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There is substantial evidence that the consistent application of the process tools and methods of flight deck management (CRM) has yielded improvements in the performance of flight crews in error avoidance, identification, trapping and correction or mitigation in operational flying. There is also ample evidence of operational shortcomings in flight crew performance extending beyond the flight deck, particularly in interactions with the air traffic control system and controllers (ATC), contributing to or directly stimulating consequent degrading of operational performance in these critical interactions. This paper reports an effort to adapt and apply specific tools and methods derived from those of the Quantum-Pro® Management System of cockpit resource management to engage the controller as a "time/task-shared crew member" and critical partner in professional flying and to effectively counter errors or shortcomings that arise in flight crew interactions with ATC, hence to improve performance of these partners in operational flying, both in terms of the ATC situation and the flight situation of the participating crew.

Introduction

The safety and utility of operations in the National Airspace System (NAS) are dependent upon the performance of the key elements of that system, especially the flight crews and controllers that form its backbone, both as distinct agents of the system and as nodes on the network that constitutes the system. More simply, flight crews and controllers are critical partners in achieving and sustaining the essential high reliability of the NAS system. While there is opportunity for conflict in aims and priorities, the system performs at its best, and serves us all best when the particular authorities and responsibilities of flight crews and controllers are implemented in ways that complement and enhance their relationship.

Consequently, there has been great interest in the performance of flight crews and controllers in this context. The performance of flight crews in particular has been well studied, and process tools and methods of flightdeck management (CRM) in particular have yielded performance improvements in error avoidance, identification/trapping and correction or mitigation in operational flying. At the same time, there is also ample evidence of operational shortcomings in flight crew performance extending beyond the flight deck, particularly in interactions with the air traffic control system and controllers (ATC), contributing to or directly stimulating consequent degrading of operational performance in these critical interactions.

This paper reports an effort to adapt and apply specific tools and methods derived from those of the Quantum-Pro® Management System of cockpit resource management to engage the controller as a "time/task-shared crew member" and critical partner in professional flying and to effectively counter errors or shortcomings that arise in flight crew interactions with ATC, and hence to improve performance of these partners in operational flying, both in terms of the ATC situation and the flight situation of the participating crew.

Methodological Approach

This effort was an outgrowth of a long collaboration between Daniel Webster College (DWC) and Cockpit Management Resources, Inc. (CMR) for implementation of the Quantum-Pro® Management System (QMS) in the undergraduate programs at DWC. This collaboration resulted in a phased implementation of QMS first for multi-pilot operations, then adapted for single-pilot operations (Teller, Mudge, & Brown, 2001), and further adapted for implementation in air traffic control operations.

Shortcomings in flight crew interactions with ATC
A literature search was combined with database queries (NTSB, ASRS) and flight crew interviews to discern common modalities of error or deficiencies in flight crew interactions with ATC, noting that degradation of operational performance may be the result of either operational error(s) or unrealized operational advantage available from the interaction. Five issues were identified as targets:

- Discrete communications errors, including “readback” and “hearback” errors
- Errors, omissions or degradation of situation

awareness (SA) through misinterpretation of operational information obtained through the interaction with ATC, or failure to obtain operational information available from ATC

- Confusion about the scope or constituent elements of an ATC instruction or clearance that went unrecognized or unchallenged by the flight crew
- Operational errors by the controller that went unrecognized or unchallenged by the flight crew
- Passivity or lack of assertiveness in operational control in interactions with ATC, particularly in relationship to operations under radar vectors

Process tools and methods of QMS

The Quantum-Pro® Management System (QMS) is an error management system, designed to prevent error, trap error before it presents as an operational event, and mitigate the consequences of error that has emerged as an operational event. QMS consists of specific process tools and methods, including core Professional Responsibilities (PRs) and Standard Management Procedures (SMPs) with demonstrated effectiveness in error management. Specific process tools and methods were examined and identified as candidates with significant potential for adaptation and application to these perceived deficiencies in flight crew interactions with ATC. The results of this effort are reported below.

Constraints on time/task sharing

This effort was in part based upon the premise of the controller as a "time/task-shared" crew member and critical partner. While it seems clear that the controller is a critical partner and is "time/task-shared" with other participating flights and other duties, there are real and significant constraints on the controller's participation and interaction with the flight crew. The impact of specific process tools and methods intended to improve pilot-controller performance must be realistically matched with the "cost" of those methods in the interaction, and justified by the intrinsic "benefits" to that interaction.

Development, implementation and testing

The candidate process tools and methods were adapted by the authors and introduced over several offerings of the senior seminar in the DWC flight operations curriculum entitled Crew/ATC Integration. Students enrolled in this course had been previously introduced to the candidate tools and methods as applied to both single-pilot and multi-pilot flight operations, and participated in case studies and other active instructional exercises to refine and validate the adapted tools and methods. These tools and methods were concurrently tested and validated in interactions with ATC in the associated flight practicum (Crew/ATC Integration Flight Practicum) in both interactive flight/ATC simulation scenarios and in operational flying in high-density air traffic environments in the Northeast corridor (Boston – New York – Washington, D.C.). Student flight crew performance was evaluated and scored by a supervisory instructor against ten criteria for evaluation, each area judged on a three-point scale: No credit, Pass, Pass with Distinction. For interactive flight/ATC simulation scenarios, a supervisory ATC instructor collaborated in the scoring of student flight crew performance.

On-going results

The results of this effort continue in active use for undergraduate pilot education at DWC. Students enrolled in the senior seminar Crew/ATC Integration and the associated flight practicum continue to be trained in the adapted tools and methods and evaluated for their effective use of these tools and the resulting impacts on flight crew interaction with ATC. Since all enrolled students complete the knowledge/skill training, direct comparisons with a control group in this setting are not possible. Nevertheless there continues to be high correlation between the effective use of these process tools and methods and the evaluation of the flight crew performance in interactions with ATC.

Process tools and methods and their application

Communications protocols and tools

Interactions between flight crews and ATC remain almost exclusively in the domain through VHF voice communications. Critical clearances/instructions and reports are regulated by flight operations rules (14CFR Part 91) and other non-regulatory standard procedures (AIM, Chapter xx). Studies of routine communications and errors in pilot – controller interactions suggest that these measures are largely effective and that explicit communications errors are infrequent events (Cardosi, Falzarano & Han, 1998). This effort suggests rather that a larger problem is the deficiencies or degradation of the situation awareness (SA) of flight crews and controllers, with the partners each having an incomplete or inaccurate awareness of the full operations situation, plans and intents. This study does not focus on the fundamental adequacy of established rules and standard procedures, but rather how these measures may be enhanced by certain communication tools and methods of QMS to address the gaps and deficiencies in situation awareness. The process tools and methods, taken together, can be seen largely as in part structuring communications requirements applicable to the partnership, and means for more effective communications interactions.

Adapted process tools and methods

Nine specific process tools and methods of QMS were adapted and applied to effectively counter errors or shortcomings that arise in flight crew interactions with ATC, hence to improve performance of these partners in operational flying. The adapted tools and methods are inventoried below. The application of these measures to identified errors deficiencies in flight crew interactions with ATC are described in the next section.

Closed-loop communication. This tool requires that each message element in an ATC interaction be meaningfully acknowledged by the receiver, with attention by the sender to that acknowledgement to confirm accuracy. While the verbatim readback of critical clearances and instructions required by regulation can be seen as examples of this tool, evidence suggests that responses which contain a meaningful paraphrase of the message may have intrinsic benefits as the rewording gives greater evidence that the message was (or was not) received and understood.

Bottom Lines. Bottom Lines are pre-established limits, beyond which the crew will not allow the flight to go. Immediate action is required whenever a Bottom Line is reached or exceeded. In ATC interactions, Bottom Lines may include procedural limits such as clearance limits, airspace or altitude limits, limits radar vectors off route, holding instructions, expected further clearance times, or other procedural limits. Applied to the ATC partnership, the flight crew will explicitly review and confirm applicable procedural limits and whenever such predetermined limits do not sufficiently protect the safety of flight, additional Bottom Lines will be set and acknowledged by all crewmembers.

Back Doors. For every interaction with ATC, especially those involving Bottom Lines, there must be a designated Back Door, or designated action to correct or recover from the situation. Sometimes multiple back doors, or side doors, may be required.

Briefings. The crew will conduct a systematic brief including anticipated ATC interactions prior to each flight, each takeoff, each new flight phase, and before any unusual or critical situation. It must: 1) be relevant to the particulars of the flight and ATC situation; 2) identify and deal with each strength or resource and each weakness or constraint in the flight or ATC situation. Key points of the briefing will be efficiently communicated to ATC as necessary to ensure that plans and intents are clear and consistent with the ATC situation.

Concept Alignment Process. The Concept Alignment Process is a method for on-going validation of the flight crew situation awareness, to ensure that it is complete and accurate, and consistent with ATC's sense of the flight/air traffic situation. The process includes on-going disciplined and systematic inquiry to reveal data or information which, if confirmed, may challenge the prevailing SA, acknowledgement and subsequent validation of any such "challenges," and revision to the SA based on the outcome of these checks. When flight safety is potentially threatened, a conservative response to ensure safety of flight is required while the challenge is verified or disconfirmed from other information sources. Applied to the ATC partnership, critical elements of the flight crew SA will be communicated and validated with ATC, and prompt and efficient inquiries made of ATC to ensure an accurate sense of the air traffic situation.

Short Term Strategy. The Short Term Strategy process (STS) is used for effective planning and decision-making whenever situations are encountered not adequately addressed by standard procedures. The STS process is a logical extension and effective complement of Naturalistic Decision-making (NDM) (Klein, 1991), especially well suited for use in novel or complex flight situations. STS is "primed" by robust situation awareness, encourages lateral thinking in the development of an effective response, and mandates mental simulation as a tool for validation and disciplined monitoring to ensure the desired outcome. Applied to the ATC partnership, the crew will solicit plan alternatives and supporting flight information from ATC, brief and validate critical elements of the plan with ATC, and request assistance in monitoring to ensure a successful outcome. In addition, the flight crew will make prompt and efficient inquires in response to ATC clearances and/or instructions to ensure that the ATC "plan" for the flight is well understood and validated by the flight crew as consistent with flight operations constraints and limitations.

Safety Gate. A Safety Gate is a brief structured pause in the operational flow, especially associated with critical flight phases, for a brief mental review of the operation or procedure to be conducted and the flight's status and readiness in all respects. Applied to the ATC partnership, the flight crew will initiate a brief operational check with ATC to ensure that critical elements of clearance or instructions are clear, and validated.

State of the Flight Situation and State ± 2 Callout. State of the flight situation is an adaptation of a QMS tool which focuses attention on monitoring the load on crew members and the adverse performance impacts of underloads and overloads, especially in critical flight situations. The process requires explicit acknowledgement of a "State ±2" condition so that corrective action can be immediately implemented. Applied to the ATC partnership, the flight crew will report critical over/under load conditions and solicit ATC assistance in implementing adequate countermeasures to ensure safety of flight.

Monitor and backup. QMS mandates a positive obligation to targeted monitoring and timely backup to other members of the crew, and several of the specific process tools and methods cited here include explicit means to implement that mandate. As applied to the ATC partnership, it is normative for ATC to closely monitor the actions of participating flights and to take prompt action to correct any deviations, at least as pertains to ATC procedures, clearances, and instructions. The flight crew will invite and welcome these appropriate measures of partnership, and will closely monitor communication and use other available means to monitor and provide constructive backup for actions by the controller.

Application of process tools and methods to targets

Five issues were identified as targets for application of process tools or methods to improve flight crew interactions with ATC, to avoid/trap/mitigate operational errors or capture unrealized operational advantage available from the interaction.

Discrete communications errors

Studies of routine communications and errors in pilot–controller interactions suggest that explicit voice communications errors including "readback" or "hearback" errors are infrequent events.

Still, the application of the tools and methods reported here offer benefit in this area through two primary effects: discrete benefit of rigorous implementation of *closed-loop communication*; the general effect of more rigorous monitoring of air traffic situation and voice communications resulting from implementation of other process tools especially *Bottom Lines* and *Back Doors*, and the *Concept Alignment Process*.

Closed-loop communication. Rigorous implementation of closed-loop communications in all interactions within the flight crew establish a heightened alertness to making and checking detailed acknowledgements of routine communications, which combine with and reinforce a general expectation of flight crew – ATC communication discipline to yield very high reliability in communications interactions with ATC.

Communications impact of other tools. The general effect of more rigorous monitoring of air traffic situation and voice communications resulting from implementation of other process tools reinforces the heightened communications alertness noted above. It is difficult to differentiate these direct benefits from the constructive benefits derived from improved situation awareness which are highlighted below.

Errors or degradation of situation awareness (SA)

Errors, omissions, or degradation in the situation awareness of both partners can arise from unhelpful compartmentalization of information available to each, resulting in the partners each having an incomplete or inaccurate awareness of the full operations situation, plans and intents. The application of the tools and methods reported here offer significant benefits, leading to a dramatic reduction in such errors or degradation.

Bottom Lines and *Back Doors.* The explicit review and confirmation of procedural limits and attention to setting additional limits focuses helpful attention on the *Bottom Lines* intrinsic to the situation, and predisposes the flight crew to prompt action to correct or recover when such limits are reached. The combined effect is a direct counter to frame bias in situation awareness (which can result in retaining stale SA) and continuation errors in execution.

Concept Alignment Process. The on-going disciplined and systematic inquiry intrinsic to this process tool, combined with rigorous validation and revision to SA based upon the outcome of these efforts yield direct and substantial benefits in flight crew SA, and heightened attention to the air traffic situation as it may impact the flight crew. Targeted inquiries of ATC about details of the air traffic situation serve to highlight gaps in SA, plans and intents of both parties. These results combine to yield timely recognition of changes to the operational situation, again providing a direct counter to frame bias in situation awareness and highlighting the need for re-planning to avoid continuation errors in execution of a plan which is no longer responsive to the particular challenges or constraints of the flight or air traffic situation.

Short Term Strategy and *Briefing.* The STS process tool is implemented when situations are encountered and recognized which are not adequately addressed by the current plan or standard procedures. Inclusion of the controller as source of plan alternatives and supporting flight information alerts ATC to the situation faced by the flight crew and recruits the controller's aid in resolving the challenge. Subsequent summary *briefing* of the plan provides an opportunity for validation by the controller on the basis of the expanded resources and information available to ATC which may not be explicitly known or realized by the flight crew. Similarly, the flight crew is primed to make prompt and efficient inquiries of ATC in response to clearances/instructions to ensure that the ATC "plan" is well understood and is not in conflict with flight operations constraints and limitations which are known to the flight crew but may not be explicitly known or realized by ATC.

Safety Gate. The brief structured pause in the operational flow provided by this process tool provides an explicit elicitation for subconscious or unexpressed concerned about the flight situation to blossom into actionable form, an added counter to stale situation awareness and associated continuation error. Extending the pause to ATC in the form of an efficient and targeted "final check" or "cross check" invites the different perspective of the controller, and encourages a similar check by the controller.

Unrecognized confusion about clearances/instructions
Confusion about the scope or constituent elements of an ATC instruction or clearance, including embedded information or contingencies, can occur even when the basic meaning of the clearance or instruction seems plain. The communication may even be properly acknowledged by the flight crew, from which both parties may infer a complete and accurate understanding of the message. The application of the tools and methods reported here offer some active countermeasures leading to a significant reduction in these unrecognized and unchallenged errors.

The heightened attention to procedural limits from implementation of *Bottom Lines* and *Back Doors*, and more rigorous management of situation awareness from the *Concept Alignment Process* yields benefits in this area as well. A flight crew that is much more engaged in these matters will be more alert to and more able to discern embedded information and contingencies intrinsic to a clearance.

State of the Flight Situation and State ±2 Callout. These types of errors are also an unwelcome potential consequence of challenging operational tempo, either under heightened load or very light loads on the partners. Under normal conditions, the constituent elements are adequately processed and realized by the flight crew, and accepted as a condition or factor in the instruction. Under stress, these elements may go unrecognized by the flight crew. The increased attention to monitoring and managing the load on the crew, especially during critical flight situations, counters unrealized over/under load conditions and provides means to manage load more effectively and can counter these adverse performance consequences.

Monitor and backup. The increased attention to targeted monitoring and timely backup by the flight crew, and active invitation of these measures by ATC can yield more timely detection and recognition of operational errors due to confusion about the particulars of an ATC instruction or clearance.

Unrecognized or unchallenged errors by ATC

Flight crews will not typically closely scrutinize the contextual implications of routine interactions with ATC or question/challenge those interactions unless there is explicit and substantive adverse consequence for the flight. While crew members might remark to one another about discontinuities, such as late calls, confused call signs, awkward vectors or transitions, flight crews will rarely deem it appropriate or helpful to comment directly to ATC about these issues, thus missing an opportunity to provide timely feedback and correction of ATC error. The application of the tools and methods reported here offer some active countermeasures leading to a reduction in this pattern of withholding these insights and in unrecognized and unchallenged errors by ATC.

The commitment to active partnership arising from implementation of the several process tools and methods described in this study reinforces the positive obligation of the crew to provide such timely and effective feedback. The *Concept Alignment Process* actively encourages prompt and efficient inquiries made of ATC to ensure an accurate sense of the air traffic situation, and prompt attention to miscues or oversights before they can propagate to more serious errors. Similarly, implementation of the *Short Term Strategy* process results in prompt and efficient inquiries in response to ATC clearances and/or instructions to ensure that the ATC "plan" for the flight is valid and not in conflict with operational constraints and limitations of the flight.

Monitor and backup. Again in this area, the increased intentionality to targeted monitoring and timely backup by the flight crew of their ATC partner, will serve to counter the natural and tacit acceptance of low level errors and oversights by ATC, and yield much more active and timely backup to ATC to ensure that such minor miscues do not propagate to more serious errors by ATC.

Passivity or lack of assertiveness in operational control in interactions with ATC

The high quality and high reliability of ATC services to flight crews can and often does lull the unwary into tacit acceptance of "control" by ATC, and a corresponding lack of close scrutiny of clearances and/or instructions for potential conflicts, particularly when receiving radar vectors or similar advisories. The application of the tools and methods reported here directly counter any tendency toward passivity in situation awareness or operational control and offer active countermeasures to these issues.

The nine specific process tools and methods of QMS adapted and applied to effectively counter errors or shortcomings that arise in flight crew interactions with ATC serve as a network of interlocking measures that greatly enhance active attention to and appropriate assertiveness in relationship to their ATC partners.

The heightened attention to procedural limits from implementation of *Bottom Lines* and *Back Doors*, more rigorous management of situation awareness from the *Concept Alignment Process*, the intentional collaboration of the *Short Term Strategy*, and the more active engagement with ATC in mutual *Monitoring and backup*, all contribute to an active and committed partnership with ATC.

Conclusions and need for further study

The process tools and methods reported here were adapted by the authors and introduced over several offerings of the senior seminar in a flight operations curriculum entitled Crew/ATC Integration. Students enrolled in this course had been previously introduced to the candidate tools and methods as applied to both single-pilot and multi-pilot flight operations, and participated in case studies and other active instructional exercises to refine and validate the adapted tools and methods. These tools and methods were concurrently tested and validated in interactions with ATC in the associated flight practicum (Crew/ATC Integration Flight Practicum) in both interactive flight/ATC simulation scenarios and in operational flying in high-density air traffic environments in the Northeast corridor (Boston – New York – Washington, D.C.). Student flight crew performance was evaluated and scored by a supervisory instructor against ten criteria for evaluation, each area judged on a three-point scale: No credit, Pass, Pass with Distinction. For interactive flight/ATC simulation scenarios, a supervisory ATC instructor collaborated in the scoring of student flight crew performance.

The training and implementation of these process tools and methods yielded substantive improvements in the operational performance of the student flight crews, not only in the direct scoring of the "Effective Partnership with ATC" evaluation objective but also in the more essential measures of the achievement of safety and utility and successful completion of the assigned LOFT flight task.

Comprehensive data for the past five years of implementation has been collected and tabulated. Analysis of the data and correlation of the data with subsequent performance in pilot certification and line-operational flying is in progress, and will be reported in subsequent study.

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