Investigation of Single-pilot Operation Accidents

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Introduction

A recent study[1], comparing accidents involving one-pilot versus two-pilot business jet operations in a 37-year period, revealed that 37 percent of the analyzed accidents involved jets crewed by one-pilot versus 63 percent with jets crewed by two pilots. Even though the number of two-pilot accidents was higher, single-pilot ones resulted in more fatal crashes. Embraer has assisted investigation authorities in several events involving single-pilot operations and valuable lessons were learned from these events in terms of training, publications, as well as investigation procedures and safety factors involved once single-pilot operations have peculiar characteristics when compared to two-pilot operations. Embraer has looked deeper into operational aspects present in the occurrences with the objective to identify trends, develop improvements and enhance the investigation process.

For a thorough understanding, this paper presents the concept of single-pilot operation, its certification requirements, limitations and the profiles of the pilots who usually crew aircraft in single-pilot operations . This paper aims to share Embraer's experience gathered from years supporting investigations of this type of occurrence worldwide, with the purpose to provide investigators with important aspects to be observed throughout the investigation of occurrences involving single-pilot operations, as well as to point-out the importance of turning the lessons learned from these occurrences into assertive and feasible recommendations.

Single-pilot jets - background

Most business jets are certified in the transport category because they have maximum certified takeoff weights greater than 12,500 pounds (5,670 kilograms), the threshold between large and small aircraft, certified under part 25 and part 23 rules respectively[2] [3]. One of the various differences in the certification rules between small and large aircraft is the requirement for at least two pilots in the large transport category airplane[4].

In almost every area of certification, the standards for jets have been more rigorous than the ones for turboprop airplanes. One of those standards had been the requirement for two pilots, which remained in force until 1977 when Cessna won approval for single-pilot operation of its Citation I-SP with the intent to market it against small twin turboprops[5]. Since then, other small jets were also certified to be crewed by one pilot such as the Eclipse 500, Mustang, Premier I, Phenom 100, Phenom 300, Honda Jet and some Citation versions. Most single-pilot jets are very light jets (VLJ), which fall under the small aircraft category once they usually have maximum take-off weights under 10,000 pounds (4,535 kilograms).

For many years, cockpits of aircraft certified under part 23 requirements were simple in design and used instruments and systems that were also similar in operation. This made it easy for pilots to transition safely from one part 23 aircraft to another. However, because of the continuous growth of modern technology and the reduced cost of electronic components, newer and more complex integrated avionics are increasingly being installed in part 23 airplanes. These new systems have changed the appearance, operation, as well as man-machine interface.

14 CFR part 23, §23.1523 establishes the criteria for determining the minimum flight crew and in order to have an aircraft certified as single-pilot, some aspects such as workload, pilot interface with the cockpit equipment and degree of automation must be consistent with having only one pilot onboard the aircraft. The following are some known workload factors considered significant when analyzing and demonstrating workload for minimum flight crew determination[6]:

- The impact of basic airplane flight characteristics on stability and ease of flight path control.

- The accessibility, ease, and simplicity of operation of all necessary flight, power, and equipment controls, including emergency fuel shutoff valves, electrical controls, electronic controls, pressurization system controls, and engine controls.

- The accessibility and conspicuity of all necessary instruments and failure warning devices such as fire warning, electrical system malfunction, and other failure or caution indicators. The extent to which such instruments or devices direct the proper corrective action is also considered.

- The complexity and difficulty of operation of the fuel system, with particular consideration given to the required fuel management schedule required by e.g. structural, or other airworthiness considerations. Additionally, the ability of each engine to operate continuously from a single tank or source that is automatically replenished from other tanks if the total fuel supply is stored in more than one tank.

- The degree and duration of concentrated mental and physical effort involved in normal operation and in diagnosing and coping with malfunctions and emergencies, including accomplishment of checklist, and location and accessibility of switches and valves.

- The extent of required monitoring of the fuel, hydraulic, pressurization,

After the certification authority determines that the proposed design allows the pilot to physically manage the cockpit from the left seat, actual flight testing will determine if the airplane can be approved for single-pilot operation. The results from these flights base the Flight Standardization Board (FSB) Report, specifying training, checking and currency requirements to flight crew operating the referred aircraft [7].

In this case, it is the airplane that is approved for single-pilot flying, not the pilot. Therefore a training program must be developed by the aircraft manufacturer and it needs to be approved by the certification authorities in accordance to the FSB report.

From the owner pilot perspective, single-pilot operation is all about flexibility and it is understandable why most of them prefer to fly their business jets without a copilot. The convenience of taking off when you want, staying there as long as you want, and all other aspects of operating your own aircraft are at least a little more complicated when you need an extra pilot.

Single-pilot Operation - Human performance

In aviation, the decision making process has been an area of interest for investigators and aviation safety professionals. The occurrence of errors in the decision making process is usually related to the aviation context itself which is surrounded by quick-changing scenarios, as well as challenging factors that may compromise crew performance, such as complexity of systems and level of automation.

Workload is defined as the relationship between an individual's capacity to perform a task (mental and/or physical), and the level of system and situational demands associated with the performance of that task. The basic notion is related to the differences between the amount of resources available in the operator (human being) and the amount of resources demanded by the task. Tasks that demand much of the human resources are considered high workload tasks. Conversely, tasks that demand little of the human resources (capacity) are considered low workload tasks.(4)

Human error is often related to workload, and there is usually a positive correlation between excessive workload and the occurrence of errors. It should be noted that errors could also be associated with low workload. Levels of workload that are too low are often found in fully automated systems where the operator serves largely as a monitor of the automated processes. In these cases the operator/pilot may become inattentive and/or bored, and this situation is generally referred to as task underload. At the opposite extreme, levels of workload that are too high often cause the pilot to miss important information, fail to perform tasks, make errors or engage in task shedding in an attempt to reduce workload.

The single-pilot operation introduces a different dynamics in the cockpit when compared to a dual-crew operation. The decision making process and the overall management of the flight lays on the solo pilot and, therefore, the automation plays a very important role in reducing the workload throughout the flight. Even though aircraft systems are known to be very reliable, they are not equipped with airmanship as humans are and, therefore, single-pilot operation increases the need for threat and error management, adequate training, planning and decision making.

Since a second pilot is not available to support the operation, the solo pilot is responsible for the flight planning, systems monitoring, flying the aircraft, communication and self-evaluation that provides the necessary feedback for further performance improvement. When combined, these actions demand a significant cognitive and psychomotor workload(8),which varies throughout the operation depending on the flight phase, weather, terrain, infrastructure, among other factors.

Psychomotor skills, related to the ability to control the aircraft, are specially demanded on takeoffs, landings and emergency situations and are less demanded during cruise phase. On the other hand, cognitive skills are demanded throughout the entire flight and are related to the satisfactory conclusion of the operation in each flight phase, operation of the different systems, performance assessments, reading and execution of emergency procedures, emotion control, among others[(9)].

During normal operation, the workload can be generally foreseen on each phase of the flight, allowing the pilot to anticipate the actions and reduce workload. On emergency situations, exceptional events require specific actions from the pilot (immediate or not). The degree of complexity associated to an emergency will determine the urgency and sequence of actions to be taken by the pilot. Generally, these situations increase the pilot's workload who shall keep focused on managing the flight while applies the necessary measures to manage the emergency.

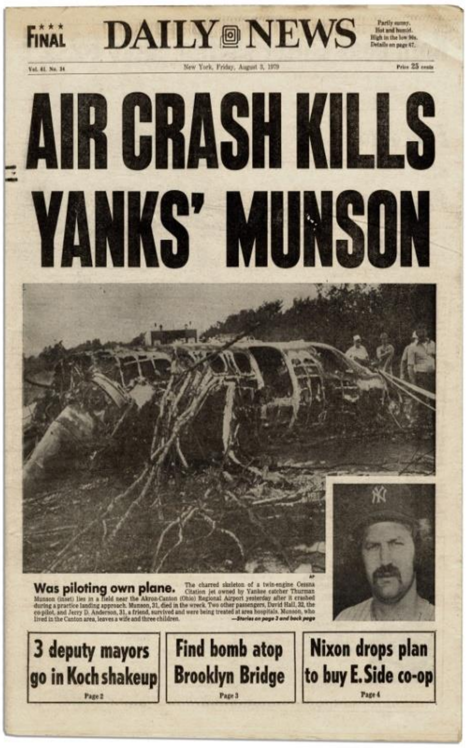
The workload on normal and abnormal operations is taken into account when an aircraft is certified as single-pilot and the absence of one crewmember in the cockpit is a characteristic of this kind of operation and not a limiting factor for a good operational performance[(6)].

Single-pilot Operation - History of occurrences

A 2015 analysis[(1)] comparing accidents involving one-pilot versus two-pilot business jet operations from 1977 through 2014 revealed that, from a statistics standpoint, there is only a slight safety advantage to having a multiple cockpit crew in single-pilot jets. The analysis examined 107 accidents, 40 of which were in jets piloted by a one-pilot crew versus 67 accidents in jets crewed by two pilots. Although there were more two-pilot accidents, half of the single-pilot accidents were fatal crashes compared with 45 percent of two-pilot accidents. Figure 1 shows the statistics by types of accidents.

Type	1 Pilot	2 Pilots	Total
Total Accidents	40	67	107
Accidents as percent of total	37%	63%	100%
Fatal accidents	20	30	50
Fatal accidents as percent of total	50%	45%	47% (avg)
Fatalities	58	102	160
Fatalities per accident	1.25	1.53	1.39 (avg)
Runway excursion on landing	12	26	38
Approach or landing	11	14	25
Takeoff or departure	6	6	12
Go-around	2	5	7
Midair	1	1	2
Runway collision	0	1	1
CFIT	2	10	12
Loss of control flight into ground	3	1	4
Loss of control flight/recovery	1	0	1
Ditching	1	0	1
Bird strike substantial damage	1	2	3

Figure 1 - AIN Statistics: Accident totals by number of pilots


FINAL

DAILY NEWS

Partly sunny. Hot and humid. High in the low 90s. Details on page 47.

New York, Friday, August 3, 1979

Price 25 cents

AIR CRASH KILLS YANKS' MUNSON

Was piloting own plane. The charred skeleton of a twin-engine Cessna Citation jet owned by Yankee catcher Thurman Munson (inset) lies in a field near the Akron-Canton (Ohio) Regional Airport yesterday after it crashed during a practice landing approach. Munson, 31, died in the wreck. Two other passengers, David Hall, 32, the co-pilot, and Jerry D. Anderson, 31, a friend, survived and were being treated at area hospitals. Munson, who lived in the Canton area, leaves a wife and three children. —Stories on page 3 and back page

3 deputy mayors go in Koch shakeup — Page 2

Find bomb atop Brooklyn Bridge — Page 3

Nixon drops plan to buy E. Side co-op — Page 4

On August 2nd, 1979 a Citation 501 crashed in Akron, Ohio, flown by the New York Yankees catcher Thurman Munson. The accident got a very extensive media coverage but one very important aspect was not reported by them: This was the first fatal crash involving a single-pilot certified light-jet. According to the NTSB final report, the probable cause of the accident was the pilot's failure to follow the appropriate checklist and to recognize the need for, and to take action to maintain sufficient airspeed to prevent a stall into the ground during an attempted landing[10].

This accident, followed by several others throughout the years, raised questions about the safety of single-pilot operations, whether they are inherently less safe when compared to a two-pilot operation. The fact is that there are no evidences that this accident could have been avoided if there had been another pilot sitting on the right seat.

Out of the 107 accidents with business jets certified for single-pilot operation, 67 were crewed by two qualified pilots while 40 were crewed by one qualified pilot. Going deeper into the numbers, approximately 45% of the two-pilot accidents resulted in 102 casualties while 50% of the single-pilot accidents resulted in 58 casualties. Even though the percentages of fatal accidents are similar, the numbers show that more people perished in two-pilot accidents from 1977 to 2014.

The most frequent type of accident was runway excursion on landing and most of them were survivable. Runway excursions with more serious results typically happened due to the crew's inadequate decision-making process, such as electing to continue on an unstable approach and land[1]. The study revealed that 26 runway excursions happened on two-pilot operations versus 12 on single-pilot operations, more than double.

The study showed that the number of accidents are proportional to the fleet size. Therefore, the fleet that has produced more aircraft is likely to have more accidents, statistically-wise.

Every flight, single-pilot or not, has hazards and some level of risk associated with it. It is critical that operators and pilots are able to differentiate, in advance, between a low risk flight and a high risk flight, and then establish an assessment process and develop risk mitigation strategies to address flights throughout that range. A risk assessment tool allows pilots to identify the risk profile of a flight in its planning stages.

Many corporate operators may have the perception that having two qualified pilots onboard the aircraft reduces the risk level and provides the operation with a higher level of safety than having just one pilot. Even though the numbers presented herein do not support this perception, many operators choose to limit their single-pilot operations according to the profile of the mission as a way to mitigate the risks in specific operations.

Single-pilot Operation accidents - The investigation

After the investigation authority has been notified of an accident, it is likely that the go-team will be launched to the crash site. It is important to remember that a single-pilot accident is no different than any other accident and all necessary precautions must be taken to ensure the safety of the group during the on-site activities. Such precautions include a thorough risk assessment prior to deployment of the team, use of appropriate safety equipment, health precautions, among others.

The following topics present suggested lines of investigation for a single-pilot accident, based on Embraer's experience with this kind of event throughout the years. The events described herein are based on final reports from accident investigations worldwide.

Activities at the crash site

Recorders

Most very light jets (VLJs) are equipped with a cockpit voice recorder (CVR) unit and it is imperative that the recorded audio is not overwritten after the accident. Since many accidents are survivable and the damage to the aircraft are usually not very extent, it is not uncommon for the aircraft to be powered-up after the event. Therefore, whenever feasible, upon notification of the accident, the investigator shall instruct the operator of the aircraft to pull the associated circuit breaker and keep the aircraft powered-off so that the unit is de-energized, preventing the audio from being overwritten. If, for any reason, this is not feasible, the investigator shall do it immediately upon arrival at the crash site. Some aircraft may have more than one recording unit, so it is important that all related circuit breakers are pulled. The Phenom 100 and 300 are equipped with a combined voice and data recorder installed in the rear section of the aircraft. The Phenom 300 has an additional FDR unit installed in the front section of the aircraft (optional) and there are different circuit breakers for each unit.

Central Maintenance Computer (CMC)

The aircraft's central maintenance computer stores several important information. Aircraft with advanced avionics presents advisory, caution and warning messages depending of the type of malfunction. These messages are logged in the CMC's memory and can be downloaded for further analysis if the unit is not damaged. If it is safe to power-up the aircraft, the investigator should download the data on-site. In most cases, the unit is removed from the aircraft and preserved for further analysis at the manufacturer of the component. Embraer Phenom 100 and 300's CMC records, among other parameters, the latitude, longitude and groundspeed of the aircraft upon take-off and landing and they are able to transmit the CMC logs to an Embraer server every time the aircraft lands, thus allowing investigators to quickly determine the touchdown point of the aircraft within minutes after the accident takes place.

Pictures

Just like any other accident, the investigator should not hesitate to take as many pictures as possible, even if it feels like they will not be of help in the future and, also, remember to document everything before they are touched or moved. It is not recommended to delete photos from the camera, so that the file number sequence is not disrupted. Recording videos can also be a helpful tool to register the condition of certain parts of the aircraft and the accident environment. Sometimes, time available in the crash site may be limited and narrated high-definition videos can be a quick and reliable way to document the crash site.

Cockpit

Since most VLJs are not equipped with a FDR unit, cockpit pictures are a very helpful resource for operational analysis of single-pilot accidents. They will show the positions of knobs, switches, push-buttons, flap lever, landing gear handle, emergency parking brake lever, condition of oxygen masks, emergency equipment, whether a performance data card was filled out for that phase of flight, etc.

The investigator should also take pictures of the onboard aircraft manuals covers to register which revision of the manuals the crew was using.

After taking as many pictures as possible in the cockpit, the investigator may want to try the push-buttons and document their positions since they are very difficult to be identified by pictures.

Passenger cabin

Detailed passenger cabin pictures will show the investigators the conditions of seat belts, use of emergency exits, use of emergency equipment, safety card information, etc. This will help the investigator gather data for the survival factors investigation.

External pictures

External pictures may also be a source of information for further questions about the aircraft damage. It is very important to take pictures of the wings, flap panels positions, flap actuators, flight control surfaces, trim tabs, engines general conditions (fan blades, cowling, oil level) pitot tubes, angle of attack vanes, landing gears general conditions (including tires, wheels and brakes), general condition of doors and emergency exits and any other items the investigator finds relevant

Crash site and surroundings

As mentioned above, runway excursion is the top one type of occurrence with VLJs. It is important to document runway conditions (drainage, holes, surface uniformity), runway markings (touchdown point, braking marks, hydroplaning marks), runway departure point, impact marks etc.

GPS markings

A handheld GPS is very helpful for the investigator to put together a crash site sketch. Using the GPS, the investigator can mark the location of debris, touchdown point, runway departure point, as well as record individual tire mark tracks throughout the runway. It is important to remember that, for a better accuracy, all markings must be done within the hour. In addition to that, it is recommended that the investigator records a tracking over a known region, such as runway edges, so the recorded markings and tracks can be adjusted on the map if necessary. Figure 2 shows the green tracking recorded along the runway edges during the on-site activities further used to calibrate the position of the tires marks recorded over the runway.

Figure 2 - Recorded GPS tracking along the runway threshold used as reference for calibration

Lines of investigation

Depending on the country, pilots are allowed to get their initial and recurrent training in the full flight simulator or in the actual aircraft. Most part 91 VLJs crewmembers come from twin-engine piston and turboprop aircraft and VLJs are usually their first jet experience. They are usually businessmen and do not fly on a daily or weekly basis.

Most accidents involving VLJ operation are essentially related to operational aspects and the following factors have been present on the majority of the events that Embraer has analyzed.

Training
It is recommended to research the crewmember's training history, back to basic training at the flight school, to identify possible learning difficulties the pilot might have had in the past or behavior profiles that could be identified in the accident.

Previous equipment flown by the crewmember
An aircraft differs from an automobile where one can drive different models and operate their systems without major difficulties. Each aircraft has different systems, procedures, limitations and handling characteristics and it is not uncommon for VLJ pilots, who have logged hundreds of hours on twin-piston engine or turboprop aircraft to revert to their previous knowledge on those aircraft and get the procedures mixed in their minds. The same can happen to pilots who logged thousands of hours on wide-body jets.

In one event, the pilot was monitoring the fuel levels in each wing after takeoff and noticed a certain difference between those tanks. While still climbing and without getting any fuel imbalance CAS messages, the pilot decided to open the fuel transfer valve to balance the fuel and commanded a turn, which aggravated the imbalance to a point where one of the wings got really heavy and large aileron trim deflection was necessary to keep the wings leveled. The pilot requested to turn back and the aircraft landed uneventfully. During the investigation, while interviewing the pilot, he mentioned that he opened the cross feed to balance the fuel. However, the aircraft he was flying at the time of the occurrence did not have a cross feed system, but a gravity fuel transfer system. The pilot was relatively new to this aircraft type and brought his previous knowledge from the equipment he had flown for over 5 years prior.

Passenger on the right seat.
It is not uncommon for a passenger to seat in the right seat during single-pilot operations. Based on previous accidents analyses, some of these passengers were pilots, not type rated in the aircraft, and were assigned operational duties such as callouts, communications, FMS programming, aircraft configuration and even the landing itself. Having someone seating in the right seat does not decrease the single-pilot operation safety itself but if, during critical phases of the flight, the pilot in command is engaged in extra activities (not expected in single-pilot operations) such as explaining the functioning of the aircraft systems and monitoring the actions taken by the person seating in the right, higher cognitive skills might be demanded and may affect the pilot's capacity to focus on what is relevant to the flying task. In some countries such as Brazil, the person occupying the right seat may not operate the aircraft or its systems unless this person is fully type rated in the aircraft.

In one event, when the aircraft was still on the ground before takeoff, the crew received a crew alerting system (CAS) message, indicating a brake fail condition which they attempted to reset, unsuccessfully. They decided to continue their departure and the CAS message stayed active for the entire flight. There was a pilot type rated in the aircraft occupying the left seat and another pilot on the right seat who was not type rated in the aircraft. The pilot on the left was flying the airplane for most of the flight and conducted a GPS approach. Just before landing the pilot on the right took over and, after touchdown, discovered that they had no brakes. The airplane began skidding after the emergency parking brake (EPB) handle was pulled.

In another event, the aircraft overran the runway limits after landing on a water contaminated runway. The pilot seating on the left was type rated in the aircraft and the pilot on the right was not. According to the FDR data, the touchdown occurred approximately 1,700 feet (520 meters) past the runway threshold. As per the CVR, the pilot seating on the right, who was not type rated in the aircraft, landed the aircraft with verbal assistance from the pilot on the left.

Motivation
Motivation is a drive that causes one to act or behave in certain ways. The word "motivation" itself is neutral in meaning and may have positive or negative connotations such as making safe decisions or taking risks. Human error is context dependant and is usually aggravated by personal characteristics such as experience, self confidence, pride, etc. This combination may lead individuals to ignore evidences in favor of anything they disagree with and give more weight to information that confirms what they know to be true. Such tendency is known as confirmation bias. Owner pilots are usually successful businessmen who are used to taking risks in their professional lives and such personal characteristic is sometimes brought to the cockpit, influencing the pilot's decision-making process.

In one event, the aircraft experienced a runway excursion after landing on a water-contaminated runway. Upon takeoff from the origin airport, the weather conditions at the destination were favorable to a landing under visual flight rules (VFR) but throughout the flight, weather conditions at the destination started to deteriorate. The pilot reported difficulties in coordinating clearances with the ATC. The approach would initially be conducted to the southeast but due to the start of precipitation over the airport, the runway in use changed. In the meanwhile, in the base leg, with the runway in sight, the pilot was instructed by the ATC to perform a 360-degree turn to maintain separation from 3 other traffic in the pattern. Precipitation increased over the airport and even though visibility was reduced, the pilot configured the aircraft for landing, continued with the approach and ended up skidding off the runway. The pilot reported that he was motivated to land due to the previous difficulties with ATC and also due to the weather. He was concerned that if he had to go around, he would not be able to proceed back to the airport due to the deteriorating weather. The pilot's motivation played a very important role in his decision-making process, leading him to take unnecessary risks. Even though this was a single-pilot operation, this was not the case of an owner pilot operating the aircraft. The pilot was an experienced captain, with over 17,000 hours logged in the commercial aviation.

Human Stress

Stress has been a frequent cause of accidents in aviation. Defining stress is not a simple task since its causes, also known as stressors, come from different sources.

There are several good definitions of stress, but the following is very interesting: "Stress is the state of dynamic tension created when you respond to perceived demands and pressures from outside and from within yourself" [(11)]

Basically, this definition states that stressors are present in both external and internal factors. By nature, stressors can be environmental (e.g., temperature, noise, luminosity), psychosocial (e.g., family, work, friends) and psychological (e.g., health, hunger, well-being). Stressors cause the human body to have responses that are usually common and sometimes non-specific ones and the magnitude of the responses are proportional to the relevance of the stressors to each individual.

Human performance is intimately related to stress level. As stress rises, one's motivation and attention also rises, causing performance to improve. If the stress level becomes too high, motivation and attention degrade, leading to a reduced performance.

As mentioned before, owner pilots of VLJs are usually successful businessmen who use their own aircraft for business. A businessman, tight on schedule and flying himself to an important business meeting usually brings his expectations, strategies and concerns to the cockpit, which increases his level of stress, possibly leading him to a scenario of self-imposed pressure where his performance is likely to be degraded.

Aircraft Performance

Performance has been a contributing factor in most single-pilot accidents. Not the aircraft performance itself but the crew's assessment about it and adherence to the aircraft limitations and performance numbers. The accidents analyzed by Embraer, in which performance was a factor, resulted either in runway excursions or loss of control in-flight.

Landing Distance

In almost all runways excursions, the available runway length is not sufficient for the aircraft to stop within the runway limits as a result of the actual runway condition, approach speed, aircraft configuration, tailwind, long flare, brake application delay, etc.

Design regulation requires manufacturers to provide landing distance figures for dry runways. Landing distances for wet runways are determined by simply multiplying a factor over the dry landing distance and this multiplication is mandated by operational requirements. Figure 4 illustrates an example of required landing distances for a Phenom 100[12]. The dry unfactored landing distance provided by the manufacturer is determined in two parts, as shown in figure 3. The first part corresponds the airborne distance, which is the distance between the point in trajectory in which the aircraft is 50 ft above runway surface and the touchdown point. The second part is the ground distance, which is the distance from touchdown to the complete stop. The ground distance may be divided into a transition phase, where the decelerating devices are beginning to be applied, and a full braking phase, with the decelerating devices fully in operation.

If deviations are present in the approach, such as Vref overspeed, tailwind, aircraft high over runway threshold and long flare, the numbers provided by the aircraft manufacturer will no longer be valid once more runway length will be required for the aircraft to stop within the runway limits. Such deviations are often present in runway excursions involving single-pilot operations, and the reason is that these operators do not have flight data monitoring programs associated with their operations. These programs feature logics to identify certain patterns in routine operations, with the objective to enhance flight safety by identifying potential risks and modifying training programs accordingly.

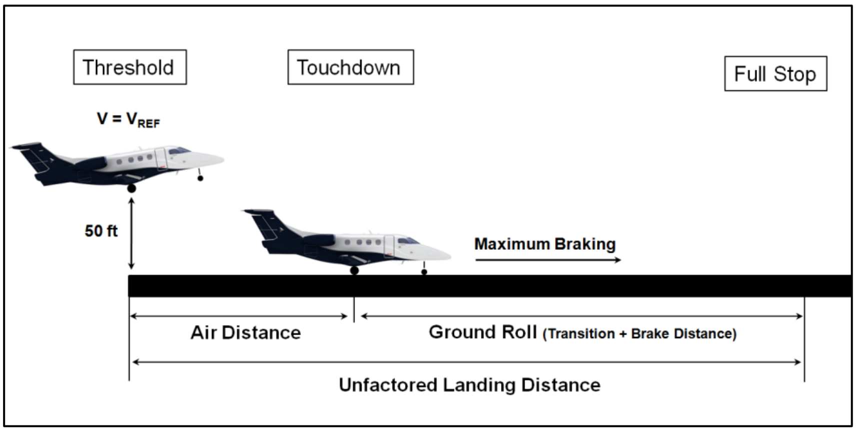


Figure 3 - Segments of a landing - Unfactored landing distance

LANDING DISTANCE (m) – ISA

ENGINE ICE PROTECTION OFF/ON – WINGSTAB OFF
ZERO SLOPE – 10 kt TAILWIND – FLAP FULL

ALTITUDE (ft)	WEIGHT (kg)	SPEEDS			FACTORED		UNFACTORED		CONTAMINATED RUNWAYS (m)
		V_{REF} (KIAS)	V_{AC} (KIAS)	V_{FS} (KIAS)	DRY (m)	WET (m)	DRY (m)	WET (m)	
Sea Level	3400	91	94	111	1465	1684	879	1099	1684
	3500	91	95	112	1452	1670	871	1089	1670
	3600	91	97	114	1440	1656	864	1080	1656
	3700	92	98	115	1441	1657	865	1081	1657
	3800	93	99	117	1467	1686	880	1100	1686
	3900	94	100	118	1490	1713	894	1118	1713
	4000	95	101	120	1514	1741	908	1135	1741
	4100	97	102	121	1538	1769	923	1154	1769
	4200	98	103	122	1563	1797	938	1172	1797
	4300	99	104	124	1587	1825	953	1191	1825
	4400	100	105	125	1616	1858	970	1212	1858
	4500	101	107	126	1641	1887	985	1231	1887
1000	3400	91	94	111	1491	1714	895	1118	1714
	3500	91	95	112	1478	1699	887	1109	1699
	3600	91	97	114	1466	1686	880	1100	1686
	3700	92	98	115	1467	1687	880	1100	1687
	3800	93	99	117	1493	1717	896	1120	1717
	3900	94	100	118	1517	1745	911	1138	1745
	4000	95	101	120	1542	1773	925	1156	1773
	4100	96	102	121	1567	1801	940	1175	1801
	4200	98	103	122	1592	1830	955	1194	1830
	4300	99	104	124	1617	1860	970	1213	1860
	4400	100	105	125	1646	1893	988	1235	1893
	4500	101	107	126	1672	1923	1004	1254	1923
2000	3400	91	94	111	1516	1744	910	1137	1744
	3500	91	95	112	1503	1729	902	1128	1729
	3600	91	97	114	1491	1715	895	1119	1715
	3700	92	98	115	1492	1716	895	1119	1716
	3800	93	99	117	1519	1747	912	1140	1747
	3900	94	100	118	1544	1776	927	1158	1776
	4000	95	101	120	1569	1805	942	1177	1805
	4100	97	102	121	1595	1834	957	1196	1834
	4200	98	103	122	1621	1864	973	1216	1864
	4300	99	104	124	1647	1894	988	1235	1894
	4400	100	105	125	1676	1928	1006	1257	1928
	4500	101	107	126	1703	1958	1022	1277	1958
3000	3400	91	94	111	1544	1776	927	1158	1776
	3500	91	95	112	1531	1760	919	1148	1760
	3600	91	97	114	1519	1747	912	1139	1747
	3700	92	98	115	1520	1748	912	1140	1748
	3800	93	99	117	1548	1780	929	1161	1780
	3900	94	100	118	1573	1809	944	1180	1809
	4000	95	101	120	1599	1839	960	1199	1839
	4100	97	102	121	1625	1869	975	1219	1869
	4200	98	103	122	1651	1899	991	1239	1899
	4300	99	104	124	1678	1930	1007	1259	1930
	4400	100	105	125	1709	1965	1025	1282	1965
	4500	101	107	126	1736	1996	1042	1302	1996

Maximum Landing Weight or Climb Limited Weight exceeded.

Figure 4 - Required landing distances for the Phenom 100

In one event, the aircraft experienced a runway overrun after landing in a wet runway. Onboard the aircraft were four passengers and two pilots. The aircraft was heavy, only 143 pounds (65 kilograms) below the maximum landing weight. There had been recent rain showers over the destination airfield and marginal VFR conditions prevailed. The pilot on the right was not type rated in the aircraft and was handling communications and the avionics, being verbally assisted by the pilot in command. The available landing distance was 3,600 feet (1,100 meters) and, according to the operational manuals, for the given weight and approach flaps, a distance of 4,124 feet (1,257 meters) would be required for a full stop, which was greater than the available landing distance. In addition to that, the approach was performed with a Vref overspeed of 10 knots and a 7-knot tailwind component, which increased the required landing distance. The aircraft departed the end of the runway at 37 knots and collided with a fence. This aircraft type provides the crew with wind information and in the referred event, neither the pilot in command nor the pilot in the right checked the tailwind component in the avionics.

Most part 91 operators do not have policies in place for assessing whether sufficient landing distance exists at the time of arrival, even when conditions (including runway, meteorological, surface, airplane weight, airplane configuration, and planned usage of decelerating devices) are different and worse than those planned at the time the flight was released.

In-flight performance
The manufacturer also provides performance numbers for climb, cruise, descent, holding and driftdown so the crew can plan the flight as to fuel consumption and operational limitations considering aircraft weight, altitude and ISA deviation.

Some part 91 operators of single-pilot VLJs do not have a large background in aviation, especially when it comes to high-performance aircraft. Some important aspects of performance and aerodynamics may not be well comprehended by these individuals, leading to a non-adherence to the published performance numbers, resulting in a flight outside the certified envelope.

In one event, the aircraft experienced a loss of control in-flight at 41,000 feet. According to the planned flight profile, the aircraft should step climb to flight level (FL) 390 and maintain leveled flight for approximately 30 minutes before climbing to FL410 which was the final cruising level. However, prior to takeoff, one of the passengers did not board and the pilot in command assumed that being one passenger lighter would allow the aircraft to climb straight to the final cruising level. The pilot in command spent a large amount of time explaining the aircraft systems to the person seating on the right seat, who was not type rated in the aircraft and thus, he failed to identify the airspeed slowly decreasing to a point where the stick pusher was activated and, subsequently, he did not react appropriately, leading to a series of pitch oscillations until it finally stalled and entered in an uncontrolled dive. Controlled flight was reestablished 44 seconds later, at FL295 and the aircraft proceeded to its final destination.

Safety Recommendations

Most of the single-pilot accidents have several contributing factors in common and just like in any other type of aircraft, safety recommendations for single-pilot accidents are the most important and valuable product of the investigation. They suggest a course of action to improve airworthiness, operational, policy or any other safety issue identified and they can be issued at any time during the investigation. They are based on findings of the investigation, and may address deficiencies that are not directly related to what is ultimately determined to be the cause or a contributing factor for the accident. The investigator must keep in mind that repetitive patterns that cause accidents exist due to weaknesses in the aviation system and even not being mandatory, safety recommendations is an effective way to enhance aviation safety and break certain tendencies.

Conclusion

This paper went through several subjects with the purpose to provide a manufacturer's perspective learned from years supporting single-pilot accidents investigations. The complexity of these topics makes it impossible to compile all the knowledge that is desirable to be part of the repertory of next generations of investigators in a single paper. However, I hope this paper, which originated from Embraer's commitment to continuously assist investigations involving its products, may serve as a reference and contribute to better investigations, with the purpose of making air transport safer.

Acknowledgement

Writing this paper would not have been possible without the expertise and good will of all Embraer colleagues that volunteered their time to support me.

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