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A Concept and Plan for the Development of a Weather Support Subsystem for Air Traffic Control

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16. Abstract

This report summarizes the results of a study to: (1) investigate the primary needs of air traffic controllers, flow controllers, and central flow controllers for weather information, (2) define a cost effective system concept to meet these needs, and (3) lay out a plan for the development of the proposed weather subsystem to support Air Traffic Control.

The recommended system will provide rapid generation and dissemination of reliable user oriented observations and very short range severe weather forecasts (up to 30 min.) to facilitate controller planning. This new capability will: 1) reduce weather induced controller work load peaks, 2) permit controllers to coordinate and preplan aircraft rerouting for weather avoidance, 3) achieve an improved balance between the inefficiency of overreaction and the essentials of safety, 4) facilitate controller response to pilot requests for weather data on a work load permitting basis, and 5) enable the issuance of accurate weather advisories. The system will also provide rapid generation and dissemination of reliable short range forecasts (up to 4 hours) to permit early introduction of necessary flow control procedures. This new capability will: 1) decrease problems for controllers, 2) increase acceptance of flow control, and 3) increase traffic flow efficiency without decreasing safety.

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ABBREVIATIONS AND ACRONYMS

AFOS - Automation of Field Operations and Services

AMOS - Automatic Meteorological Observation System

ARTCC - Air Route Traffic Control Center

ARSR - Air Route Surveillance Radar

ARTS - Automatic Terminal Radar System

ASR - Airport Surveillance Radar

ATC - Air Traffic Control

ATCRBS - Air Traffic Control Radar Beacon System

AV-AWOS- Aviation Automated Weather Observation System

AWANS - Aviation Weather and NOTAM System

AWEP - ARTCC WEather Processor

AWS - Air Weather Service

BRITE - Bright Radar Indicator Tower Equipment

C - Current Conditions

CAT - Clear Air Turbulence

CFCF - Central Flow Control Facility

CONUS - Continental U.S.

CRD - Computer-Readout Device

CRT - Cathode Ray Tube

DABS - Discrete Address Beacon System

FAA - Federal Aviation Administration

FSS - Flight Service Station

INACS - Integrated National Aviation Communication System

LAWRS - Limited Aviation Weather Reporting Station

MAPS - Meteorological and Aeronautical Presentation System

MTI - Moving Target Indicator

NAFAX - National Weather Facsimile Network

NAFEC - National Aviation Facility Experimental Center

NAS - National Airspace System

NBWS - Narrowband Weather Subsystem

NDC - National Distribution Circuit

NMC - National Meteorological Center

NWS - National Weather Service

Abbreviations (Cont.)

PIREP - Pilot Report
PVD - Plan View Display
RAMOS - Remote Automatic Meteorological Observation System
R&D - Research and Development
RVR - Runway Visual Range
S - Short Term (0-4 hr) Forecast
SCC - System Command Center
SDC - State Distribution Circuit
SSF - System Support Facility
STC - Sensitivity Time Control
SVR - Slant Visual Range
SWAP - Severe Weather Avoidance Plan
SWEP - SCC WEather Processor
TCA - Terminal Control Area
TIPS - Terminal Information Processing System
TRACON - Terminal Radar Control
TWEP - TRACON WEather Processor
WBRR - Weather Bureau Radar Remote
WMSC - Weather Message Switching Center
WRAP - Weather Radar for ATC Planning
WSA - Weather Subsystem for ATC
WSFO - Weather Service Forecast Office

Service A data:

SA - Surface Observation
SW - Supplementary Weather
SP - Special Weather
FT - Terminal Forecasts
FA - Area Forecasts
WW - Severe Weather Forecasts
WH - Hurricane Advisories
NOSUMS - Notice to Airmen Summaries

Abbreviations (Cont.)

FD - Winds and Temperatures Aloft

WS - SIGMENTS

WA - AIRMETS

SD - Radar Weather Reports

UA - Pilot Reports

NOTAMS - Notices to Airmen

AS - Surface Analysis

FS - Surface Forecast

1.0 INTRODUCTION

1.1 Executive Summary

This document is the culmination of a study to: (1) investigate the primary needs of air traffic controllers, flow controllers, and central flow controllers for weather information, (2) define a cost effective system concept to meet these needs, and (3) lay out a plan for the development of the proposed Weather Subsystem to support Air Traffic Control (WSA).

Today's principal weather system limitations must be considered in the context of major FAA objectives for ATC to: (1) minimize controller work load peaks, (2) increase capacity and economical airspace use, (3) increase safety, (4) satisfy pilot needs, and (5) increase automation. A cataclysmic failure will not result from the continued use of the present system; however improvements must be made to achieve the above objectives by satisfying controller weather needs and by developing a weather support system in harmony with other FAA developments. To support these objectives controllers need more accurate and fresher weather data presented in a user oriented fashion.

Presently, the radar depiction of weather to controllers consists of low resolution, unreliable images of precipitation areas. The regions of severe weather hazardous to aviation are not well defined, and the controller's view of the weather is inferior to that provided to the pilot by airborne radar and visual observation. This results in a dichotomy with pilots requesting course deviations around storm cells without knowing traffic locations and controllers trying to maintain minimum separations without knowing the severe weather sites.

Weather problems at one airport or sector impact traffic control in a large geographic region around the affected location. The dissemination of the relevant surface observations and PIREPs today is largely manual, resulting in products too stale to permit appropriate decision making before problems develop. The data are not generally presented to the controller in a truly user-oriented fashion. The wealth of potential PIREP data has been largely untapped. Today's weather data management system is yet to truly benefit from modern computer communication and data management. Moreover, it has not kept pace with the automation of the ATC system.

The cost benefit of an improved weather subsystem can be based upon traffic delays and accidents. Delay cost estimates, primarily due to excess fuel consumption for the U.S. airlines ranges from $60 to $260 million. Some of these delays unnecessarily result from controller overreaction to unknown conditions caused by poor weather data. A single jumbo jet accident can result in hundreds of deaths with a legal settlement exceeding a $100 million plus the loss of a $25 million aircraft. Serious weather accidents, although rare, can result from turbulence, wind shear, slippery runways, etc. The savings from reduction of these costs by even a few percent could totally amortize a new system.

Controllers primarily need an accurate indication of current significant weather conditions plus a very short term forecast (0-30 min) of those conditions that are likely to change during the few tens of minutes an aircraft traverses a sector. Significant data include radar depiction of turbulent thunderstorm cells; surface observations of sky cover, ceiling, visibility, weather type, obstructions to vision, pressure, temperature, dew point, wind direction, wind speed, gusts, altimeter setting; wind shear along the flight path; and the locations and motion of wake vortecies. These data are needed to minimize controller overreaction to unknown weather conditions, to reduce controller work load peaks caused by unexpected course deviation requests and unexpected actions by neighboring sectors, and to promote the safe coordinated landing and rerouting of aircraft.

Flow controllers and central flow controllers primarily need a good indication of current conditions plus a short range forecast (0-4 hr)* of storm fronts and conditions affecting airport capacity. Ideally flow control would facilitate flight plan changes around affected routes before takeoff and would provide a basis for holding aircraft on the ground if unable to land at their selected destination. This would alleviate traffic congestion and save fuel.†

A unified connected system is essential to simultaneously support the most significant weather needs of terminal and en route controllers, flow controllers, and central flow controllers. The effect upon ATC of a weather

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*More than 90% of the flights are less than 4 hours.

†Recently, to avoid landing delays, the fuel advisory and departure procedure held Chicago bound flights on the ground at 150 airports. This procedure saved 658,000 gallons of fuel during a one-day test.

disturbance is not restricted to the place where it occurs. The major system, data communication, and data management conclusions are:

1. Computerized weather data processors are needed in the system command center, en route centers, and major TRACONs to manage and process the meteorological data base. These processors will provide the controllers and flow controllers with user oriented products on computer readout devices at each control position. Storm cell data will appear directly on the Plan View Display (PVD). Computerized data management is essential to assure rapid data dissemination to controllers. A secondary benefit is the limited number of people employed in the new subsystem.

2. To assure rapid data dissemination these weather processors must be interconnected to each other and to the many sensor data sources. Communication data rates are typically under 300 bits/sec and could easily use standard telephone lines or be integrated into the proposed Integrated National Aviation Communication System (INACS).

3. Controller needs for fresh, up-to-date surface observations and radar data are more stringent than the Flight Service Station (FSS), National Weather Service (NWS), or Air Weather Service (AWS). Service A does not in general satisfy ATC freshness needs.

4. Maximum exploitation should be made of the meteorologist at the System Command Center (SCC). The NWS development of computerized communication and display embodied in the Automation of Field Operations and Service (AFOS) system and the National Distribution Circuit (NDC) can largely provide the automated aids needed by the SCC meteorologist. This development has been paid for by the NWS. The SCC is the only location in the ATC system requiring a meteorologist. The NDC is also a valuable data source for the en route and TRACON weather processors.

5. The recent decision to co-locate FSS Hubs and en route centers affords the opportunity to share resources. FSS and ATC are interested in much of the same data base.

6. In the long term, airborne meteorological sensor data could be automatically transmitted via the DABS data link. In the near term, FSS and en route center collocation permits tapping the wealth of PIREP data available from controllers for mutual benefit. These PIREPs could be collected and interpreted especially for selected routes in all weather (good or bad) conditions. Simple aids can facilitate this collection without adversely affecting controller work load.

It is important that certain sensor developments be actively pursued to support the WSA. The primary sensor concerns are:

1. The existing surface observation development programs within the FAA and NWS (AV-AWOS, Semi-Automated LAWRS, AMOS, RAMOS) should satisfy ATC needs provided the data is rapidly disseminated.

2. A wind shear and wake vortex sensor development program is being actively pursued and when developed should interface with the TRACON weather processor.

3. The ASRs, with appropriate modification, should be able to satisfy terminal control weather radar needs. The ARSRs can not satisfy en route control. This follows primarily from en route requiring storm cell tops to permit overflight whereas two dimensions suffice for terminal control where avoidance must be around cells. In addition both the ASR and ARSR radars can only provide sufficient resolution to 75 Km range which suffices for terminal control but falls short of covering the en route airspace.

4. A new or significantly modified joint use weather radar network can simultaneously satisfy en route control, NWS, and AWS needs. ATC requirements for fresh data are in general more stringent than those of either the NWS or AWS.

The recommended development plan will achieve a prototype demonstration, a design specification and an initial operating capability of the system concept within five years of program initiation. During the five year development cycle certain operational improvements can be achieved, particularly: (1) an ASR weather modification to identify storm cells to controllers, (2) an AFOS system to support the SCC, and (3) improved PIREP acquisition and distribution.

Development is subdivided into three program elements. The first program element focuses on the computerized weather data processors to manage, process, communicate and display user-oriented data to controllers, flow controllers, and central flow controllers. The second program element, the ASR Weather modification, and the third element, the joint use Weather radar, are meant to provide the needed radar data for terminal and en route control respectively. A joint use weather radar capability must be demonstrated before the NWS, and AWS deploy their next generation radars in the early 1980's to assure appropriate features are included. Other needed sensor developments are currently being actively pursued by the FAA and are not included in the development plan.

Subsection 1.2 provides an overview of the major elements and features in the recommended system. Those readers, without the need for details, may skip to the development plan in Section 5. The body of the report is meant for the most interested reader and is divided into four sections with supporting appendices. Section 2 considers the principle limitations of today's system, the long-term needs and those needs that can be satisfied by the early 1980's. Section 3 describes the recommended system from a user's viewpoint focussing attention on the meteorological products and displays. Section 4 considers the system architecture to interconnect the data sources, process the data to satisfy the needs, and supply the products described in Sections 2 and 3. Section 5 considers a plan for the development of the proposed subsystem.

1.2 The Recommended System Concept

The proposed system concept has been developed to eliminate the major problems with today's system. The recommended system will provide rapid generation and dissemination of reliable user oriented observations and very short range severe weather forecasts (up to 30 min) to facilitate controller planning. This new capability will: 1) reduce weather induced controller work load peaks, 2) permit controllers to coordinate and preplan aircraft rerouting for weather avoidance, 3) achieve an improved balance between the inefficiency of overreaction and the essentials of safety, 4) facilitate controller response to pilot requests for weather data on a work load permitting basis and 5) enable the issuance of accurate ATC weather advisories. The system will also provide rapid generation and dissemination of reliable short range forecasts (up to 4 hours) to permit early introduction of necessary flow control procedures. This new capability will: 1) decrease problems for controllers, 2) increase acceptance of flow control, and 3) increase traffic flow efficiency without decreasing safety.

The system will employ small computer processors at each en route center and major terminal area for weather data management, automated alerting, weather radar netting, and automated generation of very short range severe weather forecasts. The terminal ASR radars are to be modified and the en route ARSR network is to be augmented by joint use (NWS, FAA, AWS) Weather Radars to provide accurate, fresh, high resolution data for storm cell depiction and automatic generation of very short range severe weather forecasts for controllers. The collocation of automated Flight Service Station Hubs with ARTCCs will facilitate rapid dissemination and interpretation of PIREPs. Display of weather data to controllers is to be provided by an upgraded version of the Meteorological and Aeronautic Presentation System (MAPS) at the ARTCCs and the Terminal Information Presentation System (TIPS) at the major terminals; radar weather data is to be available on the Plan View Display (PVD). Separate weather display consoles are provided for central flow control, flow control and terminal supervisor use. A telephone line computer communication network will interconnect existing and future sensors for rapid dissemination of weather information. The full data base available in real time to the System Command Center meteorologist through the computer managed system will facilitate analysis of impending weather problems before they produce ATC problems. The short range forecasts of severe weather, generated automatically, will be monitored by the SCC meteorologist and will be available for flow control applications. These data are to provide a nationwide capability similar to that provided to the New York Center by the resident meteorologist as a part of the Severe Weather Avoidance Plan (SWAP).

1.2.1 The Supporting Communication Network

The communication network required to support the system can easily be provided by low data rate telephone links; see Fig. 1.2.1. The three new components comprising the ATC weather subsystem include: 1) the SCC WEather Processor (SWEP), 2) the ARTCC WEather Processor (AWEP), and 3) the TRACON WEather Processor (TWEP). A new joint use (NWS, AWS, FAA) Weather Radar for ATC Planning (WRAP), network, provides storm cell data.

Data flow requirements demand connectivity between SWEP and each of the 20 AWEPs (within the Continental United States) and between each AWEP and its associated TWEPs. The low required data rates permit use of standard telephone lines or a network such as the proposed Integrated National Airspace Communications System (INACS). The particular communication structure is not critical providing data delays are very small. Moreover, where geographically advantageous, single links can service several AWEPs, although redundant routing is planned for system reliability. The interchange of data with the FSS Hubs is facilitated by collocation with the ARTCCs. Digitized low rate weather radar data is provided to the en route centers by the WRAPs. A single link can serve several WRAPs where geographically advantageous. Some weather radar data will be provided through the narrow band links with the associated ATC surveillance radars.

The system generates its own weather data, but also depends on available standard weather products as currently distributed over Services A and C from the Weather Message Switching Center (WMSC). Preferably, in the future, these products will be provided by the National Weather Service through connection

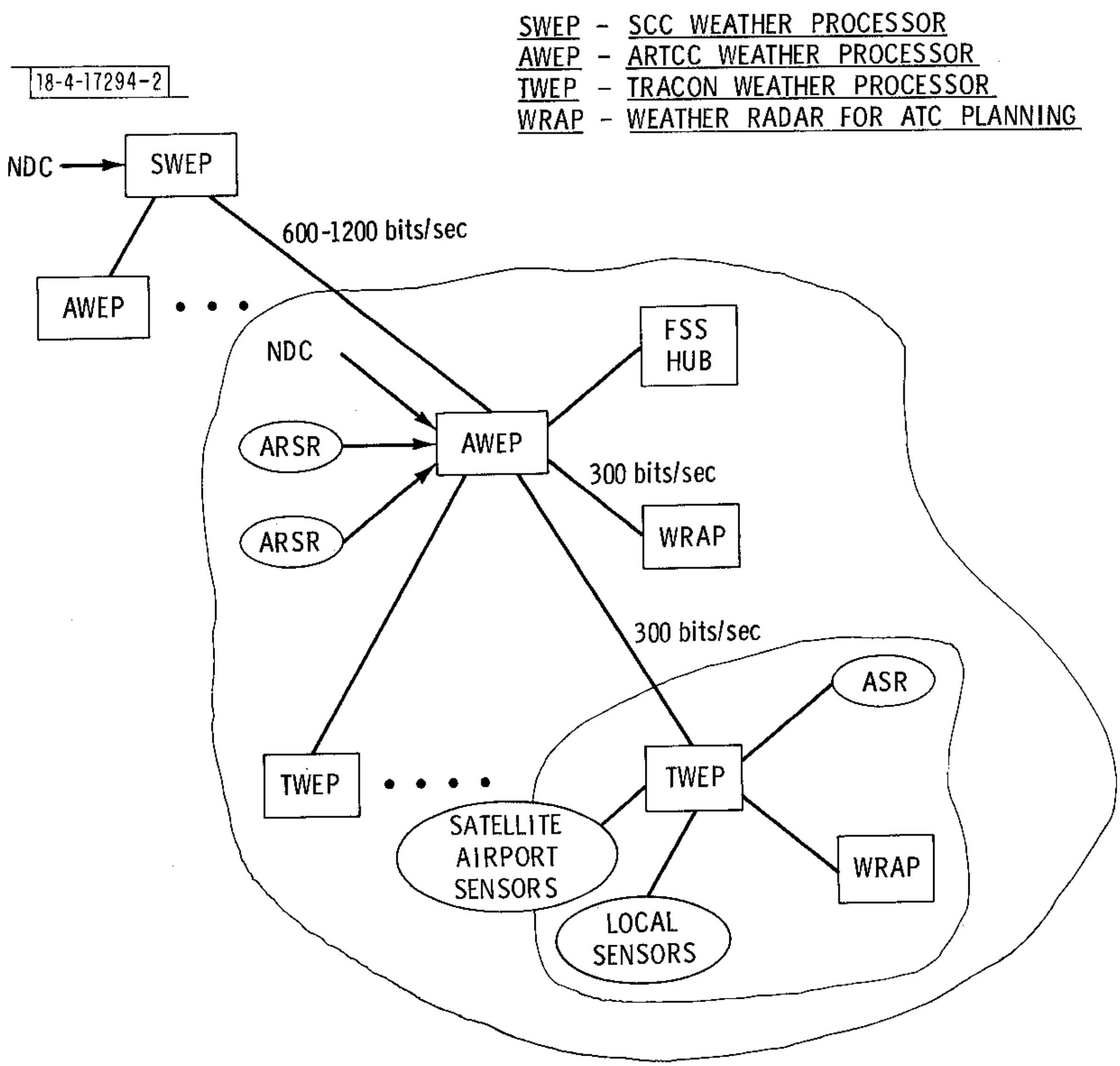

Fig. 1.2.1 Supporting communication network.

with the National Distribution Circuit (NDC). Observation data collected by the ATC facilities will be input through this same network.

1.2.2 The ARTCC WEather Processor (AWEP)

The AWEP, to be installed in each en route center, is to handle all the weather data management, processing, automated forecast generation, intra-center display, formatting, input/output and the communication control; see Fig. 1.2.2.

Input radar data from each associated WEather Radar for ATC Planning (WRAP), ARSR in regions without proper WRAP coverage, and ASR are to be processed within the AWEP to produce one composite-netted picture of current storm cell conditions and the very short term (up to 30 min) storm cell forecast. The resulting weather situation displays, illustrated in Fig. 1.2.3, are selectable by controllers on the PVD and are transmitted to other facilities. Hazardous storm cells can be indicated by C's or graphically, along with their important parameters. Very short term forecasts (up to 30 min) are selectable in 5 min. increments.

Weather observations are obtained from the associated Terminal WEather Processors (TWEPs), the NWS communication automation through their National Distribution Circuit (NDC), and/or Service A. Changes in terminal meteorological conditions are quickly transmitted from the TWEP to the AWEP to ensure controllers have accurate data. These products are selectable on the controllers weather Computer Readout Device (CRD).

The major collection and dissemination of interpreted PIREPS would be performed within the FSS Hub facility; the appropriate aids are provided to facilitate the acquisition of PIREPS from controllers. PIREPS received from the FSS automation would be managed and formatted within the AWEP for rapid display to the affected controller.

The controller input/output will consist of an alphanumeric/graphical weather CRD and a keyboard selection device. Weather radar storm cell and forecast products can be displayed either on this display or the PVD. Important (alert) data will automatically be displayed.

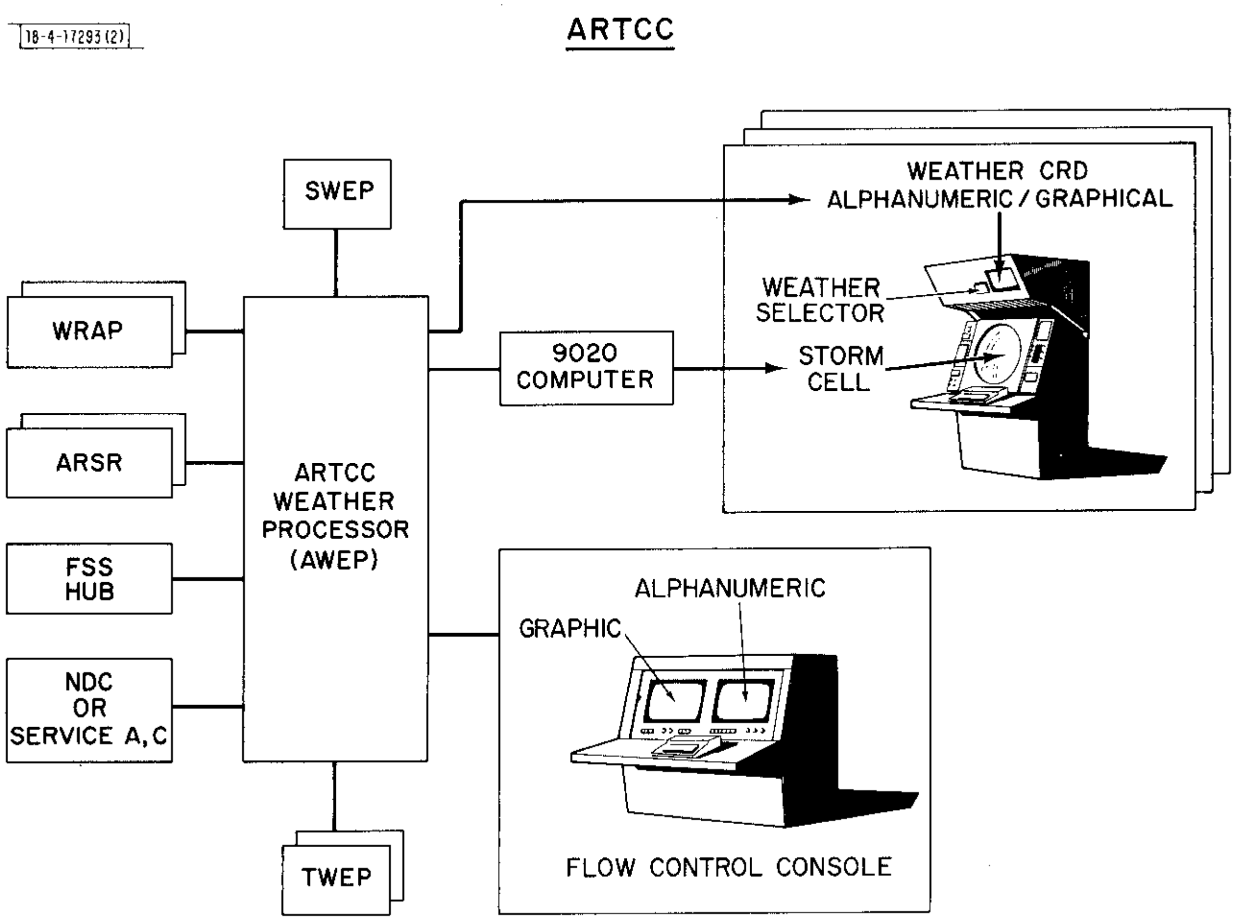

Fig. 1.2.2 ARTCC weather processing and dissemination.

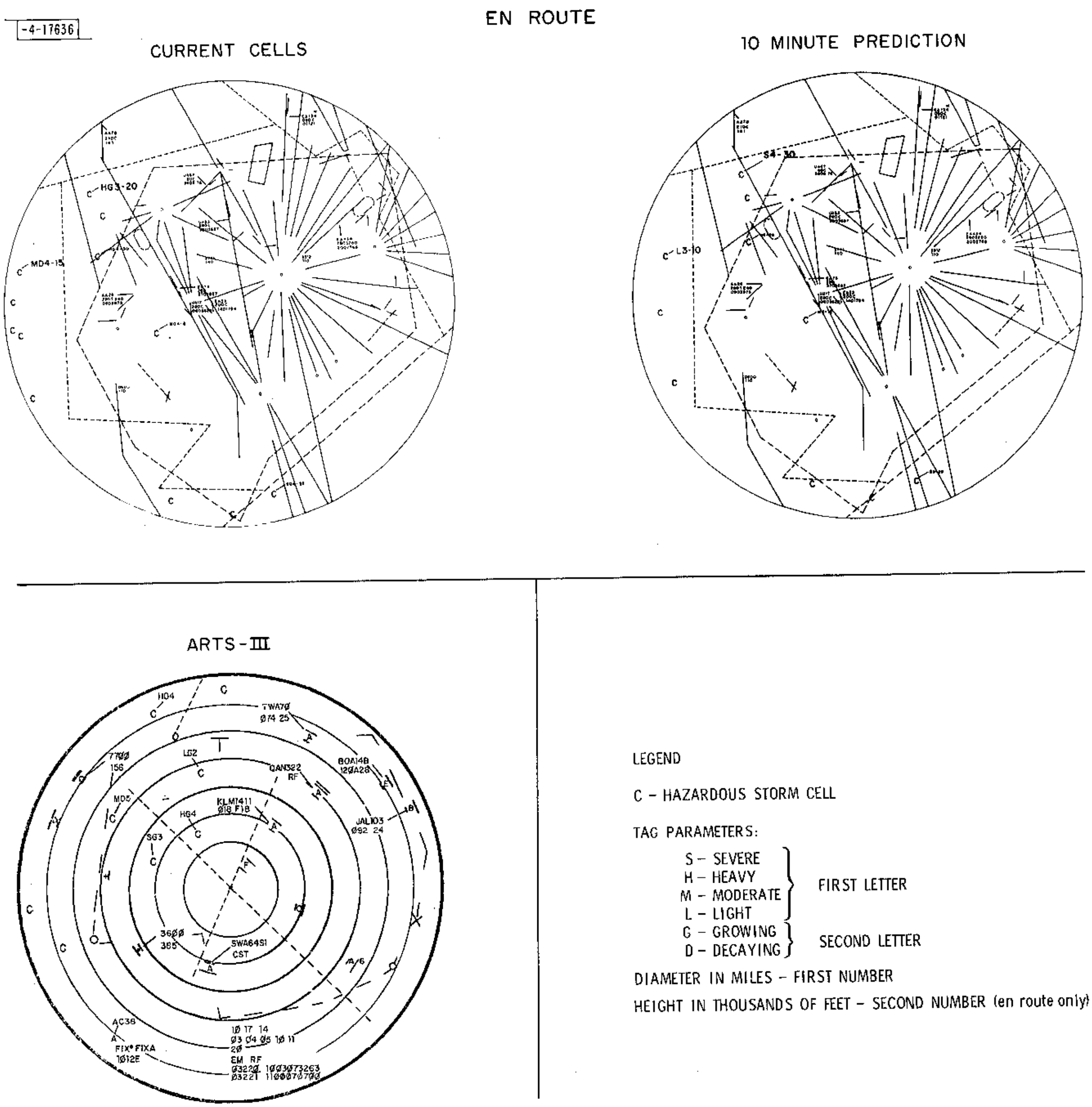

Fig. 1.2.3 Candidate weather situation displays.

The flow controller input/output will consist of a graphical and textual display with keyboard data recall and entry. All controller weather products plus a short range forecast (up to 4 hours) of storm front activity, provided by the System Command Center WEather Processor (SWEP), will be selectable by the flow controller. Where necessary the SCC meteorologist will interpret the data for the flow controller via a voice phone link.

1.2.3 The TRACON WEather Processor (TWEP)

The TWEP, to be installed at the TRACONs, is to handle all the weather data management, processing, intra-terminal display, formatting, input/output and communications control of terminal weather data; see Fig. 1.2.4. This processor will be less complex than the mini-computer system required for the AWEP.

A consistent description of storm cells is derived from the ASR or if available, a nearby WRAP and made available for display on the controllers PVD; see Fig. 1.2.3. This data is also transmitted to the AWEP for further processing to produce the very short term (0-30 min.) cell forecast which is then transmitted back to the TWEP for display to terminal controllers.

All observation and local sensor data, e.g., RVR, visibility, ceiling and sky cover, wind shear/wake vortex, altimeter setting, wind speed and direction, temperature and dew point, etc., for the airport and those satellite airports receiving approach control from the TRACON are to be resident in TWEP. The surface observation sensor developments like AV-AWOS, Semi-Automated LAWRS, AMOS and RAMOS will facilitate the timely automatic collection of this data especially during rapidly changing conditions. The TWEP maintains this common terminal wide data base. There are a number of reasons for transmitting this data directly to the TWEP: (1) controllers need the data, (2) only one interface is needed between the TWEP and the controller displays instead of separate interfaces with each sensor, (3) new sensors (like the wind shear/wake vortex sensor) can be easily interfaced with the TWEP, and (4) other data users can access the entire terminal wide weather data base with one interface at the TWEP.

The TWEP also receives from the AWEP surface observations from nearby airports, PIREPS and the short range (0-4 hr) storm front forecast.

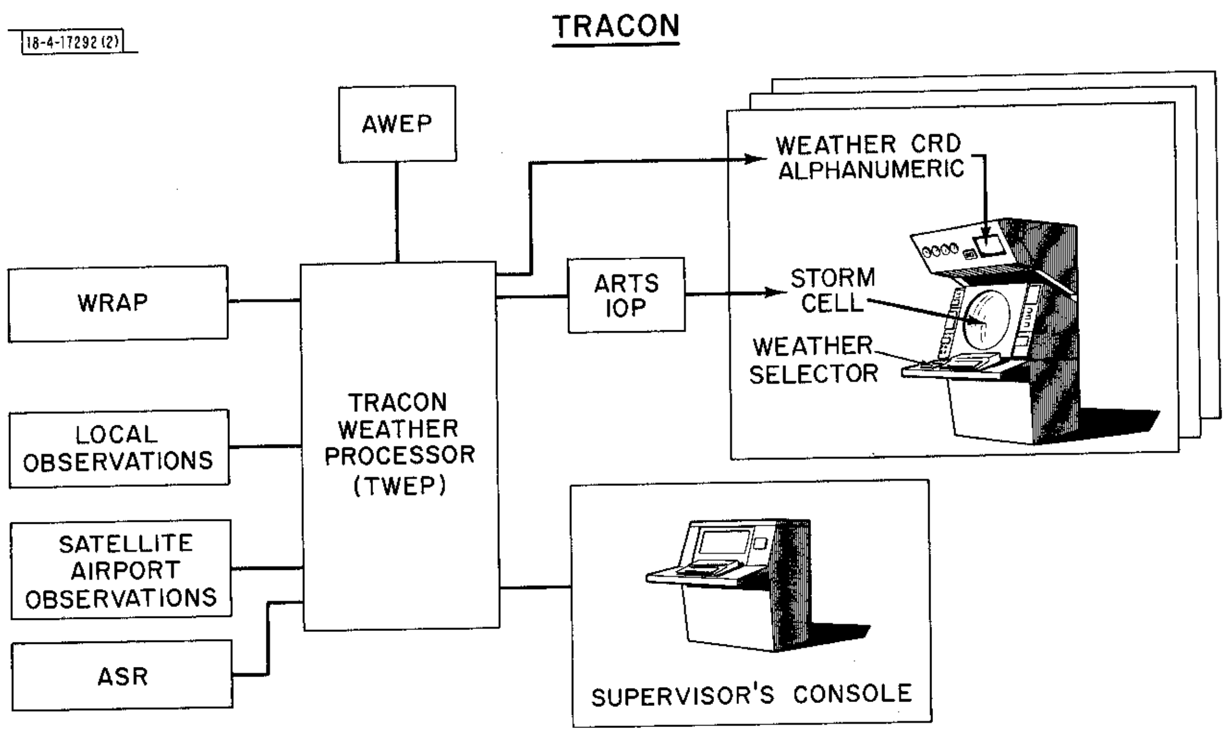

Fig. 1.2.4 TRACON weather processing and dissemination.

The controller input/output will consist of a textual CRD display, a graphic display on the PVD, and a keyboard selection device. Important (alert) data will automatically be displayed. The user input/output will facilitate rapid data retrieval. The same data will also be provided to the tower.

The supervisors input/output will consist of a single graphical/textual display with keyboard data recall and entry. All controller products plus a short range (up to 4 hour) storm front forecast will be selectable. Where necessary the SCC meteorologist will interpret the data via a voice phone link.

1.2.4 The SCC WEather Processor (SWEP)

The SWEP, to be installed at the System Command Center, is to handle all of the weather data management, processing, automated forecasting, display formatting, input/output, communications control and interface with the SCC automation system. See Fig. 1.2.5 for its relationship to the rest of the system.

The SCC has the only full time meteorologist (an NWS employee) in the ATC system. To effectively serve flow control, his data base must be as good or better than that available in the en route centers and terminals; this is not always the case today. An AFOS terminal (the NWS's computerized communication, processing and display terminal) is recommended to form the nucleus of the SWEP. It is well matched to the meteorologists needs: (1) minimizing his clerical tasks, (2) providing good access to the NWS data base, (3) it has been developed for NWS meteorologists, (4) it will be a low cost solution having been developed by the NWS, and (5) it should be upgradable for the special aviation weather tasks.

Input radar data from the AWEP is to be processed within the SWEP to provide a national netting of current storm activity plus the short range (0 to 4 hr) forecast. This data will be presented to the meteorologist who will review and monitor system operation, and provide special interpretation to the central flow and flow controllers. The meteorologist will have the authorization, responsibility and support equipment to change incorrect weather products based upon his assessment of new data. Short range forecast data and associated meteorologist's inputs will be formatted for transmission to the AWEPs. Routine

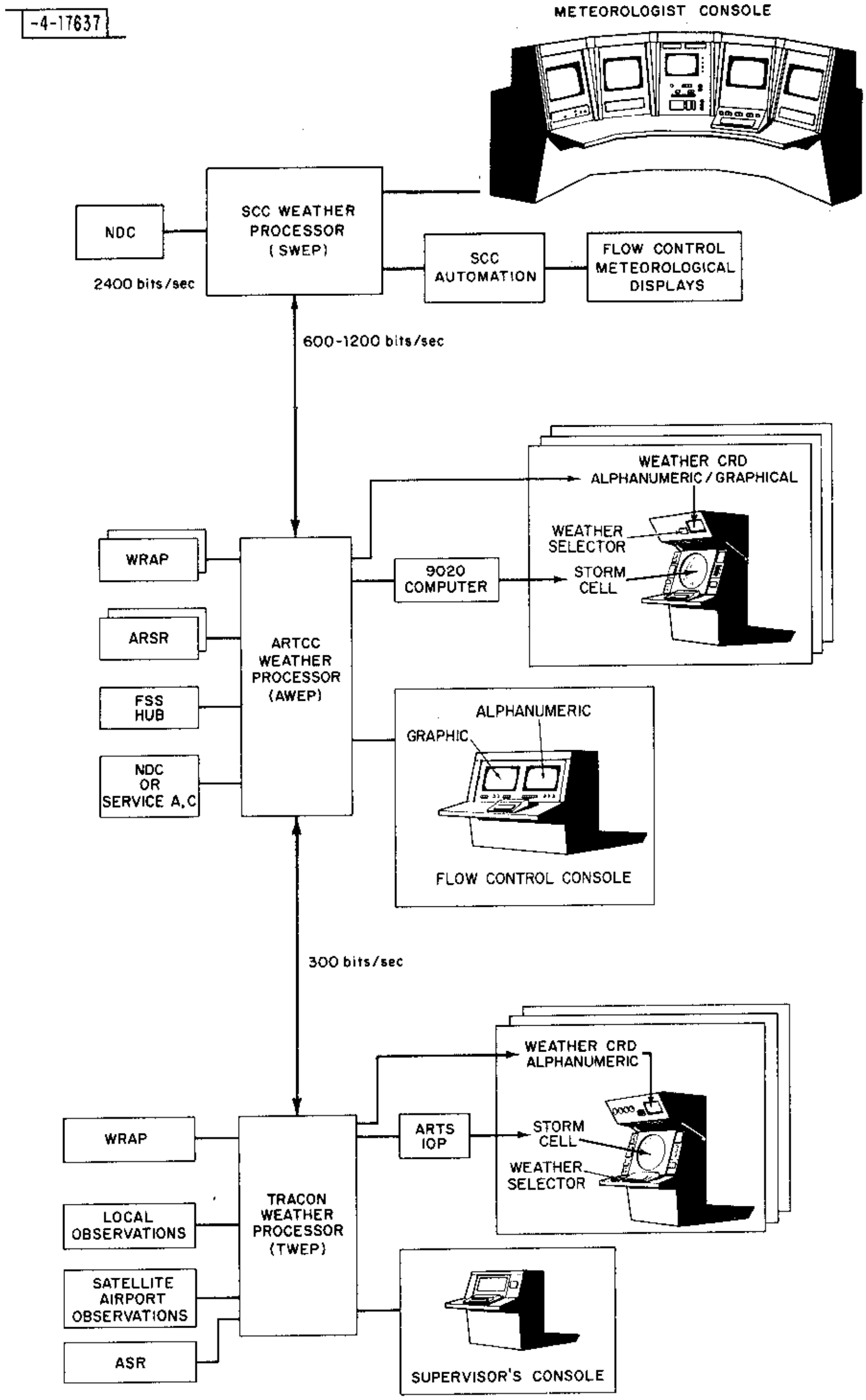

Fig. 1.2.5 Weather subsystem for ATC.

weather observations and forecasts will be obtained from the NDC; changing terminal conditions and PIREPs will be obtained from the AWEPs. Built-in automated alert features will provide the meteorologist with early data on emerging problems. Graphic and alphanumeric products prepared by the meteorologists will be formatted for presentation to the SCC flow controller and transmission to the AWEPs. The meteorologist's input/output will consist of several graphic/textual displays, and operator entry devices. Communications with TWEPs will take place through the associated AWEPs. Phone voice links will permit special interpretations when necessary to flow controllers and terminal supervisors.

1.2.5 Evolutionary Issues

In developing this concept for a weather subsystem it was recognized that nothing should impinge upon the controller's primary responsibility of keeping aircraft separated. The fresh and accurate weather data will provide controllers a capability to stay on top of the weather picture and thereby reduce the number and impact of unexpected pilot requests for deviations. The controller has complete freedom to select or not select displays he deems necessary. No demand is made upon the controller to act as a link between the weather information system and the pilot; however the mechanisms are provided to enhance a common understanding of the weather situation for mutual benefit.

This system concept provides the air traffic controller with the same types of weather information he receives today, i.e., radar weather data, surface observations, and PIREPs. The major departure from the present system is that this data will be fresh and accurate. This is accomplished with modern computer processing, data management and communication. No totally new sensors are recommended for the FAA. A modification is recommended for the ASRs and the next generation of NWS and AWS radars should be designed for compatibility with FAA needs in the en route centers. Full utility is taken of NWS communications, automation, and the present and planned surface observation network. This is not a totally new subsystem, but rather one that takes full advantage of the NWS present and planned capabilities as well as using state-of-the-art technology to augment and upgrade today's extensive ATC weather subsystem.

2.0 NEEDS AND BENEFITS

2.1 Principal Limitations with Today's System

The current weather support system has evolved differently in each control facility depending upon local conditions (Fig. 2.1.1). For instance, en route controllers receive Service A data in a variety of ways - paper, Computer Read-out Device (CRD), viewgraph, or verbal. TRACON controllers receive observations from satellite airports by phone and in some instances the flight data printer. Some data is informally passed along from controller to controller along the handoff lines. Between facilities verbal information is transmitted by phone lines. Within facilities much data is hand copied or verbally transmitted.

Controllers are individuals[1]; some make use of only essential weather data while others actively use and seek additional information for their own traffic planning and to advise pilots. This variability exists even for controllers occupying the same sector. It was thus concluded that any weather system must allow for flexibility in controller use and should not be inflicted upon him arbitrarily.

The differences in methods of acquiring, displaying and using weather information is not necessarily a limitation of the present system. The limitation must be considered in the context of: (1) controller workload, (2) capacity, (3) safety, (4) pilot needs, and (5) the ability to support automation. A few illustrative problems reflect upon these limitations:

- Controllers become visibly uneasy during adverse weather conditions. Primarily this results from a breakdown in the well ordered traffic flow, forcing reroutings. This increases his work load and to compensate controllers will increase the separation distance between aircraft thereby frequently unnecessarily decreasing capacity.

- Severe weather, particularly that due to convective thunderstorms, causes significant disruptions to the safe, orderly flow of aircraft and an increase in controller work load. Presently, the radar depiction of weather to controllers consists of low resolution, unreliable images of precipitation

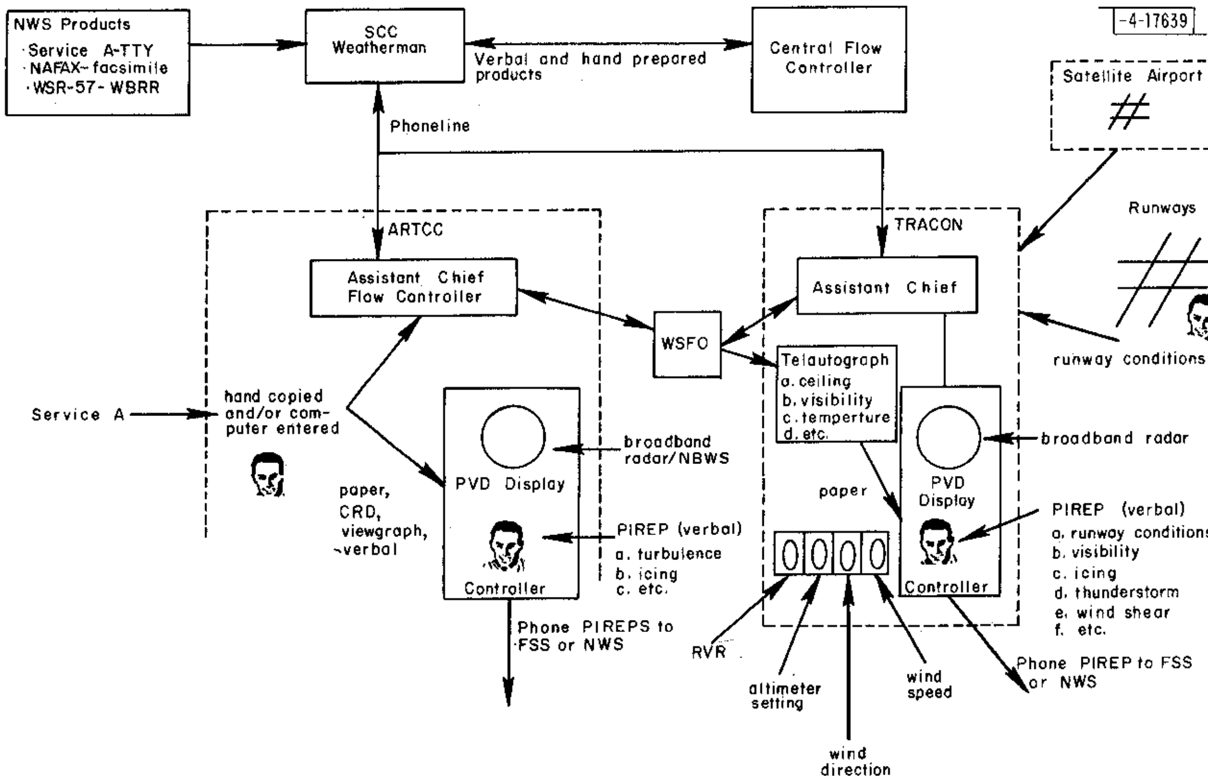

Fig. 2.1.1 The ATC weather system today.

Fig. 2.1.1 The ATC weather system today.

areas. The regions of severe weather hazardous to aviation are not well defined[2] which limits the ability of controllers to assist pilots without airborne radar. In addition the controllers image of the weather is inferior to that provided to the pilot by airborne radar and visual observations. This results in a dichotomy with pilots requesting course deviation around storm cells without knowing traffic locations and controllers trying to maintain minimum separations without knowing the severe weather sites. One aircraft may deviate around a storm cell to the right and the very next aircraft may request a deviation to the left. Even the request for a deviation from the first aircraft may surprise the controller. This disadvantage hampers coordinated rerouting and the efficient exercise of air traffic control procedures today[3] and may impact the computerized automation plans associated with conflict resolution, Intermittent Positive Control (IPC), and Metering and Spacing (M&S).

Weather problems at one airport or sector impact traffic control in a large geographical region around the affected location. Thunderstorms, fog, rain, changing winds, etc., can reduce the acceptance rate, change the approach fixes, close a runway, or change the active runway. Such events may force the rerouting of aircraft through a number of sectors which aggravates the controllers peak work load when he is caught by surprise. This is especially severe when it involves a line of closely spaced aircraft and the next sector suddenly refuses to accept additional aircraft. The largely manual handling of surface observations and PIREPs, and the delays associated with Service A result in data frequently being too stale to permit appropriate decision making before problems develop. PIREPS, a valuable source for adverse conditions, are frequently lost or delayed because the work required for distribution conflicts with higher priority tasks. The slow dissemination and the fragmented uninterpreted form makes them almost valueless for traffic control and of marginal use for preflight planning. The orderly collection of the wealth of PIREP data from controllers and pilots, and the rapid dissemination of interpreted reports to affected controllers and the FSSs would significantly enhance the utility of this data source. In the near term, a PIREP specialist could collect, interpret, and disseminate the data. In the long term, to relieve the pilot, the air to ground digital data link could automatically acquire data from airborne sensors.

The above are a few of the most illustrative limitations. Two conclusions can be drawn; for weather information to be useful it must be accurate and fresh. The following sections consider the specific meteorological weather needs and the benefits to be derived.

First the specific en route, terminal and flow control needs for weather data are considered, ignoring the ability of present technology to economically or physically meet these needs. These should be viewed as long term goals and, where possible, the WSA architecture should permit the incorporation of these features as the technology advances. The second part discusses the needs which can be met with current technology and implemented between now and the early 1980's. They are incorporated into the system concept described in Sections 3 and 4. The reader is encouraged to carefully read Section 2.2, since there are a number of concepts and definitions presented which are necessary for a full understanding of the system description. Finally the costs related to delays and accidents are considered.

2.2 User Needs - Long Term Goals

In this section, the weather information needed within the ATC system to meet the objective of improved safety, efficiency, and economy are discussed. Attention is restricted to only the most important needs of en route controllers, terminal controllers, and flow controllers. For convenience, the en route and terminal controllers will sometimes be referred to simply as controllers. Flow controllers at each ARTCC and the central flow controllers at the SCC are both referred to here as flow controllers.

Although the needs of the three types of terminal controllers[73] (approach, departure and tower) are different, it is premature to precisely specify the individual differences. At this stage in the WSA development, it is necessary to determine what meteorological information is needed by at least one terminal controller. If a meteorological product is available in the terminal the dissemination to all users desiring the product is easy and can be left to the final design. This is consistent with the Terminal Information Processing System (TIPS) study[1] which concluded that, "Meteorological and Status Information were determined to be required by all primary and secondary control positions. Its display should be adaptable to individual control positions." They also observed that the personal preferences of individual controllers occupying the same position varied. With computer generated display of weather products, each controller could select the desired products as he occupied a position by keying the number of a personal computer file listing the desired data.

ATC automation has reached the point whereby traffic flows in an orderly pattern and control uncertainties have been largely removed, except under adverse weather conditions. The unpredictable or unexpected deviation request around a thunderstorm, the unexpected refusal of an adjacent sector to accept any more aircraft, the unexpected aborted landing, and many others, have a severe impact upon the controller work load peaks and severely impedes orderly traffic flow. Alerting the controller to conditions which will affect the aircraft in his sector permits the appropriate preplanning, smooths out the work load peaks and facilitates the flow of traffic without overreaction. In general, controllers need good weather information:

- to reduce work load peaks
- to facilitate coordinated routing and rerouting
- for hazard avoidance
- to balance overreaction and safety
- to respond to pilot needs

Controllers need a detailed description of current conditions and a forecast of those conditions that are likely to change during the few tens of minutes an aircraft traverses a sector.

Flow controllers, on the other hand, are more concerned with how many aircraft an air route or terminal can accommodate and are not particularly interested in specific aircraft. A subsynoptic* description of conditions within an en route center's control area thus satisfies the flow controller's needs. This should include forecasts of meteorological conditions that will exist along a route or at a terminal when an aircraft is scheduled to arrive. Ideally, flight plan changes would be made before an aircraft takes off, or an aircraft would be held on the ground if unable to land at its destination, thus avoiding the excess fuel consumption and airborne congestion in the terminal area. A reliable short range forecast for a period less than 4 hours would take care of the majority of aircraft being handled by the ATC system. For example, the number of arrivals at Chicago and New York vs. Aircraft Loading to Landing Gate Time are plotted in Fig. 2.2.1 and 2.2.2. A 4 hour forecast would affect 93% of the aircraft before takeoff for either of these destination airports.

In Table 2.2.1, the most important weather product needs of controllers and flow controllers are tabulated. Relevant weather phenomena are listed along the left side and various ATC activities are listed along the top. The ATC activities are divided into the two user classes, controllers and flow controllers. The letters C, V and S stand for the time frame needed to describe the meteorological phenomena where:

> <u>C</u> stands for the best available description of "current conditions." It may be based upon the last available measurements or Pilot Reports (PIREPs).

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*Subsynoptic refers to spatial scales between 100 and 1000 km.

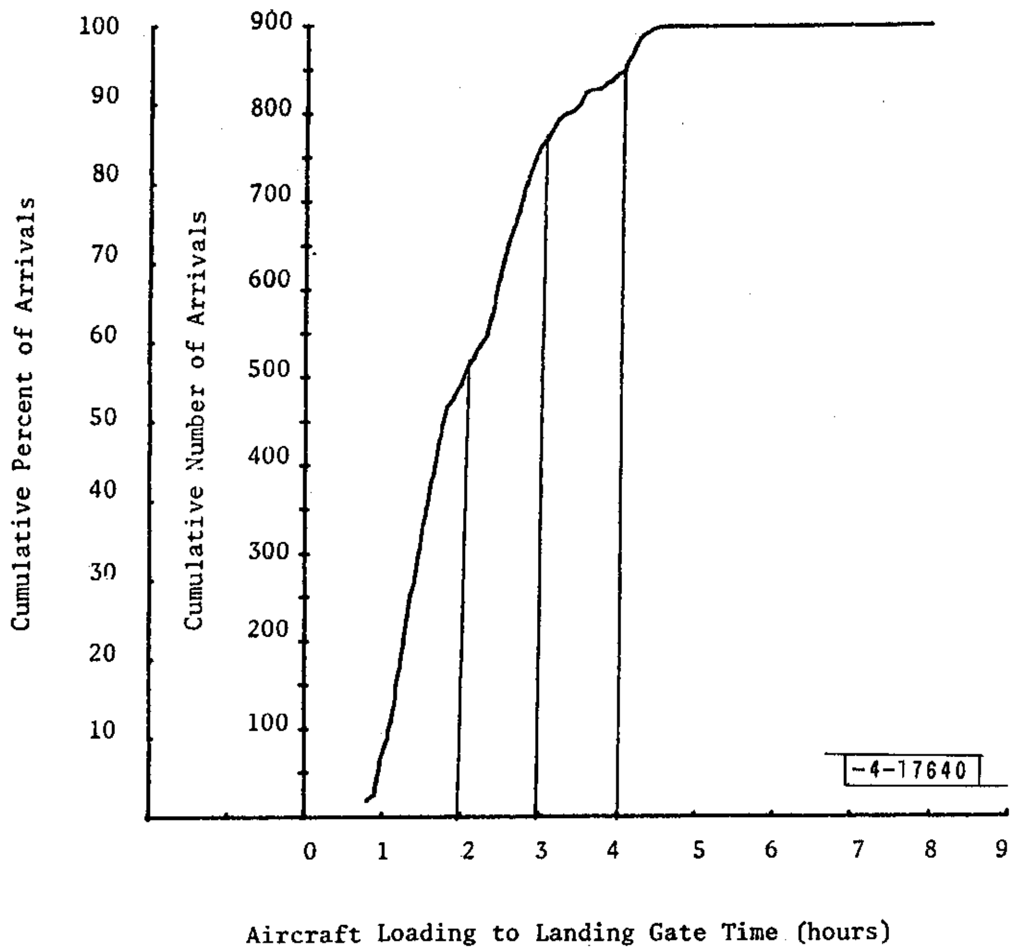

Fig. 2.2.1 Chicago daily arrivals.

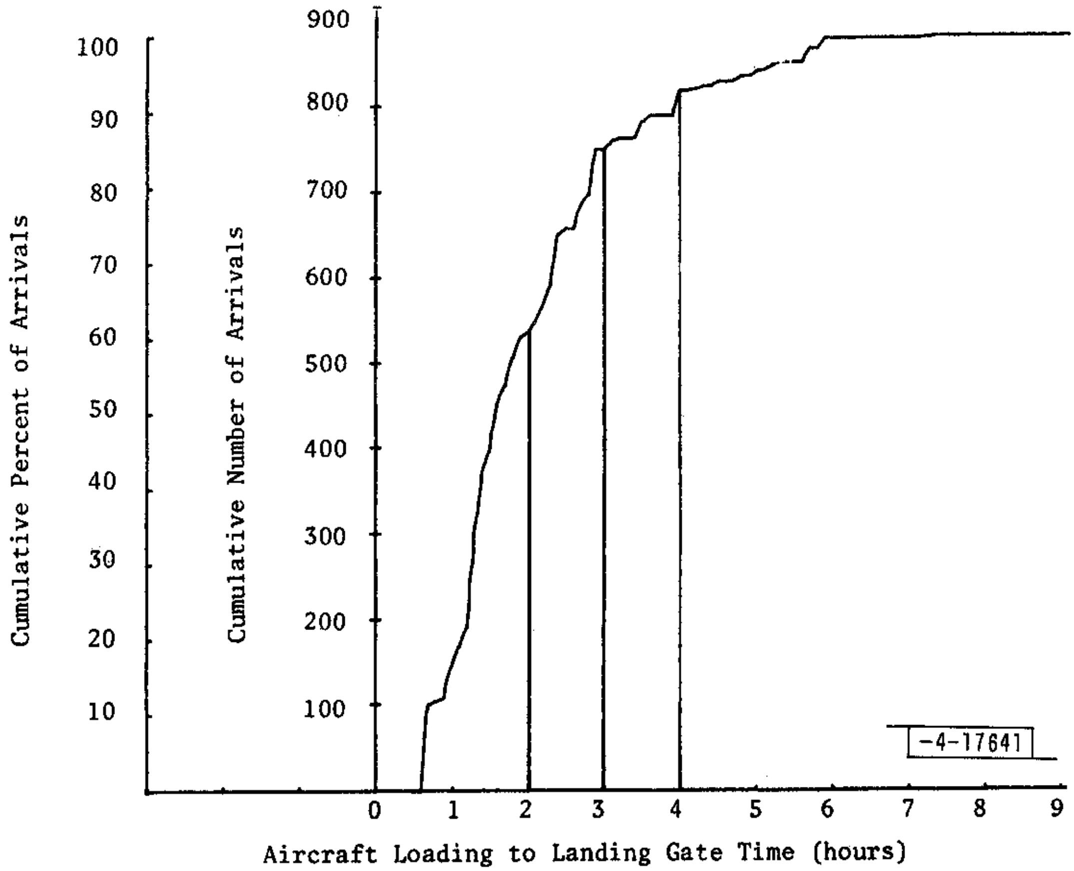

Fig. 2.2.2 New York (Kennedy, LaGuardia, Newark) daily arrivals.

	Controllers						Flow Controllers	
	Anticipate Deviation Requests/ Give Avoidance Advisories	Route/ Altitude Guidance	Holding Pattern Selection	Metering and Spacing	Runway Utilization and Selection	Altimeter Setting	Airport Capacity and Closings	Air Route Utilization
Convective Turbulence	$V_{t,e}$	$V_{t,e}$	$V_{t,e}$	V_t	V_t, S_t		S_f	S_f
Runway Surface Conditions: Surface Rainfall Freezing Rain Snow Ice				V_t	V_t, S_t		S_f	
Low Level Winds + Wind Shear	V_t			V_t	V_t, S_t		S_f	
Wake Vortex	C_t			V_t	V_t, S_t		S_f	
Cloud Height, Ceiling + visibility				V_t	V_t, S_t		S_f	
CAT	$C_{t,e}$	$C_{t,e}$	$C_{t,e}$	C_t				S_f
Winds Aloft		C_e		C_t				S_f
Icing	$C_{t,e}$	$C_{t,e}$	$C_{t,e}$	C_t				S_f
Barometric Pressure						$C_{t,e}$		

TABLE 2.2.1

MAJOR METEOROLOGICAL PRODUCTS NEEDED TO SATISFY CONTROLLER AND FLOW CONTROLLER FUNCTIONS IN THE LONG TERM

V stands for "very short range forecast." It includes a mesoscale* description of current conditions plus a prediction of conditions in a few tens of minutes (i.e., a time frame matched to the dwell time of an aircraft in a sector). It may be based upon current measurements and PIREPs.

S stands for a "short range forecast" for a period up to 4 hours. It includes a subsynoptic description of current conditions plus a series of forecasts from 1/2 to 4 hours. It may be based upon last available measurements, PIREPs and NWS forecast products.

The subscripts "t", "e", or "f" in the table indicate that the product is needed by terminal, en route, or flow controllers, respectively. Generally, C and V products are for use by controllers. Meteorological phenomena indicated with a C do not change quickly enough, or the effect of meteorological changes are not relevant enough to require a very short range forecast. Items indicated with a V, as for example convective turbulence, do change significantly in the few tens of minutes an aircraft traverses a sector. Most short range forecasts, S, are to assist flow controller planning. The terminal is also interested in a short range forecast to plan for the runway configuration which will maximize its capacity. The absence of an entry in the table means that the impact of the meteorological phenomena, although perhaps of interest, is not considered significant enough to call for a forecast product.

The primary user of the forecast product is indicated in the table; however, there may be secondary users. For example, en route controllers also have a use for terminal weather, but their needs are secondary to those of the terminal controller. In other words, the en route controller's needs for terminal weather are not sufficient to justify developing a terminal forecast just for him; however, if one exists, then this information should be made available. Knowledge of weather conditions outside the controller's sector, primarily in adjacent sectors and nearby terminals, enables the controller to preplan for the effect of control actions in neighboring sectors. It also permits the controller, time permitting, to assist the pilot.

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*Mesoscale refers to spatial scales between 1 and 100 km.

It is important to note that a C, V, or S product for different users may not be the same. For example, a very short range forecast of convective turbulence intended to assist a terminal controller in runway selection must have finer spatial resolution than that needed by an en route controller, i,e., the spatial resolution must be matched to the flexibility the controller has in using the airspace.

2.3 User Needs - Satisfiable in Near Term

Many of the weather data entries shown in Table 2.2.1 cannot effectively be provided with today's state of the art. The objective between now and the early 1980's should be to satisfy a selected subset of the product needs. Features which should be included in this next step are tabulated in Table 2.3.1 along with the data sources. The motivation behind this table was to extract the weather products from Table 2.2.1 for which there are promising solutions from both technical and economy viewpoints. The most important aspect of this next step is in the hazardous weather area with thunderstorms, low-level wind shear and wake vortices having special attention.

With modern digital radar processing,[5] preferably using a pencil beam radar, thunderstorm cell locations, severity, height and diameter, plus a very short range forecast (V) of these parameters would be available for graphical display upon controller PVDs (this is described further in Section 3.1). The very short range cell prediction would be based on the recent movement of current cells and the expected growth of new cells. These products are for use by controllers in determining where the hazardous conditions are now and where they will most likely be up to a few tens of minutes from now. They are designed to help the controller coordinate rerouting and respond to requests for help in avoiding hazardous conditions. The time span of the prediction is designed to match the transition time of an aircraft in his sector. The spatial resolution is designed to span features that cannot be avoided such as runways, approach and departure routes, and holding areas. For these forecasts, the severe weather conditions are defined by small local reflectivity increases (cells) on radar observations of the weather. Ground clutter and anomalous propagation (a serious problem with the Narrowband Weather Subsystem) are largely eliminated. Objective forecast techniques (computer forecasts) are required to process the available data in a timely manner so the controller is aware of the hazardous conditions before they occur, not after. This improved capability is not intended to remove the responsibility for thunderstorm avoidance from the cockpit. However, if the controller can preplan for, instead of react to, deviation requests his work load and job tension are decreased and the capacity, especially in the terminal area should increase.

Weather Phenomena	Controller Functions: Anticipate Deviation Requests/ Give Avoidance Advisories	Route / Altitude Guidance	Holding Pattern Selection	Metering and Spacing	Runway Utilization and Selection	Altimeter Setting	Data Source for Controller Products
Convective Turbulence	$V_{t,e}$	$V_{t,e}$	$V_{t,e}$	V_t	V_t		Radar & PIREPs
Runway Surface Conditions: Surface Rainfall Freezing Rain Snow, Ice				C_t	C_t		Airport Crew, PIREPs, Surface Weather Observations
Low Level Winds + Wind Shear	C_t			V_t	V_t		Radar, Low Level Wind Shear Sensor, Anemometer, Wind Vane and PIREPs
Wake Vortex	C_t			V_t	V_t^*		Wake Vortex Sensor
Cloud Height, Ceiling + Visibility				C_t	C_t		RVR, SVR, Ceilometer, Visual Observations, and PIREPs
CAT	$C_{t,e}$	$C_{t,e}$	$C_{t,e}$	C_t			PIREPs
Winds Aloft		C_e					PIREPs, Radiosonde Observations and NWS Forecasts
Icing**	$C_{t,e}$	$C_{t,e}$	$C_{t,e}$	C_t			PIREPS, NWS Forecasts
Barometric Pressure						$C_{t,e}$	Barometer

*Predictions on the order of a minute.

**Of concern to G.A. primarily.

C - Current Conditions

V - Very Short Range

TABLE 2.3.1

WSA FEATURES AND DATA SOURCES

Weather Phenomena	Flow Controller Functions		Data Sources for Flow Controllers Products
	Airport Capacity and Crossings	Air Route Utilization	
Convective Turbulence	S	S	Radar & NWS Products
Runway Surface Conditions: Surface Rainfall Freezing Rain Snow, Ice	S		NWS Products and Terminal Observations
Low Level Winds & Wind Shear			
Wake Vortex			
Cloud Height, Ceiling & Visibility	S		NWS Products & Terminal Observations
CAT		S	NWS Products & PIREPS
Winds Aloft		S	NWS Products & PIREPS
Icing**		S	NWS Products & PIREPS
Barometric Pressure			

S - Short Range

TABLE 2.3.1 (Cont.)

WSA 1980 FEATURES AND DATA SOURCES

A second, longer time span, short range forecast (up to 4 hour) is needed to anticipate larger areas or sectors where thunderstorms will occur. This forecast is based upon radar data, surface observations and NWS products. The purpose of this forecast is for use in planning air route changes to keep traffic away from areas where deviations and resulting traffic delays will occur. The time span of interest is governed by the time required to effectively reroute the traffic and by the time the severe weather system will affect particular routes. The spatial resolution is governed by the size of severe weather systems such as squall lines or rain bands responsible for closing a route or terminal. These short range forecast techniques must detect disturbances that will develop into hazardous conditions before they are evident on radar and must predict the develop- development, motion, and decay of the hazardous convective activity. Computer generated objective forecasts are needed to interpret the large amounts of data available for forecast preparation in a timely manner.

The two other weather related phenomena, low-level wind shear and wake vortices are particular hazards to landing aircraft. With accurate measurements of wake vortex locations and prediction of their movement, landing separations could be minimized with the associated increase in terminal capacity. The development of sensors for both phenomena is being actively pursued under FAA sponsorship.

Notice that many of the data sources in Table 2.3.1 are quite similar to those used today. The WSA will provide better acquisition, distribution and display of these data. These data sources may not completely satisfy controller needs as, for example, PIREPs for CAT, winds aloft, and icing. With PIREPs, the controller can only obtain data from the airspace where there are aircraft, and the controller must rely upon pilot cooperation. The transmission of PIREPs via radio is very cumbersome and much data is either lost, misreported, or never obtained. A digital data link is needed to automatically obtain airborne meteorological measurements for automatic processing without pilot or controller involvement. It is unlikely that a digital data link will be sufficiently deployed for this purpose during this next WSA development step (1980). Thus, PIREPs will have to be treated in a largely manual manner as they are today with hopefully more orderly collection and dissemination procedures.

The above discussion focuses upon ATC needs; the system to implement the results in Table 2.3.1 are described in Sections 3 and 4. This architecture stresses a netted system which avoids duplication and integrates the many separate sensor developments into a unified system, thereby minimizing processor and communication costs. The design is flexible to accommodate the evolutionary changes which will certainly come about.

2.4 Delay Costs and Accidents

Delays and accidents are very costly to aviation and even a few percent decrease in their costs justify a significant expenditure in developing the WSA. It is impossible to quantify the actual delay and accident reduction resulting from the recommended system. Nor is it possible to quantify the cost benefit from reducing controller tension and work load peaks. However, it is shown below that delays, especially in flight, annually cost the airlines tens to hundreds of millions of dollars. Similarly, each accident of a jet aircraft can exceed a hundred million dollars.

2.4.1 Delays

ATC delay statistics for delays in excess of 30 minutes[6,7] are presented by category in Table 2.4.1. It is evident from these data that weather is is the major factor affecting delays and most delays are caused by terminal area conditions especially those affecting runway usage. Typically, arrival delays outnumber departure delays by a factor of two with only a few percent being en route delays. An improved aviation weather subsystem with an accurate forecast of terminal conditions and severe en route conditions would permit users to balance the relative costs of cancelling before takeoff, holding, or diverting to another terminal. Furthermore, it would permit flow controllers to anticipate route and terminal capacity. A recent FAA test of the fuel advisory and departure procedure, designed to be used when weather or other factors cause aircraft landing delays, indicates the magnitude of the possible saving. "The procedure saved 658,446 gal. of fuel during a one-day test when Chicago-bound flights were held on the ground at 150 airports until they could be accepted at Chicago's O'Hare International Airport with a minimum of airborne delay."[72]

Many different delay cost estimates have been made; for example:

- The air transport association[8] estimates the annual cost of scheduled airline delays to be around $90 million.
- The cost of jet fuel to U.S. Air Carriers for domestic flights in 1974 was roughly $2.1 billion (8.2 billion gallons[9] at $0.25 a gal). If even the small percentage of 3% of this fuel consumption were attributable to airborne delays, an annual fuel delay cost of $63 million is incurred.

TABLE 2.4.1

ANNUAL ATC DELAY STATISTICS

	Percentage of ATC Delays in Excess of 30 min			
	1971	1972	1973	1974
Total Weather	89	89	74	64
Below Minimum	28	17	17	15
Low Ceiling/Visibility	13	13	15	9
Thunderstorms	17	17	15	21
Snow/Ice	11	21	9	10
Wind	11	13	12	7
Nonspecific	9	8	6	2
FAA Equipment	2	3	5	6
Airport/Runway Closure	4	3	14	14
Volume	3	3	5	14
Other	2	2	2	2

The cost per airborne minute of jet fuel to the U.S. carriers for domestic flight in 1974 was roughly $5.3/min (8.2 billion gallons consumed in 6.5 million hours[9] at $0.25/gal).* Assuming an average delay of 5 minutes per operation and 10 million operations per year results in an annual fuel delay cost of $260 million.

The data in Table 2.4.1 shows that a large percentage of these delays are weather related. Since no weather modification is planned, except for possible advances in fog modification, a high percentage of delays will continue to be attributable to weather. However, better weather information systematically used will promote an efficient ATC system and will hold delays, especially airborne delays, to a minimum. An improved aviation weather subsystem reducing these delays by only a few percent, no matter which delay cost estimate is taken, would reasonably justify an annual expenditure of several million dollars, on purely economic grounds.

2.4.2 Safety

Safety provides the other cornerstone for the development of an improved aviation weather subsystem. The law suits resulting from the death of a couple hundred people on a jumbo jet can easily exceed a hundred million dollars not including the 25 million dollar cost of a jumbo jet. Of the meteorological conditions affecting safety, turbulence plus factors affecting safe landings and takeoffs are the most important.

From a review of accident reports and statistics it is evident that severe turbulence is the meteorological phenomenon most affecting safety throughout all portions of flight. Brunstein[2] has summarized the damage and loss of life attributed to turbulence involving U.S. air carriers for the period 1964 through 1969. His results are summarized in Table 2.4.2 which shows that turbulence was involved in 22% of all accidents, with convective turbulence (turbulence associated with severe weather, thunderstorms, squalls, etc.) and CAT (turbulence associated with clear air conditions) both being significant. In addition there was little change in the accident incidence over the six year period. These accidents resulted in 228 fatalities, 127 serious injuries, 5

*The average cost per airborne minute of jet fuel for a Boeing 727 experienced by the major airlines during the third quarter of 1974 was also $5.3/min.[10]

TABLE 2.4.2

AIR CARRIER TURBULENCE ACCIDENT STATISTICS 1964-69[2]

Year	Number of Air Carrier Accidents	Number Involving Turbulence	Number Known To Involve: Convective Activity	Number Known To Involve: CAT	Turbulence Accidents Per 10^5 Aircraft Hours Flown
1964	79	15	9	5	0.35
1965	83	14	12	2	0.30
1966	75	13	7	4	0.26
1967	70	13	8	4	0.22
1968	71	22	11	10	0.33
1969	63	20	11	9	0.30
1964-69	441	97	58	34	0.29

aircraft destroyed, and 4 substantially damaged. It is important to note that, of these 97 turbulence-involved air carrier accidents, 11% occurred during ascent 22% during descent, and 65% during normal cruise. Thus turbulence is an important safety factor in all phase of flight. However, the most severe accidents have occured during descent.

Although not separately categorized in these accident statistics, low-level wind shear is a hazardous phenomenon that falls within the scope of the WSA. Wind shear is at times a consequence of nearby thunderstorm activity. Avoiding the vicinity of active storm cells will therefore reduce the incidence of low-level wind shear as well as convective-turbulence-induced accidents. The crash of an Eastern Airlines aircraft in New York on June 24, 1975, apparently involved wind shear associated with thunderstorm activity. The Ozark Airline flight that crashed in St. Louis on July 25, 1973[11] is another example of an accident related to thunderstorm activity near the approach path.

Brunstein points out that there were many cases where the flight crew was aware of the turbulence possibility but the controller was unable to authorize a deviation because of a traffic conflict or other control problem. With good data the controller would be able to preplan for such deviation requests without ordering the pilot to take any action. As the traffic density increases[12,13] the control of aircraft becomes more sensitive to weather. This was especially true in the New York area where separation minimums were violated by aircraft deviating without controller permission[3] to avoid storm cells. One of the reasons for implementing the Severe Weather Avoidance Plan (SWAP) during the summer thunderstorm season was to enable planning for, instead of reacting to thunderstorm activity.

There are even incidents[2] of aircraft flying into convective turbulence which was not detected by airborne weather radar. At the same time the controller did not observe weather on the surveillance radar display and thus was unable to respond to the pilot request for aid. Surveillance radars are optimized to see aircraft, not weather. Photographs of NWS weather radar scopes taken during such incidents have indicated severe thunderstorms and thus weather radar data should be provided to controllers or the weather detection capability of the surveillance radars should be improved.

It is evident from reviewing accident reports that poor visibility while on final approach is a significant contributor to accidents. Contrary to flight regulations, many pilots have descended below the minimum decision altitude before seeing the runway and crashed.[14,15,16,17]

Runway surface condition is clearly critical to the safety of landing and takeoff. For instance, freezing rain, snow and excessive rainfall can cause the runway to be very slippery. Hydroplanning[18,19] has caused aircraft to slide off the end of the runway. Cross wind is another important phenomenon affecting runway safety, since each aircraft has a maximum crosswind component with which it can safely land and taxi. Thus good measurements of final approach visibility, runway surface conditions, and surface winds are important to improve safety. Terminal controllers have additional interest in these conditions to enable the selection of runways for maximum efficiency.

Finally, the wake vortex problem has become important with the introduction of wide body aircraft. The crash of a DC-9[20] at Fort Worth in 1972 showed that even large aircraft are affected. Measurements of the wake vortices produced by large aircraft[21] confirmed the severity of the problem.

3.0 USER FEATURES

The intent of this section is to show: (1) the weather products and displays provided to en route and terminal controllers, the team supervisors, the flow controller and the system command center, and (2) how the users will benefit from these features. The system architecture indicating where data come from how they are processed and the rather modest communication requirement is left for Section 4.

Figure 3.0.1 illustrates the major user features. The controllers PVD and the separate weather CRD (possibly MAPS and TIPS) are primarily used to display storm cells and textual data, respectively. The CRD could also display some non-weather data. The supervisors or flow control console provides access to all weather products used by controllers and specially designed forecasts for one to four hour planning. The SCC weather console is primarily used by the SCC meteorologists to serve the central flow controllers. Data is exchanged between the SCC, ARTCCs, and TRACONs at a very modest data rate. In the following subsections the displays illustrated in Fig. 3.0.1 will be described in more detail. These display depictions are helpful in describing the overall WSA concepts and it should not be misconstrued as a recommendation for these precise displays.

18-4-17347-1

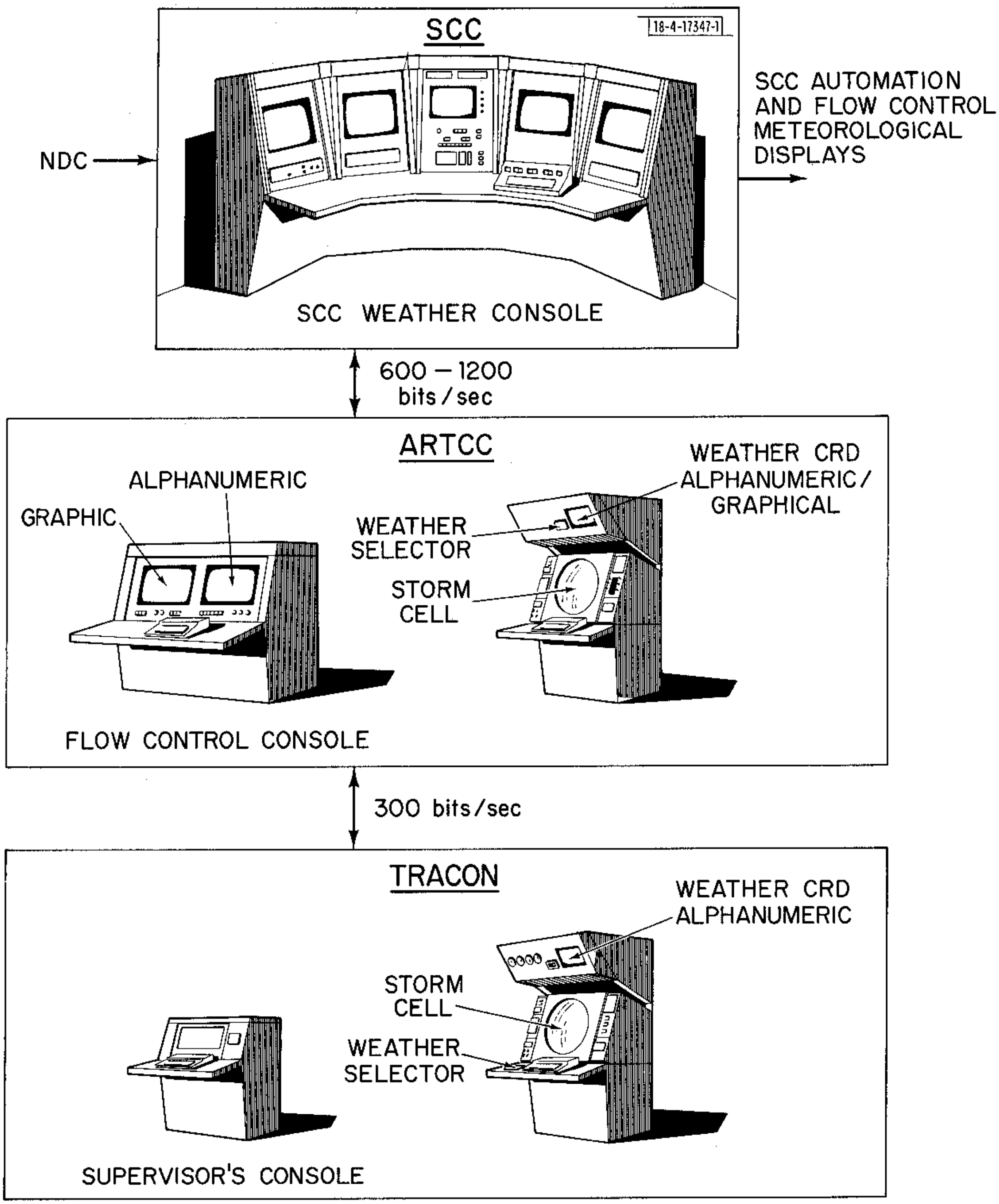

Fig. 3.0.1 Weather subsystem for ATC user features.

3.1 PVD Display of Radar Weather Data - En Route and Terminal

Both terminal and en route controllers should be provided with a good reliable graphical depiction of the hazardous storm cells without cluttering the PVD. Recent experimental[5] results indicate that the hazardous storm cells are relatively small physical entities (roughly 1-4 miles in diameter) which can be identified with appropriate processing of pencil beam weather radar data. By sacrificing the ability to measure cell tops, a similar capability is possible with appropriate processing of ASR or ARSR radar data, but only to a 45 mile range - quite adequate for terminal areas but not en route.[5]

More specifically, consider the sequence of possible controller displays in Figs. 3.1.1-3.1.7 which are selectable as needed. First consider Fig. 3.1.1 where the potentially hazardous cells are indicated on the PVD by the letter C with tags indicating the cell parameters (these tags should be selectable to avoid cluttering the PVD if the controller has more important data to display). The first letter of the tag indicates the cell intensity; the second letter whether it is growing or decaying; the first number indicates the cell diameter in miles; and the second number the cell height in thousands of feet. The letter meanings are:

- S - severe
- H - heavy
- M - moderate
- L - light
- G - growing
- D - decaying

Thus the tag SG4-25 indicates a severe growing cell 4 miles in diameter and 25,000 ft high.

Controllers should also have a very short term forecast of where these cells will be in 5 to 30 minutes. These predictions could be selected by pressing a button which advances the cells (but not the aircraft) by 5 minutes each time. The 10-minute prediction is illustrated in Fig. 3.1.2 where the tags are the same as in Fig. 3.1.1 except the indication of growth or decay (G or D) is deleted.

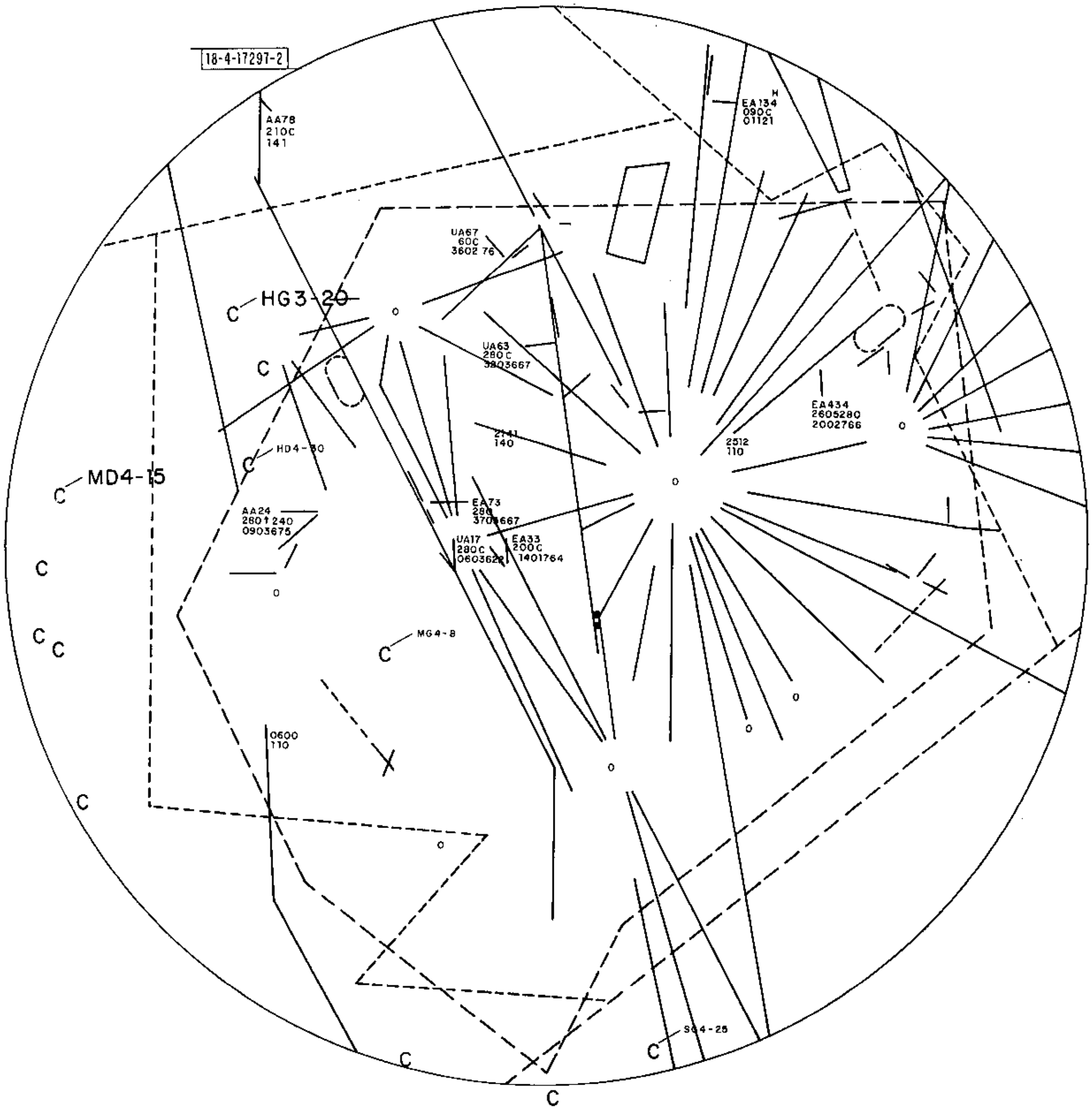

Fig. 3.1.1 Candidate weather situation display - current conditions.

18-4-17298-2

10 MINUTE PREDICTION

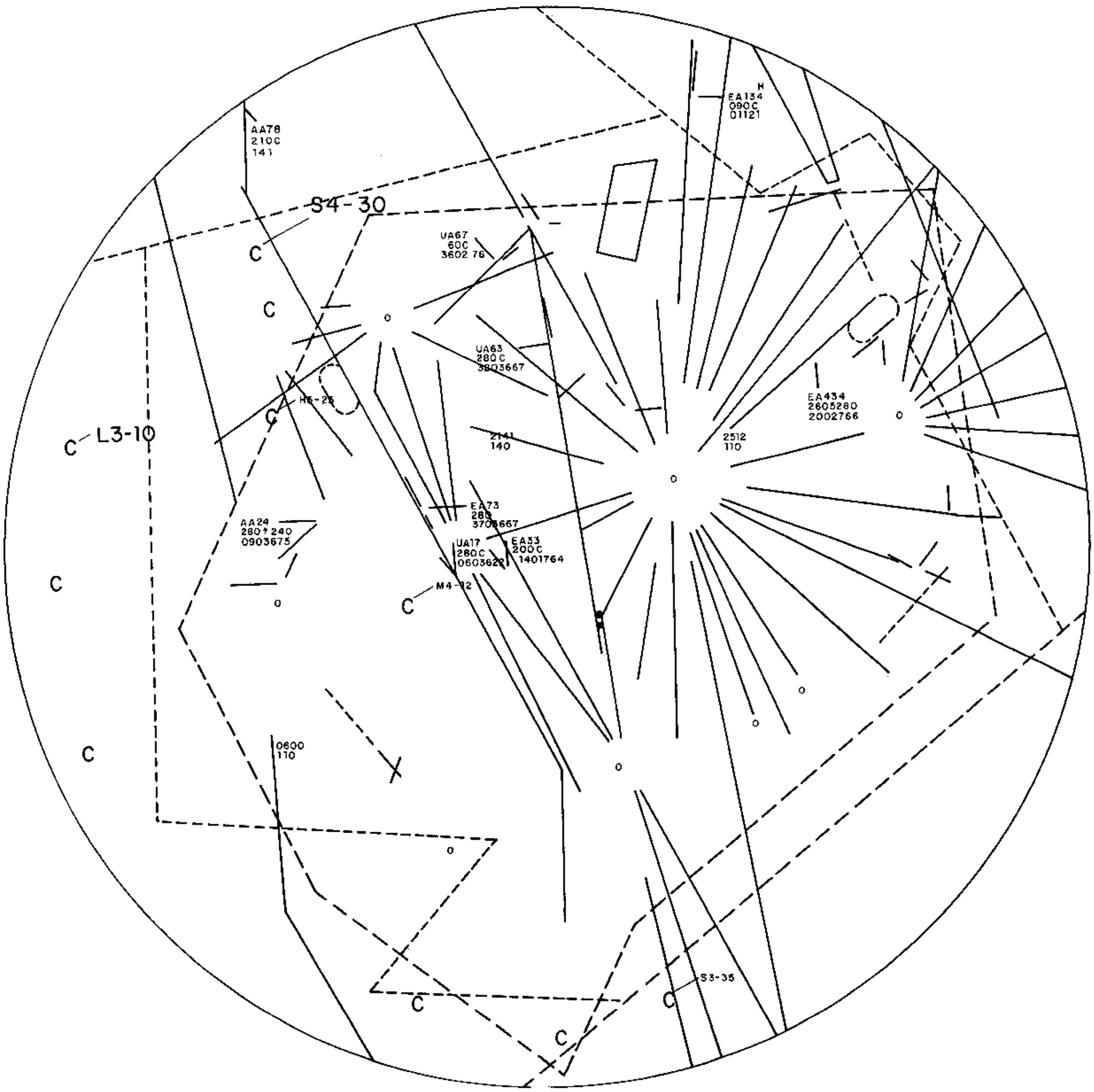

Fig. 3.1.2 Candidate weather situation display - 10 minute very short range forecast.

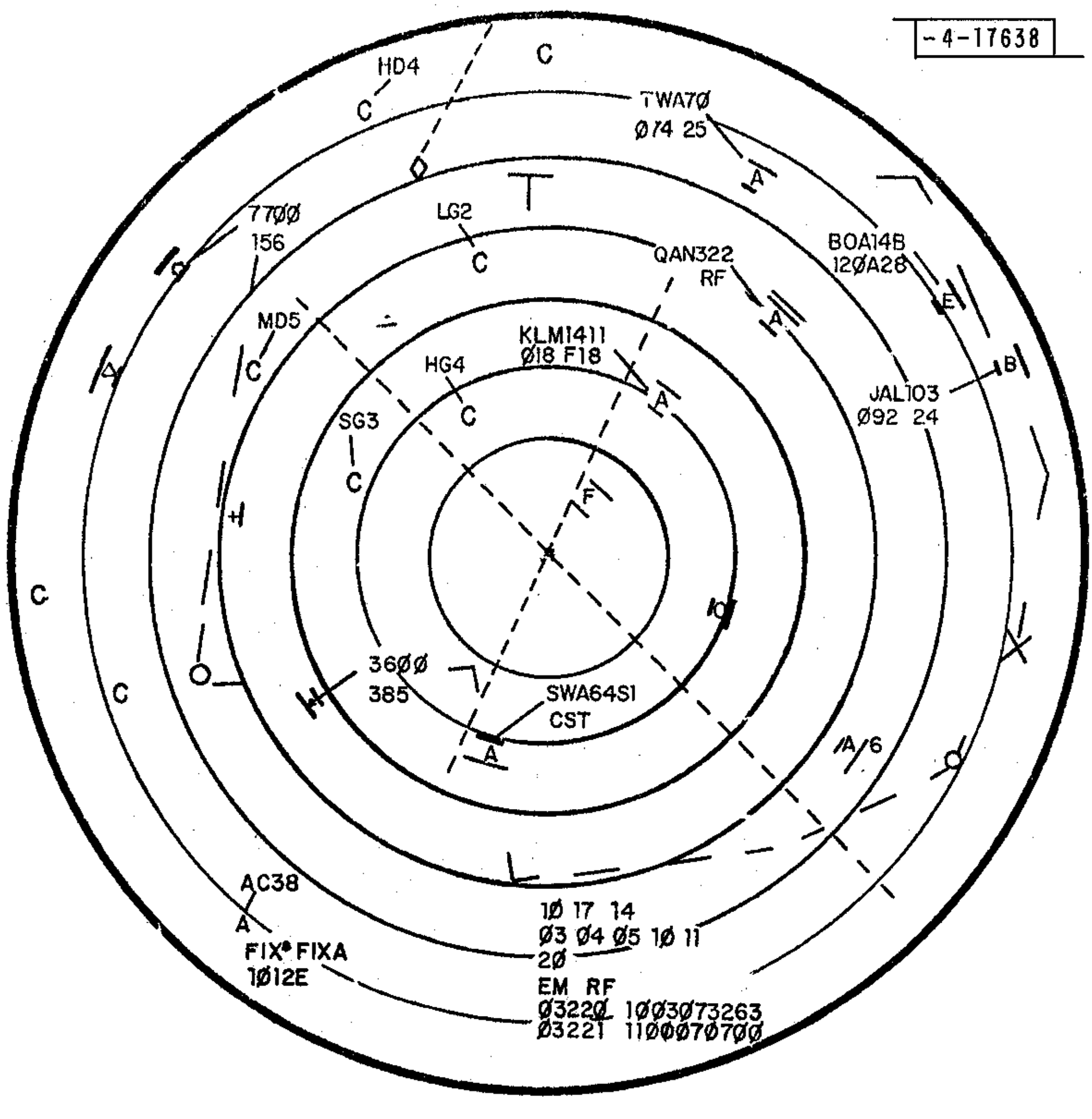

Fig. 3.1.3 Candidate ARTS III weather situation DISPLAY - no cell tops.

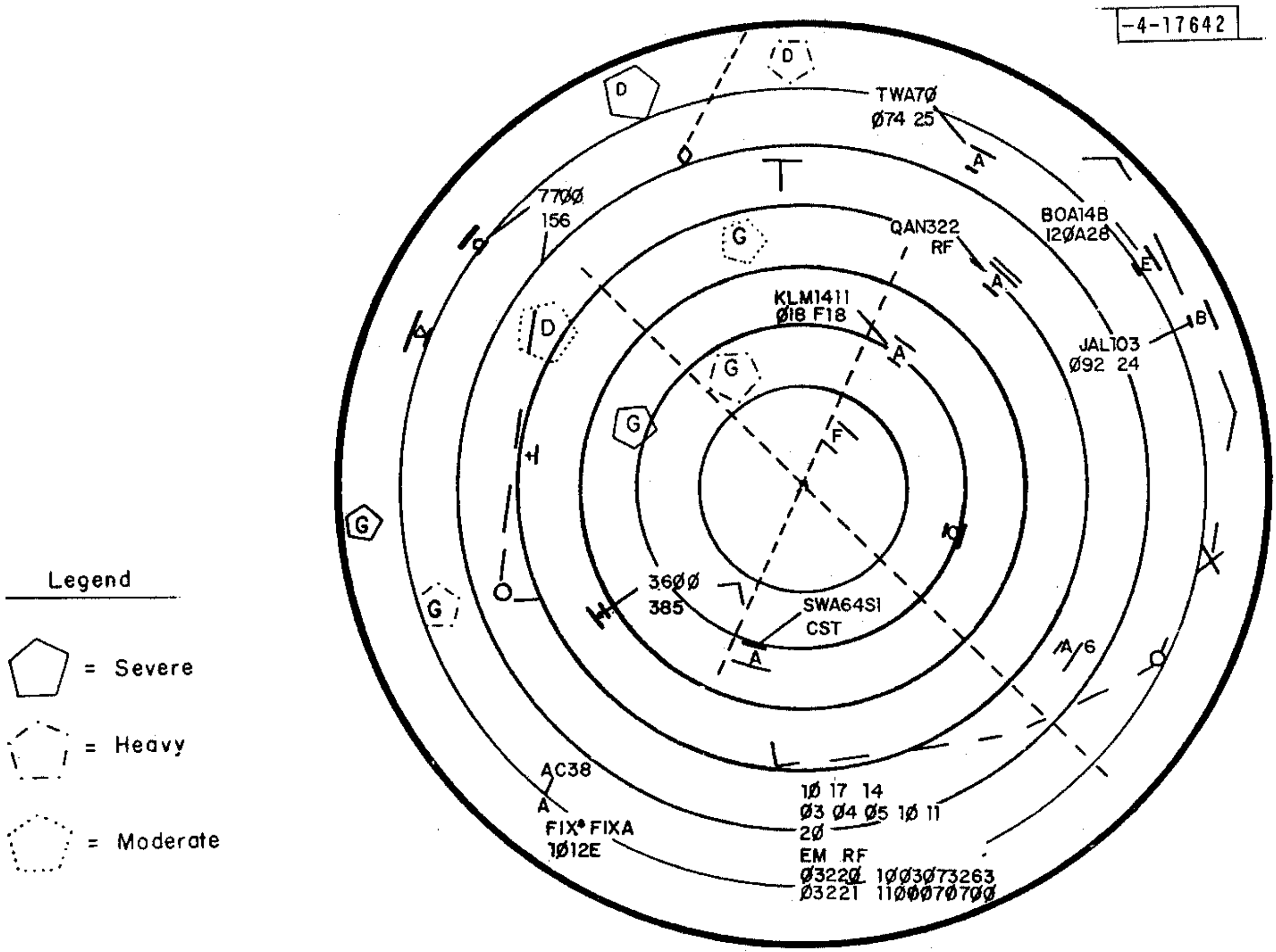

Fig. 3.1.4 Candidate ARTS III weather situation DISPLAY - no cell tops.

18-4-17301

Fig. 3.1.5 Candidate low reflectivity, fixed threshold weather contour.

18-4-17302

Fig. 3.1.6 Candidate high reflectivity fixed threshold weather contour.

18-4-17643

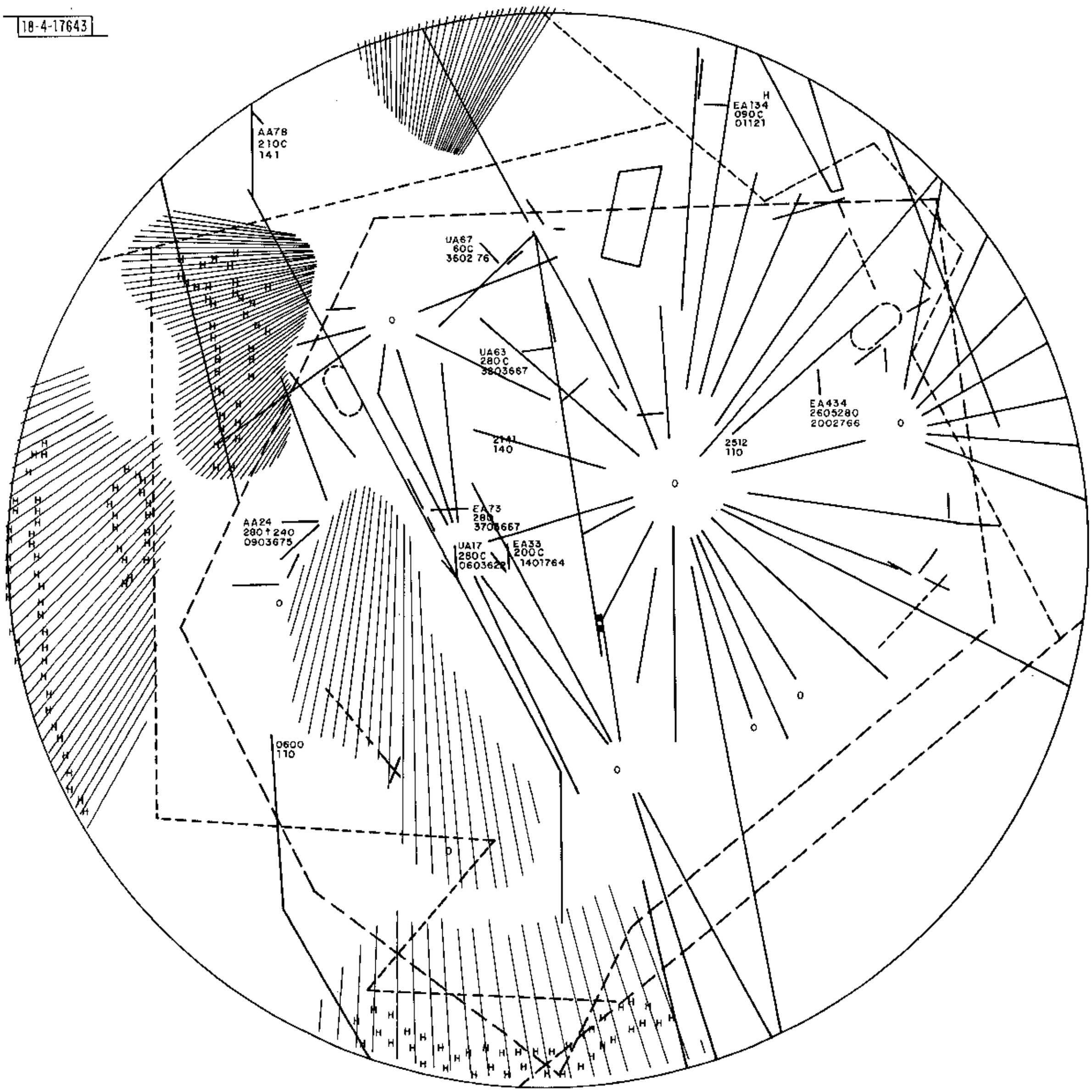

Fig. 3.1.7 Narrow band weather subsystem.

The following scenario indicates how this is useful. Consider the aircraft AA78 at 21,000 ft in the upper left corner of Fig. 3.1.1 which will intersect cell HG3-20 (heavy, growing, 3 miles in diameter with a 20,000 ft top) in 10 minutes. The controller, noting that this cell is still growing, can advance the cell 10 minutes and observe as shown in Fig. 3.1.2 that this heavy cell is predicted to be S4-30 (severe, 4 miles in diameter with a 30,000 ft top). The controller is thus alerted to warn the pilot or expect a deviation request from the pilot. With this type of good presentation, the controller can plan for and coordinate the rerouting around the hazardous cells.

Since most TRACONs would be served by an ASR which is unable to supply height data, candidate ARTS-III weather situation displays are depicted in Fig. 3.1.3 and 3.1.4.

It is expected that controllers will eventually only use the cell data and forecasts. However, during the early implementation stages, controllers should have access to 2 threshold contours as is available with the narrowband weather subsystem (NBWS). These could be selectable by the controller as illustrated in Figs. 3.1.5 and 3.1.6. The fixed threshold contours indicated with Ws and Hs are for widespread rain (low reflectivity) and heavy rain (high reflectivity). These low and high rain contours do not indicate aviation hazards and thus the PVD display need only approximate the actual contours to within a few miles. This flexibility simplifies the contour display algorithms. Note that the potentially hazardous cells indicated in Fig. 3.1.1 must be accurately located on the PVD. For comparison, the presentation of the NBWS is shown in Fig. 3.1.7.

The precise form for the PVD display of current conditions and very short term forecasts will require a human factors study. The above are simply illustrative examples.

3.1.1 Utility of Storm Cell Heights

In the en route airspace, storm top information is very useful since many aircraft can fly over the cells. In the terminal area where aircraft must fly around or through a cell, the height information is not as important, except as an indicator of turbulence. Although height information would also be useful in the terminal area, it is not as valuable as in the en route airspace. Thus a fan beam ASR is more suited to satisfy a terminal controller's weather data needs than an ARSR is for en route controllers. In addition, due to partial beam filling, fan beam surveillance radar data can not be used to produce reliable weather situation displays as illustrated in Figs. 3.1.1-3.1.4 beyond 45 miles.[5] This is well suited for terminal control but not en route.

3.2 En Route Controller Alphanumeric/Graphical Display

Each control position should have a separate CRD display for presentation of alphanumeric and possibly graphical weather data. This same CRD may also be used for non-weather data. The presentation of several pages of data tailored to each control sector is well suited for this job. Data requests other than page selection should be kept to a minimum and should rarely be needed if the pages are designed properly for each sector. Special requests on a rare occasion can be handled as they are today by phone links or by means to be determined during system development.

3.2.1 Alphanumeric Pages

The system should be capable of presenting most of the data presently available on Service A, although in the future this same data will be more conveniently received from the NDC, FSS Hub Automation or directly from the airport terminal. The message types include:

- Surface observation (SA)
- Terminal forecasts (FT)
- Notices to airmen (NOTAMS)
- Pilot reports (UA)
- Supplementary weather (SW)
- Area forecasts (FA)
- Severe weather forecasts (WW)
- Hurricane advisories (WH)
- Notice to airmen summaries (NOSUMS)
- Forecast winds and temperatures aloft (FD)
- SIGMETS (WS)
- AIRMETS (WA)
- Radar Weather reports (SD)
- Surface forecast (FS)

In addition the same CRD display could be used for non-weather data as for example:

- restricted areas
- communication frequencies
- preferred traffic routes
- outages
- approach plates

The best method of formatting these data should await the MAPS experimental results at Leesburg. An appealing method is to have the data relevant to each sector stored on some small number of data pages. Page 1 might include all the data normally used by this sector and would be the one normally displayed. An example of this from the MAPS[22] demonstrations is illustrated in Fig. 3.2.1. Page 2 might be a longer listing of SAs, page 3 PIREPS, page 4 NOTAMS, etc. It is most important that these pages be designed for each controller. Controllers do not have the time to read through long lists of data.

Service A data is not timely enough for surface observations when conditions are changing quickly. Surface observations should automatically come directly from the major hub airports during quickly changing conditions for display on the CRD (see Sections 4.2.2.2 and 4.3.4 for the details of accomplishing this).

PIREPs, as presently available on Service A are of little value to controllers; the delays are too long. However, timely PIREPs could be very valuable to controllers especially from higher/lower sectors or adjacent sectors. Controllers usually have good PIREPs for their own sector and this information needs to be collected and disseminated quickly to other sectors for display on the CRD. FSS automation must be involved in this process. One method is discussed in Appendix A3.

3.2.2 Selectable Alphanumerics

It may be beneficial to reserve the bottom line of each page for selecting SAs and FTs for terminals not normally displayed, particularly those outside the ARTCC boundaries. This would enable the controller to respond to

WEATHER SEQUENCE ATC-64 (3.2.1)

DCA SA 1603 015 SCT 025 OVC - BS 37 28 2015 2910
IAD SP 1635 010 SCT 020 OVC + BS 35 30 2722 2915
BAL SA 1605 026 SCT 034 OVC 33 29 3125 2922
ICG FRZLV SFC. LGT ICGIC OCNLY H-MDT IN SNW SHWRS AREAS
TURBC. LGT OCNLY MDT BLO 70 IN SNW SHWR AND OVR RUF TRRN TIL 227

RESTRICTED AREAS

R6608 OPEN R6611 SFC 40000 151300-151430 R6612 SFC 40000UFN

COMMUNICATION DATA

ADW 135.55 319.2 ORF 128.15 306.9

IAD 134.25 269.6 ORF D 135.4 363.2

DCA 11 123.8 360.7 GVE 128.05

FLOW CONTROL

ZDC - TFC OVRFLY ZDC CTA FOR ARPTS BLO RTED AS FOLLOWS:

SDF LEX CVG VIA EMI J6 FRR J134 FLM DRCT: HTS CRW VIA EM1 J6 J134 J78

ZNY - TFC DPTG OR OVRFLY ZDC CTA AND ZNY CTA AT FL230 OR BLO RTED VIA V39

ABE V29 LHY V58 PWL ETC.

OUTAGES

CSN VOR O/S 14150-1600 RDUZ 307.9

ORF 24005

Fig. 3.2.1 CRD display from MAPS demonstration.

pilot requests for destination airport conditions. Naturally, this would have to be on a controller time permitted basis. Whether or not this extra feature is cost effective or even desirable must be determined.

3.2.3 Graphics

There are a number of potential graphical applications for both weather and non-weather users. Only the weather uses are discussed here. Considering that a graphics capability will significantly increase the cost of these CRD displays, careful consideration should be given to its effectiveness. Potential applications for weather graphics include:

- The radar weather display of current conditions for a region larger than the control sector. This would enable the controller to anticipate storm movements into his sector and to alert pilots concerning storms in neighboring sectors. The controller could also avoid cluttering the PVD with the weather display except when he is alerted to a problem on the separate CRD. This is not a substitute for selecting the weather graphics on the PVD.

- PIREPs tagged to their geographic location; i.e., instead of a tabular listing, PIREPs could appear on a map indicating the reporting location.

3.3 Terminal Controller Alphanumeric Display

Each approach, departure, and tower control position should have an alphanumeric CRD display for weather data. Graphics, although potentially useful, cannot be justified here. Surface observations for the airport or satellite airports for which the controller is providing approach, departure or local control are the most important data to present. This includes sky cover, ceiling, prevailing visibility, weather type, obstruction to vision, sea-level pressure, temperature, dewpoint, wind direction, wind speed, gusts, altimeter setting, runway visibility - RVV or RVR, wind shear and wake vortex. Where possible these should be continuously updated from automatic sensors and controllers should be alerted when a meteorological parameter has changed significantly. This could be handled by flashing the parameter on the CRD until an acknowledge button is pressed and possibly also flashing a light on or near the PVD to alert the controller to look at the CRD. A nice feature of a CRD is that when new sensors are deployed, as for example, the wind shear/wake vortex sensor, the display can be adapted to accommodate the new information with no additional hardware.

In addition surface observations, NOTAMS, and holding delays for a few nearby airports should be displayed with updates at least once an hour. The update interval should be automatically adaptable to the rate conditions are changing. This would enable the terminal controller to advise the pilot, concerning an alternate destination, when landing conditions are marginal, below minimum or in an emergency.

Other important data includes PIREPs, automatic alert messages, and messages generated by the terminal supervisor. In addition some non-weather data could be displayed as for example restricted areas, communication frequencies, and facility outages.

A representative CRD display appears in Fig. 3.3.1; this is a modified version of the MAPS display illustrated in Fig. 3.2.1.

WIND SHEAR & WAKE VORTEX ATC-64 (3.3.1)

WEATHER SEQUENCE

DCA SA 1603 015 SCT 025 OVC - BS 37 28 2015 2910

IAD SP 1635 010 SCT 020 OVC & BS 35 30 2722 2915

BAL SA 1605 026 SCT 034 OVC 33 29 3125 2922

ICG FRZLV SFC, LGT ICGIC OCNLY H-MDT IN SNW SHWRS AREAS

TURBC. LGT OCNLY MDT BLO 70 IH SNW SHWR AND OVR RUF TRRN TIL 227

RESTRICTED AREAS

R6608 OPEN R6611 SFC 40000 15130-151430 R6612 SFC 40000UFN

COMMUNICATION DATA

ADW 135.55 319.2 ORF 128.15 306.9

IAD 134.25 269.6 ORF D 135.4 363.2

DCA 11 123.8 360.7 GME 128.05

OUTAGES

CSN VOR O/S 141500-1600 RDUZ 307.9

ORF 24005

Fig. 3.3.1 Illustrative terminal controller CRD display.

3.4 Flow Control/Supervision Console

The flow controller, with his weather console, should have access to:

- all the weather data, graphical and alphanumeric, available to controllers
- graphical short range forecasts (0-4 hr) of squall lines and fronts (possibly 1/2, 1, 2, and 4 hour predictions updated every 20 minutes).
- selected weather graphics from the NDC or FSS Hub Automation
- special graphical messages generated by the SCC meteorologist
- special alphanumeric messages generated by the SCC meteorologist, or TRACON supervisor

A console with two CRD displays, one graphical and one alphanumeric, plus a keyboard entry and selection device should satisfy these display needs. However, the design should be modular to allow for additional CRDs in en route centers with particuarly severe conditions.

The keyboard entry and selection device in addition to selecting data is to be used for:

- sending alert messages to individual controllers, TRACONs, and the SCC meteorologist
- entering PIREPs

The easy access of the weather data available to controllers provides the flow controller with a good indication of current weather conditions. The short range forecast (0-4 hrs) is automatically computer generated at the SCC and transmitted to this CRD display. This will enable the flow controller to plan the traffic flow for changing conditions.

An important feature is the ability to display the same graphics on both the SCC weather console and the flow control console at the ARTCC. This would, for example, permit the SCC meteorologist to provide real time interpretative aid based on graphical products during telephone requests.

3.5 TRACON Supervisor's Console

The supervisor's console should be able to display:

- all the alphanumeric data available to controllers,
- the current and very short term storm cell data for a region larger than the terminal area,
- graphical short range forecast (0-4 hr) of squall lines and fronts (possibly 1/2, 1,2 and 4 hour predictions updated every 20 minutes).
- special alphanumeric messages generated by the SCC meteorologist or the ARTCC flow controller.

A console with one graphical/alphanumeric CRD plus a keyboard entry and selection device should satisfy these display needs. However, the design should be modular to allow for additional CRDs to be added.

The keyboard entry and selection device is also used to:

- send alert messages to individual controllers, towers, the flow controller and the SCC meteorologist,
- entering PIREPs,
- entering terminal observations which cannot be obtained from automated sensors.

Since most TRACONs are relatively small, supervisors can obtain most of the important data from looking over a controllers shoulder. Thus the display features of this console can be limited.

The short range forecast permits the TRACON to coordinate the traffic flow with the ARTCC flow controller for changing conditions.

The same graphics should be displayable on this console, the flow control console, and the SCC weather console to permit a three-way discussion and meteorologist interpretation of conditions.

3.6 SCC Meteorologist

Once the SCC meteorologist has a timely aviation weather data base that is at least as good as is available in the en route centers and terminals he may well have difficulty keeping up with the requests for his service unless some automated aids are provided. This data includes:

(1) the NWS data base from the NDC. He is the only person in the ATC system trained to interpret their products

(2) the storm cells and very short range forecasts (0-30 min) transmitted from the en route centers and terminals

(3) timely reports on changing surface observations

(4) computer generated short-range forecasts (0-4 hr) based upon radar data, surface observations, and NWS products

Presently he has the data in item (1) through the high speed Service A teletype drop and NAFAX. These are printed on paper and require extensive clerical efforts to put in a usable form. The Service A could be computer interfaced but NAFAX can not. He has storm data through the direct dial up of the NWS radars; however this data is frequently stale, inaccessible and is not processed to depict aviation hazards. The quality of the facsimile printout is poor. He frequently does not receive reports on changing terminal conditions until after a problem has developed. Finally the forecasts generated by the NWS are for a longer time frame than the 0-4 hours most needed for ATC flow control.

With a good data base the meteorologist's functions will include:

(1) interpreting available graphical and textual products to the central flow controllers, flow controllers and terminal supervisors,

(2) anticipating aviation weather problems before they happen and alerting the affected facility, and

(3) monitoring and correcting if necessary the automatic computer generated forecasts (short range and very short range).

Item (1) is an expansion of his present duties, item (2) he tries to do now but is rarely able to with the available data base, and item (3) is a completely new task. To accomplish these tasks the meteorologist will find great value in a computer driven display terminal with good user-oriented alerting and recall aids. He should be able to display, alter and add to the products available on the terminal area supervisors console, and the en route centers flow control console. An interface is also needed with SCC automation to permit the meteorologist to work up the appropriate graphical and textual displays which are appropriate to the central flow controllers. The recommended architecture to achieve this is discussed in Section 4.4.

4.0 RECOMMENDED SYSTEM ARCHITECTURE

4.1 Overview

The WSA satisfies most of the controller and flow controller needs for timely, user-oriented weather products. The selected architecture connects and unifies the many weather sensor developments and integrates the WSA into NWS automation, FSS automation, and FAA communication plans. Careful consideration has been given to avoid duplication of NWS services and particular attention has been given to minimizing communication costs.

The system architecture employs three types of weather processors referred to as the ARTCC WEather Processor (AWEP), the TRACON WEather Processor (TWEP), and the System Command Center WEather Processor (SWEP). These are small computers which are linked together in a tree-like communication structure as illustrated in Fig. 4.1.1. The main function of these processors is to satisfy the needs expressed in Sections 2 and 3 of controllers for both graphical (primarily radar) and alphanumeric data. Each processor has four major functions which will be described in detail in the following sections:

data storage and management,
data processing,
data communication, and
display formatting.

Each computer maintains the data base and provides the automated data handling which is relevant to the controllers, flow controllers or supervisors it serves. The data processing digests the weather data for suitable presentation to the meteorologically untrained controllers. Appropriate processing also permits use of very low data rate links between the various system nodes. For example, as illustrated in Fig. 4.1.1, 300 bits/sec between the AWEP and TWEP, and between the WRAP and AWEP provides all the ATC meteorological data requirements for radar and local observation data. The data rates on the links between the SWEP and each AWEP cannot be specified at this time, but are in the 600-1200 bit/sec peak data rate range. It makes little difference whether the particular communication support system is a dedicated link or integrated with other data flow,

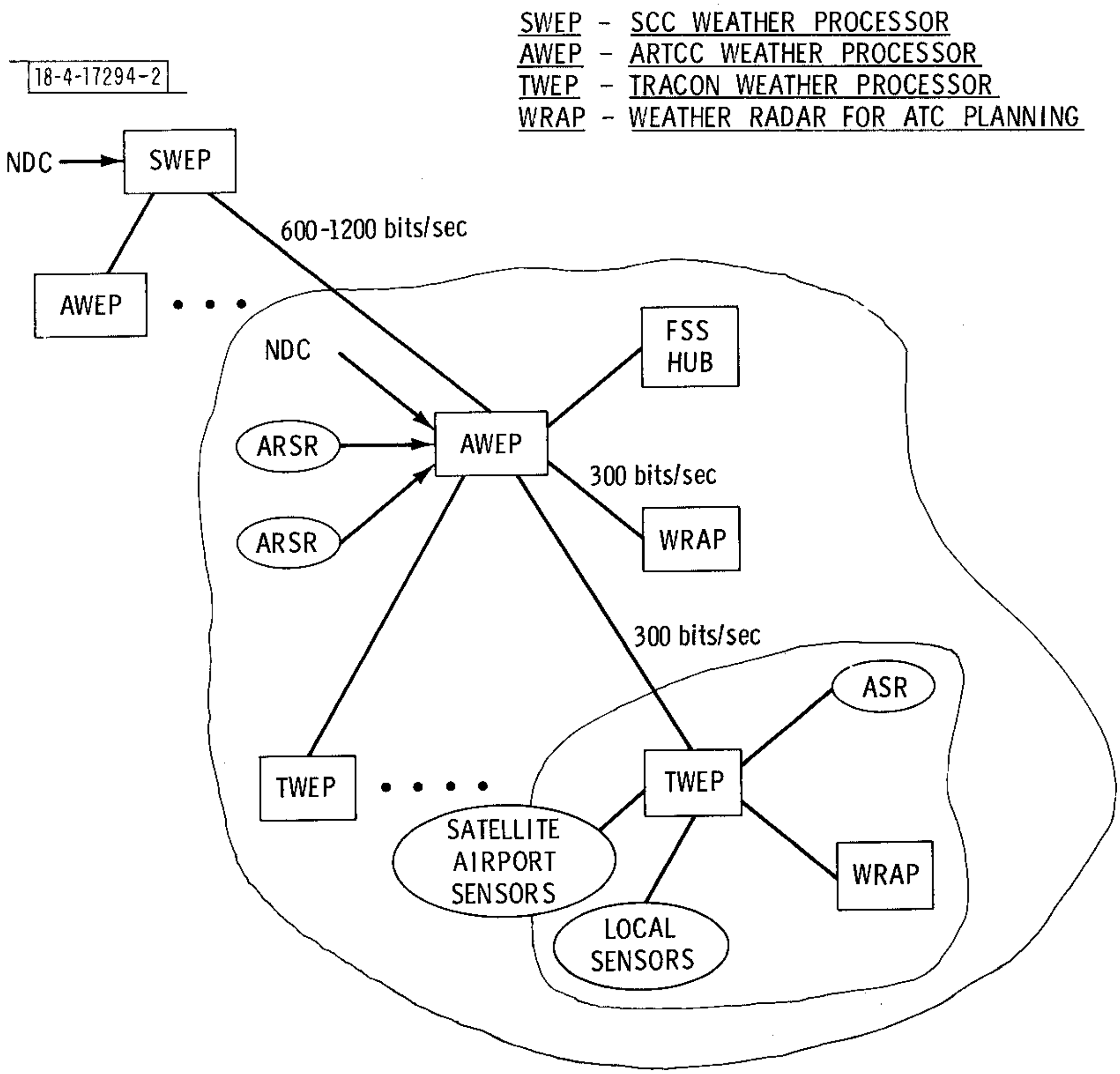

Fig. 4.1.1 Weather subsystem for ATC structure.

provided sufficient capacity is provided and queing delays are small. Integration of the communication into the proposed Integrated National Aviation Communications System (INACS)[23] is a very sensible approach. Section 4.5 discusses the communication structures in more detail.

4.2 ARTCC WEather Processor (AWEP)

The AWEP, illustrated in Fig. 4.2.1, is an important element in the WSA architecture. It provides regional collection and dissemination of timely weather data to and from the terminal areas and simultaneously satisfies ARTCC needs. This regional centralization enables netting of data for enhanced utility, significantly simplifies the TWEP design, and avoids the extra communication costs of TWEP processors talking with each other. The collocation of the FSS hubs at the ARTCC centers would permit resource sharing for mutual benefit. In the final design, the AWEP functions described here may be most economically achieved by combining them with the FSS hub automation.

4.2.1 AWEP Processing

4.2.1.1 Radar netting. The AWEP processor combines the radar weather data from the WRAPs, ARSRs, and ASRs within the ARTCC to produce the best possible unified picture of current weather conditions. More specifically, consider Fig. 4.2.2a, where two radars are providing a different weather depiction of the fixed threshold contours and the individual cells in their overlapping coverage region. Such a presentation to a controller whose sector spans these two radars would be confusing and clutter the PVD display. By combining the data as illustrated in Fig. 4.2.2b, controllers will be provided a consistent, easily interpreted presentation.

The combining of data in regions of overlapping coverage also results in a higher quality depiction in this overlapping region than would be possible with a single radar. The exact method of radar netting is left to an R&D program. Methods to explore include:

(1) a simple weighted average with the weights depending upon the type of radar and range,

(2) the maximum value being most conservative, and

(3) specific boundaries for each radar with no multisensor averaging.

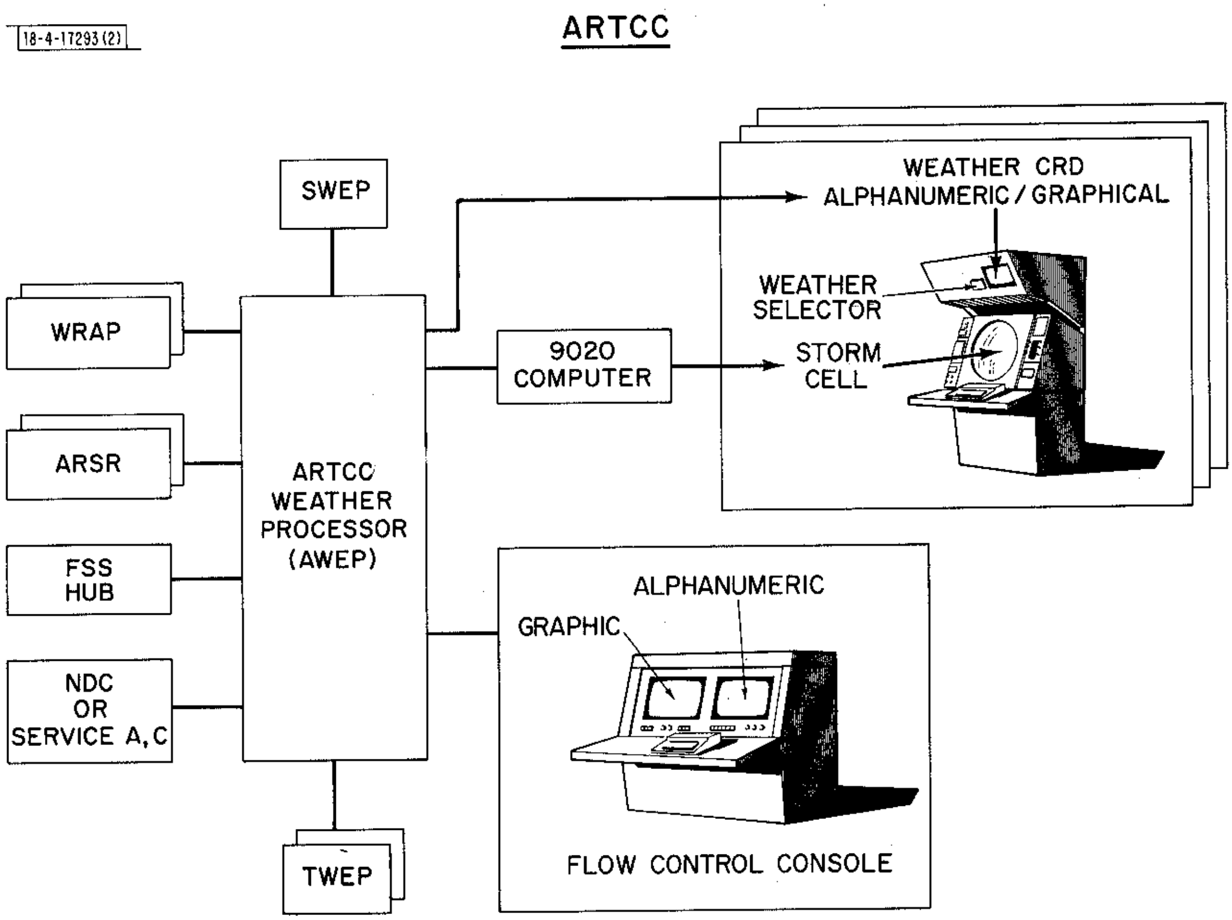

Fig. 4.2.1 The ARTCC weather processor (AWEP).

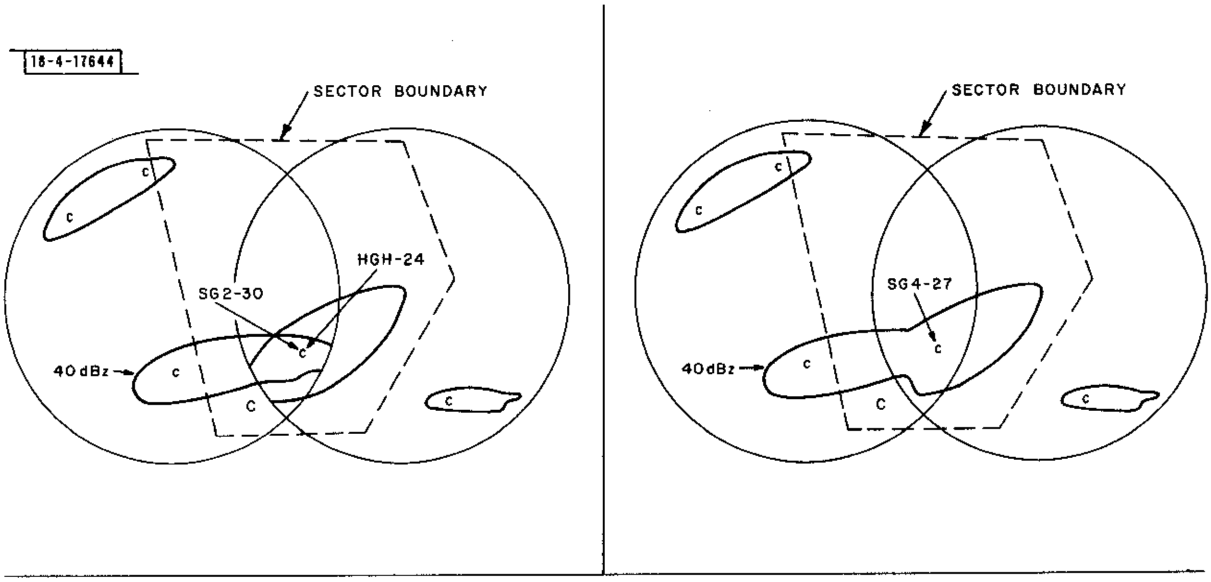

Fig. 4.2.2 Radar netting.

4.2.1.2 Radar performance monitoring. An important useful by-product of radar netting is performance and calibration monitoring of the radars. Consistent large differences in the cell parameter estimates or the threshold contours is a good indication that the radar is out of calibration. The AWEP will keep running statistics and send an alert to the supervisor's console when radar calibration maintenance is needed. This is not a substitute for periodic on-site calibration.

4.2.1.3 Very short range cell forecast. The very short range forecast of cell positions and parameters (0-30 min.) is best done within the AWEP, instead of at the radar site or at the TWEP, for four reasons:

- to do a good job, especially near the radar boundaries, the cell forecasts should be based upon the netted radar data,
- the extra complexity in having the AWEP processor perform the very short term forecast is more than offest by simplifying the more numerous TWEP and WRAP processors,
- the very short range forecast will use wind field data which is readily available in the AWEP from its connection with the NDC or Service C.
- the very short range forecast will be needed by the en route controllers anyway.

The very short range forecast will be based upon cell tracking and wind fields. The exact algorithm will have to be determined in an R&D program. For more details, the reader is referred to Reference 5.

4.2.2 Data Storage and Management

Data request delays cannot be tolerated by controllers and it is thus important that all weather products for ARTCC controllers be stored in the AWEP in a form suitable for immediate retrieval. Having to request data from other WSA processors or the NWS on a routine basis with the immediate retrieval requirement would complicate the communication requirements. Thus, relevant meteorological data should be routinely transmitted to the AWEP from the radars, the NWS, and any TWEP equipped terminals.

The flow controllers similarly need quick data retrieval; however, occasional delays of a few minutes are tolerable. For instance, special requests from the SWEP processor or meteorologist for conditions in other centers need not be answered immediately.

More specifics on the data to be stored in the AWEP follows.

4.2.2.1 Radar weather data. After the processing discussed above, the netted radar of current ARTCC conditions and the very short range cell forecasts are stored in the AWEP for display to controllers. The short range forecast (0-4 hr) of squall lines and frontal movement which is computer generated at the SWEP is also stored in the AWEP for use by flow controllers.

4.2.2.2 Local terminal observations from the TWEPs. Terminal observations, especially from any TWEP-equipped TRACONs, should be transmitted to the AWEP periodically from all automated sensors. The update interval should be adaptable to the rate of change of the measured parameters (see Section 4.3.4 for details). This will enable: (1) flow controllers to quickly spot deteriorating terminal conditions, (2) controllers to give pilots up-to-date data, and (3) partially alleviate the uncertainty controllers have in feeding aircraft into the terminal area. More specifically, the terminal observation data, which should be transmitted to the AWEP if available in digital form from automated sensors, includes: sky cover, ceiling, visibility, prevailing visibility, weather type, obstruction to vision, sea-level pressure, temperature, dewpoint, wind direction, wind speed, gusts, altimeter setting, runway visibility - RVV or RVR, wind shear and wake vortex This data represents only 300-400 bits from each airport (1 bit/sec for updates every 20 minutes), would be available from the TWEP data base, and can thus be readily obtained with a negligible impact upon the AWEP-TWEP data link. In addition, these surface observations may be useful in the short range forecasts (0-4 hr) at the SWEP.

4.2.2.3 Selected NDC products. The NDC[24-27] is a source for:

- terminal observations from locations not connected to a TWEP,
- terminal forecasts useful to both controllers and flow controllers,
- PIREPS
- wind and temperatures aloft on a synoptic scale (useful in the preparation of very short term cell forecasts).
- graphical weather maps - these cannot be specified now since the computerized replacement of facsimile is still in developmental stages. However, some of these products should be useful for flow control planning.

Most of the above NDC data will also be needed by the FSS automation. The graphical weather products which are presently available on NAFAX are more applicable to FSS but possibly useful to ATC. A partial list of these include:

- 200, 300, 500, 700, 850 Mb analysis
- 36 hr heights/isotachs forecast - 300 Mb
- Radar summary
- 12 hr upper wind and temperature prog. - 9,000, 18,000, 30,000 and 39,000 ft
- Low level winds aloft - second standard level above surface, 5,000, 8,000 and 10,000 ft
- Intermediate level winds aloft - 14,000, 25,000, 30,000 and 35,000 ft
- Surface prog. - 12 and 24 hour
- Significant weather prog. - 12 and 24 hour
- NMC surface analysis
- NMC weather depiction

Considering the overlap of interest in the NDC data base, combining the FSS automation processor with the AWEP is a good approach to investigate. A communication system to support FSS automation may be a source for this data instead of the NDC.

4.2.2.4 Service A and C. Should the NDC not be available, the terminal observations, forecasts, wind and temperature aloft data is available on these two services.

4.2.2.5 PIREPs. Stale PIREPs, an hour or more old, are of little utility for controlling traffic and thus the present Service A is not suited for ATC. With colocation of the FSSs in the ARTCCs, the PIREPs relevant to the ARTCC would readily and quickly be available. Improved procedures to obtain PIREPs on a routine and structured basis from controllers could be instituted. For a further discussion, see Appendix A3.

4.2.2.6 Alert messages. The flow controller, assistant chief, the FSS personnel, and the SCC meteorologist should be able to send special alert messages to any location in the WSA. These should be in a free format. The AWEP stores and routes the messages to the designated user. Although it is envisioned that the number of alert messages will be small, this is an important feature.

4.2.3 Display Formatting and Automated Alerting

Display formatting involves presenting the data in an appropriate form for display on the controller's PVD, weather CRD and the flow controller's two CRDs. These displays and what goes on them have been discussed in Sections 3.1, 3.2 and 3.4.

The controller's weather display and the flow control console are relatively straightforward design tasks since it does not involve an interface with existing ATC equipment. A human factors study is needed to determine the appropriate formats.

The storm cell data on the PVD is complicated by the necessary interface with the NAS 9020 computer. This interface will involve a design tradeoff between what is desirable from a human factors viewpoint and what is possible with the 9020. Displays like those in Figs. 3.1.1-3.1.6 are possible; however, human factor studies may end up preferring different display formats.

4.2.4 Data Communication

The AWEP is the regional collection and distribution point for weather data. This regional centralization should minimize processor and communication costs.

4.2.4.1 Data collection. The AWEP receives digital weather data from:

- WRAP radars, at 300 bits/sec, only when there is measurable precipitation. The data includes cell positions, reflectivity, height, and diameter, plus one or two fixed threshold contours.
- ARSRs for regions not covered by WRAP radars
- TWEPs - ASR or WRAP radar data, surface observations, PIREPs
- SWEP - short range forecasts, special messages
- NDC, Service A and C, or FSS automation weather data.

4.2.4.2 Data distribution. The AWEP transmits digital weather data to:

- SWEP - netted radar data, terminal surface observations, PIREPs, and special messages
- TWEP - netted radar data, very short range forecast, terminal observations from other terminals, PIREPs, the short range forecast originating at the SWEP, and special messages.

4.3 TRACON WEather Processor (TWEP)

The WSA design architecture stresses a unified system, connected elements, minimum communication, with growth potential as technology advances. There are a number of ongoing FAA and NWS sensor developments whose outputs should be tied together in a unified system to support aviation weather. These include digitized radar, AV-AWOS,[28] Semi-Automated LAWRS, wind shear and wake vortex, AMOS, RAMOS, etc. Each of these provides digital data for use by ATC, FSSs, and the NWS. The TWEP should serve as the centralized collection and dissemination point for the weather data collected from airports for which the TRACON provides approach and departure control. All digital weather data destined for terminal controllers should first pass through the TWEP. It is important that these FAA and NWS sensors be computer compatible with the TWEP. This centralization has a number of advantages:

- there is only one interface with the controller's displays,
- the digital computer processing allows for easy expansion to include future sensors,
- other potential data users can access the terminal weather data base with a single TWEP computer interface instead of separate interfaces with the many sensors at different locations,
- avoids the proliferation of computers,
- simplifies the communication network and most likely decreases its cost.

The TWEP processor is considerably smaller than the AWEP; the data processing is minimal, the amount of data stored and managed is small, and there are only a small number of controllers and controller displays. The TWEP role in the WSA is illustrated in Fig. 4.3.1.

4.3.1 ASR Radar Data

It appears preferable to have an on-site ASR weather processor preferably combined with the Moving Target Detector (MTD)[29,70,71] aircraft surveillance processor to produce the fixed threshold contours and identify cell location, intensities and diameter. These data are transmitted to the TWEP for

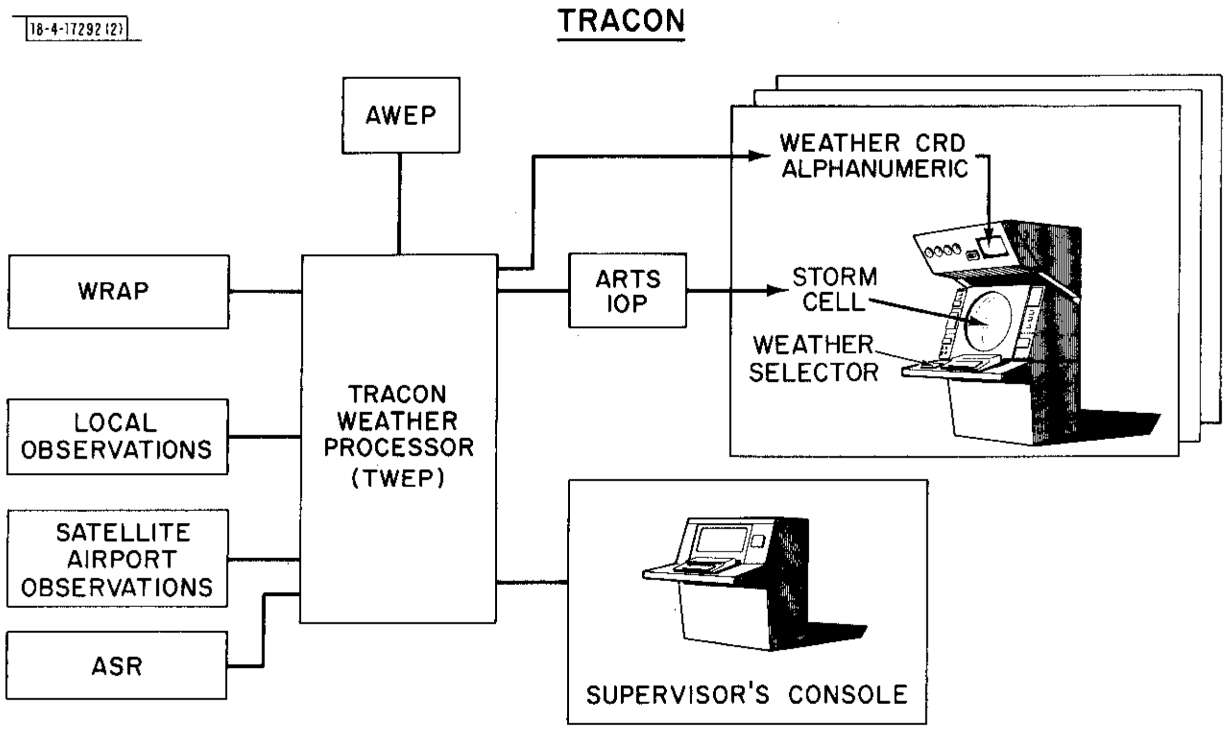

Fig. 4.3.1 TRACON WEather processor (TWEP).

display on the terminal controller's radar scope. The TWEP also transmits this data to the AWEP for radar netting and receives in return the very short range forecast (5-30 min) and an updated depiction of current conditions based upon netted radar data. Whether the controller's display of current conditions is just from the ASR or the netted radar from the AWEP will depend upon the distance to the nearest radar in the net. Even if the netted radar is preferred, the ASR data should be available for display in case of a communication failure with the AWEP.

Since the ASR is usually on the airport, communication costs between the ASR and TWEP are not a prime consideration. It may thus be preferable for the TWEP to assume part of this ASR weather processing. This decision will have to wait for the ASR modification program results.

4.3.2 WRAP at the Airport

If there is a WRAP providing terminal area coverage then it will be used instead of the ASR with the addition of storm cell top information.

4.3.3 Wind Shear and Wake Vortex

It is too early in this sensor development to determine the precise role of the TWEP; however, the TWEP should be involved in alerting the controllers of hazardous conditions. Whether this is in the form of the hazard location on the PVD, and alert message on the PVD or weather CRD, or simply a red and green light remains to be determined.

When wind shear or wake vortex conditions exceed some threshold, periodic updates should be sent to the AWEP to alert en route controllers and flow controllers of changing terminal area acceptance rates. Once every 20 minutes should normally be sufficient; however the update rate should be adaptive to the fluctuation rate of the wind shear and wake vortex parameters.

4.3.4 Automated Surface Observations - AV-AWOS, Semi-Automated LAWRS, AMOS, RAMOS, etc.

4.3.4.1 Coordination with TWEP. These automated sensor developments should be carefully coordinated with the TWEP; the digital observations should be accessible. The parameters include as many of the following as can be automatically measured:

cloud height
sky cover
present weather - precipitation [yes/no], freezing precipitation
pressure
temperature
dew point
wind direction
wind speed
gusts
altimeter setting
prevailing visibility
runway visibility (RVV)
RVR

Those that cannot be automatically measured should be observed at least once an hour and manually entered. More frequent observations should be made and entered when conditions change significantly. The above parameters represent at most 300-400 bits, which is a very small quantity of data.

One scenario for integrating these sensors into the TWEP is illustrated in Fig. 4.3.2. The automated sensors at the airports for which the TRACON provides approach control are accessible to the TWEP with automatic dial up using standard voice grade phone lines; dedicated lines are not needed. The time interval between transmissions should be automatically adaptable and initiated by the sensor. Once an hour should normally be sufficient; however, during quickly changing conditions, every 5 minutes might be necessary. Forming a loop with dedicated lines or integrating this data with other ATC communication data may be more advantagious in some places. The only important requirement is that data, especially when conditions are changing, be rapidly transmitted to the TWEP.

For the larger airports usually collocated with the TRACON, the controllers (approach, departure, and tower) need a frequent update of the local conditions. Presently, they receive a continuously updated meter reading of altimeter setting,

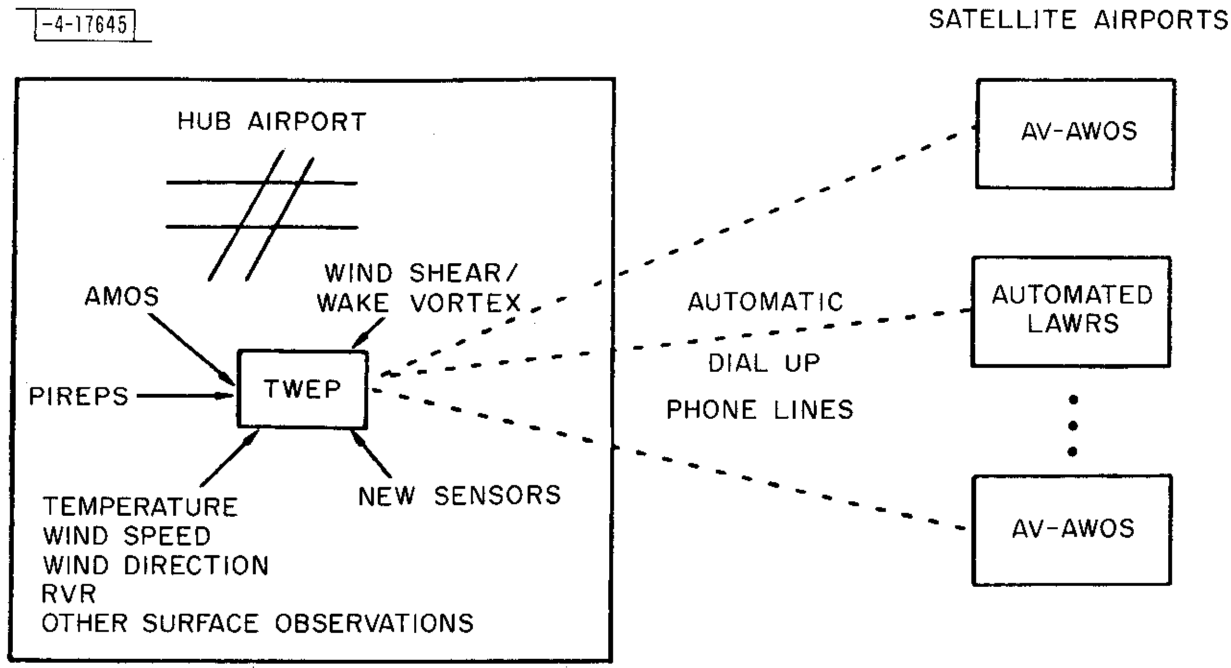

Fig. 4.3.2 Common terminal weather data base.

wind direction, wind speed, and when conditions warrant, RVR. This service should be continued except possibly the present meters at each control position should be eliminated and the data presented on the controller's weather CRD via the TWEP. Some meter readout in the TRACON may be advisable for backup.

4.3.4.2 TWEP management of surface observations. The TWEP provides the approach, departure and the collocated tower with the most recent updates of local terminal observations. In addition, periodic summaries are sent to the AWEP. The update interval should be adaptable but will rarely be more frequent than every 20 minutes. These summaries include the most recent reading plus peaks and averages over the reporting interval. With digital computer processing, the nature of these peak and average reports can be specified and changed once AWEP needs are more clearly understood.

4.3.5 Other Functions

The TWEP receives surface observations from the AWEP for nearby airports (not controlled from this TRACON). This data should be accessible by controllers on the weather CRD to assist pilots.

The supervisor should be able to enter PIREPs and other messages into the TWEP for display to controllers and transmission to the AWEP.

Improved procedures should be developed for obtaining runway surface conditions. This is especially important during slippery conditions such as snow, ice, and surface water. Whether this should be from automated sensors or from the runway crews should be looked into.

4.4 SCC WEather Processor (SWEP)

The NWS is undergoing an automation program[24-27] of Weather Service Forecast Offices (WSFO) and Weather Service Offices (WSO). This involves a mini-computer based display terminal at each WSFO called Automation of Field Operation and Services (AFOS). This automation system stresses computers talking with computers which are interconnected via the digital National Distribution Circuit (NDC). Virtually all the products presently carried on the many teletype circuits (A,C,0, etc.) plus the facsimile products will be digitally circulated nationwide on the NDC for display on the AFOS terminals.

The AFOS terminal is recommended to form the nucleus of the SWEP for the following reasons:

- The NDC products and the AFOS display flexibility are well matched to the SCC needs for quick, timely, automated access to the NWS data base,
- The clerical tasks presently performed by the SCC meteorologist are minimized,
- AFOS has been developed for NWS personnel and thus any meteorologist provided by the NWS for SCC duties will be trained to use it,
- Life cycle costs are minimized since the NWS is developing AFOS and there will be maintenance economics associated with the large number that will be in the field,
- It should be upgradable to interface with the AWEPs and TWEPs for access to the changing surface observations, storm cell data, the very short term cell forecasts and PIREPs,
- It should be reprogramable to generate the special aviation weather products like the short range (0-4 hr) squall line and frontal movement forecast. This will be based upon the storm cell data, surface observation, and rawinsonde data, This may require additional mini-computer computation power but the same AFOS displays should suffice.

A means is needed for displaying to the central flow controllers the picture worked up by the meteorologist on the AFOS terminal. A decision should be coordinated with the SCC automation plans. Should the AFOS terminal be installed before SCC automation is realized, then there are a number of temporary options ranging from the present rear screen viewgraph projections to a large screen video projection* directly interfaced to the AFOS terminal. The latter type of equipment is rapidly evolving with a number of systems on the market or being developed.

The recommended installation of AFOS equipment[25] for the Central Flow Control Facility (CFCF) room of the SCC is depicted in Fig. 4.4.1. Note that some AFOS equipment is positioned nearby the flow controllers.

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*For example, Video Beam Television produced by Advent Corp. Cambridge, Massachusetts.

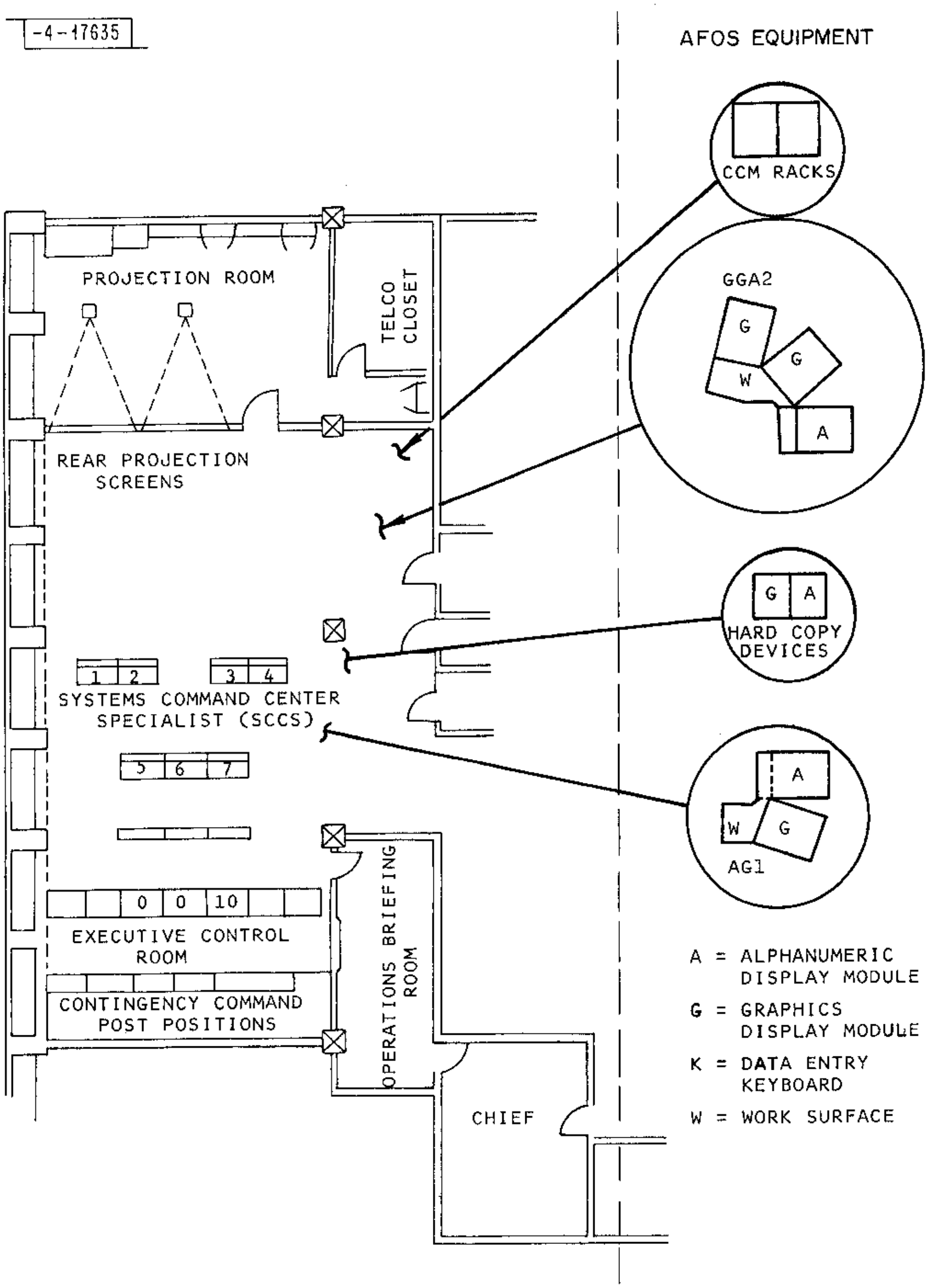


Fig. 4.4.1 Recommended CFCF control room layout.

4.5 Communication Structure

Data communications for collection and dissemination of weather data plays a significant role in today's system[30,31] and will assume even greater importance in future, more automated systems.

An analysis of the data flow on the various links connecting ATC facilities and NWS facilities has led to the estimates of peak data rate requirements in Table 4.5.1. Efficient coding in terms of storm cells and contours permits the weather radar graphic data to be transmitted at the low data rate of 300 bits/sec (see Appendix A1). Between SWEP and AWEP there is some uncertainty in data rate since the peak demand depends on the type of real-time interactive graphic communication that is carried on between the SCC meteorologist and en route flow controllers.

The demand for communications capacity to support weather data flow between ATC facilities is small and can readily be accommodated by the proposed Integrated National Aviation Communications System (INACS) or most any reliable data communication network. The overall connectivity of INACS[23] is shown in Fig. 4.5.1; notice that a weather radar connection is provided.

In addition to the FAA links, weather data will be carried by the NWS on the NDC and State Distribution Circuit (SDC). A brief description of these two circuits and the nodal point processors is given in Appendix A2. For more details, see References 24-27.

The role of the links in supporting the aviation weather needs is illustrated in Fig. 4.5.2. Arrowheads indicate the direction of oneway data flow; lines without arrows imply bi-directional flow. The NDC loop connects WSFO's and the National Meteorological Center (NMC). A branch NWS - State Distribution Circuit (SDC) to a WSO indicates one method of collecting weather data from automatic meteorological observation stations (AMOS).

The left side of Fig. 4.5.2 represents the eventual configuration of an AWEP linked to a WSFO. This connection can serve for both collection and dissemination of weather data. The observation stations associated with the TWEP equipped TRACONs could pass their data via TWEP and AWEP to the NDC network.

TABLE 4.5.1

ATC WEATHER DATA COMMUNICATIONS

Links	Type of Traffic	Estimated Peak Data Rate (Bits/Sec)	Channel Type
WSFO-AWEP	Text and Graphic Weather Products; Observations	2400 (initial NDC plan) 1200 (without FSS hub)	
WRAP-AWEP	Weather Graphics	300	One Way or Dial Up
AWEP-TWEP	Text and Weather Graphics	300	Half or Full Duplex
SWEP-AWEP	Weather Graphics; Short Term Forecast; Text	600-1200	Half or Full Duplex
AV-AWOS, Auto LAWRS - TWEP	Alphanumeric Surface Observations	Negligible	Dial Up

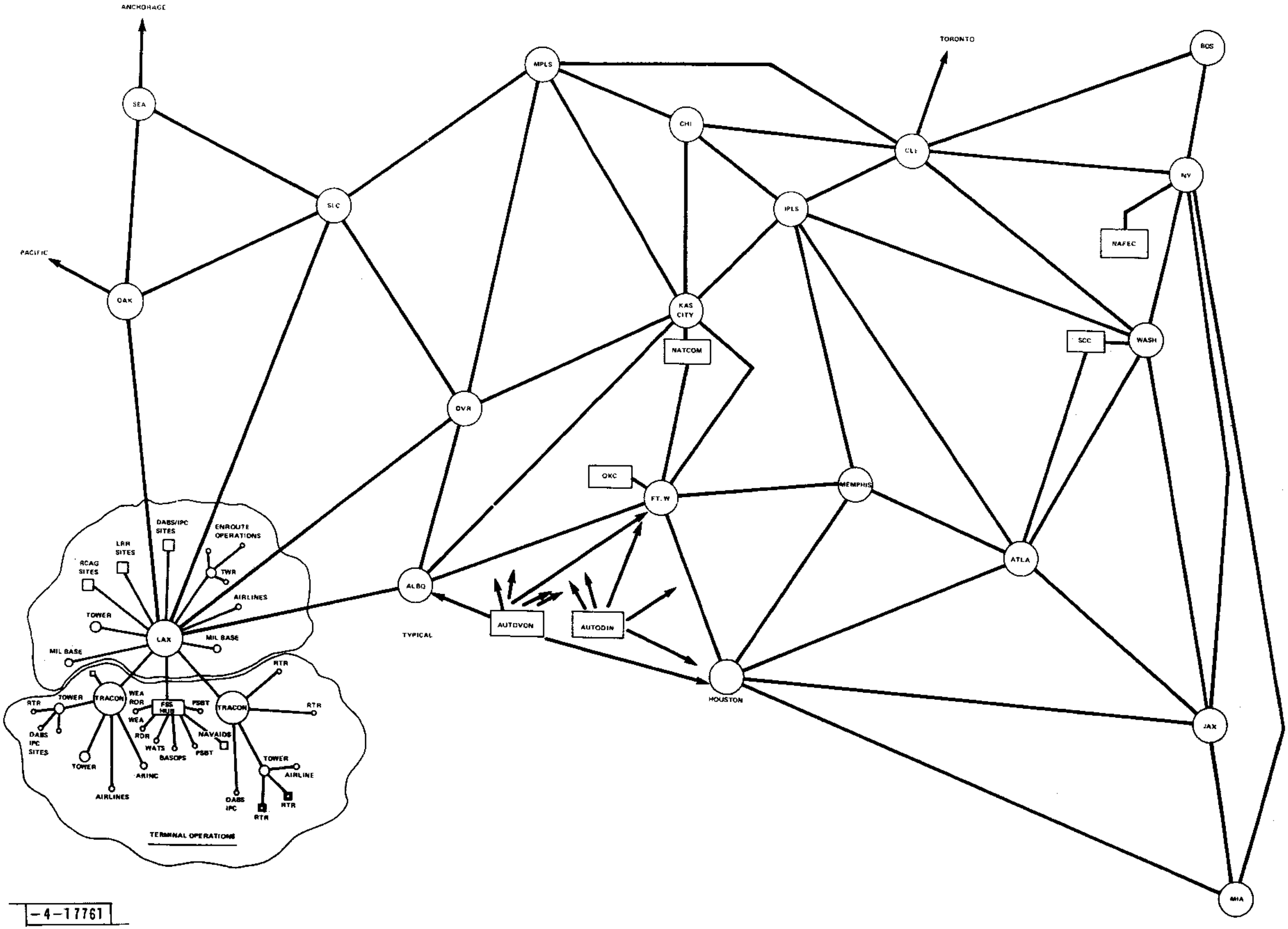


Fig. 4.5.1 Overall INACS connectivity.

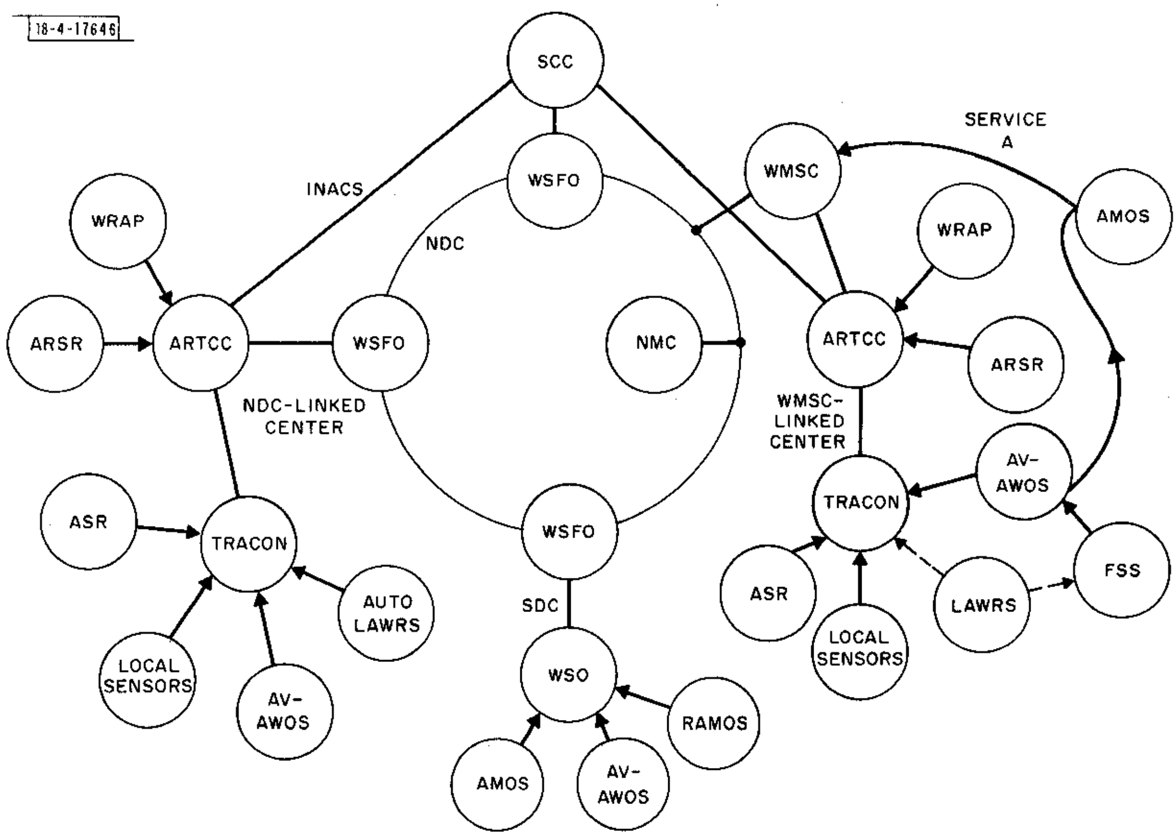


Fig. 4.5.2 Weather data network.

INACS can support the link between AWEP and SWEP via a routine that may involve several intervening ARTCC nodes.

An earlier stage in the evolution of the weather system is shown on the right of Fig. 4.3.2. Surface observations from the stations in the ARTCC area are acquired by the Weather Message Switching Center (WMSC) via Service A as in the present system. Collection of observations involves manual handling of data as indicated by the dotted lines from LAWRS to the TRACON and FSS. The AWEP obtains weather data directly from the WMSC.

Note that the two types of ARTCC modes are entirely compatible and can co-exist during an indefinite transition period. The only requirement is a tie-point between NDC and WMSC to permit exchange of data. Such an interchange capability is planned for NDC according to the AFOS development plan.[24]

The broad outline of a weather data network presented here demonstrates the need for close coordination between the FAA and NWS to assure mutual satisfaction of requirements, to avoid duplication of effort, and to clearly define interface specifications.

4.5.1 Dial-Up Links - Communication Economy

Eventually, as a network of WRAPs are deployed, the communication from these radars to the AWEP could be the major factor in communication costs. However, most of the time, in most regions of the country, there is no measurable precipitation. Automated dial-up using standard voice grade phone lines could provide the data when needed. More specifically, the WRAP processor could automatically initiate the phone link when certain thresholds are exceeded. Considering that the peak data rate is only 300 bits/sec, normal voice lines could satisfy the requirements.

The storm cell data also dominates the link between the AWEP and TWEP. A variable capacity link using dial-up may also be preferred here with only the surface observations being carried routinely.

Finally, for the AWEP-SWEP link, a dedicated 300 bits/sec line could carry the surface observations* to the SCC. When conditions warrant, a dial-up link could transmit the storm cell data to the SWEP and the short range forecasts plus special graphics to the AWEP.

Dial-up links should be used instead of dedicated lines providing the duty cycle is low enough. This decision must be made depending upon the weather conditions around each facility and the availability of other data links to multiplex data with. It is important to emphasize that the particular communication structure is not important and can vary from region to region. Rapid dissemination is the only requirement.

*The hourly and special surface observations come from the NDC. This link provides more frequent updates when conditions are changing quickly.

5.0 THE ENGINEERING AND DEVELOPMENT PLAN

The development plan (Fig. 5.0.1), will achieve a prototype demonstration, a design specification and an initial operating capability of the system concept within five years of program initiation. During the five year development cycle certain operational improvements can be achieved, particularly: (1) an ASR weather modification to identify storm cells to controllers, (2) an AFOS system to support the SCC and (3) improved PIREP acquisition and distribution.

Development is subdivided into three program elements. The first program element focuses on the AWEP, TWEP and SWEP to manage, process, communicate and display user-oriented data to controllers, flow controllers, and central flow controllers. The second program element, the ASR modification to enhance weather identification and the third element, the joint use Weather radar, are meant to provide the needed radar data for terminal and en route control respectively. Other needed sensor developments are currently being actively pursued by the FAA and are not included in this development plan.

5.1 AWEP, TWEP, and SWEP Development

The goal of this development is to design a connected system to satisfy the needs expressed in Section 2 with the features in Section 3. The system architecture in Section 4 provides the structure on which to base the design. This development is broken down into three efforts.

5.1.1 Processor Design and Interfacing

The goal is to develop the processor, display and communication equipment necessary to demonstrate the concept in operational control facilities. The major tasks are:

- Design and implementation of prototype equipment.
- Computer processor sizing and software development to process, manage, communicate, and display the data.
- Designing the supporting communication structure which takes maximum advantage of FSS Hub and NWS communication automation plans.

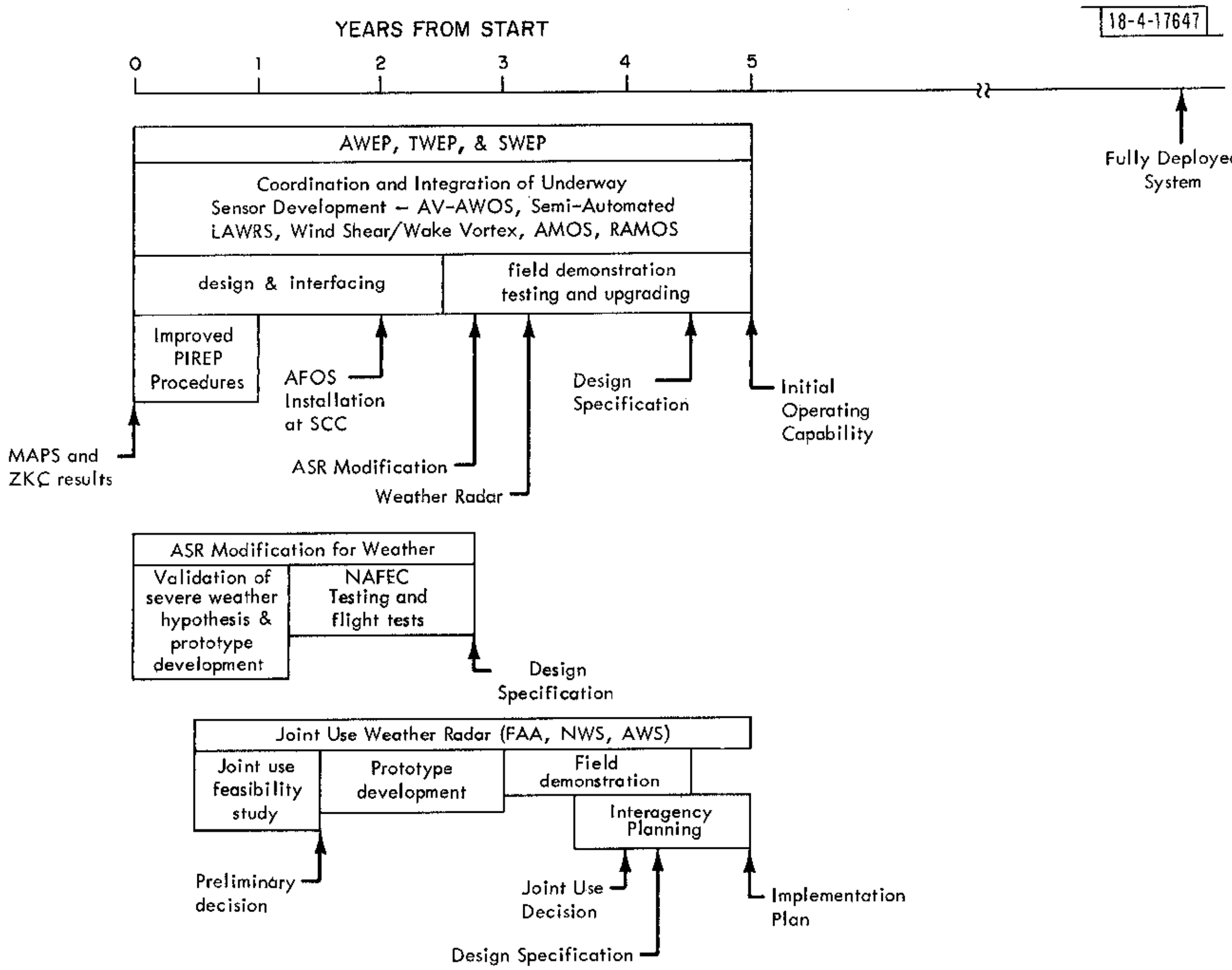


Fig. 5.0.1 The development plan.

- FSS Hub coordination to promote shared resources and avoid processor duplication especially in the en route centers.

- NWS coordination to encourage the generation of weather products, primarily forecast, in a form most applicable to ATC.

- AFOS installation and assessment at the SCC

5.1.2 Coordination and Integration of Underway Sensor Developments - AV-AWOS, Semi-Automated LAWRS, Wind Shear/Wake Vortex, AMOS, RAMOS.

The goal is the common terminal wide weather data base which is necessary to support the TRACON. These sensors, as currently being developed, should adequately satisfy ATC in the eighties. The major tasks are:

- Monitoring the sensors digital output design to ensure compatibility with the TWEP design.

- Establishing the timely communications necessary to support terminal control.

5.1.3 Field Demonstration Testing and Upgrading

The goal is the system concept validation in operational control facilities. These tests will include the processing and management of the surface observations, forecasts, ASR radar, and weather radar data to produce the displays discussed in Section 3. The major tasks are:

- To assess the benefits/cost on the TRACON, En Route, and SCC facilities.

- The implementation of weather displays and user access with the appropriate human factor considerations.

- The design and implementation of necessary upgrading based upon the operational tests

- AFOS upgrading at the SCC if necessary.

- A design specification for an operational system.

5.1.4 Improved PIREP Procedures

The goals are improved procedures for acquiring and disseminating PIREPS. The major tasks are:

- To develop improved procedures for use in the near term until the implementation of the DABS data link.
- To plan for the automatic acquisition of airborne meteorological data from aircraft via the DABS data link.

One new idea to consider in the near term is described in Appendix A3.

5.2 ASR Modification for Weather

The goal is the depiction and forecast of hazardous weather to terminal controllers with a radar weather processor integrated with the Moving Target Detector (MTD).[29,70,71]

5.2.1 Validation of the Severe Weather Hypothesis and Prototype Development

Recent MIT Lincoln Laboratory studies[5] indicate that regions hazardous to aviation due to convective turbulence can be identified with precision measurement and processing of radar reflectivity maps. The goal of this subtask is to validate this hypothesis and produce a prototype weather modification for the ASR. The major interrelated tasks are:

- A prototype ASR weather processor suitable for testing in conjunction with the MTD.
- Very short term forecast algorithm development
- Pencil beam radar and flight test experiments to assess the association of small cells with aircraft hazards

5.2.2 NAFEC Testing and Flight Tests

The goal of this subtask is to demonstrate to the FAA the validity and utility of the ASR weather processor. The major tasks are:

- Integration of the weather processor output into an ARTS III display.
- Validation flight tests.
- A design specification for an integrated MTD - weather processor

5.3 Joint Use Weather Radar (FAA, NWS, AWS)

The goal of this subtask is a weather radar network to simultaneously support FAA, NWS and AWS needs. The FAA should take a leadership role in this hardware development because their needs for fresh data are the most stringent.

5.3.1 Joint Use Feasibility Study

The goal of this study task is to conduct the preliminary investigations necessary for development of a joint use weather radar. The major tasks are:

- Understanding the needs of each agency
- Defining an experimental program to demonstrate the joint use desirability
- Strawman radar designs
- The cost benefits of a joint use weather radar network

5.3.2 Prototype Development

The goal of this subtask is to develop a prototype weather radar suitable for joint use testing. The major tasks are:

- The hardware development to implement the most promising strawman design
- A test plan to demonstrate the joint use capability

5.3.3 Field Demonstration

The goal of this subtask is to demonstrate the joint use weather radar in operational facilities. The major FAA tasks in this testing are:

- To interface with the prototype AWEP being field demonstrated at this time
- To determine the utility of the data for ATC.

5.3.4 Interagency Planning

The goal of this effort is to plan a comprehensive development and implementation program for a new joint use weather radar national network which would interface with user-agency systems for the 1980s and 1990s. The major tasks include:

- Prepare cost vs. benefit analyses
- A final decision on joint use desirability and compatibility
- Develop an engineering requirement (specification) for procuring the joint use weather radars
- Develop an implementation plan

Appendix A

A1 Data Rates

This section provides the justification for the low data rates expressed in the main part of this report. The coding methods discussed are illustrative and should not be taken as the optimum method.

A1.1 WRAP to AWEP

The following discussion considers the number of bits to describe the cells and contours at two fixed threshold levels. The relevant radar parameters are:

θ = azimuth accuracy or beamwidth

r = range accuracy

R = maximum range

The important cell attributes are:

N = number of cells

C = number of bits to specify a cell parameter:

position = $[\log_2 R/r] + [\log_2 360/\theta]$*

$$\left.\begin{array}{l}\text{intensity}\\ \text{diameter}\\ \text{height}\end{array}\right\} = \alpha \text{ bits}$$

The cells are thus described with

$$\boxed{N \times C = N \times ([\log_2 R/r] + [\log_2 60/\theta] + \alpha) \text{ bits}} \qquad (1)$$

The important fixed threshold contour parameters are:

M = number of fixed threshold contours

J = number of points in each contour

Each contour can be described by

*[x] = greatest integer in $(x+1-\varepsilon)$ for small ε.

$$[\log_2 R/r] + [\log_2 360/\theta] + 3\,J \quad \text{bits}$$

where the first two terms specify the R-θ coordinates of the starting point. It takes 3 bits to specify which of the 8 surrounding points is the next one on the contour. Thus for the M contours it takes

$$\boxed{M([\log_2 R/r] + [\log_2 360/\theta] + 3J) \quad \text{bits}} \tag{2}$$

The total number of bits per picture is found by adding (1) and (2).

To bound the data rate consider the following numerical example. The number of cells and contours was selected to be higher than should be found in practice from a WRAP radar.

$R = 200$ Km

$r = 1$ Km

$\theta = 1.1°$

$N = 50$

$M = 60$

$J = 80$

$\alpha = 17$ (intensity = 6, diameter = 5, height = 6)

Using these numbers in Eqs. (1) and (2):

bits/picture = 1700 cell bits + 15420 contour bits

= 17120 bits

Taking 60 seconds to transmit the picture, which is faster than necessary, this corresponds to

$$\boxed{285 \text{ bits/sec}}$$

The date rate is dominated by the contour data. The radar accuracy is greater than is necessary to report the fixed threshold contours. Should it be necessary to further reduce the data rate or if the number of contours should exceed the above estimate then a number of techniques can be used to compress the data by sending approximate contours. One method is to transmit every Kth contour point plus additional points in regions of high curvature. A method of sensing high curvature is to compare the distance between transmitted points to a threshold. The equation for the contour bits then becomes

$$M([\log_2 R/r] + [\log_2 360/\theta] + \frac{2J\ [\log_2(2K + 1)]}{K}) \quad \text{bits}$$

where it takes $2[\log_2(2K + 1)]$ bits to specify each successive transmitted point following the first point and there are J/K points.

Using the same example as before with K = 7,

bits/picture = 1700 cell bits + 9300 contour bits

= 10,000 bits

This corresponds to 167 bits/sec in 60 seconds.

The cell and contour data should suffer virtually no queing delay even though it takes 60 seconds to transmit a picture since the cells and contours will be produced by the radar sequentially. Actually the radar refresh rate will be somewhere between 3 and 5 minutes which allows even more time to transmit the picture than was assumed in the above examples. However, it is felt that sufficient capacity should be provided to transmit the picture in 1 minute.

A1.2 TWEP - AWEP

The data rates in each direction are considered separately. The TWEP to AWEP data includes the ASR radar data plus some surface observations for local airports. The AWEP to TWEP data includes the netted radar data, very short range cell forecast, surface observations from a few nearby airports and the short range forecast. There are also special messages and PIREPs transmitted in each direction; however, these add little to the data rates.

A1.2.1 TWEP to AWEP

The data rate equations in the last section are also applicable here for transmitting the ASR cell and contour data to the AWEP. Due to the shorter range there are proportionally fewer contours and cells. Consider the following parameters where the number of cells and contours was selected to be higher than should be found in practice,

$R = 75$ Km

$r = 1$ Km

$\theta = 1.1°$

$N = 20$

$M = 25$

$J = 120$

$\alpha = 11$ (intensity = 6, diameter = 5, height = 0)

Using Eqs. A.1.1 and A.1.2 this results in

bits/ASR picture = 540 cell bits + 6,400 contour bits

= 6,940 bits

The average Service A surface observation is 400 bits. With 10 peripheral (a high estimate) airports this represents only 4,000 bits. Even if both the radar and the surface observations needed to be transmitted in 60 seconds this results in

180 bits/sec

Actually the radar picture updates are generated every 3 to 5 minutes and the surface observations should rarely be more frequent than every 20 minutes. Thus a 300 bit/sec channel would be idle for much of the time. However, this extra capacity permits the rapid transmission of the radar data and allows for growth potential.

A1.2.2 AWEP to TWEP

The data rate equations in Section A1.1 are also applicable here with small modification for transmitting the netted radar data and very short term forecast. The very short term (0-30 min) cell forecast in 5 minute intervals requires 6 times the data rate given by Eq. (1). The contours require the same data rate given in Eq. (2). Using the same numbers as in the example in Section A1.2.1 this results in

bits/picture = 6 x 540 cell bit + 6400 contour bits

= 9,640 bits

Sending surface observations on 10 nearby airports results in 4,000 bits. Again even if both the radar and surface observation needed to be transmitted in 60 seconds this results in

225 bits/sec

Actually the netted radar data and the very short term forecast are generated every 3 to 5 minutes and the surface observations should rarely be more frequent than every 20 minutes. Thus a 300 bit/sec channel half or full duplex would be idle much of the time. This extra capacity will be partially used for special messages, PIREPs, the short range forecast and allows for growth potential as new meteorological uses are developed.

A1.3 SWEP-AWEP

The AWEP to SWEP data rate should be dominated by the radar cell and contour data, and surface observations. Twenty minute updates should be sufficient for both. Using the bits/picture number derived in Section A1.1 and assuming 30 airports to report surface observations for results in:

$$\frac{17120 \text{ bits/picture x 7 radars}}{20 \text{ min. x } 60 \text{ sec/min}} = 100 \text{ bits/sec}$$

$$\frac{400 \text{ bits/surface obs. x } 30 \text{ obs.}}{20 \text{ min x } 60 \text{ sec/min}} = 10 \text{ bits/sec}$$

for a total of 110 bits/sec.

The data rate from the SWEP to AWEP is difficult to estimate until the products carried from the SCC are specified further. Peak data rates of 600-1200 bits/sec are assumed.

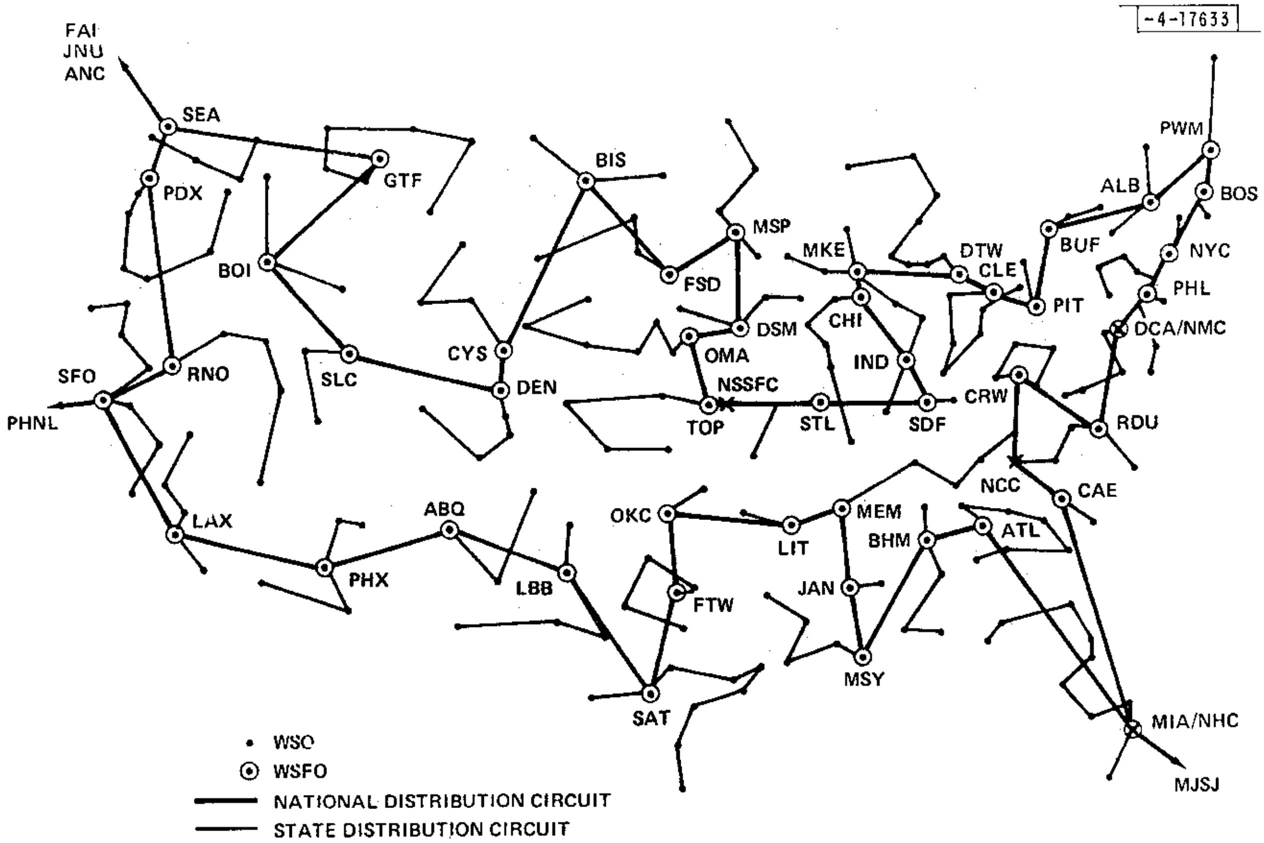
A2 NWS Weather Communications

In developing the WSA data flow network careful consideration has been given to NWS communications and automation plans. Joint usage of data links among FAA and NWS facilities exists today and will continue in the future. Currently the bulk of textual weather traffic is carried on TTY circuits terminated at the Weather Message Switching Center (WMSC) in Kansas City, MO. The future weather data users are expected to rely on the NWS National Distribution Circuit (NDC) for a large portion of the communication needs.

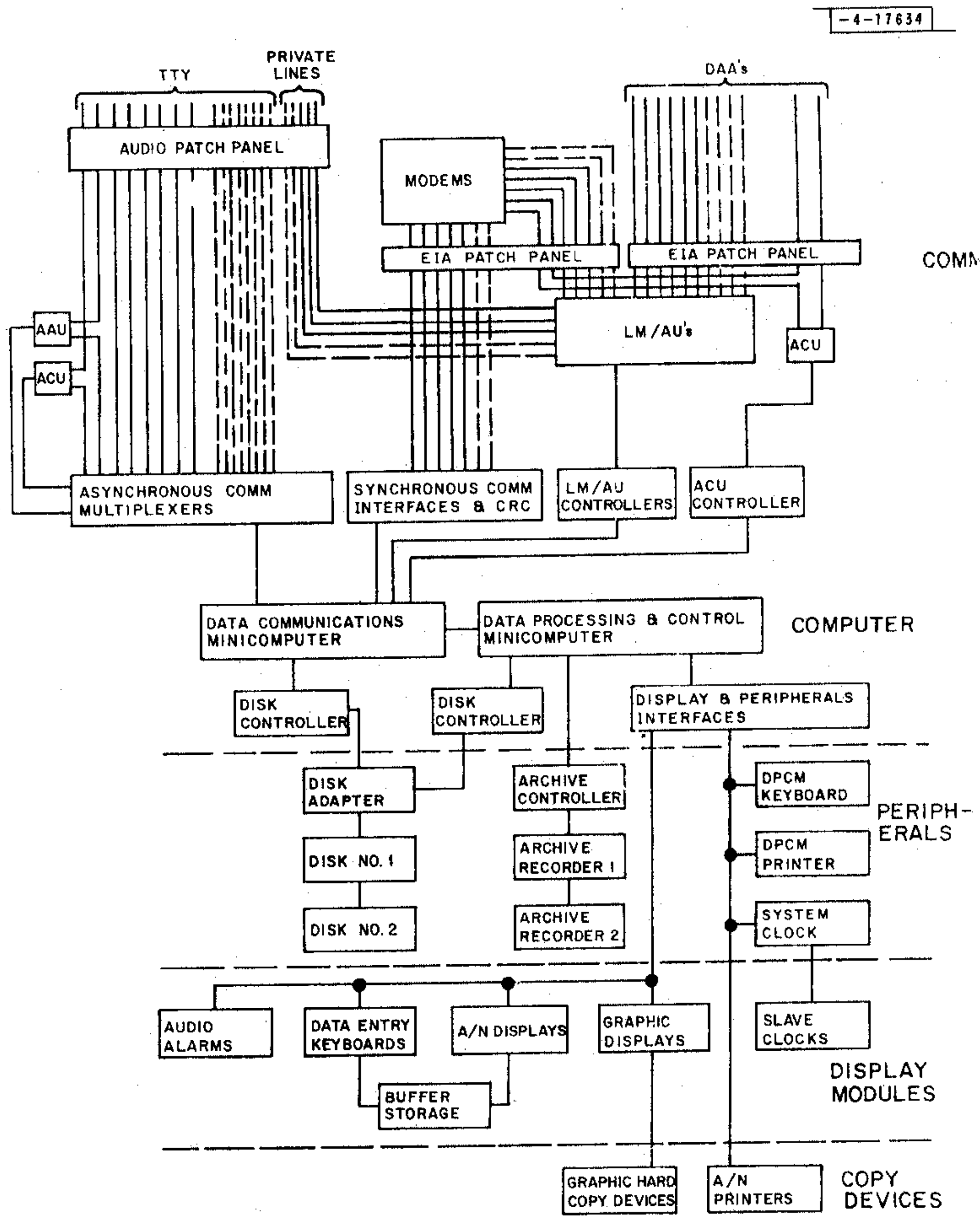
The NDC is part of the program for Automation of Field Operations and Services (AFOS)[24-27] being implemented by NWS. The planned geographical structure is shown in Fig. A2.1. Each Weather Service Forecast Office (WSFO) is a store-and-forward node on the NDC. The WSFO's link the NDC to the State Distribution Circuits (SDC). The Weather Service Offices (WSO) act as store-and-forward modes on the SDC and also serve as collection points for weather observations in their areas of responsibility. Eventually the method of data acquisition to WMSC via Service A TTY could be replaced by a network of local links to the nearest WSO and from there via SDC and NDC.

On the dissemination side the AFOS terminal has the capability of driving TTY transmitters to distribute weather products to various users. The AFOS equipment at the NDC and SDC nodes will consist of one or two mini-computers, communications interfaces, peripherals and displays. Figure A2.2 shows a WSFO type configuration. Each AFOS terminal performs the store-and-forward functions to support the network and also extracts data to maintain its own data base. The terminals are linked by 2,400 baud lines with Line Monitor/Auto-dialer Units (LM/AU) as backup in case of line failure.

The main purpose of AFOS is to assist NWS personnel in the performance of their duties. Multiple displays provide ready access to a large data base of graphic and alphanumeric weather data. The present weather facsimile equipment at the WSFO's and WSO's would be superseded by the NDC and AFOS display. The composition of forecasts is facilitated by guidance material presented in the format of the forecasts and by the editing capability of the terminal.



A2.1 NDC and SDC.



A2.2 WSFO type configuration.

The features of graphic and textual data retrieval from a national data base are desirable at the SCC for the benefit of the meteorologist and the central flow controllers. The SWEP would, therefore, be implemented with a link to a WSFO giving it access to the NDC and a data retrieval capability similar to an AFOS terminal but without the store-and-forward task.

A3 Route Oriented PIREPs

A3.1 Overview

Visits to FAA facilities and discussions with pilots indicate that PIREP information would be significantly more valuable if improved procedures were established for obtaining, interpreting and distributing the data. In the long term these could be obtained automatically from airborne sensors via an air to ground data link like DABS. However, in the short term one improved method would be to solicit PIREPs from a small number of en route aircraft of opportunity to establish a route oriented weather description. These PIREPs should be collected for roughly 600 predetermined segments of the CONUS preferred air routes. Each segment should be 50 to 100 nmi long and should include cloud tops, bases, layers, turbulence, icing, winds, temperature, etc. in all weather conditions. A PIREP specialist should prepare route PIREP summaries once an hour which should be distributed nationwide in a timely manner to the FSS, NWS and ARTCC. Selected routes could also be broadcast over the TWEB. These route oriented PIREPs are meant to supplement the present adverse weather PIREPs. The interpreted PIREPs should be quickly disseminated to the controllers responsible for these routes and the controllers feeding aircraft into these routes. This route oriented PIREP development would require coordinated FSS and ATC planning.

A3.2 Background

Reports of actual en route weather conditions are presently very hard to obtain before takeoff. PIREPs are usually only entered into Service A for adverse or severe weather conditions. Better-than-forecast conditions are often reported by pilots to controllers, but are very rarely entered into Service A. Significant conditions which usually go unreported include cloud tops and layers, and the nonexistence of forecast hazards such as thunderstorms, ice, or turbulence.

Perversely, this information is frequently available to the pilot in the air, by soliciting information from other pilots through the controller. Many controllers (work load permitting) run an informal briefing service, keeping track of recent pilot comments and passing them along to other pilots upon request.

As a result, a common technique for IFR General Aviation pilots is to go up to look (and ask) around, continuing on to their destination or retreating to their departure airport, depending on what actual weather is found.

Pilots in general are not trained weather observers. However, the pilot who has just climbed or descended through clouds is able to provide reasonably accurate cloud height information using his altimeter. Between or above cloud layers the accuracy of these estimates depend upon the pilots ability. Some information on clear space, especially when correlated with PIREPS from a few other aircraft, would enable the specialist to piece together a good picture.

A3.3 Data Collection Method

Assume that a PIREP Specialist in each ARTCC collects the route oriented PIREPS (roughly 30 per hour in each ARTCC) and severe weather PIREPS. With collocation of the FSS in the ARTCC, this task may be given to the En Route Flight Advisory Service (EFAS) persons.

In each control sector there would be an average of one or two routes for which route oriented PIREPs are collected. These could be collected from each sector, on a controller work load permitted basis, using one of the following scenarios. In all cases the controller would select one or more aircraft which have completed the desired route.

Scenario 1 - The PIREP specialist could key in the requested route which would appear on the appropriate PVD, CRD scope, or Flight Strip Printer. The controller could either collect the data himself from one or more aircraft (he may already know it) and phone it to the PIREP specialist, or ask the pilot to switch to a special PIREP specialist frequency. The last reported PIREP for each route should also appear and the controller should have the option of easily keying in "No Change,", "No Significant Information," "No Aircraft," or "Too Busy to Report."

Scenario 2 - The controller, when and if time permits, could collect the route PIREPs and routinely phone them in to the PIREP specialist once an hour or when conditions change. If no PIREP for a given route has been received for the last hour, then the computer could automatically remind the controller and indicate the last reported PIREP. Special requests from the PIREP specialists could be handled as in Scenario 1.

Scenario 3 - EFAS has a designated frequency for pilots to exchange weather information with the FSS. The PIREP specialist could broadcast requests for the route oriented PIREPs over this frequency. PIREPs from VFR (unavailable in scenarios 1 & 2) and IFR pilots could be obtained in this way. If this frequency carried enough information, then pilots might routinely monitor it. This method could supplement or possibly replace scenarios 1 and 2.

A3.4 Manpower

The PIREP specialist would have to follow 30 route segments in each ARTCC with updates every hour. Considering that weather conditions change very slowly, most of these hourly updates could be made automatically when the controller keys in "No Change" or "No Significant Weather." Thus this may not be a full time job and the EFAS person may be able to handle these tasks. He would be a prime user of the data and is receiving PIREPs from VFR aircraft. There may be more than one EFAS geographic region in each ARTCC, which would further reduce the work load.

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