

FREE FLIGHT LITERATURE SURVEY: HUMAN FACTORS RESEARCH USING EMPIRICAL STUDIES

Eleventh International Symposium on Aviation Psychology
May, 2001, Columbus, OH

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ABSTRACT

A comprehensive review of empirical studies supporting Free Flight air traffic operations is documented. Research papers are categorized by their relevance to the flight deck, air traffic management, airline operational control, and key problems that they solve. In addition to identifying current research findings, this investigation is aimed at identifying research needs not currently covered in the literature.

INTRODUCTION

Free Flight represents a major change in the operation of the National Airspace System (NAS). In this paper, Free Flight concepts and issues are discussed based on the following sources of information:

- Radio Technical Commission for Aeronautics (RTCA) Task Force 3 Free Flight Report [R95];
- Federal Aviation Administration (FAA) Free Flight URL: <http://www.faa.gov/freeflight/>;
- Concept Definition for Distributed Air-Ground Traffic Management (DAG-TM) [D99];
- NAS Architecture Version 4.0 [FAA99]; and
- Comments from Stakeholders from an e-mail survey.

Through the work of the RTCA in 1994 and 1995 [R95], Free Flight has been defined by a group of over 200 professionals from the aviation industry:

“... a safe and efficient flight operating capability under instrument flight rules (IFR) in which the operators have the freedom to select their path and speed in real time. Air traffic restrictions are only imposed to ensure separation, to preclude exceeding airport capacity, to prevent unauthorized flight through Special Use Airspace (SUA), and to ensure safety of flight. Restrictions are limited in extent and duration to correct the identified problem. Any activity which removes restrictions represents a move toward free flight.”

It is also described on the FAA Free Flight home page:

“The concept moves the NAS from a centralized command-and-control system between pilots and air traffic controllers to a distributed system that allows pilots, whenever practical, to choose their own route and file a flight plan that follows the

most efficient and economical route. Free Flight calls for limiting pilot flexibility in certain situations, such as, to ensure separation at high-traffic airports and in congested airspace, to prevent unauthorized entry into SUA, and for any safety reason.”

DAG-TM is a set of concepts being developed at the NASA Ames Research Center that allows for an advanced Free Flight air traffic management (ATM) concept that utilizes a triad of agents, as shown in Figure 1. The vision statement for DAG-TM is [D99]:

“DAG-TM is a NAS concept in which flight deck (FD) crews, air traffic service provider (ATSP) and airline operational control (AOC) facilities use distributed decision-making to enable user preferences and increase system capacity, while meeting ATM requirements. DAG-TM will be accomplished with a human-centered operational paradigm enabled by procedural and technological innovations. These innovations include automation aids, information sharing and Communication, Navigation, and Surveillance (CNS)/ATM technologies.”

As shown in Table 1, the DAG-TM paradigm has 15 Concept Elements (CEs).

Stakeholders were e-mailed to survey research issues for Free Flight. We asked researchers, scientists, engineers, professors, pilots, dispatchers, and controllers the question: *What do you think are the three most important research issues that must be addressed for Free Flight to be implemented by 2015?* The year 2015 was chosen since it is referred to in [D99] as a target date of operation. The Free Flight concepts and issues were used to identify the research issues that guided the literature survey (see Table 2).

RESULTS

Research papers from the literature search were categorized as high, medium, or low in relevance based on their empirical content supporting Free Flight research issues (RIs). Each high ranked paper was reviewed and summarized. Papers were categorized according to domain (ATM, FD, and AOC – Figure 1), DAG-TM CEs (Table 1), and Free Flight RIs (Table 2).

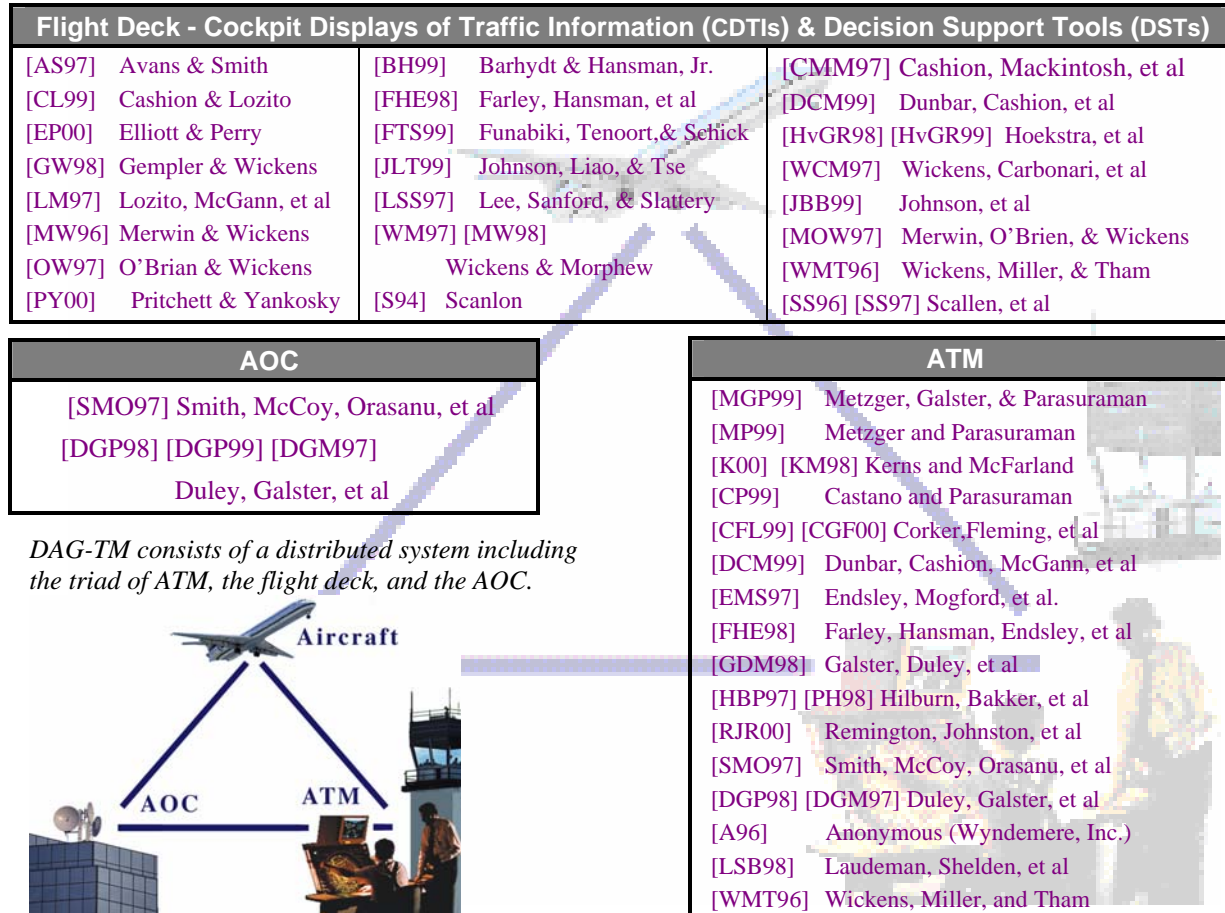


Figure 1. Empirical studies sorted by the triad formed by ATM, the FD, and AOC.

Based on an analysis of the literature, two general results emerge:

- Most of the empirical studies have been for the Flight Deck, a good amount for ATM, and very few studies have been performed for the AOC.
- A majority of the empirical studies that have been performed are related to CE 5 and a lot of studies support RIs 1, 2, 5, 6, and 11.

DISCUSSION

Many useful research findings resulted from the reviews, these are summarized as follows:

Flight Deck. Very many empirical results were revealed:

- Crews take significantly longer to detect conflicts and have increased workload in high-density conditions compared to low-density conditions.
- Crews more often detected a conflict prior to an alert than after an alert.
- It is more common for Free Flight pilots to contact the intruder aircraft than not to contact them; communication is usually prior to an alert.

- Many factors influence maneuver choice in a FD self-separation situation (including type of conflict: overtake, merging, or head-on); some studies conclude that pilots chose to maneuver vertically more than laterally, while others conclude that lateral maneuvers were chosen more often.
- Vertical maneuvers by the intruder produce an added source of workload.
- Pilots have more operational errors when being overtaken than with crossing or converging.
- While additional intent and other information (e.g., 3D flight plans) aids pilot performance in Free Flight, many studies identify a problem with clutter in such displays as traffic density increases.
- Greater degrees of intent are preferred by pilots even with associated clutter problems.
- At terminal arrivals, FMS usage tends to increase workload, requiring additional head-down time.
- Speed estimation for another aircraft and the time to closest approach proves to be a challenge to pilots and produces high levels of cognitive effort.

Table 1. The DAG-TM Concept Elements (CEs) and supporting human factors research literature.

CE	Flight Phase/CE Title	Supporting Research Literature
0	Gate-to-Gate: Information Access/Exchange for Enhanced Decision Support	[DGP98] [DGP99] [DGM97] [SMO97] [WMT96]
1	Pre-Flight Planning: NAS-Constraint Considerations for Schedule/Flight Optimization	- No Results
2	Surface Departure: Intelligent Routing for Efficient Pushback Times and Taxi	- No Results
3	Terminal Departure: Free Maneuvering for User-Preferred Departures	[BH99] [MW96] [GW98]
4	Terminal Departure: Trajectory Negotiation for User-Preferred Departures	- No Results
5	En route: (Departure, Cruise, Arrival) Free Maneuvering for: (a) User-preferred Separation Assurance, and (b) User-preferred Local TFM Conformance	[A96] [AS97] [BH99] [CL99] [CMM97] [CP99] [CFL99] [CGF00] [DGP99] [DGP98] [DGM97] [DCM99] [EMS97] [FTS99] [GDM98] [GW98] [HBP97] [PH98] [HvGR99] [HvGR98] [JBB99] [JLT99] [K00] [KM98] [LSB98] [LM97] [MOW97] [MW96] [MGP99] [OW97] [RJR00] [SS96] [SS97] [SMO97] [WCM97] [WMT96] [WM97] [MW98]
6	En route: (Departure, Cruise, Arrival) Trajectory Negotiation for: (a) User-preferred Separation Assurance, and (b) User-preferred Local TFM Conformance	[DGP99] [DGP98] [DGM97] [DCM99] [FHE98] [FTS99] [SMO97]
7	En route: (Departure, Cruise, Arrival) Collaboration for Mitigating Local TFM Constraints due to Weather, SUA, and Complexity	[DGP99] [DGP98] [DGM97] [EMS97] [FHE98] [SMO97] [S94]
8	En route / Terminal Arrival: Collaboration for User-Preferred Arrival Metering	[DGP99] [DGP98] [DGM97] [SMO97] [LSS97]
9	Terminal Arrival: Free Maneuvering for Weather Avoidance	[S94] [WCM97] [OW97] [MOW97]
10	Terminal Arrival: Trajectory Negotiation for Weather Avoidance	- No Results
11	Terminal Arrival: Self Spacing for Merging and In-Trail Separation	[PY00] [EP00]
12	Terminal Arrival: Trajectory Exchange for Merging and In-Trail Separation	[PY00] [EP00]
13	Terminal Approach: Airborne CD&R for Closely Spaced Approaches	[EP00]
14	Surface Arrival: Intelligent Routing for Efficient Active-Runway Crossings and Taxi	- No Results

- Efforts to make perceptually visible quantities that would otherwise need to be cognitively derived (e.g., point of closest approach), reduce workload and simultaneously improve performance.
- Pilot effort increases when the color of an aircraft in the CDTI changes to indicate closer proximity.
- A color CDTI allows pilots to execute maneuvers earlier than pilots without color in the CDTI.
- Brightness coding of an aircraft symbol appears to have no effect on attracting a pilot's initial attention to a conflict.
- A coplanar display (plan view and profile) has an advantage over a 3D perspective display, particularly when a vertical intruder exists.
- A tendency to choose vertical over lateral maneuvers is amplified with a coplanar display.
- Measures of flight safety favor a coplanar display over a 3D perspective display in terms of actual and predicted traffic conflicts, as well as weather conflicts.
- The most pronounced negative effect of a 3D perspective display is the effect of 3D ambiguity.
- Many aspects of the current pilot-controller voice channel remain quite adequate for Free Flight.
- When CDTIs are used in Free Flight, a statistically significant increase in the number of communication transmissions occurs (as compared to no CDTI).
- Pilots have biases to attend to different display locations first in a visual search task.
- With a datalink enabled, pilots and controllers make more voluntary suggestions to one another for specific route adjustments.
- Greater safety benefits occur using a CDTI with TCAS included instead of TCAS alone.
- Pilots are best served by displays in which traffic and weather are overlaid within the same panel, and when this information is shared with the ATSP.
- Predictive elements improve safety (reduce actual and predicted conflicts) and reduce workload, although different predictive elements affect workload in different ways.
- Providing intent information directly on a display or incorporating it into a conflict probe both lead to fewer separation violations and earlier maneuvers compared to the basic TCAS display.

Table 2. The research issues (RIs) augmented with supporting research literature.

RI	Research Issue	Supporting Research Literature
1	What will be the role and responsibility of the pilot in Free Flight?	[AS97] [BH99] [CL99] [CMM97] [DCM99] [EP00] [FHE98] [FTS99] [GW98] [HvGR99] [HvGR98] [JLT99] [JBB99] [LSS97] [LM97] [MOW97] [MW96] [OW97] [PY00] [SS96] [SS97] [S94] [WCM97] [WM97] [MW98]
2	What will be the role and responsibility of the air traffic controller or ATSP in Free Flight?	[A96] [CP99] [CFL99] [CGF00] [DGP99] [DGP98] [DGM97] [DCM99] [EMS97] [FHE98] [GDM98] [HBP97] [PH98] [K00] [KM98] [LSB98] [MGP99] [MP99] [RJR00] [SMO97]
3	What is the role and responsibility of AOC dispatchers in Free Flight?	[DGP99] [DGP98] [DGM97] [SMO97]
4	How can information distribution and collaborative decision making enable user preferences in Free Flight?	[DGP99] [DGP98] [DGM97] [FHE98] [SMO97] [WMT96]
5	How will pilots and ATSP share the responsibility for separation assurance in Free Flight?	[A96] [AS97] [BH99] [CL99] [CP99] [CMM97] [CFL99] [CGF00] [DCM99] [EP00] [EMS97] [FHE98] [FTS99] [GDM98] [GW98] [HBP97] [PH98] [HvGR99] [HvGR98] [JLT99] [JBB99] [K00] [KM98] [LSB98] [LM97] [MOW97] [MW96] [MGP99] [MP99] [OW97] [PY00] [RJR00] [SS96] [SS97] [WCM97] [WMT96] [WM97] [MW98]
6	What new CDTIs & other cockpit DSTs are needed for pilots to effectively participate in Free Flight?	[AS97] [BH99] [CL99] [CMM97] [EP00] [FHE98] [FTS99] [GW98] [HvGR99] [HvGR98] [JLT99] [JBB99] [LSS97] [LM97] [MOW97] [MW96] [OW97] [PY00] [SS96] [SS97] [S94] [WCM97] [WMT96] [WM97] [MW98]
7	What new DSTs enable greater user preferences of the AOC dispatcher in Free Flight?	- No Results
8	What DSTs enable ATSP in Free Flight?	[CP99] [CFL99] [CGF00] [FHE98] [K00] [KM98] [MGP99] [MP99] [RJR00]
9	How will airspace be dynamically managed to control workload and safety in Free Flight?	[A96] [LSB98]
10	Do current DSTs useful for Free Flight abide by human-centered-automation guidelines?	[LSS97]
11	What level of automation is required or desired in the design of new interfaces for pilots or controllers?	[A96] [AS97] [BH99] [CL99] [CP99] [CMM97] [CFL99] [CGF00] [EP00] [EMS97] [FHE98] [FTS99] [GDM98] [GW98] [HBP97] [PH98] [HvGR99] [HvGR98] [JLT99] [JBB99] [K00] [KM98] [LSB98] [LSS97] [LM97] [MOW97] [MW96] [MGP99] [MP99] [OW97] [PY00] [RJR00] [SS96] [SS97] [S94] [WCM97] [WMT96] [WM97] [MW98]
12	How will Datalink change the nature and efficiency of communication?	[DGP99] [DGP98] [DGM97] [EP00] [FHE98] [SMO97] [WMT96]

- More than one study supports an airborne separation assurance concept for Free Flight.
- Pilots voice strong opinions about a continued, active role for the controller in Free Flight.

ATSP. Many findings from empirical studies related to Free Flight provide guidance for ATSP related research:

- Both traffic load and conflict geometry (obtuse angle vs. right angle vs. acute angle) have effects on conflict detection times for the ATSP.
- The level of intent information affects controller operational errors and conflict prediction time.
- The degrading influence of low intent information is particularly severe under high traffic densities.
- Controllers find that workload attributed to Free Flight is often lower than they originally anticipated.
- Controllers feel strongly that aircraft intent should always be available to the controller, and prefer to know about intent prior to maneuver initiation.
- In high density airspace, controllers have difficulty both in detecting conflicts and in recognizing self-separating events in a timely manner.

- A conflict probe reduces workload under high volume Free Flight conditions; a probe for controllers should have a look ahead capability of well over five minutes.
- Controllers vary in their presentation preferences, perform tasks concurrently rather than sequentially, and have task dependent information requirements.
- Requests for joint changes in altitude and heading take longer to evaluate compared to those for a single change (e.g., altitude or heading).
- Free Flight is likely to bring an increased level of altitude resolution maneuvers at high volumes.
- Color-coding of altitude quickens conflict detection.
- There is no one agreed upon definition for dynamic density for either today's system nor for Free Flight.
- Dynamic density correlates better than traffic density with observed controller activity.
- The top factors influencing dynamic density include: intent, density of aircraft, number of crossing altitude profiles, heading changes, predicted conflicts, and miss distance.

AOC. A few studies result in following:

- Collaborative Decision Making (CDM) and cooperative problem solving are the primary research areas studied.
- In CDM, a shared understanding of goals, problems, constraints, and solutions is necessary.
- A distribution of responsibilities exists for different individuals at both the AOC and ATSP.

Feedback and process control loops must be modeled as a part of the CDM problem.

RECOMMENDATIONS / FURTHER WORK

Further research is needed to investigate those topics critical to Free Flight that are not currently being adequately researched:

- The effects of wind, turbulence, wake vortices, SUA, and adverse weather conditions needs to be better explored for Free Flight scenarios, otherwise, Free Flight CDTIs and DSTs could become “clumsy automation” where they decrease workload in normal operating conditions but potentially increase workload in abnormal working conditions.
- More work needs to be performed to study the transition from flight deck control authority for airborne separation to ground-based control authority.
- Empirical studies need to be performed to investigate the evolution between our current positive control system for air traffic control towards a mature Free Flight intervention by exception system.
- Further studies are needed that include consideration for mixed equipage among aircraft and consideration of multiple user classes within airspace usage and conflicts (mixed general aviation, commercial, military, helicopters, and business jets).
- More AOC simulation facilities are needed to include AOC human-computer interaction analogous to the cockpit simulators and ATC simulators that exist today; with such facilities, further research is needed to explore the important role of the AOC in CDM for Free Flight and to support RI 7 and CE 7.
- Further empirical human factors studies need to be run to support DAG-TM CEs 1, 2, 4, 10, 14, and RIs 3, 7, 9, and 10.

ACKNOWLEDGMENTS

This research was funded by the NASA Ames Research Center under contract NAS2-98005. The authors appreciate the assistance of Dr. Tony Andre of Interface Analysis Associates.

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