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Very Light Jets in the National Airspace System

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Problems that potential very light jet (VLJ) pilots of the future are having in the aircraft they currently fly, as evidenced in incident and accident reports, were analyzed. Significant problems identified include poor crew/single pilot resource management, low currency, inadequate preflight planning, avionics use difficulties, and cognitive performance issues, among others. Implications for training future VLJ pilots are discussed.

Introduction

The introduction of very light jets (VLJs, sometimes referred to as Part 23 Jets) into the national airspace system poses many challenges for almost all aspects of the industry. The pilots, some of whom may have minimal flight experience, will be operating at flight levels previously populated primarily by medium and large jet aircraft. Currently, many of these pilots are flying light twin or advanced, single-engine piston aircraft, such as Diamond Twin Stars and Beech Bonanzas, often below 18,000 feet MSL. Once in VLJs, they will be exposed to new types of weather and atmospheric conditions, must be able to operate much faster, technically advanced aircraft with systems and equipment with which they may have little previous experience (e.g., jet engines, pressurization), and will need to be able to operate primarily as single pilots. Other VLJ pilots will come from current professional pilot ranks (e.g., turboprop and business jet pilots) and will fly VLJs professionally, such as for air taxi companies. VLJ instructors and pilot mentors will need to determine the most efficient and effective ways to instruct both populations of pilots.

Through visits with VLJ manufacturers, the National Business Aviation Association (NBAA) Safety Committee identified 21 areas of greatest risk for the operation of very light jets that should be addressed during training (NBAA, 2005). Some of these risk areas are presented in Table 1. This study was undertaken to identify the kinds of problems that potential VLJ customers/pilots are having in the aircraft they currently fly and in the flight regimes in which VLJs will operate, as evidenced through incident and accident reports. This analysis will augment our understanding of the difficulties this population is likely to face during VLJ operations and will broaden our understanding of some of the NBAA's Risk Areas.

Method

Reports of incidents and accidents involving four types of aircraft (advanced single-engine, light twin, business jet, and turboprop) and occurring over a 12-month period (July 2005 though June 2006) were analyzed for this study.

Table 1. Selected NBAA VLJ Risk Areas (NBAA, 2005)

- Wake Turbulence Encounters
- Inadequate Knowledge of High Altitude Weather
- Physiological Effects of High-Altitude Operations
- Jet Blast Damage Behind Larger Jets during Ground Operations
- Inadequate Crosswind Takeoff/Landing Preparation
- Inadequate Preparation for High-rate/High-speed Climbs
- Low-fuel Arrivals Trying to Stretch Range
- Single Pilot Adherence to Checklists
- Inadequate Exercise of "Command"
- Inadequate Land and Hold Short Preparation

Contextual and demographic information that were recorded included pilot hours of experience, lighting and weather conditions, aircraft type, and the phase of flight in which the event began or occurred. Information was also recorded about a wide range of other variables regarding what occurred in the incident or accident, such as flight path deviations, problems using avionics, cognitive performance and workload management problems, collisions, incursions, malfunctions, maintenance issues, and fatigue, among others.

Incident data describing unsafe occurrences and hazardous situations were drawn from searches of reports filed with the Aviation Safety Reporting System (ASRS, 2006; ASRS, 2007). Because ASRS reports are filed voluntarily, they cannot be used to infer prevalence or incidence rates of problems within aviation, although they can provide a rich description of the qualitative nature of these events helping us to better understand why they occurred. Additionally, some issues, such as confusion using advanced avionics, may not have shown up in ASRS reports unless they had also led to some other problem, such as distraction leading to a flight path deviation (e.g., an "altitude bust").

Accident data were obtained through a search of the National Transportation Safety Board (NTSB, 2006) on-line database of accident reports. Only final reports in which Probable Cause determinations had been made were included in this study. As a consequence, accident data presented in this study cannot be directly compared with other studies of accident data, such as the Aircraft Owners and Pilots Association's NALL Report (AOPA, 2006), that are conducted sufficiently long after accidents have occurred to maximize the number of reports that are final for the period of interest.

Different kinds of information are prevalent in the two sources of data. For example, 42 of the 46 reports that identified problems with the completion of instrument procedures were ASRS incident reports. Conversely, problems with aircraft control post-landing are far more prevalent in the NTSB reports than in ASRS reports, likely because the damage such problems produce is often substantial. Other issues, however, are represented fairly equally across the two types of reports (e.g., number of reports involving aircraft malfunctions: 42 out of 170 ASRS reports, 58 out of 218 NTSB reports).

Some variables of interest were not captured adequately by either source of data, however. For example, many of the NBAA (2005) VLJ risk areas, such as Inadequate Land and Hold Short Preparation, were not captured well in the incident and accident data. Therefore, analyses of only six topics related to the NBAA risk areas are reported below.

Coding of some variables, such as type of aircraft and phase of flight (i.e., contextual variables) was very straightforward and required no interpretation. Other variables however, such as high workload or memory problems, often required some subjective judgment during coding. As a rule, coding of these variables was done conservatively. Thus, these variables were only coded if the pilot made some mention of them ("I was distracted by the funny noise in the cabin.") or if overwhelming evidence that they were present was provided in the report narratives. Therefore, the variables requiring some subjective judgment are likely underrepresented in the data analyzed.

Several manufacturers are advocating VLJ training modeled after that given to professional pilots in commercial operations. The motivation for this is that commercial aviation has a very good overall safety record and VLJ pilots will be operating in the same flight regimes with the same challenges as commercial pilots. Therefore, in this study the types of problems encountered during private flights as compared to professional flights were of interest. For the purpose of analysis, "private" or "general aviation (GA)" flights were those involving advanced single-engine or light twin aircraft flown under Part 91 of the Federal Aviation Regulations (FARs). "Professional" flights were those involving single-engine or light twin aircraft flown under FAR Part 135 or Part 121 or those involving business jets or turboprop aircraft flown under FAR Part 91, Part 135, or Part 121. Although it is fairly safe to assume that most professional flights were flown by "professional" pilots (i.e., those who fly for a living), it is not safe to assume that most GA flights were flown by pilots who do *not* fly for a living; in other words, it is possible that some of the GA flights were flown by pilots who do fly professionally but were not doing so during the GA flight.

Analyses reported below pertain to an overview of the data and contextual variables, six NBAA (2005) risk areas, and other topics that have relevance for VLJ operations.

Results

Contextual and Demographic Information

Of the 388 reports coded for this study, 218 were NTSB accident reports and 170 were ASRS reports. The data were comprised of reports involving 173 advanced single-engine aircraft (44.6%), 108 light twin aircraft (27.8%), 92 business jets (23.7%), and 15 turboprop aircraft (3.9%). Significant differences were found for the type of aircraft by the type of report analyzed (X^2 (3, N=388) = 127.18, p<.001). Turboprop and light twin aircraft were fairly equally distributed across the two types of reports but advanced single-engine aircraft were represented to a significantly greater degree in the NTSB accident reports (n=141) and business jets were represented to a significantly greater degree in the ASRS incident reports (n=83).

Most reports involved flights in visual meteorological conditions (VMC) (n=319, 82.2%) that occurred during daylight hours (n=305, 78.6%). Reports were distributed across the three FAR Parts as follows: Part 91: n= 322, 83.0%; Part 135: n= 47, 12.1%; Part 121: n= 18, 4.6%.

Pilot hours of overall experience ranged from 40-29,240 hours with a median of 2,600 hours. Pilot hours of experience in the specific type of aircraft in which they had the incident/accident ("time-in-type") ranged from 1-9,000 hours with a median of 455 hours. In terms of recent experience, pilots logged between 0-390 hours in the 90 days prior to the incident/accident with a median of 63 hours.

There were 20 accidents (9.2% of all NTSB reports) that involved fatalities resulting in a total of 33 deaths. Interestingly, none of the 39 reports involving off-airport landings resulted in fatalities.

Using the scheme described earlier, 253 GA and 134 professional flights were identified during analyses (one report had missing data and could not be placed into one of the two groups). Of the GA flights, 164 involved advanced single-engine aircraft and 89 involved light twins. Nine professional flights involved advanced single-engine aircraft, 18 involved light twins, 92 involved business jets, and 15 involved turboprop aircraft. The median number of hours of experience for the pilots of the GA and professional flights (respectively) was as follows: total time: 1700 and 5700; time-in-type: 300 and 700; and hours flown in the previous 90 days: 34 and 144.

A significant difference between the two types of flights was found according to the type of report filed (ASRS or NTSB; X^2 (1, n=387) = 68.72, p<.001). GA flights were involved in 42.6% (n=72) of the ASRS reports compared to 54.4% (n=97) that involved professional flights. Conversely, 83.0% (n=181) of the NTSB accident reports involved GA flights compared to 17.0% (n=37) that involved professional flights.

NBAA Risk Areas

Inadequate Crosswind Takeoff/Landing Preparation. Of the 34 reports involving a sudden wind encounter such as a wind gust or downdraft (almost all occurring during takeoff or landing), 29 (85.3%) resulted in an accident. Difficulty handling unexpected winds was significantly more likely to occur during GA flights (n=29, 85.3%) than during professional flights (n=5, 14.7%) (X^2 (4, n=387) = 10.83, p<.05). Additionally, 44.4% (n=28) of the 63 NTSB accident reports in which aircraft control was lost on the ground directly after landing (i.e., runway overrun, ground loop/departed side of the runway) involved crosswinds, wind gusts, and the like. Thus, the management of gusts and crosswinds is born out as a risk area by the findings in this study but it should be kept in mind that smaller aircraft are also more vulnerable to problems with crosswind than larger and/or heavier aircraft.

Inadequate Preparation for High Rate/Speed Climbs. Over half of the ASRS reports (n=87, 51.2%) and 14.7% (n=32) of the NTSB reports involved flight path deviations. Forty-two (31.3%) of the 134 professional flights involved altitude deviations, two-thirds of which occurred during climbout. Although some of these altitude deviations were related to distractions or misunderstanding specific departure procedures, several appeared to be related to gaining altitude more quickly than was anticipated, as is illustrated by the following two quotes: 1) "Performed level-off based on non turbojet experience…" (Accession #690392; ASRS, 2006) 2) "The pilot/owner/builder departed on his first solo flight in the homebuilt, jet-powered, Velocity Jet 900 airplane with no jet airplane experience or training. After takeoff, the airplane climbed above the traffic pattern altitude at '4-5 thousand feet-per-minute'…" (Accident NYC06CA118; NTSB, 2006).

Low Fuel Arrivals. Nineteen (8.7%) of the NTSB reports involved fuel starvation and two ASRS reports (1.2%) involved low fuel arrival events. A significant relationship between low fuel arrivals/fuel starvation events and type of flight was found (X^2 (1 n=387) = 4.20, p<.05) with 19 GA flights and 2 professional flights involved.

Pilot currency (i.e., number of hours flown in the previous 90 days) and time-in-type experience were also found to be important relative to low fuel/fuel starvation events. Half of the pilots who were involved in these flights (n=10) had flown 24 or fewer hours within the previous 90 days – that is an average of 2 hours or less per week. Thirteen (68%) of the fuel starvation events involved pilots with fewer than the median number of hours of experience in their type of aircraft (median = 427 hours). However, those pilots in the lowest quartile (1-119 hours) were involved in less than one third of those events (n=4). Hence, nine low fuel/fuel starvation flights were flown by pilots in the second quartile with 120-427 hours in type. One possible interpretation of these findings is that once pilots gain some (but not a lot) of experience in a new type of aircraft, they may become less conservative in their fuel estimates, management, or planning until after gaining a few hundred more hours of experience when they become a bit more conservative (or possibly more accurate) in their estimations and fuel management.

Single Pilot Adherence to Checklists (and Preflight Inspection and Preparation Procedures). The only information available that clearly concerned checklist usage in the data was that landing checklists were not used in 9 of the 16 gear-up landings that occurred – two during professional flights and seven during GA flights (however one of the nine gear-up landings also involved a gear malfunction).

Closely related to the concern that single pilots may not be diligent in the completion of formal checklists is the concern that they may not consistently follow standard operating procedures (SOPs), which are credited with much of the safety that exists in commercial aviation operations. Instances in which pilots completed inadequate (or non-existent) preflight inspections and planning (n=57, 14.7% of all reports) are examples of non-adherence to SOPs and were found equally in ASRS and NTSB reports. An off-airport landing was performed in 13 of the 29 accidents (44.8%) in which the pilots failed to perform adequate preflight planning, with 10 of these landings (76.9%) due to fuel starvation.

Pilots with all levels of recent experience engaged in insufficient preflight inspections or planning, though more of this behavior was evident in the reports involving pilots who fell below the median in terms of recent experience (n=29, 60.5%). Additionally, 70.2% (n=40) of the insufficient preflight events involved GA flights. Although this certainly validates the concerns of the NBAA Safety Committee, it also means that almost 30% of incident/accident flights involving poor preflight were professional flights (n=17). Thus, adherence to checklists and SOPs is not just a concern for single pilots or private pilots alone.

Crew Resource Management/Single Pilot Resource Management (CRM/SRM). One of the risk areas identified by the NBAA (2005) is "Inadequate Exercise of Command," which includes concerns with crew or single pilot resource management (CRM/SRM). Crew or single pilot resource management "refers to the effective use of all available resources: human resources, hardware, and information" (pg. 2, Federal Aviation Administration, 2004). It includes effective communication processes, decision behavior, workload management, and conflict resolution; timely preparation and planning; and maintaining situational awareness. Of the 388 total reports analyzed, 113 (29.1%) revealed some sort of problem with CRM/SRM.

Pilots of all experience and currency levels demonstrated problems with CRM/SRM. For example, the median number of hours flown by poor CRM/SRM pilots in the previous 90 days was 75, median total hours was 4,425, and the median number of hours for time in aircraft type was 600. CRM/SRM problems were identified in 21.0% of GA flights and 37.3% of professional flights.

Poor CRM/SRM decreases the margin of safety and is related to the existence of other problems in flight. For example, and not surprisingly, in this study a highly significant correlation between poor workload/time management (including poor CRM/SRM) and problems using avionics was found (r = .33, p<.001). Similarly, poor CRM/SRM was identified in 60 reports of flight deviations, in 29 reports involving landing difficulties, and in 9 of the 20 fatal accidents (8 of which were GA flights).

Weather. Most of the weather issues identified by the NBAA (2005) were not evident or cannot be assessed by analysis of the data used in this study (e.g., Inadequate Knowledge of High Altitude Weather). In-flight icing is of some concern to the NBAA and VLJ communities but there were few icing events recorded in the reports analyzed (n=8) and no significant difference was found between the numbers of private (n=5) and professional (n=3) pilots who had incidents/accidents in which icing played a role. Of the 50 NTSB accidents that were weather-related (including icing), 39 resulted in some type of collision or incursion event, including controlled flight into terrain (CFIT) or in-flight collision with an object (n=12), hitting some type of object or terrain on the ground (n=26), or an in-flight break-up (n=1).

Other Areas of Concern

Cognitive Performance. Six different variables related to pilot cognitive performance were of particular interest in this study: distraction, memory problems, poor decision making, poor risk perception, lost situational awareness, and cognitive processing difficulty (e.g., confusion, difficulty performing mental calculations, habit capture, etc.). Although pilots flying GA and professional flights did not differ from each other, almost two-thirds (66.5%) of the reports coded involved at least one of these cognitive performance issues (n=258; ASRS n=118, NTSB n=140). For example, not quite a third of the reports (n=121, 31.2%) involved the pilot losing situation awareness.

It was not uncommon for pilots to experience more than one type of cognitive performance problem. For example, cognitive processing problems, such as confusion, were found in 43.2% (n=48) of the reports in which poor decision-making was evident. Similarly, confusion or other such cognitive processing problems were found in 38% (n=46) of the reports in which the pilot also lost situational awareness, and in 12 of the 17 events involving high workload (70.6%) situation awareness was lost.

Cognitive performance difficulties are problematic in aviation because they directly affect safety. Of the 46 events involving pilot distraction, 31 (67.4%) resulted in flight path deviations. Flight path deviations also occurred in 38.3% (*n*=54) of the 141 reports involving cognitive processing difficulties (e.g., confusion) and in 56.2% (*n*=68) of the 121 reports involving a loss of situational awareness. Recall that variables related to cognitive performance, workload, time management and similar problems required some subjective judgment and were coded conservatively; thus, these difficulties probably occurred far more often than are reported here.

Avionics. VLJs will have highly advanced, integrated glass cockpits, so problems using avionics was also of interest in this study. Forty-one reports (10.6%), all but two of them ASRS incident reports, involved some sort of problem with avionics use (e.g., confusion about how to use the equipment, misprogramming a GPS, etc.). These problems occurred almost exclusively during three phases of flight: climbout, cruise, and arrival/approach. Climbout and arrival/approach are highly dynamic phases of flight and errors in programming or errors due to having one's "head down" and programming on the fly (say, due to poor preflight planning or in response to ATC directives) are particularly likely to show up during these phases. Thirty-three of the 41 reports (80.5%) identifying at least one problem with avionics use also involved a flight path deviation.

Problems with avionics use were strongly associated with cognitive performance problems. In fact, 40 of the 41 reports recording at least one problem with the use of avionics also involved a loss of situation awareness (97.6%). Some of these problems were related to not using the equipment correctly (e.g., wrong mode or display, misprogramming it), others were related to having one's head down to program or trying to figure out how to use the avionics and losing track of other things that were happening.

Currency. Lack of currency can be a safety risk for any pilot, and several types of problems involving potential VLJ pilots with fewer hours of recent experience were examined. Recent experience data (i.e., pilot hours flown in the previous 90 days) were available for 331 flights (211 GA and 120 professional) in the reports analyzed. As reported earlier, hours flown in the previous 90 days ranged from 0-390 with a median of 63 hours. As would be expected, 70.1% of pilots flying GA flights fell below the overall median of recent experience and 85.8% of pilots flying professional flights fell above the overall recent experience median (X^2 (3, n=331) = 103.84, p<.001).

A significant relationship was also found between the amount of recent experience and the type of report (incident vs. accident; X^2 (3, n=331) = 29.29, p<.001). Pilots who fell within the lowest quartile in terms of recent experience (24 or fewer hours within the previous 90 days) were involved in 35.8% (*n*=62) of the NTSB accidents. Of the 11 accidents resulting in fatalities (for which pilot currency data were available), six (54.5%) were flown by pilots with 24 or fewer hours flown in the previous 90 days. In other words, when currency could be determined, pilots who fell in the lowest quartile of recent experience flew over half of the fatal accidents.

Less recent experience was also significantly related to CFIT accidents, in-flight collision with object accidents (e.g., radio tower), and collision with objects on the ground, as well as other problems related to landing an aircraft. These findings are described below.

Collisions and Incursions. Over half of the NTSB reports analyzed (*n*=134, 56.9%) involved some type of collision, near collision, or incursion (e.g., near mid-air collision, CFIT, in-flight collision with an object, runway incursion, bird/animal strike, hitting something while on the ground, etc.). There was a significant relationship between hours flown in the previous 90 days and involvement in one of these types of events (X^2 (21, n= 135) = 36.70, p<.05) with more of these events involving pilots with fewer hours of recent experience. For example, 20.2% (*n*= 44) of the 218 NTSB reports involved CFIT or in-flight collision with object accidents; the median number of hours logged in the previous 90 days by the pilots involved in these events was 28. Pilots who had logged fewer than 63 hours in the previous 90 days (i.e., fell below the sample median of 63 hours) were involved in 70.0% of these accidents. Similarly, 61.1% (*n*=44) of the events in which the pilot collided with something while on the ground (e.g., cars, buildings, fences, trees) involved those pilots below the overall median in terms of currency.

Landing Problems. A substantial number of the NTSB accident reports analyzed (*n*=118, 54.1%) involved some type of problem during the landing phase of flight (e.g., hard landing, stalled it in, gear-up landings not involving gear malfunctions, landing short of the runway, etc.). Over a quarter (*n*=63, 28.9%) of the NTSB reports involved loss of aircraft control directly after landing (i.e., runway overrun, ground loop/departed side of the runway). There were also reports involving 32 gear-up landings but half (*n*=16) involved some type of landing gear malfunction. Ten (35.7%) of the 32 gear-up landings were committed by pilots who fell in the lowest quartile in term of recent experience, but again, half (*n*=5) of these events involved some type of landing gear malfunction.

Pilots in the lowest quartile of recent experience (i.e., 24 or fewer hours logged within the previous 90 days) also performed 54.3% (*n*=19) of the off-airport landings recorded.

Discussion

The NBAA Safety Committee (2005) has identified a number of issues to be addressed during VLJ training and the findings of this study corroborate six of them. A significant number of pilots, particularly those flying as private pilots, had difficulty with landings, especially when in crosswind or gusty conditions. There were a number of altitude deviations and some were related to lack of preparation for a high rate of climb, as predicted by the NBAA, but other factors – particularly cognitive performance problems such as distraction or loss of situational awareness – were associated with these flight path deviations as well.

Low fuel arrivals and fuel starvation accidents were found to be related to lack of (or minimal) recent experience as well as the amount of experience the pilots had in the type of aircraft they flew. However, these events were also found to be associated with insufficient preflight planning, most often demonstrated by pilots who were not flying in a professional capacity. Thus, the industry concern that VLJ pilots adopt commercial airline practices in adherence to checklists and following SOPs is well placed. However, pilots at all experience levels demonstrated poor checklist and preflight behavior and poor CRM/SRM, even those flying professionally, indicating that these are issues for all future VLJ pilots, no matter the type of flying they currently do.

Cognitive performance problems were highly prevalent in the reports analyzed and were related to a wide range of other problems. The data strongly suggest that to adequately address the other issues identified, cognitive performance issues such as dealing with distractions, maintaining situational awareness even while multitasking, and minimizing sources of confusion must also be addressed.

Although advanced avionics have the potential to greatly reduce workload and significantly increase safety, this is true only if the avionics are well-designed (with context of use in mind and in keeping with human factors principles) and only once their use is well understood and well practiced. It is often claimed that advanced avionics increase pilots' situational awareness, however, they also have the potential to decrease it, as was found in this study.

In addition to cognitive performance, the issue of currency is extremely important, especially for those pilots for whom the transition to a VLJ is a significant change from the aircraft they currently fly. In this study, fewer hours of recent experience was associated with a number of different problems (e.g., off airport landings, CFIT accidents, problems during landing). Maintaining currency in VLJs must be addressed, in addition to initial and recurrent training, to achieve the safest operations possible.

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