Passive Sidesticks and Hard Landings – Is there a Link?

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Passive Sidesticks and Hard Landings – Is there a Link?

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In the period between 2007 and 2017, the number of commercial aircraft equipped with passive sidesticks has more than doubled. However, a passive sidestick may limit the ability of the Pilot Monitoring to perceive the flight control inputs by the Pilot Flying therefore affecting monitoring duties. As part of a research program into Loss of Control In Flight, this paper compares accident statistics and reports for hard landings involving jet aircraft fitted with conventional coupled control inceptors and passive sidesticks.

I. Nomenclature

AAIB	=	Air Accidents Investigation Branch
df	=	Degrees of Freedom
DI	=	Dual Input
FAA	=	Federal Aviation Administration
FO	=	First Officer
FBW	=	Fly-By-Wire
IATA	=	International Air Transport Association
ICAO	=	International Civil Aviation Organization
M	=	Mean
MLG	=	Main Landing Gear
PF	=	Pilot Flying
PM	=	Pilot Monitoring
SD	=	Standard Deviation
STATSUM	=	Statistical Summary of Commercial Jet Airplane Accidents
x^2	=	Chi-squared

II. Introduction

All of the commercial Fly-By-Wire aircraft featuring sidesticks have no cross coupling in between the sidesticks. This means that if the pilot moves his sidestick the co-pilots sidestick will remain static. This type of sidestick is called a 'passive sidestick'. The philosophy of Airbus regarding the independent sidesticks is to avoid the introduction of single point failures that could affect both sidesticks [1]. These separate flight control systems also avoid friction, backlash and inertia due to their missing mechanical coupling. From a human factors point of view, this missing coupling between the sidesticks creates some considerations within a multi-crew flight deck. It limits a monitoring

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pilot to perceive the flight control inputs from the other pilot. Within a multi-crew flight deck there is the task ‘Pilot Flying’ (PF), who flies the aircraft and ‘Pilot Monitoring’ (PM) who actively monitors the flight. The Federal Aviation Administration (FAA) defines the PM tasks as the following: *“Monitoring includes the process of observing and creating a mental model, by seeking out available information to compare actual and expected aircraft state.”* [2]. In some situations, effective monitoring can be the last line of defense to prevent accidents from happening. However, on a flight deck equipped with passive sidesticks, it is hard to predict an aircraft state when the flight control inputs are not directly available for the PM. This study focusses on what the effects of passive sidesticks are on hard landing accidents within the commercial jet aviation. The first passive sidestick in commercial aviation was introduced by Airbus in 1987 on the Airbus A320 [3] . Since then the passive sidestick has been slowly introduced in the business jet aviation, making its first introduction in the Dassault Falcon 7X in 2005. By then Airbus has gained a large share in the commercial jet aviation market. In 2007 18% of the worldwide commercial jet aircraft in operation were passive sidestick aircraft, all built by Airbus. However, over the last 10 years more and more manufacturers converted to a passive sidestick system. In 2017 there are, besides Airbus, 3 other manufacturers that are building commercial jet aircraft with passive sidestick flight controls. These manufacturers are Comac, with their C919 aircraft, Bombardier, with their C series and Sukhoi, with their 100-Superjet. The total amount of passive sidestick aircraft has increased from roughly 4000 aircraft in 2007 to 9130 in 2017 [4]. Passive sidestick aircraft were now responsible for 35% of the total commercial jet aircraft worldwide in 2017. The forecast are that these number will only increase. Currently, 51,6% of all jet aircraft on order are equipped with passive sidesticks [4].

III. Considerations of the Passive Sidestick System

Although passive sidesticks are commonly used in commercial aviation, there are some considerations that come with the passive sidestick system.

A. **Communication Breakdown**

Due to the increased amount of automation introduced in modern fly-by-wire aircraft, the need to directly link the flight control inceptors from the cockpit to the flight control surfaces is gone. Instead of running physical cables from the cockpit to the control surfaces, the control surfaces are now electronically driven by the flight computer, which is electronically driven by the control inceptors. This situation requires less physical components, saves weight, allows for a more reliable system [1] and generates a more simplified system architecture. However, with the deletion of these flight control linkages, the cross-coupling between the two inceptors has been removed as well. It is suggested by several authors that the deletion of this physical interconnection removes one of the lines in which pilots communicate [5, 6]. Field & Harris described in their research the four channels in which pilots communicate with each other, the aircraft and the environment. They described that pilots perceive information from each other throughout auditory cues, peripheral visual cues and proprioceptive cues. Proprioception is defined as: “*the sense of relative position of one’s body parts and the strength of effort being employed in this movement”* [7]. The deletion of the interconnection between the control inceptors removes the proprioceptive cues for the PM. Proprioceptive cueing is used for a pilot to perceive and feel flight control movements. Field & Harris illustrated these four communication channels in figure 1. This paper stated that cues perceived by the peripheral view are still a way in which pilots communicate. However, in terms of passive flight control inceptors, this is nearly impossible. The position of the passive inceptors is on the outboard side of the cockpit making the other inceptor difficult to perceive throughout the peripheral view. In relation to yokes and center-stick flight inceptors who’s movements are much more easily captured due to the simple fact that these movements occur within the peripheral view. Next to that, the deflection of these passive inceptors is much smaller in comparison to yokes and center-sticks, making their movement even harder to perceive. For these reasons, Field & Harris concluded that the pilot of passive sidestick aircraft is much more depending on cues throughout the central vision and auditory cues in comparison to conventional flight controlled aircraft. According to Mica Endsley, this type of situation can lead to a decreased level of situation awareness. Situation awareness can be described as: *“the perception of environmental elements, the comprehension of their meaning and the projection of their future state”* [8]. In an earlier paper, Endsley concluded that the utilization of several sensory modalities for conveying information enhances situation awareness [9]. If that is true, then the opposite can be concluded as well: The removal of several sensory modalities can lead to a decreased situation awareness. Therefore the removal of two communication channels between pilots can lead to a decreased situation awareness. The removal of these communication lines leads pilots in more heavily depending on visual and auditory cues, which are already extensively used when flying a modern aircraft. Again, according to Endsley, this is the opposite of enhancing situation awareness, stating that overburdening one sensory channel is not desirable for designing situation awareness [9].

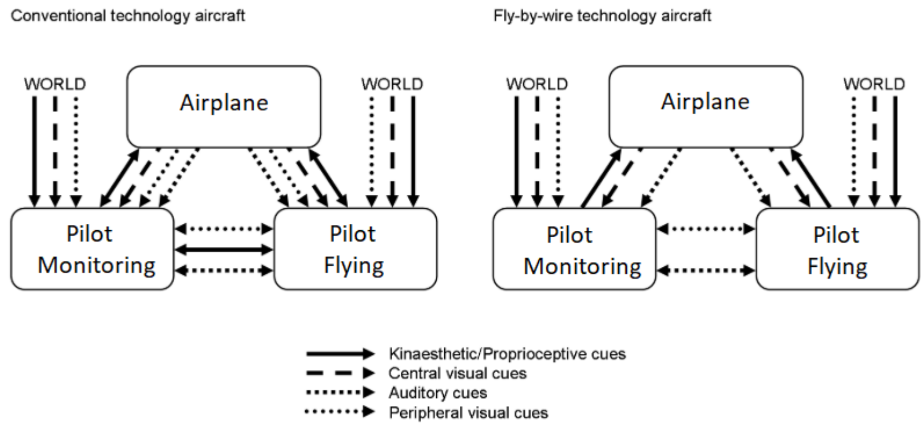

Fig. 1 Information transfer between the airplane and flight crew, adapted from [10]

B. Dual Input Logic

The passiveness of the sidestick enables the possibility of a 'DUAL INPUT' (DI). A DI occurs when both pilots are using the sidestick at the same time. The current way that all passive sidestick aircraft deal with this is by algebraically sum up both inputs. Generating a signal output with a maximum of a single stick deflection. For example, if both of the pilots push the sidestick halfway forward, the output will be equivalent as a full forwarded stick deflection. This is also true for conflicting commands. If one pilot pushes the stick fully forwards and the other pilot pulls the stick fully back, the resulting command is zero. The issue with this system logic is that the summation of the inputs generates a flight control deflection that none of the pilots want. There is an aural cue in order to notify the pilots that a dual input is occurring. Whenever a dual input is occurring an aural warning sounds saying: 'DUAL INPUT'. However, this aural warning can be muted when a higher precedence warning is sounding such as: 'SINK RATE' or 'PULL UP', as has been the case in the Air Afriqiyah accident in Tripoli [11]. Research by Dehais [12] concluded that in many situations pilots are susceptible to unintentional deafness in high stress situations in the cockpit. According to Uehara [10], dual inputs in Fly-By-Wire aircraft often occur after a sudden evolution of a situation leading to manual input corrections. In order to avoid a dual input situation, every passive sidestick aircraft is equipped with a 'Priority Take-over Push Button' located on each sidestick. When this button is pressed, the other sidestick's control inputs are canceled out. According to ICAO Annex 2 [13], the commander should always be in command stating: *"The pilot-in-command of an aircraft shall have final authority as to the disposition of the aircraft while in command"*. Therefore, if both pilots push the Priority take-over button, the captains' side will overrule. If a pilot presses the Priority Take-over button an aural alarm sounds, together with an illuminating light. A summary of these warnings can be seen in Figure 2. As mentioned by Uehara, dual inputs often occur when a sudden situation occurs. The question is, how instinctive is the priority push button when the other pilot wants to take control? According to some accident reports, the priority switch button is not instinctive at all [14,15]. The AAIB concluded several times that in certain situations in which the PM is forced to suddenly intervene, pressing the priority push button is not instinctive. It is much more instinctive in these situations to move the sidestick. In these types of situations, a dual input occurs, in which the output of the flight controls is a summation of the inputs, in many instances results in a combined output that none of the pilots initiated. Other than that, the AAIB conclude that the take-over push button is a highly cognitive action, instead of instinctive [15].

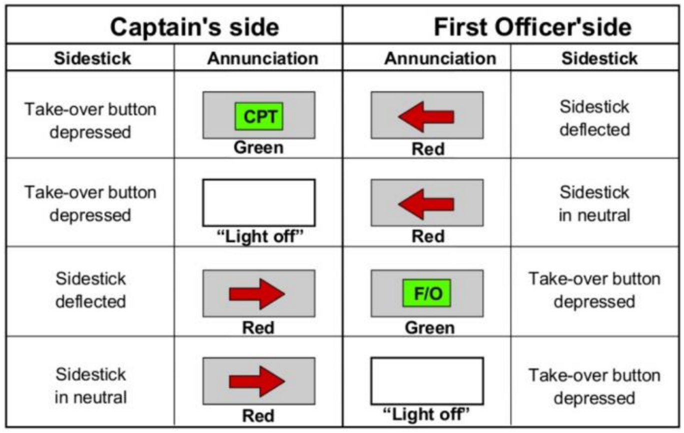

Fig. 2 Sidestick Priority Logic adapted from [16]

C. Unlinked Flight Controls on Flying Skill development

As stated above, the removal of the cross-coupling between the control inceptors also removed one of the lines in which pilots communicate. Research by Rees & Harris concluded that the physical linkage between the control inceptors also functions as a way to develop flying skills [17]. In this study, 20 ab-initio pilots flew a series of approaches in linked and unlinked flight control inceptor configuration. The results suggest that unlinked control inceptors are affecting the development of psychomotor control skills. Throughout proprioceptive cues, the ab-initio pilot gets a better feeling on how to fly an approach, simply by feeling the cues from the flight instructor. This missing learning channel might also be affecting currency levels of passive sidestick pilots. Research done by Haslbeck & Hoerman [18] showed a difference in manual flying skill degradation between long-haul pilots and short-haul pilots. They concluded that the difference lies in the lack of practice of long-haul pilots, who only are only conducting a few flights a month. If the limited amount of flying degrades the psychomotor skills from long-haul pilots, the lack of proprioceptive cuing for passive sidestick pilots could perhaps do the same thing.

IV. Methodology

A. Hard Landing definition

To develop a common understanding of hard landings, the following definition is introduced: A hard landing is defined as: '*a symmetrical and conventional landing or de-rotation with hard contact to the ground that resulted in damage to the aircraft*'. Commercial aircraft are equipped with flight data recorders that are capable of measuring vertical acceleration. However, there are several inaccuracies regarding the accelerometer hence the reason why acceleration exceedance is not used for the hard landing definition in this research. First of all, accelerometers are used to measure in-flight accelerations and are therefore not positioned in a suitable place in the aircraft for measuring landing accelerations. Because of the position, the inaccuracies of the accelerometer can lead up to 0.4g during landing [19]. Secondly, the accelerations vary in magnitude and acceleration. Since the average accelerometer captures data 16 times per second, it is impossible to determine if the recorded value is the actual maximum, minimum or some intermediate value [20]. Finally, within this research different aircraft make and models are compared, every make and model differs in maximum allowed landing acceleration. According to [19], the best way to determine a hard landing is to calculate the true vertical speed, which can be derived from flight data parameters. However, the majority of accident reports do not provide sufficient data to make this calculation and can therefore not be carried out. In order to define a hard landing, damage will be leading in the definition. So any landing that was hard to an extent that it resulted in damage, will be considered a hard landing.

B. Accident Data

This study was carried out on air accident reports of hard landings of registered Air Accident Investigation Authorities by ICAO within the last 11 years (2007 – 2017). The data set is derived from online sources. According to ICAO, there are 204 different air safety authorities. Out of these 204, there have been 119 authorities with an accessible website. Out of these 119 authorities, 72 published reports on their website. A total of 107 accident reports were obtained which fitted the pre-determined hard landing definition. In order to make a reliable comparison, some reports will be excluded from this study. First of all, turboprop aircraft will not be included in this study. Currently, there are no turboprop aircraft within commercial aviation equipped with passive sidesticks. Secondly, hard landings that occurred due to contributing weather will not be taken into account. Examples of these are wind shear, microbursts or sudden turbulence drops. Thirdly, hard landings that occurred due to mechanical failures will also be excluded. Examples of these are flight control malfunctions, autopilot malfunctions, runaway trim/elevators or erroneous flight instrumentation. Finally, hard landings that occurred during high workload situations are also excluded. Examples of these are engine inoperative, damage due to bird-strikes or landing gear failures. When taking these factors in account, there are 44 accident reports left for this study of which 23 occurred on conventional flight control aircraft and 21 occurred on passive sidestick aircraft. All of these accidents occurred in relatively good weather, and all have a human error component in common. A summary of all these reports can be found in Appendix I.

To compare the accident reports database, a cross-reference is being used. The Boeing Statistical Summary of Commercial Jet Airplane Accidents (STATSUM) shows an annual overview of the accidents within commercial jet aviation. Within the past 10 years, the Boeing accident statistics are showing 39 hard landing accidents that resulted in damage. These statistics are only mentioning the aircraft type, operator and a small summary, therefore extensive research on this database is not possible. However, the Boeing Accident Statistics is inconsistent with the accident reports acquired from the accident investigating authorities. The data gathered from air accident reports showed 28 accidents that are not mentioned in the Boeing STATSUM. The other way around, the Boeing STATSUM is mentioning 18 accidents that are not found in the accident reports. Out of these 18 accidents, no additional reports were accessible.

V. Results

A. Difference in Pilot Experience

Out of the 44 accident reports, 39 reports mentioned the amount of hours flight-experience of the pilot flying on aircraft type. An independent t-test was conducted to compare the flight experience of the pilot flying on passive sidestick aircraft and conventional flight controlled aircraft. There was a significant difference in experience for pilots whom suffered hard landings a with passive sidestick aircraft (M = 993.00, SD = 989.90) and pilots whom suffered a hard landing with conventional flight controlled aircraft (M = 2814.33, SD = 3232.36); t = -2.45, p = 0.02, (two-tailed). The magnitude of the difference in the means is large (eta-squared =0.76). This difference in experience becomes more evident if the data is capped at 300 flight hours on type (Fig. 3). In 44% of the hard landings cases that occurred with passive sidestick aircraft happened with pilots with less than 300 hours experience on type. For conventional flight controlled aircraft, this is only 19%. A chi-square test for independence (Yates' Continuity Correction) indicated no significant difference between the two groups with less than 300 hours on type χ^2 *(1 df) = 0.81, p=0.17*.

Another finding is that out of the 20 accidents with passive sidestick aircraft, 4 of these (20%) occurred during an instruction flight or line training flight. This means that in 28% of the cases there was a valid flight instructor on the flight deck and a 3rd safety pilot present in the cockpit. For the conventional flight control aircraft this was only 1 case.

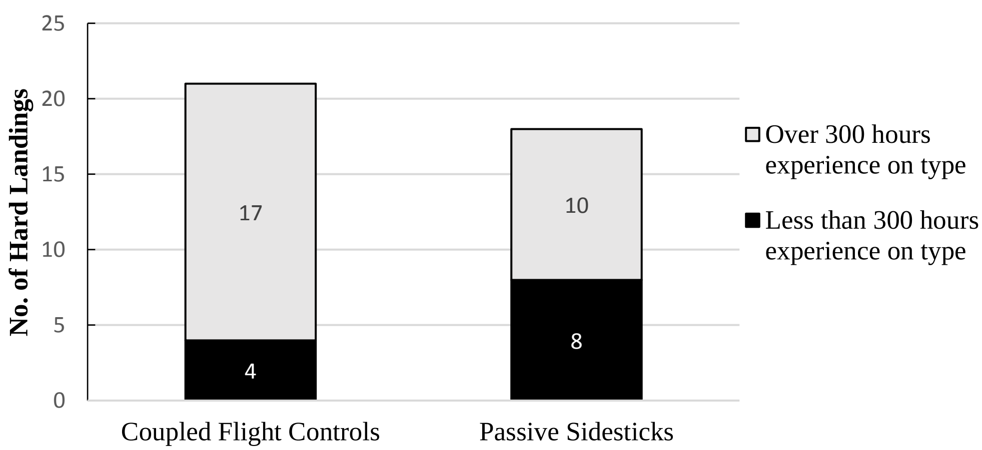

Fig. 3 Hard landings and experience breakdown

B. Passive Sidestick System Logic Contribution

Out of the 20 hard landings with passive sidestick aircraft, 12 reports mentioned the passive sidestick system that may have contributed to the hard landing. In 38% of the passive sidestick hard landings a 'DUAL INPUT' occurred, which in many cases worsened the situation. In 8 cases (40%) of the hard landings, either the accident investigation authority or the PM stated the inability for the PM to perceive flight control inputs from the pilot flying. In 4 cases (20%) the investigating authority mentioned the instinctiveness of the priority take over push button to some extent contributing to the hard landing. As mentioned previously, these factors are caused by the way the system is designed. In a coupled flight control environment none of these factors are relevant.

C. Unstable approaches

The current literature pointed out that half of the hard landings in commercial jet aviation are the result of an unstable approach [20,21]. Every report out of the 44 available reports mentioned the approach being either stabilized or unstable. The overall dataset showed that 50% of the accidents followed an unstable approach. However, it is not evenly distributed among passive sidestick and conventional aircraft. For the conventional aircraft, 79% of the hard landings are considered to be unstable approaches. For passive sidestick aircraft, this number is 19%. This means that 81% of the passive sidestick hard landings are stable approaches but mainly wrongly initiated flare maneuvers (Fig 4). A chi-square test for independence (with Yates' Continuity Correction) indicated a significant difference between the two groups χ^2 *(1 df) = 13.294, p=0.00, phi= 0.59*. According to Cohen [22] the phi coefficient value of 0.59 is considered to be large. This means the magnitude of the significance is large. This indicates there is a significant difference between the amount of stable and unstable approaches between the two groups.

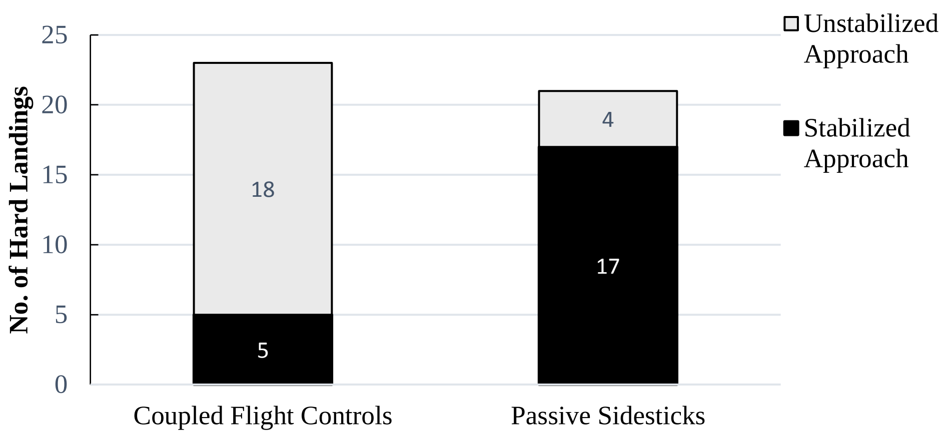

Fig. 4 Hard Landings and stabilized approaches

D. Other results

Several parameters been taken into account that did not show any significance or correlation. Firstly, the different types of flight controls were compared to the normal acceleration of their hard landing. This is data is measured in normal acceleration taken from the accident reports if mentioned. However, there has been no significant difference between the two types in terms of severity of the hard landing. Secondly, the majority of the air accident reports classified the damage of the hard landing. There is no significant difference between the two aircraft types in terms of damage classification.

E. Daytime or Night-time conditions

According to several studies, pilots are more vulnerable to make errors during daytime operation in comparison to night-time operations. De Mello [23] investigated the different times to which pilots are likely to make a mistake in airline operations. His conclusion is that pilots are the most vulnerable to mistakes during the early morning and afternoon. Concluding that the risk of encountering an error in early morning operations is the highest. Similar results of Shapell [24] shows that the majority of air transport accidents take place during VMC conditions in daylight conditions. The results of the accident reports are in line with these results. There have been 32 hard landing accidents (76%) that took place during daylight conditions, and 8 hard landing accidents (19%) during the night and 2 accidents during meteorological twilight (4%). These results tend to be in line with the results of Shappel, who concluded respectively 70% of the accident occurred during daytime conditions, 25% during night conditions and 5% during meteorological twilight [24].

F. Single-aisle aircraft

No distinction has been made in this dataset towards the difference between wide-body aircraft and single aisle aircraft between the two groups. Unexperienced pilots usually fly smaller aircraft and once they gained more experience they tend to fly bigger aircraft. In order to make this distinction the difference is also made between the two groups solely on single0aisle aircraft, to see if the experience levels still differ. However, if the dataset is filtered on single-aisle aircraft only, all the results remain significant. First of all, the flight cycle comparison stays significant with a Chi-square (with Yates' Continuity Correction) χ^2 *(1 df) = 0.94, p=0.2*. Secondly, the difference in experience between conventional (M = 2974.33, SD = 3607.27) and passive sidestick (M = 849.50, SD = 880.02) remains significant: t = -2.21, p = 0.41, (two-tailed). The effect size for this significance resulted in an eta squared of 0.81, which means a large magnitude of significance. If the amount of flight hours is capped at 300 it still shows no significance: χ^2 *(1 df) = 0.41, p=0.11*. The differences in stabilized and unstable approaches remain significant for single-aisle comparison χ^2= 19.95, p=0.00 phi=0.83) also with a large effect size suggesting a large magnitude of significance. There have been insufficient hard landing accidents with wide-body aircraft to do an accurate significance testing on wide-body aircraft.

VI. Discussion

This study investigated the differences in hard landing accidents between passive sidestick aircraft and aircraft fitted with coupled flight controls. First of all, there is a significant difference in the experience of the pilot flying between the two aircraft types. Pilots of passive sidestick aircraft are significantly less experienced when they encounter a hard landing. This could have several reasons. The main reason for this difference in experience could be the inability for the PM to perceive the flight control inputs. This could be the case since 20% of the hard landing accidents with passive sidesticks occurred during a line training flight with a flight instructor as PM. This in combination with a PF with limited experience suggests that it could be more difficult to detect or intervene a hard landing for the PM on a passive sidestick aircraft. As the current literature pointed out [17], it is more difficult to learn to fly without linked controls. In the light of these results, it could mean that inexperienced pilots could also have more difficulties learning how to land on a passive sidestick aircraft. This in combination with a flight instructor that cannot effectively monitor the flight control inputs can be the main reason for the experience difference between the two aircraft types. Another key result from this study is the significant difference in the number of unstable approaches. According to [20, 21] half of the hard landings that occur are the result of an unstable approach. Within the dataset this is clearly the case. In 50% of the cases, the hard landing was a result of an unstable approach. More interesting is the breakdown between the two different aircraft types. For passive sidestick aircraft only 19% of the hard landings were unstable approaches. This means that 81% of the hard landings that occurred with passive sidestick aircraft are stable approaches but the initialization of the flare was incorrect. This effect can be explained by the relatively large amount of inexperienced pilots who might encounter difficulties in the flare maneuver. Another reason could be that the passive sidestick aircraft that occurred within the dataset are designed to change flight control laws at a radio altitude of 50ft. This changeover from normal flight law to direct flight law might introduce some human factor issues for inexperienced pilots. The results from this study, based on air accident reports, tend to be in line with the current literature [5, 10, 15, 16]. It is recommended that these scenarios should be experimentally tested, to gather further research data to evaluate the effects of passive sidesticks by considering complex human factors.

Appendix I Summary of Collected Air Accident Reports

Date	Aircraft type	Registration	Summary
21-02-2007	B737-300	PK-KKV	The aircraft touched down hard at Juanda Airport, Indonesia, which resulted substantial damage to the fuselage, wheel wells and landing gears
28-05-2007	A320-200	C-FNVV	During a landing at Los Angeles Airport, United States, the aircraft bounced and touched down hard with a recorded 3.07g normal acceleration resulting in a damaged landing gear.
05-07-2007	A320-200	G-DHJZ	The aircraft landed heavily on Runway 32 at Kos Airport, Greece, causing substantial damage to the aircraft's main landing gear. It touched down with a high rate of descent, following a late initiation of the flare by the co-pilot, who was undergoing line training
31-08-2007	A340-400	EC-JFX	The aircraft touched down hard at Quito airport, Ecuador with a drift angle of 7º resulting in damage to the undercarriage.
01-11-2007	B737-200	PK-RIL	The aircraft landed on runway 35 at Malang airport, Indonesia. The aircraft bounced twice after the initial severe hard landing resulting in substantial damage to the landing gear.
16-12-2007	Bombardier CL600	N470ZW	During the approach at TFGS Airport, Rhode Island, United States, the FO misunderstood a statement by the captain and reduced power to idle. The aircraft developed a high sink rate and during the flare stalled, impacting the runway at a high vertical rate.
08-01-2008	A321-200	F-GUAA	The aircraft touched down hard at Algiers Airport, Algeria following a bounced landing resulting in a 3.3g acceleration resulting in substantial damage to the landing gear struts.
07-02-2008	B717-200	VH-NXE	The aircraft sustained a hard landing at Darwin Airport, Australia, resulting in structural damage to the fuselage
18-07-2008	A321-200	G-DHDJ	During a landing at Manchester Airport, United Kingdom, the aircraft was not flared sufficiently and a hard landing occurred resulting in a crack in a wing rib gear support lug.
28-07-2008	A321-200	G-MARA	The aircraft made a hard landing in a flat attitude at Manchester Airport, United Kingdom, in which the nose landing gear sustained internal damage.
23-03-2009	MD-11F	N526FE	As result of a hard landing, the aircraft bounced repeatedly on Runway 34L at Narita International Airport, Japan. During the course of bouncing, its left wing broke and separated from the fuselage, the aircraft caught fire.
20-04-2009	767-300	CN-RNT	The aircraft touched down at New York Airport, United States, with a normal acceleration consistent with a "firm" landing. As the main gear touched down, a full nose down column was applied that produced a very high nose-down pitch rate, which resulted in a hard nose gear touchdown resulting in substantial damage to the fuselage and nose gear
06-05-2009	DC-10-30	N139WA	The aircraft experienced a hard landing on runway 10 at Baltimore/Washington, United States resulting in damage to the nose landing gear and wheels
04-08-2009	A320-200	CS-TKO	The aircraft experienced a very hard landing on Ponta Delgada's runway 30, Portugal, causing substantial damage to both main landing gears.
24-05-2010	Embraer ERJ-145	F-GUBF	The aircraft landed hard on to Ljubljana Airport, Slovenia, resulting in a deformed main landing gear shock absorber.
27-07-2010	MD-11F	D-ALCQ	During the landing phase on runway 33Left in Riyadh, Saudi Arabia, the aircraft bounced during the initial firm landing, which was followed by two hard landings. The aft fuselage ruptured and the aircraft eventually stopped on the side on the runway.
03-10-2010	B767-300	G-OOBK	The aircraft landed heavily on Runway 09 at Bristol Airport, United Kingdom. The de-rotation was rapid and damage occurred as a result of the force with which the nose landing gear met the runway.
12-12-2010	B777-200	F-GSPI	After touchdown of the main landing gear, the captain pushed the nose down firmly, the nose wheel bounced hard several times without dampening resulting in a damage nose wheel gear.

13-04-2011	A330-200	G-GZCB	The aircraft touched down hard at Caracas Airport, Venezuela resulting in a damaged landing gear strut.
30-07-2011	Bombardier CL-600	EC-ITU	The aircraft touched down hard with the nose and main landing gear on Barcelona Airport, Spain, resulting in substantial damage to the landing gear.
22-07-2011	B737-300	PK-GGO	The aircraft touched down on runway 17 of Malang Airport, Indonesia, resulting in substantial damage to the engines and landing gear.
26-09-2011	DC-95	YV136T	The aircraft made a hard touch down at Puerto Ordaz causing both engines' (JT8D) pylons and support structures at the airframe to crack.
14-02-2012	A319-111	G-EZFV	The aircraft made firm contact with the runway of London Luton Airport, United Kingdom. The normal acceleration recorded at touchdown was 2.99g, which is classified as a Severe Hard Landing and resulted in a gear replacement.
20-06-2012	767-300	JA610A	The aircraft experienced a bounce when attempting to land at Runway 16R of Narita International Airport and had a damage to the fuselage and gears.
29-08-2012	A320-200	EC-KDG	The aircraft produced a hard landing on Berlin Tegel Airport's runway 26R (Germany) and bounced with the tail contacting the runway resulting in substantial damage to the gear and tail section.
10-04-2013	A320-200	G-OZBY	During rejected go around on Prestwick airport, United Kingdom, the aircraft de-rotated rapidly resulting in substantial damage to the nose gear.
20-05-2013	A320-200	UR-WUB	The aircraft touched down hard at Kiev Airport, Ukraine, with a high pitch, resulting is damage to the landing gear and tail section.
25-10-2013	Bombardier CL-600	EC-JYA	The aircraft landed hard at San Sebastian Airport, Spain, resulting in a damage landing gear.
16-01-2014	A320-200	EI-EZV	The aircraft landed hard with a normal acceleration of 2.75g on London Heathrow, United Kingdom, resulting in 4 minor injured crewmembers, damage is not reported.
01-02-2014	B737-900	PK-LFH	The aircraft landed hard at Surabaya Airport, Indonesia, resulting in a broken wheel hub.
22-02-2014	B737-800	OK-TVT	The aircraft sustained damage during a hard landing in gusting winds at Teicera Airport, Portugal. The aircraft suffered substantial damage to the landing gear.
01-10-2014	Embraer 190	PH-EZV	The aircraft touched down hard at Schiphol Airport, The Netherlands, due to a wrongly set autopilot mode. The aircraft suffered substantial damage to the nose landing gear.
10-05-2014	A319	C-FZUG	The aircraft touched down hard on Montego Bay airport, Jamaica, exceeding the design criteria of the landing gear resulting in a gear replacement.
24-11-2014	747-800F	LX-VCC	The aircraft landed in Libreville, Gabon but touched down hard resulting in substantial damage to the landing gear and fuselage.
15-02-2015	A321-200	VT-PPD	The aircraft bounced during landing on Mumbai Airport, India and subsequently made a hard landing during the second touchdown resulting in damaged landing gear shock absorbers
14-03-2015	A330-300	9M-MTA	The aircraft experienced a hard landing on Melbourne Airport, Australia, of a magnitude requiring replacement of the aircraft's main landing gear.
25-04-2015	A320-200	TC-JPE	The aircraft landed hard on Istanbul Airport, Turkey causing damage to the right hand main gear and engine, the crew conducted a go around and during landed the right main gear collapsed.
14-07-2015	A320-200	VT-IEO	The aircraft was involved in hard landing incident during landing at NSCBI Airport, India, with a normal acceleration of 3.12g, resulting in a change of landing gear.
22-11-2015	B737-300	EX-37005	The aircraft touched down hard at Osh Airport, Kyrgyzstan, causing all gear to collapse and separate.
16-07-2016	A321-200	D-ASTP	The aircraft landed hard on Fuerteventura Airport, Spain, which resulted in substantial damage to the landing gear.
13-09-2016	737-300F	PK-YSY	The aircraft landed hard on Wamena Airport, Indonesia, resulting in the separation of both main landing gears
03-07-2017	A320-200	G-EZAW	The aircraft landed hard at Munich Airport, Germany, resulting in a damaged nose gear and left main landing gear.

18-09-2017	Embraer-145	XY-ALE	The aircraft encountered hard landing while landing to runway-11 of Sittwe Airport, Myanmar, resulting in substantial damage to the wings and landing gears
01-12-2017	A320-200	SX-ORG	The aircraft suffered a severe hard landing at Pristina airport, Kosovo, resulting in a gear replacement.

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