were positioned in various initial conditions, and the pilots were asked to land every scenario (i.e., no go arounds were allowed). At the conclusion of day 1, the pilots completed a post-simulation questionnaire and a verbal debrief was completed.

On the second day of the experiment, pilots were provided a briefing document, a flight card (Fig. 2), and a laminated card with the proposed go-around criteria. The pilots were briefed on the schedule, procedure, and go-around criteria. It was stressed to the pilots that the pilot monitoring should check the criteria at 500 ft, and either pilot should call for a go-around at 300 ft if the aircraft was outside of the criteria or if he/she felt uncomfortable with the approach.

Following the briefing, each crew flew 72 approaches divided among four 1-hour simulator sessions. Each pilot flew 4 training scenarios followed by the full test matrix. The runs were randomized for every pilot, and the pilots alternated between pilot-flying and pilot-monitoring roles between each session. The first four runs of the first session were training runs with nominal approach conditions. The pilots were asked to land the first two training runs and conduct a go-around at 300 ft for the second two training runs.

The pilot flying flew each approach and the crew either landed or performed a go-around during each scenario. The pilots were told prior to each run whether there was departing traffic on the parallel runway to make sure the pilots were completely aware of the situation. During the approach, the pilot monitoring was tasked with calling out any deviations from the go-around criteria and then was to call for a go-around if the criteria were not met at the 300-ft go-around gate. If the crew chose to conduct a go-around, they used their company's standard operating procedure and climbed towards the missed approach altitude of 3000 ft. The evaluator terminated the simulation as the aircraft passed through 2000 ft. If the crew chose to land, the pilot flying was asked to meet the touchdown criteria as closely as possible and then to use maximum manual braking and full reverse thrust to bring the aircraft to a complete stop on the runway. The pilot monitoring was allowed to provide call-outs to assist the pilot flying, as per their airline policy or personal preference. After the aircraft had come to a complete stop, the simulator was repositioned for the next run, and the pilots completed their post-run questionnaires on their tablets (see Section III.E).

After completing all simulator runs, pilots filled out a post-simulation questionnaire. This questionnaire asked about the pilots' preferred stable approach criteria based on their experiences during the experiment, and about which factors influenced their decision to go around the most. Finally, each crew received a debriefing providing more details about the true nature of the experiment. The experiment described in this paper took place on the second day of testing.

III.E. Dependent Measures

Three dependent measures were captured for runs that passed through the 300-ft gate: target airspeed deviation, glideslope deviation, and localizer deviation (ΔV_{target}, ΔGS, and ΔLOC). These measures were compared to their respective go-around criteria thresholds (Table 2).

Next, different dependent measures were captured depending on whether the crew performed a go-around or landed during each run. If the pilots chose to go around, the primary dependent measures taken at the initiation of the go-around included: altitude, target airspeed deviation, localizer deviation, glideslope deviation, and rate of descent deviation (h, ΔV_{target}, ΔGS, ΔLOC, and $\Delta \dot{h}$). The go-around initiation point was defined as the point 2 seconds before the point with the maximum throttle increase over 1 second. During the go-around execution, three dependent measures of the maximum aircraft state were captured: maximum pitch θ_{max}, maximum angle of attack α_{max}, and maximum load factor $n_{z\ max}$.

If the run ended in a landing, three main objective dependent measures specifying the landing performance were recorded and analyzed: longitudinal and lateral touchdown location (x_{td} and y_{td}) and sinkrate at touchdown ($\dot{h}_{td}$). These measures related directly to the landing performance criteria pilots had to meet (Fig. 2). Data capture for these variables occurred when the main gear touched the runway. When multiple touchdowns were recorded (i.e., a bounced landing occurred), the maximum longitudinal distance and maximum sinkrate out of all touchdowns were used. The lateral distance always corresponded with the maximum longitudinal distance. In general, this meant that for a bounced landing, the sinkrate used belonged to the first touchdown, and the longitudinal and lateral touchdown location used belonged to the last touchdown.

Subjective dependent measures were recorded using a questionnaire administered on a tablet computer at the end of each run. Pilots first rated their workload, fatigue, and perceived risk of the completed landing or go-around (in that order) on a 20-point scale by moving a slider bar with their fingers. Only the ends and midpoints of the slider bars were marked with "low," "average," and "high." Next, pilots were asked about the acceptability of the 300-ft decision height and the go-around criteria from an operational safety point of view. Once again, a slider bar with a 20-point scale was used. The low end of the scale was marked as "clearly unacceptable," the middle as "indifferent," and the high end as "clearly acceptable." Next, the pilots were asked if they performed a go-around. If they responded with a yes, three questions followed. The first asked about the factors influencing their decision. The factors were selected from a list including the following: slow, fast, low descent rate, high descent rate, below glideslope, above glideslope, localizer deviation, power setting, bank angle, wind, visibility, turbulence, runway length, and runway condition. Then, the second and third questions asked the pilot if his/her decision would have been different if the runway was longer or the braking action was better. If the pilot answered no to the question about whether a go-around was conducted, he/she was asked one additional question: were the go-around criteria met at 300 ft. The purpose of this question was to gauge whether the pilot was aware of the aircraft approach state at the 300-ft gate. Note: both the pilot flying and the pilot monitoring filled out the post-run questionnaire, resulting in two sets of subjective data for each run.

IV. Results

Data were successfully captured from all 24 participants in the HITL study. Data from the simulator and tablet questionnaires were parsed using MATLAB® and then analyzed using various tools including MATLAB® and JMP®[7].[8] Statistical analyses were conducted using JMP®. In this section, the results and data analysis will be presented for both the objective performance data and subjective questionnaire responses. The traffic condition (departing traffic from runway 28L) did not introduce significant differences in the results. Therefore, for brevity, the traffic condition is not discussed further in the remainder of this section, and data are aggregated over the traffic conditions in all tables and figures. Depended measures are depicted in histograms. Continues black lines indicate the medians of the data and dashed black lines indicate the proposed go-around criteria boundaries or touchdown performance criteria boundaries, if applicable.

IV.A. Performance Data

Simulator data were collected from all 64 measurement runs of each crew (768 runs in total). The primary goals of the analysis of the dependent measures were to determine which approach parameters, if any, had the strongest influence on the run outcome, and to evaluate the implementation of the proposed go-around criteria. Each run had two possible outcomes: a go-around or landing. Different sets of dependent measures were collected from each run depending on the outcome. Of 768 total runs, 416 resulted in a go around, and 352 runs resulted in a landing.

A decision tree was constructed using JMP® to analyze the factors that determined whether a flight landed or went around.[9] A condensed version of the decision tree is shown in Fig. 8. The parameters shown in the figure include: the count of runs in each split of the tree; the likelihood-ratio chi-square splitting criterion value (G^2); the LogWorth statistic ($-log_{10}(p\text{-value})$); the response levels coded as 0-flight landed and 1-go around performed; and the rate, predicted probability, and count of each response level in each branch.

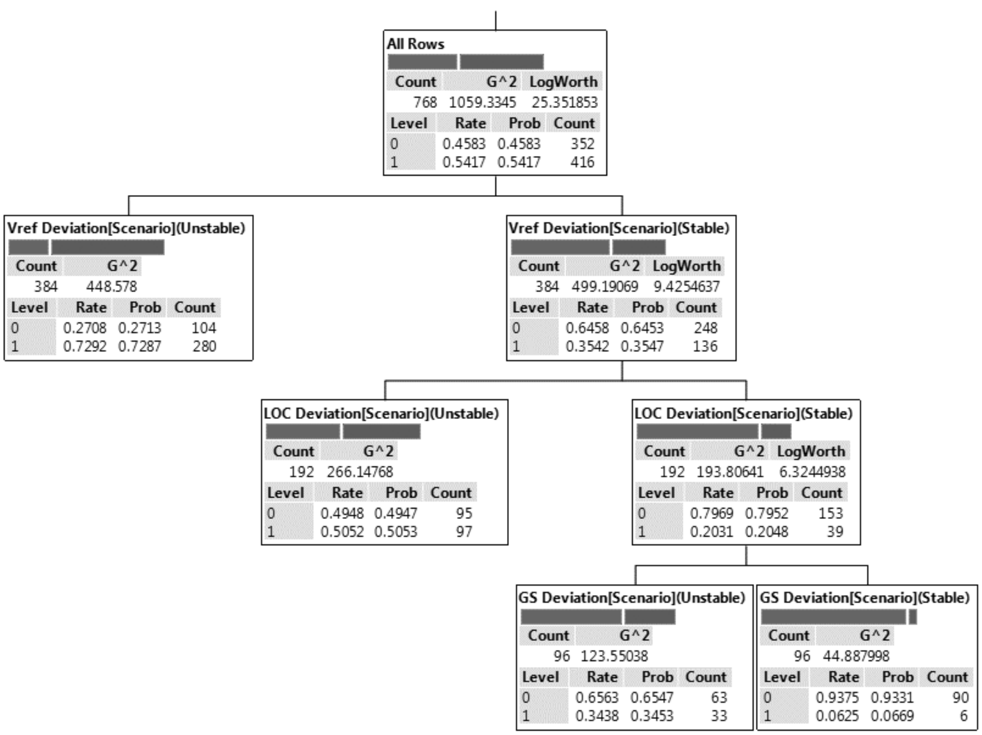

Figure 8. Go-around decision tree.

The factors included in the model were airspeed condition, localizer condition, glideslope condition, traffic condition, and pilot number. The first split in the decision tree was the airspeed condition; meaning that airspeed had the strongest influence on the go-around decision. If airspeed was unstable, the next split was by pilot number; in fact, if the airspeed condition was active, six of the pilots would always perform a go around. If airspeed was stable, localizer condition had the strongest influence on the go-around decision followed by pilot number. There were five pilots who performed a go-around every time the localizer condition was activated.

IV.A.1. Analysis of Go-Around Runs

Runs that resulted in a go around were analyzed at three points. First, the approach state at the 300-ft gate and the initiation of the go around was captured, including height above ground, airspeed, localizer deviation, glideslope deviation, and rate of descent. Next, the maximum values of several critical aircraft parameters (pitch, angle of attack, and load factor) during the go around were captured to investigate if any go arounds resulted in undesired outcomes.

Fig. 9 summarizes the aircraft state with respect to the proposed criteria at the point of go-around initiation for the 416 runs that a go-around was performed. Fig. 9 indicates that for the runs that resulted in a go around, in more than 50% of the cases, the go around was initiated before reaching the 300-ft gate. That is, of 416 go-around runs, 231 (109 runs in the Boeing and 112 runs in the Airbus) went around above the 300-ft gate. Approximately 20% of the go-around runs were stable at 300 ft. The remaining runs that performed a go-around violated one or more of the go-around criterion. The majority of B737 runs that performed a go around after being unstable at 300-ft violated the airspeed criterion. In the A330, the airspeed criterion was less frequently violated; however, significantly more violations of the glideslope criterion occurred.

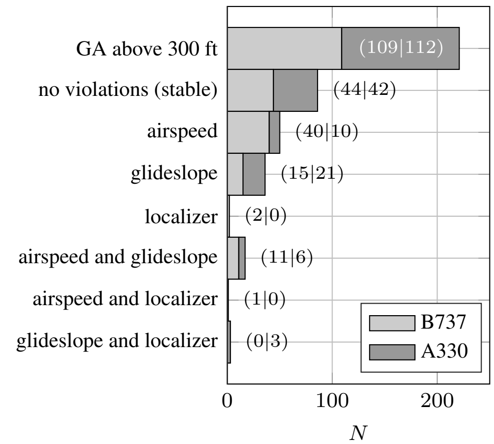

Figure 9. Aircraft state at go-around initiation for go-around runs with respect to violation of go-around criteria ($N = 416$).

Fig. 10 provides a histogram of the go-around decision altitude for both aircraft types (Median (Mdn) = 366 ft and 376 ft for the B737 and A330, respectively). This result indicates, in line with the data in Fig. 9, that pilots frequently made the decision to go around before the 300-ft gate. Fig. 9 also indicates the portion of runs for which the TAWS was activated. The TAWS was activated more frequently in the B737 compared to the A330. A go around was initiated because of a TAWS activation much more frequently below 300 ft in the B737.

Rate-of-descent deviations with respect to the TAWS critical rate of descent at the go-around initiation are shown in Fig. 11. A negative rate of descent deviation means the TAWS was activated when the go-around was initiated. The median rate-of-descent buffer above the TAWS critical rate of descent was 11.8 ft/s in the B737. In the A330, the median rate-of-descent buffer was 15.6 ft/s. In line with Fig. 10, more runs in the B737 compared to the A330 had a TAWS activation, indicated by negative values of $\Delta\dot{h}$.

Histograms of target airspeed, glideslope, and localizer deviations, and rate of descent at the go-around initiation are shown in Fig. 12. A negative localizer deviation means the aircraft was to the right of the runway; that is, the direction of the introduced instability. B737 and A330 data are depicted in separate plots. As can be seen from the distributions, pilots were often too fast and above glideslope when a go-around was initiated. However, median target airspeed and glideslope deviations were still relatively small (Mdn = 8.1 kts and 0.1 dot, and 5.2 kts and 0.2 dot for the B737 and A330, respectively). Fig. 12 indicates that for most runs, the localizer deviation was less than 1 dot when a go around was initiated (Mdn = -0.2 dot and -0.1 dot for the B737 and A330, respectively). Most localizer deviations

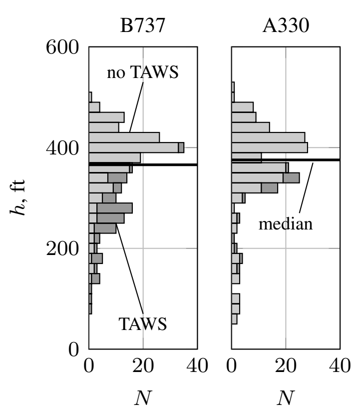

Figure 10. Height above ground at go-around initiation.

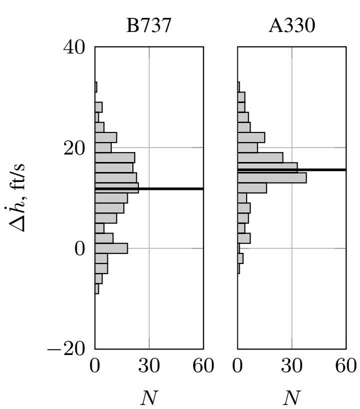

Figure 11. Rate-of-descent deviation at go-around initiation.

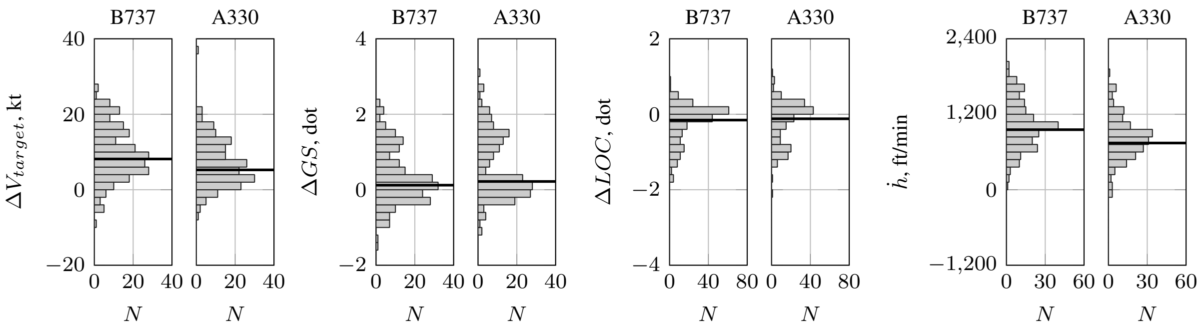

Figure 12. Aircraft state at go-around initiation.

were to the right of the runway. Finally, the median rate of descent at the go-around initiation for the B737 was 955 ft/min or close to the nominal rate of descent of 900 ft/min. The median rate of descent at go-around initiation for the A330 was 743 ft/min. The rate of descent reached values as high as 1922 ft/min and 1781 ft/min in the B737 and A330, respectively. Comparing the B737 and A330 data in Fig. 12, the distributions and medians are similar.

Fig. 13 provides histograms of maximum pitch attitude, angle of attack, and load factor during the go-around maneuver. The start of the go-around maneuver was the point where the go around was initiated. No extreme values were observed for most runs. However, in some runs, the maximum angle of attack reached values as high as approximately 14 deg, and the maximum load factor reached values as high as 2 g.

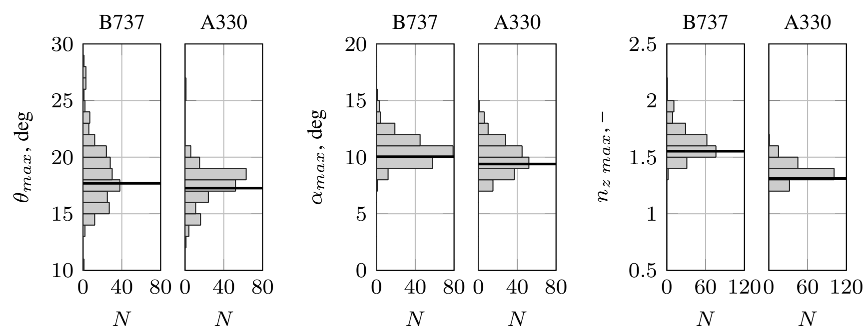

Figure 13. Maximum aircraft state during go around.

IV.A.2. *Analysis of Landing Runs*

Runs that resulted in a landing were analyzed at two points. First, the approach state at the 300-ft gate was captured, including airspeed, localizer deviation, glideslope deviation, and rate of descent. The data were used to determine whether each run was stable. Then, the touchdown performance was analyzed with respect to the introduced instabilities and the aircraft state at the 300-ft gate. The goal was to determine whether the touchdown performance of the flights outside of the go-around criteria at 300 ft were degraded compared to the flights that were inside of the criteria at the go-around gate.

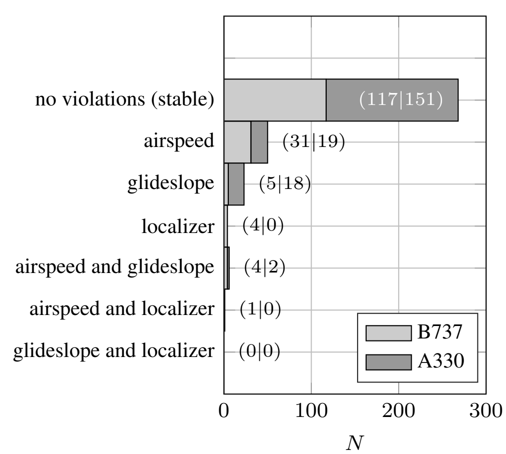

Figure 14. Violated criteria for landing runs ($N = 352$).

Fig. 14 provides the percentage of runs for which the aircraft was on a stable approach or outside of one or more of the proposed go-around criteria at the 300-ft gate for the runs that resulted in a landing for both aircraft types. Fig. 14 indicates that for approximately 75% of the runs that resulted in a landing, the approach was stable at 300 ft. Of the 162 runs in the Boeing simulator that continued to the landing, 45 runs did

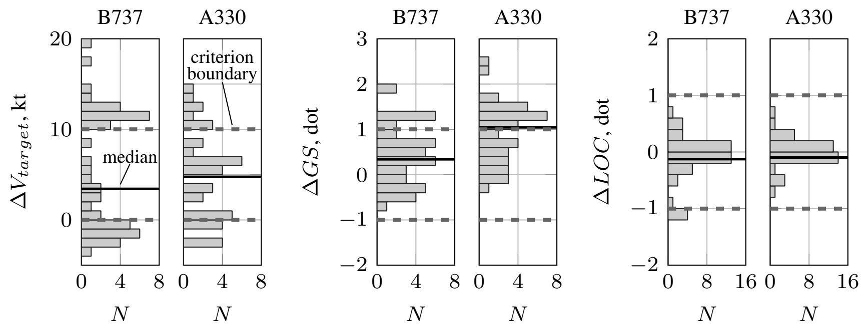

Figure 15. Target airspeed, glideslope, and localizer deviations at 300 ft for unstable landings.

not meet the go-around criteria at the 300-ft gate. Thirty-nine runs in the A330 simulator were unstable at 300 ft and landed. The majority of Boeing runs that continued to land after being unstable at 300 ft violated the airspeed criterion. In the Airbus simulator, the airspeed criterion was less frequently violated; however, significantly more violations of the glideslope criterion occurred.

Histograms of target airspeed, glideslope, and localizer deviations at 300 ft for the unstable landings are shown in Fig. 15. B737 and A330 data are depicted in separate plots. Similarly to Fig. 14, Fig. 15 indicates that more violations of the target airspeed criterion occurred in the smaller B737, and more violations of the glideslope criterion occurred in the larger A330. The aircraft was both too slow or too fast for some runs in both aircraft types. Note that the target airspeed for the B737 was 153 kts, and for the A330 was 141 kts ($V_{ref} + 5$ kts). Of the B737 flights that violated the airspeed criterion, only two runs violated the criterion by more than 5 knots. When the glideslope criterion was violated, the aircraft was always too high; that is, above glideslope. Only a few violations of the localizer criterion occurred in the B737, and none in the A330 (Fig. 15).

Touchdown parameters (longitudinal touchdown point, lateral touchdown point, and sink rate at touchdown) were analyzed to determine if the unstable flights at 300 ft had degraded touchdown performance. The touchdown performance parameters for runs that were stable or unstable at 300 ft are depicted in Fig. 16. This figure shows aggregate B737 and A330 data. Fig. 16 indicates that pilots generally landed long for stable and unstable landings (Mdn = 700 ft or 653 ft from the start of the touchdown box for stable and unstable approaches, respectively). Pilots generally landed well within the lateral touchdown criteria (Mdn = 1.5 ft or 0.7 ft from the centerline, respectively). Finally, pilots mostly landed with a sinkrate below 6 ft/s for stable and unstable landings (Mdn = 4.24 ft/s and 4.42 ft/s, respectively). A one-way ANOVA was performed on each type of instability (airspeed, glideslope deviation, and localizer deviation) vs. each touchdown parameter (longitudinal touchdown point, lateral touchdown point, and sink rate at touchdown). The results, summarized in Table 6, show that the state of the aircraft (stable vs. unstable) at 300 ft did not significantly impact touchdown performance. This is also evident from the similar distributions of landing performance parameters for stable and unstable landings in Fig. 16.

Table 6. Oneway ANOVA F, p-values for the effect of instabilities on touchdown performance.

		Dependent Measures					
		Longitudinal TD Point		Lateral TD Point		Sink Rate at TD	
Independent Variables	df	F	p	F	p	F	p
Airspeed unstable	1,349	0.5164	0.4729	0.6809	0.4098	2.6526	0.1043
LOC unstable	1,349	0.0055	0.9409	0.0067	0.9349	0.2190	0.6401
GS unstable	1,349	0.0418	0.8381	3.8713	0.0499	1.8856	0.1706

(shaded) = significant ($0.01 \leq p < 0.05$)
(unshaded) = not significant ($p \geq 0.05$)

IV.B. Subjective Data

The subjective data were analyzed to better understand the pilots' perceptions of each approach and their opinions of the acceptability of the proposed go-around criteria. Subjective data were collected from a written pre-simulation questionnaire, tablet questionnaires following each run, and a written post-simulation questionnaire that was completed at the conclusion of the experiment. The tablet questionnaire data provided information on the pilot's assessment of

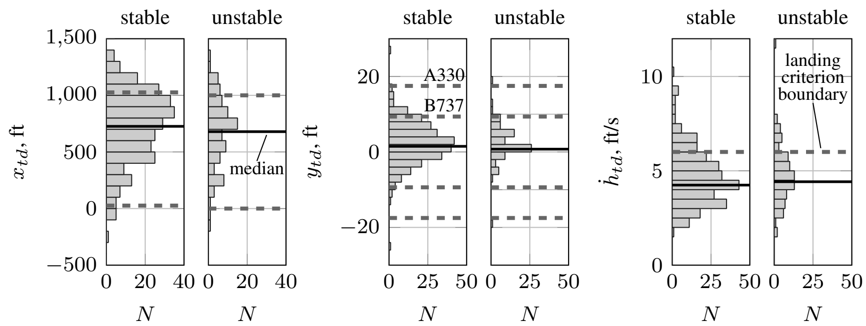

Figure 16. Landing performance for stable and unstable landings (aggregate B737 and A330 data).

Table 7. Workload and risk mixed model analysis statistics.

Independent Variables		Dependent Measures			
		Workload		Risk	
	df	*F*	*p*	*F*	*p*
Localizer Deviation	1,1506	55.8126	<.0001	80.8755	<.0001
Glideslope Deviation	1,1506	5.5712	0.0184	8.4510	0.0037
V_{ref} Deviation	1,1506	48.0169	<.0001	81.6296	<.0001

= highly significant ($p < 0.01$)
= significant ($0.01 \leq p < 0.05$)
= not significant ($p \geq 0.05$)

each approach and go-around or landing. Additionally, the pilots provided feedback through the tablet questionnaire on the acceptability of the proposed criteria and go-around gate. In this section, a numeric analysis of the tablet data is presented, followed by a summary of the written questionnaire responses.

IV.B.1. Tablet Data

The tablet data analysis was driven by the following set of research questions: 1) what effect did the introduced instabilities have on perceived workload, fatigue, and risk, 2) did the pilots in the study find the 300 ft go-around gate acceptable, 3) did the pilots in the study find the proposed criteria acceptable, and 4) what factors had the strongest influence on the pilots' decision to go-around?

To answer the first question, a mixed model was constructed for workload, fatigue, and risk using the injected instabilities and run number as the fixed effects and the pilot ID number as a random effect.[10] The mixed model results revealed a number of findings. First, the variability in the response was driven more by the pilot than the fixed effects. In fact, the model estimated that over 70% of the variability in the responses could be attributed to the pilots. Less than 30% of the variability was driven by the approach parameters. Nonetheless, as demonstrated in Table 7, the analysis did reveal that introducing instabilities in the approach did have a statistically significant effect on workload and risk responses. Particularly, if an V_{ref} deviation or localizer deviation was injected into the scenario, workload and risk assessments increased. Glideslope deviation had a significant effect on the responses, but its effect was not as strong as V_{ref} deviation and localizer deviation. The fatigue response was primary a function of pilot ID (accounting for 87.7% of the variability in the response) and run number ($F = 12.2966$, $p < .0001$). The approach parameters had little effect on fatigue scores.

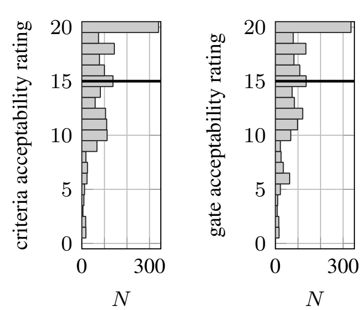

Figure 17. Subjective ratings of criteria and gate height acceptability.

To address questions 2 and 3, pilots were asked to rate the acceptability of the go-around criteria and the 300 ft go-around gate for that particular run on a scale of 1 to 20 with 1 being completely unacceptable and 20 being completely acceptable. In general, pilots rated the acceptability of the criteria and the proposed 300 ft go-around gate high. The histograms of the responses are shown in Fig. 17. A mixed-model analysis determined that if a V_{ref} deviation occurred during a run, the pilots tended to rate the acceptability of the gate height and criteria slightly lower than the nominal case. The localizer deviation had a marginal effect on the gate height acceptability ratings, but glideslope deviations had no effect on the ratings.

Pilots were also asked if they performed a go-around to select the reasons that influenced their decision. Pilots were allowed to select multiple parameters. The options that the pilots could select on the tablet questionnaire and the percent of the go-around runs that each parameter was selected are summarized in Table 8. As shown in the table, the top two reasons that pilots chose to perform a go-around was too fast or localizer deviation.

If the pilots chose to perform a go-around, they were also asked if their decision would have been different if the runway was longer or had better braking action. After less than 1% of the runs, the pilots said they would have landed if the runway had been longer, and after all the runs the pilots responded that they would have made the same decision to go around if the runway condition had been better.

If the pilot landed a run, they were asked whether the go-around criteria were met at 300 ft. The response was compared to the aircraft state at 300 ft from the simulation data to evaluate the pilot's awareness of the aircraft state at 300 ft. The pilots response on whether the aircraft was stable at 300 ft was consistent with the simulator data for 487 out of 587 cases that the pilots said a landing was performed (470 stable and 17 unstable). The pilots reported being unstable 27 times at 300 ft, even though the aircraft was stable based on simulator data. In 73 cases, the pilots reported being stable, but the aircraft was actually unstable based on the simulator data. Typically in these cases, either the airspeed criterion (36 cases) or the glideslope criterion (50 cases) was violated. Only during 10 cases did the pilots mistakenly think that the localizer criterion was met. There were only six occurrences when two criteria were violated, but the pilot thought the aircraft was stable; in every other case, only one criterion was violated.

IV.B.2. Written Questionnaire Responses

In addition to the tablet survey after each run, pilots completed a written questionnaire after the completion of the experiment. In the first question, the pilots were asked whether they found the proposed criteria acceptable from an operational and safety point of view. Ten of 24 pilots stated they thought the new criteria were unacceptable. Five of the pilots that found the criteria unacceptable stated that the 300-ft gate was too low, and they would be more comfortable with a 500-ft gate. Other reasons for not finding the criteria acceptable included wanting tighter tolerances on localizer and glideslope deviation and wanting language allowing momentary deviations. Several pilots who stated that the criteria were acceptable noted that they felt the criteria maintained safety while being simple to follow.

In the second question, the pilot was asked whether he/she believed that the proposed criteria were an improvement over their airline's current policy. Eleven pilots responded yes, 11 responded no, and 2 stated they had no preference. Seven of the pilots that stated they preferred their airline's criteria said they preferred a 500-ft or 1000 ft gate. Reasons pilots gave for responding that the criteria were an improvement included: the criteria were simple, easier to train, better defined, and kept the pilot monitoring engaged.

Table 8. Reasons for performing a go-around.

Parameter	Percentage of runs
Too fast	46.2 %
Localizer deviation	41.1 %
Above glideslope	31.0%
High rate of descent	24.9 %
Wind	23.4 %
Runway length	14.4 %
Turbulence	12.6 %
Runway condition	12.1 %
Power setting	7.6 %
Bank angle	5.6 %
Below glideslope	4.5 %
Too slow	4.1 %
Low rate of descent	0.6 %

The third question asked the pilots if the 300-ft decision height should be changed. Half the pilots said yes, and the other half said no. Of the pilots that said the gate should be changed, seven said the gate should be at 500 ft, two said that the gate should be at 500 ft VMC and 1000 ft IMC, one said the gate should be at 200 ft, and one pilot did not provide an alternative gate height.

In the fourth question, the pilots were asked how they would change the proposed criteria based on what they experienced in the simulator. The pilots were given eight options for parameters to select and a field to enter a value for each selected parameter. The results are summarized in Table 9. The first column of the table shows each parameter and the number of pilots who selected to change the value from the proposed criteria. The third column shows the number of pilots who stated that the criteria should be changed to the value in the second column. The counts in column three do not always sum to the response total in the first column because some pilots checked that a parameter should be changed, but did not provide a value.

The final question of the written questionnaire allowed the pilots to leave open-ended remarks about the study. In general, many pilots stated they enjoyed the study and found the experience valuable. Four pilots reiterated their view that the proposed criteria are good. Two pilots urged that the gate should be at 500 ft or 1000 ft.

Table 9. Post simulation written questionnaire responses for question 4.

	Value	Count
Lateral deviation - 7 responses	0.5 dots	3
	1 dot	2
Vertical deviation - 8 responses	0.5 dot	2
	1 dot	1
	1.5 dot	3
Rate of descent- 9 responses	1000 ft/min	8
Airspeed - 12 responses	0/+10	4
	0/+15	1
	-10/+10	1
	-5/+10	1
	-5/+15	1
Bank angle - 7 responses	10	1
	15	2
	5	1
	7	1
	8	1
Configuration - 6 responses	Final configuration	1
	Fully configured	4
	Gear/flaps	1
Power setting - 10 responses	Spooled	5
	Stable and spooled	1
	Stabilized	4

V. Discussion

The results of the study provided valuable insight into go-around decision making and the acceptability of the proposed 300-ft go-around gate and criteria. Using the results and analysis that were presented in the previous section, several observations were made with regard to go-around decision making and the proposed gate height and criteria.

V.A. Observations on Go-Around Decision Making

Based on the survey results, the decision to go around was solely based on the state of the aircraft on approach; fewer than 1% of the respondents said their decision would have been different if the runway was longer, and no pilots said their decision would have been different if the runway condition were better. The pilots in the study noted this was because the acceptability of the runway had been determined well before this stage of the approach.

The analysis presented in the previous section demonstrated that high airspeed was a key driver in the go-around decision-making process. High airspeed was the number one reason that pilots selected when completing the question on why a go around was performed, and the decision tree analysis performed on the result of runs showed that the injected airspeed instability had the strongest effect on the outcome of each run. Localizer deviation was found to be the second-most-important factor in the go-around decision based on analysis of both the objective and subjective data. The results showed that glideslope did not have a strong influence on the go-around decision, which might have been a consequence of the pilots flying possibly using visual guidance instead of the ILS.

One acknowledged shortcoming of the experiment is that the induced instabilities are highly unlikely to occur in real operations making several of the pilots uncomfortable and possibly leading to a higher number of go arounds. This is especially true for the induced localizer instability. However, pilots also might have been quicker with correcting the instabilities, as the nature of the instabilities became apparent after the first few runs and pilots might have started to anticipate them, leading to fewer go arounds.

V.B. Acceptability of Proposed Go-Around Gate and Criteria

The tablet questionnaire data revealed that, generally, pilots rated the acceptability of the gate height and criteria high after each run; however, only 60% of the pilots stated the gate height and criteria were acceptable during the post-simulation written questionnaire at the end of the experiment. Many of the pilots that found the proposed gate height and criteria unacceptable preferred a 500 ft or 1000 ft go-around gate. Several of these pilots expressed concern about the risk of a 300-ft gate and did not believe there was a sufficient reason for lowering the gate height. The go-around decision point data supports this finding because more than half of the go arounds were executed prior to the 300-ft gate. However, several pilots stated that they were uncomfortable with the induced instabilities and chose to perform a go around as soon as the aircraft became unstable, which might have skewed the data.

Although the tablet responses on the acceptability of the gate height and criteria were mostly favorable, analysis of the tablet questionnaire data showed that the pilots rated the acceptability of the criteria and gate height lower when airspeed was high. This could be a result of the compressed time-line before landing when the aircraft is fast. One takeaway from this outcome is that having checks of stability earlier in the approach is important to ensure that the aircraft is either within or trending to the stability criteria well before the 300-ft mark.

One measure of the validity of the proposed criteria was how often it was violated during the experiment. In the B737, the criterion most often violated before landing was the airspeed limit. However, most were only 1 or 2 knots over the upper bound of the airspeed criterion. This highlights one of the difficulties in setting hard limits for stabilized approach criteria. Even though these flights were technically outside of the criteria, their landing performance was indistinguishable from the stable flights. For this reason, many pilots recommended that momentary deviations be permitted.

In the A330, most of the unstable flights that landed violated the glideslope criterion. One possible reason for this is that the pilots may have switched to a visual approach rather than using the ILS guidance. For this particular runway, the PAPI and ILS do not coincide, meaning that if the pilot was using the PAPI rather than the ILS, the glideslope could trend towards unstable. Additionally, in a wide-body aircraft, the ILS antenna is relatively far from the pilot's eyes, creating more discrepancy between ILS and visual guidance. This finding demonstrates the difficulty in defining hard limits for flight-path deviations. The several types of guidance that a pilot might be following to land the aircraft have to be considered; meaning either the criteria might have to be more complex to cover all types of flight path guidance, or flight path can only be loosely defined using such wording as ”on flight path.”

One question the pilots were asked after a run was landed was whether the aircraft was stable at 300 ft. This was to gauge whether pilots were able to correctly assess the approach relative to the proposed criteria. In most cases, based on the tablet responses, pilots correctly identified whether the aircraft was stable at the 300-ft gate. When the pilots did misclassify the stability of the aircraft, they were typically either too fast or off the glideslope. It is possible that the turbulence made it difficult to determine whether the airspeed was stable. In many cases, the aircraft was only a couple knots fast, which is within the amount of airspeed fluctuation caused by moderate turbulence. These fluctuations might have led the pilot to believe the criteria were met when technically they were a little fast. The glideslope misclassification likely was affected by the PAPI and ILS not coinciding for the runway. Again, this highlights the difficulty of setting hard limits on approach parameters, and perhaps momentary deviations should be allowed.

In general, the acceptability of the criteria was highly dependent on each pilots personal risk tolerance; therefore, it is unlikely that criteria can be developed that will satisfy every pilots mental model of a stable approach. As the tablet and written questionnaire responses showed, pilots in the study were split on whether the proposed criteria and gate height were acceptable. The pilots who found the criteria unacceptable had a variety of reasons for their assessment, such as lack of an engine spooled parameter, lack of a rate of descent limit, and finding the airspeed criterion overly restrictive.

VI. Conclusions

An experiment was conducted using B737-800 and A330-200 Level D full-flight simulators with the objective to capture pilot feedback and decision-making with regard to proposed, hypothetical, go-around criteria developed based on previous research, and to assess crews' awareness of the aircraft state on approach. Twenty-four type-rated airline pilots were briefed on proposed, hypothetical go-around criteria and flew 36 approaches. Data from a total of 786 approaches were captured and analyzed.

The captured objective simulation data were analyzed using techniques including mixed-model analysis and decision-tree analysis to evaluate the proposed criteria and to better understand the go-around decision-making process. In addition, subjective data collected through post-run questionnaires administered on a tablet and post-simulation written questionnaires captured each pilot's opinion of the the proposed criteria.

Using the subjective and objective data analysis, a number of conclusions were drawn:

1. The objective data suggest that a 300-ft gate is viable with some criteria adjustments such as adding an engine spooled parameter or rate of descent threshold. In general, pilots rated the acceptability of the criteria and the proposed 300-ft go-around gate high at the end of each run. However, 40% of the pilots were uncomfortable

with the 300-ft gate after completing the experiment. Placing more emphasis on checking approach stability and using active call-outs at 1000 ft and 500 ft above ground level might make more pilots comfortable using a 300-ft go-around gate. Additional training might be needed to reinforce the concept of having two stabilized approach gates and a go-around gate.

2. The most important factors that drove go-around decision making during the experiment were airspeed and localizer deviation.

3. Allowing for momentary deviations from a stabilized approach should be considered.

4. The acceptability of the criteria is highly dependent on each pilot's risk tolerance.

In conclusion, the objective and subjective results provided valuable information needed to develop updated go-around criteria. The proposed criteria performed well, and most pilots would find the criteria acceptable with some minor adjustments. The next steps of the research are to further evaluate the operational implications of the proposed criteria and to further study abnormal states during go arounds. With this approach, unstable approach rates might be reduced, and overall approach and go-around safety can be increased.

Acknowledgments

The authors would like to thank the simulation engineers and support personnel who contributed to the experiments. We especially thank Randall Cooper, Ricky Zoellner, and Larry Miller from the Flight Operations Simulation Laboratory at the FAA Mike Monroney Aeronautical Center in Oklahoma City for their valuable contributions in setting up and running the experiments. We also thank Doug Rodzon for being a test pilot on the A330 simulator. We would like to thank Hossein Eghbali from the FAA William J. Hughes Technical Center for the continued program support. Finally, we would like to thank the pilots who participated in the experiments and experiment-planning workshops.

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