GENERAL AVIATION SINGLE PILOT IFR AUTOPILOT STUDY

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ABSTRACT

Five levels of autopilot complexity were flown in a single engine IFR simulation for several different IFR terminal operations. A comparison was made of the five levels of complexity ranging from no autopilot to a fully coupled lateral and vertical guidance mode to determine the relative benefits versus complexity/cost of state-of-the-art autopilot capability in the IFR terminal area. Of the five levels tested, the heading select mode made the largest relative difference in decreasing workload and simplifying the approach task. It was also found that the largest number of blunders was detected with the most highly automated mode. The data also showed that, regardless of the autopilot mode, performance during an IFR approach was highly dependent on the type of approach being flown. These results indicate that automation can be useful when making IFR approaches in a high workload environment, but also that some disturbing trends are associated with some of the higher levels of automation found in state-of-the-art autopilots.

Seven subjects were used in the tests, two NASA test pilots and five IFR rated pilots with various levels of IFR and autopilot experience. Each subject flew 27 data runs, for a total of 189 runs for this study. This included the 25 different combinations of five autopilot modes and five different approaches. The extra two runs per subject were repeats for replication purposes. The order of presentation was randomly determined for each pilot. Each data run lasted from 10 to 20 minutes, depending on the specific approach being flown. The ceiling and visibility for each run were randomly chosen from three conditions predefined for each of the five approaches. They were: (1) 15.2 m (50 ft) ceiling and 0.8 km (0.5 mi) visibility for the given approach, (2) published minimums for the given approach, or (3) 61 m (200 ft) above ceiling and double visibility of published minimums for the given approach. All the runs were flown in moderate turbulence (1.2 m/sec (4 ft/sec)) and 20 kt winds from a predefined direction. The piloting task consisted of flying the specified approach, making the required pilot reports, and performing a side task.

EXPERIMENTAL DESIGN

- o SUBJECTS (7)
- o NUMBER OF RUNS (189)
- o RUN LENGTH (10-20 MIN)
- o WEATHER (BELOW MIN, AT MIN, ABOVE MIN)
- o TASK

Five levels of autopilot automation were tested. The five, in order of increasing levels of automation, consisted of 1) no autopilot (NA - the basic aircraft); 2) wing leveler (WL); 3) heading select (HS - a heading select directional gyro was used in this mode); 4) heading select with lateral navigation coupling (HC - this mode included lateral guidance for both very high frequency omni range (VOR) and instrument landing system (ILS) navigation); and 5) heading select with lateral navigation coupling and altitude hold with vertical navigation coupling (HAC). In addition to the previously discussed capabilities this mode also included a choice of pitch attitude hold, altitude hold, or vertical navigation guidance (i.e., glideslope coupler).

AUTOPILOT MODES

- NA no autopilot
- WL wing leveler
- HS heading select
- HC heading select with lateral nav coupler
- HAC heading select with lateral nav coupler and altitude hold with vertical nav coupler

Five airports and their associated radio nav aids located in the general vicinity of Langley Research Center were programmed and used in this study. The types of approaches included two ILS approaches, one VOR approach, one Loc BC approach, and one NDB approach. These approaches, and other pertinent information, are given in more detail below.

APPROACHES

Airport	Runway	Approaches	Display	Wind
Norfolk, VA	5	ILS	CDI	091^{o}/20 kt
Atlanta, GA	8	ILS	CDI	225^{o}/20 kt
Newport News, VA	25	Loc/BC(Holding)	CDI	290^{o}/20 kt
Franklin, VA	9	VOR	CDI	332^{o}/20 kt
Wakefield, VA	20	NDB	Fixed compass card	155^{o}/20 kt

(From ref. 1.)

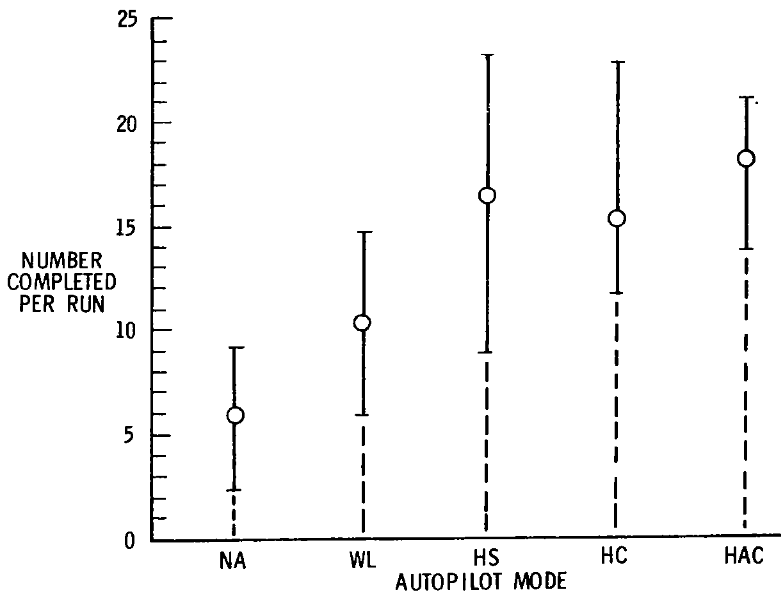
The data taken during each approach consisted of flight technical error, ground track and profile plots, pilot workload rating and comments, and side task results.

DATA

- FLIGHT TECHNICAL ERROR
- GROUND TRACK AND PROFILE PILOTS
- PILOT WORKLOAD RATINGS
- PILOT COMMENTS
- SIDE TASK RESULTS

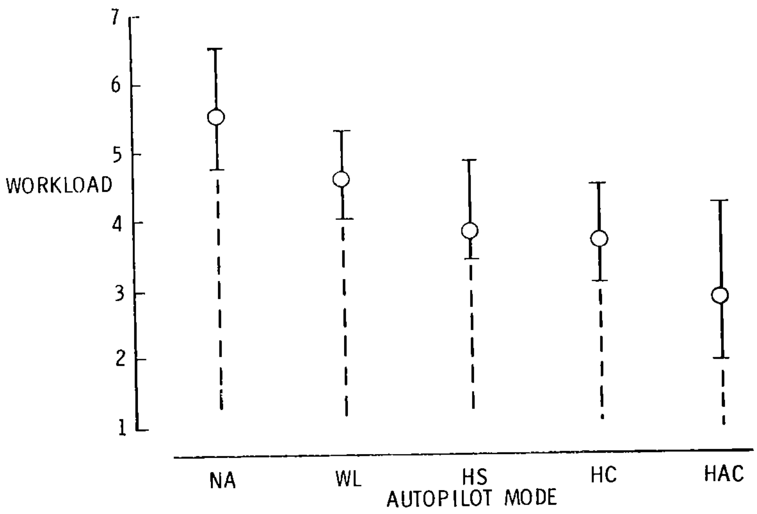
The side task results, in general, are representative of all the data. This figure shows the average number of problems completed per run during all the approaches for all the subjects at each level of autopilot complexity. The upper and lower limit bars represent the maximum and minimum of the averages of the individual subjects at each level of autopilot complexity. Implicit in using a secondary task is the assumption that the more difficult the task, the fewer problems completed, hence the higher the workload associated with the primary task. As can be seen by the data, the workload tends to decrease (increased secondary task performance) as automation level is increased. Significant, however, is the leveling off of the workload for automation levels greater than the HS mode. One interpretation of this phenomenon is that beyond the HS mode the subject trades off the workload associated with flying the control task for the workload required to monitor the autopilot's control of the flight task. This results in little net difference in primary task workload beyond the HS mode.

Average number of side tasks
(From ref. 1.)

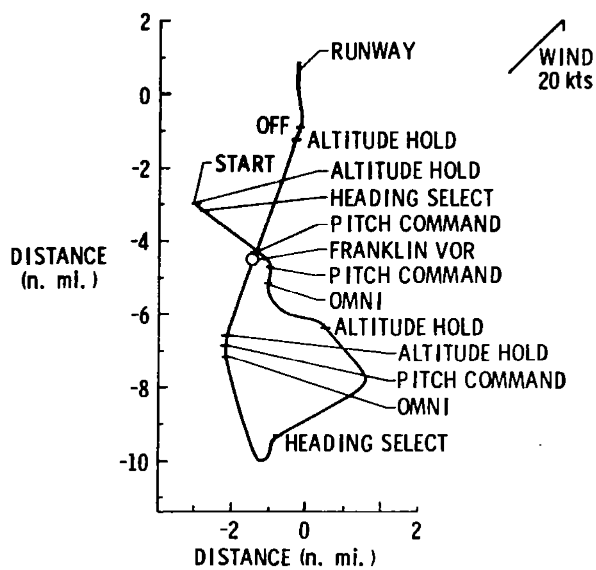


This figure shows a similar relationship with respect to subjective pilot workload ratings. At the end of each run the subject rated the primary task on a workload scale of 1 to 7 with 1 designated as the easiest and 7 as the hardest. It should be realized that this type of rating technique typically produces a relative workload rating of difficulty rather than an absolute workload rating. The format of this figure is similar to that of the previous figure; i.e., shown is the average workload rating per run during all the approaches for all the subjects at each level of autopilot complexity. The upper and lower limit bars represent the maximum and minimum of the averages of the individual subjects at each level of autopilot complexity. These results tend to agree with the side task results; i.e., increased automation decreases workload. There is also a slight leveling off of the workload beyond the HS mode, but it is not as dramatic as in the side task data.

Workload ratings
(From ref. 1.)

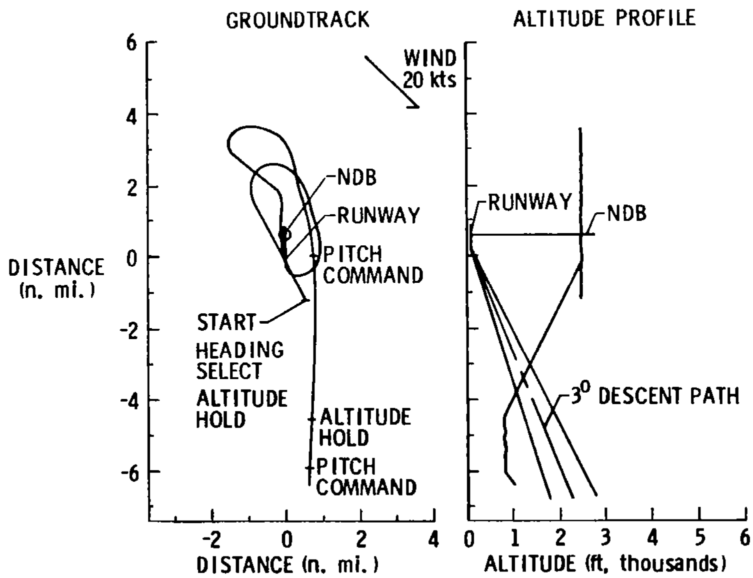


Several disturbing trends were noted as the level of autopilot automation was increased. In general, an increased level of automation tends to take the pilot out of the aircraft control loop. He becomes a manager of the autopilot functions. The effects of this change in duty appear to be emphasized in the HAC mode. The subjects were more likely to lose track of where they were in the approach. It seemed that in monitoring the autopilot the pilot would associate instrument readings with the autopilot functions rather than with situational awareness. Therefore, if the autopilot functions were either set incorrectly or interpreted incorrectly, the subject would frequently perform the wrong task, thinking that everything was normal. This would frequently lead to an incident or blunder. An example is shown below (Franklin VOR approach, HAC mode). The run began with the autopilot set in the heading select mode. After crossing the VOR, a right turn to the outbound course was initiated. At this point the autopilot was switched to omni coupler to intercept and track the outbound course. However, the subject had neglected to reset the correct bearing on the CDI. Therefore, the autopilot reintercepted and tracked the original bearing of the CDI. Eventually, he realized his mistake and set the correct outbound bearing on the CDI. The aircraft then took up a 45° intercept path to the new bearing. After a fair amount of time he still had not intercepted the outbound course turn using to the time into the approach he decided to make a pseudo procedure turn using heading select. At this point in time he also set in the correct inbound heading on the CDI. Upon completion of the procedure turn he continued in heading select until the CDI needle came alive. He then selected omni coupler and completed the approach without further incident. It is likely this incident would not have been detected in the real world.



Ground track Franklin VOR approach. HAC autopilot mode.
(From ref. 1.)

Another subject (Wakefield NDB approach, HAC mode) made his final let down on an outbound heading. He leveled off and made his missed approach without ever realizing his mistake. Another interesting facet related to this run is the fact that the NDB at Wakefield is located on the airport. The missed approach should have been executed when, if in this case, the NDB was crossed. In fact several otherwise normal runs were also flown at Wakefield in which the missed approach was executed prior to crossing the NDB inbound. It seems that the subjects would time their outbound leg and use this time, rather than the NDB crossing, to execute their missed approach. The 45° left headwind on the inbound heading was obviously a contributing factor in these incidents. These results imply a lack of positional awareness.



Wakefield NDB approach. HAC autopilot mode.
(From ref. 1.)

The results of this study suggests several general implications. Automation can reduce pilot workload, but a poor pilot interface with complex levels of automation can lead to disastrous blunders. In general, an increased level of automation tends to take the pilot out of the aircraft control loop. He becomes a manager of the autopilot functions. It seemed that in monitoring the autopilot the pilot would associate instrument readings with the autopilot functions rather than with situational awareness. The problem appears to be almost as if the pilot thinks of the autopilot as a copilot and expects it to think for itself. He allows himself to become completely engrossed in other tasks once the autopilot is set. Hence, he is frequently late in resetting new functions or he may become confused as to exactly where he is in the approach and not reset all the necessary functions or controls.

IMPLICATIONS

- AUTOMATION IS BENEFICIAL "BUT"
- PILOT BECOMES AUTOPILOT MANAGER
- LOSS OF SITUATIONAL AWARENESS
- AUTOPILOT/COPILOT

The results of this study indicate that automation is desirable when making IFR approaches in a high workload environment, but also that some disturbing trends are associated with the higher levels of automation as presently implemented in state-of-the-art autopilots. It is believed, however, that a better man/machine interface could alleviate these problems. The data further suggest that the heading select mode may currently be the best choice for the IFR approach task when considering both benefits and costs.

CONCLUSIONS

- AUTOMATION DECREASES WORKLOAD.
- THE MEASURED WORKLOAD BEGAN LEVELING OFF AT THE HEADING SELECT MODE.
- THE LARGEST INCREMENT OF BENEFIT WAS OBTAINED WITH THE HEADING SELECT MODE.
- THE MAJORITY OF THE BLUNDERS OCCURRED WITH THE MORE HIGHLY AUTOMATED MODES.
- AUTOMATION IS BENEFICIAL BUT CAN LEAD TO PROBLEMS IF NOT JUDICIOUSLY INTERFACED WITH THE PILOT.

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