Airborne-Based Conflict Probe

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Glossary

AAR	Airport Arrival Rate
AATT	Advanced Air Transportation Technology
ACARS	ARINC Communications Address and Reporting System
ADS-B	Automatic Dependent Surveillance - Broadcast
A/FD	Airways/Facilities Directory
AIM	Airman’s Information Manual
AIRMET	Airman’s Meteorological Observation
AOC	Airline Operations Center
APATH	Airborne Planner for Avoiding Traffic and Hazards
ARINC	Aeronautical Radio Inc.
ARTCC	Air Route Traffic Control Center
ASD	Aircraft Situation Display
ASO	Aircraft Systems and Operations
ASOS	Automated Surface Observation System
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
ATM	Air Traffic Management
ATMP	Air Traffic Management Partnership
AWOS	Automated Weather Observing System
B757	Boeing 757
CASSY	Cockpit Assistant System
CDM	Collaborative Decision Making
CDU	Control-Display Unit
CTAS	Center/Tracon Automation Sysem
DC-9	Douglas Aircraft 9
DFW	Dallas-Fort Worth, TX
DUATS	Direct User Access System
EDCT	Expect Departure Clearance Time
EFAS	Enroute Flight Advisory System
EICAS	Engine Indication and Crew Alerting System
ETE	Estimated Time Enroute
ETMS	Enhanced Traffic Management System
ETOPS	Extended Twin (Engine) Operations
FAA	Federal Aviation Administration
FANG	FMS Air Traffic Management Next-Generation
FAR	Federal Aviation Regulations
FL	Flight Level
FMS	Flight Management System
FSS	Flight Service Station
GA	General Aviation
GDP	Ground Delay Program
GIV	Gulfstream IV
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
IP	Information Processing
JFK	John F. Kennedy Airport, NY
HIWAS	Hazardous InFlight Weather Advisor Service
LAT	Latitude
LAX	Los Angeles, CA

LF	Low Frequency
LONG	Longitude
MEL	Minimum Equipment List
MINIT	Minutes In Trail
MIT	Miles In Trail
MOA	Military Operations Area
MN	Minnesota
MSP	Minneapolis Airport, MN
NAS	National Air Space
NM	New Mexico
NOM	National Operations Manager
NOTAM	Notice To Airmen
NRP	National Route Program
NWS	National Weather Service
NY	New York
PDC	Pre-Departure Clearance
PERF	Performance
PIC	Pilot In Command
PIREP	Pilot Report
R&D	Research and Development
RCO	Remote Communications Outlet
RTCA	Radio Technical Commision of America
RVR	Runway Visual Range
SAN	San Diego, CA
SCC	System Command Center
SELCAL	Selective Calling
SFO	San Francisco, CA
SFP	Strategic Flight Planning
SIDs	Standard Instrument Departure
SIGMET	Significant Meteorological Obeservation
SME	Subject Matter Experts
SOC	Systems Operation Center
STAR	Standard Terminal Arrival
SUA	Special Use Airspace
SWAP	Severe Weather Avoidance Plan
TCAS	Traffic Alert and Collision Avoidance System
TFM	Traffic Flow Management
TIBS	Terminal Information Broadcast Service
TMC	Traffic Management Coordinator
TMS	Traffic Management Supervisor
TPA	Turbulence Plot Area
TRACON	Terminal Radar Control
TX	Texas
VFR	Visual Flight Rules
VOR	Very High Frequency Omnidirectional Rangefinder
ZAB	Albuquerque ARTCC
ZFW	Fort Worth ARTCC

Preface

This report documents research undertaken by the National Center of Excellence for Aviation Operations Research, under Federal Aviation Administration Research Grant Number 96-C-001. This document has not been reviewed by the Federal Aviation Administration (FAA). Any opinions expressed herein do not necessarily reflect those of the FAA or the U.S. Department of Transportation.

Executive Summary

There is currently a great deal of excitement in the world of commercial aerospace because of a renaissance that is being fostered by a concept broadly known as Free Flight. Free Flight is a notion that has resulted from a number of parties (airlines, manufacturers and suppliers, and government air traffic control and regulatory authorities) seeking to develop a "blueprint" for improvements to an aging and decrepit air traffic control system that threatens the economic viability of those seeking to use the domestic National Airspace System (NAS). Borne out of a need to address system inefficiencies and capacity problems that artificially inflate the direct operating costs of airlines and package carriers, the Free Flight concept seeks to reduce the amount of restrictions placed on aircraft transiting the NAS.

However, Free Flight is currently not a unified concept, and it is not clear that all it's proposed instantiations solve the intended problems or that they solve them in a way that results in a favorable cost/benefit balance. It does seem evident, though, that a more sophisticated capability to strategically replan individual flights in a way that satisfies a variety of global and local constraints, will be needed to enable any Free Flight instantiation. Whether Free Flight means unrestricted maneuvering, more airline freedom in flight plan filing, or simply more coordinated, flexible re-planning solutions to unforeseen congestion or weather problems, sophisticated flight planning will be required to optimize fuel economy, satisfy multiple constraints of multiple stakeholders in real-time, and provide feedforward aircraft "intention" data for traffic flow management and airline fleet planning. Strategic flight planning/replanning in a Free Flight environment is the focus of this effort.

Rather than locking-in to a particular Free Flight concept, the approach taken here is to revisit the basic flight planning/replanning process in today's environment, identify inefficiencies, and develop solutions that address those inefficiencies. Developed solutions should enable Free Flight but might offer benefits independent of Free Flight as well. This effort addresses an airborne capability, and the emphasis is therefore on block-to-block replanning, since that will more likely require a more substantial flight deck capability than pre-departure flight planning.

Interviews were conducted to collect descriptive data on current flight planning/replanning practices and inefficiencies. Four classes of airspace user and two air traffic service providers were interviewed:

- General Aviation
- Corporate Aviation
- Airlines (both large, inter-continental carriers and small, niche operators)
- Package Carriers
- Air Traffic Control System Command Center
- Air Route Traffic Control Center

A wide cross section of airspace user and stakeholder perspectives is needed to understand varying interests and inefficiencies in order to influence efforts associated with NAS modernization.

The interview data are presented in terms of summary descriptions of planning/replanning goals, constraints, functions, information, and information sources for each of the operator classes. Further, a typical replanning scenario is described from the perspective of the various operator classes and stakeholders. From these data, routing or flight planning/replanning inefficiencies are identified. They generally fall into three categories:

- All stakeholders in the planning or replanning process are not included in decision making
- Decisions are not based on the best information
- System inflexibilities exist which limit optimal solutions

Each of these inefficiencies create delays and indirect routing that, from the airline perspective, are at the heart of schedule integrity and fuel usage improvements that they wish to achieve. It is worth noting that fuel optimization is not nearly as important to airlines in minimizing their direct operating cost as is maintaining their published schedule of operations.

Based on a formal analysis of stakeholder goals derived from the interviews, flight replanning functions and information are reallocated to the different stakeholders, and an airborne functional concept depicting flight deck functions, information and information flow for flight planning/replanning is developed based on this reallocation. The general conclusion is that by involving airline operating centers and flight crews more in the flight replanning process (especially for those scenarios involving global constraints such as major weather events or traffic congestion problems where their involvement is currently lacking), more optimal (from a combined stakeholder perspective) replanning solutions can be derived. This does not necessarily mean that aircraft need more maneuvering or separation authority. It also does not assume a “free maneuvering” capability. Additionally, when replanning tasks are shared in a collaborative decision making sense among air traffic service providers, airline operations centers, and flight crews, then they need shared information in common formats with collaboration aids to assist referencing common events and phenomena. These functional and informational changes on the flight deck should not only reduce current replanning inefficiencies by involving all stakeholders and allowing decisions to be made on the best information, but it should also improve the predictive capability and situation awareness of all parties, which will be required to support the more flexible routing promised by Free Flight.

1.0 Introduction

1.1 Purpose of the Current program

The ultimate objective of this effort is to develop an airborne strategic flight replanning concept (during block to block operations, versus pre-flight) that enables maximum aircraft and airline efficiency for commercial aircraft in a future Free Flight environment, including consideration of constraints on the flight path that may be imposed by congested airspace, traffic flow into terminal areas, airline scheduling and fleet requirements, weather, special use airspace (SUA), traffic, terrain, and others. Free Flight is an envisioned paradigm-shift in the way air traffic management is performed, intended to reduce operational inefficiencies, and with implications for how strategic flight replanning is done on the flight deck. However, the emphasis of the airborne flight replanning concept developed here is on reducing routing inefficiencies, not on Free Flight per se. The general strategy, therefore, is to describe and analyze flight planning and replanning in today's environment, particularly in regard to current inefficiencies. Based on these analyses, an airborne flight replanning concept will be formulated; it may contribute to implementation of Free Flight, and it may help reduce inefficiencies independent of Free Flight. The concept will include description of replanning function allocation between ground personnel (AOC, ATC) and flight crew, flight deck replanning information requirements and information flow to support the airborne replanning concept, and will touch on other flight deck issues such as human-automation function allocation, flight crew interfaces, and integration of the concept with existing flight deck functionality. Since this is a problem-driven approach, we will first review the operational inefficiencies.

1.2 Inefficiencies Addressed

The overriding concern of the AATT program is capacity problems within the National Airspace System (NAS) and worldwide. Capacity limitations stifle future traffic growth, and cause inefficiencies in current operations. Routing inefficiencies, some capacity-related and some not, include delays and diversions, and excessive fuel burn due to indirect routing. These problems are not evenly distributed within the system; the problems are more acute in high density traffic areas (e.g., east coast and below 35000 ft), high volume terminal areas (e.g., Chicago), and on "bad flying" days (e.g., extensive weather systems, low visibility). The largest capacity bottleneck is the combination of high traffic airports and IFR conditions, and while more efficient routing is necessary, it is not sufficient to solve this problem. Hence we believe that touting capacity improvements as the main objective of the airborne strategic replanning concept addressed here is ill-advised. We can, however, do much to benefit airline operations if we can mitigate the inefficiencies that have root causes in the current system of flight planning and replanning.

A recent analysis (Chew, 1997) states that the primary product of an airline is its schedule and the primary operational goal of the airline is to maintain schedule integrity. Chew indicates that airlines view the critical operational problems facing scheduled airlines today to be (1) delays and (2) route and altitude inefficiencies. Delays are far and away the most critical problem because they jeopardize schedule integrity. Better flight planning and replanning may help reduce these significant airline operational inefficiencies.

1.3 Approaches to Mitigating Inefficiencies

Many different programs and solution paths are addressing many different aspects of the problem, and it is easy to be overwhelmed by the complexity, diversity, and apparent overlap of the different perspectives and approaches. At the risk of over-simplification, we have reduced the efforts that are addressing inefficiencies in aircraft routing to two basic classes: (1) those that propose to eliminate artificial routing constraints and procedures associated with an archaic air traffic control infrastructure (this includes eliminating assigned airways and altitudes, allowing aircraft to "maneuver at will," and providing aircraft with self-separation authority); and (2) those that propose to improve the process of flight planning and replanning by assuring that decisions and information that support them account for the goals and interests of all stakeholders. The basic assumption of the first approach is that each flight crew would be better able to maximize their aircraft's efficiency if they have freedom to select and modify their route, while the basic assumption of the second approach is that if the goals, constraints, knowledge, and information "owned" by all stakeholders in the route planning process can be considered simultaneously, routes that are more efficient, from a collective stakeholder perspective, would result. In this context, Table 1 provides a framework which illustrates our approach (Strategic Flight Planning or SFP) in relation to others, both in regard to the approach, problems addressed, and risks.

Table 1. General approaches to route inefficiencies

Approach	Program	Main problem addressed	Risks
Remove **procedural** constraints from flight planning	· RTCA Free Flight · ATMP · Flight 2000 · APATH	fuel efficiency	· Viability of self-separation · Equipage · Cost · Loss of predictability for TFM
Improve **process** of flight planning & replanning	· FANG · CDM · APATH · ATMP · SFP	delays fuel efficiency	· Communication links · Equipage

The approach of the Aircraft Systems and Operations (ASO) element of the NASA AATT program is to develop and evaluate aircraft system concepts and requirements that enable user efficiency and flexibility while avoiding hazards in a Free Flight environment. Free Flight has been simply defined as a safe and efficient operating capability under instrument flight rules 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, and to ensure safety of flight (RTCA, 1997). Thus Free Flight is an Air Traffic Management (ATM) solution, with the implicit assumption that if operators can select their path and speed in real time with fewer restrictions, there will be an economic and/or safety benefit. The Air Traffic Management Partnership (ATMP) concept (Lockheed, 1997) further assumes that airborne self-separation is a requirement for operators to be able to reap maximum economic benefits in a Free Flight environment. While these efforts are primarily focused on the first general approach to eliminating routing inefficiencies described above (i.e., Free Flight), the intention is to develop comprehensive solutions. The effort described here focuses on the second approach, and should be complementary to other parts of the ASO element of AATT.

Another related distinction that should be mentioned concerning different approaches to reducing routing inefficiencies is that between the functions of Tactical Hazard Avoidance and Strategic Route Planning. The latter, which is focused on here, directly impacts operating efficiency. The former, which is often the focus of Free Flight, is a safety-related function which is assumed to be required to enable the more flexible routing envisioned by Free Flight. We view two distinctions here -- tactical vs. strategic situations and hazard avoidance vs. route planning. These distinctions generally coincide, that is, hazard avoidance is a tactical function and flight planning is a strategic function. When the aircraft is in a situation where there is imminent actual or potential danger from an encounter with a hazard, there is a time-pressured, safety-driven flight control goal to maneuver the aircraft to avoid the hazard. Efficiency of operation is moot. The maneuver serves immediate goals. The time scale may vary from seconds to minutes, but it is tactical in the sense that it has perceived immediacy, requires the full attention of the flight crew on short term objectives, and the primary high level function is flight control.

Conversely, when the aircraft is in a situation where new information or circumstances require or suggest a change in the flight plan or a deviation in the current route, be it from weather, ATC constraints, wind changes, traffic, etc., there is a time-relaxed (usually), economy/operational constraint-driven planning goal to develop and execute a new route. Efficiency of the operation may be key. The change serves long-term goals. The time-scale for completion of the task may vary from minutes to tens of minutes, requires a broad horizon of awareness (i.e., the big picture of mission management), and the primary high level function is navigation/flight planning. Entities such as traffic, turbulence, convective weather, icing conditions, and terrain can be hazards to be tactically avoided or constraints to be accounted for in strategic flight planning. The difference in how they are viewed by the flight crew depends on the goals, functions, and time-scale that comprise the situation.

This effort focuses on strategic route planning, and directly addresses tactical hazard avoidance and Free Flight only in the sense that strategic planning for avoidance of other individual aircraft may need to be accommodated in combination with planning for avoidance of other constraints to enable more efficient and safe routing in a more flexible, unstructured air traffic environment.

2.0 Problem Definition Study

Our approach in this effort, then, is to step back from both Free Flight as a solution and self-separation as an operational assumption for Free Flight. We began by conducting operator and stakeholder interviews to allow us to describe flight planning and replanning in today’s environment, including the routing problems and inefficiencies that helped motivate the Free Flight concept in the first place. We also describe flight deck equipment (Appendix A) related to flight planning to provide a more comprehensive understanding of how planning/replanning is performed today. The first question to be asked then, both of any overall Free Flight operational concept, and of the airborne component, is, “does it have the potential to reduce delays and/or increase path and speed efficiency?” We take a building-block approach to understanding current operational inefficiencies and flight planning processes, and then develop assumptions about Free Flight and reasonable airborne concepts based on that understanding. We attempt to apply “out-of-the-box” thinking, but solutions and approaches must be tempered by their tenability in real world operations. Only two assumptions about potential solutions are made:

(1) any viable Free Flight concept will have an airborne component because ATM is necessarily a distributed function with data, knowledge and authority residing both on the ground and aircraft; and

(2) more efficiency and dynamic capability in airborne strategic route planning will be an important part of the an overall Free Flight concept because greater route flexibility and a more efficient ATM system ultimately depend on the ability to strategically plan, predict, and coordinate the movement of individual aircraft in the airspace for purposes of traffic flow management.

2.1 Method

Because the overall objective of this program is to develop a flight deck functional concept for strategic flight planning/replanning, and because such a concept would be used primarily in the process of in-flight replanning, we wanted to ensure that all of the current goals, functions, constraints, information, and resulting inefficiencies in flight planning and replanning were adequately represented and accounted for in our study. A general overview of this process is shown in Figure 1.

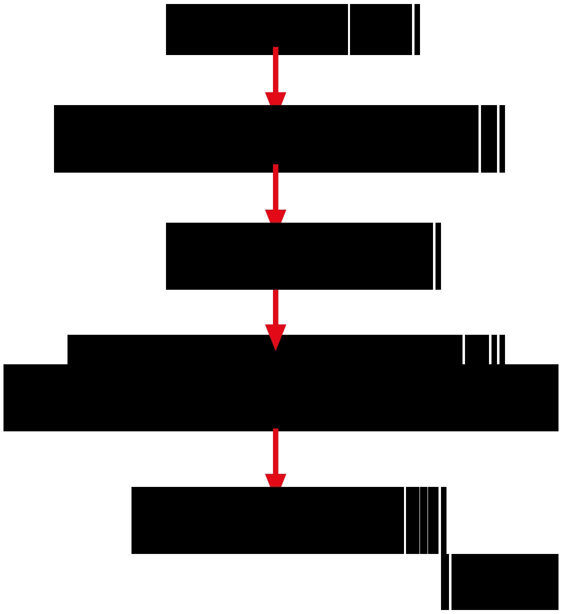


Figure 1. Process for conducting study

First, we interviewed flight dispatchers from a variety of aircraft operators to better understand and document the planning and replanning processes currently being used. These subject matter experts were selected from several major airlines with sophisticated AOC support, a small, niche market airline with minimal AOC support, a business jet fleet operator, a major cargo carrier, and a general aviation pilot. In each case, we followed a structured interview format that was intended to identify stakeholders and goals, planning/replanning sub-functions, what constraints were managed, what information was used and where it came from, and what inefficiencies were encountered, both for planning and for replanning. We also interviewed air traffic facilities personnel to get their perspective on flight planning/replanning as related to air traffic management goals.

2.2 Results

The “raw” data from the operator interviews are included in Appendix B. The results are summarized below, highlighting the significant operator class commonalties and distinctions for flight planning and replanning. The summary is intentionally brief and selective, and interested readers are encouraged to read the raw interview data; there are many interesting comments and insights that are not captured here. The results are divided into descriptions of planning and replanning, and then under each category, common descriptions that apply to all operator classes are presented first, then descriptions unique to each operator class are presented. In the replanning description, information processing (IP) tasks are introduced as a useful way to illustrate differences among operator classes in allocation of replanning tasks to stakeholders. Finally, since replanning is the focus here, a typical replanning scenario is described from the perspective of ATC and each operator class to help illustrate differences in replanning perspectives among operator classes and stakeholders.

2.2.1 Flight Planning

2.2.1.1 Operator Classes Commonalties

The fundamental purpose of a flight conducted under Instrument Flight Rules (IFR) is for Air Traffic Control to provide assistance in the basic separation assurance function because the pilot may not be able to “see and avoid” other aircraft. When a flight is conducted under an approved IFR flight plan then the pilot, or flight crew, may assume that ATC is sharing the responsibility for collision avoidance.

To facilitate the collision avoidance function, there are a minimum set of requirements that must be met in order to file and fly a flight under Instrument Flight Rules. The Airmen’s Information Manual (AIM) states:

> Prior to departure from within, or prior to entering controlled airspace, a pilot must submit a complete flight plan and receive an air traffic clearance, if weather conditions are below VFR minimums.

The AIM also goes on to declare that the flight plan should be filed at least 30 minutes in advance of the departure in order to allow the air traffic service providers a chance to process the flight plan in a timely manner and avoid departure delays.

Included in the flight plan is a requirement to provide information about the aircraft, including its weight class (if a “heavy,” over 300,000 lb.) and navigational and transponder capabilities. In addition, the route of flight (including requested cruise altitude) must be indicated in the flight plan.

An increasingly important purpose of flight planning is to allow traffic flow managers and air traffic controllers to predict and manage congested air space and traffic flow problems.

In order to fly an FAA-approved flight plan under Instrument Flight Rules, there are a minimum number of tasks that must be completed, whether the flight will be conducted in a Cessna 172 or a Boeing 777. The adjacent figure shows a flow diagram of the tasks outlining the sequence of events for developing an IFR flight plan.

At this point we will note the common **Goals**, **Constraints**, **Information** used, and the **Sources of Information** in the flight planning process among the various classes of airspace user.

It is usually the case that all airspace users have as their primary **Goal** the safe and efficient transport of aircraft and cargo (including passengers) between Points "A" and "B." Safety is always first, but efficiency of operation is also a universal goal. How efficiency manifests itself (i.e., the relative priority of various efficiency sub-goals) depends on the class of operator and therefore will be discussed in the operator class-specific sections below.

Constraints vary greatly between the different classes of operators, but a common set includes: payload and range based on fuel capacity, ability to penetrate different types of weather safely (e.g., low visibility landing and en route icing conditions), terrain, congested airspace and other ATC constraints, individual traffic, SUA's, winds aloft, aircraft capabilities (e.g., in terms of altitudes that can be flown), and crew qualifications -- particularly with regards to low landing minima.

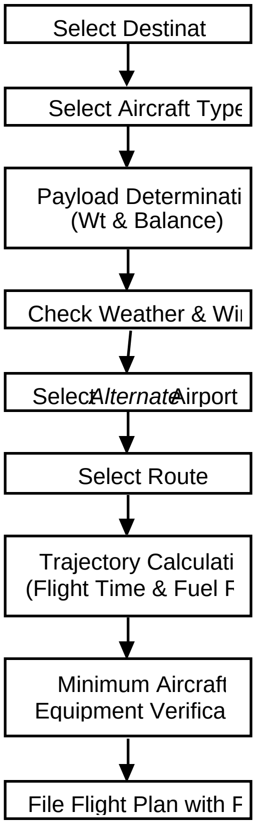


Figure 2. Tasks involved in flight planning

The area of **Information** used and the **Source(s) of Information** is an evolving domain. Information that is required for all forms of flight planning, independent of user class, includes:

- Aircraft Navigation Capability (Including Transponder)
- Aircraft Performance Data
- Aircraft Restrictions (Inoperative Equipment)
- Airport Data (Destination and Selected Alternate)
- Crew Qualifications (with regard to Aircraft Capability, e.g., CAT II)
- Route Data (Airways and Navigation Aid status)
- Weather Information
- Congested Airspace, Delays

First and foremost, the pilot, or flight crew must have access to aircraft performance information supplied by the manufacturer. In addition, route data that are relevant to the navigation capabilities of their aircraft are required as is current weather associated with the region in which the flight will be operated. The quality and recency of information actually available varies widely among operator classes.

What varies the most among the various user classes we've investigated is the **Source of Information** that goes into the development of a flight plan. The more sophisticated the operation (in terms of multiple agents participating in the development of the flight plan) the more likely that the source of information contributed to the flight plan comes from other than the pilot.

2.2.1.2 Flight Planning Unique to Operator Classes

General Aviation

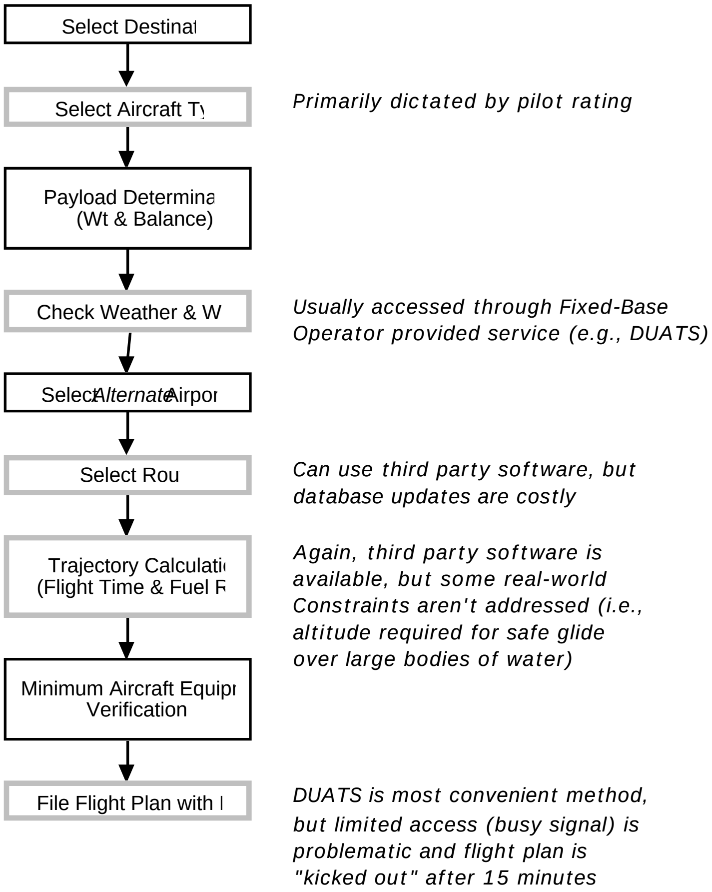
World View (Goals/Constraints)

The primary consideration, or **Goal**, in conducting flight operations is safety of flight. There are a number of **Constraints** to contend with, but the primary ones with unique aspects for GA include:

- Weather
- Pilot currency (instrument rating)
- Landing or tie-down fees
- Gas prices
- Rental car availability
- Food availability

Differences in Flight Planning Task Sequence

The tasks are fundamentally unchanged from those listed in the earlier section on flight planning. Of course the **Information** and **Information Sources** vary a great deal depending upon the sophistication of the pilot and the Fixed-Base Operator, if any, that is used as a service provider. The Task Flow Diagram, Figure 3, shows modifications to the sequence of steps by outlining changes to **Information Sources**.



Primarily dictated by pilot rating

Usually accessed through Fixed-Base Operator provided service (e.g., DUATS)

Can use third party software, but database updates are costly

Again, third party software is available, but some real-world Constraints aren't addressed (i.e., altitude required for safe glide over large bodies of water)

DUATS is most convenient method, but limited access (busy signal) is problematic and flight plan is "kicked out" after 15 minutes

Figure 3. Tasks involved in flight planning (General Aviation)

Corporate Aviation

World View (Goals/Constraints)

While the high level goals of safety and efficiency are shared by corporate operators, efficiency, such as that related to "least fuel" flight planning, is usually secondary to "least time" goals of corporate passengers. Burning fuel at a faster rate to get passengers to their destination faster is acceptable practice.

Constraints, Information and Tasks involved in Flight Planning

Immediately a distinction was made between Domestic and International Operations. The first portion of the discussion dealt with Domestic trips.

Domestic

One of the key distinctions between Domestic and International operations for the Honeywell pilots is in function or task allocation. When the flight is operated domestically, the pilot usually handles all relevant aspects of flight planning.

The main **constraints** and related **information** are weather en route, at the destination, and at an alternate landing sight (if the destination weather is marginal). Some of the first questions that runs through the pilot's mind when examining Terminal Forecasts are:

- Is an Alternate required?
- The threshold for the consideration of an alternate is whether or not the weather is VFR at the destination.
- If the weather is marginal at the destination the pilot will ask the to-be-transported party(ies) if they would prefer waiting or landing at a near-by city and proceeding via ground transportation to their destination.

Next, the pilot is concerned about fuel **constraints** and **information**, including:

- The fuel load required to accomplish the mission.
- Diversion requirements.
- Ferry-fuel (Honeywell Flight Ops has a software package that logs the fuel prices from previous trips to those cities).

Next comes consideration of routing and ride quality along the most direct route of flight. The pilot will check various **information sources**, such as NOTAMs for the primary destination and alternate airports. Frequently the pilot will examine free sources of weather, such as "The Weather Channel" and, in the twin cities, the Public Service television service provided by Kavouras, to determine gross weather patterns (i.e., fronts, convective weather, etc.).

Next the pilot will try to obtain a Slot Time for the arrival at the destination airport. Frequently our aircraft, which are technically General Aviation aircraft, must compete with other General Aviation aircraft at large airports which are usually dominated by air carrier operations. These airports, such as Chicago O'Hare or Washington National have very scarce Landing Slots available to General Aviation aircraft on an hourly basis, and, in some cases, the competition for these available slots is very keen (especially at airports with large numbers of business jets, such as National). Once a landing slot time has been established the pilot will examine the actual route of flight.

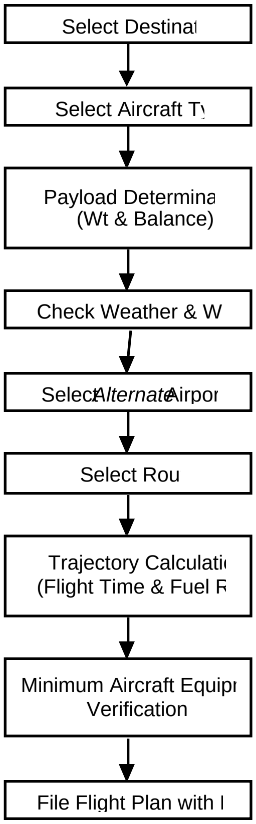
With regards to actual routing, Honeywell Flight Operations complies with minimal Standard Instrument Departure/Standard Terminal Arrival requirements, but flies a Great-Circle route between the city pair. The Honeywell Primus FMS, equipped on both the GIV and Citation X, has the capacity to store routes, so low-altitude routes between close city pairs (such as Washington D.C. and New York City) are stored in the FMS and used as required.

International

When the flight is to be international, flight planning functions are allocated to Universal Weather Services (800/231-5600). This service provider charges per use and per sheet of information provided.

Universal provides flight planning functions and information, including:

- Weather Briefing Services
- Airport Slot Times
- Arrangements for Fuel
- Airport & Landing Fees (which can be as high as $5,000)
- Identifies Country Landing Requirements (Points of Entry Identified, Landing Documentation, Visas, etc.)
- Arrangements for Hotels/Transportation
- Arrangements for Hanger Space or Aircraft Protection
- Coordination with Local Airport Handlers (Landing/Takeoff Times reported back to Universal)



Third-party suppliers (e.g., Universal) will develop the flight plan, determine paperwork requirements such as

- *Port of Entry*
- *Overflight fees*
- *Overflight registration*
  - *Visa requirements*
- *etc*

In addition these suppliers will provide Wx briefing, determine optimal route, file alternate, develop a flight plan, file the flight plan, and deliver the paperwork to the pilot(s) at any specified location.

These suppliers will work with the local FBO to support ground operations including fueling, storing the aircraft, and, if needed, security arrangements for the aircraft and passengers.

Figure 4. Tasks involved with flight planning (Corporate Aviation)

Two hours before the scheduled departure, Universal will dispatch (to your hotel) all the required paperwork for the flight, including the weather briefing and the filed flight plan (Figure 4).

Most of the international flights are flown above the oceanic track system (above FL410).

Airline

Three airlines were sampled as part of this program. Two airlines are major carriers (in the top four of passengers carried within the U.S.) and one airline is a small, regional carrier that started as a charter operation.

These airlines provide a representative cross sampling of routes, equipment type, and sophistication in their respective Airline Operations Centers.

World View (Goals/Constraints) It was remarkable to witness the dichotomous response to the question of "What type of flight plan do you fly?" Two carriers were most concerned with "Least Fuel," whereas the other carrier was concerned with "Least Time." (Interesting to note that none of the carriers were developing "Least Cost" flight plans.)

Constraints: One of the major carriers operates equipment on long routes which results in "tank" limited situations. This means that fuel is the primary consideration in the flight being non-stop. This occurs internationally on their long-haul flights, (MSP-Hong Kong, Detroit or JFK or Boston to Narita), where the available capacity of the aircraft is not used in order that the range/Gross Weight tradeoff will allow them to fly non-stop to the destination (it is a company policy for one of the major carriers to try to avoid a stop along the way for additional fuel). Even in the domestic U.S. their DC-9 fleet flies long routes which are at the upper end of their range, resulting in "tank" limited concerns with cargo and passengers.

Another constraint for one of the major carriers in international routing is the issue of overflight fees. Russia, and to some extent Canada, as the result of the privatization of Canadian ATC, charge high overflight fees making circuitous routing preferable from an economic standpoint.

Another constraint in the flight planning process for one of the major carriers is turbulence. It prides itself on identifying and subsequently avoiding turbulent air masses in order to provide a smoother ride to their passengers. To that end, its' Meteorology department develops Turbulence Plot Areas (TPAs) and provide them to the flight crews so that if replanning does become an issue, they have information at hand regarding areas and altitudes to avoid in the replanning process.

In the SOC there is a software package that updates the Turbulence Plot Area based upon new meteorological information obtained from private companies or NWS. This software is designed to examine all the currently active flight plans (airborne aircraft) to determine if a Turbulence Plot Alert should be issued.

Another set of constraints came from the other major carrier in the form of a list:

1. Weather / Turbulence
2. Acceptable routing - ATC authorized
3. Acceptable altitude - ATC authorized
4. Navaid outages
5. Required Nav systems
6. Terrain clearance (drift down requirements)
7. Payload capability

Information Used in Flight Planning

One of the major carriers uses all the information on the following list, but was keen to point out that Weight and Balance come from personnel located in Memphis, as opposed to Load Planners that are a part of the Minneapolis-based SOC.

Meteorology	Forecast and current information on en route winds, temperature, turbulence, icing, and other phenomena
Maintenance	Aircraft MEL and CDL status; aircraft routing; planned and required maintenance
Crew Schedule	Crew training and qualification records; duty time and flight time limitations
Load Planning	Departure and arrival runway, flap selections and allowable weight calculations; takeoff power settings; aircraft loading schedules, and constraints
Aircraft Data	Tail number-unique fuel flow and fuel burn characteristics; performance capabilities and limitations
Station Data	Availability of runways, gates, and ground equipment; fuel cost and availability; fuel tankering analysis
Nav Data	Database containing all FAA preferred and company routes, published waypoints, airways, SIDs, and STARs
Marketing	On-time performance history and sensitivity per city-pair, i.e., to/from hub; connecting passenger matrix and flight availability
Flight Schedule	Relational database linking all flights in the operating schedule; aircraft routing, fuel tankering and delay analyses

Tasks Involved in Flight Planning:

There were two classes of tasks, important and support, identified for developing a flight plan at one of the major carriers, see Figure 5:

Important (“attended to first”)

- Payload determination and coordination with load planners for weight and balance calculation
- Alternate airport determination
- Route selection
- Re-dispatch point determination for long range flights
- Aircraft minimum equipment verification

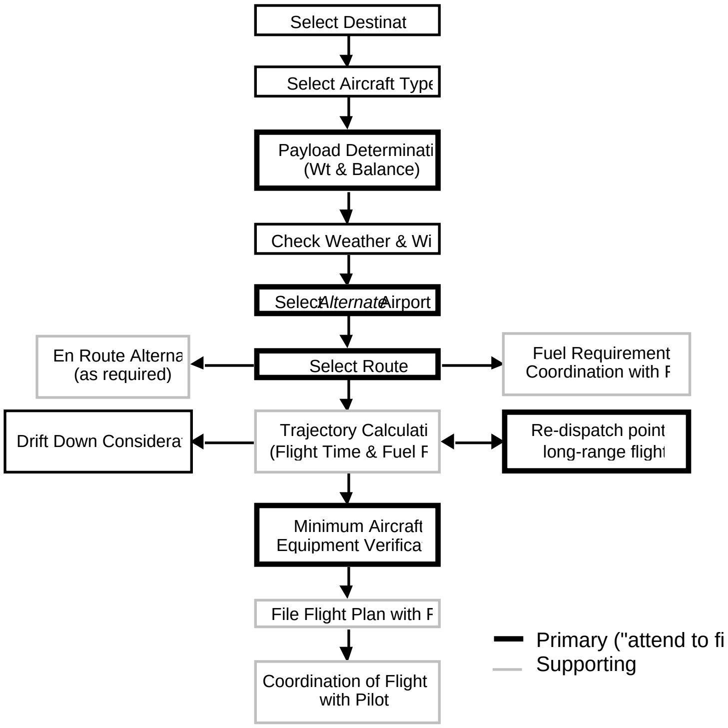


Figure 5. Tasks involved with flight planning (Airline)

Supporting (“necessary to complete, not the first priority”)

- Speed and altitude profile calculation, and estimation of flight time
- En route alternate selection (as required)
- Fuel requirement calculation and coordination with fuel loaders
- Coordination of the flight plan with the pilot
- Flight plan filing with the FAA

Historical information is also taken into account when assigning aircraft type and estimating load capacity requirements. One of the major carriers takes into account the last 7 calendar days and the last 7 same-day-of-the-week (i.e., the last 7 Tuesdays) when estimating load/passenger capacity requirements.

The other major carrier listed the key activities in flight planning, although not in any particular order as:

1. Route construction
2. Route initialization
3. Access Upper Air weather
4. Payload input
5. Release calculation
6. ATC Filing

The carrier listed the following as rules that are FARs attended to when flight planning:

1. Fuel requirements - Destination weather, alternate criteria, etc.
2. Terrain clearance / Depressurization
3. Route construction - Airways vs. Direct segments vs. LAT / LONG.
4. FAA Pref Routes / NRP Route requirements
5. Communication / Navigation system requirements
6. MEL requirements
7. ATC Filing - Formats and Times
8. ETOPS - Routes and en route alternates
9. Restricted airspace areas, Special use areas
10. Aircraft Performance requirements

That same carrier also listed the following as situations that change the importance of flight planning goals:

1. Airline dependability performance (scheduled block times)
2. Payload capability
3. Airport status / curfews
4. Passenger connections
5. Aircraft status (MEL)
6. Crew legality

Package Carrier

One major package carrier was sampled as part of this program. The carrier has requested to remain anonymous.

World View (Goals/Constraints) Safety, carrying all the volume as efficiently as possible. The primary business objective for the package carrier is to fly as much cargo as *fast* as possible to the next station in order to satisfy delivery schedules, whether connecting cargo, sorting cargo at the main distribution center, or flying the cargo to regional distribution centers for delivery. Extra volume may cause the plan to be filed for a slow airspeed because the extra weight reduces the amount of fuel that can be carried. Also, some airports are landing weight-restricted. Their schedule is driven by the sorting requirements; inbound flights from the west coast are most critical. They protect some flights more than others because of the priority of the volume, where it's going, or how much time they have.

Constraints: Many of the package carrier constraints are shared with other operator classes (e.g., Airport conditions, clutter on the runway, snow, ice, en route weather, alternates weather, drift down requirements, type of aircraft, airport altitude, temperature, pressure, MELs and CDLs, crew time, crew qualifications, traffic densities). Unique constraints include problems with the sort: For example, having a conveyor belt break, can cause problems across the board. Sometimes, the biggest problems can happen during good weather conditions because everyone departs on time and arrives at once and everyone has minimum fuel on board because no one expects to hold; if a problem develops, such as a flat tire on the runway, people don't have enough fuel to hold and everyone has to divert. One such incident can counteract many flights' worth of fuel saving practices, so this company carries a little extra fuel for unexpected events. One decision dispatchers have to make is, when an aircraft is holding and the holding time is unknown, should they divert and put on more fuel so they can get in when conditions clear at the expense of losing their place in line if conditions clear sooner. Also, ground support at an airport can affect diversion decisions: do they have the necessary loading equipment, fueling, electrical, air, etc., and do they meet the aircraft's airport performance and Navaid requirements?

Information Used in Flight Planning

The information used by this cargo carrier in developing flight plans is virtually indistinguishable from an airline. This carrier operates its flights under FAR Part 121, so there is a dispatcher providing all the same functions as are performed at an airline, including flight planning, collating a weather briefing, and then providing a flight-following function during the flight itself.

Tasks Involved in Flight Planning

Flight planning tasks for the package carrier are shown in Figure 6. After determining the destination, flight planning begins by assessing aircraft status to make sure there are no MEL or CDL items on it that would create a restriction. CDL items involve physical aspects of the aircraft, such as an airplane may be missing a small slat, the landing lights won't retract, lens caps may be missing, etc. They look at destination and departure weather, and aircraft type, to make sure they can do the mission with the required payload and fuel. Also, is the airplane certified for the airport conditions (CAT II or III)? Same with the crew. Then they generate a flight plan with projected payloads, and they might adjust that number based on history. Also, they see whether the flight will run on schedule or not because they need the airplane. They'll also do a fuel analysis to see whether it makes sense to tanker fuel. "I look at all my airplanes at one time for all the MEL/CDL items, then when I'm looking at the weather, you have a geographical region, so you have a feel for the en route weather, now you're looking for individual destinations and their alternates, then you just put it in the computer and let it cook and see how it looks, and make adjustments as necessary."

On the night side, the dispatchers come in around 10:45 and do the flight plans to get them over to fueling by midnight. The planes aren't all there yet, but the fuelers can start their process of figuring how much fuel goes on the trucks. But on some nights there are a lot of tail swaps due to mechanicals or additional volume or airport conditions, so they want to get the work done early to stay ahead of the curve. "We do things sometimes earlier than we need to do because we're not sure if the computers are going to stay up."

There may be minor adjustments to the schedule from month to month, primarily for taxi times due to construction at airports, or equipment changes. November and December see major changes due to increased volume; "we put some extra hub facilities in for the peak season."

A typical dispatcher is responsible for about forty flights in a shift. The dispatcher may talk to Flow Control to "get a feel for an airport, what's their arrival rate, how are we routing, are we going over the standard inbound fixes." The dispatcher may call the tower to get runway visual range since this isn't provided in the new weather release formats and they need it real-time. They may call ATC for special cases, such as an airplane with both transponders inoperative or an unusual MEL item that creates a restriction (such as on speed). The tower may call the dispatcher to find out if they have any special flights planned, such as small jets.

They aren't taking advantage of the NRP yet, and the interviewee thinks they could gain some additional advantages if they were. However, they don't need it at night, when most of their operations occur, so it may be of limited utility to them.

If the dispatcher has filed a flight for a particular route for a reason (such as drift down requirements, wind, etc.), he or she should indicate the reason on the flight plan to prevent the crew from accepting direct from ATC that may not be advantageous.

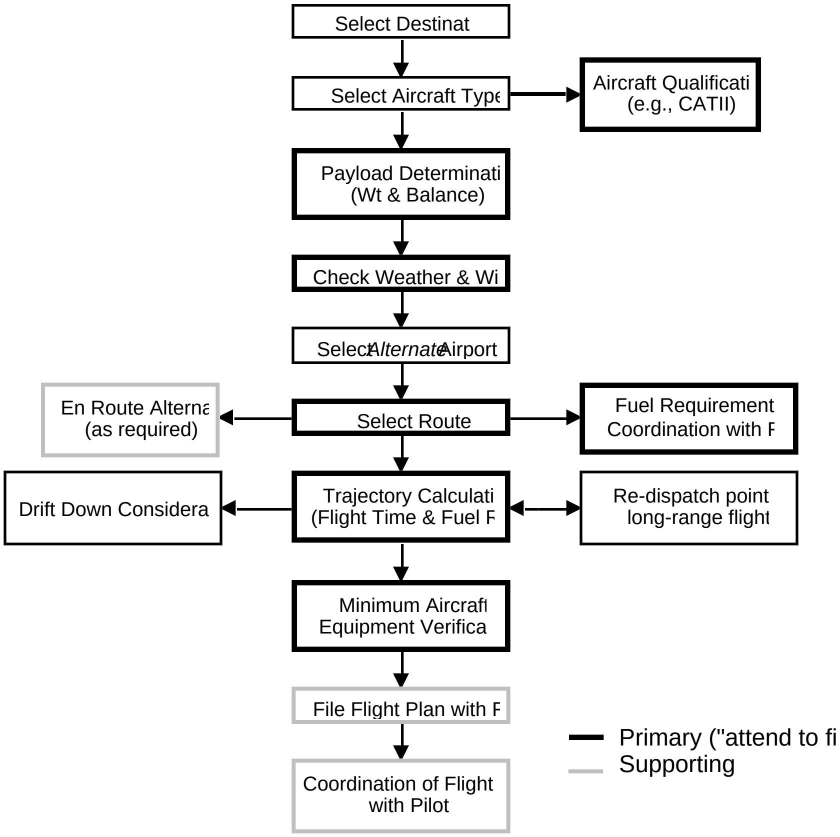


Figure 6. Tasks involved with planning (Package Carrier)

Their airplanes fly as fast as they can most of the time. If they slow down, it's usually because the airplane was brought in to cover for a broken airplane and now there's hope that the broken airplane can be fixed, or it's so far past the sort that a late arrival won't hurt any more.

2.2.2 Flight Replanning

This section is organized differently than the flight planning section. Goals, constraints, information, and information sources, which were main categories discussed for flight planning, are not fundamentally different for flight replanning. What is different are causes for replanning, task allocation, and inefficiencies. Thus this section will be organized according to these categories. A section describing a typical replanning scenario from different operator class and stakeholder perspectives is included to help the reader understand the complexities and multidimensional nature of replanning.

Flight planning and replanning can be decomposed into operational tasks or information processing tasks. In the previous section on flight planning, tasks were described in operational terms. In this section, we describe replanning tasks in information processing terms. This is done for replanning because it allows us to better illustrate differences among operator classes in terms of allocation of replanning tasks to different stakeholders. A simple information processing model of flight guidance from Abbott (1993) will be used to describe replanning unique to each operator class. It will be elaborated on later as well, since replanning information processing tasks are fundamental to our proposed function allocation of flight replanning among different stakeholders and the resulting airborne replanning concept.

2.2.2.1 Operator Class Commonalties

The FAA also has rules regarding the airborne replanning of a flight conducted under Instrument Flight Rules:

> In addition to altitude or flight level, destination and/or route changes, increasing or decreasing the speed of an aircraft constitutes a change in a flight plan. Therefore, at any time the average true airspeed at cruising altitude between reporting points varies or is expected to vary from that given in the flight plan by plus or minus 5 percent, or 10 knots, whichever is greater, ATC should be advised.

Causes for Replanning

It is usually the case that some constraint or factor changes from when the flight plan was originally developed that causes the pilot or flight crew to replan. There are many such changes common to all operator classes:

- late departure
- weather
- traffic
- change in destination or alternate status
- winds
- aircraft (different performance than predicted, or mechanical problem)
- medical problem

Replanning tasks

The actual tasks involved in replanning are a subset of those for planning. Major differences are that (1) real time data (e.g., airplane status, performance, fuel burn, weather, etc.) are available rather than predictions and models of those data used in flight planning and (2) from the flight crew's perspective, there are fewer data and resources to call upon, and pilot workload becomes an issue because replanning must compete with other flight deck tasks and activities that need to be performed.

Inefficiencies

Overall inefficiencies will be summarized at the end of this section, as a lead-in to solutions.

2.2.2.2 Replanning Unique to each Operator Class

General Aviation

Causes for Replanning

Reasons for replanning are not that much different than for other airspace user classes, except pax discomfort (comparable to medical emergency, but much less severe/more common) and "a change of mind" are added.

Replanning / Information Processing Loop

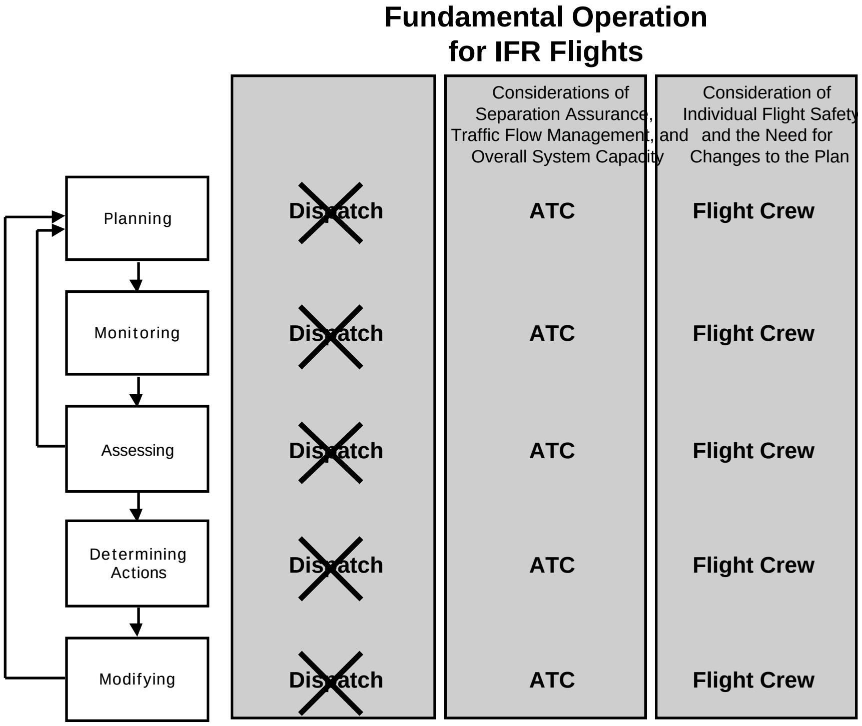


Figure 7. Information processing loop involved with replanning (General Aviation)

Replanning in a single-pilot IFR environment is the most basic form of replanning in Instrument Flight Conditions, and for the pilot is very tough in terms of workload. It is easiest to let ATC specify the route modification (ATC will already have a proposal in mind if they are requesting the route modification). Regardless of whether or not the flight plan modification has been supplied by ATC, the pilot is still responsible for determining if the proposed reroute is safe as well as performing the time and fuel burn calculations, see Figure 7 above.

Inefficiencies

The biggest inefficiency facing low-end general aviation pilots is the inability to obtain real-time information for weather that will be encountered along the route of flight. If the pilot cannot see it, then it doesn't exist. ATC, of course, will advise of severe weather or icing conditions along the route of flight, but not necessarily in a timely manner that will allow the pilot to make decisions when it is optimal or most convenient.

Corporate

Causes for Replanning

The primary cause for replanning in the corporate aviation environment is weather at the destination, but unlike airlines, the imperative goal is providing *timely* transportation for the passengers to their intended destination. In this regard, the flight crew will frequently develop a candidate list of alternatives and ask the passengers which alternative they would prefer to execute. Examples of these alternatives would include:

1. immediately landing at the nearest available airport and obtaining ground transportation
2. holding to see if the weather 'clears up'
3. land and refuel at a nearby airport and wait for the weather to 'clear up'
4. *etc.*

Replanning / Information Processing Loop

Similar to General Aviation, the Corporate pilot or flight crew is largely unsupported in their rerouting decisions, see Figure 8.

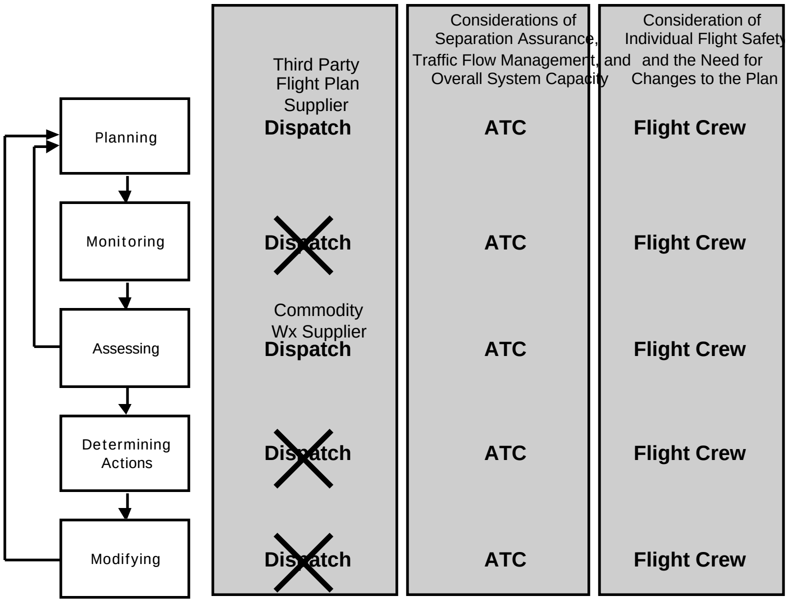


Figure 8. Information processing loop associated with replanning (Corporate Aviation)

Greatest Inefficiencies

Similar to General Aviation, the inability to obtain real-time weather information is the key obstacle to efficient operations.

Airlines

Causes for Replanning

One of the major carriers provided the following list as possible causes for in-flight replanning:

- Destination change
- Alternate change
- Reroute (For weather, ATC, or other reasons)
- Significant change from planned en route winds
- New re-release analysis
- Use to provide a better (more accurate) assessment of the flight's performance for flight following
- Search for optimum route / altitude
- On-time performance
- Airport curfew
- Crew legality

Replanning/Information Processing Loop

As a follow up to the previous list, the major airline was asked if there was a sequence, or order to the tasks involved with flight planning within the AOC. The answer follows:

- New route construction
- New route initialization
- Access latest upper air weather data
- Input other desired variables (alternate, fuel load, aircraft weight, current position, etc.) into replanning system
- File with ATC as necessary to forward to international ATC centers

Sometimes the ARTCCs will offer more direct routing to one of the major carrier's flights. The SOC believes that their flight crews have been sufficiently briefed that they no longer categorically accept what is offered, but in fact do coordinate with the SOC to determine if there is an operational gain to be made by accepting the offered route.

One of the major carrier's SOC representatives expressed concern regarding the idea of each aircraft being solely responsible for replanning. The obvious issue is that the flight crew is not aware of "big picture" concerns for the airline; if they accept an opportunity that would take more time than is required for a nominal flight between that city-pair, they could exceed allowable crew duty times. This would have a profound impact on the system, i.e., no crew available to take over the flight at the destination because the in-bound crew cannot fly for 8 hours (the prescribed duty-rest cycle).

When asked about the idea of locating a high-resolution color printer on the flight decks of the fleet, the SOC rep thought that would be enormously beneficial in promoting a shared "world-view" of the routing situation, thereby allowing a better dialog between the flight crew and the dispatcher. Figure 9 shows the participation of the major stakeholders in the replanning information processing tasks for scheduled airlines.

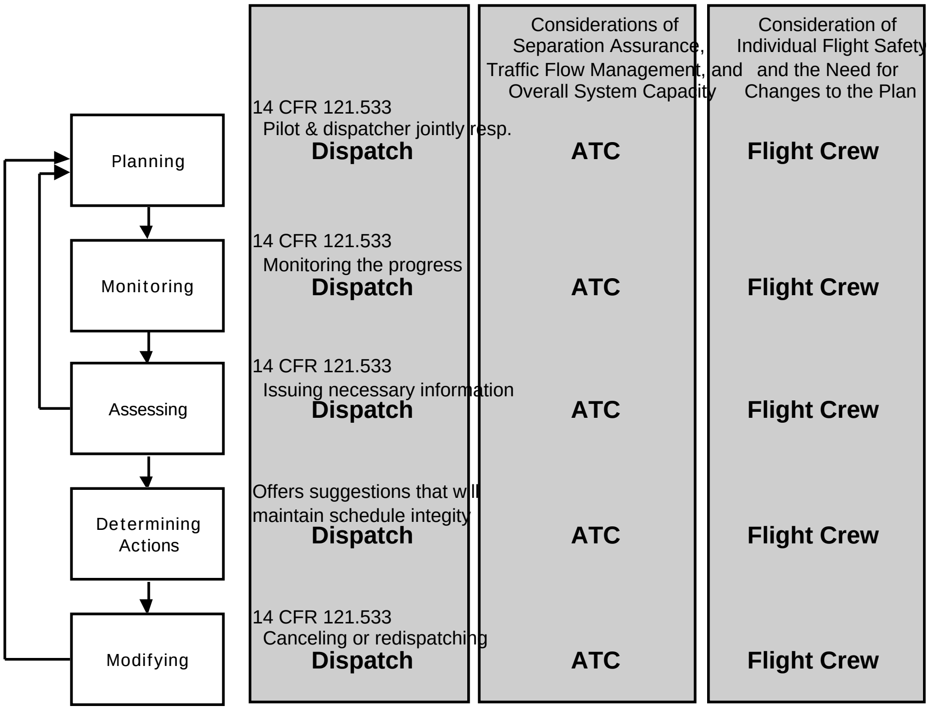


Figure 9. Information processing loop associated with replanning (Airline)

Greatest Existing Inefficiencies

(1) Working with Central Flow Control on rerouting (in reaction to non-normal operations, such as severe weather) is not a well-structured effort. No existing protocol is in place that guides those interactions. Sometimes Central Flow Control will "work with you"; other times they are unapproachable.

(2) Communications during non-normal operations could be improved. Held up as a show case example was a North-East Regional Hotline that is put in place between various ATC facilities (Control Towers, TRACONs, and ARTCCs) when severe weather (i.e., blizzards) disrupts operations. The purpose of the hotline is to facilitate communications, with regards to coordinating traffic flows, between these facilities. The airlines benefit by "eavesdropping" on the conversation because it allows them to anticipate actions that will be taken by ATC personnel, such as:
   - closing runways
   - redirecting traffic flows (in-bound and out-bound from airports)
   - preferred routing that is temporarily put into place

(3) Realistic Holding Times (e.g., "Expect Further Clearance"). With the "tank-limited" flights that one of the major carriers operates, such as DC-9s at the limit of their range, it is important that they receive realistic estimates of airborne delays in order to avoid unnecessary diversions.

In our exposure to the small, niche airline, there were a number of inefficiencies that were unique to the size, scale, and technological sophistication of their operation. For example, the flight crew is completely reliant on voice communication with dispatch and ATC for any information (weather, congested airspace, route optimization calculations, etc.) that would help them replan. Right now, if they had opportunity to choose a different route after becoming airborne, they would not have the tools or information needed to make a choice.

ACARS is a pipe dream for this small carrier. Equipping with any expensive item not mandated is out of the question unless the return-on-investment or increased operating capability is big, quick and obvious.

General view is that kinds of time/fuel efficiency improvements that Free Flight promises are:

(1) unlikely to be realized;
(2) not applicable to their operations (east coast, max FL350);
(3) too costly for them to afford in terms of initial investment in equipment;
(4) too scary in terms of pilot responsibility for self separation; and
(5) of a magnitude that is considered within the “noise” of their operation.

Free Flight advantage for this small airline would be:

(1) reduced delays, both departing and en route; and
(2) better information, particularly to avoid diversions and replans to stop at unscheduled airports because of insufficient fuel due to bad wind data, excessive vectoring, etc.

Unnecessary diversions and delays are much bigger dollar items than the fuel savings of optimal routes.

Package Carriers

Causes for Replanning

The most common causes for replanning are winds that are worse than forecast, or the crew may call and say they’re burning fuel faster than predicted in the flight plan, possibly due to a mechanical problem. The airplane may develop a problem that requires them to slow down, preventing the fuel burn they expected and putting the airplane over landing weight, so plans have to be made to burn the extra fuel off. ATC may vector them significantly off the route. Or weather at the alternate may go down. If no other nearby alternates are available, it may be safest to divert en route rather than continue to the destination even though it may still be open. Or they may decide to add a leg en route, or overfly a planned stop. If an airplane breaks, an airplane with a light load may stop there. The most prominent reason is weather at the destination or alternate. More major replanning is done for international flights where they don’t get the track or altitude they expected. If a diversion is required, the dispatcher will send the message over ACARS. If the crew is late in the approach, this avoids distracting them at a crucial time. Such a diversion request may be made if, for example, the airplane on approach is going there to cover for a broken airplane and the broken airplane’s been fixed, or another airplane is broken worse in a different location; in either case, the airplane on approach is no longer needed at that location.

Replanning/ Information Processing Loop

The allocation of replanning information processing tasks for the package carrier is similar to that illustrated above for scheduled airlines (Figure 9).

Greatest Existing Inefficiencies

The inefficiencies experienced by the cargo carrier are not generally different from those of the airline, although the low traffic volumes at night mean that these inefficiencies are not confronted as often by the cargo carrier. The primary complaint about ATC operations is that they may be overly conservative in running capacity reduction programs and setting miles-in-trail requirements higher than might be needed. The need to continually call the tower to get RVR at the landing airports was cited frequently as a workload issue. The primary unique characteristic of the cargo carrier's operation is the use of the sweep airplane, which must remain as flexible as possible; more than perhaps any other airline operation, the sweep airplane is characterized by constant replanning. Such frequent replanning can place heavy demands on ATC and cause them to become resistant to further changes. This suggests that the major change ATC could make to accommodate the needs of the cargo carrier is to better support flight operations that require constant replanning and refiling.

2.2.2.3 Replanning Scenarios

The purpose of this section is to provide real-world scenarios as examples of the sorts of procedures and inefficiencies experienced by both Air Traffic Service providers and different classes of Air Space Users. The treatment of real-world inefficiencies begins with two different Air Traffic Service provider facilities (ATCSCC-Air Traffic Control System Command Center and ARTCC-Air Route Traffic Control Center) followed by the four classes of Air Space User:

- General Aviation
- Corporate Aviation
- Airline
- Package Carrier

The remainder of this section is organized as follows:

- Air Traffic Control System Command Center - Scenario of severe weather affecting ZFW
- Air Route Traffic Control Center - Scenario of severe weather affecting ZFW
- General Aviation - Scenario of severe weather affecting flight from Roswell, NM to Decatur, TX
- Corporate Aviation - Scenario of severe weather affecting flight from Ensenada, Mexico to Love Field, TX
- Airline - Scenario of severe weather affecting flight from San Diego, CA to DFW and specific idiosyncrasies of airline airborne replanning for aircraft equipped and not equipped with ACARS
- Package Carrier - Scenario of severe weather affecting flight from San Diego, CA to DFW

Context for Scenarios

All of the flights originate in the western portion of North America with the intention of landing in the Dallas-Ft. Worth area. A bad weather situation develops west of DFW, affecting arrivals from the west. At the time of flight plan filing, there is a forecast for some convective weather potential in an eastbound cold front forming a 200-mile North-South line centered over Lubbock (ZFW airspace), blocking the straight line route to DFW and closing an arrival gate. Pre-departure weather information looks good. Following the aircraft's departure the weather unexpectedly forces replanning. The timeline is as follows:
1500Z: Ceiling 10,000 at Abilene (120 West of DFW).
1800Z: Ceiling 2500 at Abilene.
1830Z: Several cells have developed in a line 75 miles east of DFW, extending northward.
1920Z: ZFW closes the BOWIE (NW) arrival gate, routing traffic to the remaining gates.

Scenario: Air Traffic Control System Command Center, Herndon, VA

The ATC System Command Center's (SCC) mandate is to coordinate the activities of ATC facility traffic managers (en route centers, mostly) and airline traffic managers to determine and negotiate solutions to flow problems. With the bird's-eye view of US traffic they are in a unique position to anticipate and work out long-range problems which may not be visible in an en route center's smaller domain. They provide solutions to flow problems by either holding aircraft on the ground or slowing down aircraft in the air.

The SCC is organized similarly to an airline's dispatch and flight following operation -- a large ballroom with traffic management positions arranged on the floor according to geographic area. Overhead are 8 big-screen computer displays, configurable for many screens (whatever is showing in the controlling terminal), but typically showing weather maps for areas of interest, several Aircraft Situation Display (ASD) areas, traffic flow graphs, and a list of control programs in progress. You can get a good overview of what's going on from anywhere on the floor.

However, in addition to these initiatives, their role in providing the communication path can't be underestimated. Problems are solved simply by getting ATC facility representatives and airline traffic managers talking together. On this particular day the cold front over Texas was being carefully watched to anticipate possible problems.

The SCC operates 24 hours a day. Each day starts with a 5 am national telecon brief of relevant weather. At 8:15 and 12:30 another national telecon brief is held where weather, airport status, and other noteworthy information is communicated. Telecon participants generally include representatives from FAA regional offices, all 21 en route centers (ARTCCs), and AOCs. The mid-day brief may include as many as 50 participants.

What information is available prior to a situation developing?

> **1000Z**: Prior to going home, the night shift SCC supervisor initiates the 5 AM (local time) national weather briefing telecon. The summary from the SCC Weather Desk indicates a moderate cold front currently over western Texas, with possible thunderstorms over the DFW area at about 2000Z. The text of the weather brief is included in the briefing package for the National Operations Manager (NOM) at the Severe Weather Desk, and at the stations of the East and West NOMs.
>
> **1315Z**: The SCC initiates the daily 8:15 national telecon with the SCC East and West NOMs, FAA Regional Offices, ARTCC Traffic Management Supervisors (TMS), and participating airline traffic managers. The telecon is initiated from the Severe Weather Desk (the NOM's station). Participants call in at the designated time and are connected via the automated teleconferencing system. Normally the west coast does not join at this hour.
>
> No flow management initiatives are currently in progress. The weather system is now in west-central Texas with no thunderstorm activity indicated. Airport arrival rates and other significant traffic-related airport data are summarized by the East and West NOMs for each major airport in their respective areas.

How do the stakeholders learn of the developing situation?

> **1530Z**: Deteriorating weather in central Texas prompts the SCC to initiate a telecon with Traffic Management Supervisors (TMS) at Albuquerque, Fort Worth, Kansas City, Memphis, and Houston ARTCCs, as well as with the DFW TRACON TMS and the traffic manager at American Airlines. The purpose is to discuss a Severe Weather Avoidance Plan (SWAP) to manage a possible disruption at DFW due to anticipated

weather. The weather system will likely coincide with the “noon balloon” arrival push at DFW. The following flow management options exist to handle the imbalance between the arrival and arrival rates at DFW:

The more complete list of flow initiatives is as follows (from least to most severe). These initiatives are used to control arrivals at a single airport.

1. **Expanded Miles-In-Trail (MIT) / Minutes-In-Trail (MINIT)**. This flow initiative is preferred by all stakeholders. When arrival or en route congestion occurs, and adequate airspace allows, orderly in-flight delays may be used to control flow. The SCC specialists have substantial resources to predict weather, arrival rates, and traffic direction. This information is used to help determine a miles or minutes in trail solution for hand-offs from one ARTCC to another.

The remaining initiatives involve holding aircraft still on the ground, planning to arrive at a problem airport.

2. **Internal Ground Delay Program (GDP)**. The GDP assigns delayed departure times (Expect Departure Clearance Time - EDCT) to flights planning to arrive at an overloaded airport. The GDP is normally used when reduced arrival rates are expected to last for several hours. Arrival delays are assigned according to an algorithm which tries to preserve the original arrival order. An “internal” GDP is one where only flights originating in the same center are delayed - penalizes short flights in favor of long flights. Presumably the delay is not expected to be long term, and that by the time yet-to-depart longer flights arrive, the problem will have passed. Delays are calculated for each individual flight in such a way as to evenly regulate the arrival rate without additional imposing flow control measures. The SCC specialist uses software tools which operate on the Enhanced Traffic Management System (ETMS) database of flight information to assign EDCTs to affected flights. Airlines issued an EDCT are expected to depart at the assigned time with a tolerance of -5/+15 minutes. The scope of ground stops and GDPs may also be varied. “Internal” programs involve delay actions implemented only within the ARTCC containing the problem airport. Internal programs are used when the delays are of short duration. The expectation is that that by the time the yet-to-depart longer flights arrive, the problem will have passed.

3. **Internal ground stop**. A ground stop holds aircraft on the ground for a specified amount of time, usually one hour. This initiative is taken when an airport is temporarily overloaded due to arrival bunching or a passing weather system, for example. “Internal” means only arrival flights originating within the same center are affected.

4. **First Tier GDP**. The “first tier” represents a wider affected area than the “internal”. In general, each center’s first tier includes all departure points in the abutting centers. The intent is to include longer flights in the GDP when the problem is expected to last longer. All arrival flights originating in first tier are affected.
5. **First Tier ground stop**.
6. **National GDP**. Includes all 21 centers.
7. **National ground stop**. Most restrictive initiative for an airport.

How does replanning occur?

1530Z: The graphic arrival picture given by the Aircraft Situation Display (ASD) shows the majority of DFW traffic arriving from the east - from Houston and Memphis ARTCCs. On a normal day the Fort Worth ARTCC is able to delay arrivals within its own airspace to meet the DFW arrival rate. However, if weather slows arrivals, and especially if one out of four corner arrival gates closes, additional delays will need to be absorbed by surrounding ARTCCs. Recognizing this, the SCC NOM proposes that if needed, a miles-in-trail program will be instituted for hand-offs to Fort Worth ARTCC from the surrounding ARTCCs. This telecon is the opportunity for the affected ATC facilities or airlines to comment on or negotiate the solution. Sometimes there may be other factors which need to be considered, but today there is no dissent.

1630Z: The daily afternoon telecon is held with the SCC, FAA Regional offices, ARTCC Traffic Management Supervisors (TMS), and participating airline traffic managers. This time the west coast participates. The agenda is the same as the morning telecon. The group is briefed on the Texas weather situation.

1830Z: The DFW stakeholders are again called to a telecon following a request by Fort Worth ARTCC. The DFW hourly arrival rate has been lowered to 96 from 102. It is decided that the SWAP discussed earlier is to be implemented immediately. Based on the traffic flow picture, miles-in-trail is instituted until 2000Z for all DFW arrivals handed off to Fort Worth ARTCC as follows: Albuquerque: 20 miles, Kansas City - 10 miles, Houston - 15 miles, Memphis - 10 miles.

1920Z: The TMS at Fort Worth ARTCC advises the SCC that the northwest DFW arrival gate at Bowie is being closed due to weather. He coordinates with sector controllers to identify the last aircraft to go through, and begins a plan to re-route arrivals to the remaining corners. The SCC NOM and specialists monitor the situation. Since all of the DFW arrival push traffic is already airborne and close to DFW no additional inter-center flow initiatives are taken except to extend the current SWAP to 2100Z. The problem is now primarily confined to Fort Worth ARTCC and the DFW TRACON and Tower (DFW operates 3 towers during daylight hours).

Conclusion and Commentary

The SCC is often required to make decisions which are not popular with it's users (airlines and other ATC facilities). The airlines prefer of course to keep to their schedules as much as possible, while controllers find their job easier when delay programs are implemented. Cultural differences exist between airline operators -- some prefer to fly and hold, while others are more open to ground delays. The current low price of fuel is believed to make ground delays less popular. Controllers flow program requests are often denied because the SCC data does not support a delay solution.

In general however, many of the problems handled by the SCC would not be visible at a lower level, nor could efficient solutions be devised.

Scenario: Fort Worth ARTCC

The Fort Worth ARTCC controls high altitude traffic over most of northern Texas. Within this airspace are numerous TRACONs, but the DFW TRACON is the dominant facility. TRACON airspace shape is typically described as resembling an upside-down wedding cake, with the airspace in the center extending down to the ground, but starting at higher levels moving out from the center. The DFW TRACON fits this general description, with the widest (highest) layer forming roughly a circle with a diameter of about 54 nm , geographically centered on DFW airport and extending up to 10,000 feet. While DFW is the primary airport served by the TRACON, Dallas Love Field, and several smaller airports are also within it’s airspace. Generally, arrival and departure routes are strictly defined to manage the flow of traffic.

Airways and ATC procedures direct DFW arrivals to four ‘corner post’ arrival gates arranged in a square about 25 nm outside of TRACON airspace, prior to entering the TRACON. Fort Worth ARTCC controllers issue speed and vector instructions to arrival aircraft to regulate flow through these gates to meet the arrival rate limit set by the TRACON. The TRACON arrival rate limit is normally a function of the airport limit set by DFW Tower, but sometimes the airport arrival rate is not the limiting factor (weather in the TRACON airspace, for example). On a VFR day with all runways available, DFW can land about 102 airplanes per hour. On most days, a single fix at each arrival gate is used to channel inbound traffic. However, each corner is actually configurable to support two arrival streams if necessary (two fixes) when allowed by the TRACON. In practice, only one corner is used in this configuration at any given time.

A typical jet arriving to DFW would be controlled as follows:

1. an abutting ARTCC would hand off the aircraft to Fort Worth ARTCC at cruise altitude and airspeed.
2. Fort Worth ARTCC would begin to sequence the arrival with others to the filed arrival gate, using speed control and vectors to provide spacing as needed to support the TRACON arrival rate.
3. At some point the controller would issue a descent, which may or may not be negotiable by the pilot.
4. Following hand-offs between at least 2 Fort Worth ARTCC sectors, the aircraft would be handed off to the DFW TRACON, where a combination of vectors, speed constraints, and altitude constraints would be issued to direct the aircraft to the final approach course.
5. Once established on final the aircraft would be handed off to a DFW Tower.

On a normal day, aircraft delays to meet the arrival rates are absorbed within the Fort Worth ARTCC and DFW TRACON. However, when delays must extend beyond Fort Worth ARTCC, procedures require that the System Command Center be notified to assist in developing an inter-ARTCC flow management solution.

What information is available prior to a situation developing?

1630Z: The relevant sector controllers are well aware of the impending weather disruption. Not only can they see the weather drawn on their radar scopes, but the TMC has briefed controllers. The TMC works in a separate area of the control floor. When required, the TMC’s job is normally done standing, since it is required to move around viewing and interacting with several display stations - weather, CTAS, ASD, radar, etc. Sector controllers and supervisors are kept in contact via a hand-held portable radio (walkie-talkie).

How do the stakeholders learn of the developing situation and how does replanning occur?

1830Z: The TMC participates in the telecon with the SCC to plan a SWAP. Following the telecon, sectors controlling arrivals are briefed. Due to light rain, DFW Tower has lowered the airport arrival rate to 96 to allow more time on the runway for arriving aircraft. This causes a ripple affect on delays extending outward from DFW airport, but Fort Worth Center is still able to absorb delays to meet the lower rate without passing inbound restrictions to other ARTCCs.

1920Z: The controller in the sector containing the Bowie arrival gate, sees abundant precipitation on the scope and has increasingly less space to safely vector aircraft around a developing cell. He notifies the TMC that he is closing Bowie. Having the ASD view of inbound traffic, and arrival rate predictions from the CTAS histogram, the TMC immediately notifies the SCC that the planned SWAP is now required. The TMC devises a plan to distribute the existing Bowie inbound traffic among the remaining arrival gates. On coordinating with the TRACON, the TMC also decides to open up the southwest gate (Glen Rose) in a double configuration. At the sector controlling Bowie, the D-side controller (data entry and management), under the direction of the TMC, begins to modify flight plans to re-route Bowie inbound traffic. Flights already in Fort Worth ARTCC control are handled with vectors and sector to sector communication.

1940Z: With the Bowie closure under control, the TMC begins to plan for the re-opening of Bowie. Knowing that the weather is moving eastbound, a contingency plan is begun to handle a possible closure of Bonham, the northeast arrival gate.

Conclusion and Commentary

- TRACON & Tower & Center rivalry - don’t see each other’s problems
- Procedures & routes not variable - point about corner closing doesn’t permit vectors around due to departure routes
- Excessive vectors

Scenario: General Aviation - Piper Cherokee 180.
Roswell, NM -to- Decatur, TX . Operated VFR under FAR Part 91.

What information is available prior to departure? FAR 91.103 requires that the pilot-in-command be adequately briefed on all information concerning a planned flight, including weather reports and forecasts.

- Commercial TV and Radio weather reports, internet. Multiple public sources show a weak Eastward moving cold front over central Texas with possible precipitation developing. No severe weather is predicted. These sources are not aviation-oriented and don't provide specific information such as ceiling and visibility, but are likely to contribute to the non-professional pilot's go/no-go decision and route planning.
- FSS pre flight weather briefing. Includes NOTAMS, SIGMETS, etc.
- TIBS - Telephone Information Briefing Service. Recorded telephone data. Menu selection allows weather briefing and forecast for general routes of flight from the local major metropolitan area to different compass directions. NOTAMS and SIGMETS are not included.
- DUATS [provide graphics] - Direct User Access System. Available via modem to a home computer. Use is free but is restricted to current holders of an Airman Medical Certificate. Registration is required, to control use and to record accesses for possible accident or lost aircraft investigation.
- ASOS - Automated Surface Observation System. Available via voice telephone or VHF. Computer-generated voice report on periodic automatically gathered meteorological data from the ASOS site. Includes ceiling, visibility, precipitation, barometric setting, temp, wind, rainfall accumulation. Available at Roswell, NM

General Aviation Scenario

1400Z: The pilot-in-command (PIC) calls the ELP FSS via the national 800 number for pilot briefings (1-800-WX-BRIEF, or 1-800-992-7433) At departure time there are no relevant AIRMETS, SIGMETS, or other weather advisories to indicate that VFR flight from Roswell, NM to Decatur, TX (40 nm NW of DFW) would not be possible today. However, light rain may be expected in East-Central Texas. Icing should not be a problem below 10,000 feet. The PIC records the wind information for planning his flight. A few minutes later the PIC calls back and files his VFR flight plan for a 1500Z departure from ELP to Decatur. Distance is 520 NM. Estimated time en route 5 hr. at 125 kt. Altitude 9500 feet (odd + 500 for eastbound VFR). The aircraft is fueled to the "tabs", giving a range of 6 hr. allowing the legal 30 minute reserve.

This route of flight is such that there are a number of MOAs that will not allow a direct, great-circle route between the departure and destination airports. By flying at 11,500 feet, Joe will fly underneath most of them but still need to cross or avoid several MOAs which extend below 11,500. Most of these MOAs are published as active from sunrise to sunset. However, whether or not they are actually hot can only be learned from Fort Worth Center once airborne. Three choices exist regarding these MOAs: 1) fly through and stay alert, 2) route around, or 3) if Center flight following indicates the areas are cold, fly through safely. Using his portable GPS, the pilot plans alternate routes to avoid active MOAs. Which options he will fly will be determined in the air when center gives him an activity status. Avoiding all MOAs will add about 26 nm to the route.

1500Z: PIC departs Roswell. Following a few traffic advisories from the tower the PIC is approved to proceed on course and change frequencies. The first call is to Albuquerque FSS (via the Roswell RCO) to activate the flight plan at 1500Z. On reaching 11,500 feet, the PIC calls ZAB center for flight following and is immediately handed off to ZFW center, which agrees to provide flight following. Weather is a high thin overcast with 50 miles visibility. . ZFW indicates that the Reese 2 and Reese 4 MOAs are active, so the pilot flies the alternate route, about 10 miles out of his way.

How does the pilot learn of the developing situation? The VFR GA pilot has only his eyes and VHF radio for situation awareness. The PIC is using the following services:

- visual observation
- FSS when able. Remote sites allow voice radio contact with regional FSS's.
- TWEB - NWS continuous broadcasts over LF or VOR voice.
- weather Advisory Broadcasts - broadcast locally by Centers once on all frequencies when severe weather within 150 miles of facility.
- HIWAS - Hazardous in-flight weather Advisor Service. Continuous broadcast of significant weather advisories. Replacing weather Advisory Broadcasts. Instructions for HIWAS (including monitor frequency) are broadcast once on Center and Terminal frequencies. FSS's will also broadcast instructions once.
- AWOS - Automated weather Observing System. Weather at airports, transmitted on local discrete VHF or voice VOR. Range 24 nm, 10,000 feet. 30-20 seconds each minute. Frequencies found in Airport/Facility Directory and approach plates.
- En route Flight Advisory Service (EFAS, or Flight Watch) (for 5,000-17,500) 122.0. Give Center, nearest VOR, get weather information.

Scenario Continued

1800Z: PIC has been using flight following with Fort Worth Center, with no discussion other than hand-offs and hourly off-frequency requests to talk with FSS (via the Lubbock and Breckenridge RCOs) and Flight Watch. Reports continue to indicate that a 9,000 ceiling feet all the way to DFW with visibility 25 miles. Approaching Abilene, PIC notices visibility decreasing to less than 15 miles and observes a line of clouds ahead with a ceiling which appears to be about 8,000 feet. Monitoring the ZFW Flight Following sector frequency, he overhears center discussing vectors for weather. He contacts Ft. Worth FSS, via the Breckenridge RCO, where he learns that the NWS is now forecasting marginal VFR at DFW by 2000Z with possible local thunderstorms, and light rain is reported at several airports north of his route. One PIREP about 50 miles east is reporting a 6,500 foot ceiling. The PIC reports his own observation in a PIREP.

How does replanning occur?

- maps on lap
- Airport/Facility Directory on lap
- flight following advisories

Scenario Continued

1810Z: Based on observation and the information from FSS and Flight Watch, the PIC checks the sectional and decides descend to 5,500 feet and to deviate to the south, hoping to skirt around the weather. After about 45 minutes, he decides continuing to fly in an easterly direction is too risky. Using the sectional and the A/FD, he locates an airport near his route (Abilene) with surface observations reporting VMC, and with fuel, car rental, and lodging nearby. After one last call to FSS for the surface observation report, he enters the airport coordinates into his GPS and changes course.
1830Z: The PIC lands at the alternate airport in light rain. Once on the ground, he calls FSS via the 800 number and closes his flight plan. His flying is over for today.

Conclusion and Commentary

Regardless of a lack of sophisticated avionics or AOC-like support, the GA pilot has a tremendous amount of information available before the flight departs. Published aviation periodicals (VFR sectional maps, A/FD's) and full-time ubiquitous radio and telephone access can provide weather during the flight.

Flight Service Stations are the primary source of current data to the GA pilot. The periodic nature of weather data supplied to FSS's can produce latencies which may be significant in the case of fast-developing weather. Weather data is typically provided by a contractor (e.g., Kavouras) in periodic updates, and by periodic surface (hourly) and atmospheric (winds done twice daily) observation. A near-real-time common weather source for the current FSS network and equipped aircraft would be a great benefit.

Scenario: Corporate Gulfstream IV. (FMS equipped)
Ensenada, Mexico -to- Love Field, TX. Operated IFR under FAR Part 135.

What information is available prior to departure? In addition to the general requirement given in FAR 91.103 for basic information pertaining to a flight, the FAR Part 135 IFR operator is required to use weather information from an "approved" source as given in FAR 135.213. Approved information comes from the National weather Service (NWS), or a source approved by the NWS or FAA. FSS and DUATS are approved sources. Since the aircraft is departing from a foreign city, the pilots of the flight use a third party supplier of flight planning services (such as Universal in Houston, TX) to provide additional weather information for the planned route of flight, as well as providing a liaison service with the fixed-base operator services for the airport in Ensenada, such as fuel, food, and hanger services.

Corporate Aviation Scenario

1400Z: Since the ABC Corporation Gulfstream IV N123AB primarily flies domestically, ABC only uses a third-party commercial flight planning service when flying internationally. The third party service provider will fax to the flight crew all the relevant information required for the flight, including: fuel requirements, an optimized routing, weather forecast along the route of flight, and recommended alternates.

1500Z: The PIC is notified that his passengers will be ready to go in 30 minutes. He calls the third-party flight planning service provider and notifies them they will depart at 1545Z. Meanwhile, the PIC checks the fueling process and enters the flight plan in the FMS.

1550Z: With the ABC execs on board, the PIC gets his taxi and takeoff clearance from the local control tower. In just a couple of minutes the flight is airborne and contacting ABQ center for permission to enter US air space.

How does the pilot learn of the developing situation?

- En route controller
- Overheard
- weather radar
- A third-party weather service provider (data links graphical weather information directly into after-market avionics installed on the flight deck)

Scenario Continued

1645Z: Once established on the airway and climbing to the cruise altitude, the first officer uses the graphical weather display to bring up the DFW weather graphic. The airport situation looks good, but some precipitation is observed on the western edge. The first officer pulls up the national weather picture for another look, and sees scattered precipitation in a line through central Texas. No other weather appears on their route but he decides to keep and eye on the Texas situation.

1820Z: After routine hand-offs through numerous sectors, N123AB is now talking to ZFW. There appears to be some rerouting around weather west of DFW, and the graphical weather display helps to portray the situation to the flight crew in real-time.

How does replanning occur?

1840Z: N123AB is issued a vector taking it off the flight plan and asked to descend to FL290. Based on graphical weather data, it appears the controller is planning to vector N123AB northward around a cell blocking the route to BOWIE. The PIC estimates this will add 10-15 minutes to the arrival time and requests vectors to the Southwest arrival gate (Glen Rose). The request is denied. The first officer reprograms the FMS, adding a place/bearing/distance waypoint at a location which he guesses they'll be turned inbound. The FMS shows a 14 minute arrival delay with adequate fuel reserves.

1920Z: ZFW notifies N123AB that the Bowie arrival gate has been closed due to weather. His is vectored to Glen Rose and instructed to hold there and plan a Glen Rose Three arrival. The graphical weather display shows heavy precipitation covering the Bowie arrival gate. The first officer programs the FMS as instructed. The arrival delay is now 19 minutes, but the fuel reserves are still within the legal minimum.

1955Z: Following successive descents in a holding pattern, N123AB is instructed to proceed with the Glen Rose Three arrival.

2020Z: N123AB lands on 18R following an ILS approach.

Conclusion and Commentary

By having current graphical weather information, the N123AB crew had information on the DFW situation, although the resolution, formats, and coverage of this third-party weather information is not necessarily adequate to support all flight replanning decisions. Had they been able to plan better, they would have saved perhaps 40-50 minutes off their flight, which arrived at the DFW fixed-base operator almost an hour later than expected. However, the situation awareness provided by the weather information justified the control instructions and avoided possibly of the PIC using the radio to request an explanation for the longer course.

They were victims of the 'four-poster' Metroplex arrival arrangement at DFW. When their destination arrival gate closed, they were required to wait in line for a slot at a different arrival gate, which by then was backed up.

Scenario: Airline ABC DC-9 (w/out ACARS).
San Diego, CA -to- Dallas/Ft. Worth, TX. Operated IFR under FAR Part 121.

What information is available prior to departure? Commercial airlines vary greatly in their flight planning sophistication. As a minimum, all have the same access to FSS data. The most complex AOCs have staff and services to plan and monitor all aspects of a flight. At the low end of sophistication, canned lateral routes and altitudes are used, and the dispatcher provides departing pilots with a weather briefing similar to that which may be obtained from FSS. Often, wind-optimized routes are obtained from service providers. The airline dispatcher provides the flight crew with a paper weather summary of winds aloft and forecast conditions at the destination and alternate as well as the flight plan, including relevant information (NOTAMS, SIGMETS, equipment limitations, etc.) and files the flight plan with ATC approximately an hour and a half

Airline Scenario

1500Z: ABC Airlines dispatcher performs pre-flight work for Flight ABC123, DC-9 service from San Diego to DFW. An equipment check shows the airplane on the ground at San Diego and the MEL is met. The crew is available. A quick check for traffic constraints and weather at DFW is done. Airline ABC employs its own Met staff, but continues to use public weather sources such as NWS, FSS, as well as a domestic weather service provider. The dispatcher guesses that unusual delays into DFW are unlikely today - fuel is ordered based on the expected loading and assuming a nominal flight. Since the DC-9 doesn't have an inertial navigation or GPS capability, it must fly jet airways from VOR to VOR to perform en route navigation. The PERF (performance) department has been pressuring dispatch to limit over-fueling, and the recommended amount for this route already is already +5% for the typical DFW 2000Z arrival delays. The usual company, or "canned," flight plan is filed with ATC. Departure time is 1700Z, with arrival at DFW at 2000Z.

15:30Z: ABC Airlines files the flight plan with the departure ARTCC.

1600Z: The captain and first officer arrive at the local flight operations center at SAN (this can be a lounge or simply the gate area depending upon the airline and the station) and review the national weather forecasts, winds aloft, other information pertaining to this flight available at the dispatch office. The weak weather disturbance over Texas is noted but does not appear to be a factor. They carry the printed flight plan and weather brief to the aircraft, which is now at the gate, and continue their pre-flight planning. ABC's DC-9s are not FMS equipped. The crew is expected to remain with the aircraft for the scheduled return flight from DFW to SAN.

1650Z: The passengers are loaded and the ABC123 crew calls dispatch for release, including a weather update, loading and fuel verification. The aircraft is pushed back.

1710Z: ABC123 departs SAN on time (±15 minutes).

How does the pilot learn of the developing situation?

- En route controller
- AOC informs the crew of developing weather situation
- Overheard from other aircraft on Center frequency (the "partyline")
- Weather radar, if the aircraft is close enough to the weather cells

How does replanning occur?

It is usually the case that the AOC will anticipate the need for rerouting before the aircraft is in the vicinity of the weather. This means the AOC is developing a replanning solution prior to ATC considering a reroute for the aircraft in question. The dispatcher at the AOC will, usually, develop a new route that skirts the inclement weather in order to minimize the added flight time, which they equate with schedule disruption.

The dispatcher will make some preliminary estimates of fuel required for the new route to determine if the aircraft has sufficient fuel onboard to make fly the new route. If there is not enough fuel to fly the new route with the original alternate (and the required reserves), the dispatcher may examine the option of declaring a new alternate. This will require a quick check of the new alternate's weather situation. When the new route is deemed to be "reasonable" from the dispatcher's perspective, they will contact the crew using a direct VHF link, such as SELective CALling (SELCAL), inform the flight crew of the developing weather situation and suggest the reroute. The flight crew will then perform their own calculations of fuel required for the new route. If the flight crew deems the replan a reasonable strategy, they will contact ATC and request an amended flight plan.

Conclusions and Commentary

While the AOC is working to replan the aircraft's route around weather, ATC may be making plans for rerouting entire jetways around severe weather situations. ATC's enact Severe Weather Avoidance Plans (SWAP) that move entire jetways to the North/South or East/West around regions of severe weather. The effect of a SWAP is similar to throwing a boulder into a stream. The water flowing down the middle of the stream is moved to the edge of the rock, the water flowing near the edge of the stream flows an even further, more extreme route along the edge of the stream. This metaphor is appropriate for jetways in a SWAP situation. The jetways that were headed directly for the severe weather are moved so they barely skirt the weather (similar to the AOC strategy for rerouting). The jetways that were barely skirting the weather are moved further away from the weather in order to "make room" for the traffic that has been moved to barely skirt the weather.

The upshot of this is that the anticipatory move on the part of the AOC can actually work against them. If they re-file the flight plan to barely skirt the weather, prior to the SWAP being enacted, then the aircraft will be pushed further away from the weather when the SWAP is put into place. Unfortunately the ability to append intent to a flight plan is not currently supported, otherwise the airline (AOC and flight crew) engaging in this anticipatory behavior could "save" their place in line by declaring they spotted the developing weather situation first - and "First Come, First Served" is an operating philosophy of the US Air Traffic Control system. The philosophy is simply not supported at the current time, because the intent of flight plan changes is information that is not entertained in the current system. The air traffic service provider only has tools to deal with WHAT, not WHY.

Scenario: Airline Boeing 757 (ACARS equipped).
San Diego, CA -to- Dallas/Ft. Worth, TX. Operated IFR under FAR Part 121.

What information is available prior to departure? Similar to the DC-9 story above, the AOC develops the route to be flow, taking into account payload, MEL, and fuel considerations and files the flight plan with ATC. Unlike the DC-9, the B757 can have the flight plan data linked directly into the FMS, using ACARS, which is a time-saver and reduces the potential for a keystroke error on the part of the flight crew.

How does the pilot learn of the developing situation?
Same as the DC-9 scenario.

How does replanning occur?
AOC replans, as before, but there is the capability to uplink informational messages via ACARS as well as the proposed flight plan amendment.

Conclusions and Commentary
Same as DC-9 scenario.

Scenario: Package Carrier Boeing 757 (ACARS equipped).
San Diego, CA -to- Dallas/Ft. Worth, TX. Operated IFR under FAR Part 121.

*Change to Baseline Scenario**.*** The basic scenario needs for a weather related event is fundamentally the same between an airline and a package carrier when both are operating under FAR Part 121. What makes for an interesting scenario is the difference in fleet operations with regards to a specific aircraft becoming unavailable, and the resulting actions taken to accommodate the load.

In the short scenario to be described, rather than a weather event, the package carrier aircraft will suffer a mechanical malfunction which requires it to land in Albuquerque, NM.

What information is available prior to departure? Similar to the airline story, the package carrier has a dispatch department that provides them information on payload, fuel, route of flight, and files the flight plan with the departure ARTCC approximately 2 hours in advance of the departure.

How does the pilot learn of the developing situation?
In this scenario, the aircraft has a clogged oil filter develop in the left engine. The Engine Indication and Crew Alerting System (EICAS) cautions the pilot of an oil OVERTEMP in the left engine, which requires the flight crew to shut the engine down and divert to a nearby airport.

As the crew completes the ENGINE SHUTDOWN CHECKLIST and performs the nominal tasks associated with notifying ATC of their problem and a request to land at ABQ, they inform their dispatcher that the aircraft is being diverted.

How does replanning occur?
It is the case that package carriers operate “sweep” aircraft for just such a situation. The sweep aircraft has been launched from an east coast city and takes up a holding pattern in a portion of sparsely used airspace awaiting word from dispatch of any problems with any of the east coast traffic headed towards the company’s main distribution center. When the east coast flights all report that they can make the airfield where the main distribution center is

located, the sweep aircraft begins to fly west to be closer to any aircraft flying in from the west that might experience a malfunction.

When the San Diego -to- DFW flight reports they will divert to ABQ, the sweep aircraft immediately requests a new route to ABQ. Meanwhile, the dispatcher will generate a new flight plan for the sweep aircraft, including the fundamental elements of payload, fuel, and route. It can be the case that the sweep aircraft cannot accommodate the full load of the disabled aircraft (i.e., a B747 has a malfunction and must divert, and the sweep aircraft is a B757). It is in this special case that the dispatcher may be called upon to find creative solutions to solve the problem of getting the payload to the distribution center. These solutions can include:

- diverting another airborne aircraft in the vicinity
- contracting with another airline or carrier to carry some of the payload
- contacting the local distribution center to determine if they can carry some of the payload, via truck, to another city for transport

Conclusions and Commentary

This system works well for the package carriers. It is the package carriers belief that the sweep aircraft is a “nuisance” to air traffic controllers because of it’s loitering behavior while waiting for assignment.

2.3 Inefficiencies Summary

The explicit inefficiencies documented appear to fall into the following general categories:

- Incomplete information (e.g., intent behind flight plan change)
- Poor timeliness, quality, or format of information
- Poor information transfer
- Lack of cooperation in meeting different stakeholder re-routing goals
- Inadequate equipage
- Conservative separation standards
- Lack of ability of ATC to accommodate dynamic replanning
- Invariable routes and procedures

These inefficiencies were not always explicitly tied to driving economic problems, that is, delays, inefficient fuel usage, etc., but it was clear to us that schedule-related economics were the main airline or operator drivers to which these inefficiencies were associated.

The last three items, expressed by the package carrier operator and in the ARTCC scenario, are related to the mainstream issues of Free Flight. The other inefficiencies relate more directly to CDM types of issues. These latter inefficiencies, which are the ones that will be focused on in our analysis, fall into two general categories: those due to stakeholders who have a vested interest in the process not being involved in the decision making; and those due to the decision makers not having the best information on which to make their decisions. Table 2 illustrates these inefficiencies. For many current day scenarios and airlines, the bottom right quadrant is representative of the biggest category of inefficiencies in the flight planning process, especially for en route strategic replanning.

Table 2. Classes of inefficiencies in the flight planning/replanning process

Decision-Maker	Information Sources	
	Best	Not Best
Major Stakeholder	All Stakeholders involved in routing decisions with best information	All Stakeholders involved in routing decisions, but using less than ideal information
Not the Major Stakeholder	All Stakeholders are not involved in routing decisions, but decision-makers have best information	All Stakeholders are not involved in routing decisions, and decision-makers do NOT have best information

The issue of **Stakeholder** in the flight planning process is perhaps the area easiest to target for change in an attempt to eliminate, or at least greatly reduce, inefficiency. Once the class of airspace user involves more than one agent (a party other than the actual pilot) for developing and submitting the flight plan to ATC, the opportunity for inefficiencies to manifest become numerous. A notable example of inefficiency with regards to Stakeholder involvement in flight planning is the example provided by the feedback loop for an unaccepted flight plan, between dispatcher, air traffic control, and flight crew. Currently, if a flight plan submitted to the departure Air Route Traffic Control Center (ARTCC) is unacceptable, usually due to traffic flow constraints unknown to the airline, there is no mechanism for providing feedback to the Stakeholder most interested in routing the aircraft to maintain schedule integrity, namely the dispatcher at the airline. Instead, a new route (that satisfies the constraint) is developed by ATC and delivered to the flight crew at Pre-Departure Clearance (see Figure 10).

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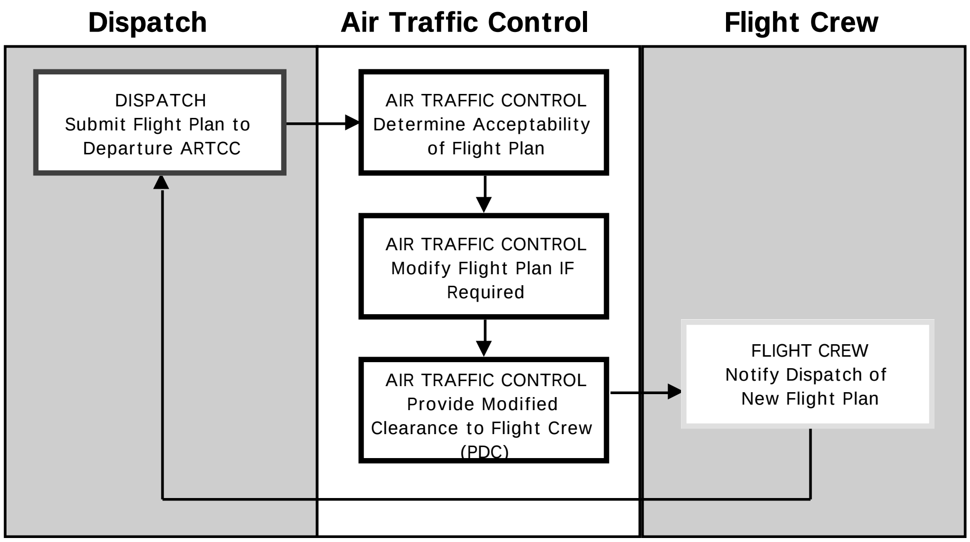

Figure 10. "Butched" flight plan notification is to flight crew, *not* dispatch

The flight crew has entered the aircraft with the original flight plan developed by their dispatcher, and has begun preparing the aircraft (including programming any flight path automation) to support that flight plan. This is always a period of high workload as the flight crew completes last minute items preparing the aircraft for the flight. An amended clearance disrupts the sequence of events by forcing the flight crew to re-address issues associated with fuel and weather for the new route of flight. In addition to the consideration of adding to an already high workload condition as a potential source for error, the fundamental issue that needs addressing is taking control of flight planning away from the dispatcher (the primary Stakeholder) who is most concerned with the impact of the required change and the subsequent effect on schedule integrity.

3.0 Solutions

3.1 Free Flight

In 1994, a number of interested parties assembled to address existing inefficiencies in the National Air Space and to critically examine the Air Traffic Control paradigm. The motivation for the air and package carrier participants was to identify a means to evolve a more efficient Air Traffic Management system and subsequently influence the R&D and procurement efforts by the federal government to achieve those changes.

The resulting *Free Flight* concept is the outcome of those efforts. Both the RTCA working groups and their counterparts at the FAA have provided a phased timeline for the introduction of those efforts. One legitimate criticism that can be levied against the available literature on Free Flight is that the concept is described from an outcome-oriented viewpoint, not from a more traditional description of equipment and procedural implementation details. This has left the concept of Free Flight open to a wide variety of interpretation. At its core, Free Flight is

> “ ... 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 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.”[1]

This provides a fairly clear goal, but the exact implementation details are lacking. This raises several risks that must be considered when weighing the utility of the free flight solution against other options.

Some envision Free Flight as ultimately enabling aircraft to “maneuver at will.” This is perhaps what has fueled notions of autonomous aircraft that are capable of self-separation, and conjures up visions of aircraft maneuvering wherever and whenever they want without any coordination or negotiation with other stakeholders. We believe it is important to dispel this notion of Free Flight. In its purest form, Free Flight means that both separation and traffic flow constraints are provided to individual aircraft in terms of discrete time/position states. For example, an aircraft is provided with a Required-Time-of-Arrival at a specified approach fix, or with a time window during which it can’t be at a particular position and altitude. It is left to the aircraft, the airline, or some combination to satisfy the time/position state by manipulating the path and speed of the aircraft. If the time/position state can be met, then the aircraft can “maneuver at will” in the process. We believe that such an “open-loop” ATM system is untenable, at least for high density airspace. The reason is this: each aircraft is a potential constraint on other individual aircraft and traffic flow as a whole, so a perturbation in one aircraft’s route without feedforward to predict the

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[1] Final Report of RTCA Task Force 3: Free Flight Implementation. (Section 3.1.1, pg. 23)

consequences on other aircraft paths, or overall traffic flow, could create an unstable, chaotic state. This suggests, unlike the connotation of the phrase "maneuvering at will," that the strategic aspect of airborne flight planning, especially prediction and the coordination and sharing of information, plans, and goals among a variety of shareholders, may need to increase, rather than decrease, in Free Flight. This doesn't imply less flexibility; it means that greater flexibility may require greater planning, coordination and collaboration.

Examples of more modest Free Flight goals that involve better, more coordinated strategic flight replanning include:

1. Free Flowing - The freedom from ATC congestion initiatives such as ground stops, Ground Delay Programs (GDP) and others;
2. Free Filing - The ability for the user to file and reasonably expect to fly pre-planned User Preferred Trajectories (UPT) (Beatty, 1997).

It is our belief that these Free Flight goals can be accomplished with a combination of a more dynamic strategic replanning capability that includes a significant airborne component and air traffic management improvements that relax some of the route and procedural inflexibility's.

3.2 Collaborative Decision Making (CDM)

The idea of allowing all Stakeholders with vested interest to participate in decisions related to the appropriate course of action is at the heart of the Collaborative Decision-Making (CDM) paradigm. In a nutshell, the CDM paradigm shift allows airline dispatchers to work interactively with traffic flow managers to draw-down their own demand on airports when the capacity of an airport changes. Without CDM, if an airport were to experience a reduction in capacity (i.e., reduction in the Airport Arrival Rate-AAR) it is up to ATC to use measures, sometimes draconian actions such as ground stops, to reduce the demand on the facility prior to an airborne holding mess developing over the affected airport. A good example of this sort of reduced capacity is a transient period of low visibility, such as morning fog, that will reduce the AAR. In the past, ATC might issue a ground stop affecting all aircraft that were going to arrive during the period of forecasted fog. The problem with this approach is that it allows no flexibility to airlines trying to recover from this irregular operation. The affected aircraft are in effect quarantined; they can do nothing else but wait for the ground stop to be removed. In the current CDM paradigm, the forecasted reduction in capacity is broadcast over a wide-area network (the AOCnet) from ATC to all participating airlines. A specific time limit is placed on the airlines to draw-down demand. If the airlines accommodate the reduced capacity by reducing their own demand (thus reducing the aggregate demand on the arrival rate) prior to the time limit, then ATC will not need to enact any measures, such as a ground stop. This freedom allows the airlines to reduce the impact of the reduced capacity at one airport on their overall schedule as they see fit.

An example serves to illustrate the point. Imagine that SFO is forecast to experience fog between 6:00-8:00am, effectively reducing the AAR by half. Further imagine that Airline XYZ, has two flights from LAX to SFO scheduled to arrive between 6:00 and 8:00am. If a ground stop were issued by ATC, then those aircraft will load the passengers on the two scheduled flights and occupy the departure gate at LAX until they receive clearance to leave. This not only frustrates the paying passenger, it effectively blocks the gates at LAX which were expected to be cleared so that incoming aircraft could use them. With the flexibility afforded by CDM, the airline might choose to cancel outright one of the two flights, load as many passengers off the canceled flight onto the one that will proceed to SFO, and offer future travel vouchers for those passengers willing to wait for a later flight. This allows at least one aircraft to proceed on to the destination, and now leaves the airline only trying to recover from having one aircraft, and associated crew, out of place instead of two. What has occurred with the shift to CDM is it allows the Stakeholder that is most concerned with the outcome to control what happens.

Taking this back to the earlier example of unaccepted, or “Butched,” flight plans, if ATC were to share with the dispatcher the specific constraint that made the first flight plan unacceptable, the dispatcher, armed with this new information, can replan, taking the ATC constraint into consideration, and provide a new flight plan that optimizes the airline’s parochial concern, namely maintaining the schedule (see Figure 11 below).

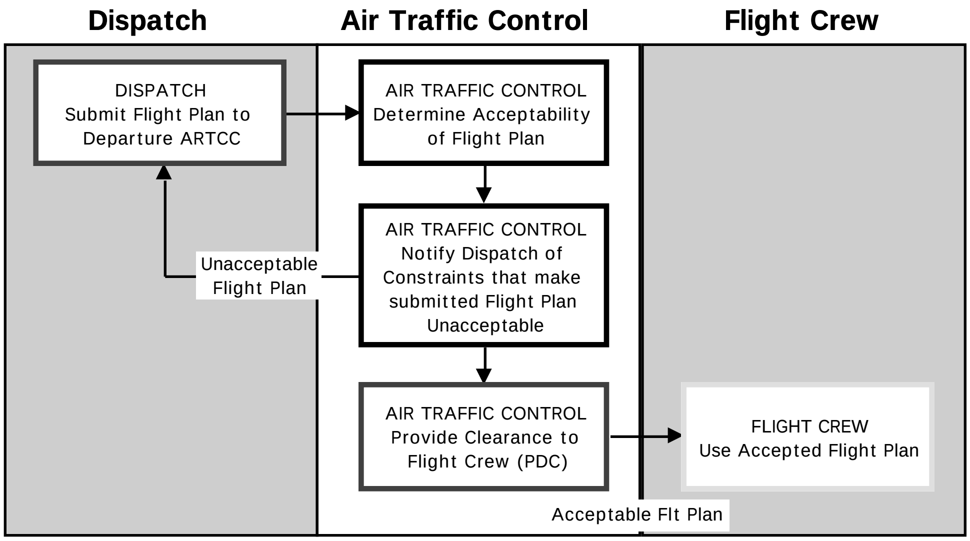


Figure 11. ATC constraints shared with dispatch in order to avoid “Butched” flight plans

3.3 Other relevant work

Previous work has been conducted on autonomous “agents” that aid the flight crew, or pilot, in making changes to the flight plan. These efforts all address more sophisticated flight planning/replanning functionality consistent with the dynamic planning capability needed in a future Free Flight environment. Below is a brief review of the more relevant efforts.

Cockpit Assistant System - CASSY

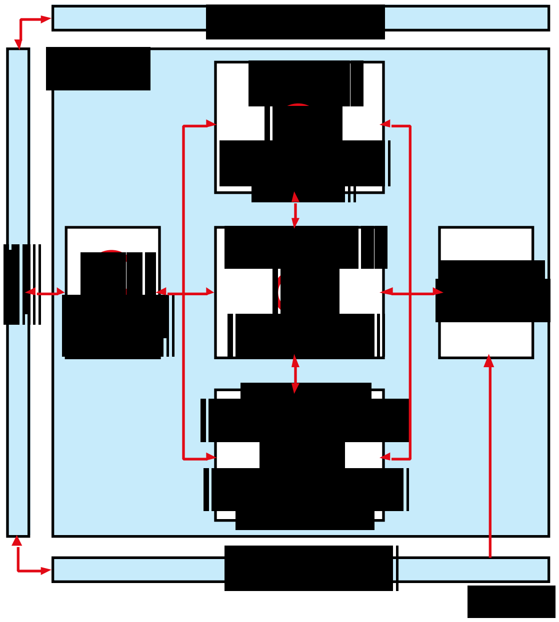


Figure 12. CASSY architecture

In Germany there has been a joint effort between the University of the German Armed Forces, Munich and the DASA-Dornier company to develop a knowledge-based Cockpit Assistant System (CASSY) to improve flight safety under instrument flight conditions. Included in CASSY are modules to support Automatic Flight Planning, a Piloting Expert, and Pilot Intent and Error Recognition, see Figure 12. These modules not only develop plans as recommendations to the pilot; they also monitor the pilot's actions and evaluate hazardous situations that may occur in the environment. Finally, CASSY provides a Dialog Manager for a single interface with the variety of functions that CASSY provides, including the data link interface with ATC regarding modifications to the flight plan.

For the purposes of this report, the most relevant CASSY module is the Automatic Flight Planner (AFP). This software provides a detailed trajectory, including elapsed time for waypoint passage. Interestingly, the AFP module only requires the pilot to input the destination. The AFP will provide reroutes and alternate landing sites based upon changing weather conditions or the status of aircraft systems, Figure 13.

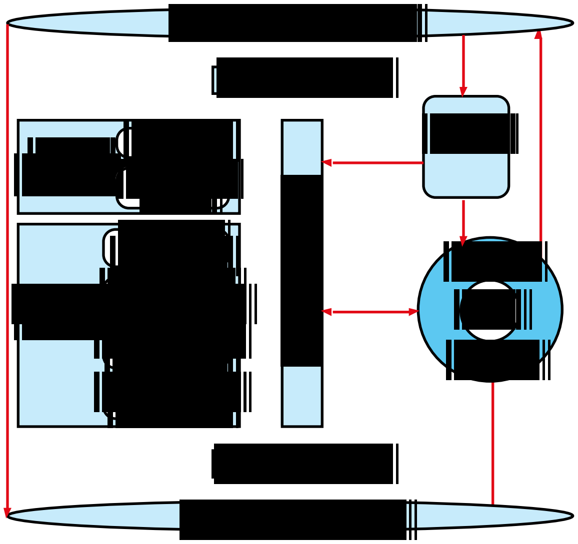


Figure 13. CASSY replanning module

The AFP provides the crew with a selection of replanning alternatives. Any of these alternative choices can be accepted, modified or ignored. In addition, the AFP periodically updates the flight plan with respect to usable ground-based navigation aids, current wind conditions, and the progress of the flight along the flight plan.

DIVERTER

In the late 1980s, as part of NASA's Advanced Transport Operations program, the Lockheed Aeronautical Systems Company-Georgia Division worked on decision-support tools to aid pilots in performing flight replanning while airborne. The Lockheed concept/prototype was called "DIVERTER." The primary emphasis on the DIVERTER program was to compile data from a distributed number of sources, such as present position, fuel, maintenance status of the aircraft, aircraft handbooks, performance data, weather (en route, and relevant terminal areas), instrument approach charts, and applicable Federal Aviation Regulations, to guide the pilots in replanning a flight once an event (i.e., severe weather) would cause the flight crew to consider changing their destination. The primary motivation for the DIVERTER effort was to provide an automated resource that could consider landing alternatives in the light of a diversion requirement and make a replan suggestion to the flight crew in a timely manner.

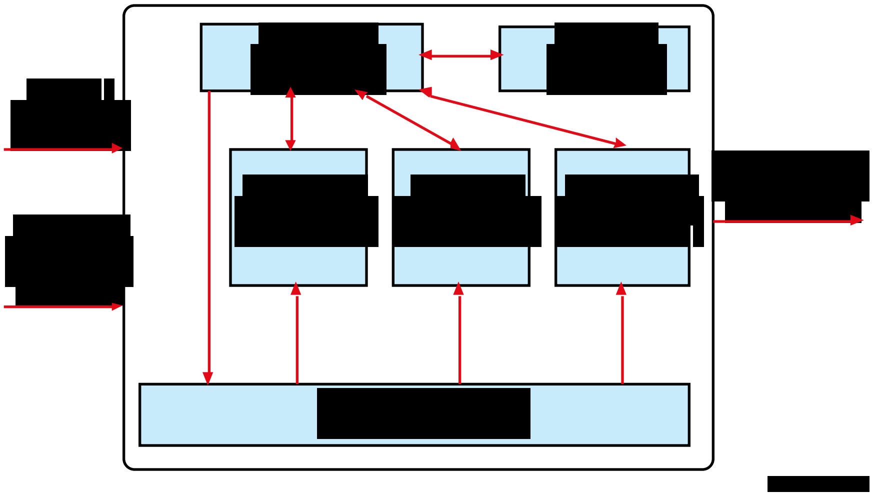


Figure 14. DIVERTER architecture

As part of the DIVERTER effort, a Functional Analysis was made of the activities a pilot must execute when performing in-flight replanning as a reaction to a diversion event. Appendix A of the NASA Contractor Report 182070 (*"DIVERTER" Decision Aiding for In-Flight Diversions*) provides a preliminary framework (Figure 14) for considering the decisions to be made in the in-flight replanning process. Unfortunately, the analysis doesn't clearly document who's performing the tasks (it is implied that all the tasks are being performed by the flight crew). As part of the activity reported in this study, we propose to explicitly identify the sources of information and which party (flight crew, dispatcher, air traffic controller, or some combination) is performing each replanning sub-task.

Pilot's Associate

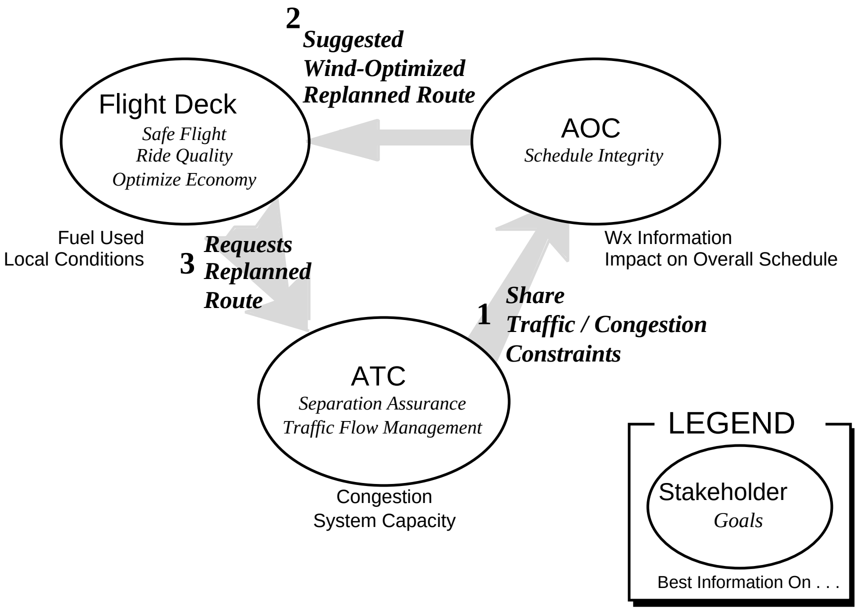
The Pilot's Associate program was intended to be the first large scale introduction of artificial intelligence technology into the fighter cockpit. The intended applications were mission and route planning, situation assessment, systems status assessment, and an intelligent pilot-vehicle interface that would recognize pilot intentions, reduce pilot workload, and detect pilot errors. Two teams worked on parallel programs: the McDonnell Aircraft Company team worked on a system for air-to-ground missions, and the Lockheed team worked on one for air-to-air missions. The program was successful in developing useful new technologies, such as pilot goals recognition and dynamic workload analysis and management. However, none of the technology objectives have been transferred into operational systems. Further developments are being pursued under the Rotorcraft Pilot's Association program.

3.4 Strategic Flight Replanning (our approach)

Our interviews indicated the largest planning/replanning inefficiencies are associated with the flight planning/replanning processes and information transfer. There are associated inefficiencies related to relatively inflexible air traffic routes and procedures. Our approach focuses on three aspects of replanning:

1. Re-allocating replanning tasks and in general making the replanning process more collaborative;
2. Providing better information to stakeholders (especially the flight deck) to support CDM; and
3. Increasing airborne replanning functionality to enable a more sophisticated dynamic replanning capability.

We do not address current ATM route and procedure inflexibility directly, but other tasks under AATT do, and the work here should support a more flexible ATM system. We believe that a meaningful airborne concept to support Free Flight does not necessarily result in a more autonomous aircraft. There are several parties, or stakeholders, with an interest in the flight path of a given aircraft. Inefficiencies can arise when a stakeholder with a more one set of interests makes route decisions that usurp another set of interests for a different stakeholder. The most efficient solution is the one that includes all stakeholders in decision making; perhaps giving primary decision making responsibility to the stakeholder with the broadest set of interests, but accommodating the more limited interests of other stakeholders. We have attempted to allocate responsibilities to stakeholders based on the scope of their interests rather than making a priori assumptions about function allocation, with the objective of arriving at the most efficient overall solution. Figure 15 illustrates the general "involve all stakeholders" approach to planning that emerges from the interview data (and is supported by the more formal analysis of those data presented in a later section).



Our belief is that significant operational improvements will have a greater chance of realization with an airborne concept that maximizes improvements in flight crew awareness and problem solving (flight planning) capability and minimizes changes in authority over execution of plans.

Figure 15. Allowing the vested Stakeholders to make key decisions

This does not mean that self-separation or certain increases in aircraft autonomy should not be considered if they have economic benefit without significant cost or safety penalties. In fact, we believe self separation is practical and would have high payoff in oceanic and in certain high density airspace, such as terminal area airspace associated with landing operations at airports with closely-spaced parallel runways. But it should be kept in mind that such concepts are not goals or assumptions; they are solution concepts that should be evaluated in terms of the operational costs and benefits in achieving the goals of more efficient or safer operations.

Planning and replanning, as mentioned earlier, can be decomposed into information processing tasks -- an observable action is the end point, preceded by sensing and processing of information and decision making. Data and information from the aircraft, its systems, aircraft and ground personnel, and the environment must be collected and processed in order to understand the situation, identify goals, determine potential actions, and select and execute a particular action. The point here is that only the last step or task, (e.g., “approve and execute an action”) is traditionally associated with authority or autonomy issues. We can envision a Free Flight scenario where final authority over the execution of a maneuver in real time is little different than in today’s environment (this does not mean that ATC routing and procedures are not changed to be more flexible, but we don’t assume reallocation of responsibility), but the flight crews’ roles and responsibilities in the information processing steps leading to the maneuver (e.g., situation assessment, problem/opportunity identification, planning, determination of alternate plans of action) are significantly different. Hence, when we refer to a “flight deck-centered” concept for Free Flight, we mean that we are focusing on new concepts for the flight deck component of a distributed system for gaining efficiencies in air traffic management; we do not mean that the flight deck concept is the key component of that system, or that the flight crew necessarily assumes final authority over route planning or separation.

4.0 Flight Deck Replanning Function/Information Analysis

To support this general approach, we systematically analyzed the goals, constraints, functions, information and stakeholders involved in planning and replanning. The objective of the analysis was to reallocate functions and information using the explicit criterion that any function that served multiple goals of multiple stakeholders should be performed collaboratively by those stakeholders. Additionally, the information supporting shared functions should be distributed to all stakeholders participating in the functions. The general methodology is shown in Figure 16.

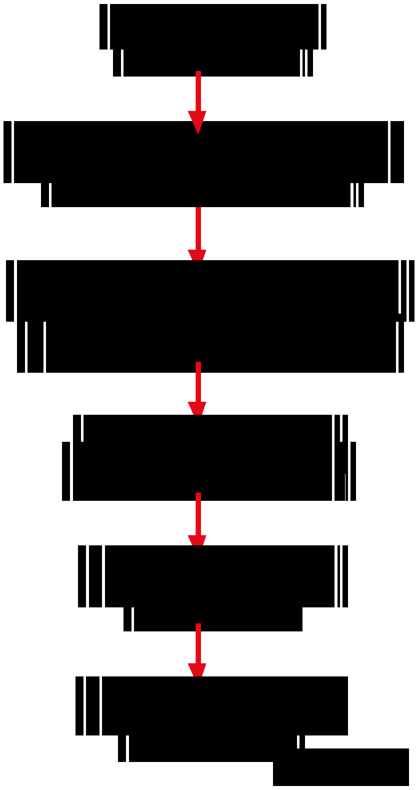

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Figure 16. Process for conducting flight deck replanning function/information analysis

First, based on the interview data, each goal was associated with a stakeholder (or multiple stakeholders, where appropriate) The stakeholders were categorized as **fleet**, **area**, and **individual aircraft** in order to determine the scope or level of concern for each. For example, an AOC would be a **fleet** level stakeholder because their objectives have to do with optimizing the schedule across their fleet. ATC would be an **area** level stakeholder because their primary objectives concern traffic flow and conflict avoidance within a geographic area. **Individual aircraft** level concerns are generally those of the flight crew, but also relate to passenger goals.

Each goal was then associated with **constraints**, **functions**, and **information**. The ultimate purpose of this step was to determine how information requirements should be allocated to stakeholders; in order to do this, the constraints were identified to ensure completeness of any associated functions and information. Functions were then allocated to stakeholders based on the association between goals and stakeholders, and primary, secondary, and tertiary responsibility for each function was assigned. Finally, these results were used to allocate information requirements to the stakeholders. It should be noted that the distinction between constraints, functions, and information can be fuzzy at times; this is acceptable for the present purpose, to ensure comprehensive identification of the information requirements. The complete analysis is shown in Appendix C.

5.0 Design Implications

5.1 Function reallocation

In the above analysis, we identified the information used in flight planning and replanning and the functions associated with the goals and constraints of each stakeholder. Based on the interests and responsibilities of the various stakeholders, we then allocated functions and their associated information requirements to stakeholders. This resulted in what we believe is a more rational assignment of responsibilities to stakeholders than exists in the current system.

Three stakeholders, the air traffic service provider (controller), the dispatcher, and the flight crew, have an interest in determining the future flight path. In today’s environment, the controller generally has the greatest control over what route is eventually flown by an aircraft in most replanning scenarios. In the program plan for this effort we made the distinction between global constraints (affect many aircraft) and local constraints (affect one or a few aircraft). Air traffic services has global constraints in terms of separation assurance, sector congestion, arrival sequencing, and overall traffic flow. Airlines have global constraints in terms of fleet considerations and maintaining schedule integrity. The controller’s interest in the safety of aircraft within a region or meeting traffic flow demands isn’t any more “global” than the fleet operator’s interests in the overall efficiency of their fleet. However, controller route decisions may end up usurping the interests of the fleet operator in arrival sequences within the fleet (to make crew, equipment, and passenger connections as efficient as possible) or fuel use and time en route tradeoffs. In some cases, collaborative re-routing may allow the broad interests of air traffic services and the fleet operator, as well as local interests of an individual aircraft, to be satisfied simultaneously without significant compromise by any party; collaboration simply allows identification of a solution that satisfies all constraints which would have otherwise been missed. In other cases, where constraints must be prioritized and compromises made, collaboration allows all stakeholders to communicate their interests and priorities and perhaps help develop solutions that more fairly distribute the “costs” of compromise solutions across stakeholders. It should be made clear that when we suggest compromised or collaborative decisions that provide more economic benefit to the airlines, we of course do not mean that safety be compromised; we mean, rather, that solutions that are developed primarily for the convenience or convention of one stakeholder be compromised, assuring no negative impact on safety.

The information processing associated with flight replanning provides a framework for identifying the implications of the analysis on reallocation of functions among stakeholders and, of specific interest to this effort, the changes in airborne replanning sub-functions. Computational or information processing models will be briefly described, and then the Abbott (1993) model will be used to illustrate the proposed changes in flight replanning function allocation among stakeholders.

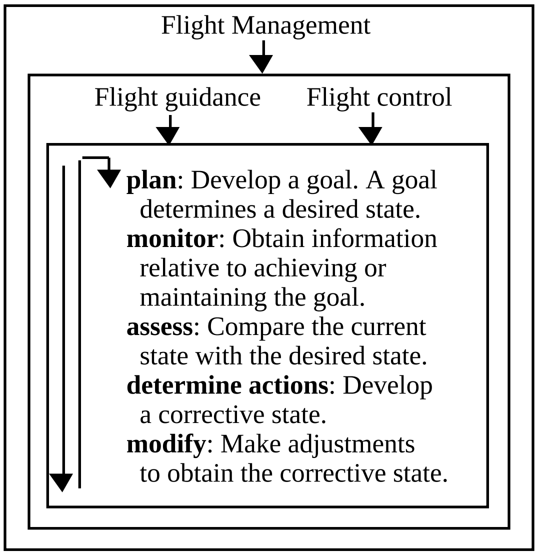
Computational descriptions. All functions, whether they are performed by humans or automated systems, involve not only the observable actions themselves, but also the sensing and processing of information requisite to the actions (and, in fact, sometimes information processing occurs but does not result in execution of an observable task [e.g., a pilot processes data in a non-normal situation to determine whether to divert, but decides to continue to the original destination.]) Data and information from the aircraft, its systems, aircraft and ground personnel, and the environment must be collected and processed in order to understand the situation, set goals, make decisions, and determine the appropriate actions. It is useful to decompose functions in this way because it is asserted that it is at the level of information processes that the activities, information, and authority of ATC, AOC and the flight crew can be systematically analyzed and allocated.

Abbott (1993) presents a functional decomposition of commercial flight deck activities from both an operational function (e.g., flight management, communication management, etc.) and computational function (e.g., monitoring, assessing, determining actions, etc.) perspective, and thus is a useful starting point for describing an airborne functional concept for strategic flight planning to support Free Flight.

Flight Management

In the Abbott (1993) scheme, flight management is the first-level function of managing all parameters relative to flight planning, guidance, and control. This function directly supports the mission goal of the vehicle (to move passengers and cargo from airport gate to airport gate safely and efficiently). This function is more comprehensive than the functionality of a conventional flight management system; it entails all the flight management functions currently performed by the flight management system and the flight crew relative to control of the aircraft, and guidance along and planning of the aircraft's route. The flight management function itself is divided into two major subfunctions: flight guidance and flight control. These two subfunctions are further subdivided or decomposed as shown in Figure 17.

Figure 17. General elements of flight management



For this analysis, the flight guidance subfunction is considered to be the strategic part of flight management and the flight control subfunction is the tactical part. The strategic aspect of flight management is described further below.

Flight guidance

Flight guidance is the function of developing a desired plan of flight, determining necessary resources, monitoring the progress of the flight, assessing the current situation, and adjusting the plan of flight as necessary. In this definition, it is important to note that the plan of flight is much more encompassing than what is traditionally considered a “flight plan.” Flight guidance is further decomposed into the following elements.

Planning: This element involves the determination of the destination airport and other intermediate goals to include: flight-environmental factors, Federal Aviation Regulations (FARs) and other pertinent regulations, flight-planning procedures, and the resources necessary to obtain those goals. The planning goals include the determination of lateral, vertical, and speed (or speed and time) routing subgoals.

Monitoring: This element involves the gathering of all available information about the current vehicle state and the desired vehicle state. That is, where am I, where am I supposed to be? This includes gathering information relative to the current environmental factors, FARs and other pertinent regulations and procedures, and the available resources (e.g., fuel, crew endurance).

Assessing: This element is the activity of comparing the current vehicle state (e.g., current lateral position) with the desired state (the current subgoal from planning, e.g., the planned lateral position). This is effectively a feedback loop in terms of tracking any differences between the current and desired states, as the basis for determining the success of the current plan and the need for corrective actions. This element includes assessing flight-environmental factors, FARs and other pertinent regulations and procedures, and the available resources that may influence the current state or obtaining a desired state.

Determining actions: This is the subfunction of determining modified guidance or planning actions needed to reach the desired state from the current state.

Modifying: This is the “respond” element, which includes adjusting, changing, or creating a subplan (or subplans) to accommodate the assessed situation. This is the application of the actions from the “determining actions” element.

To provide a concrete example of how such a computational model can be applied to an airborne strategic flight planning concept, we depict the model with definition of processes tailored to real time flight replanning, regardless of where they are performed (Figure 18).

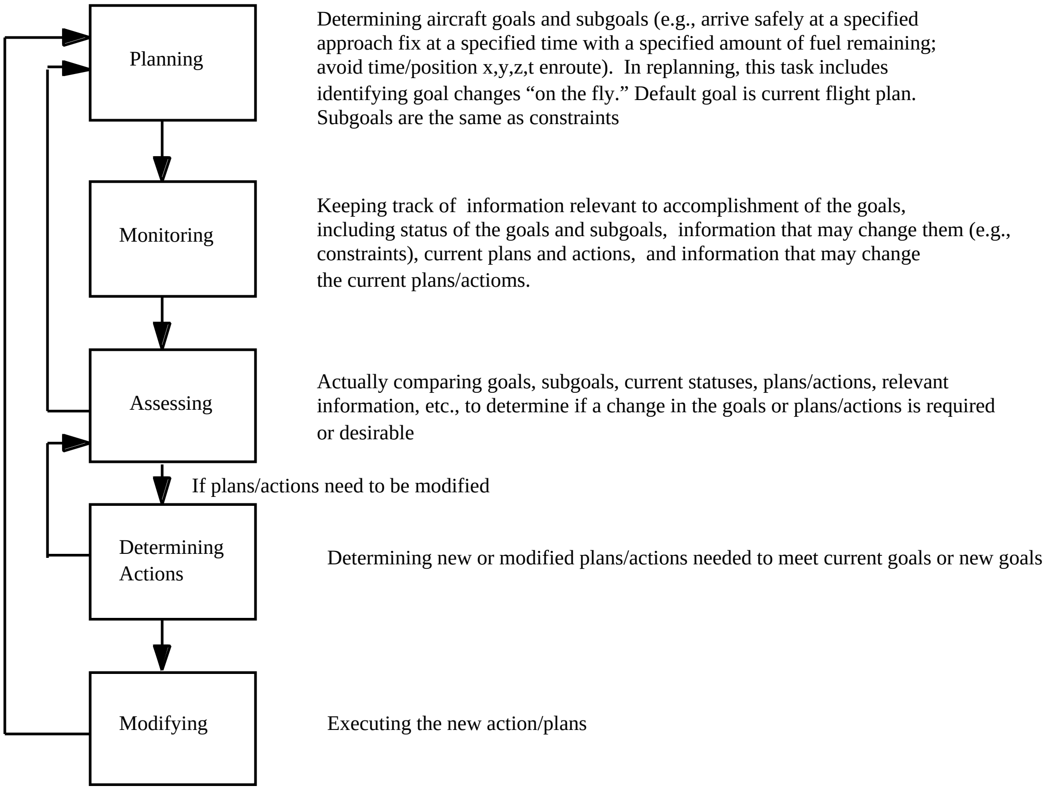


Figure 18. Flight replanning information processing model

Figures 19-23 illustrate who performs each process in today’s environment for rerouting around “over-the-horizon” weather. The order of the processes are modified from above to be more representative of the replanning function: A plan is already in place, so monitoring is the first task, and re-assessing goals (re-planning) follows determination of the need to replan (assessing). The most important points to make in the current scenario are:

1. The flight crew is only peripherally involved in all the information processing tasks leading up to the need to assess whether they can comply with the new plan (or clearance) and
2. The dispatcher is only peripherally involved in the replanning and determining actions tasks (however, the more sophisticated airlines are currently becoming more involved in these tasks).

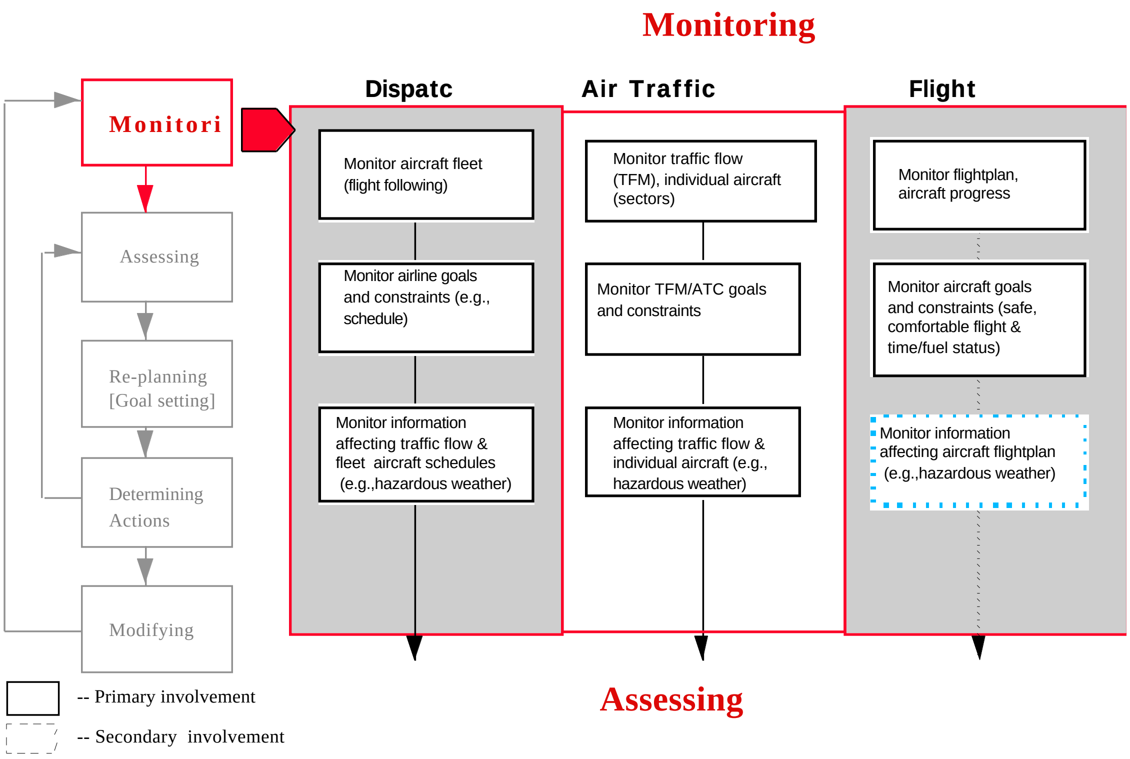


Figure 19. Monitoring in Today's environment

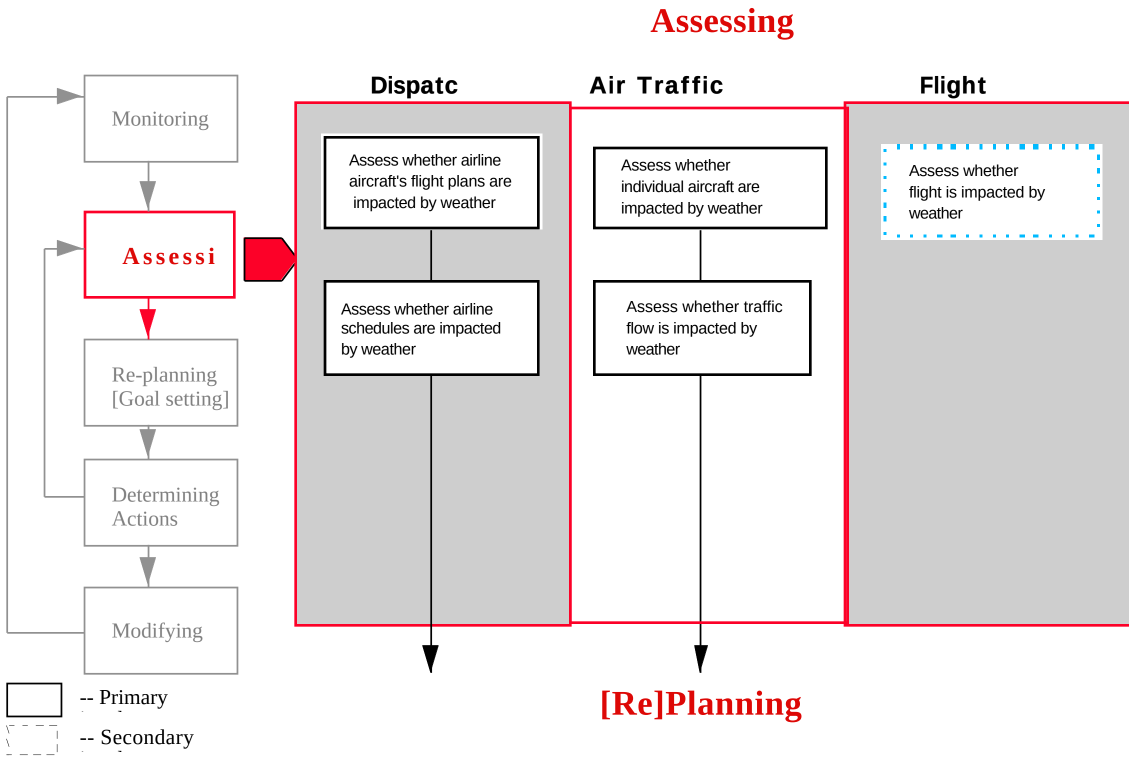


Figure 20. Assessing in Today's environment

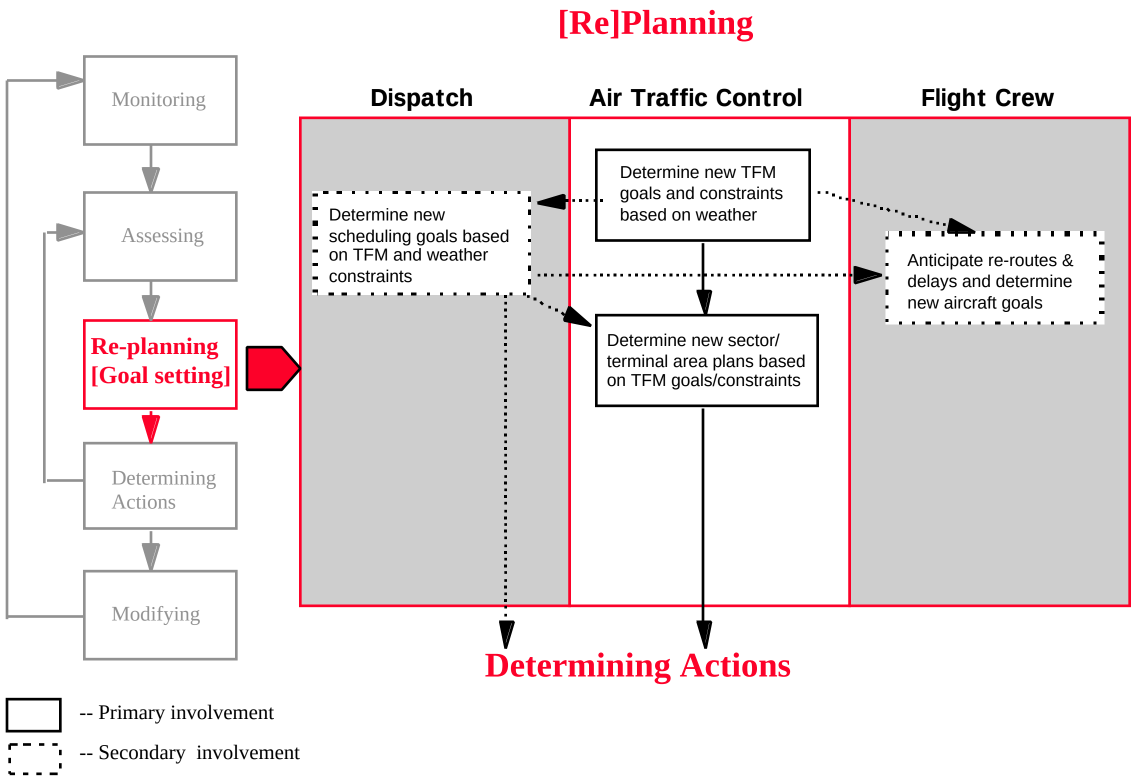


Figure 21. Replanning in Today's environment

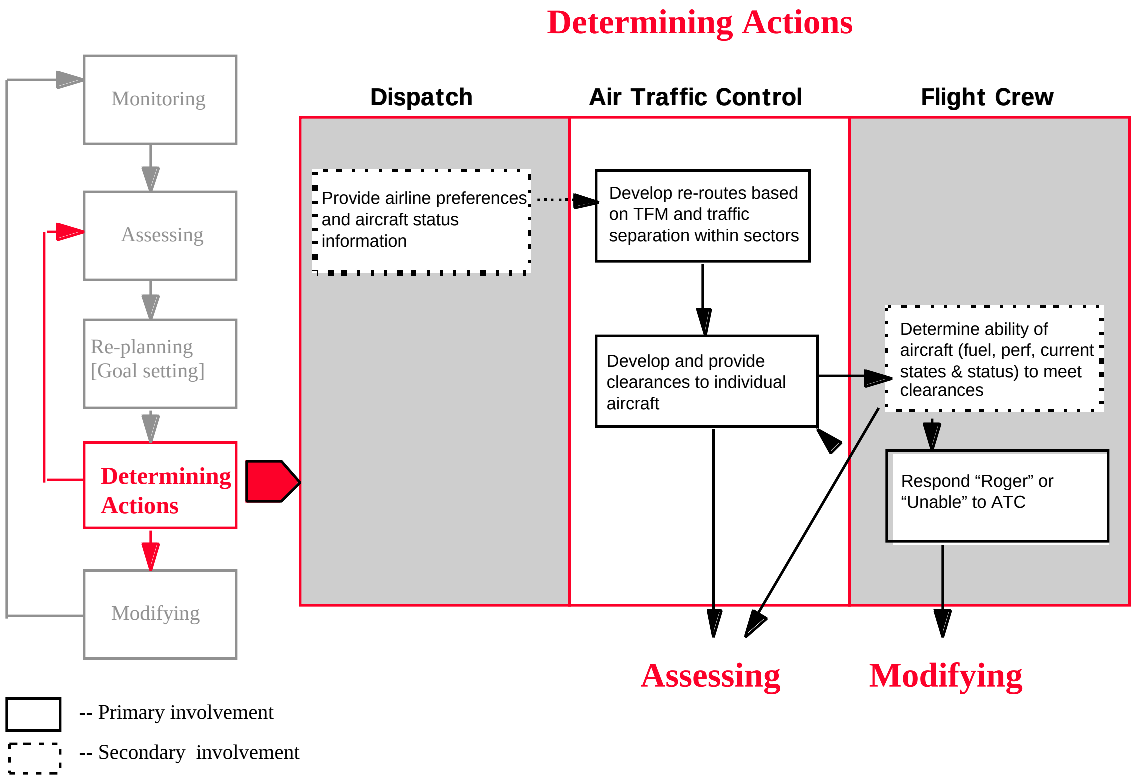


Figure 22. Determining actions in Today's environment

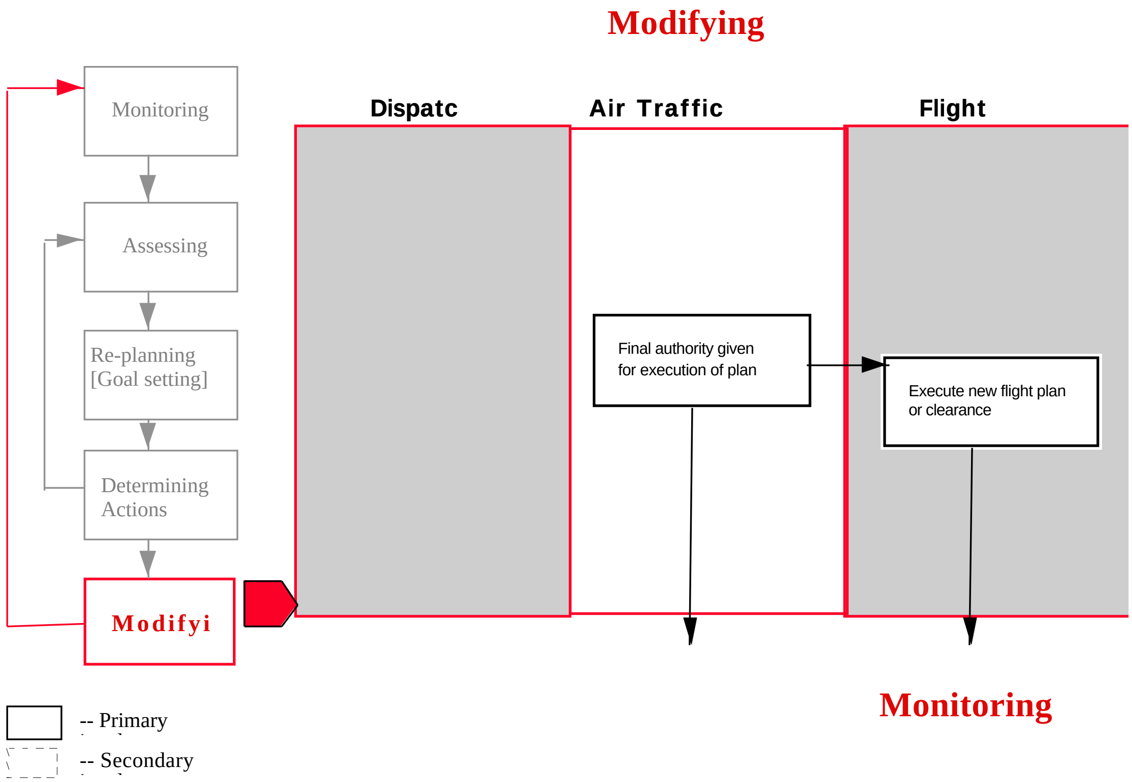


Figure 23. Modifying in Today's environment

Finally, an airborne concept that embraces a more active role of AOC and the flight crew (FC) in monitoring, assessing, [re]planning (setting new goals), and determining actions for the same scenario in a Free Flight environment is illustrated by showing changes in who performs each of the computational processes of flight replanning (Figures 24-28). The main Free Flight - current ATM environment differences implicit in these figures are that:

1. Flight crews and AOC’s play a much more active role in monitoring, assessing, re-planning and determining actions;
2. For any rerouting scenario affecting original position/time goals, new position/time goals are created;
3. Technology allows AOC, ATC, and the FC to share flight replanning goal, constraint, and information in common formats in real time; and
4. Modifying goals or plans is an iterative process that requires feedforward loops to predict the impact on other aircraft and traffic flow as a whole.

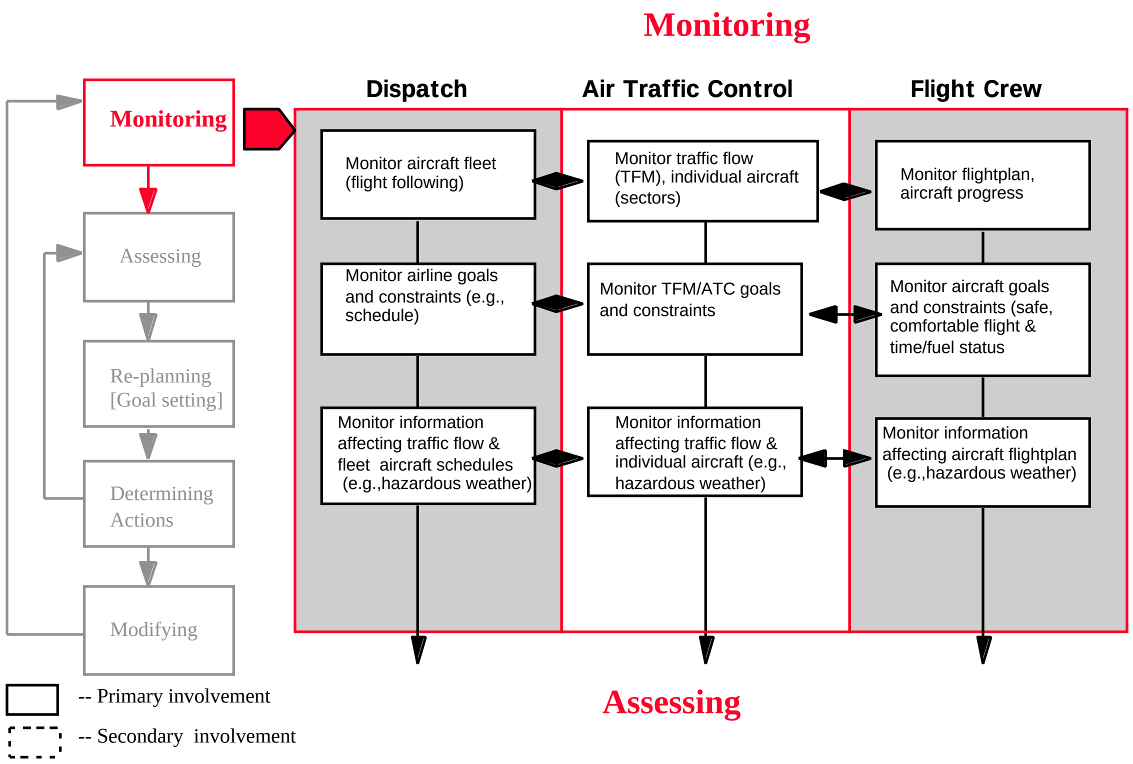


Figure 24. Monitoring in Free Flight environment

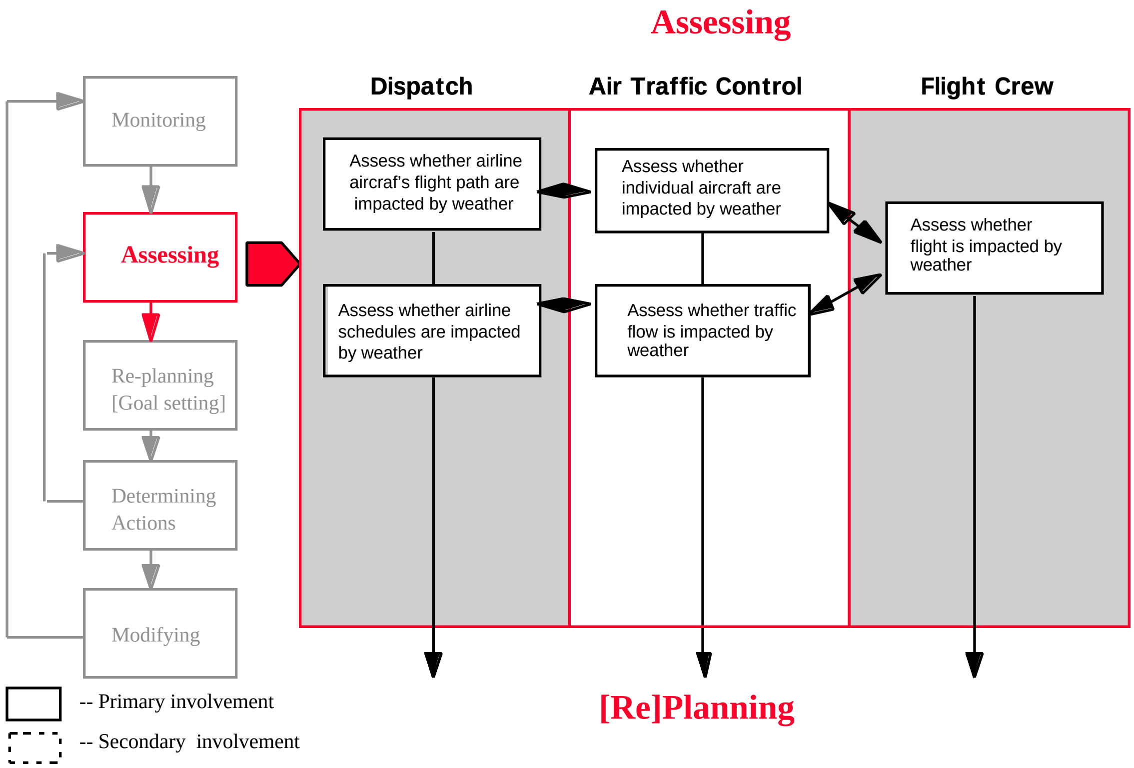


Figure 25. Assessing in Free Flight environment

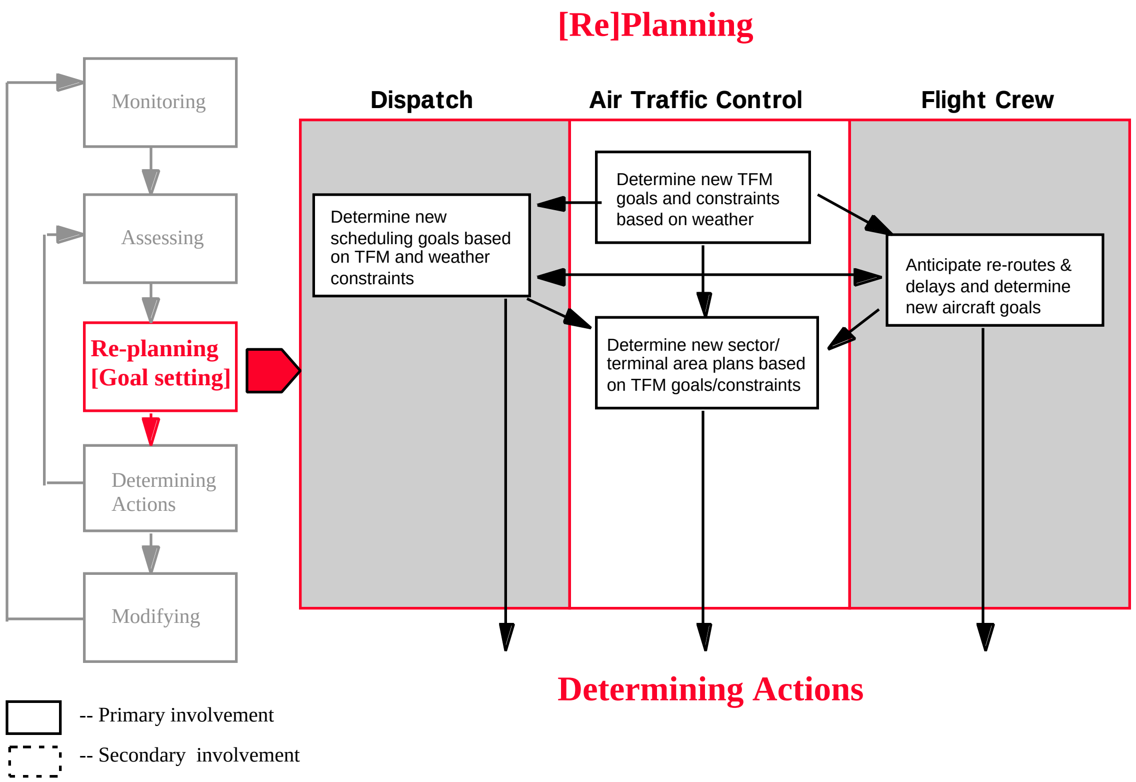


Figure 26. Replanning in Free Flight environment

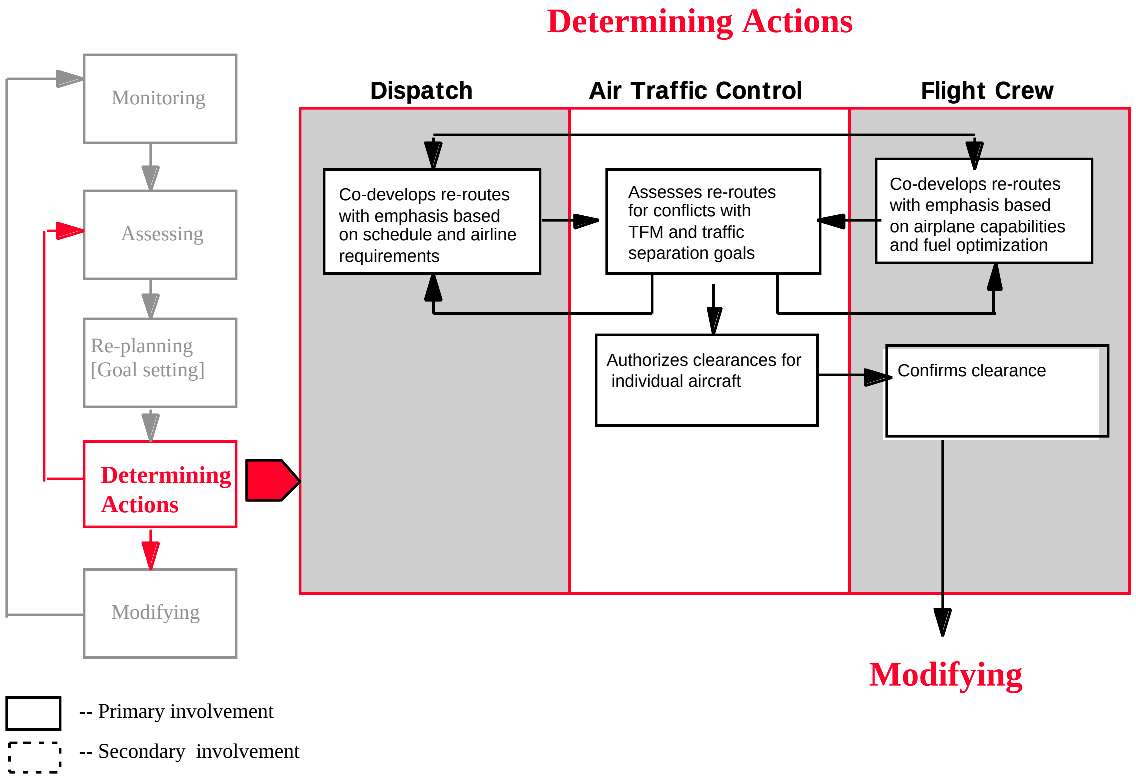


Figure 27. Determining actions in Free Flight environment

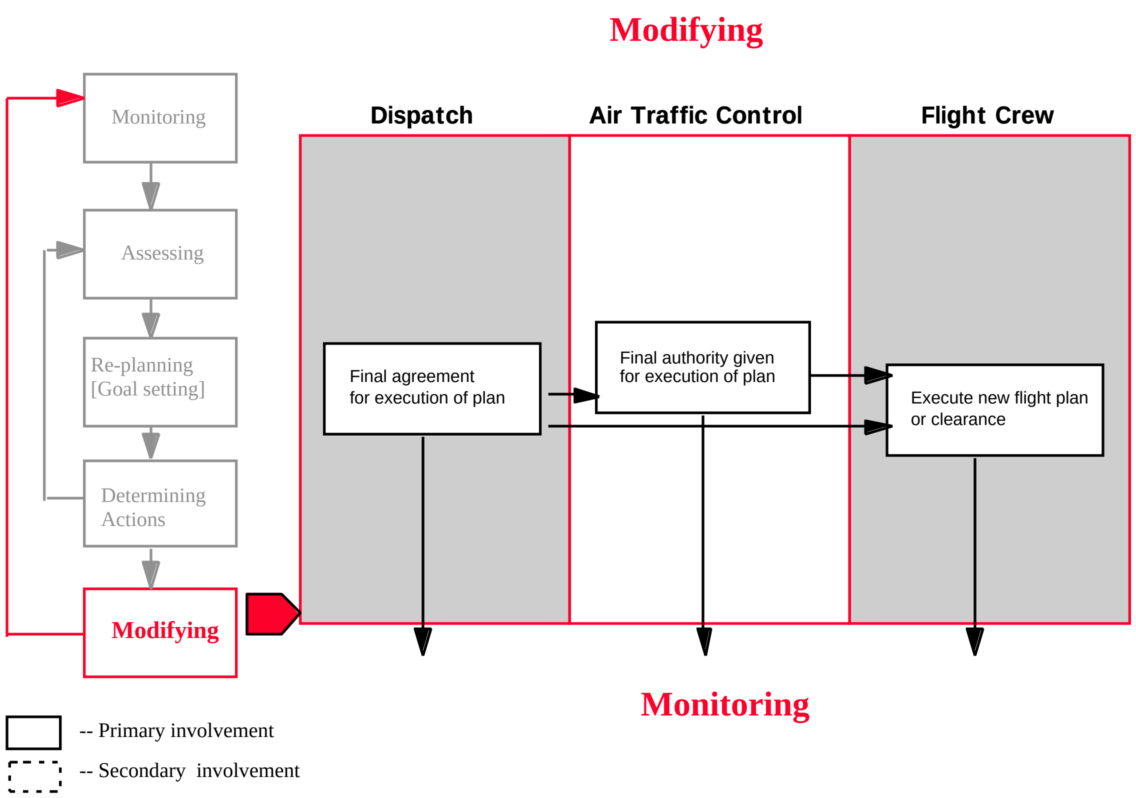


Figure 28. Modifying in Free Flight environment

Figure 29 summarizes the flight replanning functions that are proposed for the flight deck, highlighting those that are new or expanded based on the re-allocation analysis. It should be pointed out that the primary replanning operational tasks of constraint resolution, path optimization, and alternate selection, will have to be much more sophisticated than on today’s aircraft in order to support greater dynamic flexibility in replanning (including strategic replanning to avoid traffic) and to support real-time negotiation and collaboration in making replanning decisions. Figure 29 also provides the mapping, at a general level, between information processing descriptions and operational descriptions of flight replanning sub-functions.

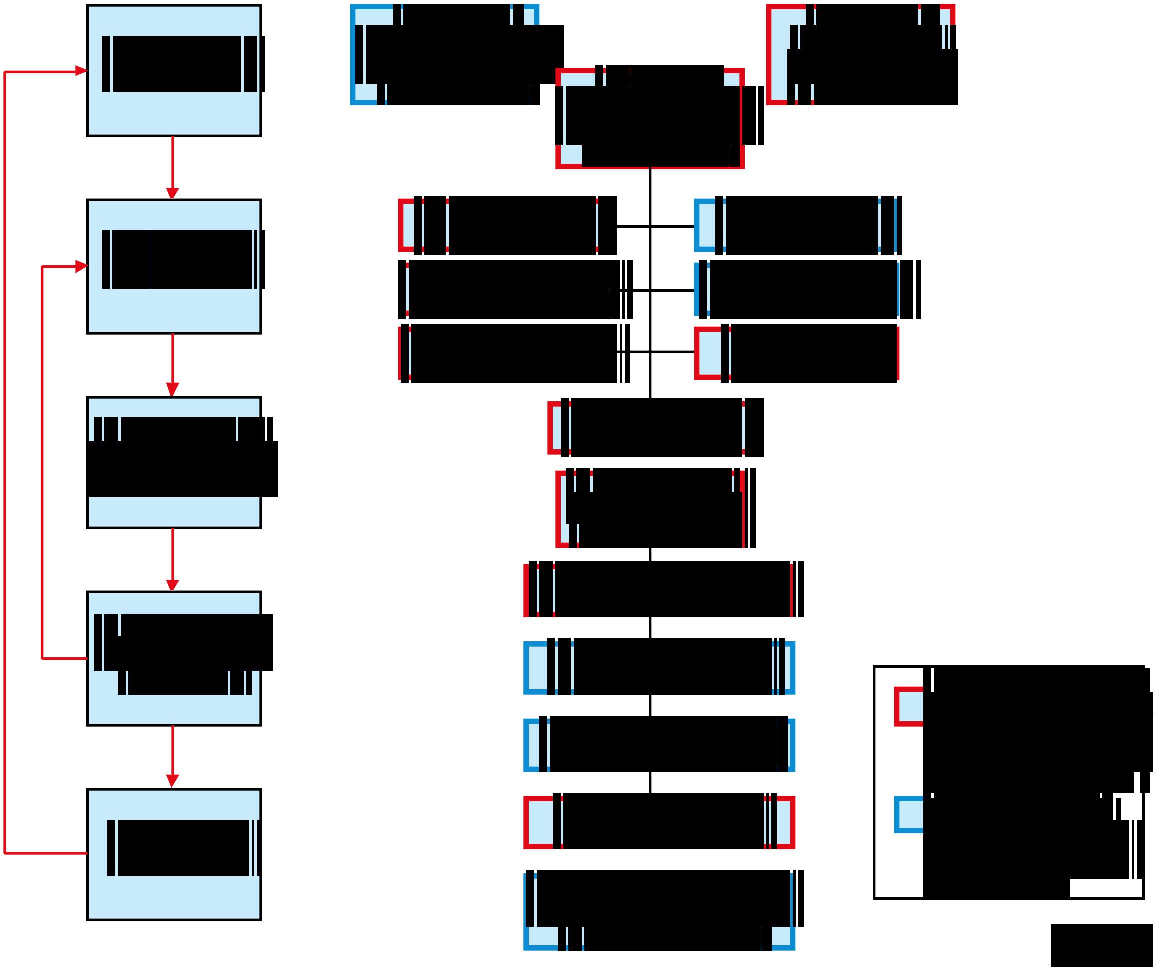


Figure 29. Functions associated with flight planning

5.2 Flight Deck Information Requirements and Information Flow

Having determined the flight replanning functions and allocated them to stakeholders, the next step was to allocate information requirements. For the flight deck, information requirements were arranged according to information sources (Aircraft, AOC, ATC, and Environment), with some information being shared between multiple sources. This is shown in Figure 30.

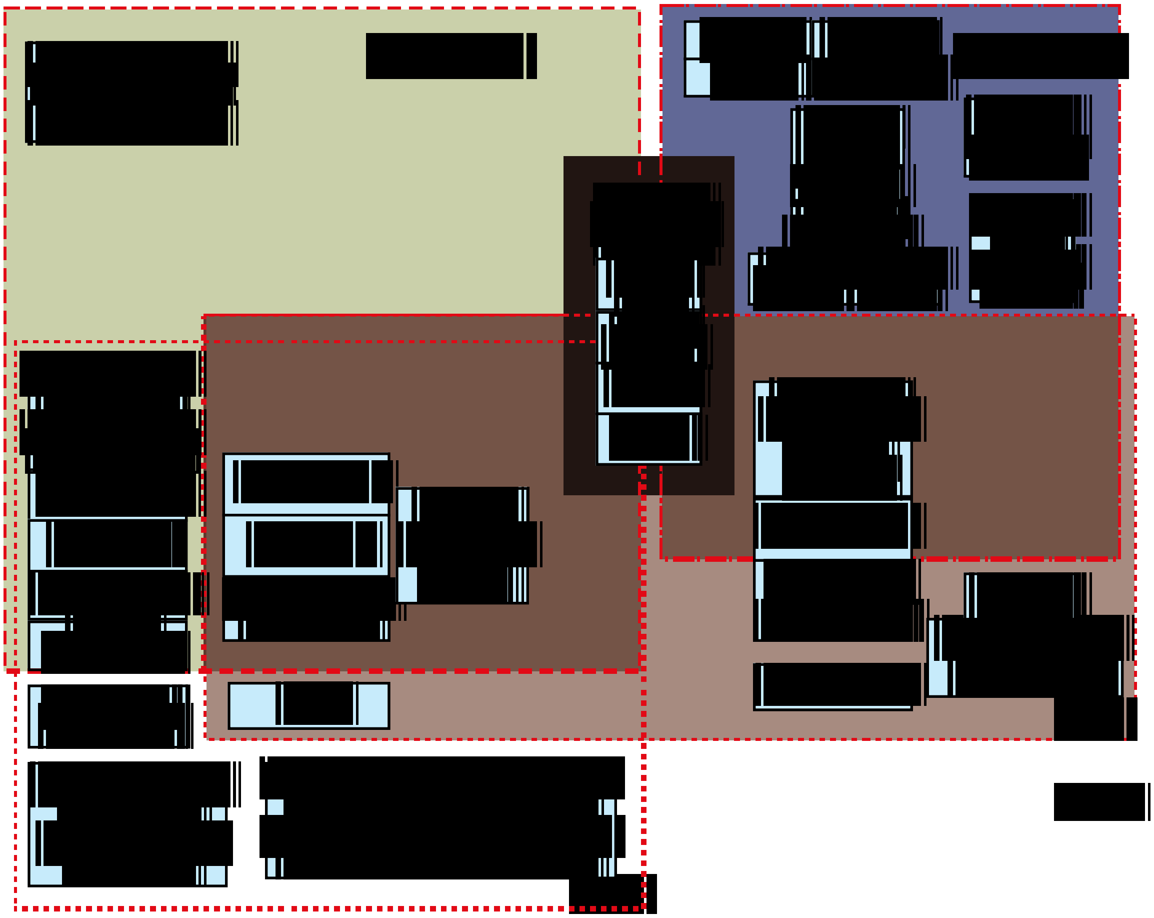


Figure 30. Information shared across Stakeholders

This figure shows information requirements for the flight deck according to the source of the information or the stakeholder with responsibility for the associated function. The central focus of the figure is the region where the flight deck, AOC, and ATC all exercise control over the flight path (they each provide flight path information with the intent of determining the path to be flown). This, then, is an area where controlling interests can clash, and represents a possible source of inefficiencies because a stakeholder with one set of interests (such as flow management or separation assurance for ATC) can usurp the decisions of a stakeholder with another set of interests (such as schedule integrity for the AOC). For example, the controller may issue a re-routing clearance directly to an aircraft without regard for the fleet scheduling objectives of the AOC, preventing AOC from realizing the objectives that led to the original route plan. This depiction provides a convenient means of gathering the information requirements into a structured format and starting the development of a model of information flow. It also allows areas where conflicts or inefficiencies may arise to be identified.

A second theme related to this figure is that all the information displayed in the figure (whether it is “owned” by a stakeholder, or environmental information that can be obtained from a variety of sources), are required to support either: (a) identifying the need for replanning; (b) identifying new flight replanning goals and constraints; or (c) developing plans of actions that simultaneously satisfy all identified goals and constraints. Since part of the replanning process involves resolving conflicts among goals and constraints of various stakeholders, real time collaborative resolution requires that all stakeholders possess the same information. This follows from one of the fundamental premises of CDM, that is, in order to make collaborative decisions, decision makers must share mental models of the situation and solution space. This is best supported by not only having the same information, but also by having it in common formats and having aids that facilitate reference to a phenomenon or event (e.g., the ability to point to a weather system on a graphical map).

For the flight deck, this shared information serves a second purpose; it provides pilots with situation awareness that, even if they don't play a major role in replanning decision making, allows them to anticipate changes and thus manage their workload and overall mission more effectively. In a Free Flight environment, this has potentially enormous benefits in avoiding time critical maneuvers. In the ASO element of AATT, for example, a major goal of the overall Free Flight concept is to provide for more efficient operations while improving safety. One instantiation of improving safety has been described as a three-tiered approach to avoiding hazards. Between strategic planning (1st tier) and tactical hazard avoidance (2nd tier), we should be able to virtually eliminate the occurrence of a time critical warning (3rd tier) such as a Ground Prox or TCAS alert, which is the final line of defense. One of the keys to using strategic planning as a means to reduce the frequency of tactical hazard avoidance and time critical events is providing pilots with the ability to anticipate situations, resulting in their being able to avoid them completely or deal with them more effectively when they do occur.

5.3 Flight Deck Human-Automation Function Allocation

The analysis does not touch on the issue of how the proposed airborne flight replanning functions are then allocated between flight deck automation and the flight crew. A human-centered design philosophy (e.g., see Billings, 1991; Palmer, Rogers, Press, Latorella & Abbott, 1995) suggests that pilots should be involved and informed in decisions and functions that are flight-critical. This would suggest that making the airborne flight replanning function highly automated is ill-advised. On the other hand, because of the computation-intensive, real-time nature of resolving, or collaborating on resolution of, multiple, dynamic flight path constraints with a fuel- or time-, or cost-optimized solution, a high degree of automation is indicated. This raises the increasingly frequent dilemma of devising a useful way to intertwine human and automation capabilities in a way that keeps pilots involved and informed, yet fully exploits automated capabilities. One class of solution that has considerable empirical support is to use automation to filter and chunk information and suggest alternate solutions with benefit/risk and probability information, but allow pilots to make final decisions. A system which allows pilots to input information because of the inherent supperiority humans have in pattern-matching and relating previous experience to the conditions at hand. Such systems are referred to as mixed-initiative systems, and they provide for the input of data and information by either humans or automated systems at various stages of processing, allowing automation to "crunch" on more complete data than it might be capable of generating on its own. These kinds of issues will become paramount as we work out the details of what promises (or threatens) to be a very complex, dynamic airborne function.

5.4 Flight Crew Interfaces

The analysis also does not address the issue of flight deck interfaces. But we can speculate on some central issues that will arise as this work progresses. First and foremost, we are advocating the presentation of considerably more information on the flight deck to support a large flight crew role in flight replanning and flight crew situation awareness and anticipation/prediction. Current flight planning information is distributed on a variety of displays, including the Navigation Display, various Flight Management System (FMS) Control Display Unit (CDU) pages, communication displays (e.g.., ACARS) and paper materials (manuals, charts, flight plans, etc.). By introducing more information and adding the requirement of (1) common formats to build shared mental models, (2) graphic tools to allow reference to common information by distributed stakeholders, (3) more frequent updates and redundancy of information to improve its reliability and accuracy, (4) flexible, intuitive methods of manipulating views, formats, and adding/subtracting information, and (5) graphical information integration to allow a "big picture" view, an enormous display/control burden is added to an already informationally-inundated flight deck. This creates a tremendous challenge.

Developing an integrated replanning "constraint" display alone is a Herculean task. Imagine trying to convey all the "spatial" constraints on flight replanning on one integrated 8" x 8" display; convective weather, turbulence, congested airspace, traffic flow constraints, special use airspace, individual traffic, winds, terrain, etc., all displayed in a meaningful way without clutter or occlusion. Further, depicting all this three-dimensional information in a way that supports the need for lateral and vertical planning and awareness with different range and resolution requirements is a significant issue. The communication links to support real-time collaborative decision making are not trivial either, both in terms of the communication media and pilot interfaces. Again, the interface issues related to the solutions proposed here are daunting, and will require innovative, possibly paradigm-shifting solutions, possibly requiring a hierarchy of information elements based on the analysis conducted as part of the present program.

5.5 Flight Deck Integration

Flight Deck integration must be addressed at architectural, functional, configuration, and pilot interface levels. A new flight replanning concept, especially one which includes assumptions about access of sensed, stored, and datalinked information by new processing modules, must assure that those information links can be supported by the system architecture. The new functionality must "play" with existing functionality, that is, if some sub-functions are already supported in existing boxes, then the new, more comprehensive functionality must interface to those functions and resolve any incompatibilities. The configuration and interfaces must take into account existing constraints (e.g., number and size of displays) and existing, competing requirements for supporting hardware and conduits (e.g., datalink, voice channels, processing boxes), and either propose a "clean slate" solution or a solution which adds devices, boxes, displays, etc., to support new functionality on a flight deck that may be very limited in the ability of existing resources (automation, interfaces, and humans) to accommodate new functions.

5.6 Flight Deck Functional Architecture

As a final step in this effort, we used the reallocation of functions and information along with the resulting information flow to develop a conceptual view of the functional architecture required to support the proposed flight deck role. Because this program was intended to concentrate on the flight deck, we did not elaborate on the ground system views; nonetheless, the information contained in the supporting analysis can be directly applied to the development of such views. Also, because the replanning functionality, constraints, and information needed on the flight deck differ for aircraft supported by sophisticated AOCs and those without such support, we developed a view of the architecture for each type. These conceptual architectures constitute a primary technical deliverable of the program. These are shown in Figures 33 and 34. The major differences are that for operators without an AOC, airline or fleet constraints are removed, more information must be available on the flight deck or from third parties because the AOC is not available as a source of information, and the flight deck will have more flight planning/replanning involvement and responsibility and will collaborate only with ATC on replanning solutions.

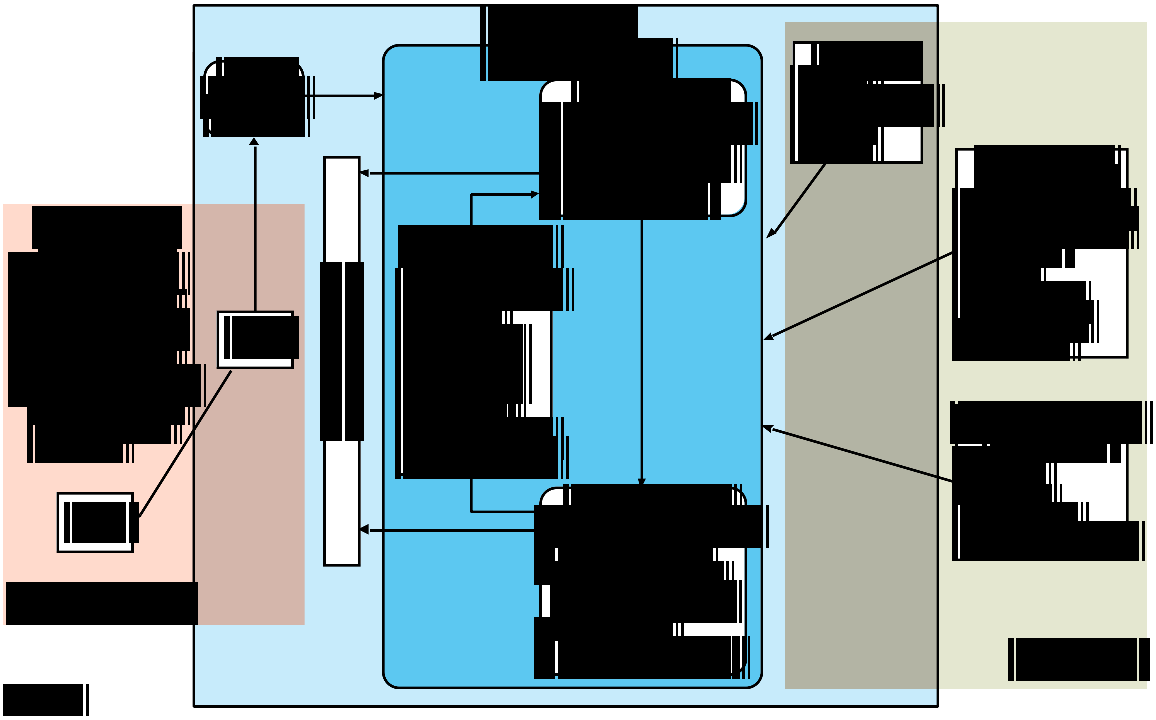


Figure 31. Functional architecture for a flight deck without dispatch-type support

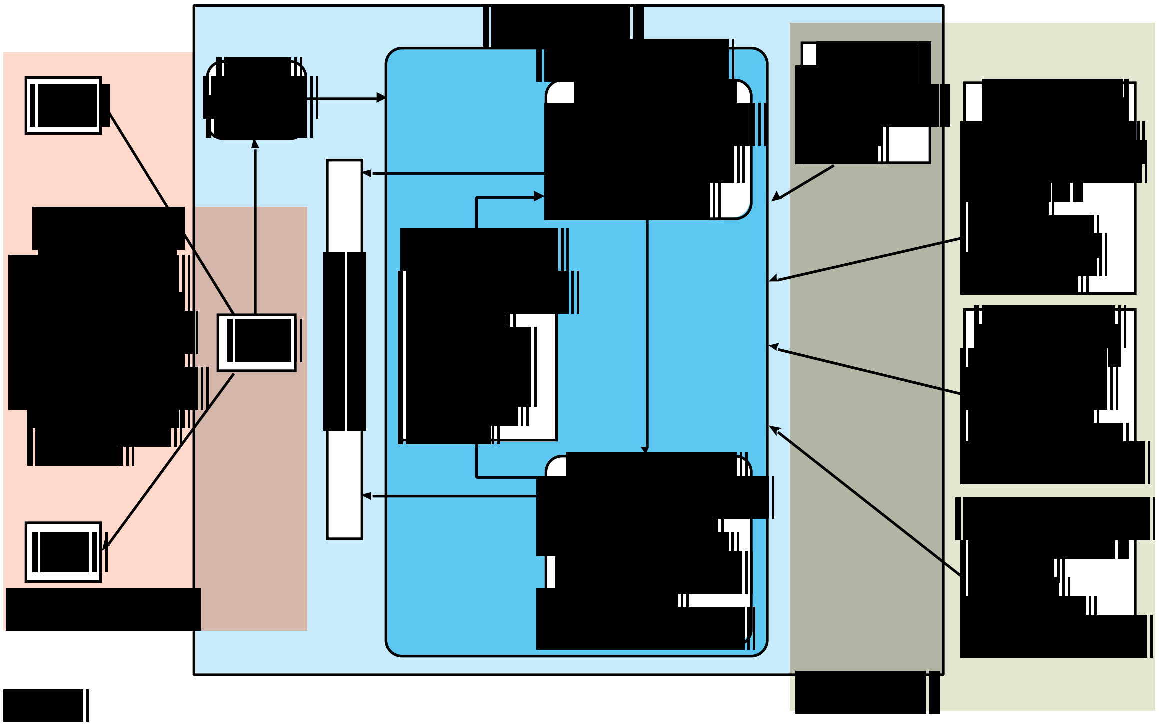


Figure 32. Functional architecture for flight deck with ground-based dispatch support

The general structure of the replanning functionality is based on the earlier decomposition of replanning into the information processing tasks of monitoring, assessing, [re]planning, determining actions, and modifying. This IP model of replanning can be reduced to two major sub-functions: (1) situation assessment, that is, monitoring and assessing the need for replanning and identifying the new goals and constraints; and (2) route replanning, that is, determining the ability to meet the new goals/constraints, determining the most effective route solution, selecting alternates, setting priorities (e.g., least time, least fuel, or least cost), optimizing the route based on winds, and executing the plan. These two sub-functions are the core of flight replanning on the flight deck. In the figures, the situation assessment sub-function is referred to as "conflict probe," since the use of this label refers to similar functionality in other efforts.

In Figure 31 (operators without an AOC), various constraint data are input to the conflict probe to determine if there are any impediments to the flight path. Data comes from several sources, including onboard sensors and databases, and information datalinked from ground sources. Since there can be duplicate, conflicting, and ambiguous data, the conflict probe must perform a data integration function. Raw or processed constraint data can be fed through to pilot displays to provide graphical flight planning constraint depiction. The conflict probe compares the constraints to the current flight plan (or to the aircraft trajectory based on guidance information if the aircraft is not being automatically flown to the flight plan) to determine if there are conflicts. These conflicts are brought to the pilots' attention. If the path includes a departure from or arrival to an airport, the conflict probe checks for potential obstacles, such as towers or construction equipment, from the airports data base. It also determines whether the flight path will encounter an area of traffic delays, based on data on current and projected conditions sent over data link by air traffic management services, and that any required times of arrival are satisfied. It also makes sure that no restricted areas will be encountered. In a free flight environment, where intent information is broadcast by other aircraft, it also checks for potential traffic conflicts based on these intent statements. Then, it checks for possible penetration of adverse weather conditions. All of these data are provided through data link from airport information services, air traffic management, other aircraft, and weather services. In addition, weather radar returns can be incorporated into the weather check for near term decision support.

Terrain is checked for two purposes: first, to make sure that the projected flight path does not intersect terrain; and second, to make sure that the aircraft is qualified for engine out conditions over the flight path terrain. Aircraft drift down procedures and qualifications are incorporated into this check to ensure that the projected path is legal.

Because there is no AOC keeping track of crew time limits for operational legality, a crew data base is checked to ensure that the projected landing time does not extend past the crew's legal limits. Finally, the condition of the aircraft is also checked for path legality. Factors considered here are MEL and CDL items that would restrict the projected path (including altitude and speed limits) and aircraft qualifications, such as ETOPS, restrictions to the continental US, ability to fly over water legally, and landing qualifications. If any of these checks returns a restriction, the system indicates the nature of the restriction to the crew.

The flight guidance system, for the purposes of this architecture, consists of all the sources of guidance information, including the yoke or sidestick and the throttle. This is necessary because the flown path can be determined from any of these sources depending on the modes; if the crew are flying the aircraft manually, it is still necessary to anticipate flight path restrictions. Otherwise, the crew may assume that a manually flown trajectory is free of conflicts when no restrictions are indicated, when the lack of such indications is actually due to the loss of conflict protection under manual flight control.

After the need to replan has been established and the new goals and constraints identified, the route replanning sub-function performs the calculations required to develop a new flight plan that meets all the constraints while optimizing according to specified time, fuel, or cost criteria. Again, many sources of information are required to support these functions, including airport, aircraft performance, and aircraft status databases, and winds and constraint information from ground sources. One human-centered option for the output of this function is that several routing solutions with trade-offs are graphically presented to the flight crew to support the flight crew's collaboration with ATC to agree on final routing. In this regard, it should be noted that ATC is shown on both the left and right side of the figures; this is to depict ATC's dual role (which applies to AOC in Figure 32 as well) as a data/information source on the one hand, and as a collaborative decision maker on the other. Another point that should be made is that it is assumed that the conflict probe and route replanning functions will be performed iteratively, as new solutions that are generated need to be re-checked to assure that they do not violate any unidentified or new constraints. There may be iteration during the collaborative decision making process between human agents as well.

The architecture for an aircraft with AOC support (Figure 32) is more complex because of the inclusion of AOC as both a data and information source and a collaborator for replanning decisions. New constraints must be considered, such as schedules, connections, fleet maintenance requirements, crew duty cycles, etc., and collaboration on replanning solutions is a three way process instead of a two-way process. Much of the flight deck replanning processes may be redundant or overlapping with AOC planning/replanning capability; this redundancy, however, may be desired in a more unstructured air traffic environment, and the airborne replanning functionality may have aircraft status and current data inputs that make it's solution more precise.

In addition, the airports data base and its associated obstacles data base may be more limited than in the aircraft without AOC support because the airline may implement standard departure and arrival procedures based on airport conditions. However, the required times of arrival check is extended to cover RTAs given by both air traffic management and by the company. This allows for the possibility that the company will give an individual aircraft a time restriction to adjust the arrival sequence within the fleet (such as asking a lower priority aircraft to arrive at a fix no earlier than a certain time). This type of restriction would enable the dispatcher to meet a sequence requirement while leaving the means of doing so, by adjusting either the speed or the path or the best combination of the two, to the flight crew and the avionics, rather than requiring the dispatcher to issue a speed requirement based on less precise estimates.

The weather data base for an aircraft with AOC support may be different than that for an aircraft without such support. For example, the company may maintain proprietary weather data with unique characteristics, such as turbulence maps. Although the function of the aircraft data base may be similar to its function in an aircraft without AOC support, it may provide the added value of a final check against dispatcher errors. For example, if the dispatcher mistakenly files a plan to an aircraft with landing visibility below the legal limit for the aircraft, the aircraft data base, coupled with RVR data in the airports or weather data bases, would notify the crew that the proposed plan is not legal for current conditions.

Although these two figures provide a functional architecture view of how replanning would be performed, it is not meant to imply any particular technological solution for the replanning components or for the overall architecture of the flight deck. That is why we have not assigned specific checks to existing pieces of equipment, such as the FMS. There are many possible equipment configurations that could meet the functional requirements implied by the proposed architectures. This, then, does not restrict the proposed architectures to either an existing flight deck configuration or an entirely new one, but allows for the possibility of incorporation into either.

5.0 Conclusions

The general conclusion is that by involving airline operating centers and flight crews more in the flight replanning process (especially for those scenarios involving global constraints such as major weather events or traffic congestion problems), more optimal (from a combined stakeholder perspective) replanning solutions can be derived. This does not necessarily mean that aircraft need more maneuvering or separation authority. It also does not assume a "free maneuvering" capability. Additionally, when replanning tasks are shared in a collaborative decision making sense among air traffic service providers, airline operations centers, and flight crews, then they need shared information in common formats with collaboration aids to assist referencing common events and phenomena. These functional and informational changes on the flight deck should not only reduce current replanning inefficiencies by involving all stakeholders and allowing decisions to be made on the best information, but it should also improve the predictive capability and situation awareness of all parties, which will be required to support the more flexible routing promised by Free Flight.

6.0 Future Work

A logical next step is to flush out the functional architecture described here and develop specific concepts for the processing and pilot interfaces required, including how they would be integrated with existing functions and features. Any proposed interface concepts must consider information transfer and communication requirements as well as data base and processing capabilities to support real time collaborative decision making in the replanning process. It does not necessarily have to assume a flight management system box, but it does have to integrate with other flight management functions. It also needs to consider the presentation of presumably much greater quantities of graphic environmental information in the context of limited display space. Differing display requirements stemming from some information supporting multiple functions (e.g., weather information serving situation awareness, flight control, and planning functions) must be considered. Just as importantly, crew procedures must be considered in conjunction with new flight replanning functionality and information management demands, in order to assess workload bottlenecks and procedural conflicts. Test of a more sophisticated airborne replanning capability to accomplish modest Free Flight goals (e.g., Free Flowing or Free Filing [Beatty, 1997]) and more ambitious Free Flight goals (e.g., free maneuvering) would be appropriate. It could be compared with current replanning capabilities, and more sophisticated systems that are ground based.

Appendix A
Current flight deck equipage relevant to flight planning/replanning

Existing Systems

Navigator

Flight Plan

A flight plan is a series of waypoints that define an intended route of flight. At a minimum, each waypoint in the flight plan must be defined laterally. As an option, some navigators provide the ability to define a vertical constraint at the waypoint. The course between two waypoints in the flight plan is called a flight plan leg. The navigator calculates the course for each leg in the flight plan. The active flight plan can include the route to the primary destination followed by the route to the alternate destination.
The number of waypoints that make up the flight plan varies with manufactures. The Honeywell Business and Commuter Aviation Systems FMS allows 100 waypoints per flight plan.

During flight, the active flight plan automatically sequences, so the first leg of the active flight plan is the active leg that is referenced to the guidance parameters.
The flight plan may also consist of flying published procedures such as Standard Instrument Departures (SID), Standard Terminal Arrival Route (STAR), approaches, and missed approach procedures. These procedures are stored in the navigation data base and retrieved by the pilot and entered into the flight plan. This reduces pilot workload and possibility of entering incorrect waypoint names and latitude/longitudes.

The flight plan may also consist of complex types. These legs types are based on other parameters to determine when the leg sequences. For example, may missed approach procedures require the aircraft to climb to an altitude and then turn left or right and fly to a holding fix. The location at which the aircraft will reach the turn altitude is not defined as a latitude/longitude. The navigator waits until the altitude constraint is satisfied and then commences the turn.

The waypoints that make-up the flight may consist of waypoints from the navigation data base, pilot defined waypoints, or temporary waypoints.

Some FMS allow the ability to load flight plans from external source into active flight plan. This may consist of datalinks or reading of flight plan from standard 3.5” floppies carried onto the aircraft by the flight crew.

Data base

The content of the data base varies with each navigator. There exist few requirements in existing certification standards regarding the required content of the navigation data base. The only requirement is the navigator must store the approach procedure and missed approach procedure if it is to be certified for flying approaches.

Each manufacturer tries to provide maximum content to data base. This provides maximum flexibility to the pilot for entering flight plan information without having to enter latitude/longitudes.

A typical navigator contains the following contents of the navigation data base:

1. Airport Reference Points (ARP)

2. Airport runways
3. NAVAIDs (VOR, VORDME, TACAN, VORTAC, NDB, ILS, LOC, BAC, SDF, LDA)
4. Intersections
5. Airways
6. Pilot defined waypoints
7. Pilot defined stored flight plans
8. Terminal approach procedures (SID/STAR/Approach)

The size of the navigation data base varies greatly between manufacturers depending upon the operational capability of an aircraft. For example, a single engine general aviation aircraft operating the in the 48 contiguous states would require a data base that covers that area. A large business jet that travels internationally would require a world wide data base.

Navigation

The basic navigator uses a single sensor for position information. This may consist of a VOR/DME, LORAN-C, IRS, or more commonly GPS.

Navigators using VOR/DME for input integrate the change in position to compute aircraft velocities.

LORAN-C, IRS, and GPS navigators use the position and inertial velocities from the sensor.

Some navigators are able to interface to multiple sensors for computing aircraft position. These navigators contains logic in software to transition between sensors if failures occur in sensors or the quality of the sensor degrades. These navigators select the best sensor to compute optimum position.

More sophisticated FMS will also have polar capability. These FMS are able to handle the unique problems associated with polar operations.

Lateral Navigation

Lateral navigation is the function of the FMS that sends commands to the flight guidance computer to laterally steer the aircraft.

There exist different methods of lateral navigation. The basic navigator flies leg transitions “open loop”. Once a waypoint sequences, the navigator flies a heading to intercept the next leg of the flight plan.

More sophisticated FMS fly a ground track during leg transitions. The FMS is able to compensate for changing wind and maintains the aircraft on the computed ground track. This allows the FMS to maintain the aircraft in protected airspace during an airway transition, fly holding patterns including entry and exit procedures, procedure turns and holding pattern course reversals for approach procedures.

Vertical Navigation

VNAV is the function in the FMS that sends commands to the flight guidance computer for vertical control of the aircraft. VNAV can be used to climb, cruise, and descend the aircraft on the pilot selected speed schedules. These speed schedules can be defined to meet the operational objective of the flight. For example, to reduce cost, the cruise speed schedule chosen could be Long Range Cruise (LRC) or to reduce time enroute, maximum speed may be chosen.

On more sophisticated aircraft, the vertical descent path can be defined as a geometric angle as opposed to a vertical descent rate.

VNAV is not a required minimum function for navigators today

Performance

The performance function of the navigator varies greatly between manufactures. At a minimum, navigators provide ETA to waypoints in the flight plan using current groundspeed. More sophisticated FMS provide fuel management estimates for the flight plan, estimate optimum altitude, cruise modes (LRC, maximum speed, maximum endurance), and step climbs. Step climbs are enroute climbs made to higher altitudes by the aircraft to reduce fuel consumption. These climbs are necessary enroute because of aircraft weight, it is not possible to climb directly to the higher altitude. As fuel is burned, the altitude is achievable for the aircraft.

What-if situations is the capability of the pilot to determine the consequences of the flight if a performance parameter is changed. For example, the pilot may ask “what if I fly at maximum speed instead of long range cruise at this altitude”. The FMS allows the pilot to enter the necessary data and provide the new fuel requirements and ETA.

Thrust Management (Autothrottle)

Some FMS are equipped with a full flight regime autothrottle. These FMS mange the vertical and speed of the aircraft. Full flight regime means the autothrottle can be used from takeoff to landing.

When combined with vertical navigation, autothrottle provides the ability of the pilot to fly complex vertical flight plans involving descent and speed requirements.

Navigation display

Navigation displays vary with each aircraft. The low end general aviation aircraft consisting of a “panel mount” navigator, has a built in CDI and does not interface to displays on the flight deck. The CDI provides crosstrack information.
The more complex navigators interface to electro-mechanical displays, and EFIS displays. EFIS integrates other situational information such as waypoints, NAVAIDs, airports, and weather radar displays.

Pilot interface

Interface consists of rotary knob and a few dedicated keys for dedicated functions such as direct-to. The interface requires pilot remembering functions and how to activate them.

More sophisticated FMS provide a CDU with alphanumeric keyboard. These FMS have multiple function keys that may be used for dedicated task, such as radio tuning, direct-to, etc.

Flight deck interface

No minimum requirement today.
Able to tune radios
Provide information for driving displays for non-essential functions (Airshow)
Initialization of sensors

Interface to flight deck printers

Data Link

This section discusses exiting datalinks used by aviation.

ACARS

The Aircraft Communications Addressing and Reporting System (ACARS) was developed and implemented for the aviation industry by ARINC (Aeronautical Radio Inc.) in the mid 1970's. It was designed to cut down on flight crew work load by utilizing computers on board aircraft and at ground facilities to exchange routine reports and messages. It consists of an air/ground network which enables aircraft to automatically transfer information from onboard sensors by VHF radio link to ACARS ground facilities. It is then relayed via the ground stations to a central computer processor where the data is converted into inter-airline operational messages.

The Management Unit (MU) onboard the aircraft receives ground to air messages from the radio transceiver and controls the transmission of air to ground transmissions. It is also connected to sensors onboard the aircraft. These sensors provide automatic Out, Off, On, and In time reporting (OOOI). Off and On events are typically recorded using sensors connected to the aircraft's landing gear. In and Out events are usually triggered with the opening or closing of the passenger doors, or the release or application of aircraft brakes. The GMT of these events are recorded and transmitted to the ground.

AFIS

Automated Flight Information System is manufactured by AlliedSignal. AFIS provides the ability for the flight crew to transmit and receive textual information. This consists of flight plans, weather, air traffic control clearances, and messages. This information is displayed either on a dedicated AFIS display or another display capable of interfacing to AFIS (such as an FMS).

AFIS interfaces to the airborne radiotelephone or SATCOM installed on the aircraft. Using modem technology, AFIS places a telephone call to the Global Data Center and connects to a modem. The requested data is transmitted and stored onboard the aircraft. This data is then available for display on board the flight deck.

Airshow GENESYS™

Airshow GENESYS is an existing system installed on may business aircraft today and is manufactured by Airshow, Incorporated (website is www.airshowinc.com). The GENESYS system provides text and graphics for aircraft flight deck and cabin displays. The flight deck display usually consists of approximately a 6" LCD monitor mounted on the center pedestal or next to the co-pilot. This display is capable of displaying the following data when requested by the flight crew:

1. Airport weather - this consists of NOWRAD radar images for airports in the USA.
2. National weather - this image displays radar images for the USA. It is a composite of the NOWRAD images.

3. Satellite weather - consisting of worldwide images from visible and infrared satellite cameras.
4. Textual weather - the pilot is able to request METAR, TAF, NOTAM, PIREP for domestic and international airports
5. Cabin displays - able to view the same data being displayed in the cabin.

The cabin displays consist of the following data:

1. Geographic maps for the flight and current aircraft position
2. Names of cities and geographic land marks
3. Current aircraft altitude, groundspeed, temperature, distances, and ETA
4. Display of Airshow Network features which include:
   - News
   - Sports
   - Weather
   - Financial information

The GENESYS system interfaces to the airborne radiotelephone or SATCOM installed on the aircraft. Using modem technology, the GENESYS places a telephone call to the Airshow Communication Center and connects to a modem. The requested data is transmitted and stored onboard the aircraft. This data is then available for display. A NOWRAD radar image requires approximately 2-3 minutes to receive onboard the aircraft. Airshow uses 4800 baud modems for data transfer.

Appendix B
Raw planning/replanning interview data

Summary of NWA SOC Meeting

Goal: Use Least Fuel Plan.

Constraints: NWA operates equipment on long routes which results in "tank" limited situations. This means that fuel is the primary consideration in the flight being non-stop. This occurs internationally on their long-haul flights, MSP-Hong Kong, Detroit or JFK or Boston to Narita, where the available capacity of the aircraft is not used in order for the range/Gross Wieght tradeoff will allow them to fly non-stop to the destination (it is a company policy for NWA to avoid a stop along the way for additional fuel). Even in the domestic U.S. their DC-9 fleet flys long routes which is at the upper most of their range, resulting in "tank" limited concerns with cargo and passengers.

Another constraint for NWA in international routing is the issue of overflight fees. Particularly Russia, and to some extent the result of the privitization of Candian ATC, charge high overflight fees making circuitous routing preferable from an economic standpoint.

Another constraint in the flight planning process for NWA is turbulence. NWA prides itself on identifying and subsequently avoiding turbulent airmasses in order to provide a smoother ride to their passengers. To that end, the Meteorology department at NWA develops Turbulent Plot Areas (TPAs) and provide those to the flight crews so that if RE-PLANNING does become an issue, they have information at hand regarding areas & altitudes to avoid in the replanning process.

In the SOC there is software package that updates the Turbulence Plot Area based upon new meteorological information obtained from private companies or NWS. This software is designed so that it will examine all the currently active flight plans (airborne aircraft) to determine if a Turbulence Plot Alert should be issued.

Information Used in Flight Planning:

NWA uses all the information on the list, but was keen to point out that Weight & Balance comes personnel located in Memphis, as opposed to Load Planners that are a part of the Minneapolis-based SOC.

Meteorology	Forecast and current information on en route winds, temperature, turbulence, icing, and other phenomena
Maintenance	Aircraft MEL and CDL status; aircraft routing; planned and required maintenance
Crew Schedule	Crew training and qualification records; duty time and flight time limitations
Load Planning	Departure and arrival runway, flap selections and allowable weight calculations; takeoff power settings; aircraft loading schedules, and constraints
Aircraft Data	Tail number-unique fuel flow and fuel burn characteristics; performance capabilities and limitations
Station Data	Availability of runways, gates, and ground equipment; fuel cost and availability; fuel tankering analysis

Nav Data	Database containing all FAA preferred and company routes, published waypoints, airways, SIDs, and STARs
Marketing	On-time performance history and sensitivity per city-pair, i.e., to/from hub; connecting passenger matrix and flight availability
Flight Schedule	Relational database linking all flights in the operating schedule; aircraft routing, fuel tankering and delay analyses

Tasks Involved in Flight Planning:

There were two classes of tasks, important and support, identified for developing a flight plan at NWA:

Important ("attended to first")

- Payload determination and coordination with load planners for weight and balance calculation
- Alternate airport determination
- Route selection
- Re-dispatch point determination for long range flights
- Aircraft minimum equipment verification

Supporting ("necessary to complete, not the first priority")

- Speed and altitude profile calculation, and estimation of flight time
- En route alternate selection (as required)
- Fuel requirement calculation and coordination with fuel loaders
- Coordination of the flight plan with the pilot
- Flight plan filing with the FAA

Historical information is also taken into account when assigning aircraft type and estimating load capacity requirements. NWA takes into account the last 7 calendar days and the last 7 same-day-of-the-week (i.e., the last 7 Tuesdays) when estimating load/passenger capacity requirements.

Issues Associated with Replanning

Sometimes the ARTCCs will offer more direct routing to NWA flights. The SOC believes that the NWA flight crews have been sufficiently briefed that they no longer accept what is offered, but in fact do coordinate with the SOC to determine if there is an operational gain to be made by accepting the pro-offered route.

The NWA SOC representative that was met with expressed concern regarding the idea of each aircraft being soley responsible for replanning. The obvious issue of that flight crew not being aware of "big picture" concerns for the airline, but the opportunity is presented to the flight crew of taking more time than is required for a nominal flight between that city-pair, which in some cases could exceed allowable crew duty times. This could have a profound impact on the system, i.e., no crew available to takeover the flight at the destination because the in-bound crew cannot fly for 8 hrs (the proscribed duty-rest cycle).

When asked about the idea of locating a high-resolution color printer on the flight decks of the fleet, the SOC rep thought that would be enormously beneficial in terms of a shared "world-view" of the routing situation, thereby allowing a better dialog between the flight crew and the dispatcher.

Greatest Existing Inefficiencies

(1) Working with Central Flow Control on rerouting (in reaction to non-normal operations, such as severe weather) is not a well-structured effort. No existing protocol is in place that guides those interactions. Sometimes Central Flow Control will “work with you” other times they are unapproachable.

(2) Communications during Non-normal operations could be improved. Held up as a show case example was a North-East Regional Hotline that is put in place between various ATC facilities (Control Towers, TRACONs, and ARTCCs) when severe weather (i.e., blizzards) disrupte operations. The purpose of the hotline is to facilitate communications, with regards to coordinating traffic flows, between these facilities. The airlines benefit by “eavesdropping” on the conversation because it allows them to anticipate actions that will be taken by ATC personnel, such as:

  - closing runways
  - redirecting traffic flows (in-bound and out-bound from airports)
  - preferred routing that is temporarily put into place

(3) Realistic Holding Times (e.g., “Expect Further Clearance”). With the “tank-limited” flights that NWA operates, such as DC-9s at the limit of their range, it is important that they receive realistic estimate of airborne delay in order to avoid unnecessary diversions.

Flight planning/replanning functional analysis
Structured interview with Spirit Airlines Head Dispatcher

Background information

Airline/Company/Organization (if applicable): Spirit Airlines (fly a fleet of approximately a dozen DC-9's among Detroit, Boston, Newark, Kennedy, Atlantic City, Orlando, Ft. Lauderdale, Ft. Myers, Myrtle Beach & Tampa)
Position: Head of Dispatch (Dispatch size: about 6 people during normal working hours)
Function: Dispatch, Flight planning, Weights/Balances, Flight following, etc.

Flight planning description

Describe the sequence of **activities** that you typically perform in developing and filing a flight plan. Include your **goals** in flight planning, the **constraints** that you must consider, the **information** you need and its **source**, and other **stakeholders** that are part of the flight planning process [interviewee should be queried for each bolded item repeatedly during discussion].

Flight plan: Flight plan includes climb and descent profile, cruising altitude (includes performance at several altitudes), speed, alternates, flight no., equipment, time of departure, route of flight, total in-flight time, burn (include 8 minutes taxi), pax, reserve fuel, total fuel, MEL items, CDO (configuration deviation that might affect performance), remarks (e.g., what to expect at destination, jump seat riders, etc.). Engines, flap settings, temperatures, winds, preferred runways for takeoff and landings (this could change if winds shift, so there will be a difference between plan and optimal real time flight).

Activities:

Flight planning starts as soon as shift starts. Sequence -- Look at night before, turnover log, night dispatchers briefing, NOTAMS, winds, weather, ATC advisories, unusual things that need special attention -- try to get big picture of where equipment is, does it make sense, what is projected flow, maintenance reqts, pax and luggage reqts, etc. Often times full pax load and luggage load (e.g., during Christmas or golf season) will dictate which equipage is used (e.g., their "hush-kitted" aircraft have less range or greater weight constraints). All this is to try to get a handle on equipment allocation for the day's flights. Are there company mandates, who is the crew (e.g., some crews are more willing to take an aircraft without the Autopilot). Part of big picture is Charter flights, which have some weird requirements in terms of destinations, so have to look at fuel prices, unique aspects of those flights, etc. (note: Flight crew doesn't always have big picture of why some of these decisions are made in terms of equipment, optimal route planning. Crews are a little more in dark without FMS's. Rely on dispatch more heavily.)

Once equipment is set, they try to start flight planning for a particular flight 90 minutes to 2 hours ahead of time, and try to get plan filed 60 minutes before flight. They don't like to start planning further than 2 hours ahead of time because things can change so much. They have a dispatcher alert on display that tells them when to get going on flight plan for particular flight. They also have alerts in systems that will tell when airports go below minimums, TFU advisories, weather advisories, etc. They have 3rd-party software that actually does the flight planning (Jeppesen, I think). They have all the numbers for their aircraft (from Douglas -- big books that show performance depending on engine, model, etc.) -- information on the departure and destination airports, alternates, winds, equipment, etc., are input, and the program figures out optimal flight plans from a fuel burn perspective (speeds, altitudes, climb & descend profiles, runways, etc.). Lots of factors to consider in each part of plan -- for example, with alternates, they look at weather, which airports they have agreements with for refueling, what the fuel prices are, how easy they are to get in and out of, etc. They don't like to list Atlanta as an alternate for example, because they can be waiting on the ground for a couple of hours to get refueled because Delta gets priority from the fuel providers. Wasn't clear to me whether constraints could be entered into software program for lateral route planning, or if that is done by hand. Big difference from aircraft to aircraft. The flight plan will actually show $0 default in terms of optimal altitude, and show extra $$ for flying different altitudes (e.g., 33000 - $0, 31000 - $153). Fuel estimates are based on straight-in distances from A to B. Flight plan is automatically sent to center and printed. Usually a matter of minutes before ATC responds that it is filed. Crew can't pick it up until 30 minutes before flight- center sends it to departure control, crew on ground picks up departure clearance 30 minutes before flight. Sometimes departure clearance is not there.

Goals:

Three overall goals of flight planning (in order of priority): safety, integrity of schedule, economics.

Constraints: (in general order of priority; hard vs soft constraints was more meaningful to interviewee. h=hard, s=soft)

Equipment selection:
maintenance requirements h
bulk up or zero fuel weight problem (need to bump bags) h
equipment weight limitations and ranges h
airplane performance limitations h
utilization costs (depends on aircraft efficiency, leasing/ownership, etc.) s
head count s
aircraft ownership (owned or leased) s
bag count s
pilot preferences s

Route planning:
weather h
congested airspace h
special use airspace h
ATC constraints (general) h
ground congestion (like a closed runway) h
fuel consumption s
airplane performance s

Information (source):

SIGMETS
PIREPS
NOTAMS
ATIS
Custom-alerts
Weather (3rd-party (Aldrin), NWS, and any other source available) -- 15 min updates
Traffic (centers or TMU) -- TMU has CETA addresses for all airlines - computerize and automatically send advisories to all airlines.
Aircraft (aircraft weights, performance, etc. -- modeled in database)
Connections, schedule impacts (scheduling, station personnel)

Winds (3rd party)
Maintenance reqts (maintenance)

Generally, go by published data. But if something doesn't make sense, will start making calls to verify if data are right. For example, if two weather reports 15 minutes apart are drastically different, they will make calls to verify. Some alerted items, some human "logic checks" of data.

Stakeholders:

ATC
Dispatch
Aircraft
Pax
Maintenance
Schedulers
Station personnel
Airline

Specific questions:

Q. Do certain activities have to occur at certain times?
A. The equipment issues are figured out first, then route planning.

Q. In what order are constraints considered
A. All hard requirements are considered first (weather, congestion) then efficiency items

Q. What are the key aspects of the operational context that affect planning? (For example, class of operator, long haul vs short haul, normal vs irregular operations)
A. Charter vs scheduled flights, normal vs abnormal (wide-spread weather, congestion, etc.) flying day

Q. What situations or conditions change the importance of flight planning goals?
A. Safety is always first, integrity of schedule always second. If no connecting flights, economics and integrity of schedule may be closer together in priority, but order doesn't change.

Q. What situations or conditions change the importance of flight planning constraints?
A. Many of the soft constraints go out the window when the hard constraints (weather, congestion, maintenance) are overriding.

Q. Which constraints affect just a single aircraft vs several aircraft vs an entire fleet?
A. Weather and congestion can vary in their effects, but usually cascade. Performance and maintenance reqts are usually individual aircraft.

Q. How do you deal with dynamic factors, that is, how often do you need information updates? A. Would like wind updates a lot more often. Don't like to plan too far ahead. Check as many different sources of weather as possible.

Q. How do you handle uncertain or probabilistic information?
A. Don't plan too far in advance, check often and multiple sources.

Q. What information about the aircraft is needed by related functions (traffic flow management, conflict management, airline scheduling) to support planning? How do you get that information? A. Dispatch gets position reports from aircraft, try to keep periodic communication with aircraft. Situations where they need to get in touch with crew, but they have to go through ARINC connections, etc. Sometimes a problem where can't get a hold of crew. So communication links are still not completely reliable. Pilot may have dialed in wrong frequency, lost communication, etc. TMU gets update info from airplane as they are passed along from sector to sector or center to center (also radar information). Relationship with ATC is very good. Dispatch tries to be sensitive to ATC requirements - on a bad weather day, they know ATC will be harried, so try to comply, not have lots of special requests, etc.

Q. What are the major decisions that have to be made in flight planning? Who normally makes them?
A. Equipment (dispatcher, maintenance), flight plan (dispatcher). Spirit dispatch had to schedule flight crews, etc., at beginning when they had just a few planes, but now big enough that there is separate scheduling department. Natural growth to break out different functions into different departments. Next step will be to evolve a flight following department. Dispatch is responsible for safety and legal aspects of flight plan. Flight following responsible for making sure of departure times, arrival times, published delays, fuel out, fuel in, etc.

Q. Explain the roles of each of the stakeholders in flight planning
A. Dispatcher makes decisions, but has hard constraints (e.g., maintenance) that must be taken into account. ATC can accept or reject filed flight plan.

Q. Under what circumstances (e.g., system failure, airport closure, etc.) does the nominal collaboration for flight planning change?
A. Roles change once aircraft is in air (see later section)

Q. How is flight planning collaboration different for different circumstances?
A. More constrained on "bad" flying day (lots of weather, congestion)

Flight replanning description (dispatcher considers replanning to be any change to flight plan after filed; as a consequence, overriding theme is late departures, which are common phenomena. See attached list of causes of late departures)

Describe the sequence of **activities** that you typically perform in replanning a flight plan during flight. Use the example of diverting around a major weather system. Include your replanning **goals**, the **constraints** that you must consider, the **information** you need and its **source**, and other **stakeholders** that are part of this replanning process [interviewee should be queried for each bolded item repeatedly during discussion].

Activities

Generally, activities of replanning and planning are similar. Usually have to calculate burn and time, figure out where aircraft is now, so use real location, what ATC has told them is their projected route, actual fuel on board, etc., and dispatch does recalculations - minutes and burn, fuel remaining at destination. Dispatch replans the flight plan if the change is required before the flight leaves the gate. When in air, dispatch provides info, doing recalculating of fuel, weight, etc. to see if they can still make destination. Replan is after crew has paperwork, pax loading is set, etc., and something comes up that requires delay, equipage change, route change, etc. Anything where weights change, pax changes, etc. because of some factor. Different numbers than original plan are utilized. Also, if there is a diversion required, dispatch will file a new flight plan from the diversion airport to the original destination if the flight can continue on (e.g., unanticipated stop for refueling). Replanning in the sense of changes to the planned route, speed, altitude, destination STAR or runway, etc. after the aircraft is airborne, is primarily the responsibility of the flight crew, with supporting information from dispatch. They do not re-dispatch. (Which is flight planning from point A to some place along the way -- can't make it to destination on fuel on board). They will just plan for a fuel stop if they need it.

If changes are things like speeding up to make up time or re-routing around a storm cell, dispatch considers those deviations, not replans. Route deviations are entirely up to the pilot. Flight replanning in the more formal sense of filing a new or modified flight plan while enroute, involves lots of communication between dispatch and the aircraft. For example, dispatch will relay information to the flight crew about new weather or traffic advisories that will likely affect their flight at some point in the future. Sometimes the flight crew will already have this information, and sometimes they will not. If there are changes required in alternates, or a diversion is required, dispatch does the calculations for fuel burn predictions, optimal altitudes, etc. When airplane is in air, joint decision making between crew and dispatch. When diverting for fuel, flight crew will request clearance real time, and make diversion. Then while on ground, new flight plan will be filed. Flight crew will provide position information, fuel remaining, etc. Dispatcher monitors every minute of flight -- gets a lot of alerts that they can convey to flight crew. Dispatch will re-file -- they have autofiling, so plan automatically goes to proper center. For diversions such as mechanical or medical, nearest suitable airport. No questions. Get message from crew, may ask dispatch for weather, ATIS, etc. May be split decision, or crew may make decision on where to go.

Late out of gate. If delay on ground, then causes replanning of fuel, weight, etc. May be on “congo line” -- in line with other aircraft, so you can't go back to gate or if you do you get on line in last slot. Also winds, fog (on the field). A major issue is whether you are legal to launch (which you aren't if destination field is below minimums). Once launched, then if airport closes in, different situation. May hold, and then depending on fuel, go to alternate. Dispatch replanning is really focused on before aircraft leaves ground; after in air, general impression is that the crew is the major decision maker, for example as to whether to hold for awhile or to divert. Get info from dispatch, like weather prediction, etc. Once decision is made to divert, dispatch may be involved in planning to alternate, calling alternate airport, etc. Alternates should already have been assessed so diversion is to “acceptable” alternate. But pilots may have to divert to somewhere that isn't a standard alternate. Have to call FBO (fixed base operator) and see if they can accommodate them. Wherever they divert to, they have to rely on good will to help with situation, pax, fuel, etc. Much more on their own when diverting to an unplanned airport. When diverting to another airport serviced by Spirit, usually because of weather, worry most about which way is weather moving, which affects what further delays are most likely. This is more important than other logistics, pax connections, etc. Talk to crews on the ground at that airport as well.

List as many possible causes for in-flight replanning as you can think of. (from most to least common)

Late departure (see attached sheet for listing of reasons for late departures)
Weather changes
Traffic (congestion) changes
Airport surface changes (runway closed, accident, etc.)
Winds (changes or data errors), i.e., insufficient fuel
Medical emergency (often goes hand in hand with other problems (weather, congestion)
Mechanical problems

Goals

Goals and priorities are same as for planning.

Constraints (generally in order of priority, h= hard, s=soft)

weather changes h
congested airspace changes h
special use airspace changes h
ATC constraint changes (general) h
ground congestion changes at destination (like a closed runway) h
wind changes or errors h
alternate airport status change h
crew duty/rest cycles h
airplane model performance errors h or s
turbulence h or s
connecting pax (no FIM's (flight interruption manifests) s
on-time performance s
fuel efficiency s
fuel prices (will consider in choice of new alternate) s
station personnel schedules s
FBO agreements s
maintenance resources s

note: Tried to get her to prioritize between on-time performance and fuel efficiency, but she wouldn't. I think those issues related to deviations are outside her areas of concern. Dispatch doesn't really think about replanning or deviations for fuel optimization once aircraft is airborne. Saving fuel in the course of a single flight is considered within the "noise." Never told to watch their fuel burn.

Answers to individual questions did not vary that much from "planning" questions. Main differences are use of real data vs modeled data for aircraft performance, fuel remaining, weights, etc., and much more decision making by pilots versus dispatchers. Dispatchers still major source of information (relay traffic, weather advisories to flight crew) and computations (they "run the numbers"). This is a function of on-board equipment. Don't think of replanning at all in terms of increasing fuel efficiency once aircraft is airborne.

Information (sources):

Main difference from planning is that real airplane data is substituted for model data where possible, and other real time data, instead of predictions (e.g., weather, congestion) are used.

Stakeholders:

Same as for planning

Flight planning/replanning in a freeflight environment

It is anticipated that aircraft will be given more freedom to plan their optimal flight paths in the future freeflight environment (remind interviewee of freeflight definition). If you were able to perform flight planning without ATC-imposed airway, altitude or speed restrictions, describe how you think flight planning and replanning would be different than in today's environment.

How do you envision flight planning goals, constraints, information, and activities changing in a freeflight environment? (step through original description and ask how it would change)?

Free flight: immediate impression of dispatcher was that this would be chaos. She can’t fathom that freeflight will benefit anyone. Airline taking responsibility for separation, adding pilot tasks to worry about spacing, separation. Dispatch needs to know where aircraft are (this may go away with technology). Just skeptical about concept, especially in airspace (east coast) that they fly in. Fearful of safety aspect -- e.g., personalities of crews and ability to negotiate with other aircraft in a civil fashion-- both want to avoid conflict by going to next best altitude or lateral path - which one gets better deviation? May need CRM to include negotiation process with other aircraft for deviations to avoid separation violation. All for saving minutes and fuel, but until she sees it working, will be a skeptic. What about a Captain with 100 hours in left seat who has to make decisions about deviating for separation - could be a problem. Concern about dispatch awareness of where aircraft is, but also kind of overriding issue of “operational control” of aircraft- dispatch relinquishing authority to flight crew, which means other airline concerns may not be considered appropriately.

Dispatch won’t be able to help as much in weather awareness, etc., if aircraft have more independence in planning the route (because dispatch doesn’t have as much awareness of where the aircraft is going in order to anticipate conflicts). Seemed like she was focusing more on self-separation aspect of free flight than on removing of artificial constraints and enhancing the ability to plan and replan for optimal routes. But within their operation, they don’t have the technology to support the ability to “fine tune” the flight plan enroute in order to increase fuel efficiency, their company doesn’t seem to worry about fuel savings at that level (“in the noise”), and in the area (east coast) and altitudes (29000-35000 ft) they fly, don’t see many “direct to’s” happening even in freeflight environment. Could see feasibility for longer haul operations, less congested areas, and higher altitudes.

American Airlines Experience with National Route Program

The purpose of this article is to provide a general explanation of the evolution and implementation of the NRP at the Airline Operational Control (AOC) level might be of interest.

For some years the FAA has attempted to offer users more latitude in the selection of user preferred trajectories (UPT) between city pairs that were constrained by the existence of IFR preferential routes ("prefs"). In effect, these routes were not just "preferred" but were virtually mandatory. If the user filed any route but the "pref" it was likely that ATC would re-clear the flight via the FAA "pref" anyway.

The first attempts to allow UPTs on these routes had many names, such as the "Wind Route Program" and others. These programs contained rules that defined departure and arrival routes and times of availability by city pair. These rules were not only restrictive but were sometimes difficult to implement in the then current computer flight planning systems.

Many of these programs were organized into a single Advisory Circular (AC 90-91) in the spring of. While much of this AC covered the rules of route construction, there was one line that seemed to offer the airlines some freedom from the complicated rules. Buried on page 3 was this sentence "Flights, regardless of point of departure, destination, or filed altitude, which are coordinated via other than published High Altitude Preferred IFR Routes through the ATCSCC." Clearly this meant that any route for any flight might be flown if prior coordinations was provided.

At some airlines, flight dispatchers were simply given the AC and told "see what you can do with this". At others, modification of computer flight planning systems were attempted, and still others ignored these changes and continued to file the FAA "pref" routes.

At American Airlines we attempted to both integrate the new rules into our flight planning software and began to experiment with the effectiveness of ATCSCC coordinated routes. It soon became evident (in 1992) that ATCSCC coordinated NRP routes had the potential for significant savings. In the second quarter of 1993 we added both personnel and computer resources to this effort.

The manner in which we implemented the coordinated NRP is as follows:

1) Approximately 6 hours before flight departure several routes between the city pairs are analyzed and ranked by shortest "wind distance" at operating altitudes available for the planned aircraft type.

2) Every hour, the airline ATC Coordinator (a specialized dispatch position) is presented with a list of flights and possible route assignments. This list contains all flights greater than 700nm that operate on FAA Pref city pairs and have some route that is at least 10 wind distance miles shorter than the FAA Pref.

3) These flights are analyzed, using normal flight planning parameters, for fuel and time savings over the FAA Pref route, as well as for operational feasibility (for more information on the airline flight planning process, see "Airline Operational Control Overview" document, 93-CRDA-0034). If the savings are found to be over a certain value, a Teletype message is sent to ATCSCC describing the planned operation.

4) ATCSCC will coordinate the planned route with the affected centers (when necessary) and call the ATC coordinator with an approval or denial. If the request has been denied, often the dispatcher and ATCSCC will discuss the reason for denial and a new request may be generated.

At American Airlines we log all requests sent to ATCSCC for NRP approval. This automated log contains the Flight number, city pair, fuel and time calculated for the pref route, fuel and time calculated for the NRP route, as well as the planned departure time and altitude requested.

The initial review of the NRP log summaries showed that the range of approval rates was between 47-79%, depending on the ATC Coordinator. We soon discovered that some coordinators were actively looking at the system choke points, designing new routes that were both time/fuel efficient, and were avoiding points or routes that would have resulted in a denial of NRP status from ATC.

Over the period from 1992 to 1994 our non-pref approval rate went from 47% to 89% and our annual calculated fuel savings from 4.9 to 19.6 million pounds.

Late in 1994 the FAA announced its intention to expand the “NRP” in January 1995. The new plan was to allow UPTs without coordination with ATCSCC, provided the fights initial cruise altitude was above a prescribed value and the first and last 200nm were operated on approved published routes. The prescribed altitudes were planned to be lowered incrementally throughout 1995 until FL290 was reached. During this time the users were allowed to qualify under either old NRP rules (AC 90-91) or “expanded” NRP rules, whichever produced the greatest benefit. In many cases flights operating on short routes at low altitudes were much better off under AC 90-91 rules than “expanded” NRP rules.

Until the NRP “expansion”, a flight might qualify for NRP status in two ways (rule based or coordinated), but in each case the flight was to be filed with “NRP” in the remarks section of the flight plan. This alerted controllers that while this flight was not on the FAA pref, all required coordination had been accomplished. Now a new airborne element was introduced, where a pilot or controller might initiate a non-pref route change, for a flight above a certain altitude, and no downline coordination was required. Additionally, in some cases, pilots and/or controllers were inadvertently de-optimizing flight plans by attempting “direct” routings that were not fuel/time efficient.

Also, the “expanded” NRP created some unexpected problems for pre-flight planning. Since qualification for NRP status now depended on the altitude reached, the dispatcher was faced with the possibility that a change in payload might lower altitude capability and put the flight back on a pref routing, thus increasing fuel burn. It was also unclear where the 200nm limitation began or ended since many Standard Instrument Departures (SIDs) and Standard Terminal Arrival Routes (STARs) were not 200nm long. Also, in other ARTCCs the flows for some high density areas (NYC) sometimes began at points greater than 200nm from the destination.

These are not insurmountable problems, as we learned under the old coordinated NRP. However, under the “expanded” NRP, the feed-back loop was cut off. Now, if the flight plan met the new rules, no message was sent to ATCSCC for coordination and so information on flow problems was not routinely available.

Due to these problems and other controller concerns the altitude lowering of the “expanded” NRP was halted in July. It is expected to resume in November 1995.

It is interesting to note that many view the NRP as beginning in January 1995 and seem to ignore the data and experience collected in the previous 3 years.   Among the many issue raised by the NRP in its many forms are the following:

1) Sometimes trying to simplify a complex, multifaceted problem may not make matters better but worse.

2) All airlines do not take advantage of flight planning freedom in the same manner. We may want to review industry flight planning standards and practices to see if some restrictions are internal to the airline and not a limitation of the ATC system.

3) In order to make the NRP work there needs to be a common understanding of how the system is to work at many levels. In this case it seems that training of pilots, controllers, dispatchers and other flight planning specialists might not have been well accomplished.

4) Although I did not discuss it in this narrative, the establishment metrics and the collection of data was not well formulated. This makes success very hard to quantify.

5) It seems that flight planning is a distributive process involving ATC, flight deck and ground based flight planners. We need to identify the correct allocation of resources to each component part.

Flight planning/replanning functional analysis
Structured interview with Air Traffic Management Coordinator of a Major US Cargo Carrier

Background information

Airline/Company/Organization (if applicable): A major US cargo carrier, chose to remain anonymous

Position: Air Traffic Management Coordinator, former dispatcher and controller

Function: Dispatch, Flight planning, Weights/Balances, Flight following, etc.

Flight planning description

Describe the sequence of **activities** that you typically perform in developing and filing a flight plan. Include your **goals** in flight planning, the **constraints** that you must consider, the **information** you need and its **source**, and other **stakeholders** that are part of the flight planning process.

Activities:

They look at the aircraft to make sure there are no MEL or CDL items on it that would create a restriction. CDL items involve physical aspects of the aircraft, such as an airplane may be missing a small slat, the landing lights won't retract, lens caps may be missing… They look at destination and departure weather, and aircraft type, to make sure they can do the mission with the required payload and fuel. Also, is the airplane certified for the airport conditions (CAT II or III)? Same with the crew. Then they generate a flight plan with projected payloads, and they might adjust that number based on history. Also, they see whether the flight will run on schedule or not because they need the airplane. They'll also do a fuel analysis to see whether it makes sense to tanker fuel. "I look at all my airplanes at one time for all the MEL/CDL items, then when I'm looking at the weather, you have a geographical region, so you have a feel for the en route weather, now you're looking for individual destinations and their alternates, then you just put it in the computer and let it cook and see how it looks, and make adjustments as necessary."

On the night side, the dispatchers come in around 10:45 and do the flight plans to get them over to fueling by midnight. The planes aren't all there yet, but the fuelers can start their process of figuring how much fuel goes on the trucks. But on some nights there are a lot of tail swaps due to mechanicals or additional volume or airport conditions, so they want to get the work done early to stay ahead of the curve. "We do things sometimes earlier than we need to do because we're not sure if the computers are going to stay up."

There may be minor adjustments to the schedule from month to month, primarily for taxi times due to construction at airports, or equipment changes. November and December see major changes due to increased volume; "we put some extra hub facilities in for the peak season."

A typical dispatcher is responsible for about forty flights in a shift. The dispatcher may talk to Flow Control to "get a feel for an airport, what's their arrival rate, how are we routing, are we going over the standard inbound fixes." The dispatcher may call the tower to get RVR since this isn’t provided in the new weather release formats and they need it real-time. They may call ATC for special cases, such as an airplane with both transponders inoperative or an unusual MEL item that creates a restriction (such as on speed). The tower may call the dispatcher to find out if they have any special flights planned, such as small jets.

They aren’t taking advantage of the NRP yet, and the interviewee thinks they could gain some additional advantages if they were. However, they don’t need it at night, when most of their operations occur, so it may be of limited utility to them.

If the dispatcher has filed a flight for a particular route for a reason (such as drift down requirements, wind, etc.), he or she should indicate the reason on the flight plan to prevent the crew from accepting direct from ATC that may not be advantageous.

Their airplanes fly as fast as they can most of the time. If they slow down, it’s usually because the airplane was brought in to cover for a broken airplane and now there’s hope that the broken airplane can be fixed, or it’s so far past the sort that a late arrival won’t hurt any more.

Goals:

Safety, carrying all the volume as efficiently as possible. Extra volume may cause the plan to be filed for a slow airspeed because the extra weight reduces the amount of fuel that can be carried. Also, some airports are landing weight-restricted. Their schedule is driven by the sorting requirements; inbound flights from the west coast are most critical. They protect some flights more than others because of the priority of the volume, where it’s going, or how much time they have.

Constraints:

Airport conditions, clutter on the runway, snow, ice, en route weather, alternates weather, drift down requirements, type of aircraft, airport altitude, temperature, pressure, MELs and CDLs, crew time, crew qualifications. Traffic densities based on destination. Problems with the sort, such as having a conveyor belt break, can cause problems across the board. Sometimes, the biggest problems can happen during good weather conditions because everyone departs on time and arrives at once and everyone has minimum fuel on board because no one expects to hold; if a problem develops, such as a flat tire on the runway, people don’t have enough fuel to hold and everyone has to divert. One such incident can counteract many flights’ worth of fuel saving practices, so this company carries a little extra fuel for unexpected events. One decision dispatchers have to make is, when an aircraft is holding and the holding time is unknown, should they divert and put on more fuel so they can get in when conditions clear at the expense of losing their place in line if conditions clear sooner.

Ground support at an airport can affect diversion decisions: do they have the necessary loading equipment, fueling, electrical, air, etc. Also, airport performance requirements, navaids.

Information (source):

Status of airplanes and crews, National Weather Service and in house forecasts, RVR, airport status.

Stakeholders:

Customers, employees, flight crews, contingency, maintenance control, crew scheduling, aircraft routing.

Specific questions:

Q: What do you do when an airplane breaks down?

A: They keep a hot spare airplane in strategic locations, and they also operate a “sweep” airplane that leaves empty from an airport on the east coast and flies ready to divert to any location on the eastern half of the US. If an aircraft breaks down, the sweep airplane will refile for the broken airplane’s location. Sometimes, several refilings are needed because maintenance situations can be very dynamic. If no diversion is required, the sweep airplane goes into a hold at 39,000 feet near the home airport until the last eastern region airplane takes off. The sweep airplane continues to be available as the focus of operations shifts to the west. If an airplane breaks and no other recovery is possible, (for example, the sweep airplane may already be committed to another problem and no other aircraft can be diverted to pick up the extra cargo), a subcontractor may be used. As a last resort, the documents may be moved to a small airplane.

Q: What kinds of deadlines do you have to deal with?

A: They try to have the paperwork to the gateway at least two hours before departure. At some gateways, they may call earlier and ask for the fuel because the airplane’s there and the fueler’s available.

Q: What kinds of constraints might affect large numbers of airplanes or the entire fleet?

A: Weather at the home airport, of course. Also, if a belt breaks during the sort, the whole fleet can be held up. Low pressure can place major constraints on payloads, especially for the older jets.

Q: How often do you get information updates?

A: Part of it depends on the stage. Going to the west coast, landing minimums aren’t of much interest until the airplane is close to the destination. But then, RVR becomes critically important, and real-time RVR would be very useful. Now, the dispatcher has to continually call the tower to get it. Also, real-time payload information would be useful; payloads on the dispatch form are estimated, but the fueler may put more on than was asked for, or winds may be worse than expected, or the crew might have to stay low longer than expected; several events may cause the actual payload to differ substantially from what was estimated, and the difference may drive decisions about whether diversions are needed or not.

Q: What kind of information have you wanted but not been able to get right away?

A: RVR. Also, any changes by ATC to a flight plan, or if ATC rejects the flight plan. The first time the dispatcher finds out about either of those is when the crew calls prior to departure.

Q: What are the major decisions you have to make in flight planning?

A: Whether the airplane can do the mission, whether the crew can do it, how to swap airplanes to meet requirements and whether to do so based on probabilities of success (for example, should a CAT II qualified airplane and crew be substituted for a non-qualified airplane and crew in order to ensure one mission while compromising on another, or should the substitution not be made in hopes that conditions at the airport of concern will clear?). Also, why is the airport CAT II? Is it due to weather or navaid problems? And how does the dispatcher's decision affect other areas? What may be an easy decision for the dispatcher may make things much harder for another group. So they look at weather and trends and decide whether putting extra fuel on the airplane will solve the problem most easily.

Q: Are there broad categories of circumstances or events that would change how you do flight planning in fundamental ways?

A: If they lose the computers, they have to do everything manually. If the system has to be brought down later, they have to do everything in advance.

Flight replanning description

Describe the sequence of **activities** that you typically perform in replanning a flight plan during flight. Include your replanning **goals**, the **constraints** that you must consider, the **information** you need and its **source**, and other **stakeholders** that are part of this replanning process.

Activities

The major difference with replanning is that now they have actual data rather than estimated data (particularly for payloads, altitudes, and winds). When the dispatcher determines that replanning is needed, he or she sends the crew an ACARS message requesting position, altitude, airspeed, payload, and fuel. Then he or she puts the information into the computer and changes speeds, altitudes, or path to determine what the effects would be.

List as many possible causes for in-flight replanning as you can think of (from most to least common)

Winds are worse than forecast, or the crew may call and say they're overburning, possibly due to a mechanical problem. The airplane may develop a problem that requires them to slow down, preventing the fuel burn they expected and putting the airplane over landing weight, so plans have to be made to burn the extra fuel off. ATC may vector them significantly off the route. Or weather at the alternate may go down. If no other nearby alternates are available, it may be safest to divert enroute rather than continue to the destination even though it may still be open. Or they may decide to add a leg enroute, or overfly a planned stop. If an airplane breaks, an airplane with a light load may stop there. The most prominent reason is weather at the destination or alternate. More major replanning is done for international flights where they don't get the track or altitude they expected. If a diversion is required, the dispatcher will send the message over ACARS. If the crew is late in the approach, this avoids distracting them at a crucial time. Such a diversion request may be made if, for example, the airplane on approach is going there to cover for a broken airplane and the broken airplane's been fixed, or another airplane is broken worse in a different location; in either case, the airplane on approach isn't needed at that location any more.

Goals

Same as for planning.

Constraints (generally in order of priority, h = hard, s = soft)

Same as for planning.

Information (sources):

Same as for planning, except now it's real data rather than estimated.

Stakeholders:

Same as for planning.

Specific Questions:

Q: Can you describe any nightmare scenarios?

A: Fog at the home airport, or snow. Power or communications disruptions. In these cases, you're working nonstop diverting airplanes, keeping release times current, replanning for when the problem clears, and keeping ATC informed that when it does, it's going to be a mad dash. Also, trying to prioritize arrivals and let the crews know what's going on.

Q: How often does ATC reject your flight plan?

A: The centers often go down for maintenance. One departure location requires them to file flight plans by 5:00 Z because Chicago center goes down frequently. If the center goes down and comes back up, they have to refile to get a discreet beacon code assigned to the flights. At the home airport, they have standard departures; instead of rejections, what happens more often is that departure won't have the takeoff clearance and the dispatcher will wonder why.

Appendix C
Flight deck planning/replanning function/information analysis

The purposes of the analysis portion of this study are to:

- determine who the major stakeholders in the route planning process are
- determine what objectives each stakeholder has in the process
- determine what constraints each stakeholder must accommodate
- determine what functions must be performed to meet the identified goals
- allocate functions to stakeholders based on their goals
- determine the information requirements of each stakeholder

The results of this analysis will provide the functions and information requirements to be supported in the eventual system architecture. After completing the analysis, we provide a proposed architecture for flight deck systems based on the results; because the ground systems were not the primary focus of this work, we do not provide a similar depiction for the ground based systems.

Stakeholders:

The stakeholders in the current process include:

- passengers
- freight shippers
- aircraft operators
- pilots
- Air Traffic Controllers
- Traffic Flow Management
- Airline Operations Centers

These stakeholders can be categorized for analysis purposes into three general levels:

- individual aircraft control level (including pilots, passengers, and shippers)
- area control level (to include management of areas of airspace, currently the responsibility of FAA facilities and personnel)
- fleet control level (currently the responsibility of the operators and their operations centers)

After reviewing the data obtained from interviews with airline operations personnel, private aircraft operators, and so forth, we have identified the goals and indicated the associated stakeholders shown in Table A.

Goals	Fleet	Area	Individual Aircraft
Passengers: get to destination early or on time, be comfortable, minimize cost			**X**

Take a desired course (e.g., tour flight) (GA)			**X**
Shippers: get cargo to destination early or on time, minimize cost			**X**
maintain safety	**X**	**X**	**X**
maintain overall schedule	**X**		
have resources available: · aircraft · crew · ground support	**X**		
avoid turbulence		**X**	**X**
avoid weather	**X**	**X**	**X**
save fuel	**X**		**X**
save time	**X**		**X**
compensate for:			
· late departure	**X**		**X**
· weather change	**X**		**X**
· traffic change		**X**	**X**
· airport status change	**X**	**X**	**X**
· wind change	**X**	**X**	**X**
· medical emergency	**X**	X	**X**
· mechanical	**X**	X	**X**
· bad model or prediction data	X		**X**
· pax discomfort (GA)			**X**
· arbitrary change of plans (GA)			**X**
save equipment costs	X		
save crew costs	**X**		
enforce route decision	X	**X**	**X**

Table A: The goals of route planning and their associated stakeholders

In the next step, each goal is associated with its relevant constraints, functions, and information requirements, shown in Tables B.

Goals	Constraints	Functions	Information
Passengers: get to destination early or on time, be comfortable, minimize cost	area congestion	anticipate delays	· preflight: predicted · in flight: actual

	schedule	plan departure and arrival times	times: · departure · arrival connections
	turbulent areas	fasten seat belts	turbulent areas time to enter, leave

Goals	Constraints	Functions	Information
Take a desired course (e.g., tour flight) (GA)	area congestion	avoid area congestion	area congestion levels, current and anticipated
	turbulent areas and altitudes	avoid turbulence	turbulent areas and altitudes, current and anticipated
	weather	· avoid weather · predict weather	weather (current and anticipated): · departure · en route · arrival
	aircraft performance: · takeoff · landing · altitude · speed · payload · range pilot currency (GA) landing fees (GA) aircraft capabilities (GA) time/attention it takes to replan (GA)	plan route (or change route): · lateral path · altitudes · speeds · payloads · fuel · weight and balance · alternates	· payload · winds · performance requirements · delays · taxi times · weight · fuel costs · lateral path · speeds · altitudes · alternates · RVR · pressures · weather · congestion · traffic delays · fuel range · aeronautical charts (GA) · freezing level charts (GA)
	restricted areas	avoid restricted areas	restricted areas and schedules

	airports: · size · navaids · qualifications · ground support · curfew · noise · construction · company presence · maintenance facilities · arrival rates · arrival procedures · altitude · runway conditions · RVR	assess diversion sites	airports: · size · navaids · qualifications · ground support · curfew · noise · construction · company presence · maintenance facilities · arrival rates · arrival procedures · altitude · runway conditions · RVR · performance requirements · taxi times · weather · FBO agreements · fuel prices · in/out speed
	winds	optimize for time, fuel	winds
	pressure	assess pressure impact on aircraft	pressure maps
	temperature	determine temperature performance impacts	temperatures
	overflight fees	compare route costs	fees map
	terrain	avoid terrain	· drift down procedures · departure procedures · terrain conflict detection
	obstacles	assess drift down, takeoff, landing requirements	· obstacles data base · obstacles conflict detection
	traffic	· avoid traffic · maintain separations	traffic: · types · locations · intentions
		check company route options	company routes
	ATC procedures	check procedures	procedures

Goals	Constraints	Functions	Information
Shippers: get cargo to destination early or on time, minimize cost	schedule	plan arrival times	schedule

Goals	Constraints	Functions	Information
maintain safety	turbulent areas and altitudes	avoid turbulence	turbulent areas and altitudes, current and anticipated
	weather	· avoid weather · predict weather	weather (current and anticipated): · departure · en route · arrival
	aircraft performance: · takeoff · landing · altitude · speed · payload · range pilot currency (GA) aircraft capabilities (GA) time/attention it takes to replan (GA)	plan route (or change route): · lateral path · altitudes · speeds · fuel · weight and balance · alternates	· payload · winds · performance requirements · delays · taxi times · tail number history · flight history · weight · lateral path · speeds · altitudes · alternates · RVR · pressures · maintenance schedule · aircraft data · weather · congestion · traffic delays · fuel range · aeronautical charts (GA) · freezing level charts (GA)

	aircraft qualifications: · CAT · ETOPS · RNP · etc. maintenance weight limits aircraft range performance limitations utilization costs aircraft ownership	assign aircraft to flights	aircraft qualifications: · CAT · ETOPS · RNP · etc. aircraft performance MEL items CDL items maintenance requirements
	crew: · time limits · qualifications	assign crews to flights	crew: · time limits · qualifications
	restricted areas	avoid restricted areas	restricted areas and schedules
	aircraft status: · MELs · CDLs · maintenance schedule	assess aircraft assignments	aircraft limitations: · MELs · CDLs · maintenance schedule
	airports: · size · navaids · qualifications · ground support · curfew · noise · construction · company presence · maintenance facilities · arrival rates · arrival procedures · altitude · runway conditions · RVR	assess diversion sites	airports: · size · navaids · qualifications · ground support · curfew · noise · construction · company presence · maintenance facilities · arrival rates · arrival procedures · altitude · runway conditions · RVR · performance requirements · taxi times · weather · FBO agreements · fuel prices · in/out speed
	winds	optimize for time and fuel	winds
	pressure	assess pressure impact on aircraft	pressure maps

	temperature	determine temperature performance impacts	temperatures
	terrain	avoid terrain	· drift down procedures · departure procedures · terrain conflict detection
	obstacles	assess drift down requirements	· obstacles data base · obstacles conflict detection
	traffic	· avoid traffic · maintain separations	traffic: · types · locations · intentions
	ATC procedures	check procedures	procedures
	current aircraft status	gather status information	flight status: · position · lateral path · altitude · speed · payload · fuel on board · mechanical · performance · passengers · crew · connections · arrival times · priority

Goals	Constraints	Functions	Information
maintain overall schedule	area congestion	plan arrival sequences · within fleet · between fleets	times: · departure · arrival connections: · passengers · cargo · crew · aircraft
	resources availability	assign resources to flights: · aircraft · crew	· aircraft status · crew status · ground support availability
	turbulent areas and altitudes	avoid turbulence	turbulent areas and altitudes, current and anticipated

	weather	· avoid weather · predict weather	weather (current and anticipated): · departure · en route · arrival
	aircraft performance: · takeoff · landing · altitude · speed · payload · range	plan route (or change route): · lateral path · altitudes · speeds · payloads · fuel · weight and balance · alternates	· payload · winds · performance requirements · delays · taxi times · tail number history · flight history · weight · fuel costs · lateral path · speeds · altitudes · alternates · RVR · pressures · maintenance schedule · connections · aircraft data · weather · congestion · traffic delays · fuel range · aeronautical charts (GA) · freezing level charts (GA)
	aircraft qualifications: · CAT · ETOPS · RNP · etc. maintenance weight limits aircraft range performance limitations utilization costs aircraft ownership	assign aircraft to flights	aircraft qualifications: · CAT · ETOPS · RNP · etc. aircraft performance MEL items maintenance reqts
	crew: · time limits · qualifications	assign crews to flights	crew: · time limits · qualifications
	restricted areas	avoid restricted areas	restricted areas and schedules

	aircraft status: · MELs · CDLs · maintenance schedule	assess aircraft assignments	aircraft limitations: · MELs · CDLs · maintenance schedule
	airports: · size · navaids · qualifications · ground support · curfew · noise · construction · company presence · maintenance facilities · arrival rates · arrival procedures · altitude · runway conditions · RVR	assess diversion sites	airports: · size · navaids · qualifications · ground support · curfew · noise · construction · company presence · maintenance facilities · arrival rates · arrival procedures · altitude · runway conditions · RVR · performance requirements · taxi times · weather · FBO agreements · in/out speed
	winds	optimize for fuel and time	winds
	pressure	assess pressure impact on aircraft	pressure maps
	temperature	determine temperature performance impacts	temperatures
	overflight fees	compare route costs	fees map
	schedule	assign flight priorities	· number of connections by flight · priorities · time · schedule
		estimate fuel burn and delays	historical information · loads · delays
	sector workload	estimate traffic delays	sector status: · boundaries · densities · delays

	current aircraft status	gather status information	flight status: · position · lateral path · altitude · speed · payload · fuel on board · mechanical · performance · passengers · crew · connections · arrival times · priority

Goals	Constraints	Functions	Information
have resources available: · aircraft · crew · ground support	area congestion	plan arrival sequences · within fleet · between fleets	times: · departure · arrival connections: · passengers · cargo · crew · aircraft
	resources availability	assign resources to flights: · aircraft · crew	· aircraft status · crew status · ground support availability
	weather	· avoid weather · predict weather	weather (current and anticipated): · departure · en route · arrival

	aircraft performance: · takeoff · landing · altitude · speed · payload · range pilot currency (GA) landing fees (GA) aircraft capabilities (GA) time/attention it takes to replan (GA)	plan route (or change route): · lateral path · altitudes · speeds · payloads · fuel · weight and balance · alternates	· payload · winds · performance requirements · delays · taxi times · tail number history · flight history · weight · fuel costs · lateral path · speeds · altitudes · alternates · RVR · pressures · maintenance schedule · connections · aircraft data · weather · congestion · traffic delays · fuel range · aeronautical charts (GA) · freezing level charts (GA)
	aircraft qualifications: · CAT · ETOPS · RNP · etc. maintenance weight limits aircraft range performance limitations utilization costs aircraft ownership	assign aircraft to flights	aircraft qualifications: · CAT · ETOPS · RNP · etc. aircraft performance MEL items maintenance requirements
	crew: · time limits · qualifications	assign crews to flights	crew: · time limits · qualifications
	aircraft status: · MELs · CDLs · maintenance schedule	assess aircraft assignments	aircraft limitations: · MELs · CDLs · maintenance schedule

	airports: · size · navaids · qualifications · ground support · curfew · noise · construction · company presence · maintenance facilities · arrival rates · arrival procedures · altitude · runway conditions · RVR	assess diversion sites	airports: · size · navaids · qualifications · ground support · curfew · noise · construction · company presence · maintenance facilities · arrival rates · arrival procedures · altitude · runway conditions · RVR · performance requirements · taxi times · weather · FBO agreements · fuel prices · in/out speed
	winds	optimize for fuel and time	winds
	pressure	assess pressure impact on aircraft	pressure maps
	temperature	determine temperature performance impacts	temperatures
	fuel prices	assess fuel tankering options	fuel prices
	terrain	avoid terrain	· drift down procedures · departure procedures · terrain conflict detection
	obstacles	assess drift down requirements	· obstacles data base · obstacles conflict detection
	schedule	assign flight priorities	· number of connections by flight · priorities · time · schedule
		estimate fuel burn and delays	historical information · loads · delays

	current aircraft status	gather status information	flight status: · position · lateral path · altitude · speed · payload · fuel on board · mechanical · performance · passengers · crew · connections · arrival times · priority

Goals	Constraints	Functions	Information
avoid turbulence	turbulent areas and altitudes	avoid turbulence	turbulent areas and altitudes, current and anticipated
	weather	· avoid weather · predict weather	weather (current and anticipated): · departure · en route · arrival
	restricted areas	avoid restricted areas	restricted areas and schedules
	winds	optimize for fuel and time	winds
	current aircraft status	gather status information	flight status: · position · lateral path · altitude · speed · payload · fuel on board · mechanical · performance · passengers · crew · connections · arrival times · priority

Goals	Constraints	Functions	Information
avoid weather	weather	· avoid weather · predict weather	weather (current and anticipated): · departure · en route · arrival

	RVR	determine landing requirements	RVR
	aircraft qualifications: · CAT · ETOPS · RNP · etc. maintenance weight limits aircraft range performance limitations utilization costs aircraft ownership	assign aircraft to flights	aircraft qualifications: · CAT · ETOPS · RNP · etc. aircraft performance MEL items maintenance requirements
	crew: · time limits · qualifications	assign crews to flights	crew: · time limits · qualifications
	restricted areas	avoid restricted areas	restricted areas and schedules
	aircraft status: · MELs · CDLs · maintenance schedule	assess aircraft assignments	aircraft limitations: · MELs · CDLs · maintenance schedule
	airports: · size · navaids · qualifications · ground support · curfew · noise · construction · company presence · maintenance facilities · arrival rates · arrival procedures · altitude · runway conditions · RVR	assess diversion sites	airports: · size · navaids · qualifications · ground support · curfew · noise · construction · company presence · maintenance facilities · arrival rates · arrival procedures · altitude · runway conditions · RVR · performance requirements · taxi times · weather · FBO agreements · fuel prices · in/out speed
	winds	optimize for fuel and time	winds
	pressure	assess pressure impact on aircraft	pressure maps

	temperature	determine temperature performance impacts	temperatures
	overflight fees	compare route costs	fees map
	terrain	avoid terrain	· drift down procedures · departure procedures · terrain conflict detection
	obstacles	assess drift down requirements	· obstacles data base · obstacles conflict detection
	traffic	· avoid traffic · maintain separations	traffic: · types · locations · intentions
		assess company route options	company routes
		assess jetway options	jetways
	ATC procedures	assess procedures	procedures
	current aircraft status	gather status information	flight status: · position · lateral path · altitude · speed · payload · fuel on board · mechanical · performance · passengers · crew · connections · arrival times · priority
		enforce route decision	route information and rationale

Goals	Constraints	Functions	Information
save fuel save time compensate for: · late departure · weather change · traffic change · airport status change · wind change · medical emergency · mechanical · bad model or prediction data · pax discomfort (GA) · arbitrary change of plans (GA)	area congestion	plan arrival sequences · within fleet · between fleets	times: · departure · arrival connections: · passengers · cargo · crew · aircraft
	turbulent areas and altitudes	avoid turbulence	turbulent areas and altitudes, current and anticipated
	weather	· avoid weather · predict weather	weather (current and anticipated): · departure · en route · arrival

	aircraft performance: · takeoff · landing · altitude · speed · payload · range pilot currency (GA) landing fees (GA) aircraft capabilities (GA) time/attention it takes to replan (GA)	plan route (or change route): · lateral path · altitudes · speeds · payloads · fuel · weight and balance · alternates	· payload · winds · performance requirements · delays · taxi times · tail number history · flight history · weight · fuel costs · lateral path · speeds · altitudes · alternates · RVR · pressures · maintenance schedule · connections · aircraft data · weather · congestion · traffic delays · fuel range · aeronautical charts (GA) · freezing level charts (GA)
	restricted areas	avoid restricted areas	restricted areas and schedules
	winds	optimize for fuel and time	winds
	overflight fees	compare route costs	fees map
	fuel prices	assess fuel tankering options	fuel prices
	terrain	avoid terrain	· drift down procedures · departure procedures · terrain conflict detection
	obstacles	assess drift down requirements	· obstacles data base · obstacles conflict detection
	traffic	· avoid traffic · maintain separations	traffic: · types · locations · intentions
	sector workload	avoid traffic delays	sector status: · boundaries · densities · delays

		assess company route options	company routes
		assess jetway options	jetways
	AC procedures	assess procedures	procedures
	current aircraft status	gather status information	flight status: · position · lateral path · altitude · speed · payload · fuel on board · mechanical · performance · passengers · crew · connections · arrival times · priority

Goals	Constraints	Functions	Information
save equipment costs	resource availability	assign resources to flights: · aircraft · crew	· aircraft status · crew status · ground support availability
	turbulent areas and altitudes	avoid turbulence	turbulent areas and altitudes, current and anticipated
	weather	· avoid weather · predict weather	weather (current and anticipated): · departure · en route · arrival

	aircraft performance: · takeoff · landing · altitude · speed · payload · range	plan route (or change route): · lateral path · altitudes · speeds · payloads · fuel · weight and balance · alternates	· payload · winds · performance requirements · delays · taxi times · tail number history · flight history · weight · fuel costs · lateral path · speeds · altitudes · alternates · RVR · pressures · maintenance schedule · connections · aircraft data · weather · congestion · traffic delays · fuel range · aeronautical charts (GA) · freezing level charts (GA)
	aircraft qualifications: · CAT · ETOPS · RNP · etc. maintenance weight limits aircraft range performance limitations utilization costs aircraft ownership	assign aircraft to flights	aircraft qualifications: · CAT · ETOPS · RNP · etc. aircraft performance MEL items maintenance requirements
	aircraft status: · MELs · CDLs · maintenance schedule	assess aircraft assignments	aircraft limitations: · MELs · CDLs · maintenance schedule

	airports: · size · navaids · qualifications · ground support · curfew · noise · construction · company presence · maintenance facilities · arrival rates · arrival procedures · altitude · runway conditions · RVR	assess diversion sites	airports: · size · navaids · qualifications · ground support · curfew · noise · construction · company presence · maintenance facilities · arrival rates · arrival procedures · altitude · runway conditions · RVR · performance requirements · taxi times · weather · FBO agreements · fuel prices · in/out speed
	winds	optimize for fuel and time	winds
	pressure	assess pressure impact on aircraft	pressure maps
	temperature	determine temperature performance impacts	temperatures
	terrain	avoid terrain	· drift down procedures · departure procedures · terrain conflict detection
	obstacles	assess drift down requirements	· obstacles data base · obstacles conflict detection
		estimate fuel burn and delays	historical information · loads · delays

	current aircraft status	gather status information	flight status: · position · lateral path · altitude · speed · payload · fuel on board · mechanical · performance · passengers · crew · connections · arrival times · priority

Goals	Constraints	Functions	Information
save crew costs	resource availability	assign resources to flights: · aircraft · crew	· aircraft status · crew status · ground support availability
	weather	· avoid weather · predict weather	weather (current and anticipated): · departure · en route · arrival
	crew duty time restrictions	estimate crew duty time	· delays · taxi times · flight history · alternates · connections · aircraft data · weather · congestion · traffic delays · fuel range
	aircraft qualifications: · CAT · ETOPS · RNP · etc. maintenance weight limits aircraft range performance limitations utilization costs aircraft ownership	assign aircraft to flights	aircraft qualifications: · CAT · ETOPS · RNP · etc. aircraft performance MEL items maintenance requirements
	crew: · time limits · qualifications	assign crews to flights	crew: · time limits · qualifications

	restricted areas	avoid restricted areas	restricted areas and schedules
	aircraft status: · MELs · CDLs · maintenance schedule	assess aircraft assignments	aircraft limitations: · MELs · CDLs · maintenance schedule
	airports: · size · navaids · qualifications · ground support · curfew · noise · construction · company presence · maintenance facilities · arrival rates · arrival procedures · altitude · runway conditions · RVR	assess diversion sites	airports: · size · navaids · qualifications · ground support · curfew · noise · construction · company presence · maintenance facilities · arrival rates · arrival procedures · altitude · runway conditions · RVR · performance requirements · taxi times · weather · FBO agreements · fuel prices · in/out speed
	winds	optimize for fuel and time	winds
	schedule	assign flight priorities	· number of connections by flight · priorities · time · schedule
		estimate fuel burn and delays	historical information · loads · delays
	sector workload	avoid traffic delays	sector status: · boundaries · densities · delays

	current aircraft status	gather status information	flight status: · position · lateral path · altitude · speed · payload · fuel on board · mechanical · performance · passengers · crew · connections · arrival times · priority

Goals	Constraints	Functions	Information
enforce route decision		communicate route choice rationale	route information and rationale

Tables B: Relationships between constraints, functions, and information requirements that are relevant for each identified goal

It should be noted that there are many overlaps in constraints, functions, and information requirements between goals. These overlaps will determine those areas where pilots, controllers, and airline operations personnel will require shared information.

Function Allocations

The next step is to allocate the functions identified in Tables B to the various levels of control, and their associated personnel, based on the relationships between the functions in Tables B and their goals, and between the goals and their associated levels of concern in Table A. For example, if the function “avoid traffic delays” is associated with the goal to “save crew costs”, and this goal in turn is applicable to the “fleet control” level of concern, then the airline operations personnel will be assigned the function of “avoid traffic delays”. This same function may also be assigned to other personnel, but the specific information requirements associated with the function may differ from level to level.

Individual aircraft functions are assigned to the flight deck and are the responsibility of the flight crew. Area control functions are assigned to the air traffic controller, traffic flow management, and other regulatory personnel whose job is to manage the flow of traffic across fleets. Fleet level control functions are assigned to the airlines operations personnel whose job is to manage resources within fleets. Where functions are assigned to multiple parties, a shared responsibility exists. In these cases, preference should generally be given to airline operations personnel for fleet management issues, controllers for area management issues, and flight crews for flight deck level issues. Therefore, numbers are assigned to each function to indicate primary, secondary, or tertiary responsibility, except for those functions without constraints (these functions involve assessing options rather than managing constraints; an example is to check company route options).

Route planning functions are assigned relative responsibility based on free flight assumptions. For example, in the current environment, the controller has primary responsibility for determining the ultimate path and altitude of an aircraft. In the anticipated environment, the controller is expected to intervene only when traffic constraints prevent the aircraft from following its desired path, so the operator is assigned primary responsibility for lateral path, altitude, and speed assignment (because of the operator's need to balance resources across the fleet), the flight crew are assigned secondary responsibility (because of their potentially superior knowledge of their own flight situation) and the controller is assigned tertiary responsibility.

Individual Aircraft Functions:

anticipate delays (3)
plan arrival and departure times (2)
communicate turbulence effects to passengers (onset, offset times, etc.) (1)
avoid area congestion (2)
avoid turbulence (2)
avoid weather (2)
anticipate weather (2)
determine landing requirements:
- RVR (1)
- weight (1)

plan route:
- lateral path (2)
- altitudes (2)
- speeds (2)
- payloads (2)
- fuel (2)
- weight and balance (2)
- alternates (2)

avoid restricted areas (2)
assess diversion sites (2)
optimize for time, fuel (2)
assess low pressure effects on aircraft (2)
determine temperature effects on performance (2)
compare route costs (2)
avoid terrain (1)
avoid obstacles (1)
avoid traffic (1)
avoid traffic delays (3)
check company route options
check jetway options
check ATC procedures (2)
gather status information (1)
communicate route choice rationale

Area Functions:

avoid turbulence (3)
avoid weather (3)
predict weather (3)
plan route
- lateral path (3)
- altitudes (3)
- speeds (3)

avoid restricted areas (3)

avoid terrain (3)
maintain traffic separations (1)
check procedures
gather status information
plan arrival sequences between fleets (1, possibly 2 if barter system between operators)
avoid traffic delays (2)
assess jetway options
communicate route choice rationale

Fleet Functions:

avoid turbulence (1)
avoid weather (1)
predict weather (1)
plan route:
- lateral path (1)
- altitudes (1)
- speeds (1)
- payloads (1)
- fuel (1)
- weight and balance (1)
- alternates (1)

assign aircraft to flights (1)
assign crews to flights (1)
avoid restricted areas (1)
assess aircraft assignments (1)
assess diversion sites (1)
optimize for time and fuel (1)
assess low pressure impact on aircraft (1)
determine temperature performance impacts (1)
avoid terrain (2)
assess drift down requirements (1)
check takeoff and landing performance for obstacle clearance (1)
check ATC procedures
gather status information
plan arrival sequences within fleet (1)
compare route costs (1)
assign flight priorities (1)
estimate fuel burn and delays (1)
estimate traffic delays (1)
assess fuel tankering options (1)
determine landing requirements (1)
assess company route options
assess jetway options
estimate crew duty time (1)
communicate route choice rationale

Information Requirements:

Having allocated functions to the airline, regulatory, and flight personnel, the next step is to do the same with information requirements based on their relationships to the functions. The following list contains these information requirements and their allocations.

Individual Aircraft Information Requirements:

predicted delays
actual delays
departure time
arrival time
connections
turbulent areas:
  - time to enter
  - time to leave
area congestion levels:
  - current
  - anticipated
turbulent areas and altitudes:
  - current
  - anticipated
weather (current and anticipated):
  - departure
  - en route
  - arrival
payload
winds
performance requirements
taxi times
weight
fuel
lateral path
speeds
altitudes
alternates
RVR
pressures
congestion
traffic delays
fuel range
aeronautical charts (GA)
freezing level charts (GA)
restricted areas and schedules
airports:
  - size
  - navaids
  - qualifications
  - ground support
  - curfew
  - noise
  - construction
  - company presence
  - maintenance facilities
  - arrival rates
  - arrival procedures
  - altitude
  - runway conditions
  - RVR
  - runway conditions

  - performance requirements
  - taxi times
  - weather
  - FBO agreements
  - fuel prices
  - in/out speed

temperatures
fees
drift down procedures
departure procedures
terrain data
terrain conflicts
obstacles data
obstacles conflicts
traffic:
  - types
  - operator
  - flight number
  - locations
  - intentions

company routes
ATC procedures
flight schedule
aircraft qualifications:
  - CAT
  - ETOPS
  - RNP
  - etc.

aircraft performance
MEL items
CDL items
maintenance requirements
crew:
  - time limits
  - qualifications

flight status:
  - position
  - lateral path
  - altitude
  - speed
  - payload
  - fuel on board
  - mechanical
  - performance
  - passengers
  - crew
  - connections
  - arrival times
  - priority

jetways
route information and rationale
sector status:
  - boundaries
  - densities

- delays

Area Control Information Requirements:

turbulent areas and altitudes, current and anticipated
weather, current and anticipated:
  - departure
  - en route
  - arrival

winds
RVR
congestion
restricted areas and schedules
aircraft limitations:
  - MELs
  - CDLs

airports:
  - size
  - navaids
  - qualifications
  - curfew
  - construction
  - arrival rates
  - arrival procedures
  - altitude
  - runway conditions
  - RVR
  - taxi times
  - weather

drift down procedures
ATC procedures
terrain data
terrain conflicts
obstacles data
obstacles conflicts
traffic:
  - types
  - operator
  - flight number
  - positions
  - intentions

flight status:
  - position
  - lateral path
  - altitude
  - speed
  - payload
  - fuel on board
  - mechanical
  - performance
  - connections
  - arrival times
  - priority
  - route information and rationale

  - special conditions (medical, fuel, etc.)

sector workload and capacity
sector boundaries

Fleet Control Information Requirements:

turbulent areas and altitudes, current and anticipated
weather, current and anticipated:
  - departure
  - en route
  - arrival

aircraft performance and requirements:
  - payload
  - winds
  - performance requirements
  - delays
  - taxi times
  - tail number history
  - flight history
  - weight
  - lateral path
  - speeds
  - altitudes
  - alternates
  - RVR
  - pressures
  - maintenance schedule
  - aircraft data
  - weather
  - congestion
  - traffic delays
  - fuel range
  - aeronautical charts (GA)
  - freezing level charts (GA)

aircraft qualifications:
  - CAT
  - ETOPS
  - RNP
  - etc.
  - MEL items
  - CDL items
  - maintenance requirements

crew:
  - time limits
  - qualifications

restricted areas and schedules
airports:
  - size
  - navaids
  - qualifications
  - ground support
  - curfew
  - noise
  - construction

  - company presence
  - maintenance facilities
  - arrival rates
  - arrival procedures
  - altitude
  - runway conditions
  - RVR
  - performance requirements
  - taxi times
  - weather
  - FBO agreements
  - fuel prices
  - in/out speed

winds
pressure maps
temperatures
terrain data
drift down procedures
departure and arrival procedures
terrain conflict detection
obstacles data
obstacles detection
ATC procedures
flight status:

  - position
  - lateral path
  - altitude
  - speed
  - payload
  - fuel on board
  - mechanical
  - performance
  - passengers
  - crew
  - connections
  - arrival times
  - priority

flight schedules:

  - departure times
  - arrival times

connections:

  - passengers
  - cargo
  - crew
  - aircraft

aircraft status
crew status
ground support availability
fees
number of connections by flight
flight and connection priorities
historical information:

  - loads
  - delays

sector status:
- boundaries
- densities
- delays

fuel prices
company routes
jetways
route decision rationale

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