

TACTICAL vs. STRATEGIC BEHAVIOR: GENERAL AVIATION PILOTING IN CONVECTIVE WEATHER SCENARIOS

Kara A. Latorella, Crew Systems Branch, NASA Langley, Hampton, Virginia
James P. Chamberlain, Aviation Operations & Evaluation Branch, NASA Langley, Hampton, Virginia

ABSTRACT

We commonly describe environments and behavioral responses to environmental conditions as “tactical” and “strategic.” However theoretical research defining relevant environmental characteristics is rare, as are empirical investigations that would inform such theory. This paper discusses General Aviation (GA) pilots’ descriptions of tactical/strategic conditions with respect to weather flying, and evaluates their ratings along a tactical/strategic scale in response to real convective weather scenarios experienced during a flight experiment with different weather information cues. Perceived risk was significantly associated with ratings for all experimental conditions. In addition, environmental characteristics were found to be predictive of ratings for Traditional IMC (instrument meteorological conditions), *i.e.*, aural weather information only, and Traditional VMC (visual meteorological conditions), *i.e.*, aural information and an external view. The paper also presents subjects’ comments regarding use of Graphical Weather Information Systems (GWISS) to support tactical and strategic weather flying decisions and concludes with implications for the design and use of GWISS.

INTRODUCTION

“Strategic” / “Tactical” Behavior

Operators in complex systems, and those who study these systems, use the terms “strategic” and “tactical” to both prescriptively and descriptively characterize operational modes. We see these terms used in a wide variety of operational domains, from business to disease control, and at various levels of systems, from the perspective of a commander of a military campaign, to the pilot of a single aircraft in that campaign. Planning literature also describes this continuum by contrasting models that focus on the ability to generate goals and to hierarchically develop actions based on these goals (more strategic); and the ability to identify significant environmental events and behave responsively to these (more tactical) (*e.g.*, Hayes-Roth & Hayes-Roth, 1979). In an informal study, Schutte (1997) derived general definitions for these terms by asking pilots and aviation crew systems researchers to provide five verbs and a short paragraph describing each behavioral mode. Strategic verbs listed by more than one respondent included (frequency reported): plan (13), think (5) evaluate (3), anticipate (3), prioritize (2), decide (2), and project (2). Tactical verbs listed by more than one respondent included: respond (6), act (6), react (5), do (5), fly (5), control (4), avoid (4), maneuver (2), and evaluate (2) (Rogers & Feyereisen, 1998). Rogers’ (1996) investigation of task management suggests that pilots distinguish between strategic and tactical modes based on the amount of time pressure exerted by the situation. Pilots’ efforts when in a strategic mode are aimed at solving known and anticipated task (*cf.* Funk & Braune, 1999) and workload (*cf.* Raby & Wickens, 1994) management problems. When time-constrained, and in tactical mode, pilots suggest that they

execute tasks according to a predefined mental list, where the order of tasks in this list is based on the urgency with which they must be addressed. Based on the Schutte survey, the card sorting and interview tasks in Rogers’ 1996 study, and other card sorting and interview tasks, Rogers & Feyereisen (1998) proposed three dimensions to distinguishing between tactical and strategic behavioral modes: 1) urgency, or the amount of time available; 2) breadth or scope of the event horizon – how much experience is considered and how focused one’s attention is to a specific task and the current point in time; and 3) depth of processing – or the degree to which knowledge-based processing (Rasmussen, 1986) is used, rather than behaving in a skill-based manner. Rogers & Feyereisen (1998) describe tactical behavior as the inner region of this three dimensional model, the centroid of which is defined by the current time, a narrow focus of attention, and a shallow level of information processing. The relative size of these cubic representations of tactical/strategic behavior can vary with personality, experience, stress and workload (Rogers & Feyereisen, 1998). Based on additional interviews and card sorting tasks, this model was refined to emphasize that subjects consider prediction and planning the signature of strategic behavior, whereas they consider the actual performance of immediate tasks as indicating tactical behavior. Further, the pilots in their study suggested that strategic behavior includes the performance of planned activities, emphasizing the notion that environmental certainty is an element of defining whether one ought to be performing strategically or reacting tactically.

Weather Flying

The goal of the NASA Aviation Safety Program’s Aviation Weather Information (AWIN) element is to decrease

accident associated with weather. Because GA aircraft operate in areas of more hazardous weather, are less resilient to weather hazards, and GA pilots have a wide range of skill and experience, weather is particularly hazardous for GA. One can consider two polar approaches to GA weather flying. One approach emphasizes the importance of gathering preflight information to gain the most elaborate and comprehensive view of the weather, and upon which to make a Go/No-Go decision, determine if the flight is to be conducted under instrument flight rules (IFR); and to plan a route, destination and alternates and fuel requirements. The other approach is to ensure that take off and departure are safe, that there's a reasonable expectation of being able to land at the intended destination, or close to it, and to avoid weather along the way. Those who ascribe to this approach compensate for a lack of precise planning by accepting flexibility in their planned time and place of arrival, and by ensuring adequate resources (fuel) to afford flexible route changes, vertical avoidance maneuvers, and possibly interim landings (Latorella *et al.*, 2001). They may also depart under visual flight rules (VFR), assuming they can obtain an IFR clearance in flight if necessary.

In flight, extensive weather information gathering and contingency planning results in better plans for an anticipated situation – which may not evolve as predicted: “*Strategy in battle and flying seems to last until the war starts* (McClellan, 2002).” However, this results in higher immediate workload – which could interfere with visual or instrument scanning and positional or aircraft performance awareness, and cause other pilot error and negative consequences. Taking a see-and-avoid approach for weather in flight relies on the ability to detect weather hazards in time to respond appropriately and for the aircraft to physically evade the hazard. The risks associated with this approach are that weather hazards may not be detected until they are encountered, through failures of attention or information; and that escape options may not be available due to the nature of the hazard, aircraft performance capabilities, and pilot skill level. Reliance on avoidance also may result in sub-optimal solutions, and successively reduced options, whereas a plan that remains viable can more successfully optimize on mission safety, efficiency, and comfort goals.

Clearly, different sources of weather information are amenable to supporting what is notionally considered “strategic” and “tactical” behavioral modes. Weather information that is spatially or temporally displaced from the pilot’s current perspective, has low spatial or temporal resolution, or is phenomenological in nature is most appropriate for developing a general plan of action, for identifying potential hazards, and doing so when workload is not prohibitive. Weather information that is local, current, and action-oriented, *i.e.*, has a learned associated response plan or provides one, is more appropriate for immediate use.

Currently, most GA pilots receive most of their weather information from “out the window” visual cues and aural cues; *i.e.*, monitoring automated reporting systems (*e.g.*, HIWAS, ATIS, AWOS/ASOS, etc.), or through conversations with

ground support operators (*i.e.*, Flight Watch, ATC) and overhearing conversations of other pilots with these ground support operators. The weather information available to GA pilots is currently both insufficient, and ill-formatted for in-flight decision-making (Latorella & Chamberlain, 2001). GWISs aim to improve both the nature of information available to pilots in flight as well as the quality of this information’s presentation to better support in-flight decision-making. The FAA Flight Information Services Data Link (FISDL) program has recently made such systems available.

State-of-the-art FISDL-supported GWISs include free text products, including surface observations (METAR) and special observations (SPECI), terminal area forecasts (TAF) and amendments (TAF AMEND), significant meteorological observations (AIRMET, SIGMET, Convective SIGMET), pilot observations (PIREP), and alerts for severe weather watches (AWW). For a fee, these units also can display symbols representing ceiling and visibility categories (based on METARs), and Next Generation Radar (NEXRAD)-sensed graphical representations of precipitation indicating areas and intensity of precipitation, and by inference, convective activity. This information is updated nominally every 5 minutes and is displayed by coloring blocks 4km-square by 6 levels of intensity. Government/Industry design guidance (RTCA, 2000), information in the FAA’s Aviation Information Manual, and product literature (Honeywell, 2001) all emphasize that the appropriate use of this information is for strategic decision-making and that this information should not be used as the sole source for making weather decisions, rather to supplement information from existing sources.

This paper discusses how GA pilots described strategic and tactical behavior with respect to weather flying; it evaluates the significance of the coverage of hazardous convective weather, the distance from this weather, and the confidence pilots have in their weather picture, as predictors of their scale responses indicating the extent to which they consider a situation strategic/tactical; and finally it discusses how pilots might use GWISs and the features they found supportive of strategic and tactical behavioral modes.

METHOD

The NASA AWIN program’s CoWS (Convective Weather Sources) study provided the data for this analysis. This flight test compared GA pilot performance with three different sets of weather information sources in a flight experiment. On each test scenario a NASA test pilot flew three GA pilots, the subjects, toward convective weather of moderate or greater intensity. Subjects did not perform flying duties during these flights but were given representative loading tasks that also provided them positional awareness. Flights were conducted under IFR but in VMC. One subject received an experimental condition representing the weather information typically available to a GA pilot in IMC. This “Traditional IMC” condition (aural) consisted only of aural weather information. Another subject received the “Traditional VMC” condition (window+aural) in which visual cues provided by an “out-the-window” view augmented the

aural cues. The third subject received the “GWIS-augmented IMC” condition (display+aural), in which subjects had access to an aviation GWIS as well as aural cues. The GWIS provided METAR text information, and a moving map display for the continental US that included present position, contextual features (geo-political boundaries, rivers, interstates), selected aviation contextual features (NAVAIDS, airports), and a color-coded, 4km-square resolution graphical depiction of up-linked NEXRAD information to indicate convective weather.

Before pre-experiment briefings, subjects completed the Preliminary Questionnaire that asked, among other things, for the time-to-encounter from a variety of weather conditions for which they would still consider the situation strategic. Subjects then received a mission motivation and briefing; a local terrain, NAVAID and airport identifier review; a route briefing for the flight to be taken; practice on forms and procedures to be used during the in-flight phase, and were given a variety of preflight weather briefing materials for the flight. The subject who would use the GWIS on that flight received a standardized training program that described features, functions, and update rates. Subjects were not informed that this tool is only for strategic purposes.

The in-flight portion of the experiment started after the aircraft had climbed to cruising altitude and when the aircraft was approximately 120 nautical miles (nm) from the first convective weather area of moderate or greater intensity. The outbound leg of the in-flight portion ended when approximately 20nm from this area, or at approximately 100nm from the initial experiment starting point, whichever occurred first. Throughout the outbound leg of the in-flight portion, subjects were given either a Position Update task (for positional awareness and task loading), a Weather Situation Awareness (WXSA) Questionnaire, or were provided aural weather information (from an automated HIWAS station, Flight Watch, or ATC). These events were scheduled to occur nominally every 4 minutes, for approximately every 11nm at the 170 knot cruising speed. The WXSA Questionnaire contained items that, among other things, assessed subjects’ estimation of distance and bearing from the nearest cell of moderate or greater intensity, their confidence in the weather picture, the degree to which they thought the situation was strategic / tactical, and the degree to which continuing along the planned route was “extremely risky” / “entirely safe.” At the conclusion of the outbound leg, subjects were asked to complete the Inbound Questionnaire, which contains NASA-TLX (Hart & Staveland, 1988) derived scales for workload assessment, asked subjects to indicate other weather sources that would have been helpful, and asked about their flight decisions. The subject with the GWIS then completed a Usability Questionnaire that included questions about what was useful for tactical vs. strategic decision-making. A short debriefing session to assess experimental scenario validity followed each flight, and an extensive debriefing session followed the third flight for each team. Four teams of three GA pilots provided the data for this experiment. Information Set was a within-subject factor, and the order of these three conditions was counterbalanced over three levels of cross-

country flight experience. The CoWS study formally compares the three experimental conditions based on a within-subject design with four teams of three. This experimental design served as the basis for the in-flight data analysis presented here. In addition to data from the 12 core subjects, analysis of the Preliminary Questionnaire includes 6 additional subjects’ responses, and analysis of the GWIS Usability Questionnaire includes 2 additional subjects’ responses (from teams that did not complete the required three flights).

RESULTS

Subjects were asked to characterize tactical and strategic situations with respect to weather flying. In addition, for eight types of convective weather scenarios, subjects were asked to provide the closest time (in minutes) away from a weather phenomenon at which they would still think they would be responding to it strategically; that is, when would they begin to behave more tactically towards the situation. Six of these weather phenomena were described as an area of severe thunderstorms perpendicular to, and extending some distance (5nm, 10nm, 15nm, 20nm, 30nm, 50nm) to either side of the route of flight. Finally, we explore the GWIS features that subjects said support tactical vs. strategic performance.

Definitions of Strategic / Tactical Weather Flying

On the Usability Questionnaire, subjects were asked to define strategic and tactical situations with respect to using the GWIS and identify its features that supported strategic and tactical use. Subjects again generally characterized strategic use of the GWIS as for flight planning, identifying a safe route, being proactive, planning to avoid encountering hazards and the need to respond tactically to weather, obtaining a big picture of the weather, and determining the type of flying they would be doing (IFR or VFR). Subjects characterized tactical use of the GWIS as for “steering” or “maneuvering” to avoid weather hazards they would otherwise encounter, “threading” through cells, exiting hazardous weather, and responding in a “reactive,” “immediate,” way to “local” phenomena. Two subjects indicated that this tactical reaction would be within 5-10 minutes of encountering, one reported that it would be within 25nm of their position, another reported within 50nm.

Subjects’ Delineations of Strategic & Tactical

The preliminary questionnaire forced subjects to define strategic / tactical delineations, for different weather scenarios, in terms of time-to-encounter, assuming that they were enroute and flying a Cessna Turbo 210. These weather scenarios were described as: 1) an isolated cell with yellow radar return along the route of flight; 2) an isolated cell with red radar return along the route of flight; 3) an area of severe thunderstorms perpendicular to, and extending 5nm to either side of the route; 4) an area of severe thunderstorms perpendicular to, and extending 10nm to either side of the route; 5) an area of severe thunderstorms perpendicular to, and extending 15nm to either side of the route; 6) an area of severe thunderstorms perpendicular to, and extending 20nm to either side of the route; 7) an area of severe thunderstorms perpendicular to, and

extending 30nm to either side of the route; 8) an area of severe thunderstorms perpendicular to, and extending 50nm to either side of the route. Table 1 shows the closest time-to-encounter when subjects would still consider their response to the weather scenarios (as enumerated above) as strategic.

Table 1. Strategic/ Tactical Delineation Times (minutes).

Scenario	N	Mean	Median	Min	Max
1	17	23.5	20	10	45
2	17	16.5	15	10	30
3	17	20.9	20	5	30
4	17	26.8	30	10	45
5	17	30.9	30	15	30
6	17	36.2	40	20	55
7	17	40.6	40	20	60
8	16*	45.6	45	25	60

(* One subject did not provide a response to scenario 8.)

Scenarios 3 to 8 can be considered a continuum of cases where the width of the storm area, as centered on the intended route, increments by 5nm to either side. Table 1 shows that subjects' state that they would begin responding tactically to a storm area further away when the lateral extent of storm is broader. A logistic regression model with no constant term describes this increasing function (tactical delineation time = $11.82 * \ln(\text{storm extent})$) and that this relationship explains the vast majority of variability in the data ($R^2 = 0.92$) and is highly significant ($p < 0.0001$). Comparing scenarios 1 and 2 shows that subjects, on average, also respond tactically further away from a red radar return along the route flight than a yellow one ($F(1,32)=5.364, p=0.027$).

Influences on In-Flight Strategic/Tactical Ratings

Separate step-wise regressions were performed for each of the experimental cue conditions to assess the explanatory power of the individual differences among subjects, the distance to the nearest cell of moderate or greater intensity that is within +/- 45 degrees of the aircraft's heading, the relative offset position of this cell, and subject's confidence in their understanding of the big picture of the weather situation and assessment of the situation's risk level (Table 2, coefficients were standardized and missing data was eliminated listwise).

The "perceived risk" term met entry criteria for all experimental conditions (p (F-statistic) < 0.05 for entry; and > 0.10 for removal) but was most highly associated with tactical/strategic ratings in the Traditional IMC condition, and was significant at a much lower level in the GWIS condition. Different second terms were significant for each of the experimental condition regressions on tactical/strategic ratings. The relative position (within a +/- 45° arc centered in front of the aircraft) of the nearest convective cell of moderate or greater intensity was significantly associated with tactical/strategic ratings for the Traditional IMC condition. The range, or distance, to this cell was significant for the Traditional VMC condition. Only subject differences provided a significant second variable for the GWIS equation.

Table 3. In-flight Regressions on Tactical/Strategic Ratings.

	Traditional IMC	Traditional VMC	GWIS IMC
Equation:	-2.247	-18.160	95.163
<i>Constant</i>	($t=0.137, p=0.892$)	($t=-1.791, p=0.087$)	($t=8.399, p<0.001$)
<i>Term 1</i>	<i>Risk</i> 0.601 ($t=4.298, p<0.001$)	<i>Risk</i> 0.174 ($t=5.669, p<0.001$)	<i>Subjects</i> -0.599 ($t=4.115, p<0.0001$)
<i>Term 2</i>	<i>Position</i> 0.422 ($t=3.028, p=0.006$)	<i>Range</i> 0.511 ($t=4.889, p<0.0001$)	<i>Risk</i> 0.317 ($t=2.177, p=0.039$)
Model R^2	0.496	0.763	0.449
Model F-test	$F(2,26)=12.79$ ($p<0.0001$)	$F(2,23)=37.11$ ($p<0.0001$)	$F(2,26)=10.61$ ($p<0.0001$)

GWIS Features and Strategic / Tactical Behavior

Following a flight, subjects who used the GWIS completed a usability questionnaire that probed their use of this technology to support tactical and strategic weather decision-making. Subjects reported that weather depictions at larger map scales (those over 100nm were specifically mentioned), and the ability to derive an integrated perspective of surface conditions based on surface observation (METAR) symbols supported strategic decision-making with respect to weather flying. One subject noted in particular that the value of a GWIS is that they can obtain weather reports for areas out of range of AWOS stations. One subject also noted that Flight Watch, the traditional aural source of weather information, assists him with strategic use of weather information – highlighting the complement of GWIS technology and existing sources.

Subjects indicated that knowing cell intensities (colored graphics), proximity to weather (cell locations and aircraft location), and having weather radar and observations for alternates and destinations supported tactical use of the GWIS. Subjects also mentioned that additional features would further support tactical use of the GWIS, such as: range rings (to support distance and bearing estimates), higher resolution graphical weather data (to aid precise course changes), arrows on cells (indications of cell movement), airway graphics, and indications of whether the phenomena could be penetrated, circumnavigated, or required a course reversal.

DISCUSSION

The results from this work have several implications. They provide empirical data toward a model of tactical and strategic behavior in aviation. All regression equations demonstrate the significant association of perceived risk and characterization of tactical/strategic, although this association was less pronounced for the GWIS condition. Results highlight the importance of environmental cues in determining the degree to which one is responding in a tactical/strategic manner. In particular, we note that relative location is the most salient cue for tactical/strategic distinction in Traditional IMC conditions, whereas distance from convective weather is most important, perhaps because it is most salient, when in Traditional VMC conditions. Interestingly, for the in-flight ratings, the significance of these environmental cues

evaporates when GWISs are used, and individuals appear to significantly differ on some other, as yet unexplored, factor. Rogers & Feyereisen (1998) theorize that uncertainty of the environment is highly correlated with pilots' tactical/strategic characterization, however this factor, as expressed inversely by their confidence in their "big picture SA," was not significantly explanatory to predict this distinction on the in-flight ratings for this convective weather-flying scenario.

The application of these empirical results and the development of a more robust general model serve to develop more advanced aviation information systems, here a GWIS, that provides information and information formatting appropriate to pilots' behavioral modes in a context-sensitive manner. Whereas the extent of avionics certification required for an aviation information system hinges on the use of the information it provides, specifically whether it is to be used for tactical avoidance of hazards or advisory information for strategic planning, definition of how pilots use a GWIS is of paramount importance. Analysis of CoWS usability assessments and debriefing commentary indicates that GA pilots are likely to use GWISs tactically, as well as strategically, even when the temporal or spatial resolution of the weather information is insufficient for this purpose (Latorella & Chamberlain, 2002). This conclusion is further supported by the types of features that subjects indicated would be important to incorporate into GWISs, particularly aids to determining relative distance and bearing to cells, and requests for assessing response options.

Regardless of industry/FAA design assumptions, FAA pilot guidance, or product documentation warnings to the contrary, it is evident that pilots need tactical weather information, and are predisposed to use compelling graphical representations of convective activity in this manner. This points to three important requirements for this technology. The first is for interface designs that convey the reliability and relevance of weather information, and explicate the limits of information for tactical use. The second is to improve support of tactical weather flying. Improved weather hazard detection will be accomplished through more rapidly sampled, precise, and spatially-extensive weather sensing and dissemination, faster update rates and spatial coverage of weather information to make better weather products. Improved data dissemination technologies will make this information available to flightdeck systems. Improved interface design, interpretation and response aiding and perhaps automated execution will assist the pilot in assimilating and using this information to best advantage. Finally, GWIS implementation should include corresponding training to ensure appropriate use of this technology. Underlying all these is a need to convey the appropriate behavioral mode to pilots given their skills, aircraft and equipment capabilities, and the environment, e.g., weather phenomena. Understanding the variability of pilots' definitions of tactical vs. strategic behavior and environmental modes and the determinants of this variability is necessary to ensure appropriate development of GWIS technology. This paper suggests some important factors towards this distinction.

REFERENCES

- Funk, K. & Braune, R. (1999). *The AgendaManager: A Knowledge-Based System to Facilitate the Management of Flight Deck Activities*, SAE 1999-01-5536. 1999 World Aviation Congress, San Francisco, CA.
- Hart, S.G. & Staveland, L.E. (1988). Development of NASA-TLX: Results of empirical and theoretical research. In P.A. Hancock & N. Meshkati (Eds.) *Human Mental Workload* (139-183). North-Holland: Elsevier Science.
- Hayes-Roth, B. & Hayes-Roth, F. (1979). A cognitive model of planning. *Cognitive Science*, 3, 275-310.
- Honeywell International Inc. (2001) *Bendix/King KMD 550/850 Multi-function Display. Flight Information Services (FIS) Pilot's Guide Addendum*. Honeywell International Inc., Olathe, KS.
- Latorella, K., Pliske, R., Hutton, R., & Chrenka, J. (2001) *Cognitive Task Analysis of Business Jet Pilots' Weather Flying Behaviors: Preliminary Results*. NASA-TM-2001-211034.
- Latorella, K. & Chamberlain, J. (2002). Graphical weather information system evaluation: Usability, perceived utility, and preferences from General Aviation pilots. *SAE General Aviation Technology Conference & Exhibition (Paper 02GAA-3)*.
- Latorella, K. & Chamberlain, J. (2001) Decision-making in flight with different convective weather information sources: Preliminary Results. *Proceedings of the 11th International Symposium for Aviation Psychology*.
- McClellan, J.M. (2002) Strategy v. tactics. *Flying*, January, p. 11.
- Schutte (1997) *Unpublished manuscript*, also cited as personal communication in Rogers & Feyereisen (1998).
- Raby, M. & Wickens, C.D. (1991). Strategic behavior in flight workload management. *Proceedings of the 6th International Symposium on Aviation Psychology*, 1130-1135.
- Rogers, W. (1996). Flight deck task management: A cognitive engineering analysis. *Proceedings of the 40th Human Factors and Ergonomics Society*, 239-243.
- Rogers, W. & Feyereisen, T. (1998). An analysis of strategic and tactical crew behavior. *Honeywell Technology Center Technical Report*. Honeywell Technology Center, Minneapolis, MN. (NASA Contract: NAS1-20219).
- RTCA, Inc. (2001) *Minimum Operational Performance Standard for Flight Information Services-Broadcast (FIS-B) Data Link, RTCA/DO-267*, RTCA Inc. SC-195, Washington D.C.

ACKNOWLEDGMENTS

We gratefully acknowledge the many people at NASA Langley Research Center and at Honeywell who aided this experiment: our project pilot, Charles Cope, for many safe and successful flights; our Crew Chief, Leo McHenry, for maintaining a safe airplane; Dave Mcluer, Lee Joyce, Ed Radwanski, and Bob Kendall for their outstanding support of the ground and airborne systems; Barry Golembiewski for his excellent weather forecasting; Regina Johns for assistance with subject procurement and scheduling; Barbara Trippe for aircraft and pilot scheduling; Jim Joyce at Honeywell and Tim Sobolewski at CLH for their ongoing support of the AWIN system, and Brian Haynes of United Airlines for his vision, drive and enthusiasm in bringing this GWIS from concept to reality.