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Efficient Transfer of Weather Information to the Pilot in Flight

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I. INTRODUCTION

This is a final summary report of an investigation of methods for efficient transfer of weather information to the pilot in flight. A pilot many times during a typical flight has very critical decisions to make. Some of these decisions relate to actions that must be taken with respect to weather conditions enroute or at the destination. For good decision-making, the best possible weather information needs to be available and this can be achieved with greatest certainty by providing the most recent information.

One source [1] reporting on a review of accident data states that over the past 10 years weather has been a cause or a factor in 25% of all general aviation accidents and 40% of all fatal accidents. The question is logically raised as to why such a high level in spite of improvements in forecasting and dissemination of weather.

A quick answer is that in spite of improvements in weather data handling through automation and computer-aided forecasts, the accuracy of the forecasts has not improved significantly. With respect to dissemination, the improvements such as with EFAS (Enroute Flight Advisory Service), remote severe weather depiction facilities (remote radar scopes) and satellite observation, apparently are not sufficient to offset the greater press for utility from expensive aircraft. Clearly, more improvements are needed and a weather uplink capability to the cockpit is consistent with these needs.

A superficial observation by a layman might raise a question of need for automation in the flow of weather to the pilot. A brief experience in the cockpit during times when decisions must be made regarding alternate routes and destinations because of adverse weather will certainly convince most skeptics. One major consideration the pilot has is maximum endurance of his flight. How long can he stay aloft with the fuel he has? This single factor strongly motivates him to make decisions in the minimum amount of time. It follows then that there is a great need for data to flow to him in a rapid manner.

The current technique for acquisition of weather information is well known to those involved in aviation. The pilot keys his transmitter and requests from a person on the ground certain pieces of information. For example, he may ask for current weather reports and forecasts. He may ask for a verbal description of a radar reflectivity map. Responses are usually received promptly but misunderstandings as to what is wanted complicate matters and verbal responses giving, for example, descriptions of irregular radar weather patterns take time and seldom produce the precise image in the pilot's mind that replicates the radar pattern being presented on the ground equipment. The point being made is that transfer of data verbally is slow, inefficient, and imprecise many times, and this occurs at times when it can least be tolerated.

Efficient transfer of weather information is essential simply because there is much data available and the capability using the radio spectrum to provide for the data transfer is really quite limited. All evidence and study point to use of the radio spectrum as the best, and most practical, basic resource for accomplishing the link of the aircraft with the ground.

The Federal Communications Rules place some very profound restrictions on what possibilities exist for use of the radio spectrum. Investigation shows that use of spectrum space inside the TV, FM broadcast frequency band allocations is virtually ruled out because the information to be considered for aiding the pilot is not useful with respect to the general public; therefore, does not fit the requirements for allowing a general broadcast. General public would not benefit from such broadcasts; hence, use of these frequencies are not permitted even though they have some of the most unused capability that has been identified. Admittedly, there are also groups with designs on these frequencies. These groups, at the very least, would be formidable competitors for the channel space.

In order to maintain a practical flavor, this study was forced to focus very quickly on use of presently assigned aeronautical radio channel space. One such capability is the voice channel on the VHF OmniRange. Another is a dedicated VHF voice channel such as the ATIS (Automated Terminal Information Service). ATIS is a continuous voice broadcast of the airport information giving the pilot immediate access to terminal weather, runway operations and notams for a given airport. Use of a VHF channel means that most aircraft presently have equipment, e.g., antennas and receivers that will operate satisfactorily with these frequencies. Still another possibility is DABS, the Discrete Address Beacon System or now becoming known as Mode S. While of slightly different concept in that it must be interrogated, it must be given full consideration as to its potential for the future handling of weather data. Section III.D addresses some of the factors encouraging and discouraging the use of Mode S.

Because any uplink capability will demand information be handled efficiently and that efficient modulation techniques be used. Accordingly, special concern has been given to these. Two separate reports have been produced under this grant which reviews these two issues, respectively, in detail. They are shown as [2] and [3] in the Bibliography.

The first report, titled "A Delineation of Critical Weather Factors Concerning General Aviation", identifies the critical weather items with respect to general aviation operations. Some weather phenomena which to the layman may be considered critical are put in proper perspective with respect to reliable, safe, general-aviation flight. The most critical are but three in number, viz, thunderstorms, ice, and fog.

The second report by Fischer, titled "An Investigation of Techniques for Coding and Transmitting Weather and Flight Related Information to an Aircraft", addresses the problem of getting the maximum information handling with the available radio spectrum. Obviously, the spectrum is a very limited national resource; therefore, it is incumbent on the engineer to produce a maximum data handling capability with contemporary channel assignments if acceptable uplink capability is to be realized in the near future. The Fischer report addresses different modulation techniques specifically to determine if there are means for improving data handling. Consideration is given to bandwidth compression techniques to obtain perhaps as much as a factor of 8 to 10 improvement. This obviously improves efficiency and has been the specific goal of this work.

The data uplink system concept which dates back many years in itself provides for overall efficiency in the use of channel space. The continuous data stream could obviate the need for altimeter settings to be given by voice by the air traffic controller on each call up by the pilot. Significant reduction in work load at the flight service stations is very realistic to expect because weather information will be available on call from cockpit storage.

The view is taken that the approaches to be considered to solve practically the problem of getting meaningful and timely information to the pilot during flight must produce quality results at reasonable costs. The aircraft of principal concern are the sophisticated single-engine aircraft up through the corporate jet aircraft. Costs are targeted at amounts which equal quality GA DME sets.

The fundamental motive of this work is to improve safety of general aviation operations. It is important to note that these operations take place without dispatchers and other means of monitoring critical operational factors except for the monitoring the pilot can do himself.

The safety records of the scheduled airlines are often held up as models for general aviation operations. Overlooked many times is the fact that the major air carriers have staffs of meteorologists dedicated to scrutinizing the specific routes the company flies and dispatchers who monitor the conditions for significant changes. They are well prepared to alert the flight crew of weather changes and to offer recommendations concerning diversions. A company radio channel is available for immediate call up to pass along the information.

In contrast, the general aviation pilot is essentially on his own. He is likely the only one who is looking at the particular route of his flight. He may not become aware of the crucial weather that will affect him simply because he may not know the right question to ask. Availability of a variety of information may very well provide the key so that the right question can be formulated and even answered by the weather data placed at hand by a weather uplink capability.

Safety must be related to utility. The old saw that there is nothing as safe nor as useless as an airplane in the hangar must be recognized for an element of truth. Coupled with the safety requirement is that of having the aircraft be an effective tool for its owner. Large financial investments are usually expected to yield a return. The expensive aircraft owned by many are expected to pay off in utility. If a pilot cannot make wise decisions because of lack of information and data he will be compelled to be very conservative to be safe. If he has information on weather that is timely, he can make decisions that will allow his mission to be accomplished with a minimum of waste in terms of time, fuel, money and personnel resources.

Figure 1 may be regarded as a summary. The pilot, especially during periods of adverse weather, is under considerable pressure. To provide a high probability of his having a safe flight, there are supporting factors. The weather uplink capability realistically can provide for considerable support.

One means to forecast what might appear in the future in the general aviation cockpit is to identify those innovations currently being planned for the commercial aircarrier-type aircraft. The literature being produced by some of the major producers of avionics, e.g., Rockwell-Collins, Bendix, and Sperry all clearly indicate that there will be considerable use of the cathode ray tube (CRT) to present the images used for control and navigation of the aircraft. In fact, noting the extensive use of such CRT's, one writer [4] calls the result the "glass cockpit". The availability of solid state microprocessors and reliable, high-intensity color CRT's have made this concept realistic.

Given one or more CRT's in the cockpit, four principal uses can readily be made of them. First, there is the presentation of the ADI (Attitude Directional Indicator) and next the HSI (Horizontal Situation Indicator). Another CRT can show the area nav routing such as was done with DAAS (Demonstration Advanced Avionics System). It is logical to include with this the weather depiction that would come fundamentally from radar and spherics equipment. With the advent of the coherent, doppler-type radar (called NEXRAD), superior weather radar information will be available from ground stations due principally to their greater powers, automatic, vertical-scanning capability, and resolving capability through use of large aperture antennas. Integration of route and vector positional information could logically be a future goal. Area navigational information and available heading information are those items needed to provide the raw data.

Completing the cockpit is a data-type display containing text concerning route and navigation information, area nav way points, weather sequences, notams, check lists and other similar items. The term such as multifunctional displays is appropriate because it will be possible to switch information and images from one display to another or to use split screens should one CRT fail. EFIS, Electronic

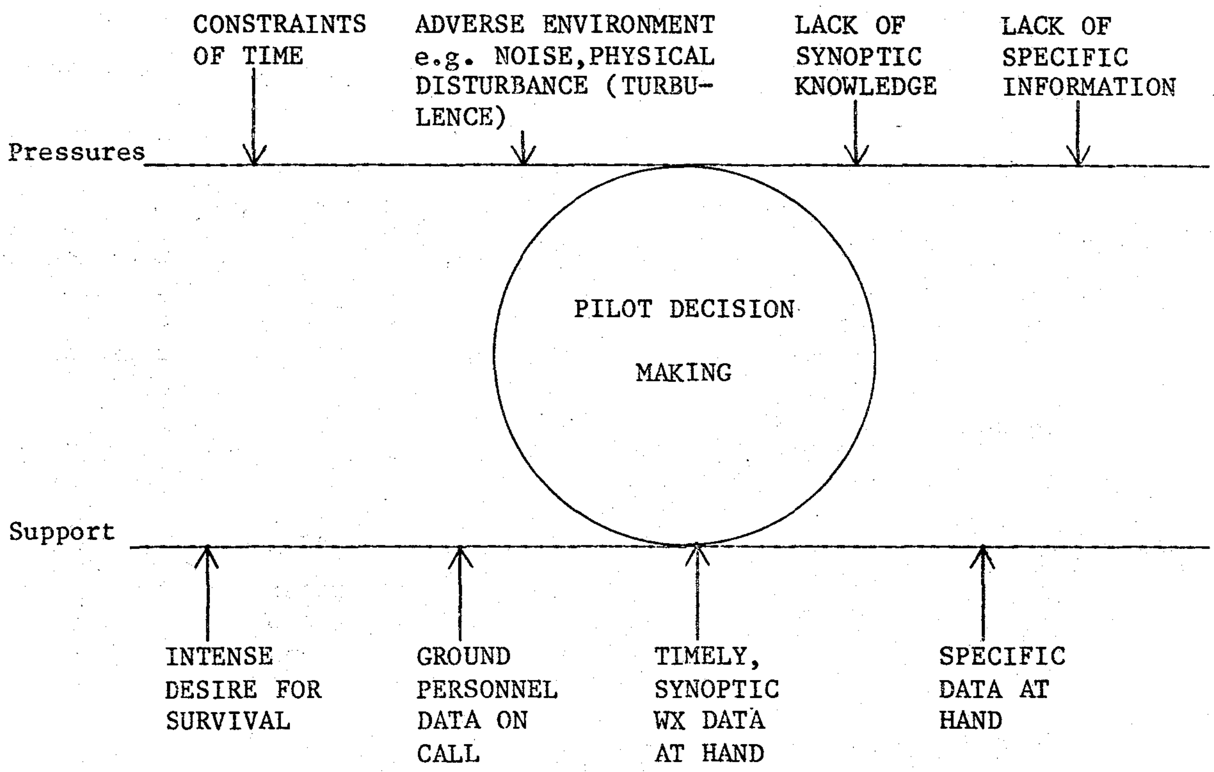

Figure 1. Factors Impacting the Pilot's Mental State During a Flight.

Flight Instrumentation System, is a new term describing the collection of CRT displays.

Certainly much development remains to be done; however, claims for real estate in the cockpit must be established and some idea on the priorities of information will soon be established by pilots and the industry.

The availability of information from the ground coming automatically via a continuous data stream is extremely appealing to the implementors of electronic flight display systems. One of the big selling factors is that the electronic displays can present more information better. With color and flash coding, it can be done in an attractive and compelling manner. The availability of a data link thus becomes more important. From this, then, comes the motivation to look at every possible means of uplinking information to the cockpit. Unquestionably, there is more information available than can be uplinked; therefore, channel space is going to be a limiting factor. In the immediate future, VOR voice channel appears as attractive as any means. Since the Federal Communications Commission officials indicate that aircraft use cannot be considered broadcast, only bands already designated for aeronautical use are considered in this work.

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II. APPROACH

The initial approach to developing a plan for providing a weather information uplink capability has been to ascertain what kinds of information would be most important and desirable to handle on the uplink. This work was performed and reported in [2]. The basis for the conclusions reached concerning the most important items identified, viz, thunderstorm locations and in-cloud icing were derived from numerous articles principally in the contemporary trade literature and from years of piloting experience.

Since there are numerous approaches on locating thunderstorms, and there is relatively little being done now to determine location of in-cloud icing, emphasis in this work for uplinking available data necessarily was placed on the handling of commonly available thunderstorm information. Unfortunately, the commonly available radar weather data is quite antiquated considering contemporary radar technology. The WSR-57 and WSR-74 currently in use by the National Weather Service represent designs 10 to 20 years old. The encouraging item is that currrently there is a joint project within the government involving the National Weather Service, the Defense Department and the Federal Aviation Administration which has, as an objective, the procurement and deployment of a modern doppler, weather radar designated NEXRAD [5] radar. This radar, based in part on prototype evaluation by the Severe Storms Laboratory, offers significant additional capability beyond that available from present radars.

In particular, the NEXRAD radar, which is a coherent-type radar with doppler capability will identify areas of turbulence, freezing level, and supercooled water above the freezing level which is the cause of airframe icing. With its one-degree pencil beam, it can provide basic information that is processed within the system to yield echo tops maps, severe weather alert maps, and pseudo 3-D graphics. Small volume elements of a storm can be resolved and turbulent motion can be resolved in terms of mean radial velocities. All of this has considerable relevance for the general aviation pilot. Getting this information to the pilot in flight can improve his flight safety.

Certain portrayals of thunderstorm data require large data handling since the format is one of video. Experience of all workers uniformly show that broadband video transmission is not required. Commercial TV interests have motivated certain industries to prepare formats for transmission on phone lines (2400 baud).

Contacts and visits were made with those industries involved in radar weather data formatting and transmission. Appendix A lists those contacts.

As a part of this investigation, a visit was made to the ARD-410 offices of the Federal Aviation Administration in Washington. This is the office responsible for the work with weather systems in

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[1] For example, Enterprise Electronics, Alabama and Arvin Diamond, Carroll, Ohio.

the FAA. Importantly, it was learned that a project was underway at MITRE, MacLean, VA., funded by the FAA, to uplink certain data formats to the aircraft on the VOR voice channel and display this information on a cockpit printer. Inasmuch as this work was well underway and in many respects had similar goals to answer questions that were originally intended to be a part of this work, the plan for this effort was altered to take maximum advantage of the MITRE work. This provides some answers for this project at essentially no cost and allows an expanded plan and view of objects for this project.

Some questions answered by the ongoing MITRE work are as follows:

1. Is the VOR channel adequate for weather transmission?

2. Is FSK (frequency shift keying) satisfactory for uplinking weather data?

3. Is it efficacious to store data on the aircraft for call up assuming 8000 bytes storage is available?

4. Is a cockpit printer the best means of providing data to the pilot?

Formal reports [6, 7] are now being prepared at MITRE where the design and fabrication have been accomplished and at Ohio University where evaluations are being performed. Preliminary indications are that the VOR channel is adequate but perhaps not optimum for handling the uplink; FSK is satisfactory, and it is efficacious to store date for call up. No answers will be available for a time on the cockpit printer versus the CRT display. It is reasonable to expect that the final answer may be a matter of personal choice and that both methods will be available as options from future manufacturers.

From all work that has been reported, there is certainly no question remaining that a real-time weather uplink to the pilot is desirable and possible. Proceeding to evolve the technology that provides the most efficient means for the uplink is both desirable and necessary.

From knowledge as to what exists in state-of-the-art capability one may conceptualize that large quantities of data are collected from meteorological observations by NWS and FAA personnel, from automatic reporting stations, aircraft observations, weather radar and spherics stations then processed at a central location and fed by land line to radio transmitters for uplinking to the aircraft. In the aircraft it is stored and displayed on-call by the pilot. Pictorially, this is presented in Figure 2.

Interest by many groups and individuals has led to a cooperative attitude by those contacted for information relating to the uplinking of weather data. Specifically, there seems to be a

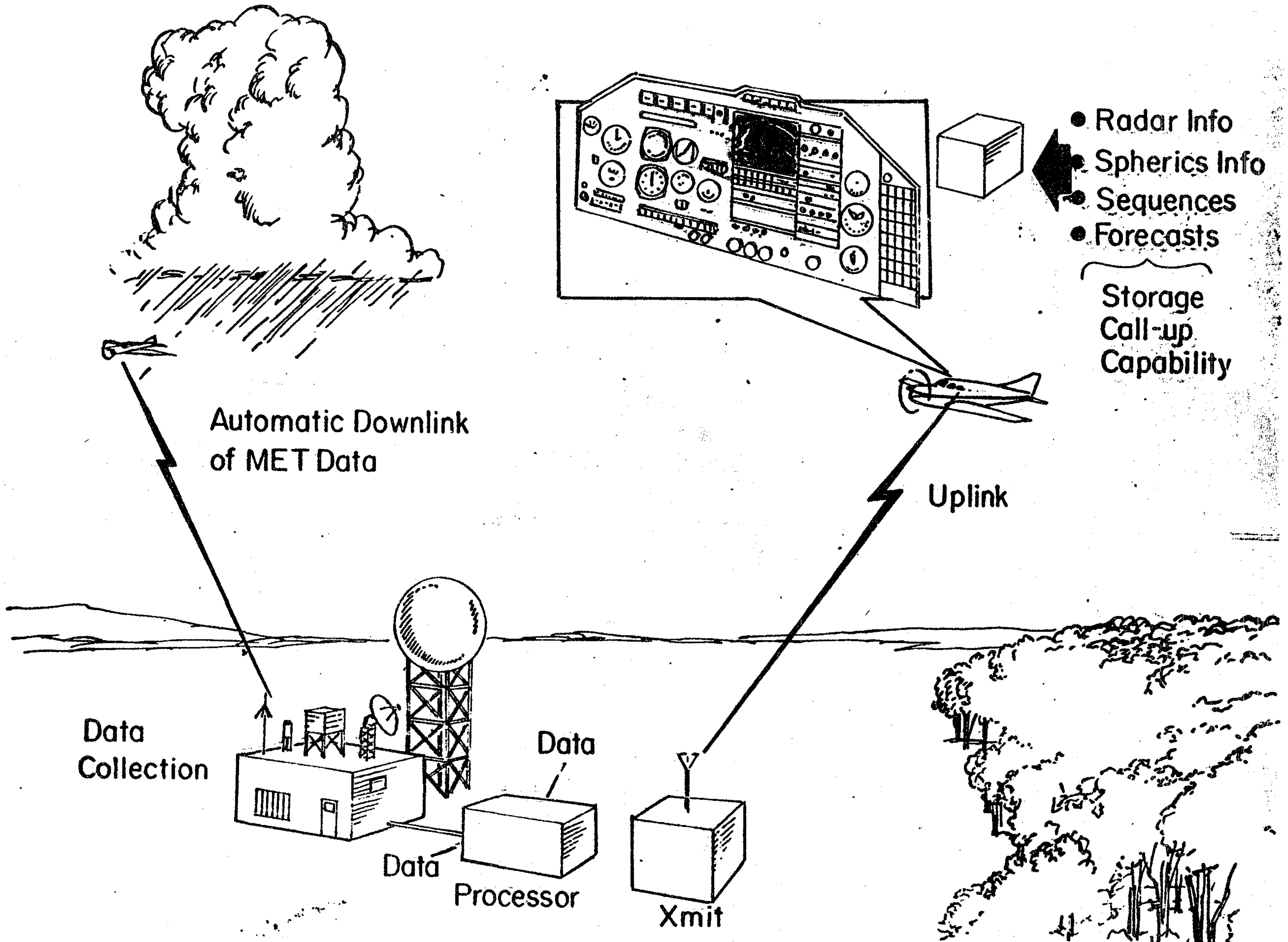

Figure 2. Shown is a Pictorial Representation of the Concept of Weather Data Collection. Processing of the Data and then Uplinking It to An Aircraft. On board the aircraft the information from the continuous data stream is stored and then presented on-command by the pilot.

burgeoning market for sale of weather information. Commercial organizations such as Weather Services International of Bedford Massachusetts, Compuserve, Columbus, Ohio and others [8] have moved to provide better weather service to pilots but on a call up basis from a ground terminal. Obviously, the availability of weather data leads to prospects of marketing specific services. It is conceivable that if government does not move to provide the service needed by the pilot in the cockpit then some entrepreneur may move to supply this.

FAA plans, however, seem to indicate that promulgation of weather information in a timely manner to pilots has a high priority. This being the case, then there is every reason to believe that government will ultimately be supplying weather uplink service.

The approach, in summary, has been directed towards efficiency in the weather data uplink. Feasibility and usefulness are expected to be well documented in the FAA/MITRE project.

III. DISCUSSION

A. Frequency Selection - Some Rationale. Some of the early considerations to provide for a data uplink was to use some of the known, but currently little-used spectrum space in the UHF TV band. Also, portions of the VHF TV band were considered viz, the vertical interval and the subcarrier possibilities with commercial TV and FM. Information received from the Federal Communications Commission staff reveal that when uplinking weather information that is not for general public consumption, use of broadcast bands cannot be permitted under current rules. Broadcast requirements are that the information must not be specialized but rather suitable for widespread use.

The most practical approach seems to be to use frequencies that have already been allocated for civil, aeronautical use. Indications are that even though military communications frequencies are lightly used, the probability of getting the military to release frequencies for this purpose is quite low.

Because the signal will be received by the aircraft, co-channel operations will be susceptable to interference should the transmitting stations be spaced less than 100 miles which is a reasonable, desired density especially in the eastern United States. This density is related in part by the range of weather radars and by the length of sequences of hourly weather observation reports.

Chamberlin [9] has developed a formal technique for specifying the density of ground stations given the minimum altitude for the coverage and the specific terrain profiles and tree cover of the earth. This work, although directed at the problem of providing coverage for air traffic control voice channels, is, nevertheless, directly applicable to this radio transmission which may be expected to be at VHF.

One attractive possibility is the use of discrete VHF communications channels made available by the 25 KHz spacing which is being implemented. All new general aviation transceivers are allowing for this channeling by providing 720 channels. Data handling on these channels would be straightforward and would permit choice from a variety of schemes for data compression and redundancy reduction to maximize the data transfer on the per unit bandwidth. The available bandwidth appears now to be approximately 12 KHz.

Looking at other possible carrier frequency assignments reveal the VOR as a good candidate. The densities of stations are variable throughout the U.S. but, in general, the coverage is adequate especially above 5000 feet. In the eastern U.S. greater density of coverage permits use below 3000' AGL in many areas.

The VOR has been used satisfactorily in the feasibility assessment program conducted by Ohio University involving the uplink system developed by MITRE. This experience points to benefits such as availability of ground equipment and operating systems and disadvantages such as the need to share data with critical navigation information content. Existing sidebands carrying the navigation information limits the bandwidth available for the weather uplink and concomitantly limits the variety of techniques which can be considered for encoding the information.

A communications simulator recently developed at Ohio University for the Air Force [10, 11] would be appropriate for investigating any of the modulation schemes appropriate for the uplink purpose.

Tacan (L-Band) which includes the DME has similar coverage as the VOR but the general aviation fleet is not as well equipped for receiving this signal nor are the modifications to obtain the weather message as easily accomplished as with the VOR. Low frequency, nondirectional beacons do not have the bandwidth capability to handle desired quantities of information desired for an uplink.

B. Information Needs. When one considers all of the possible data items which might be desirable to transmit to the pilot in flight the list becomes quite long. Paring the list down to reasonable lengths consistent with the items identified in [2] results in the following:

a) Reflectivity patterns. Rain areas, in particular, level three and greater returns, are of considerable interest to the pilot principally because of the high correlation of these rain areas with turbulence.

b) Spherics patterns. There is considerable evidence that turbulence is correlated closely with lightning discharges [12, 13].

c) Hourly sequences with altimeter settings. Flights frequently have durations greater than one hour, and, during times of low visibility at the surface which affects landings, it is important to detect trends that relate to the capability to land at all. Consideration of alternates is also important. The altimeter settings being available could obviate the need for the center controller forwarding the information by voice.

d) Forecasts. These being available allows for better planning. Revised forecasts are of greatest importance.

e) Map of cloud top heights with freezing level. This is presently considered one of the best means of depicting potential airframe icing areas and for providing indications when thunderstorms are present and the intensity of these thunderstorms.

f) Critical weather map. A critical area map is a good tool for advance planning of diversions but of limited value for weather area penetration. Critical items would be ice, turbulence and low visibility at airports affecting landings.

g) Satellite maps. At present, the use of such information in the cockpit would be limited, principally because of details and resolution that could be made available on the link. Improvements in satellite imagery and redundancy reduction techniques hold promise that in the future a sufficiently high-quality picture can be made available in the cockpit such that it will have value to the pilot in decision making concerning routing.

There are many other items further down the priority scale but indications are that bandwidth limitations will initially truncate the list to exclude such things as notams, airmets, area forecasts, winds aloft, and pressure pattern maps at the surface and other levels.

C. Weather Radar Considerations. The National Weather Service operates 111 weather radar units, 56 of which are network radars regularly reporting their observations. The remainder are local warning radars which are operated on an as-needed basis. This gives a good coverage particularly east of the Mississippi River. Sometime in the mid to late 1980's the government is expected to deploy the NEXRAD which will replace and, in some cases, augment present coverage. The availability of NEXRAD weather products in the cockpit will provide information heretofore unavailable with airborne weather radars at any price. Increased quality and coverage of the radar means increased decision-making information and the most appropriate place for this to be made available considering flight safety is in the cockpit. This information could in itself justify the cost of the weather data uplinking. With respect to capability to interpret and efficiency of uplinking, the NEXRAD product by voice will immediately demonstrate the unsatisfactory nature of trying to transmit the data by voice. The NEXRAD graphics products will not be well-handled by voice transmission. Uplink of graphics is considered important for full utilization of the radar capability.

D. Mode S (DABS) Considerations. The Mode S, formerly called Discrete Address Beacon System, also offers possibilities for the uplink. One basic purpose of this system is to offer digital communications with both up and down link capability for aircraft and this is consistent with the uplink of weather. With the added capability of providing near real-time weather, the system implementation would be encouraged and would provide justification for equipment expenditures both by the government for the ground-based equipment and with private aircraft owners for the airborne Mode S capability.

Unfortunately, there are some serious negative factors. First, the implementation dates for Mode S are well into the future and subject to further delays and changes. Waiting until this picture clears offers serious risk and the loss of capability. This, of course, means that accidents which could have been prevented were not.

Second, the system does not provide broadcast; hence, there is a need for interrogation. This means that two active systems must be involved which reduces reliability and adds complexity.

Third, the cost of the equipment will be greater than for a passive storage system. Additional features of Mode S may or may not be desired by the purchaser but he probably would not have a choice but to buy a total package which would include the Mode S that he may not need in the type of flying he does.

Fourth, ground facilities are presently in place if the VHF channels are deemed best for uplinking. Modifications and costs for ground stations are principally for phone line services which will be true for Mode S installations also. VOR station modifications are minor and not costly. Dedicated VHF communications would require acquisitions of a standard transmitter for the dedicated frequency.

E. Implementation Problems. One of the most formidable problems in any deployment of weather uplink equipments will be of the proverbial "chicken and egg" type. Manufacturers of airborne equipments to be purchased by the public will probably not begin production until ground stations are available to permit use of the system. The government may say that without immediate user need there is no justification for deployment. The obvious break in this cycle is for the government to determine the potential for increasing safety, establish some pilot projects such as is being done with MLS and set a deployment schedule for ground facilities.

IV. CONCLUSIONS

The investigation into various means to provide an efficient transfer of weather to the pilot in flight has yielded the following conclusions:

1. Real-time weather data being available on call in the cockpit will improve safety and reliability of general aviation operations to include, specifically, single pilot IFR operations. Uplink of the information to the cockpit storage unit can be efficiently done using radio channels.

2. Although the uplink concept dates back into the 1940's, recent work by MITRE under an FAA contract has produced a breadboard system which gives every indication of producing results consistent with design objectives for providing sequences and radar reflectivity maps on dot matrix printers.

3. Limited available channel space compels one to make efficient use of the radio frequencies since these are judged to be the only practical means for transfer of the weather information.

4. Efficient use of the spectrum very well may imply that data compression and redundancy reduction be used to allow transfer of all needed weather information.

5. The advent of NEXRAD provides considerable motivation for developing an uplink because of the new type data that will become available with the pencil-beam, doppler radar providing the pilot decision-making information on icing and turbulence. The information to the pilot will be superior to that presently obtained from airborne weather radar equipment. Total cost to the pilot for obtaining the NEXRAD data should be less than airborne weather radar.

6. Weather area penetration must be considered as one important need for the use of weather data uplink systems. Merely having data available without a capability to use it effectively does not complete the engineering requirement. Safety, while of paramount importance, must be linked to reliability of flight schedules. The cancellation of a flight because of possible weather is not the best solution always simply because the airplane must serve a purpose. In many cases, the airplane represents a considerable financial investment, and this brings strong pressures for utility. It forces consideration of weather area penetration whether legal considerations relative to government services encourage it or not.

7. Spherics data is important for uplinking to the pilot. There is sufficient evidence to support that electrical turbulence is associated with discharge activity.

8. Effective use of the cockpit weather displays especially for penetration purposes is tied closely with the availability of

aircraft positional information on the display. More desirable is the vector showing direction of travel. This being available, the orientation of the display for course up gives the pilot the commonly available, contemporary weather radar display but with 360-degree coverage.

9. One currently least available but very important piece of weather information that should, in the future, be made available to the pilot in flight is cloud top height information. This provides information to the flight concerning icing possibilities and also relates to thunderstorm intensity. Fortunately, this latter thunderstorm height data is being reported by the radar weather observers with the WSR-57 and 74 equipments.

10. The "chicken and egg" problem is real. Potential problems in implementation of any system for uplinking the weather will appear as manufacturers and government wait for the other to move first. Motivation for improving air safety is sufficient to allow the government to move first. MLS-type incremental deployment can be used as a model.

11. Mode S is not the most desirable means for uplinking weather. Delay in implementation of Mode S, and lack of flexibility for the user in selecting low-cost, specialized equipment are the major deterring factors.

V. RECOMMENDATIONS

These recommendations are formed recognizing the result that the concept of uplinking weather information to the pilot is feasible and highly desirable based on safety and utility needs. Limited financial resources understandably will force a cut in the rate of pursuit of any goals but a listing of these future goals is considered appropriate.

1. Efforts to optimize the data transmission rate should be made in order that high efficiency may be obtained for the use of the spectrum channel space.

2. Recognizing that the advent of multifunctional CRT displays is at hand, consideration of superposition of weather and navigational display information should be accomplished.

3. Superposition of uplinked spherics data on reflectivity patterns should be demonstrated.

4. Penetration of weather areas defined by up-linked weather information should be investigated to determine feasibility and practicality.

5. Simulation to determine the efficacy of simultaneous weather/navigational display information should be accomplished. Subject pilots should be given tasks of maneuvering aircraft to determine whether the uplinked information is effective in close avoidance of weather cells.

6. Since NEXRAD's potential for aiding pilots is very great, a thorough investigation of its suitability and applicability for uplinking should be made.

7. Spherics holds much promise for adding information with respect to turbulent areas; hence, collection of such data using ground-based facilities should be encouraged.

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VII. APPENDIX A - Contacts.

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Mr. Vince Costantino, FAA, Washington, D.C.

Mr. Joe Sowar, FAA, Washington, D.C.

Mr. Dave Harrington, FAA, Washington, D.C.

Mr. Jerry Davis, FAA, Washington, D.C.

Mr. Arthur Hilsenrod, FAA, Washington, D.C.

Mr. Gerald Markey, FAA, Washington, D.C.

Mr. James McLean, National Transportation Safety Board, Washington, D.C.

Mr. George Sarver, Federal Communications Commission, Washington, D.C.

Dr. Homer Hiser, Univesity of Miami, Florida

Mr. Jerry Carmean, Ohio University, Athens, Ohio

Mr. Richard Madden, Ohio University, Athens, Ohio

Mr. Rick Clark, Continental Cablevision, Athens, Ohio

Mr. Lew Ramey, National Weather Service, Columbus, Ohio

Mr. Joe Holbrook, WBNS TV, Columbus, Ohio

Mr. Dick Richards, Arvin Diamond, Carroll, Ohio

Mr. Neil Braswell, Enterprise Electronics, Alabama

Dr. Walter Frost, University of Tennessee, Tullahoma, Tenn.

Mr. Jean Lee, National Severe Storms Lab, Norman, Oklahoma.

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16. Abstract

Results of an investigation to identify efficient methods for providing weather information to the pilot in flight are summarized. Motivation for this work has been the need of the pilot for current weather information, sometimes in graphical form, so that he can improve the safety of his flight by avoiding areas of adverse weather. Use of discrete communications channels in the aeronautical, VHF band or subcarriers in the VOR navigation band are considered the best possibilities. Data rates can be provided such that inputs to the ground-based transmitters from 2400-baud telephone lines are easily accommodated together with additional data coming from circuits supplied from National Weather Service files.

L-Band beacons, including Mode-S, special NDB facilities, FM and television subcarriers are considered unsatisfactory due to various reasons that are identified.

The crucial weather data considered for uplinking are identified as radar reflectivity patterns relating to precipitation, spherics data, hourly sequences, nowcasts, forecasts, cloud-top heights with freezing and icing conditions, the critical weather map and eventually satellite maps. NEXRAD, the next generation ground-based, Doppler weather radar which will produce an improved weather product also encourages use of an uplink to fully utilize its capability to improve air safety.

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