

SINGLE PILOT WORKLOAD MANAGEMENT DURING CRUISE IN ENTRY LEVEL JETS

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Advanced technologies and automation are important facilitators of single pilot operations, but they also contribute to the workload management challenges faced by the pilot. We examined task completion, workload management, and automation use in an entry level jet (ELJ) flown by single pilots. Thirteen certificated Cessna Citation Mustang (C510-S) pilots flew an instrument flight rules (IFR) experimental flight in a Cessna Citation Mustang simulator. At one point participants had to descend to meet a crossing restriction prior to a waypoint and prepare for an instrument approach into an un-towered field while facilitating communication from a lost pilot who was flying too low for ATC to hear. Four participants experienced some sort of difficulty with regard to meeting the crossing restriction and almost half ($n=6$) had problems associated with the instrument approach. Additional errors were also observed including eight participants landing at the airport with an incorrect altimeter setting.

Introduction

The advent of personal jets such as entry level jets (ELJs) and very light jets (VLJs) has made a wider range of operations and missions available to private and professional pilots alike. Private pilots can now fly higher and faster than ever before and commercial ventures, such as air taxi operations and short charter flights, are now more economical. The automation and advanced technology aboard these aircraft are essential features that make flight by single pilots possible.

However, automation and advanced technology bring their own challenges. The design of glass cockpit systems currently used in these aircraft places a heavy cognitive load on the pilot in terms of long-term, working, and prospective memory; workload and concurrent task management; and developing correct mental models as to their functioning (e.g., Burian & Dismukes, 2007). These cognitive demands have been found to have a direct relationship to pilot errors committed during flight (Dismukes, Berman, & Loukopoulos, 2007). Burian (2007) found a significant correlation between poor workload and time management (i.e., poor crew and single-pilot resource management, which are abbreviated CRM and SRM, respectively) and problems using advanced avionics. Additionally, almost two-thirds of the accident reports she analyzed involved at least one of six different cognitive performance problems (e.g., distraction, memory problems, risk perception). She found that these problems were experienced at similar rates by pilots flying professionally and those flying for personal reasons. Workload management is

a crucial aspect of SRM. Best practices for single-pilot flight task and workload management must be better understood within the current operating environment and beyond as we move to an era of optimizing the national airspace system outlined in NextGen concepts (FAA, 2012).

In an exploratory simulation study we examined private and professional pilot proficiency in single pilot task and workload management using a level 5 flight training device (for simplification, a “simulator”). Participant task performance of one of the scripted high workload periods occurring during the cruise portion of an IFR flight, described below, is reviewed here. A detailed description of the entire study can be found in Burian, et al. 2012.

Method

Thirteen certificated Cessna Citation Mustang (C510-S) pilots flew an experimental flight, composed of two legs with realistic tasks in the US northeast corridor, in a Cessna Citation Mustang simulator. Performance was evaluated against airline transport pilot and instrument rating practical test standard criteria (FAA, 2008, 2010) as well as the successful completion of the scripted tasks.

Participants

Six of the 13 participants flew the Mustang as professional pilots and the other seven flew it for personal business or recreation (i.e., owner-operators). They were recruited through letters sent to the 321 airmen who possessed C510-S type ratings and lived in the contiguous 48 states of the USA at

the time we conducted the study. Participants were paid a rate of \$50 per hour and were reimbursed all travel costs.

Measures and Apparatus

Prior to flying the scripted flights in the simulator, participants completed three questionnaires pertaining to: demographics, opinions about advanced avionics and automation, and Citation Mustang and G1000 cockpit set-up preferences. Prior to flying each leg of the experimental flight, participants were provided with standard flight bag materials and a printed flight briefing packet including: a description of the flight, proposed time of departure, aircraft location at the departure airport and planned aircraft parking at the destination airport, a departure airport diagram, a completed flight plan on FAA Form 7233-1, a completed navigation log and weight and balance information including a weight and balance diagram, a complete weather briefing package, paper IFR en route navigation charts, complete Jeppesen Airway manuals with current paper departure, arrival, and approach plates, and airport and facilities directories.

The flight simulator, located at the FAA Civil Aerospace Medical Institute facilities in Oklahoma City, OK, featured a realistic Mustang flight deck with a G1000 avionics suite, digital control loaders, and a high fidelity digital surround sound system that accurately replicated flight, engine, system, and environmental sounds. The out-the-window display system included a 3D Perception 225 degree (lateral angle) spherical floor to ceiling projection screen that gave the pilot a realistic field-of-view. The G1000 default settings were adjusted to those preferred by each participant, as indicated through their questionnaires, prior to the start of data collection each day.

Eye movements of participants were tracked using a FaceLab™ v5 system consisting of non-invasive cameras, IR emitters, and software from Seeing Machines, Inc. During the experimental flights participants were asked to make instantaneous self-assessment (ISA) ratings of their workload using a small rectangular box with five numbered buttons (1 = very low workload; 5 = very high workload) when a red light at the top of the box was illuminated. Researchers controlled when the light would illuminate remotely from the experimenter's station. Once illuminated, the light stayed on for 60 seconds or until the participant pressed one of the numbered buttons. Participants were given a printed card explaining the meaning of each ISA rating for their reference in the simulator. Immediately following

the completion of each leg of the experimental flight participants completed a paper-pencil version of the NASA Task Load Index (TLX) giving subjective workload ratings on each of the TLX subscales for the flight overall, as well as for specific scripted high workload tasks or phases of flight. Following the completion of the experimental flights, audiotaped debriefing interviews were held with the participants.

Procedure

Following a review of the overall study purpose and completion of informed consent paperwork, participants were given flight briefing materials to review for a familiarization flight to be held the following day.

The simulation study began the next day with introductions, calibration of the eye tracker, the completion of a take-off and landing at KOKC. Participants then completed the familiarization flight, lasting approximately 30 minutes, from Clinton Sherman Airport (KCSM) to Will Rogers World Airport in Oklahoma City (KOKC). Participants practiced completing ISA ratings during the familiarization flight. After a brief break with beverages and snacks provided, participants were then given briefing materials for the two legs of the experimental flight and given as much time as they desired to review them and prepare for the first leg.

With the assistance of recently retired air traffic controller subject matter experts (ATC SMEs), who had experience managing traffic in the US northeast corridor, participants completed the first leg of the scripted experimental flight (Teterboro, NJ [KTEB] to Martin State Airport in Baltimore, MD [KMTN]), lasting approximately one hour. They then completed the NASA TLX for that leg. Following a break for lunch participants were given as much time as they desired to review pre-flight briefing materials for the second leg of the experimental flight (KMTN to Ingles-Hot Springs, VA [KHSP]), also lasting approximately one hour. At the completion of this flight, participants again completed NASA TLX measures, debriefing interviews were conducted, and participants were thanked for their participation.

Results

Demographics

In the year prior to the study, our 13 male participants reported flying the Cessna Mustang a mean of 153.7 hours (range: 68-350 hours) and as a single pilot in the Mustang for a mean of 138.5 hours (range: 15-350 hours). No significant differences in flight hours, experience, or self-reported skill with advanced

avionics and automation were found between owner-operators and professional pilots. Additionally, unlike other studies (e.g., Tsang & Shaner, 1998) we found no significant difference in task success as a function of age, which ranged from 29 to 61 years ($M = 48.9$ years).

High Workload Task Performance

One of the high workload periods analyzed in this study occurred approximately three-quarters of the way through the second leg of the experimental flight (KMTN to KHSP). Participants were flying at an interim cruise altitude of 16,000 ft (from an original cruise altitude at FL200) and had two major flying tasks to complete: descend at their discretion to meet a crossing restriction of 10,000 ft. 15 nm prior to a waypoint (Montebello VOR [MOL]), and prepare for an ILS runway 25 approach into KHSP, an un-towered airport. Additionally, during this period, participants could hear center controllers unsuccessfully trying to communicate with another pilot (played by one of the researchers) who was trapped under the cloud deck. ATC SMEs asked the participants to relay communication from the “lost pilot” to them and although participants could have declined, all 13 agreed.

This high workload period lasted an average of 7 minutes and 55 seconds ($SD = 31$ seconds, range = 0:07:11 to 0:08:53) and ended when ATC handed the participant pilots off to another controller at the end of the lost pilot scenario, which generally occurred around the time participants crossed MOL, less than 35 nm from KHSP. Although participant completion of the approach and landing at KHSP was not part of this defined high workload period, approach and landing briefing and preparation *were* expected to have occurred during this time. Therefore aspects of participant approach and landing performance associated with the quality of their briefing and preparation will be discussed.

Overall Flight Performance. Although at least one error was committed by each of the participants during this high workload period or during the approach into KHSP, generally they flew the aircraft within appropriate parameters. For example, all participants maintained engine temperatures below the limit of 830° and responded to all radio calls from ATC. Twelve pilots met the crossing restriction, and no excessive bank or pitch angles, or excessive yaw were observed. All participants flew close to V_{mo} (250 KIAS) during this period and their airspeeds ranged from 193 KIAS ($M = 210.85$ KIAS, $SD = 14.51$ KIAS) to 248 KIAS ($M = 243.23$ KIAS, $SD = 4.36$ KIAS) with an overall average airspeed of

228.30 KIAS ($SD = 8.80$ KIAS). Those flying slower airspeeds tended to be participants who reduced their speeds purposefully near the end of the lost pilot scenario apparently to increase the amount of time they had available to finish preparing for the approach at KHSP.

The observable errors committed during this high workload period or the approach and/or landing at KHSP can be seen in Table 1.

Table 1
Participant Errors¹ Committed

	All Participants (n = 13)	Owner-Operators (n = 7)	Professional Pilots (n = 6)
Communication/readback error ²	4	1	3
Did not report leaving 16,000 ft. MSL ³	10	6	4
Minor crossing restriction programming error	1	1	0
Major crossing restriction programming error	4	2	2
Failed to make crossing restriction	1	0	1
Misunderstood lost pilot/ATC communication capabilities ⁴	5	4	1
Minor ILS programming error	1	0	1
Major ILS programming error	7	4	3
Landed at KHSP with incorrect altimeter setting	8	3	5
Total errors	41	21	20
Mean number of errors	3.15	3.00	3.33

¹ “Errors” includes only those that were observable

² Communication or readback errors committed by four participants

³ A professional pilot did report late while descending through 15,000 ft MSL

⁴ Participants had difficulty understanding or remembering that the “lost pilot” could hear ATC but that ATC could not hear the lost pilot.

One professional pilot committed only one error when he neglected to report the initiation of his descent from 16,000 ft to ATC; all other participants

made two or more errors during this high workload period. A one-way ANOVA revealed no significant differences between owner-operators and professional pilots with regard to the number of errors committed, $F(1,11) = 0.54, p = .48$. However, two surprising findings were the large number of pilots who neglected to contact ATC to report they had initiated their descent from 16,000 ft MSL ($n = 10$) and the large number who landed at KHSP with an incorrect altimeter setting ($n = 8$).

Crossing Restriction 15nm before MOL. Participants received the clearance to descend (at their discretion) with a crossing restriction when they were 44 nm from MOL. They began their descents when they were an average of 32.96 nm ($SD = 4.44$ nm) from MOL (about 18 nm from the crossing restriction point) and were traveling an average of 224.69 KIAS ($SD = 10.21$ KIAS).

In addition to flying a descent manually, there are two primary ways to accomplish a descent using the G1000 automation: vertical speed (VS) mode and vertical path (VPTH). As its name implies, VS is an autoflight mode and is set by choosing a rate of descent in feet per minute. In contrast, VPTH is actually programmed in the G1000 and allows the pilot to indicate crossing restrictions which the automation will then ensure the aircraft meets during the programmed descent.

Twelve of the thirteen participants programmed VPTH to accomplish this task although two of them did not couple VPTH to the AP and just used its guidance to support their descent using VS (one of them did not make the crossing restriction—was 1,180 ft high). Additionally, VPTH did not capture for one participant because he forgot to change the target altitude in the altitude reference window on the PFD so he ended up using VS instead. The remaining participant used VS with no VPTH guidance as a back-up.

It took the 12 participants an average of 53 seconds ($SD = 42$ seconds; range = 00:20 to 02:09) to program the VPTH descent although there were two distinct clusters of time it took to do this programming. These clusters appeared unrelated to participant subgroup (owner-operator or professional pilot) or whether the VPTH was used for the descent or only for back-up information. The participants with the lowest programming times ($n = 8$, range = 20 to 38 seconds) took an average of 29 seconds ($SD = 7$ seconds) to do so; those with the longest programming times ($n = 4$, range = 01:35 to 02:09) took an average of 1 minute 58 seconds ($SD = 10$

seconds) to complete the programming. As expected, those taking more time to complete the programming interleaved other tasks while doing so.

One participant who unsuccessfully used VS with VPTH guidance chose an initial descent rate of 2500 fpm and continued to fly close to V_{mo} , the maximum operating speed for the aircraft. When it became apparent that he might not make the crossing restriction, he compensated by pulling back some power but waited almost a minute before increasing his descent rate to 3000 fpm (passing through 12,700 ft MSL, 2.58 nm from the crossing restriction point). Although it seemed clear that he knew he had not met the crossing restriction, he did not contact ATC to inform them. Two pilots, including the one who was unsuccessful, initially made an error when programming VPTH by placing the point where the crossing restriction was to be met 15 nm past MOL instead of 15 nm before MOL. Both caught their errors fairly quickly and corrected them.

To summarize, four of the thirteen pilots had difficulty programming the crossing restriction or descending but only one actually failed to make the crossing restriction.

Communication Assistance for the Lost Pilot. While descending to meet the crossing restriction and preparing for their approach into KHSP, pilots assisted with transmitting communication from a lost VFR pilot to ATC. Due to problems with the simulator audio system, one participant was not presented with the lost pilot scenario during leg 2. As mentioned earlier, all the other participants agreed to assist and six volunteered before ATC could even ask. Of the pilots presented with the “lost pilot scenario,” all continued to offer assistance until the situation had been resolved with the exception of one who did not transmit the final two comms from the lost pilot to ATC because he was engaged in preparation for his approach into KHSP. Five participants had at least some initial confusion as to who could hear whom during the scenario; in those cases the lost pilot clarified that she could hear ATC and only one participant continued to transmit ATC comms to the lost pilot, in addition to lost pilot comms to ATC, throughout the scenario.

Approach and Landing at KHSP. The lost pilot situation was typically resolved about the time that participants crossed MOL which is 17.3 nm from the initial approach fix (IAF) for the approach into KHSP. Some participants appeared to become a bit concerned about being ready for the impending approach into KHSP during the lost pilot scenario

and five did such things as slow down or ask for vectors or some other alternate routing that would give them added time to prepare (e.g., stay on current heading a bit longer past MOL, requested a different approach fix which was 5 miles further away from MOL, etc.). Contrary to what was expected, most pilots did not actively engage in preparing for the approach during the lost pilot scenario. Three queried ATC about aspects of the approach while assisting with the lost pilot comms (e.g., which approach could be expected) and one was observed looking at aircraft weights on the MFD, however very little of their preparation for the approach occurred during the lost pilot scenario. The other nine participants were not engaged in any observable approach preparation during the scenario.

Further analysis revealed that six pilots (three owner-operators and three professional pilots), including two who queried ATC during the scenario, had actually completed most or all of their approach preparations (e.g., reviewing/briefing the approach) before this period or the lost pilot scenario began and six participants could be observed entering in required frequencies into the radios quite early during the leg (e.g., on climb out from KMTN).

Four participants briefed the approach (i.e., reviewed the approach plate for the first time) between MOL and the IAF and one professional pilot briefed the approach very late, just before arriving at the intermediate fix. An owner-operator was never observed briefing the approach by reviewing the approach plate prior to conducting the approach, though he did scroll down to the decision height (DH) information at the bottom of the Jeppesen chart displayed on the MFD when he was 252 ft above DH.

Interestingly, of the six participants who briefed the approach before the start of this high workload period, two actually programmed the approach at that time; the other four participants waited until after passing MOL when the specific approach in use was confirmed by ATC. During the post flight debriefings, the two who programmed the approach quite early spoke of their preference to get programming finished as soon as possible, even if it meant having to change it later. Both completed the approach without difficulty.

Eleven participants programmed the approach after the end of the lost pilot scenario. The more significant difficulties encountered typically involved incorrectly programming the G1000, e.g., not activating or arming the approach, or being in the wrong autopilot mode to capture the approach.

There was a fairly even split between those who did ($n = 7$) and did not ($n = 6$) encounter difficulty in programming or executing the approach. Not surprisingly, those who briefed the approach quite early in the leg ($n = 4$, 66%) tended to have fewer difficulties programming or executing the approach than participants who completed most of their briefing activities just before conducting the approach ($n = 2$, 33%). Similarly, participants who programmed the approach quite early ($n = 2$) had no problems conducting the approach whereas only 4 of the remaining 11 (36%) participants, who programmed the approach just before or even after they had begun executing it, had no problems.

Interestingly, six of the nine participants who reported to ATC that they had gotten the automated weather report at KHSP, landed at KHSP with an incorrect altimeter setting (29.86 instead of 29.84) as did two others who did not check the weather prior to landing (see Table 1). The incorrect altimeter setting these eight participants landed with was the altimeter setting which was given to them when they descended through the transition altitude of 18,000 ft MSL much earlier in the flight, before this high workload period began.

Discussion

In this study of single pilot workload in ELJs we found no significant differences in performance, errors made, or success rates in accomplishing the major tasks analyzed due to pilot type (owner-operator or professional pilot). It is possible that the owner-operators in our study were more experienced than most or that those with less experience or skill did not volunteer to participate. It is also possible that our professional pilots fly less frequently or are less capable than non-participants but we have no evidence or reason to believe that this was so.

Workload management when piloting technologically advanced aircraft involves the allocation of mental resources to accomplish multiple tasks concurrently. Most participants completed short tasks, such as dialing in a new altitude, before moving on to other tasks. Some participants also demonstrated a similarly focused method when programming the G1000. Almost all performed other tasks concurrently such as dialing in a new heading while listening to the rest of an ATC clearance. As would be expected, most participants chose to interleave more lengthy automation programming with other cockpit tasks. Contrary to what one might expect

though, those who programmed the G1000 without interruption, e.g., for the approach at KHSP or to meet the crossing restriction, made just as many programming errors as those who interleaved other tasks while programming.

Participants utilized a variety of techniques to deal with high workload. Some chose to slow the aircraft down to “buy” time or shed or truncated a task, such as acknowledging an ATC traffic alert but then not personally scanning for the traffic. These two strategies tended to be used less often than others such as requesting vectors or alternate routing from ATC. In future studies it would be informative to evaluate the use of strategies for management of high workload that are controlled by the pilot (e.g., slowing the aircraft, shedding tasks) as compared to those involving assistance from the outside (i.e., ATC). Both are certainly necessary and appropriate in various situations and we found that those who utilized methods under their own control, such as by reducing airspeed, often accomplished the scripted tasks successfully.

Almost all participants were proactive in reducing later workload by taking care of some tasks as early in the flight as possible. This longstanding principle of completing as many tasks as possible during low workload periods to reduce the number that must be performed during periods of higher workload generally worked well for our participants, particularly the two who programmed the approach at KHSP very early. It would be interesting to examine in a future study the efficacy of this strategy for programming instrument approaches even if it means that changes are required later.

Task prioritization relative to the amount of time available is a critical part of workload management. Those participants who had not adequately briefed and prepared for the instrument approach at KHSP prior to the end of the lost pilot scenario were more likely to encounter difficulty in accomplishing the task successfully. Single pilots operating jets under NextGen must have a keen sense of the temporal aspects of flying tasks and use a variety of strategies to manage their workload to complete their flights successfully.

Single-pilot workload management is strongly associated with automation use and errors made when programming the automation. We found that when participants were confronted with high workload they tended to opt for a lower level of automation to reduce their workload in the moment (i.e., using autoflight modes as opposed to programming the

G1000), even though that meant their overall ongoing workload might be greater. A mix of both input errors and more concerning errors indicating a lack of understanding of how the automation and autoflight modes worked were observed. Input error identification strategies developed for airline crews could be adapted for use by single-pilots flying VLJs/ELJs (Berman, Dismukes, & Jobe 2012). Targeted activities are needed during training to tease out pilot misperceptions and misunderstandings about how advanced automation functions.

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