Statistical Analysis of Recent Go Around Flight Data to Study and Evaluate Skilled Pilot Monitoring

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A statistical analysis was performed on a batch of recent go-around flight data of a few major US airlines spanning a one year period. The statistical analysis investigates a few select relevant aspects of these go arounds, such as initiation altitude and altitude change, aircraft configuration, deviation from the flightpath, and energy state. These data show that only one third of the landings are aborted below 400ft, but the majority of the go arounds occur at significantly higher altitudes. Current go-around training is specifically focused on the final approach and landing phase at low altitudes and low speeds. The results of this study will support the development of a broader set of relevant scenarios for an FAA simulator experiment to study and evaluate the skills of the pilots who monitor this wide spectrum of diverse go-around conditions, with the ultimate goal to help improve pilot go-around training and technologies.

I. Nomenclature

D	=	drag, N
g	=	gravity constant, m/s^2
$\dot{h}$	=	vertical speed, m/s
L	=	lift, N
m	=	mass, kg
N_1	=	engine rotational speed, %
T	=	thrust, N
T_{GA}	=	go-around thrust, N
$T_{\max}$	=	maximum thrust, N
V	=	airspeed, kts
V_{app}	=	approach speed, kts
V_{ref}	=	reference speed, kts
$\dot{V}$	=	acceleration/deceleration, m/s^2
W	=	weight, N
α	=	angle of attack, deg
γ	=	flight path angle, deg
$\gamma_{\max}$	=	maximum flight path angle, deg
θ	=	pitch angle, deg

II. Introduction

This paper analyzes airline go-around (GA) data to inform the development of scenarios for a follow-on Federal Aviation Administration (FAA) simulation experiment with the goal to help improve pilot go-around training and technologies. A go around occurs when an aircraft is in the approach or landing phase of flight, and the pilot aborts this flight phase because it is deemed unsafe to proceed. Pilots either decide themselves to perform a go around or receive a request for a go around by air traffic control. There are various reasons to do so, either on board, such as an upset or deviation that results in an unstable approach, or external, such as a loss of separation with other air traffic or an obstacle on the runway. On average, go arounds occur with a rate of one to three per 1,000 approaches [1].

Flying a GA places special demands on pilots, especially when the GA is unexpected [2, 3]. Airline pilot training includes go-arounds, but these are focused on the final approach and landing phase, at low altitudes and low speeds. It is commonly understood, that current go-around training provided by airlines is not sufficient as it does not reflect the diverse go-around conditions pilots might experience. In recent years, research was conducted to examine potential refinements to current go-around criteria [1, 4, 5]. In addition, previous go-around studies mainly focused on specific aspects of GAs such as crew resource management [6] and spatial disorientation [7], and forecasting and classification of go-around incident data [8, 9]; however, hardly any research has been published on pilots' execution performance of go-around maneuvers as these data are usually not easily accessible.

This paper discusses a statistical analysis of recent go-around flight data of a few major US airlines spanning one year (February 2019 to February 2020) and shows that one third of the landings are aborted below 400 ft, but the majority of the go arounds occur at significantly higher altitudes. Go-around initiations at higher altitudes present specific challenges for shorter climbs such as energy management and are currently not part of airline training programs.

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III. Factors that can Influence Go-around Performance

A go around occurs when an aircrew makes the decision to not continue an approach or landing, and follows procedures to conduct another approach or to divert to another airport [10]. Go arounds can happen at any point from the final approach fix to wheels on the runway but prior to activating any deceleration device (e.g., brakes, spoilers, or thrust reversers). Pilots can initiate a go around manually, but most commercial aircraft also have a takeoff/go around (TO/GA) mode which is an autopilot/autothrottle setting activating takeoff or go-around thrust. Depending on the aircraft type, TO/GA may be activated by depressing a switch or by manually moving the thrust levers to the TO/GA position.

On average, go arounds occur with a rate of one to three per 1,000 approaches [1]. At the core 30 airports in the US, 3.9 per 1,000 arrivals resulted in a go around from October 2022 to September 2023 (fiscal year 2023) [11]. Stated another way, roughly 23,000 GAs were performed at the core 30 US airports in fiscal year 2023. The rate varies per airport (two to eight per 1,000 arrivals), and airframe, with narrow-body aircraft experiencing GAs at higher rates.

Most airlines define stabilized approach criteria in their standard operating procedures. Typically, airline procedures state that if pilots determine that the approach is unstable, i.e., outside of the criteria, they should conduct a go-around. Because the criteria are set by each operator, they vary across the industry. However, in recent years, efforts were made to develop more standardized criteria [1, 5]. The following are typical stabilized approach criteria:

- Stabilization height: 1,000 ft under instrument meteorological conditions (IMC) and 500 ft under visual meteorological conditions (VMC).
- Localizer deviation: ± 1/2-1 dot.
- Glideslope deviation: ± 1 dot.
- V_{ref} deviation: V_{ref}-5 – V_{ref}+(10-20) kts.
- Rate of descent: 1,000 ft/min.
- Power on approach: above idle, and appropriate with airspeed, approach, and condition.
- Aircraft configuration: flaps in landing configuration, landing gear deployed, and spoilers armed.
- Bank angle: wings level below 300-500 ft altitude or else less than 25 deg.

There are several factors that may influence proper execution of the go-around maneuver:

1) Startle or surprise – when go arounds are anticipated, for example, by properly monitoring stabilized approach criteria, pilots are more likely to be prepared. When go arounds are unexpected, such as those initiated by air traffic control or an alert from the aircraft, the flight crew might be surprised or startled, and, as a consequence, less prepared.
2) Autoflight configuration – the approach can be flown manually with the flight directors, using autoland (full automation), or some in-between configuration, such as manual flight inputs with the autothrottle engaged. Due to this variation, when the GA is initiated, autoflight may behave or transition differently than the flightcrew expects.
3) Crew resource management – the GA maneuver requires close coordination between the two pilots and alternating pilot flying and pilot monitoring roles might affect GA performance.
4) Air traffic Control (ATC) – GA performance can create a high workload, which can be made worse by requirements to communicate with ATC, especially just after GA initiation. In addition, ATC often assigns new flight path targets that are not briefed and not set on the mode control panel (MCP). These changes can be an additional unexpected element of the GA.
5) Go-around procedure – there can be a tension between performing the GA procedure as it is written and the need to adapt it to the specifics of the particular GA situation.
6) Aircraft state – the aircraft needs to transition from an approach/landing state to the GA maneuver. The aircraft can be in a low- or high-energy state with lateral deviations from the localizer, and fully configured for landing, making the transition difficult. In addition, the combination of high thrust and low weight can lead to high pitch attitudes and unexpected aircraft performance.
7) Environmental conditions – environmental conditions such as weather and visibility can increase maneuver difficulty. Performing the GA also requires awareness of other traffic, or nearby terrain and obstacles.
8) Training – Pilot training typically focuses on GA initiation at the missed approach point or decision altitude, which is typically below 500 ft above ground level (AGL). GAs initiated at conditions other than those used in training might be harder to perform.

The following section uses operational data for some of these factors to see what pilots have experienced in line operations. In addition, results from some unpublished studies are used to corroborate findings from the current data set or give new insights.

IV. Go-Around Data Analysis

This study considers a limited set of flight data for US operations only, and serves as a starting point to observe certain trends. It is by no means a full statistical analysis. This study looks at 1 year of flight data, from mid-February 2019 till mid-February 2020. In total, this set encompasses 3,749 go arounds. This set was compared to a few other larger sets of go-around data that are not public, and similar trends were observed over all these data sets.

A. General Characteristics of the Data Set

Overall, this set includes go-around data for around 20 different airliner models (twin aisle, single aisle as well as regional from both Airbus and Boeing) at more than 20 US airports. Single aisle aircraft are the largest majority in this data set, for two reasons. First, the single aisle aircraft (such as the Boeing 737 family and the Airbus A320 family) represent by far the largest share in the overall fleet of US airlines and operations, compared to twin aisle and regional aircraft. Second, the single aisle and regional fleet typically fly on shorter routes, which implies that they execute more landings in the same timeframe, compared to twin aisle aircraft that typically fly longer range routes. Although this data set, which is based on Flight Operations Quality Assurance (FOQA) data from airliners, contained a very wide variation in distances and altitudes where go arounds were executed, it was decided to limit this data set only to datapoints within 20 nautical miles distance from the runway threshold and below 7,000 ft altitude above ground.

The goal of characterizing this data set is to identify the range of GA maneuvers that are being flown in US line operations. These characterizations will support the development of relevant scenarios that represent the range of GA maneuvers that US-based flightcrews may encounter. The following sections describe various aspects of GA performance as observed in this data set.

B. Flight Path Targets

When a flightcrew begins an approach, they typically set their altitude window on the MCP higher than their current altitude; this altitude will be used for a missed approach, if needed. When they begin a GA, they will use that target unless ATC gives them a new target. The missed approach altitude and its related flight path targets were likely briefed. New targets were, by definition, not briefed and may lead to a higher workload for the flightcrew. The target with arguably the largest potential effect on the GA maneuver is stabilization altitude, although changes to lateral (heading/track) and airspeed targets can also add to the overall workload.

This study looked for evidence* of a change to the GA stabilization altitude to determine what percentage of GAs are flown to unexpected targets. The data set shows that 39% of GAs started with a change to the altitude window on the MCP.

C. Initiation Altitude

A GA can be initiated at any point along the approach. By regulation, airlines are required to conduct some GA training on initiation at the missed approach point, which is typically below 500 ft AGL. Figure 1 shows the percent of GA maneuvers that were initiated from different altitude bands (in 200-ft bands). The following general trends are visible in Fig. 1:

- 19% of GAs in this data set were initiated between 0 and 200 ft AGL,
- 33% were initiated at or below 400 ft AGL
- 60% were initiated at or below 1,000 ft AGL
- 14% were initiated above 2,000 ft AGL
- a small number were initiated above 5,000 ft AGL

This shows that more than half of the GAs in this study happened outside the GA training scope required by the regulations. These percentages are in line with observations in similar unpublished studies.

D. Altitude Change to Stabilization Altitude

When the approach begins, the flightcrew sets the missed approach altitude from the missed approach procedure, which is the altitude required for the GA stabilization altitude when the flightcrew cannot meet the minimum requirements. Figure 2(a) shows the altitudes (above mean sea level) at which the aircraft leveled off at the end of the GA (on the Y-axis) with respect to initiation height (on the X-axis). The figure shows that 2,000 and 3,000 ft (MSL) are the most

*Specifically, this study looked for a change to the MCP/FGU target just after GA initiation.

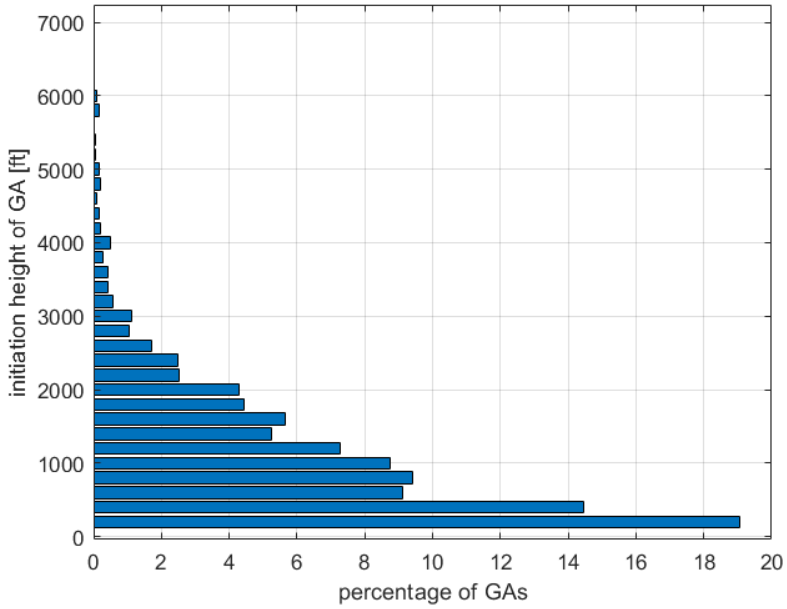
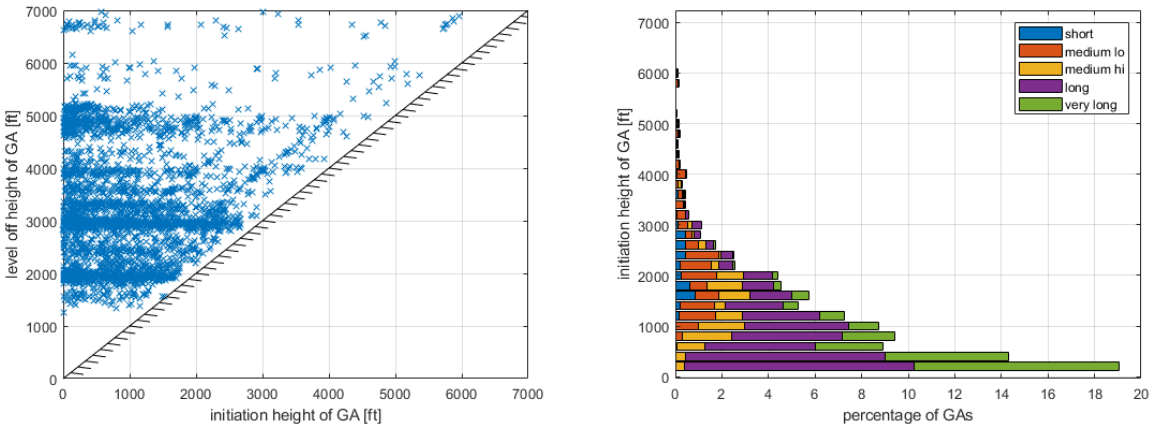


Fig. 1 Go around initiation height

common altitude targets from the missed approach procedure for initiation heights below 3,000 ft. If we assume that the GA is initiated below 500 ft AGL, these altitude targets should offer ample space to complete the GA (although complications can still occur for the flightcrew). Overall, the highest densities of data points in Fig. 2(a) are found at altitudes that are multiples of a thousand feet, and a lesser increased density is found at 1,000 ft above the initiation height.



(a) Level off vs initiation height of GA

(b) Go around initiation height divided per GA climb category

Fig. 2 Overall altitude change statistics

In many cases, as mentioned above, ATC may assign a different stabilization (target) altitude for the GA. The difference between where the GA is initiated and the stabilization altitude can contribute to difficulty in managing the GA. More specifically, if the climb is short – e.g., the GA is initiated at 2,000 ft AGL and the missed approach altitude is 2,500 ft – then using TO/GA mode with its high thrust setting can make it difficult to capture 2,500 ft without climbing through it.

The data were reviewed to determine what altitude changes (from initiation to stabilization) were occurring in line operations. Fig. 2(b) uses 200-ft bands for GA initiation and breaks out the altitude change to the stabilization altitude[†]. Instead of breaking the altitude change out in detail, five categories were used:

- Short – for altitude changes of less than 500 ft
- Medium lo – for altitude changes of 501 to 1,000 ft
- Medium hi – for altitude changes of 1,001 to 1,500 ft
- Long – for any altitude changes of 1,501 to 3,000
- Very long – for any altitude change greater than 3,000 ft

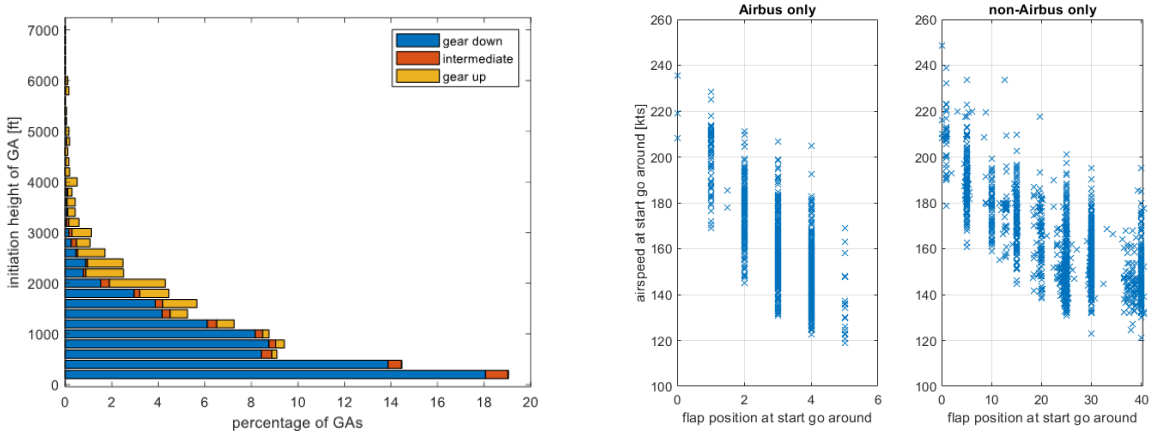
Note that climbs of more than 1000 ft (Medium hi and up) become the majority just below 2,000 ft initiation height, and really dominate below 1,000 ft initiation height. Also, climbs of 500 ft or less – potentially, the most difficult to manage – primarily occur between 1,500 and 3,000 ft.

E. Gear and Flap Position

During the GA maneuver, the flightcrew needs to retract the gear and flaps to clean the airplane up for climbing and increasing airspeed. The flaps need to be retracted according to the speed schedule. More clean-up actions are required for GA initiations at lower altitudes when the gear and flaps are fully deployed. Fig. 3(a) shows gear position at the point of GA initiation (in 200-ft bands). In the figure, the percent of GAs is broken into three sets for each GA initiation band:

- Gear down (extended)
- Gear in transition, or intermediate (between up and down)
- Gear up (retracted)

Generalizing from these data, the gear is almost always down for GAs initiated at 1,000 feet or lower. Above 2,500 feet, the gear is almost always up. The transition point seems to be for GAs that are initiated at 2,000 ft. The figure also shows that, in a small number of cases, the gear is in transition at the lowest altitudes, which may represent the gear being retracted at the start of the GA. One potential explanation of this unexpected finding is that the airlines' identification of the GA initiation point in these data likely captures the maneuver a few seconds later than when the GA maneuver is actually started, and by that time the gear is already being retracted as part of the GA.



(a) Gear positions

(b) Flap positions

Fig. 3 Gear and Flap Positions

Fig. 3(b) shows flap position by airspeed at GA initiation. The Airbus (0-5 as incremental flap lever positions) and non-Airbus (0-40 degrees flap deflection angle) flap position settings are shown on the side-by-side charts. Each X marks a GA event. Note that multiple airframes are on the same figure, and different airframes have different airspeed targets for each flap setting. In general, higher flap settings correspond to lower airspeeds. There are also cases in which flaps were in transit between two positions, especially for the non-Airbus airplanes.

[†]The MCP/FGCU altitude setting 5 seconds after the GA was initiated was used to identify the stabilization altitude.

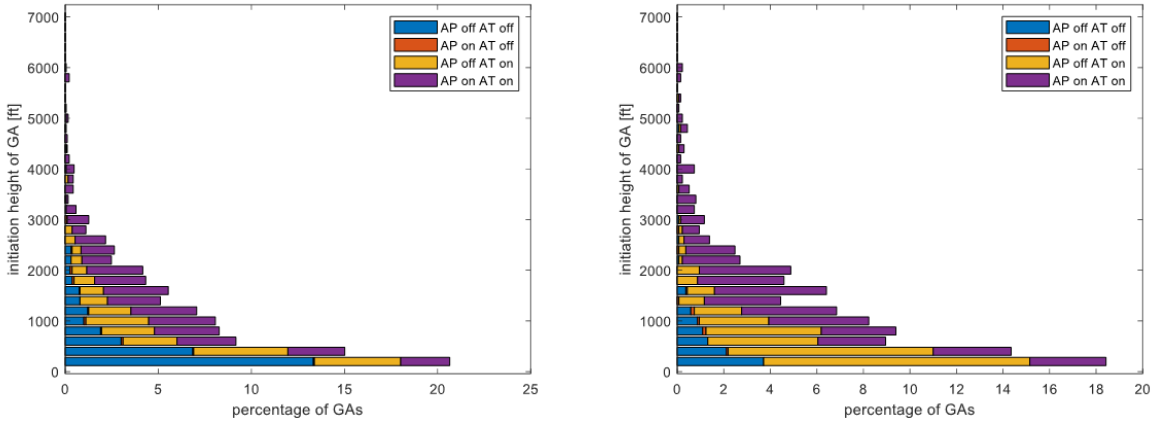
F. Autoflight Settings

On approach, prior to the GA, the airplane can be in one of four autoflight states:

- Autopilot off; Autothrottle off
- Autopilot on; Autothrottle off
- Autopilot off; Autothrottle on
- Autopilot on; Autothrottle on

This is relevant because the transition to GA can lead to a rapid change in the autoflight configuration. Generally, on approach, pilots are more likely to maintain the autothrottle after disengaging the autopilot. However, practices can vary between Airbus and non-Airbus airplanes. Fig. 4 shows which state the airplane was in when the GA was initiated. Fig. 4(a) shows only non-Airbus (Boeing and McDonnell-Douglas) airplanes. Fig. 4(b) shows the same data for the Airbus airplanes. Comparing the two figures reveals these two observations:

- It is rare that the autopilot is on with autothrottle off, but the reverse (autopilot off and autothrottle on) occurs frequently.
- The combination of autopilot off and autothrottle off is more common for the non-Airbus airplanes. This condition occurs in Airbus GAs initiated at around 1,000 feet and below but not to the same extent. That is, some level of autoflight (typically autothrottle on) is maintained down to lower altitudes for Airbus.



(a) Autoflight settings for Boeing and McDonnell Douglas

(b) Autoflight settings for Airbus

Fig. 4 Go around initiation height divided per autoflight setting

G. Position Relative to the Glidepath

Sometimes, GAs are initiated because the airplane was deviating from the glidepath. Typically, a significant deviation is defined when the airplane is offset from the glideslope (GS) or localizer (LOC) by more than 1 dot (measure shown on the primary flight display (PFD)), as also defined in most stabilized approach criteria. Fig. 5 shows the distribution of all GAs relative to the 1-dot boundaries horizontally as well as vertically (red dashed lines). One dot represents around 0.8 degrees of deviation on the LOC scale and around 0.4 degrees on the GS scale. Areas are labeled as follows:

- High – When the airplane is more than 1 dot high (above the GS)
- Low – When the airplane is more than 1 dot low (below the GS)
- Lateral deviation (left or right) – When the airplane is more than 1 dot left or right of the LOC
- On path – Within 1 dot both laterally and vertically

Combinations, such as Left High, represent a GA initiated from a location that is more than 1 dot off vertically and 1 dot off to the left. Fig. 5 overlays nine categories to capture the entire space. The figure shows that some flights were quite far away from the glidepath, but most of them are concentrated around On Path and High, and to a lesser extent Low, but both in the plane of symmetry.

Fig. 6(a) shows the percent of each of these nine categories for each GA-initiation altitude band. The most frequent cases, in order, are On Path, High, and Low. Other areas of the distribution represent a relatively small set of the GAs.

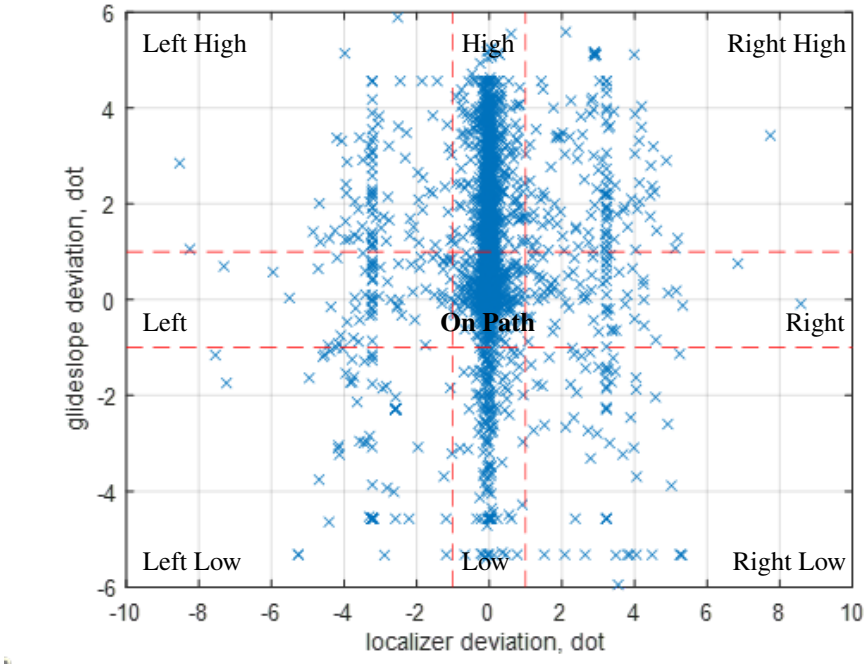
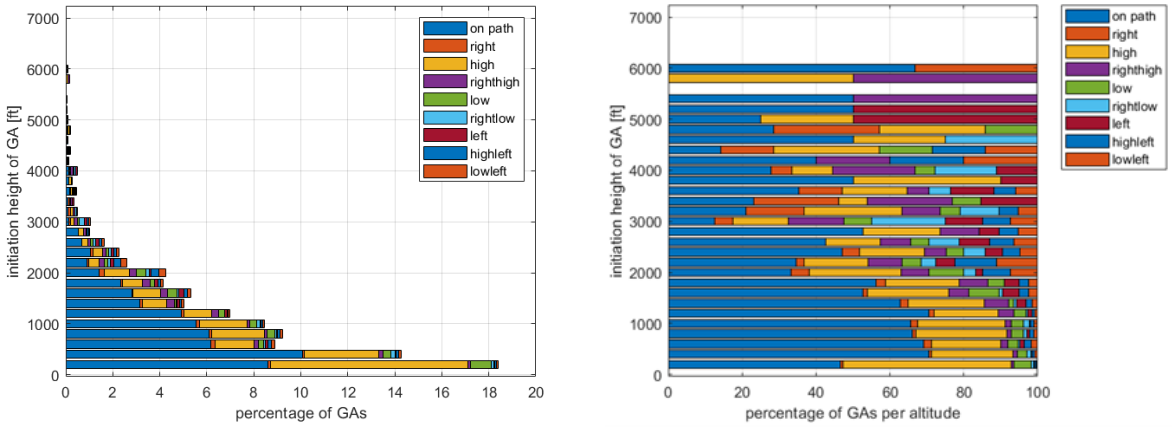


Fig. 5 Distribution of position relative to glideslope and localizer at GA initiation

Fig. 6(b) breaks out the entire set of events at each altitude band and aids in seeing the distribution at higher altitudes. Two trends across the GA-initiation altitude bands can be observed:

- At higher GA initiation altitudes – above 3,000 ft – the cases that are not On Path are more evenly distributed across the other eight areas, compared to GAs initiated from lower altitudes.
- Below 1,000 ft, High and Low areas become the dominant categories when not On Path, especially High. This is most pronounced at the lowest altitude band, where High occurs almost as frequently as On Path.



(a) Offset relative to LOC and GS by GA initiation altitude

(b) Percentage of offsets split out per altitude band

Fig. 6 Offset relative to LOC and GS by GA initiation altitude

H. Energy State

The energy state is another way in which an airplane can fail to meet stabilized approach criteria and require a GA. Fig. 7 shows the distribution of all GAs relative to the GS and the target airspeed for the approach. As above, the red dashed lines represent the boundaries on performance:

- High – When the airplane is more than 1 dot high (above the GS)
- Low – When the airplane is more than 1 dot low (below the GS)
- Fast – When the airplane is more than 10 kts above V_{app}
- Slow – When the airplane is more than 5 kts below V_{app}
- On path – Within 1 dot both laterally and vertically and less than 10 kts above or 5 kts below V_{app}

Combinations, such as Fast High, represent a GA initiated from a location that is 1 dot off vertically and more than 10 kts too fast. Fig. 7 overlays nine categories to capture the entire space. The majority of the cases are by far On Path or some form of high energy situation, either High or Fast or both.

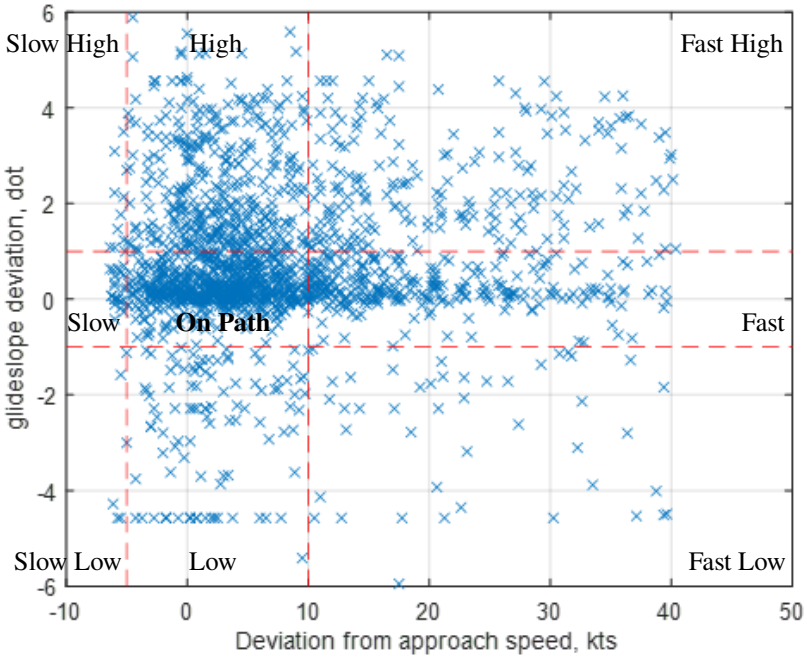
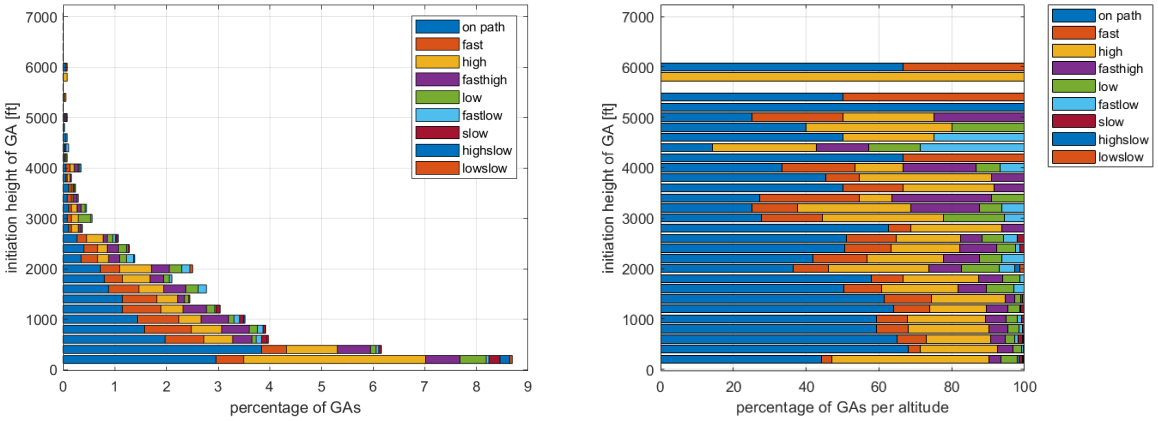


Fig. 7 Distribution of position relative to glideslope and target airspeed at GA initiation

Fig. 8(a) shows the percent of each of these nine categories for each GA-initiation altitude band. High in Fig. 8(a) is the same as High in Fig. 6(a), but the combinations are different. The most frequent cases, in order, are On Path, Fast, High, and Fast High. Together, these three latter high energy situations make up the overall majority of off path GAs, as was already observed in Fig. 7, and Fig. 8(a) confirms that this applies at all initiation heights: On Path mostly around 40%–60% and high energy mostly around 30%–50%, together accounting for around 80%–90%. Other areas of the distribution represent a relatively small subset of the GAs. Fig. 8(b) breaks out the entire set of events at each altitude bands and aids in seeing the distribution at higher altitudes. It is also interesting to look for trends across the GA-initiation altitude bands. Two similar trends as in Fig. 6 apply here:

- At higher GA initiation altitudes – above 3,000 ft – the cases that are not On Path are more evenly distributed across the other eight areas, compared to GAs initiated from lower altitudes.
- Below 1000 ft, Fast, High, and Fast High areas become the dominant categories when not On Path. This is most pronounced at the lowest altitude band, where High occurs as frequently as On Path.
- In addition, from 1,600 to 400 ft, Fast occurs more often than High. Below 400 ft, High occurs more often than Fast. This is explained by the fact that correcting for overspeed takes more time than an altitude correction. Pilots also have the tendency to keep a closer eye to their airspeed during the approach.



(a) Offset relative to GS and airspeed by GA initiation altitude

(b) Percentage of offsets split out per altitude band

Fig. 8 Offset relative to GS and airspeed by GA initiation altitude

I. Airplane Weight

The GA maneuver is typically executed when the airplane weight is significantly lower than at take-off. When an airplane has reached its destination, it is likely to be low in fuel (close to minimum fuel reserve) since fuel quantity was aligned with the mission, and fuel weight is typically 20-35% of gross take-off weight. The flightcrew may have a poor expectation for how a lighter airplane will respond to the sudden thrust increase at GA initiation.

Fig. 9 shows the airplanes' percent of maximum take-off weight (MTOW[‡]) at GA initiation. It is broken out by twin aisle, single aisle, and regional jet transports. The box plot for each class of jet transports shows the following:

- The red line is the median value (50th percentile)
- The blue box encompasses data from the 25th to the 75th percentile
- The brackets on the dashed line represent 1.5 times the quartile next to it; that is, the upper bracket encompasses all data points that are within 1.5 times the distance between the 50th and 75th quartile; the lower bracket does the same within 1.5 times the distance between the 50th and 25th quartile.
- Red crosses outside the brackets are outliers, which are data points between 1.5 and three times the interquartile range beyond either end of the box. Data points beyond three times the interquartile range are ignored.

The figure shows that the twin aisles typically are on approach with less than 70% of MTOW, whereas the regional jets are mostly above 85%. The combination of thrust level and relative airplane weight can be an indicator of the difficulty of managing the initial pitch up when the GA is initiated.

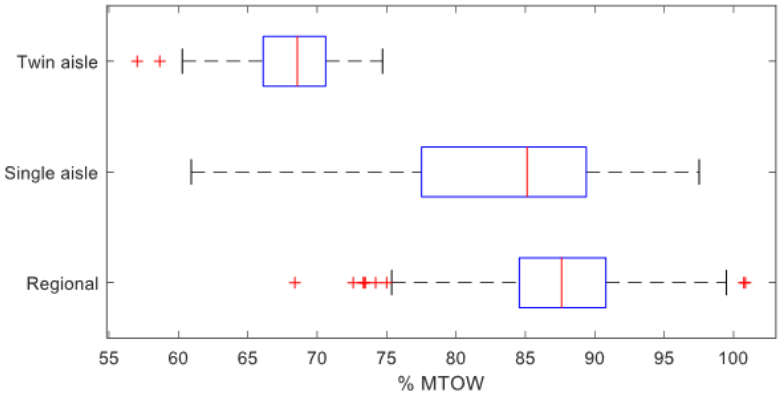


Fig. 9 Percent maximum take-off weight at GA initiation

[‡]MTOW was estimated from generic values for an airframe and may not reflect specific airplanes.

J. Thrust to Weight Ratio

As already mentioned before, a high thrust T with a low weight W can present a challenge for managing pitch and climb early in the GA maneuver. Flight mechanics show that there is a direct link between the flight path angle γ (the vertical angle between the velocity vector and the horizon) and the thrust to weight ratio. This link follows from the equations of motion. The forces acting on the aircraft follow from the Free Body Diagram as shown in Fig. 10.

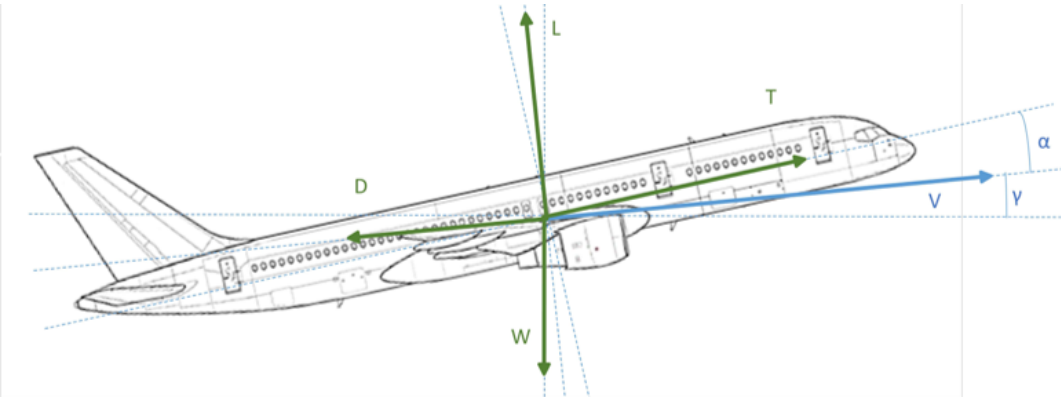


Fig. 10 Free Body Diagram with forces for a generic airliner

The equation of motion along the flight path is then as follows:

$$T\cos\alpha - D - mg\sin\gamma = m\dot{V} \tag{1}$$

where T is thrust, α is angle of attack, D is drag, m is mass, g is gravity constant, γ is flight path angle and $\dot{V}$ is acceleration/deceleration. Rewriting as follows, and assuming a small angle of attack: $\cos\alpha \approx 1$

$$\frac{T}{W} - \frac{D}{W} = \frac{\dot{V}}{g} + \sin\gamma \tag{2}$$

with weight $W = mg$. The left side of the equal sign in Eq. 2 represents the net excess force which can be used to accelerate via $\dot{V}$ and/or climb with γ as shown on the right side of the equal sign. The thrust to weight ratio plays an important role in this net excess force. To get to a thrust/weight (T/W) ratio, one needs to determine thrust. Given the limited amount of information available in the data set, the following rule of thumb was applied where thrust is computed from the average N_1 value (across engines) 5 seconds after GA initiation (since N1 ramps up over time):

$$T_{\mathrm{GA}} = T_{\mathrm{max}} \cdot N_1^2 \tag{3}$$

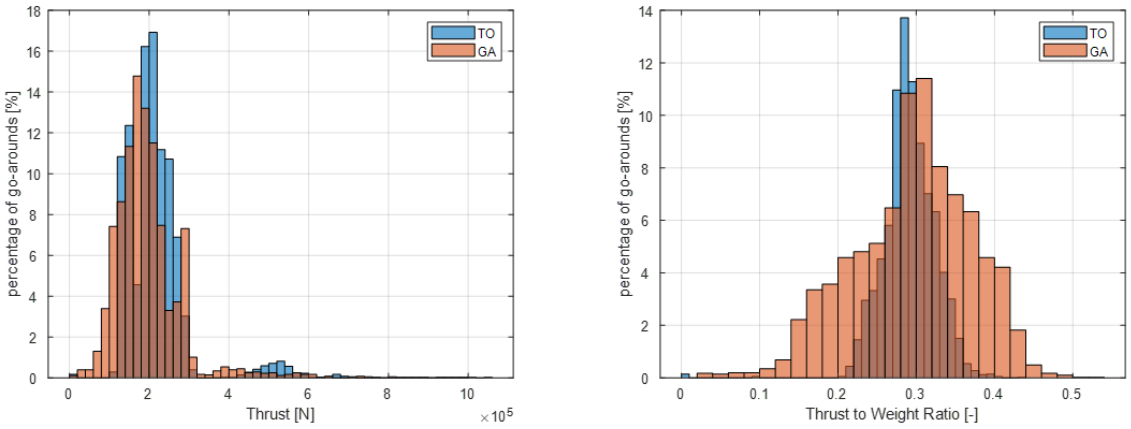
where T_{max} is the maximum thrust that all the engines on the airframe can provide.

It may also be useful to compare T/W at GA to T/W at TO as a way to characterize GA maneuver aggressiveness with respect to TO performance. Fig. 11(a) shows the distributions (in Newtons) of thrust at TO and at GA and Fig. 11(b) shows the distribution of T/W ratio (dimensionless) at TO and at GA. The darker brown indicates overlap of the two bars.

Note that the primary TO thrust distribution in Fig. 11(b) is narrower than the distribution for GA thrust. Thrust at TO is selected by the flightcrew to be appropriate for the airplane's weight. For a GA, there is probably no consideration for a thrust level, which can lead to greater variability in thrust values. TO/GA thrust may be selected, but other values may be selected manually with the thrust levers in the heat of the moment. For TO thrust, there is a small secondary distribution to the right of the primary distribution. This set of values likely represents the large, twin-aisle airplanes, which have a larger maximum thrust value.

Fig. 11(b) shows the distribution of the T/W ratio at TO and at GA. As with thrust, the GA distribution is wider than the TO distribution, but this trend is much clearer here than for thrust only. Further, the GA distribution extends to both lower and higher values.

One might expect the T/W ratio to vary across GA initiation altitudes since TO/GA is more likely to be used at the lower altitudes. Fig. 12(a) shows the T/W ratio for each GA event plotted against the GA initiation altitude. Indeed, the general trend is that higher T/W ratio values occur at low GA initiation altitudes. The data markers to the right of the



(a) Distribution of Thrust

(b) Distribution of Thrust to Weight ratio

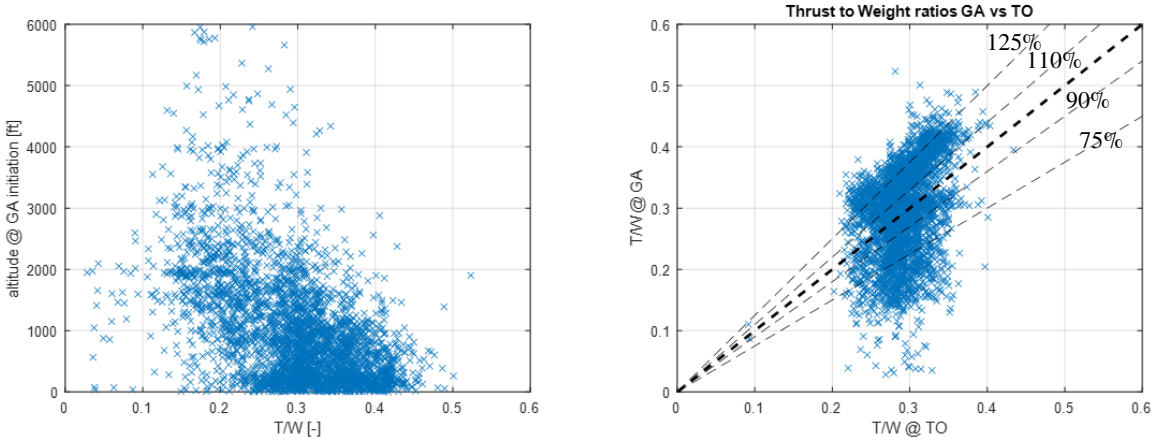
Fig. 11 Distribution of Thrust and Thrust to Weight ratio for Takeoff and Go Around

figure indicate higher thrust values and suggest more aggressive GAs, especially if the climb to the stabilization altitude is on the shorter side.

By comparing these T/W ratios at GA to the corresponding T/W ratios at TO it is possible to determine how many GAs are more aggressive than TOs. Fig. 12(b) shows each GA and compares T/W at TO to T/W at GA. The heavy dashed line cutting diagonally at a 45° angle through the scatterplot represents the same T/W ratio value for both events. As indicated, the lighter dashed lines show:

- T/W at GA is 75% of T/W at TO
- T/W at GA is 90% of T/W at TO
- T/W at GA is 110% of T/W at TO
- T/W at GA is 125% of T/W at TO

For values less than 100%, the GA was less aggressive than the TO; for values greater than 100%, the GA was more aggressive. This plot also echoes Fig. 11(b) in showing that the distribution of T/W at TO (horizontal spread) is narrower than it is for the GA (vertical spread). And, while there are GAs with high T/W ratios compared to the TO, there are some below the equal line, as well; specifically, 42% of the data points indicate $\left(\frac{T}{W}\right)_{\text{GA}} < \left(\frac{T}{W}\right)_{\text{TO}}$ (below the bold dashed line) and 58% of the data points show that $\left(\frac{T}{W}\right)_{\text{GA}} > \left(\frac{T}{W}\right)_{\text{TO}}$ (above the bold dashed line).



(a) Thrust/weight ratios at GA compared to initiation height

(b) Thrust/weight ratios at TO compared to T/W ratios at GA

Fig. 12 Thrust to Weight ratio analysis for GA initiation height

Fig. 13 breaks out the data from Fig. 12(b) based on GA initiation altitude, which is correlated with the T/W ratios in Fig. 12(a), but it also uses the categories from Fig. 12(b) to identify the altitudes where the aggressive GAs were initiated. The purple and green bars are the most aggressive and represent a larger percentage at lower altitudes, as one might expect.

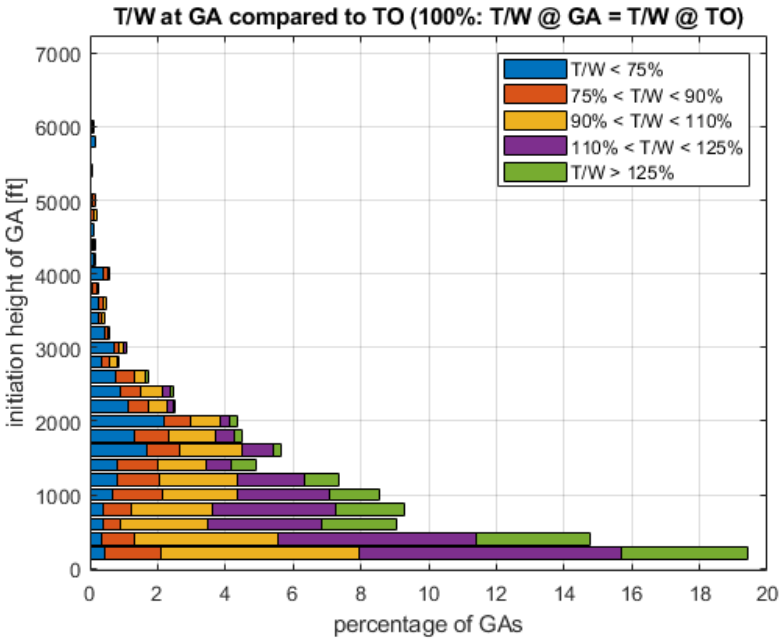
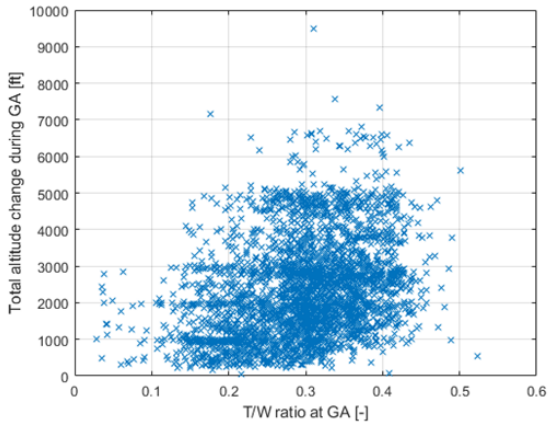


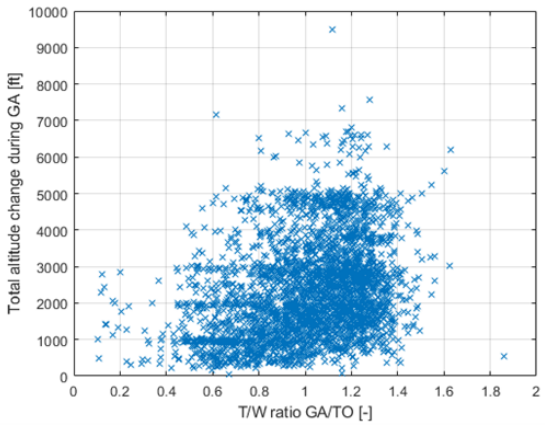
Fig. 13 Aggressiveness of thrust/weight ratio by GA initiation altitude

Finally, one can connect these T/W ratios at GA to the altitude change during the GA. Potentially most concerning are GAs that are initiated more aggressively but do not climb far to a stabilization altitude. Fig. 14(a) uses the T/W at GA and plots it against altitude change to stabilization altitude. The lower right corner of the chart reveals a number of high T/W values with climbs only 1,000 ft or less.

Fig. 14(b) uses the T/W at GA to T/W at TO ratio from Fig. 12(b). The distribution changes subtly. One change from Fig. 14(a) to 14(b) is the rescaled range of values on the x-axis; notably one data point with a 500 ft climb to stabilization altitude appears to be a more extreme outlier to the right. More research is needed into these aggressiveness metrics.



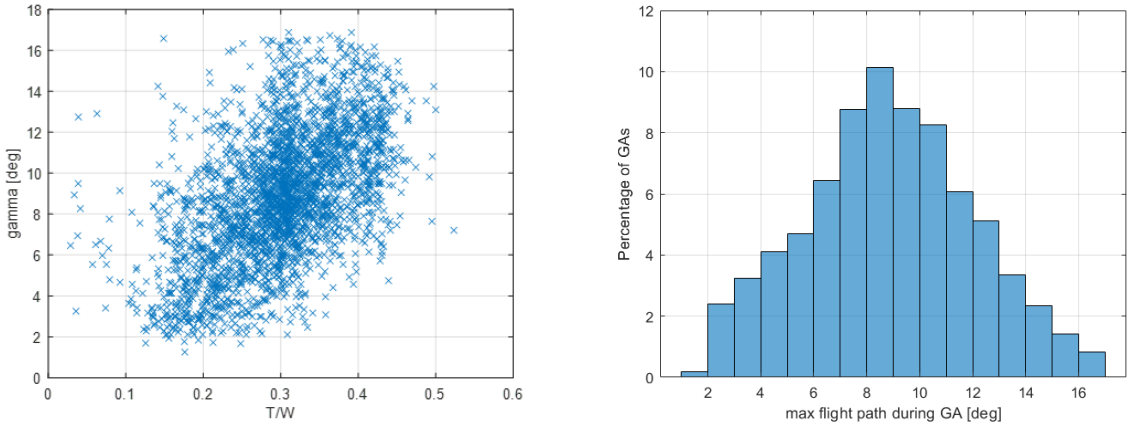
(a) Thrust/weight ratios at GA vs GA initiation height



(b) Thrust/weight ratios at GA wrt TO vs GA initiation height

Fig. 14 Thrust to Weight ratio vs GA initiation height

From Eq. (2), one can expect a connection between the T/W ratio and the maximum flight path angle $\gamma_{\max}$. Comparing the T/W ratio at the beginning of the GA with the maximum flight path angle during the GA, shows that higher ratios generally result in higher climb angles, as shown in Fig. 15(a). The maximum flight path angle seems a better aggressiveness metric than total altitude change during the GA. The histogram of the maximum flight path angles in Fig. 15(b) shows a symmetrical distribution between 2 and 16 deg, with a peak around 8 deg.

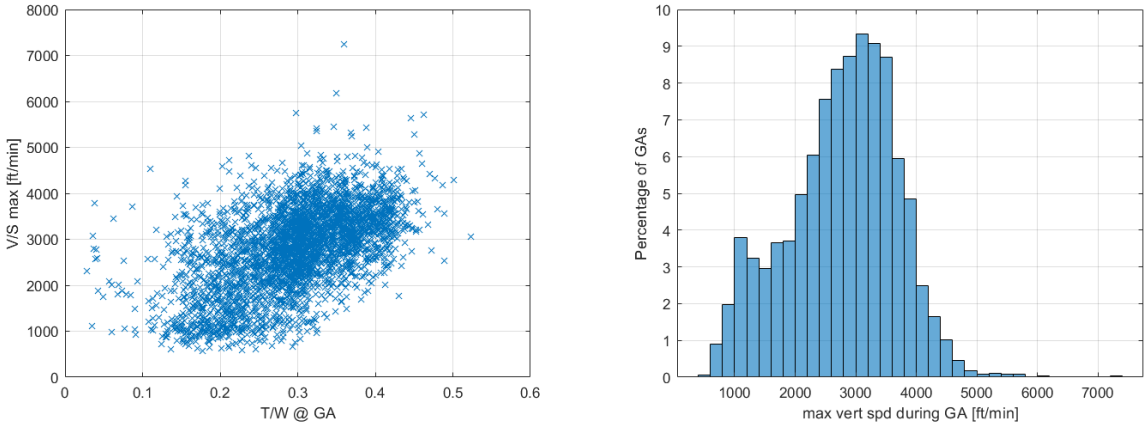


(a) Thrust/weight ratios at GA vs max. flight path angle during GA

(b) histogram of max. flight path angle during GA

Fig. 15 Max. flight path angle during GA

This section wraps up with a brief study of the maximum vertical speed during the GA. Comparing the T/W ratio at the beginning of the GA with the maximum vertical speed during the GA, shows that higher ratios generally result in higher climb rates, as can be seen in Fig. 16(a). Maximum vertical speed during GA, which is related to the flight path angle γ via $\dot{h} = V \sin\gamma$, also seems a better aggressiveness metric than total altitude change during the GA. The histogram of the vertical speeds in Fig. 16(b) shows that most maximum vertical speeds are somewhere between 1,000 and 4,000 ft per min, with a peak around 3,000 ft per min.



(a) Thrust/weight ratios at GA vs max. vertical speed during GA

(b) histogram of max. vertical speed during GA

Fig. 16 Max. vertical speed during GA

K. TO/GA Mode Engagement

The GA can be initiated by engaging the TO/GA mode, but it is not necessary to use TO/GA to fly a GA. For some airplanes, TO/GA cannot be engaged in all potential GA situations; for example, for the Boeing 737, TO/GA can only be engaged when the airplane is below 2,000 ft AGL, or, if above 2000 feet, with either the flaps extended or with the glide slope captured. While the data set did not provide information on TO/GA engagement, other unpublished studies indicated that roughly 60% of GAs involved TO/GA mode engagement.

L. Ambient Lighting

The light level can be a complicating factor for performing the GA. Night-time (dark conditions) can remove or reduce the ability to see terrain, obstacles, and traffic. While this data set did not provide time of day information, another unpublished study indicated that approximately:

- 20% of GAs occur at night
- 7% of GAs occur during twilight
- 73% of GAs occur in day-time conditions

V. Discussion

Based on the statistical analysis of the GA maneuver data as presented in Sec. IV, the following overall observations were made:

- More than half of the GAs in this study were executed above 500 ft AGL, while one third were initiated at or below 400 ft and even around 19% between ground level and 200 ft. Current regulations require airlines only to conduct GA training on initiation at the missed approach point, which is typically below 500 ft. This study shows that the training scope is very limited compared to frequently occurring real life GA scenarios.
- Because of this large spread in GA initiation heights, there is also a large spread in aircraft configuration (flaps and gear) because of the corresponding prevailing speeds and also in autoflight settings. It is noteworthy that different trends were observed in autoflight settings for different airframe manufacturers.
- Most go arounds are initiated either on the ILS path or with a glideslope deviation above the reference path anywhere between 1 and slightly more than 4 dots. There are also deviations left and right from the localizer, but these are by far less frequent. In the lowest altitude band below 200ft, high deviations above glideslope occur almost as frequently as on path situations.
- With respect to energy state, the three high energy deviations (fast, high or both) occur most frequently (30%–50%) after the On Path situations (40%–60%). Together they account for around 80%–90% of all GAs.
- Landing weight as a percentage of maximum takeoff weight is the smallest for twin aisle aircraft and the largest for regional aircraft. Single aisle aircraft are somewhat in between the two aforementioned categories. These differences are at least partially explained by the different amounts of fuel that are carried on-board that reflect the different kinds of flight requirements (long range vs. short range) between these three categories.
- An important metric in the context of GAs is the thrust to weight ratio T/W. The distribution of T/W is much wider for GAs compared to the takeoffs. The general trend is that higher T/W ratio values occur at low GA initiation altitudes. By comparing T/W ratios at GA to the corresponding T/W ratios at TO, it is possible to determine how many GAs are more aggressive than TOs. It was found that 58% of the GAs in this study were more aggressive. More aggressive GAs tend to happen more frequently below 1,200 ft. These more aggressive GAs tend to result in steeper climb angles and higher climb speeds, but this is not necessarily an issue because of the anticipated larger total altitude change during the GA up to the stabilization altitude.
- Roughly 60% of GAs involved TO/GA mode engagement.
- Around 80% of GAs occurred in daytime or twilight conditions.

The airlines that were interviewed, identified a set of rules for determining when GA performance was not satisfactory, and these were tracked over time. This set of rules was divided into three categories:

- **Established airplane hazard alerts:** these are typically conveyed to the flight crew by means of aural alerts such as low airspeed, approach to stall, overspeed (also related to flap setting or gear), excessive bank angle, traffic collision avoidance system (TCAS) resolution advisories or ground proximity warning system (GPWS) alerts.
- **Airplane performance exceeds typical predefined bounds that are set for the maneuver:** such as airspeed goes below V_{ref}, excessive pitch attitude angle or pitch rate, no positive rate of climb after gear retraction, low power setting, climb beyond 300 ft above assigned stabilization altitude or diverging from the assigned lateral path.

- **Pilot actions are different from what is expected for the maneuver:** typically, these are deviations from established procedures, such as failing to engage TO/GA mode for GAs that were initiated below 250 ft, failure to verify pitch and power settings or raising the gear before confirming a positive rate of climb.

Unpublished studies determined that, for their data set, flights that had more exceedances were generally initiated at a higher altitude and, therefore, had less time to complete the maneuver. In fact, they found that higher GA initiation altitudes significantly increase the likelihood of poor GA performance. These data also show that a high GA initiation point and unstable approach are both factors that can increase the likelihood for a poorly performed GA (i.e., leading to an undesired state). However, low initiation points on the other hand are more strongly linked to low airspeed events and some forms of stall warning.

VI. Go-Around Factors for Research and Training

The aforementioned ranges of GAs that have been flown and the various ways in which they can be executed poorly, provide a framework to develop a range of simulation research scenarios as a facilitator to understanding pilot monitoring demands. These scenarios will be critical for evaluating training. In this section, a set of proposed factors is laid out for defining the set of research scenarios. These should be considered as strong guidelines for defining a sufficiently diverse final set and are unlikely to be implemented precisely. Note that cases are strongly data driven whenever possible while others were based on reasonable choices if necessary by lack of sufficient data.

A. Initiation Altitude

The data from the previous analysis shows that GAs are initiated from somewhere below 100 ft to up above 4,000 ft. While roughly 2/3 of GAs are initiated at 1,000 ft AGL or lower, GAs should be included that start much higher as well. The proposal is to use a few GA initiation altitudes to sample across the full range. They are specified in Table 1, together with the altitude change categories which are discussed in Sec. VI.D.

B. Pilot-Initiated Versus Air-Traffic-Control Initiated Go Arounds

In line operations, this factor can potentially have a large influence on the level of flightcrew startle that occurs when the GA is triggered; however, the data set did not provide data on this issue. For pilot-initiated GAs, the flightcrew may be struggling to meet the stabilized approach criteria over a period of time. For example, they may be attempting to reduce airspeed, descent rate, or a lateral deviation sufficiently to be within the criteria at the GA decision gate. In this case, they may anticipate that a GA is a potential outcome.

An ATC-initiated call for a GA, however, can occur when the weather is good, visibility is clear, and the flight is right on the glideslope and localizer. When ATC calls for the GA in these conditions, the transition may be unexpected and abrupt.

Both types of GAs should be included in the set of scenarios for study and evaluation. However, while startle can be an important factor in GA performance, it can be difficult to produce legitimate startle in a simulator setting.

C. Missed-Approach-Procedure Versus Air-Traffic-Control Targets

The missed approach procedure (MAP) targets are likely to have been briefed and may be familiar for frequently visited airports. These targets should be in the MCP/flight guidance control unit (FGCU) prior to GA initiation. When ATC provides different targets, the flightcrew will need to hear them, acknowledge them, and enter them into the MCP/FGCU. This adds workload at the beginning of the GA. The flightcrew may also not immediately understand where they are relative to those targets – for example, how far above me is the new stabilization altitude? Both types of GAs should be included in the set of scenarios for study and evaluation.

D. Altitude Change to Stabilization Altitude

For cases in which the missed approach targets are maintained, the proposal is to use a typical stabilization altitude, such as 2,500 ft or 4,000 ft. Actual numbers will be used from the airports/approaches that are selected for training and evaluation. The altitude change can be varied by pairing these with GA initiation points that are higher or lower.

For cases in which ATC provides a new altitude target, commonly used numbers will be used that also can offer a range of altitude change values. Table 1 proposes a spread for the altitude change categories for a few initiation height samples across the full range, as was suggested in Sec. VI.A.

Table 1 Spread of altitude change categories per sampled initiation height

GA Initiation Height	Short	Medium Lo	Medium Hi	Long	Very Long
300 ft AGL			✓	✓	✓
500 ft AGL			✓	✓	✓
1,000 ft AGL		✓	✓	✓	✓
1,600 ft AGL	✓	✓	✓	✓	✓
2,700 ft AGL	✓	✓	✓	✓	
3,600 ft AGL	✓	✓	✓		

Recall from Sec. IV.D that the altitude change categories are defined as follows:

- Short – for altitude changes of less than 500 ft
- Medium lo – for altitude changes of 501 to 1,000 ft
- Medium hi – for altitude changes of 1,001 to 1,500 ft
- Long – for any altitude changes of 1,501 to 3,000
- Very long – for any altitude change greater than 3,000 ft

Below 1,000 ft GA initiation height, it is important to emphasize the long and very long altitude changes, but above this altitude the distribution between the altitude change categories becomes more evenly spread which should also be reflected in the training scenarios. Also, the training should include climbs of 500 ft or less – potentially, the most difficult to manage – which occur primarily between 1,500 and 3,000 ft.

E. Lateral Change at Go Around Initiation

Resetting a heading or track target can add workload. For setting a lateral change at GA initiation, the proposal is using either a small change ($10 - 30°$) or a larger change ($50 - 80°$).

F. Airplane State: Configuration

The data gave some insights on appropriate gear and flap configurations for different GA initiation points. For the gear, the data show that the gear is typically down for GAs that are initiated at 1,000 ft or lower, and the gear is typically up at 2,500 ft and higher. Between 1,000 and 2,500 ft, each gear setting will be used 50% of the time. The data show that flap position is appropriately related to airspeed, and airspeed and the airplane's flap schedule should be used to determine the flap position.

G. Airplane State: Autoflight

The data show that the state of autopilot (AP) and autothrottle (AT) changes as the airplane continues down the approach. Above 2,500 ft, the vast majority of flights in this sample had both autopilot and autothrottle on (AP on, AT on). Below 2,500 ft, there is an increasing transition over to either autopilot off (AP off, AT on) or both autopilot and autothrottle off (AP off, AT off); the combination of AP on, AT off is rarely used. In the non-Airbus (Boeing and McDonnell-Douglas) fleet, the majority of flights with GA initiations below 500 ft transition to AP off, AT off. The Airbus fleet are more likely to shift to AP off, AT on at the lower altitudes. Tables 2 and 3 show the schemes that are proposed for the scenarios.

Table 2 Distribution of autopilot states per altitude band for Boeing and McDonnell Douglas airframes

Non-Airbus Rules	AP On, AT On	AP Off, AT On	AP Off, AT Off
above 2,500 ft	100%	0%	0%
500 – 2,500 ft	40%	40%	20%
below 500 ft	25%	25%	50%

Table 3 Distribution of autopilot states per altitude band for Airbus airframes

Airbus Rules	AP On, AT On	AP Off, AT On	AP Off, AT Off
above 2,500 ft	100%	0%	0%
1,000 – 2,500 ft	50%	50%	0%
below 1,000 ft	25%	50%	25%

H. Airplane State: Offset

The data reveal that, for some of the GAs, the airplane was positioned more than 1 dot away from the GS and/or LOC at GA initiation. The most frequently occurring offset was being high (more than 1 dot above the GS). Above 1,500 ft, the airplane was On Path roughly 50% of the time. Below 1,500 ft, On Path increased to roughly 2/3 of the GA initiations. Overall, the airplane was High about 20% of the time. Table 4 proposes the scheme to sample from the various regions.

Table 4 Distribution of path deviations per altitude band

GA Initiation Height	On Path	High	Low	Right	Low Left
above 1,500 ft	50%	20%	10%	10%	10%
below 1,500 ft	65%	20%	5%	10%	–

Note that, functionally, left and right offsets create the same basic problems for flightcrews (unless there are parallel runways), but we will maintain the distinction to add variety to scenario presentation.

I. Airplane State: Energy

The data set also revealed that at GA initiation, some flights were trying to manage energy issues; specifically, either high and fast or low and slow. High and fast was the more likely case. Thus, it is possible to add this factor to the aforementioned offset variations in Sec. VI.H by making half of the high cases high and fast. Some of the low cases are similarly turned into low and slow.

J. Weight and Thrust (and TO/GA use)

The data set provides no information on TO/GA use, but an unpublished reference indicated that TO/GA was used on 60% of the GAs studied. It is also known from pilot reports that, in some airplanes, there is a TO/GA with additional thrust (called hi TO/GA below) that can be used in many airplanes. Table 5 proposes to specify thrust use depending on altitude. Hi TO/GA will be used only at the lower GA initiation altitudes. TO/GA will not be used as much at higher initiation altitudes.

Table 5 Distribution of thrust use per altitude band

GA initiation height	Hi TO/GA	Reg TO/GA	No TO/GA
300 ft AGL	30%	60%	10%
500 ft AGL	15%	75%	10%
1,000 ft AGL	5%	60%	35%
1,600 ft AGL	–	55%	45%
2,700 ft AGL	–	15%	85%
3,600 ft AGL	–	5%	95%

Airplane weight is also chosen appropriately to the range of % MTOW values in Fig. 9 above. These combinations should provide a range of T/W ratios across the scenarios.

VII. Summary

The information presented in this publication is meant to guide the development of scenarios for go-around research and go-around training of airline crews. This study started with a statistical analysis of a select data set with GA information, provided by a few airlines. The data analysis observed certain trends in the data that warrant extending the existing limited training scope of go arounds in the current FAA mandated airline training portfolio. Based on the observed trends and three identified categories of performance metrics that allow to evaluate how go arounds were performed, a set of important go-around factors is listed to support the development of scenarios for more extensive go-around training of airline crews. This information will serve as a foundation to develop a representative spread of suggested training scenarios that will then be used in a piloted simulator evaluation of the new training program.

Acknowledgments

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