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THEMATIC SECTION | AVIATION SAFETY AND CONTINUED AIRWORTHINESS

BowTie Methodology for the Risk Management of the Spin Maneuver During Flight Training in Brazil

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ABSTRACT

This paper aims to present the BowTie methodology as a practical tool for the Risk Management of the spin maneuver during flight instruction, identifying hazards, controls and consequences related to the loss of control in-flight (LOC-I). Exploratory research was carried out regarding its objectives, through a literature review. Initially, a comparison is made between the Brazilian and international training programs, then the particularities of this training in Brazil was analyzed. Finally, a step-by-step construction of a BowTie developed is presented to reduce LOC-I occurrences during spin training.

Keywords: Risk management; Risk assessment; Flight training; Spin; Flight control.

INTRODUCTION

The curriculums of flight training programs for civil aviation pilots in Brazil were reformulated in 2019 through the publication of the Brazilian Civil Aviation Regulation (RBAC) No. 141 "Certification and operational requirements: Civil Aviation Instruction Centers." In this case, a flight school or flying club that is approved according to this new regulation becomes certified as a Civil Aviation Instruction Center (CAIC).

Complementary to this new Regulation, Supplementary Instruction (SI) No. 141-007 Revision A (ANAC 2020) was published in 2020. This new SI brought another novelty compared to the old training manuals from the National Civil Aviation Agency (ANAC), with latest versions published between the years 1990 and 2004. It is now mandatory to train the spin maneuver in the Commercial Airplane Pilot and Airplane Flight Instructor courses. However, for the Private Airplane Pilot course, training in this maneuver is optional when a CAIC does not have an aircraft certified for this purpose.

Notwithstanding the complexity of the practical training of the spin maneuver, some new measures need to be considered for a safe flight. According to Cremonesi (2021), it is necessary to adopt specific aircraft, which may suffer load factors similar to those found in the maneuvers of the Upset Prevention and Recovery Training (UPRT). Thus, the eventual adoption of complementary training, the acquisition of new aircraft certified for this type of training or the adaptation of existing aircraft may lead to higher costs for a CAIC.

When analyzing the system of courses and schools approved by ANAC, it is observed that the majority of flying clubs and flight schools have not yet adapted to the new standard and that the new CAICs are facing this training in an unprecedented way.

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An example of this consultation is that among the 107 institutions that offer at least the practical training for commercial airline pilots, 66 are not yet adequate, 38 are adequate and 3 are suspended (ANAC, 2021a).

This new ANAC legislation is flexible and only requires a CAIC to develop a program that meets minimum competencies for each course, placing some competencies as optional, as in the case of spin prevention and recovery training (ANAC 2020) for private pilot. This flexibility brings new challenges that need to be better evaluated by the managers of each CAIC: the risk factors, risks, consequences and preventive controls available during training of the spin maneuver.

Data collected from 2010 to 2019 present in the latest statistical summary of instructional aviation in Brazil (CENIPA 2019) indicate that the loss of control in-flight (LOC-I) is the second most frequent type of occurrence in Brazil when using the Accident/Incident Data Reporting (ADREP) taxonomy, representing 17.02% of occurrences (Fig. 1). According to data from the SIPAER Panel (CENIPA 2021), 36 accidents with instructional aircraft were caused by LOC-I in Brazil in the last 10 years.

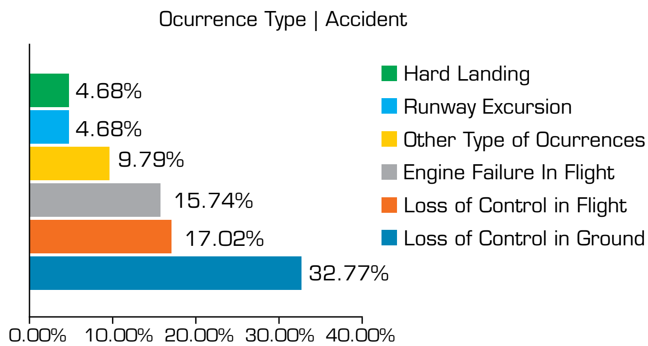

Figure 1. Percentage of accidents by type of occurrence 2010-2019.
Source: Adapted from CENIPA (2019).

According to Ud-Din (2018), both the stall and the spin maneuver are the major cause of accidents related to LOC-I. According to Cremonesi (2021, p. 16), "a type of aeronautical training for airplane pilots that was designed to mitigate the risk of accidents of the LOC-I type is the UPRT." In this case, two important normative instruments can be observed, which propose the UPRT in the initial training of airplane pilots: Doc No. 10,011, the *Manual on Aeroplane Upset Prevention and Recovery Training* (ICAO 2014), and the SI No. 141-007 Revision A (ANAC 2020).

Spin training can be part of the UPRT and should be evaluated for its applicability and risks during the initial training of airplane pilots and airplane flight instructors.

Thus, the purpose of this article is to analyze the risks of introducing the spin maneuver in the initial training of civil airplane pilots in Brazil. The specific objectives of this article are: to conduct a brief comparison between the current Brazilian and international training programs of the spin maneuver; to evaluate the following requirements of the spin maneuver in programs approved in a CAIC: airworthiness criteria, type of execution (incipient or developed stage), minimum height, number of turns, minimum training time and optimal duration of each training; and to identify the main threats and controls available during the training of the spin maneuver.

METHODOLOGY

This article is developed through the deductive method, being divided into three stages. Initially, exploratory research was carried out regarding the objectives, with a literature review, in order to understand the historical development of LOC-I accidents, UPRT training and the execution of the spin maneuver in the training of airplane pilots and airplane flight instructors. In the second stage, a comparison was made between the requirements found in SI No. 141-007 Revision A and some foreign regulations, considering the performance of the spin maneuver in approved courses. In the Brazilian case, an analysis of the technical requirements and training hours required for each course approved by a CAIC was made. In the last step, the BowTie methodology was applied to provide a pattern of analysis of the risk paths related to the execution of the spin maneuver, both in its causes and in its consequences.

The BowTie methodology is a tool that allows a risk assessment to be carried out, which can be used to analyze and show causal relationships in a certain way. This methodology allows, at the same time, to have a panoramic and summary view of the various scenarios that may exist around an occurrence, and the respective control or mitigation measures. The methodology got its name due to the shape of the diagram that is generated (Sousa 2016).

This multifactorial analysis will allow CAIC managers to better assess the benefits and risks of adopting this maneuver in approved training programs. Considerations are made whether in optional programs, such as for obtaining a private pilot license, or in the evaluation of minimum curricula in compulsory programs, where the maneuver is mandatory.

RESULTS AND DISCUSSION

Loss of Control In-Flight

The historical development of LOC-I situations and the first cases of spin recovery in 1912 are discussed by Hadingham (2012). More specifically, Brinkworth (2014) discusses the physics involved during the execution of a spin, the first recorded cases and the first adjustments in the aircraft design, which allowed a better recovery of this maneuver. According to the ANAC (2021b, p. 1, our translation), a spin is a "continuous spiral descent of an aircraft, in which the average angle of attack exceeds the stall" (Fig. 2).

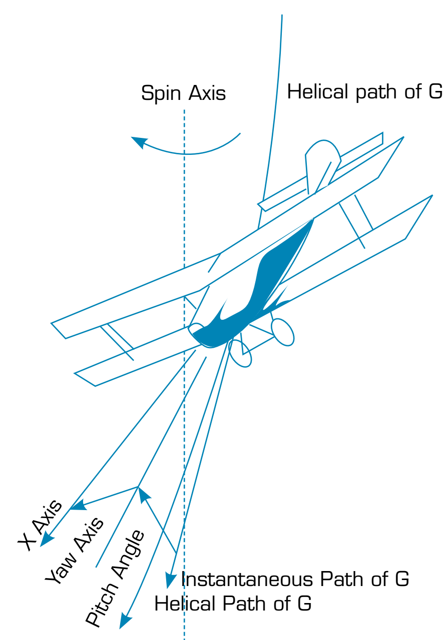

Figure 2. An aircraft in a fully developed spin.

Although initial advances have been made, both in the field of understanding the maneuver and in the structure of the aircraft to recover and better resist the spin, Bourque (2003) considers that, even so, at the end of the 1940s, accident rates related to this type of training were high. At this time, the US Federal Aviation Administration (FAA) removed the maneuver from its private pilot program.

Spin training

Although most aircraft currently in manufacture are characteristically capable of performing spins, there is no current certification requirement for pilot candidates, except for those applying for the flight instructor rating, to show that they possess any practical proficiency related to spins. Such a requirement was excluded from pilot certification criteria in accordance with CAR Amendment 20-3, adopted on June 15, 1949 (Hoffman and Hollister 1976).

Bourque (2003) continues his historical-normative analysis and observes two other moments: one, in the 1970s, when the FAA began to stimulate a training program for the prevention of spin entry, instead of promoting training for exiting this condition; and, finally, he analyzes the high rate of accidents related to flight instructors during the execution of the spin maneuver.

According to the International Civil Aviation Organization (ICAO 2014), until mid-2014, the study of aerodynamics and its effects, and practical missions focusing on stall and, in some cases, on spin recovery were the main industry parameters to mitigate the probability of occurrence of LOC-I. Therefore, there was no specific training focused at preventing abnormal flight conditions in order to obtain a private airplane pilot license or commercial airplane pilot license.

Houston *et al.* (2012) state that good piloting skills are learned from the early stages of training, and it can be assumed that better flight training in general aviation can potentially reduce the overall accident rate with this type of maneuver.

Spin Training Programs

Although Brazil is a member state and participant in the ICAO Council (ICAO 2020), its aeronautical legal system is guided by its Aeronautical Code, published by the Law 7,565, of December 19, 1986, which, through its Art. 1, says:

Art. 1. Aeronautical Law is regulated by Treaties, Conventions and International Acts to which Brazil is a party, by this Code and by complementary legislation.

§ 1 The International Treaties, Conventions and Acts, celebrated by delegation of the Executive Power and approved by the National Congress, are in force from the date provided for in them, after the deposit or exchange of the respective ratifications, being able, by means of an express clause, to authorize the provisional application of its provisions by the aeronautical authorities, within the limits of their attributions, as of the signature (articles 14, 204 to 214).

§ 2 This Code applies to nationals and foreigners, throughout the National Territory, as well as abroad, as far as their extraterritoriality is admitted.

§ 3 The complementary legislation is formed by the regulations provided for in this Code, by special laws, decrees and rules on aeronautical matters (article 12).

Thus, even if the ICAO has developed a specific manual for the UPRT, it does not necessarily need to be adopted, nor be a rigid basis for the creation of national regulatory provisions related to the topic.

In view of this technical sovereignty, Brazil published the SI No. 141-007 Revision A, *Programs of Instructions and Procedures and Manual of Instructions and Procedures* (ANAC 2020). This regulation provides the basis for a CAIC to create separate LOC-I preventive training, such as UPRT and spin recovery training, whether performed at an incipient stage or already developed.

The national standard has several training differences in relation to international regulations, summarized in Table 1.

Table 1. Summary of UPRT data.

	ICAO	FAA	EASA	CASA	ANAC
UPRT in Private Pilot Training	Not mentioned	Not mentioned	Partially required	Not mentioned	Recommended
UPRT in Commercial Pilot Training	Recommended	Not mentioned	Required	Not mentioned	Required
UPRT in Flight Instructor Training	Not mentioned	Required	Required	Required	Required
UPRT in simulators	Only on simulators with validated flight data	Only on Level C simulators or above	Only on simulators with validated flight data	Training must be conducted on the aircraft	Training must be conducted on the aircraft
Spinning training in initial courses	Includes in UPRT	Includes separate from UPRT	Includes in UPRT	Includes in UPRT	Includes separate from UPRT

ICAO: International Civil Aviation Organization; FAA: Federal Aviation Administration; EASA: European Aviation Safety Agency; CASA: Civil Aviation Safety Authority; ANAC: National Civil Aviation Authority. Source: Adapted from Cremonesi (2021).

Table 1 shows that several civil aviation authorities believe that UPRT training can be adopted at different times in pilot training. In addition, Gawron and Peer (2002, p. 22) believe that this training can occur in several ways: "academically (in the classroom), in flight (in aircraft with acrobatic capabilities), in a flight simulator, and in-flight simulation (IFS)". For Rogers and Boquet (2012), ground-based training has many benefits, but also limitations that, to be mitigated, in-flight training needs to be performed.

In the case of Brazilian legislation, training is multidisciplinary and extensive, as it is not limited to ground training (academic and simulator) but must also be carried out in flight (ANAC 2020).

Technical Requirements and Training Hours

The practical training of the spin maneuver must meet some minimum requirements, common to all practical courses where the maneuver is required by SI No. 141-007 Revision A. These requirements involve the safe choice of an aircraft and how the training will be carried out.

Initially, a CAIC must use an "aircraft certified to perform intentional spins" (ANAC 2020, p. 1). According to Coletto (2018), the planes used in this type of training have an inverted oil system that, even in flight with negative G force, continues to supply oil under pressure. Additionally, these planes have a different fuel supply system, which maintains constant pressure of available fuel at the pump, both in inverted flight and in normal flight. Among other requirements observed are implements in the engine cradle, in structural strength, in the size of the ribs, in the addition of a skylight, in the use of 4-point seat belts and in the wing supports (Conheça as diferenças… 2019).

Next, to add the spin maneuver to an instructional program, it is necessary for a CAIC to develop training that provides minimum competencies and perform the maneuver in accordance with the *Maneuver Guide*, information provided in the SI No. 141-007 Revision A. A summary of these requirements is shown in Table 2, segmented by practical course.

Table 2. Description of requirements for courses approved in a CAIC.

RBAC 141 approved course	Spin maneuver training requirements
Airplane private pilot	Stage: The spin must be performed only in the incipient stage (stall with excessive wing drop, about 45°). Minimum height: not specified Number of turns: not specified Minimum training time: Not specified Optimal duration of each training: Not specified
RBAC 141 approved course	Spin maneuver training requirements
Airplane commercial pilot	Stage: The spin should be performed in the incipient stage (stall with excessive wing drop, about 45°) and in the developed stage. Minimum height: not specified Number of turns: 1 (when developed) Minimum training time: 1 h Optimal duration of each training: 45 min
Airplane flight instructor	Stage: The spin should be performed in the incipient stage (stall with excessive wing drop, about 45°) and in the developed stage. Minimum height: not specified Number of turns: 1 (when developed) Minimum training time: 1 h Optimal duration of each training: 45 min

The Bowtie Tool and its Application

The BowTie model "is an adaptation and combination of four models: Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Cause Consequence Diagram, and Barrier Thinking" (De Ruijter and Guldenmund 2016, p. 1). Thus, it stands out as an advance in the study of Risk Assessment, "since it manages to cover in a single diagram, the visual scheme of the causes of failures and their consequences" Sousa 2016, p. 5, our translation (Fig. 3).

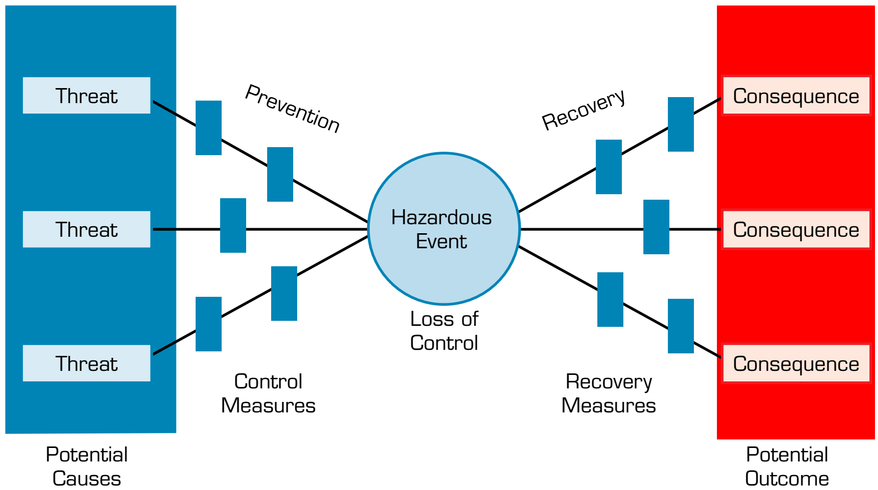

Figure 3. BowTie Model.

According to Alizadeh and Moshashaei (2015), this process involves the systematic identification of risk factors and consequences, assessment of associated risks and specification of control and recovery measures that must be implemented and maintained in a given activity. As shown in Fig. 3, the "BowTie histogram illustrates the relationship that exists around the Top Event or Main Event, with the causes on the left and the consequences on the right" (Sousa 2016, p. 3, our translation).

Both the history and methods for building a BowTie diagram are well documented. Therefore, on this occasion, only the steps of building a BowTie for the risk analysis of the spin maneuver are addressed. The BowTieXP software, version 10.2.1, from CGE Risk Management is used as a tool. The construction of the model is described in Fig. 4. The first step is the definition of the risk factor (hazard) which, in this case, is the training of the spin maneuver. Then, the LOC-I is defined as the central event (top event).

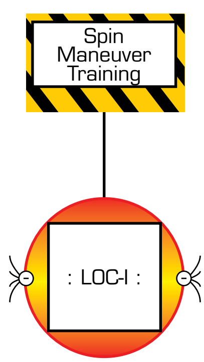

Figure 4. Hazard and Top Event.
Source: Retrieved from CGE Risk Management Solutions (2017).

In this model, the top event is affected by risk factors (threats), on the left side, which can result in consequences, on the right side.

According to Maragakis *et al.* (2009), the choice of these risk factors is made using a variety of tools and techniques, permeating four indispensable elements: people, procedures, equipment and operating environment. The primary sources for choosing each risk factor must allow a hierarchical and planned risk assessment, able to be inserted into risk management tools, such as the Risk Breakdown Structure (RBS), Risk Breakdown Matrix (Cagliano *et al.* 2012) or in risk visualization, as in the BowTie of the present work.

The RBS is a hierarchical, source-oriented risk grouping that organizes and defines total risk exposure. Each descending level represents an increasingly detailed definition of risk sources. The RBS tool is chosen because it provides an effective basis for a stratified risk classification and associated nomenclature. RBS not only serves as a framework for organizing selected risk sources, but also supports their identification (Cagliano *et al.* 2012).

According to Belcastro *et al.* (2017), these primary sources are called Primary Causes and, in the case of the development of LOC-I events, they are shown by their origins, called Causal and Contributing Factors (Table 3). All these points contribute to an aircraft flying out of its envelope and may suffer an upset event.

Table 3. Causal and Contributing Factors.

Adverse onboard conditions		
Vehicle impairment	System faults, failures and errors	Inapropriate crew action/ inaction
Inapropriate vehicle configuration Contamination airfoil Improper loading Vehicle damage to airframe and engines	Control component Engine Sensor system Flight-deck instrumentation Noncontrol component	Loss of aircraft attitude Energy or system state awareness Aggressive maneuver Abnormal control input Ineffective recovery Improper procedure Crew fatigue Impairment
External hazards and disturbances		
Inclement weather and atmospheric disturbances	Poor visibility	Obstacle
Wind shear Turbulance Rain/thunderstorms Snow/icing Wake vortices	Fog/haze Night	Fixed or moving
Abnormal dynamics and vehicle upsets		
Abnormal vehicle dynamics and control response Abnormal attitude, airspeed, angular rates, asymmetric forces or flight trajectory Uncontrolled descent (including spiral dive) Stall/departure from controlled flight		

In the case of the Brazilian flight instruction, the application of commands, piloting judgment and the pilot's low experience represent 32% of the most frequent contributing factors of LOC-I type accidents, with occurrences recorded between 2010 and 2019, as shown in Table 4.

Table 4. Incidence of contributing factors in accidents 2010-2019 [CENIPA (2019)].

Contributing Factors	Incidences
Application of Commands	16
Piloting Judgment	14
Pilot's Low Experience	10
Managerial Supervision	10
Instruction	9
Organizational Processes	6
Flight Planning	6

These three factors are translated as risk factors, being categorized and described in Table 5.

Table 5. Category and description of Contributing Factors.

Contributing Factors	Decription
Application of commands	Inadequacy of the pilot's use of the aircraft flight controls
Pilot Judgment	"Inadequate assessment of certain parameters related to the operation of the aircraft, being qualified to operate it."
Pilot's Low Experience	"Condition presented by the pilot, resulting from low experience in the air activity, in the aircraft or specifically in the type or circumstances of the operation."

The Assessment of LOC-I During Spin Training by the BowTie Method

For the application of the method in the context of the spin, control measures for each risk factor are chosen. Controls have different origins, being normally classified as organizational, technological, or personal (Aust and Pons 2020). According to the *Final Report of the European Aviation Safety Agency* (EASA) on safety aspects related to the resistance to the spin in light aircraft, some controls stand out to avoid LOC-I in flight instruction: limitation of the number of turns, limitation of reaction time, minimum altitude for the start of the maneuver, maximum altitude loss, a better stall warning system, mandatory regulatory training to identify a spin or stall entry and recovery from these situations (Hankers *et al.* 2009). According to Belcastro *et al.* (2017), the use of technologies from Resilience Engineering, notably in the aspects of Resilient Vehicle Control, can mitigate a wide variety of LOC-I conditions in real time. An example of this type of active control is the angle of attack indicator system proposed in the third Safety Enhancement produced by the Brazilian General Aviation Safety Team (Bgast) committee in 2020 (Fig. 5). This type of system allows to know the how close an airplane pilot is to the critical angle that, if exceeded, the stall will occur (FAA 2021), regardless of the aircraft weight, bank angle and temperature (Bgast 2020).

If the Top Event occurs, there are still recovery measures that can eliminate, decrease the frequency, reduce the probability or mitigate the consequences (Maragakis *et al*. 2009). Regarding the LOC-I, Bates (2021) highlights the following measures: UPRT training, a parachute system and an automatic recovery system. The course of UPRT can cause the aircraft to return to a normal flight state, culminating in the elimination of the consequence. On the other hand, the last two solutions pointed out by Bates (2021), although valid, are not practical to apply in instructional aircraft in Brazil, mainly due to the cost or unavailability of technology. Therefore, it is important to highlight that a stall alarm, or instructor interference, can be much more practical and useful measures for the reality of flight instruction in Brazil.

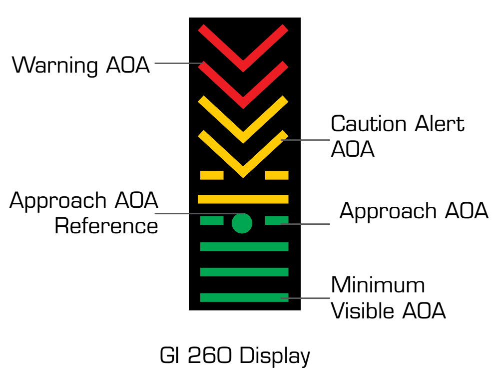

Figure 5. Angle of attack Indicator System.
Source: Retrieved from Bgast (2020).

Finally, the consequences are diverse, highlighting the following: fatalities, serious injuries, administrative fines, damage to the aircraft or loss of the aircraft (hull loss). The complete model is available as shown in Fig. 6.

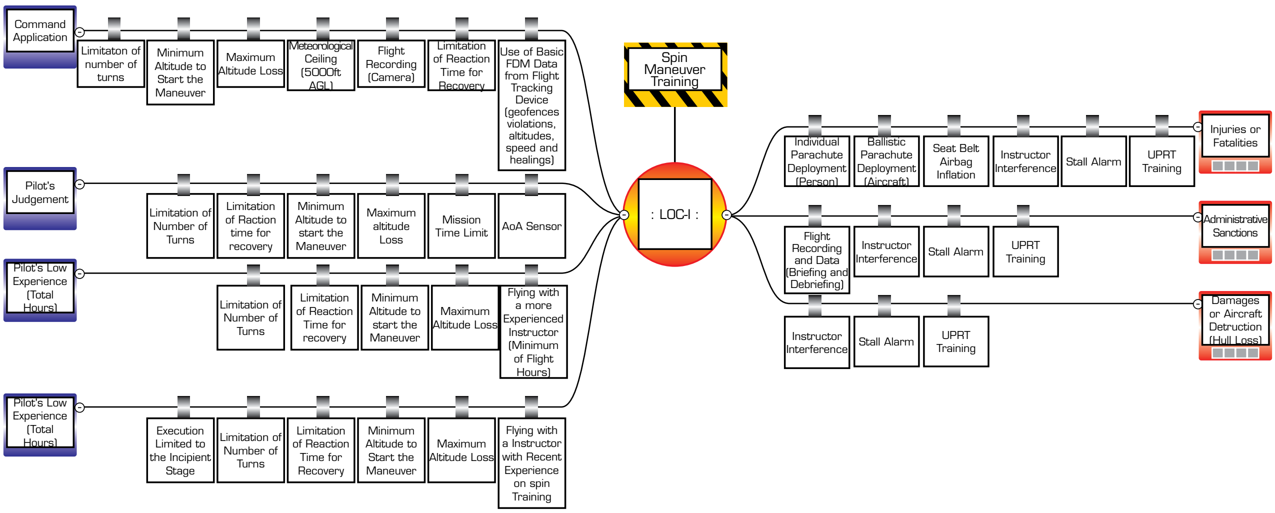

Figure 6. BowTie applied to LOC-I during the spin maneuver.

Source: Elaborated by the authors.

The Civil Aviation Authority (CAA) of the United Kingdom uses in some of its BowTie models an additional factor called Escalation Factor (CAA 2020). This can be defined as the condition that has the potential to negatively affect the effectiveness of a control barrier (Fig. 7) (Aust and Pons 2020).

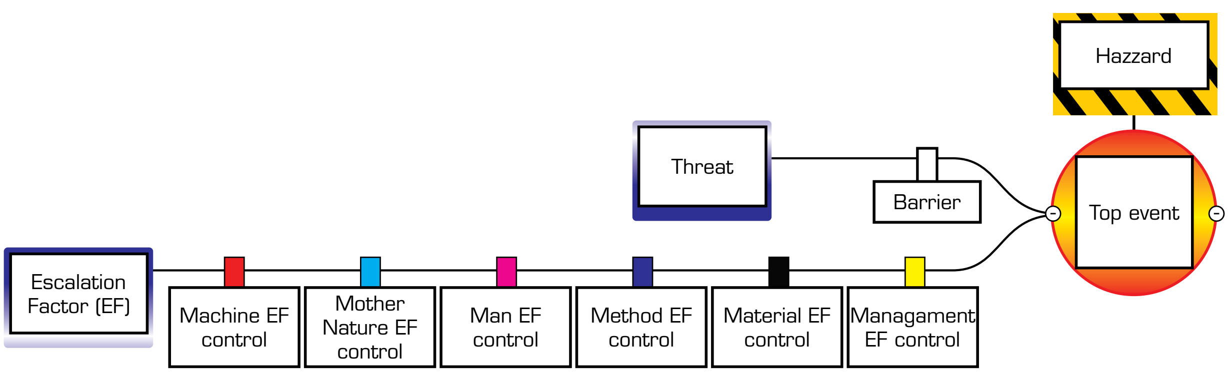

Figure 7. Trajectory of an Escalation Factor in a BowTie.

Source: Retrieved from CAA (2020).

Although this work does not use escalation factors or their respective controls, below are two Escalations Factors for LOC-I situations that the CAA (2014) uses in their BowTie (Table 6).

Table 6. Description of escalation factors.

Escalation Factor	Description
Lack of familiarization with aircraft type	It is not effective to map all appropriate controls for a piston engine aircraft operation and the company starts operating with turboprop engines
The crew cannot adapt to systems automation	Crew members cannot adapt to major system changes, such as upgrading avionics on a previously analog aircraft

Source: CAA (2014).

Analysis of Controls and Recovery Measures

When comparing the controls suggested in Fig. 6 with the current instruction requirements in Brazil, analyzed in Table 2, it is observed that the Brazilian aviation is exposed to some vulnerabilities, as shown in Table 7.

Table 7. Availability of controls and recovery measures in the Brazilian aviation.

Control	Control Description	Associated Recovery Measures	Brazilian Regulation
Limitation on the Number of Turns	The number of turns allowed in each execution of a developed-stage spin	UPRT Training; Instructor Interference; Stall Alarm; Parachute deployment (Individual and Aircraft) Seat belt airbag inflation	Limiting the number of turns is a partially present requirement
Recovery Time Limitation	Maximum time in which actuation on the controls for the recovery of the maneuver must be initiated		Time limitation for recovery is a missing requirement
Minimum Altitude for Starting the Maneuver	Minimum safe altitude or height for the start of the maneuver, where there may be a greater chance of recovery		The minimum altitude for the start of the maneuver is a missing requirement
Maximum Altitude Loss	Maximum vertical altimetry variation during the execution of the maneuver		Maximum altitude loss is an absent requirement
Mission time limit	Ideal or optimal time to perform a mission with the maneuver		Mission time limit is a partially present requirement
Flight with a More Experienced Instructor	Availability of a more experienced and proficient Instructor to train other Instructors who are not so proficient in the execution and recovery of the maneuver		Flight with a more experienced Instructor is a missing requirement

The requirements absent in the Brazilian legislation are diverse. There is, for example, no annual training program to maintain the proficiency of spin instructors. There is also no explicit height limit for starting maneuvers or time for starting a recovery. Although the Brazilian legislation provides freedom for a CAIC to develop its own controls, there is no clear example in the legislation of what these are. This lack of examples can bring limitations in the use of controls since the managers of a CAIC do not know or cannot detail all the available controls.

In addition to the difficulty of mapping these controls for application in BowTie, the use of Safety Intelligence demonstrates that risk mapping needs to be a proactive task, requiring the use of tools to make Safety Databases dynamic, such as Microsoft's PowerBI software, which can keep a civil aviation authority's Safety Dashboard up to date (Patriarca *et al.* 2019).

The complete UPRT training is the most innovative, most frequent recovery measure in this BowTie model and the most recommended in the literature to contain the top event.

LIMITATIONS

Some limitations are present in this article. First, a generic BowTie model is used. It is also possible to add to this model some Escalation Factors and a color scale for categorizing risk factors based on the 6M model (Man, Machine, Materials, Methods, Mother Nature and Management), which facilitates the creation of more controls. These features, although already present in models applied to aviation operators, lack studies for a specific application to flight instruction in light aircraft.

The work also does not carry out a qualitative or quantitative approach with pilots, operators and authorities to apply the method. This restriction, although not the object of this article, makes it difficult to validate the method.

Finally, the organizational culture of each CAIC is not evaluated. This technical lack may result in the use of ineffective controls to contain the LOC-I during training in the spin maneuver.

CONCLUSION

The article evaluates the adoption of the BowTie model in the risk assessment of spin maneuver training, with the objective of reducing the number of LOC-I type events. The study method for creating a practical BowTie model consists of a literature review and document analysis of related regulations. Through the use of the BowTie model present in this work, is explored how the controls and control measures are related to the current training programs in Brazil, providing more options to the managers of a CAIC for a better control of risk management.

The literature is not in agreement with the best methodology for creating a BowTie for civil aviation, nor does it have a diversity of models available with the context: top event LOC-I during the instruction of the spin maneuver. Creating a model depends on each industry. Even in aviation, the models available vary for each segment. In this sense, in order to develop a model suitable for CAICs, the presence of professionals with extensive experience is encouraged and necessary for the creation of correct parameters.

The regulations, despite having clear guidelines for executing the spin maneuver in certain courses, have few control parameters such as the maneuver start height or the maximum reaction time. In the case of the national standard, SI No. 141-007 Revision A, the CAIC is empowered to create additional controls, such as aircraft tracking, filming of instruction flights, or the free offer of UPRT trainings, to increase the safety of the missions.

Both in the literature and in the regulations, UPRT training is shown to be extremely effective in reducing LOC-I events. However, the main aviation authorities have not yet decided to make it compulsory, only parts of this training are presented as course requirements.

The authors recommend that in the next revision of SI No. 141-007 new parameters are included to increase safety in the training of the spin maneuver (Table 8).

Table 8. Parameter Recommendations for Spin Training.

Parameter	Private pilot – airplane	Commercial pilot – airplane	Flight instructor – airplane
Initial instructor training	3 flight hours	5 flight hours	6 flight hours
Minimum height to start the maneuver	Incipient Stage: 3,000 ft AGL	Developed: 5,000 ft AGL	Developed: 5,000 ft AGL
Limitation on the number of turns	½ turn	1 turn	1 turn
Maximum altitude loss	1,000 ft	2,000 ft	2,000 ft
Time to start maneuver recovery	5 s	10 s	10 s
Use of parachutes (individual)	Recommended	Recommended	Recommended
Use of ballistic parachute (aircraft)	Recommended	Recommended	Recommended
Annual instructor training	1 h	1 h	1 h

As suggestion for future works, the develop specific BowTie models for flight instruction in light aircraft is recommended. It is also necessary that other methodologies be explored to identify new risk factors and controls. In this way, BowTie models will be developed with increasingly adequate controls.

It is also recommended that qualitative or quantitative approaches be carried out with pilots, operators and authorities for the application of the method. Semistructured interviews and experimental research should introduce the way for method validation, given the innovative nature of this topic.

Finally, the importance of evaluating the organizational culture of each CAIC is highlighted. The use of organizational culture assessment surveys and climate surveys will be able to parameterize the limits of the results found in the previous suggestions.

AUTHORS' CONTRIBUTIONS

Conceptualization: Leitão IR, de Andrade D, Leão MS, Sarkis PAG; **Methodology:** Leitão IR, de Andrade D, Leão MS, Sarkis PAG; **Writing - Original Draft:** Leitão IR; **Writing - Review & Editing:** Leitão IR, de Andrade D, Leão MS, Sarkis PAG; **Supervision:** de Andrade D, Leão MS, Sarkis PAG.

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The data will be available upon request.

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