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Unstable Approach: Intervention and Prevention

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Abstract. This research aims to investigate the occurrence of unstable approach from teamwork process via situation awareness, and shared-situation awareness. 9 pilots were recruited for a one-hour interview to identify critical themes. The results depicted that, under congested airspace derived from peak hour and unexpected weather, in order to consume excessive aircraft in the terminal area, ATCOs were prone to issue instructions which sacrificed aircraft's safety margins to squeeze the current air traffic flow. Therefore, aircraft may be too high or too fast during approach. For team process, pilots will actively identify ATCOs intention from TCAS, radio channel, and given instructions. As a result, they will be able to predict the coming steps and make preparation in advance. To conclude, in order to balance the needs of both ATCOs and pilots. ATCOs may have to consider not only separation but the appropriateness of vertical profile. Other than that, during the team process, critical and short information should be provided to make sure both parties comprehend each others intention mutually in seconds.

Keywords. Unstable approach, system risks, team process, situation awareness, shared situation awareness, shared mental model

Introduction

Landing safety has long been an issue which receives intensive attention from researchers. Aside from the technical failures or unexpected weather condition, for most of the occurrence of landing accidents, human errors were involved [1]. To achieve proper landing stability, several landing criteria have to be fulfilled, otherwise, the approach can seem as an unstable approach. [2, 3], which may lead to severe accidents, including runway excursion, runway incursion, or hard landing. [4] According to the related research, the unstable approach and failure of go-around were responsible for the major part of aviation accidents, in 2011, 68% of the aircraft accidents happened in these two phases. [2, 5, 6].

Some research blamed the occurrence of unstable approach for pilots' situation awareness, and decision-making errors. However, based on the perspective of critical resource management (CRM), a proper system will be able to detect and address potential risks and threaten in advance [7]. Therefore, to achieve effective and radical risks reduction, not only the operators who got involved the unsafe act, but also the corresponding team work performance. Specifically, the manoeuvers of the aircraft will be determined by the air traffic controllers' (ATCOs) instructions based on the requirement of air traffic flow management, after that, pilots will follow the

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instructions to operate the aircraft accordingly. Accordingly, two aspects will affect the quality of ultimate landing, one is the appropriateness of the given instructions, another is the quality of team coordination and communication [8, 9]. Firstly, ATCO's instructions will be issued based on air traffic flow management and conflict resolution. However, the instructions, sometimes, failed to fit both parties' requirement. For example, excessive airspeed, late descent, or improper vectoring may make the pilots unable to fulfill standard landing criteria within safety margin, increasing the probability of unstable approach [8]. Secondly, at this moment, proper coordination and communication are required to eliminate potential risks [10, 11]. For dynamic landing scenario in the aviation industry, due to unequal information sharing, and highly heterogeneous working types, sometimes, it makes challenging for both parties actively supplement each other immediately. [3, 9]

Apparently, to investigate whether a system is able to achieve required performance and flexibility, the examination regarding the interaction among team members is compulsory, especially for the complicated system like aviation industry [12]. In terms of the current research about unstable approach. Firstly, most of the current research put more emphasis on the individual performance. Relevant research investigates how the pilots operated, and coped with the instability during the landing phase [2, 3], or how ATCOs provided proper instructions which facilitate landing stability [8]. Other than that, little research explores the dynamic process of communication during approach. With limited research, [9] investigated the break down during the communication process, indicating that 52% of communication conflicts occurred in approach phase. Furthermore, the mismatch of operation requirements was the most prevalent type of conflicts, which was derived from the difference between subjective priority regarding required performance.

From the perspective of the human factor, to achieve seamless teamwork within a complicated system."Shared situation awareness (SSA)" is a critical role which can be defined as the extent to which all individuals in a team hold the same value regarding the required team performance [11, 13]. And it determines whether all the works from each of the team members are able to achieve a "holistic" team performance. Based on the literature above, obviously, the mismatch of operation requirement and the difference between two parties' priority regarding performance showed that, sometimes, pilots and ATCOs failed to hold the same value and figure out a proper solution which fit both sides' requirements during the communication. Relvant research indicated that it also connects to the unwanted ultimate team performance, even though each of the team members has fulfilled their responsibility. Since an individual may not able to predict and provide necessary resources which others need [13, 14]. Therefore, the aim of this research is to uncover the root cause of the occurrence of unstable approach from the perspective of teamwork process. Specifically, this research will examine the results of team process, and clarify the corresponding decision making and communication gaps between pilots and ATCOs from the perspective of SSA.

1. Literature review

1.1. Situation awareness (SA) & Shared situation awareness (SSA)

Situation awareness (SA) has received intensive attention, especially within the aviation industry, as it is used to explore how operators make their decisions. SA represents how a person perceives different elements in the environment, how they comprehend the meaning, and how they project the status to the future [1, 15]. For level 1 SA, one perceives the critical cues from the environment. For level 2 SA, one comprehends the meaning of a situation pattern through a mental model created based on training or experience. Finally, for level 3 SA, one projects the current situation to the near future to anticipate what will happen. After a series of mental processing, the final goal and ultimate decisions can be determined. SA serves as a basis for high quality of performance, and decision-making, numerous research have indicated the importance of possession of proper SA, especially for landing. [3, 4] As in landing phase is the most dynamic situation within the whole flight trip. It's compulsory for both ATCOs and pilots to stay sharp about the probable changes.

However, SA is mainly adopted to explain an individual's decision-making process. With complicated systems in the modern aviation industry, highly heterogeneous work distribution is common to cope with the extremely dynamic environment. Therefore, SA has been further extended to the perspective of the team and examines how numerous team members integrate their work and achieve required team performance, which can be called shared situation awareness (SSA). And it can be defined as the extent to which individuals in a team hold the same SA regarding the required SA [11, 13]. And two different types of shared mental models including (1) task-related mental model, and (2) team-related mental model, have been identified by relevant research. [16]

1. The task-related mental model includes two aspects: (1) technology/equipment and (2) task/jobs. First, the task-related mental model of technology and equipment, it means the shared knowledge which enables an individual to understand the technology they are interacting with, like equipment functions, and system limitation. On the other hand, shared mental model regarding task/jobs determines whether an individual possesses sufficient shared knowledge about team task-procedure, and correspondingly strategies regarding ultimate team goal. Basically, it will not affect the quality of individual performance. However, task-related may act as a "filter" to eliminate those "proper" individual decisions, however, which is not appropriate for overall team performance. Thus, task-related mental model determines whether a team member is able to achieve "individual performance which fits team requirement".

2. Team-related mental model represents the shared knowledge about how the team members interact with one another and how other members behave during the tasks. Three different dimensions, includes: (1) coordination, (2) communication, and (3) cooperation. For the first item, it examines whether team members possess the proper strategic knowledge to actively locate the critical need of the current state [17]. For communication, it unfolds whether team members hold the shared understanding about what information is critical to provide, and how the information is conveyed. For the third dimension, it investigates whether team members are able to cooperate with each other well, including items like team spirit, and interpersonal relationship.

In this research, to achieve a better clarification about potential gaps regarding the possession of SSA, operatos mutual belief will be also uncovered. Relevant research indicated that human is able to simulate other's mind based on the mutual belief, further, enabling proper interaction without completely information exchange [18]. The results also showed that, under the fighter jet simulation, two persons who are able to simulate each's mind achieve better score [19]. However, one thing worth noting is that the possession of shared mental model doesn't directly affect the ultimate team performance. Instead, it will be mediated by the execution of team process, including coordination, communication, and cooperation [17] [14]. Accordingly, the quality of the execution of team process is determined by the required SSA of team members, which affect the ultimate performance. Thus, this research will not only investigate operators' SSA and mutual belief to examine the potential SAA gaps, at the same time, the quality of team process will be also examined to identify the current state of team communication and coordination.

1.2. Agent-based model during landing stage

To achieve a more comprehensive and detailed examination regarding to how ATCOs and pilots coordinated each other during dynamic approach phase, agents-base model (ABM) will be applied, which is a reasonable tools to unfold interaction among stakeholders, system, and procedure Although, ABM is a qualitative approach which applies computational simulation to examine how a system functions under certain environment [20]. It can still serve as a structure which fits the rich data from descriptive decision theory like mental model [21]. Therefore, an agent-based model during approach is developed, and details are shown in Figure 1 below.

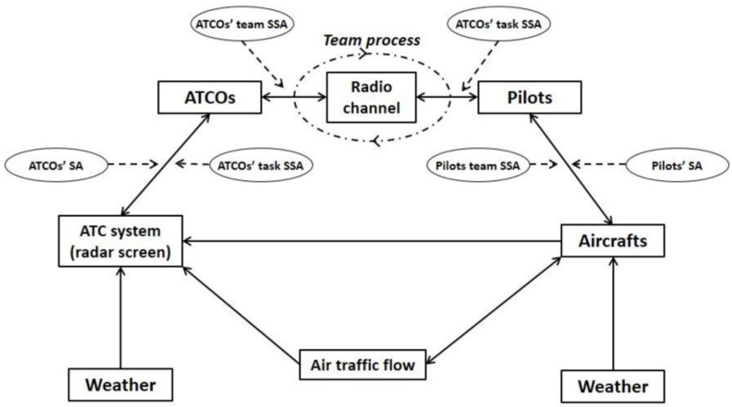

Figure 1. Agent-based model regarding communication between ATCOs and pilots during approach.

For the current system structure, ATCOs are located at a higher hierarchical level than pilots; therefore, ATCOs will check the weather and current air traffic flow from the radar screen, then issuing corresponding instructions to pilots through the radio. After pilots receive the instructions, they will either execute the instructions accordingly or provide alternatives and feedbacks to coordinate with ATCOs, making sure the instructions fit both sides' requirement. In terms of mental capabilities, respective SA is compulsory for each sides' main tasks (ATCOs for air traffic control, pilots for aircraft maneuver). On the other hand, to achieve seamless radio communication, corresponding team-related SSA are needed for them to provide critical information, and identify critical need during the team process. Ultimately, for task SSA, it determines whether team members are able to fulfill their work which fit system's requirement and strategies.

2. Methodology

2.1. Structure and participants

For the methodology, the SA and SSA will be elicited by the critical decision method, which is the event-based approach used to investigate challenging events [22]. Nine pilots were recruited and asked to provide experience regarding unstable approach. Two parts will be identified to fully explore the teamwork during the landing phase, including: (1) Given instructions from ATCOs, and the approaches pilots applied to evaluate them, and (2) following team process after instructions provision. After that, the content analysis will be carried out to categorize several critical themes which will be essential to explain the occurrence of unstable approach. For the prerequisite of the recruitment, to investigate the potential risks in the system interaction, participants pilots are required to be at least first officer with at least one-year working experience. With the possession of descent experience and skill, participants can pinpoint the underlying breakdown which may harm the landing safety effectively.

2.2. Interview questions

Two aspects will be covered in this research, including (1) Given instructions from ATCOs, and the approaches pilots applied to evaluate them, and (2) following team process after instructions reception. Corresponding probes will be applied to uncover the SA and SSA.

1. ATCOs' instructions & pilots evaluation:
   - What were the instructions you have received from the ATCOs during the unstabilized approach?
   - Please describe the state of the aircraft, how you comprehend the state, and how did you evaluate the appropriateness of the instructions? (pilots' SA)
2. Team process:
   - Please describe the team process during approach.
   - How you actively support team supplementary?What is the critical information needed to be provided? What is the vibe of cooperation?
   - To facilitate team supplementary, what kind of aspects do you think is necessary for ATCOs to possess? What kind of information do you think is necessary for ATCOs to provide? What attitude do you think is necessary for ATCOs to possess?

3. Result:

In this interview, 9 pilots were recruited, including 4 first officers (FO), and 5 captains (Capt). The participant's profile is shown in Table 1 below. And for the results of content analysis, 16 sub-themes has been converged to 33 themes. The themes which are no more than 5 frequency will not be displayed here. And these themes will be separated into two parts, including: (1) ATCOs' instructions & pilots evaluation (5 themes, and 12 sub-themes), and (2) corresponding team process (11 themes, and 21 sub-themes).

Table 1. Participants profile.

Participants	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Age	31	32	40	60	52	25	50	52	57
Position	FO	FO	FO	Capt	Capt	FO	Capt	Capt	Capt
Flying hour	1900	2000	3000	22000	30000	1450	18000	9000	12000

3.1. The reception of ATCO's instructions

This section consists of two parts, including (1) the instructions from ATCOs, and (2) the approaches pilots applied to evaluate given instructions. The overview of the codes and themes are shown in Table 2 below. Firstly, for the provision of instructions from ATCOs, two themes were identified, including the scenario background, and instructions content. As for the scenario background, congested airspace which was based on either peak hour or bad weather was frequently mentioned. On the other hand, for instructions content wise, high-speed instructions were frequently issued, other than that, ATCOs also squeezed the aircrafts sequence for better airspace utilization. Relevant instructions include taking short cut, and late descent.

As for the approaches pilots applied to evaluate the instructions, excessive airspeed, altitude were the frequently mentioned cues (SA level 1) for landing instability. Then, the remaining track miles is a critical indicator of safety margin, accordingly, the three-time rule will be applied to evaluate the current state and the window for instability elimination (SA level 2). For prediction (SA level 3), pilots are able to know the available window to eliminate instability. And it's critical to predicting 10 nautical miles ahead.

Table 2. ATCOs' instructions & pilots evaluation.

The instructions from ATCOs		
Theme	Sub-theme	Description
Scenario background: Congested airspace (41)	Peak hours (18)	ATCOs will try to consume congested air traffic flow as soon as possible (9) and manage multiple aircrafts simultaneously (4). Moreover, the communication channel will be clogged up due to frequent instructions provision (5).
	Unexpected weather (12)	Unexpected weather compressed the available airspace, leading to congestion (7), also the condition of the runway will be significantly affected (5).
Instructions content: Instructions sacrifice safety margin for better utilization of air space (43)	Maintain high speed (18)	Requested pilots maintain high speed for faster consumption of air traffic flow, which made pilots unable to decelerate on time (18).
	Unsafe sequence management(20)	Sequencing instructions which may sacrifice pilots' safety margin to consume the flow faster. Relevant instructions includes take short cut (9), late descent (7), and increase air speed for separation (3)
The approaches pilots applied to evaluate instructions (SA)		
SA Level 1: Excessive airspeed and altitude were the most common cues which pilots concerned. (33)	Either too fast or too high on LOC (14)	Excessive airspeed (8) or excessive altitude (6) when pilots intercepted the localizer.
	Too fast and too high on LOC (6)	Both airspeed and altitude were excessive when pilots intercepted the localizer (6).
	Excessive altitude due to track miles reduction. (9)	Excessive altitude because ATCOs cut down the available track miles (9).
SA Level 2: Remaining track miles is critical for coming energy management	Remaining track miles act as the margin for energy dissipation (43)	Remaining track miles and three-times rules served as the indicator of remaining safety margin (30). And it determined whether the aircraft were able to decelerate and descent in time (13).

and dissipation (75)	Deceleration will be firstly executed before descent (11)	The airspeed should be decreased to a certain gate first, preventing from high-speed descent. (11)
	The direction of the winds affected the ultimate state of the aircraft (12)	Wind direction around the terminal area is a factor which affects the results of deceleration. Head wind is preferred to help decelerate.
SA level 3: Based on the results of prediction, pilots are able to know the available window to eliminate instability. (25)	Predicted that remaining track miles were not enough for energy dissipation. (14)	Pilots realized that remaining track miles was not able to dissipate excessive altitude (4), air speed (4), or both of them simultaneously in time (6).
	Proper prediction is compulsory (4)	It's critical to predicting the state of aircraft 10 nm ahead.

*the number in the brackets represents the frequency mentioned.

3.2. Team process

This part consists of three parts to uncover the current state of team process, including (1) team process, the results of communication and coordination, (2) pilots' SSA, and (3) ATCO's required SSA from pilots' perspective. The overview of the codes and themes are shown in Table 3 below. First, for the result of team process, to coordinate properly, it's critical to actively identify each other's intention and constraints. Pilots will check TCAS, and other pilots' communication on the radio to actively identify ATCOs' intention, which helped them to determine coming steps accordingly. For communication wise, providing coming steps directly to decrease the time consumption is important. It's waste of time to elaborate the cause-result interaction.

For pilots' SSA, regarding team SSA, to achieve proper coordination, pilots will apply various approaches to achieve proper coordination, various approaches will be adopted to identify and anticipate ATCOs' intention. The mostly used approach is TCAS checking, through examining the flow of surrounding aircraft. Other than that, pilots will also listen to the communication of other pilots. All of which enable pilots to collect relevant cues, and simulate how ATCOs executed their job. In addition, to decrease the time consumption under critical scenario, pilots emphasize the direct provision of next course of action, instead of the reasoning of current state. As for task SSA, pilots also manage the air traffic flow partially, which is achieved by maintaing aeparation between the aircraft ahead, and try not to slow down too early, helping ATCOs to manage the flow easier.

For ATCOs' required SSA from pilots' mutual belief, regarding team SSA, in order to facilitate a better coordination efficiency and results, it will be better for ATCO's to express their intention directly, which facilitates pilots to actively get engaged in the team process. Furthermore, the provision of remaining track miles and assigned airspeed from ATCOs during communication also provide cues for pilots to identify ATCOs' intention. For example, more track miles than the usual might represent congested air traffic flow ahead, so pilots will prepare to decelerate in advance. As for required task SSA, ATCOs should consider the appropriateness of vetical profile, and capabilities limitation. Since, sometimes, ATCOs may over-focus the seperation maintenance, ignoring whether the aircraft are stable or not. And the appropriateness of vertical profile is the item mostly frequently mentioned, which leading to excessive potential energy state. Furthermore, different rate of deceleration among different weight of aircraft should be also taken into consideration to prevent the potential impact regarding seperation maintenance.

Table 3. Team process and corresponding SSA.

Theme	Sub-theme	Description
Team process		
Coordination: it's critical to identify each other's intention and constraints (23)	Actively identify each other's intention (15)	Both parties actively identified each other's intention. Pilots will check surrounding aircraft via TCAS (3), and aircraft current state (4) to figure out the intention of ATCOs. For ATCOs, they will actively check pilots' acceptability regarding instructions (5).
	Passive coordination (6)	Sometimes, both parties fail to reach consensus, then pilots executed the instructions directly.
Communication: information provided should be critical yet short (42)	Keep communication short and clean (11)	It's critical to keep the communication short and clean. Excessive information will congest radio channel.
	Provide coming course of actions directly to each other (24)	For both parties, it's critical to provide the information regarding to current constraints and corresponding actions directly. E.g: pilot will request extra track miles (one orbit) for operate directly where necessary.
Cooperation: professionalism matters (20)	Professionalism and training facilitate the vibe (10)	The good impression regarding ATCOs' professionalism will increase the confidence of cooperation
Pilots' team SSA		
Coordination: pilots actively anticipate and examine ATCOs' instructions (40).	pilots will apply various indirect approaches to anticipate ATCO's intention (27)	Pilots will try to actively anticipate ATCOs' intention via checking TCAS (9), the aircraft state (9), other pilots' communication from the radio (2), and information in given instructions (5).
	Pilots possess critical thinking to examine the instructions (8)	Pilots should possess critical thinking to eliminate potential risks, instead of blindly following ATCOs' instructions
Communication: The provision of coming step is critical (13)	The provision of pilots' own coming step is critical (9).	It's important for pilots to provide the next step directly (9). E.g." unable to hold due weather, is it possible to do a left-hand pattern instead of right ?"
	The alternatives should be short (3).	Pilots try to keep information short and critical to decrease the consumption of time
Cooperation: respect the instructions as possible (12)	Pilots will respect ATCO's instructions at first place (8)	Pilots will respect and follow ATCO's instruction as possible, as long as the landing safety was ensured. Since the communication takes reciprocal help.
Pilots' task SSA		
Pilots will fly the aircraft in a way which supports ATCOs requirement regarding air traffic flow management (36).	Make preparation for coming instructions (10)	Pilots will make preparation in advance for coming instructions, which is based on the current state of aircraft. (10)
	Try to actively maintain separation, among aircraft (11)	Pilots actively maintain the separation (5 nm) among aircraft to support ATCOs requirement.
	Not decelerate too early to fit ATCO's requirement (5)	Pilots will try not to slow down too early to fit ATCO's requirement regarding air traffic flow management. (5)
Required ATCOs' team SSA from the perspective of pilots		
Coordination: expressing intention helps pilots engaging the coordination (11)	It's better to express intentions during communication (4)	It's better for ATCOs to express intention via instructions. For example, due to runway change, heading to 350 degree
	The constraints of pilots should be set as priority (6)	ATCOs have to adapt themselves to the pilots' need and find another solution to sort out the situation.
Communication: surrounding information and remaining track miles are critical to	It's better to provide the state of surrounding (5)	When providing the instructions, it's better to provide the relevant surrounding instructions, like the state of air traffic flow ahead.
	Track miles and required speed are	Track miles and assigned speed are critical information which is needed to be provided, which helps pilots

being provided (21)	needed to be provided (9).	identified ATCOs' intention, and tailor their flight plan to ATCOs' need.
Required ATCOs' task SSA from the perspective of pilots		
ATCOs should comprehend the performance constraints and consideration of pilots (32)	ATCOs should ensure the appropriateness of aircraft state (11)	For ATCOs, the consideration of the appropriateness of vertical profile is compulsory, instead of over – focusing separation.
	ATCOs should know the capabilities difference among aircraft (19)	ATCOs should know the capability difference among different types of aircraft regarding declaration rate for better management of sequencing and avoid the sudden change.
	ATCOs should realize pilots' care regarding remaining fuels (9)	During vectoring the aircraft (go-around/ holding), the consideration of remaining fuel is necessary, avoid fuel emergency.
The way ATCOs issue instructions has to adapt current state of air space (8)	The instructions should be tailored to the air space (8)	ATCOs have to actively adapt to the compressed air space due to bad weather, changing the way of vectoring.

*the number in the brackets represents the frequency mentioned.

4. Discussion and conclusion

Based on the results above, it's apparent that the occurrence of unstable approach is highly connected to the appropriateness of given instructions. For ATCO's responsibilities, they have to consume the airspace congestion as fast as possible, which makes acute changes common. However, it may conflict pilots' consideration regarding landing safety, while gradual operations are preferred. As a result, how to balance the requirement for both ATCOs and pilots is critical. Accordingly, team process serves as a safety net to detect and eliminate potential landing risks, which requires both parties to actively engage in. However, due to different information sharing and the lacking of the regular form of information delievery, sometimes, it's hard for both parties to identify each other's intentions and constraints within a short period. If team process fails to achieve the required performance, the responsibilities of landing risk elimination will totally rely on pilots' experience and skill, which bring excessive mental workload.

Overall, the landing risks derived from inevitable goals conflicts are common, while they can detect and cope with proper team process. Based on the current approach, voice communication is still the major way to communicate each other. However, in the future, data-link will be applied to replace the current way [23]. All the trajectory data can be dynamically exchanged between pilots and ATCOs. However, relevant research indicated that data-link is unlikely to be implemented in the terminal area [9] Since approach phase is too dynamic to spend extra time to key in extra data to communicate, which has been mentioned by two captains in this research. However, based on the results of this research, both pilots and ATCOs have possessed required mental model to identify the overall situation with limited cues, like remaining track miles and assigned speed. Hence, as long as we can identify ATCO's mental model, and how they comprehend pilots' constraints in the future research. Then the point where both parties converges can be used as a critical basis for the development of the future supplementary system.

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