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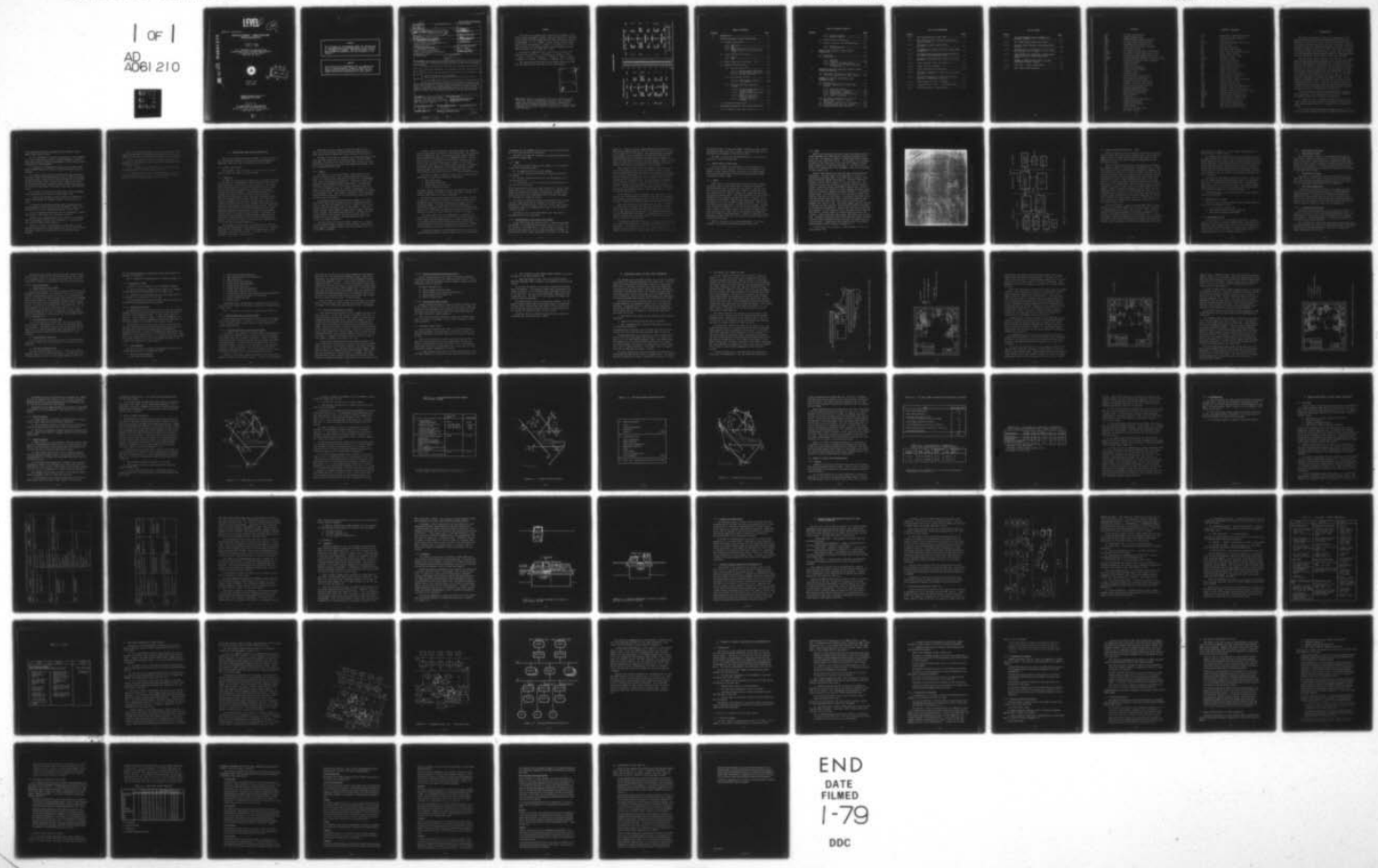

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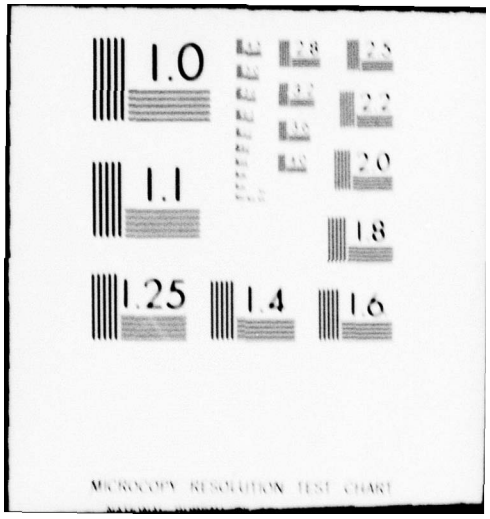
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REPORT NO. FAA-EM-78-13

EXECUTIVE SUMMARY -- TOWER CAB SYSTEM INTEGRATION ANALYSIS

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AUGUST 1978

FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
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16. Abstract

This report summarizes the principal results of the study of the integration into the tower cab of the systems being developed under the Major Systems Development Programs (MSDP).

The impact of these systems on the tower cab is analyzed from several points of view:

(1) The physical integration of the equipment in the tower cab and on the airport surface,

(2) The effect of the introduction of the new systems on the operations in the tower cab,

(3) Human factors aspects of the integration,

(4) Interface between the new systems and between the new and existing system, and

(5) Failure modes in the cab after the new systems have been introduced.

A048 306

The three interim reports of which this is the summary are: Report Nos. FAA-EM-77-10/(DOT-TSC-FAA-77-19) entitled "Characterization of Current Tower Cab Environments," dated November 1977 (210 pages); Report Nos. FAA-EM-77-16/(DOT-TSC-FAA-78-2) entitled "Tower-Related Major System Development Programs," dated March 1978 (288 pages); and Report Nos. FAA-EM-78-10/(DOT-TSC-FAA-78-6) entitled "Systems Integration Analysis for Future Tower Cab Configurations/Systems" dated June 1978 (314 pages).

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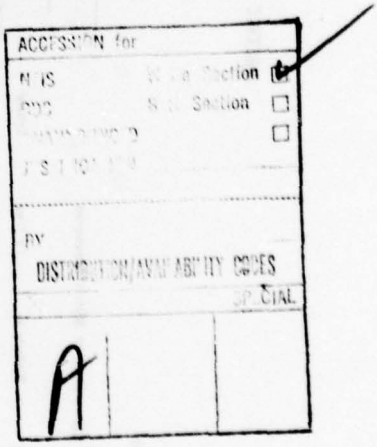
PREFACE

This report was prepared under Project Plan agreement FA-844 "Major System Development Programs Integration Analysis," sponsored by the Federal Aviation Administration, Office of Systems Engineering Management. It is a summary of three interim reports* which report on the three phases of a study of the impact on the tower cab environment of introducing Major System Development Program (MSDP) elements into the CONUS ATC system.

The material summarized here is the work of a team of TSC engineers and scientists: J. Bellantoni, R. Bland, D. Clapp, J. Coonan, D. Devoe, J. Dumanian, E. Hilborn, V. Hobbs, J. Kuhn, L. Maddock, A. O'Brien, J. Raudseps, P. Rempfer, and L. Stevenson.

The contribution of the many FAA personnel who invested both time and energy in the study must also be acknowledged.



*Report Nos. FAA-EM-77-10/(DOT-TSC-FAA-77-19), "Characterization of Current Tower Cab Environments", November 1977 (210 pages); Report Nos. FAA-EM-77-16/(DOT-TSC-FAA-78-2), "Tower-Related Major System Development Programs," March 1978 (288 pages); and Report Nos. FAA-EM-78-10/(DOT-TSC-FAA-78-6)," Systems Integration Analysis for Future Tower Cab Configurations/Systems," June 1978 (314 pages).

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

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GLOSSARY

ACID	Aircraft Identification
AMA	Airport Movement Area
AMPS	ATCRBS Monopulse Processing System
ARTCC	Air Route Traffic Control Center
ARTS	Automated Radar Terminal System
ASDE	Airport Surface Detection Equipment
ATC	Air Traffic Control
ATCBI	Air Traffic Control Beacon Interrogator
ATCRBS	Air Traffic Control Radar Beacon System
ATIS	Automated Terminal Information System
AV-AWOS	Aviation-Automated Weather Observation System
BRITE	Bright Radar Indicator Tower Equipment
CD	Clearance Delivery
CD	Common Digitizer
CFA	Center-field Anemometer
CPM	Central Processor Module
CRT	Cathode Ray Tube
CW	Continuous Wave
DABS	Discrete Address Beacon System
DAS	Data Acquisition Subsystem
DDAS	Decoding Data Acquisition System
DDC	Display, Data Entry and Control
DEDS	Data Entry and Display Subsystem
DEU	Display Enhancement Unit
DME	Distance Measuring Equipment
DPS	Data Processing Subsystem
EM	Electro-Magnetic
FD	Flight Data
FDEP	Flight Data Entry and Printout
FM	Frequency Modulation
FSS	Flight Service Station
GC	Ground Control
GFWS	Gust Front Warning System
HC	Helicopter Control

GLOSSARY - CONTINUED

HIPO	Hierarchical Input-Process-Output
IFR	Instrument Flight Regulations
LC	Local Control
LLWSAS	Low Level Wind Shear Alert System
LOS	Line of Sight
M&S	Metering and Spacing
MLS	Microwave Landing System
MSDP	Major System Development Program
MTD	Moving Target Detector
NAS	National Airspace System
NOTAMS	Notices to Airmen
PEM	Position Entry Module
PJS	Pressure Jump Sensor
RDBM	Remote Display Buffer Memory
RMD	Runway Monitor Display
RVR	Runway Visual Range
RVV	Runway Visibility Value
SRAP	Sensor Receiver and Processor
SMD	System Monitor Display
TAGS	Tower Airport Ground Surveillance
TCA	Terminal Control Area
TCDD	Tower Cab Digital Display
TDPS	Terminal Data Processing Subsystem
TFDP	Terminal Flight Data Processor
TIPS	Terminal Information Processing System
TRACAB	Terminal Radar Approach Cab
TRACON	Terminal Radar Approach Control
TRSB	Time-Referenced Scanning Beam
VAS	Vortex Advisory System
VFR	Visual Flight Regulations
WVAS	Wake Vortex Avoidance System
WSDS	Wind Shear Detection System.

1. INTRODUCTION

The tower cab integration analysis was undertaken for the purpose of identifying issues or problems associated with the introduction of new major systems into the existing ATC system's tower cab environment, and, where feasible, to postulate solutions or identify areas for further investigation by the FAA. The study, therefore, examined "first-level" issues. The conclusions drawn or solutions proposed are preliminary in nature, and are intended to be the foundation for more detailed studies or experiementation to verify feasibility and/or identify lower-level problems.

The integration analysis project was carried out over a nine-month period, January through September 1977, divided into three phases of approximately three months each. Fully two-thirds of the effort was devoted to examination, characterization, and documentation of first the existing tower cab environment, and then the various new major systems which could impact upon it. This left a rather limited amount of time for the task of integrating the information and performing the requisite analysis. It was necessary, therefore, to structure the analysis into a set of parallel independent studies to examine the integration problem from several points of view. While the results of each of the independent study efforts was exposed to an exchange review and critique, there was no opportunity to perform a second iteration through each study to resolve points of contention.

Several important factors presented themselves during the first two phases of this integration analysis which influenced the manner in which the third phase was structured.

1) Each tower cab is essentially unique in layout, use of space, and the variations employed in combining controller positions, making generalizations and standardization extremely difficult.

2) The autonomous design and development process of each new system cannot adequately address optimum presentation of total

cab information and overall workload of the controller from a human factors point of view.

3) The introduction of several large pieces of new equipment into "busy" tower cabs is likely to create problems in terms of space and operations without rearrangement of work stations and/or integration of some equipment.

4) Several of the proposed new major systems (TIPS, TAGS, ASDE, and ARTS-BRITE) will result in relatively large tower cab displays.

5) Several of the new major systems which were considered have only a minor link with the tower cab (e.g., M&S); the design of several other systems have not been sufficiently well defined, at the time of this study, to assess their impact on the tower cab from an operational, equipment-space, or human factors point of view with a high degree of certainty (WVAS, WSD, and DABS data link).

6) Several of the new tower-related major systems independently involve the use of sensors at the airport site.

7) Many of the new major systems involve new computer systems or requirements for computer system's resources or interfaces.

8) Many of the new major systems under consideration will not be deployed in the field until the mid-1980s or later, thus minimizing the issue of time-phasing between 1978 and 1985.

A set of autonomous study activities was formulated to address these points. The results are presented as follows:

Points 1 and 2, generalization of the tower cab environment and the integration of total cab information, are considered in the section on Human Factors Aspects.

Points 1, 3, and 4, the uniqueness of tower cabs, and the expected introduction of large displays into the cab from several new major systems, are considered in the Operational Aspects section.

Point 5, the possible impact of new major systems for which design concepts and/or design details are not yet firm, is considered in the section on Functional and Data Processing Aspects.

Point 6, integration of several systems utilizing sensors deployed over the airport surface is discussed in the section on Operational Aspects.

Point 7, computer system requirements, is addressed in the Functional and Data Processing Aspects section.

As a result of point 8, 1985 to 1990 deployment of most systems, the time-phasing of system installation between 1978 and the late 1980s was not considered as a vital issue.

2. TOWER-RELATED MSDP SYSTEMS DESCRIPTIONS

This section contains short descriptions of those aspects of the system being developed by the Major Systems Development Programs that affect the tower cab operations and environment.

2.1 AIRSPACE SURVEILLANCE

The new MSDP systems which have to do with airspace surveillance are ARTS IIIA, ARTS II, DABS, and AMPS.

2.1.1 ARTS IIIA

The ARTS III system being in operation at 61 airports throughout the country, an enhancement to the system called ARTS IIIA is being procured for use at the 26 largest airports. The enhancements being procured will provide the terminal area ATC system with new functions and capabilities by means of new hardware elements and software modules. The new hardware modules to be designed and procured will provide three new capabilities; multiprocessor operations, remote data acquisition and display, and use of primary radar in target-tracking. New software, including a multiprocessor executive, will provide for the continuous recording of critical data, automatic fault detection and isolation, and automatic reconfiguration and restart. These will result in fail-safe, fail-soft 24-hour operation of the system. Additional software will provide for tracking by beacon and/or primary radar of all targets within coverage. The modular construction of the software will allow the later addition of new operational functions such as conflict alert and metering and spacing. Even the basic ARTS III systems will be upgraded with the critical data-recording capability.

In the tower cab, the effect of introducing ARTS IIIA will appear on the BRITE display with which each of the cabs associated with ARTS III is equipped. Tracking will appear better - more consistent, with fewer false tracks -- and the system will be available continuously, 24 hours a day.

Eventually, new, all-digital displays may come into use, these will provide better, brighter pictures at more towers (e.g., those remote from the TRACON but within coverage of the sensor).

The ARTS IIIA systems are scheduled for installation during 1978, 1979, and 1980; remote and all-digital displays are still under development and would not be ready before 1985; conflict alert and metering and spacing are also under development and probably could not be implemented before 1980.

2.1.2 ARTS II

The ARTS II is an air-surveillance, data-processing, and display system for use in small to medium terminal area ATC systems. It is modeled after the ARTS III system, but is implemented with simpler, less expensive equipment. Provision is made in the design for both TRACON and TRACAB installations. The principal difference between them is in the display subsystem, which consists, in the TRACON version, of a number of plan-view-type displays and one tower BRITE subsystem; and in the TRACAB, of a number of tower BRITE's only. The system is composed of three subsystems which perform the functions of data acquisition, data-processing, and data entry and display.

The Decoding Data Acquisition Subsystem (DDAS) (1) accepts beacon video and azimuth information form a radar/beacon subsystem, (2) digitizes and decodes it, and (3) transmits video to the display subsystem and digital data to the computer. There are, besides various control signals, three kinds of input to the DDAS: video, triggers, and antenna synchronization. The DDAS then distributes video to the display subsystem, digitized range and azimuth data to the computer, and synchronization data, if required, to external equipment.

The Data Processing Subsystem (DPS) is made up of a Central Processor Module (CPM), a number of memory modules, input/output (I/O) channels, peripheral adapter and control modules, and a set of peripheral equipment.

Two basic types of Data Entry and Display Subsystems (DEDS) have been developed, one which is a newly developed, self-contained unit for TRACON use, and a second which provides output through existing BRITE subsystems for use in TRACAB and towers. The computer interface to be supplied with the BRITE equipment will be so designed that the BRITE Subsystem will appear to the computer to be exactly the same as the TRACON display subsystem. Therefore, the TRACAB and the TRACON may be serviced by the same computer program without differentiation as to equipment, and also, a tower BRITE position can be treated as if it were a TRACON position.

The ARTS II computer program is organized as a Master Control Subprogram, and four major operational subprograms:

a. Input Processing,
b. Functional Processing,
c. Beacon Input Processing, and
d. Display Output Processing.

The Master Control subprogram schedules the operation of the operational subprograms in response to timer interrupts, external interrupts, and flags set by other subprograms.

The Input Processing Subprogram processes the inputs from all of the devices connected to the DPS: the DDAS, the DEDS, system peripherals, and, if present, interfacility Teletype lines on high-speed modems. The Functional Processing Subprogram is a collection of routines which carry out all of the requested manipulations of flight data, maintenance of flight data tables in the memory, and selection of data from these tables for display.

The Beacon Input Processing Subprogram is responsible for accepting beacon reply messages (after they have been buffered by the Input Processing Subprogram) on a sweep-to-sweep basis, and for producing target reports containing range, azimuth, beacon code, and mode C code, the last-named being converted to altitude by the appropriate Functional Subprogram task mentioned above.

The Display Output Processing Subprogram has the job of preparing and maintaining all display tables used in the system, and

of managing the I/O command lists in such a way as to insure that all of the required data are displayed.

The ARTS II systems are scheduled for installation during the period 1977 through 1980.

2.1.3 DABS

The Discrete Address Beacon System (DABS) is a surveillance system under development which

1) is compatible with the current ATCRBS,

2) relieves certain interference and capacity problems of the ATCRBS,

3) provides increased precision in the measurement of aircraft position, and

4) incorporates a two-way digital data link which could be used for ATC or other use.

These system characteristics are made possible by a careful system design which uses a site-located data processor to schedule and manage the communication channel, and monopulse tracking both to increase the precision of measurment and to decrease the number of interrogations needed per target.

The effect of DABS on the tower cab operation will be largely indirect, appearing as better tracking in the ARTS system as displayed on the BRITE display in the cab. If the data link were implemented, some of the communications load on the controllers could be relieved.

The DABS is still in the development state; the earliest deployment would be in about 1985.

2.1.4 ATCRBS Monopulse Processing System (AMPS)

In the DABS design, RF radiation time is shared between DABS and ATCRBS. To provide DABS with enough time to carry out all of its functions, the ATCRBS share is set at around 25 percent. The effect of this reduction is to cut down the number of ATCRBS replies received from a target from about 20 to about 5 as the beam

passes it. Since the current target-detection algorithm used in ARTS and the Common Digitizer (CD) will not work with so few hits, a new scheme had to be developed. The scheme proposed with AMPS uses monopulse tracking, wherein the return from each pulse of radiated energy gives information on both range and angular distance from the centerline of the receiving antenna. Thus, a single return is sufficient to determine position although in practice, three or four returns are averaged to insure accuracy.

Three groups are working on the monopulse processing, each with its own point of view. The system built by MIT's Lincoln Laboratory and ARD-240 uses the latest, most-sophisticated design, and is a mobile unit mounted in a van. It will be operated under varying conditions in many parts of the country to test for environmental and interface effects in actual working surroundings. In use, the van is parked as near the transmitting antenna as possible, and the receiving antenna is aligned and synchronized with it. Triggers are picked off from the transmitter and used to synchronize the monopulse receiver, whose output can be recorded on tape for later analysis.

In the meantime, Texas Instruments, Inc., has built a very similar device and packaged it as part of the DABS site equipment. This receiver will be integrated into the rest of the system, and tested for compatibility and performance during DABS development.

The third version of the equipment has been built for ARD-122 by UNIVAC, and is combined with a Moving Target Detector (MTD) into a unit which is called the Super-SRAP, or SRAP II, in reference to the Sensor Receiver and Processor (SRAP) being developed for the Enhanced ARTS III program. The Super-SRAP will be used at NAFEC in a program to develop and optimize the ARTS software involved with use of this equipment.

The monopulse equipment can be used as part of the ATCRBS alone or as part of the DABS, where it handles the ATCRBS portion of the processing. If used alone, it consists of a new (receiving) antenna, a multi-channel receiver, and a digitizer-processor. The output of the processor is sent by phone line to the ARTS (or ARTCC)

processor for use. If used with DABS, it consists of the receiver and digitizer-processor, whose output is used at the DABS site to develop the final output to the ATC processors.

The AMPS is only in the development phase; if it were to be deployed, it would be about 1985.

2.2 AIRPORT SURFACE SURVEILLANCE

Two related MSDPs will contribute to the surveillance of traffic on the airport surface. The first is the ASDE-3, a new airport surface detection radar; the other is the surveillance data-processing and display system called Tower Airport Ground Surveillance (TAGS) system.

2.2.1 ASDE-3

ASDE-3 will be a primary ground-surveillance radar intended to replace ASDE-2 at the current ASDE-2 sites, and to permit a wider deployment than is now present with ASDE-2. The unit will have the same antenna-rotation rate as ASDE-2 (60 RPM) and a Display Enhancement Unit (DEU) to improve the airport map and eliminate unwanted ground clutter. The bright display will likely be the NU-BRITE display recently developed for ASDE-2. However, as an alternative to NU-BRITE, a digital-scan conversion system will be developed for use with the ASDE-3 engineering model. ASDE-3 will be a modern solid-state radar. Reliability will be high. In addition, the system parameters will be considerably different from those of ASDE-2 in order to improve the system performance during heavy precipitation. ASDE-3 will be developed to be compatible with the recently developed NU-BRITE. Except for improved rainfall performance, ASDE-3 will look (in the cab) the same as ASDE-2 with a DEU and the NU-BRITE.

ASDE-3 is currently in the development phase. If it were procured, the earliest installation would be about 1982.

2.2.2 TAGS

ASDE-3 will provide the cab with a plan-view display of the Airport Movement Area (AMA) and the location of surface traffic on the AMA. The purpose of TAGS is to add flight-identity information to such a plan-view display. The objective is to eliminate the need for the controllers to use the voice channel to obtain flight identity as is now done with ASDE-2. The chief user of TAGS will be Ground Control (GC) although it will also be provided to Local Control (LC).

Several TAGS concepts are currently under consideration for development. The most likely to be developed is one with its presentation based upon ASDE-3 (with DEU) and its identity information provided by ATCRBS trilateration. Therefore, TAGS will probably look the same as Figure 2.2-1 to the controller. This system will require two different surveillance systems, ASDE-3 to present a plan-view display and ATCRBS trilateration to provide identity and aircraft location to permit tagging each radar target. Since the system will combine both sensor systems, it is termed a hybrid system. The TAGS sensor, in this case called ATCRBS trilateration, does not use the beacon in a secondary radar mode but in a special ground-surveillance mode. Special interrogators would successively scan small cells (150 by 150 feet) on the airport-movement area, one at a time. The beacon signals would be received at multiple receiver stations, and the beacon location determined by trilateration computations. Beacon code would also be received and recorded. As with digitized radar, the position data would be processed by a filter tracker to provide smoothed position and velocity. Unlike digitized radar, beacon code would also be available. Automatic correlation with flight plan data readily obtained from ARTS would eliminate the need for nearly all manual entry by the controller. A functional block diagram of the trilateration sensor portion of TAGS is given in Figure 2.2-2.

If TAGS were to be procured, it would probably be first installed about 1985.

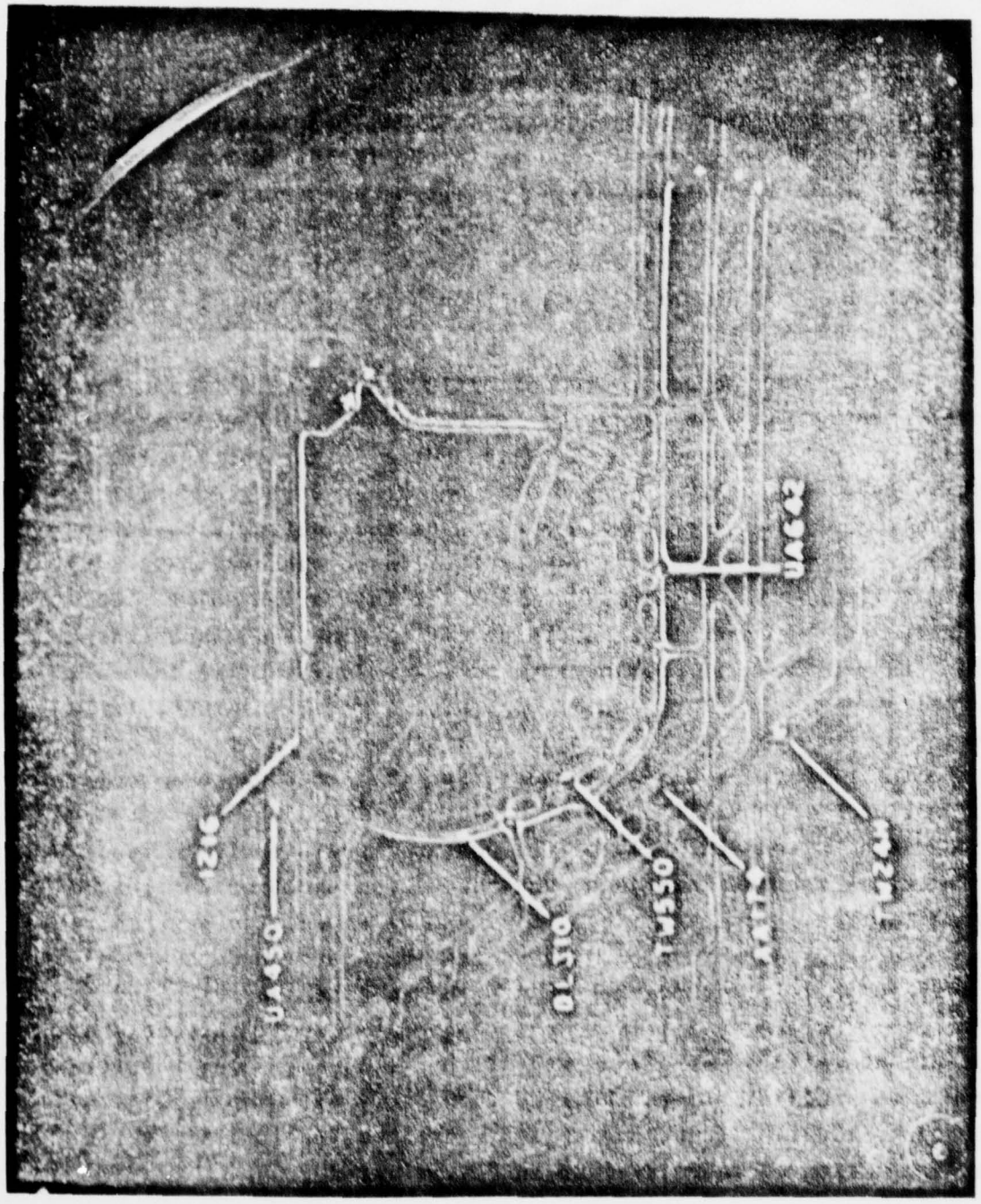


FIGURE 2.2-1. TAGS DISPLAY BASED ON ASDE-3 PPI

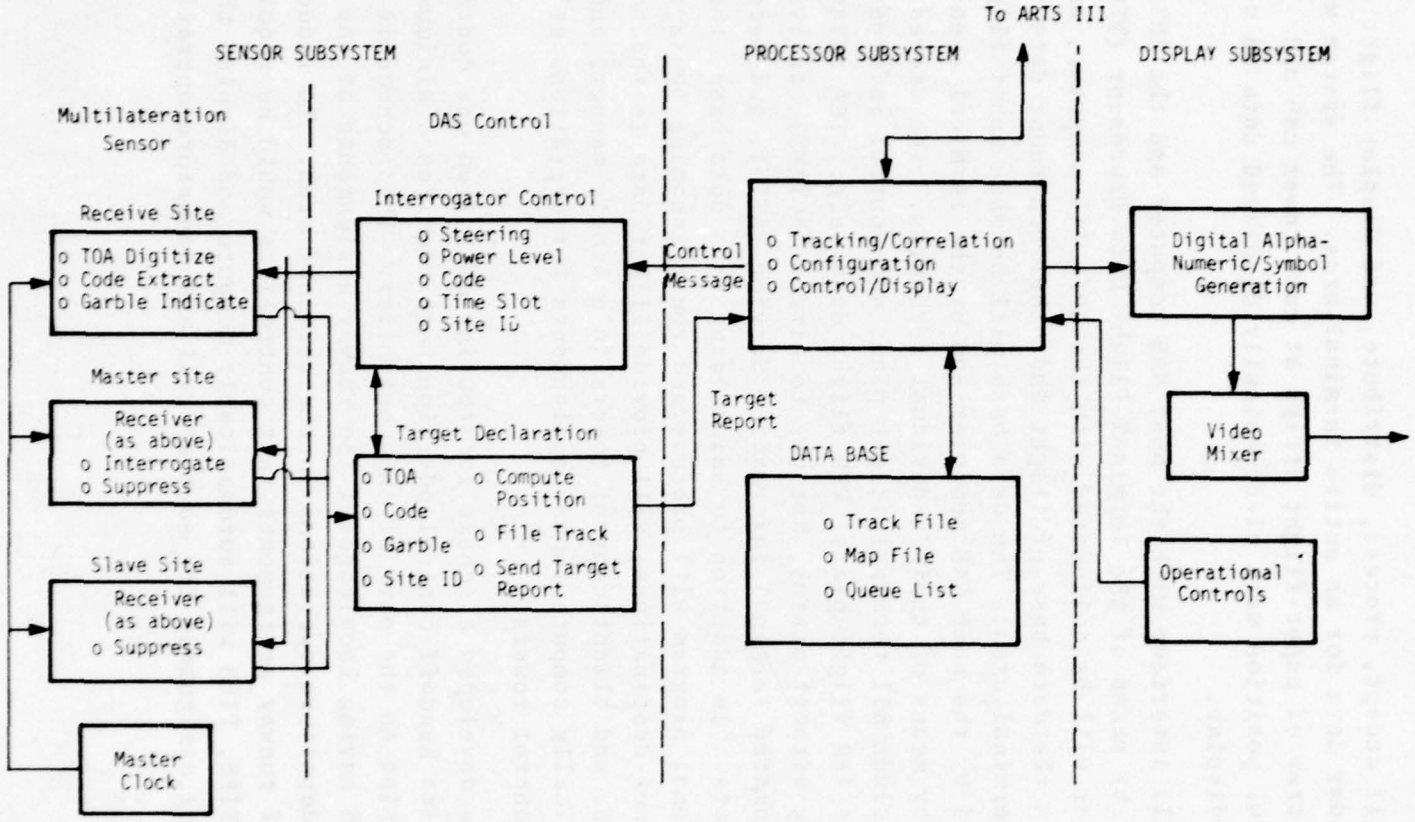


FIGURE 2.2-2. TAGS FUNCTIONAL BLOCK DIAGRAM (TRILATERATION SENSOR PORTION)

2.3 TOWER FLIGHT DATA PROCESSING -- TIPS

TIPS will accept, process, distribute, and display flight and other non-radar data for an entire terminal area. The system will replace the tray of paper-flight strips at each tower cab and TRACON control position with electronically displayed data on a new tabular display.

TIPS will interface with the host NAS computer and the ARTS III computer by means of the Terminal Flight Data Processor (TFDP). This processor will be collocated with the ARTS III computer, and will maintain the data base of flight and other non-radar data for the entire terminal area. The data base will be made up of flight data provided by the host NAS computer and by the terminal area controllers by means of their individual keyboards. The stored data will include all terminal flight plans and control information, such as IFR flight plans, VFR flight data (e.g., TCA-related information), airport status, Notices to Airmen (NOTAMS), active runways, Automated Terminal Information Service (ATIS), and meteorological data. In addition to maintaining this data base, the TFDP operational program will process and route incoming messages to their proper destinations, will provide flight data to the host ARTCC, TRACON, and client control towers in a timely manner, and will automatically compute runway assignments for operations at the client control towers.

TIPS has developed a scheme for routing data from one control position to its handoff control position that requires a minimum of buttonpushing on the part of the controller. This scheme is based on TIPS having knowledge of the runway assignments of the arrival and departure operations in the terminal area. To reduce the number of runway assignments that controllers would be required to input to TIPS, TIPS will automatically compute and display the routine runway assignment for each arrival and departure operation.

Only when the assignment is in error, would a controller be required to make an input to TIPS.

The Terminal Flight Data Processor will interface with a set of display processors. There will be a display processor for the TRACON and one for each client tower cab being serviced by TIPS in the terminal area. Each display processor will maintain the TIPS display presentations at that facility, will process controller inputs, and will perform system-monitoring and control functions. The processor will be programmed to permit operational positions to be combined, split, or shifted from one display and data entry unit to another.

Each tower cab and TRACON controller will have a tabular display for flight data and two data-entry devices. One data-entry device will be an ARTS III-like keyboard, and the second data-entry unit will be a "quick action" device. In addition, TRACON radar controllers will be able to display summary flight data on their Plan-View Displays on a "quick look" basis.

TIPS installations will take place, under current schedules, between 1982 and 1985.

2.4 WEATHER-RELATED SYSTEMS

There are three so-called weather-related systems within the Major System Development Program:

1. Vortex Advisory System (VAS),
2. Wake Vortex Avoidance System (WVAS), and
3. Wind Shear Detection System (WSDS).

2.4.1 Description of VAS

The VAS consists of a Meteorological Subsystem, including towers, wind sensors, and tower communications; a Microprocessor Subsystem, which includes processors for the meteorological data and for the VAS algorithm; and a Display Subsystem, comprising a runway display for the controller, a system-status display, a maintenance display, and a recording capability.

2.4.1.1 Meteorological Subsystem

a. Meteorological Towers

The VAS contains a network of instrumented meteorological towers whose signals are transmitted to a centrally located processor, which uses a simple algorithm to determine if wind conditions will allow vortices to persist, and then displays this information to the controllers. The tower network consists of seven 50-foot meteorological towers positioned to measure the wind close to each operating corridor.

b. Meteorological Sensors

Each tower is instrumented with three wind-velocity sensors, one at the 50-foot level and the other two at the 47-foot level. The 47-foot sensors are mounted on opposite sides of the tower to provide a measurement undisturbed by tower shadowing.

c. Tower Data Communication

Transmission of the data from the set of widely dispersed towers to the centrally located processor is accomplished with standard hardware. On each tower, a multiplexer successively samples the sensor outputs and converts them to a digital word. This word is serialized and transmitted over standard existing FAA control lines to a central facility where receivers reconvert the data to a parallel format for input to a microprocessor.

2.4.1.2 Microprocessor Subsystem

Individual microprocessors are used to process the data received via a signal wire pair from each meteorological tower. The microprocessors contain 8K of Read-Only-Memory and 8K of Random-Access-Memory. Each microprocessor is packaged on a single plug-in board, an Intel Model SBC 80/20.

The microprocessors sample the meteorological data output from each data receiver at a rate of two samples per second. The sampled wind speed (R) and wind direction (θ) are used to compute one-minute running averages ($\overline{R}$ and $\overline{\theta}$).

The VAS processors output labeled data onto a data bus with the following information for each operating region: $\overline{R}$ to 1 knot, $\overline{\theta}$ to 10 degrees, gust (if applicable) to 1 knot, the vortex condition RED or GREEN for each landing runway, and failure messages.

2.4.1.3 Display Subsystem

a. Runway Monitor Display (RMD)

The system interfaces with the air traffic controllers via the VAS Runway Monitor Display. The controller selects the operating corridor, and designates either the arrival (A) or departure (D) runway. The display thereafter accepts data with the corresponding label from the data bus. The controller display provides in digital form the wind direction, magnitude, and gust in the selected region. If arrivals are being handled by the controller, the display indicated if the vortex conditions require a 3-, 4-, 5-, or 6-mile separation between aircraft (RED), or if an all 3-mile separation (GREEN) may be used. If departures are being handled, only the wind conditions are displayed, and the RED/GREEN indications are blanked out.

b. VAS System Monitor Display (SMD)

The VAS System Monitor Display shows the wind measurements from all towers simultaneously, as well as the Red-Green status of all runways. The display could be used by the TRACON and cab supervisors to establish operating runway configurations in conjunction with other airport-operating considerations or constraints.

c. VAS Maintenance Subsystem

The VAS electronics console also houses the VAS maintenance subsystems, a SMD, keyboard, and printer, used to monitor system operation.

d. VAS Data-recording System

The Data-recording System consists of a nine-track digital magnetic tape unit with buffer electronics. All data sent to the VAS Runway Monitor Display, the VAS System Monitor Display, and

the VAS System Maintenance Display are blocked and recorded continuously on this unit.

VAS is scheduled for deployment at 11 airports during FY 79.

2.4.2 Description of WVAS

The WVAS is based on adding to VAS two features; namely,

a. Positive-sensing of ground vortex conditions to augment the prediction based on meteorological tower data, and

b. Expansion of the microprocessor to allow calculation of the spacings as a function of aircraft type.

For an approximate description of WVAS, one may take the preceding VAS description and add the following:

2.4.2.1 Ground Vortex Sensors

The ground vortex sensors would determine, for each aircraft landing, the actual vortex dissipation time, or time of translation out of the approach corridor. Several sensor types are possible: acoustic doppler, pulsed, or CW laser anemometer. At present, a linear array of anemometers deployed at right angles to the runway appears to be the most likely sensor choice.

The detection of vortices by these sensors is based on the fact that the pressure and velocity fields associated with a low-altitude vortex extend to the ground and can be detected by ground-based sensors. The array of anemometers would measure the component of wind perpendicular to the aircraft flight path. Since most of the vortex velocity field is in that direction, the passage of a vortex overhead will cause a large change (increase or decrease) in the ambient cross-wind velocity.

2.4.2.2 Mini-Computer

One processor must be capable of performing at least the following functions for each instrumented runway:

a. Met tower data-sampling,

b. Met tower data-averaging,

c. Tower sensor failure detection,
d. Wind speed and direction calculation,
e. Gust calculation,
f. Ground sensor data-sampling,
g. Ground sensor data-averaging,
h. Ground vortex detection,
i. Ground vortex motion calculation,
j. Ground sensor failure detection,
k. Calculation of ground vortex motion and wind information,
l. Aircraft-type data acceptance and checking,
m. Spacing calculation, and
n. Warning check.

In addition to the runway-specific functions above, the processor must also output system status information, including sensor failure status.

WVAS is tentatively scheduled for deployment in about 1982.

2.4.3 Possible Wind Shear Detection Systems

No Wind Shear Detection System has been selected or designed for future installation. At present, it is possible only to describe in general terms several possible systems undergoing research and development.

2.4.3.1 Low-Level Wind Shear Alert System (LLWSAS)

The intent of the LLWSAS is to utilize additional anemometers on 20-foot towers around certain airports to detect propagating wind-change zones that intersect the ground. LLWSAS is designed to detect horizontal winds associated with cold fronts and thunderstorm gust fronts. It will not detect elevated fronts such as warm fronts aloft; nor will it give information on vertical wind profiles. Finally, although it will not give any information along the flight path, per se, wind shifts observed at the surface can often be inferred to exist several hundred feet aloft.

LLWSAS is a real-time, computer-controlled, data acquisition, analysis, display, and recording system. It takes the wind-velocity

data that are received from the remote anemometers, and compares these data with the centerfield anemometer output. Wind-vector differences are computed between each remote anemometer and the centerfield anemometer (CFA). If the vector difference is large enough (currently 15 knots), it will be interpreted to mean that a significant horizontal wind shear is present which might be hazardous to aircraft operating in the terminal zone. If a significant wind shear condition is detected, LLWSAS alerts the controller by displaying the wind speed measured by the anemometer that caused the alert on a digital display located in the tower cab, accompanied by an audio alarm of about 1-second duration.

When the alarm is received, the tower controller will provide pilots with an advisory which includes the centerfield wind plus the remote site location and wind information that is displayed.

2.4.3.2 Gust-Front Warning System (GFWS)

Three meteorological parameters that accompany each gust have been identified. In the order of their occurrence, they are: a pressure increase (but not necessarily a jump), a wind shift, and a temperature-discontinuity drop. With that sequence of events in mind, the FAA sponsored the development of a comparatively simple detection technique called the Gust-Front Warning System (GFWS), consisting of arrays of pressure-jump sensors (PJS) strategically deployed on and off an airport. Each PJS is calibrated to send a coded signal via a leased telephone line to a central data-recording and test display console located in the base of the control tower. A signal is sent when a pressure rise of 0.5 mb in 120 seconds is equaled or exceeded at any site.

A vertically scanning probe will be coupled with GWFS and used primarily for the detection of frontal- and inversion-related shear. Two devices are currently candidates for further development in this area. One is the dual sensor acoustic Doppler radar, and the other is the complementing pulsed EM Doppler radar which has been installed for testing at Dulles. Together, they form a dual vertical profiler system for all-weather detection of wind-velocity in 30-meter increments from about 30-to the 500-meter level.

2.4.3.3 Advanced Ground-based Detection Devices

Several advanced ground-based sensors for remote atmosphere-probing have shown promise for the MSDP Wind Shear System. All are in an early stage of development, and no complete systems have been formulated about such devices.

The major candidates are:

a) Pulsed Doppler Microwave Radar,
b) CW Laser Radar (Laser Doppler Velocimeter),
c) Pulsed Doppler Laser Radar, and
d) CW/FM Microwave Radar.

2.4.3.4 Airborne Wind-Shear Systems

Several Airborne Wind-Shear Systems are being developed, which do not, however, interact directly with the ATC system. Among the concepts being investigated are ground/air-speed comparison, wind-difference calculation, and modified control laws/algorithms for the flight director or thrust commands.

The various wind-shear detection systems are currently under study; no plans for deployment of other than experimental systems have formulated.

2.5 MICROWAVE LANDING SYSTEM

The Microwave Landing System (MLS) is a precision approach-and-landing guidance system designed to satisfy all present civil-aviation requirements and those that can be foreseen for the next 30 years.

MLS is an "air-derived" system in which the aircraft determines its own position directly and independently of other on-board or ground elements of the ATC system. This system embodies three major categories of measurements used in deriving the three-dimensional guidance information as follows:

a. Angle-guidance measurement in azimuth and elevation using the TRSB technique at C-Band (or Ku-Band for special applications),

b. Flare guidance by the standard radar altimeter, or, alternatively, by the TRSB technique, and

c. Range measurement using a precision L-Band Distance-Measuring Equipment (DME), designed to be comparible with existing systems.

An aircraft determines its position by making the following three measurements: (1) approach-azimuth angle referenced to the runway centerline, (2) an elevation-angle measurement referenced to the horizontal, and (3) a range measurement referenced to the azimuth/DME site. The TRSB MLS is used to make the azimuth and elevation-angle measurements.

The TRSB technique consists of two basic elements: (a) the ground subsystem which scans the coverage volume in azimuth and elevation while transmitting coded signals to the aircraft, and (b) the airborne subsystem which included a receiver/processor with outputs to standard displays in the aircraft.

Deployment plans have been developed covering a phased installation over the period 1980 to 2000.

3. OPERATIONAL ASPECTS OF MSDP SYSTEM INTEGRATION

The introduction of the MSDP elements into the ATC system has the potential for causing difficulties of various sorts. In particular, the installation of the Display, Data entry, and Control (DDC) units in the tower cab and of the sensors and supporting structures on or near the airport surface could cause problems of a physical or operational nature. Two studies were undertaken to investigate aspects of these problems; the first addressed the tower cab physical layout, and the second examined the feasibility of sharing equipment towers among sensors from different systems.

The objective of the cab-layout study was to estimate the minimum integration of equipment required from a cab-operations viewpoint. Integration for cost reduction was not considered. The questions addressed were: If the current cab equipment and station layout were to be maintained, and the major DDC units were added to the cab,

a. What would be the impact on the controller duties and cab operation?

b. Would the resulting operation appear acceptable?

c. What equipment must or should be integrated to achieve satisfactory performance?

In examining these questions, only the major DDC units were considered since they would have the principal impact on the cab.

The approach taken in the study was to select airports from each of the critical equipment-based classes; i.e., classes for which two or all three major equipments (ASTC, TIPS, BRITE) would be installed, and to perform detailed analyses on each airport. From these analyses, the results were generalized to their respective classes as much as possible. The study of the Los Angeles tower cab is summarized in section 3.1 below.

The sensor-integration study investigated the feasibility of collocating the TAGS and VAS sensors on common towers. The analysis for the installation at O'Hare is summarized in section 3.2 below.

3.1 LOS ANGELES (LAX) TOWER CAB STUDY

The LAX airport layout with the cab location is shown in Figure 3.1.1. The cab is square and is aligned with the sides facing the compass directions. There are two sets of dual-lane runways, the 24's on the Northside, and the 25's on the Southside. The airport operates arrivals from the east and departures to the west about 70 percent of the time, and this includes the high-activity periods. Normally, arrivals land on the outside runways. There are six satellite-type terminals, two on the Northside and four on the Southside. One-way flow restrictions for large aircraft moving between and around the satellities require Ground Control advisories. This necessitates ramp surveillance which increases their work load. Noise-abatement procedures and terminal layout place most operations on the Southside runways. Most flights originate or terminate at the four Southside satellities. For these reasons, the Southside is of primary concern to the cab (particularly Ground Control).

Helicopters operate in to and out of the pad shown in the figure, as well as other areas in the general aviation and manufacturing area. Operations cross the approach ends of the 24's at about 500 feet of altitude, and the 25's between the approach end and the crossing taxiways at about 1500 feet.

The controller stations are indicated in Figure 3.1-2. The Ground Control position is staffed only in the event of unusually high operations rates or operational difficulties. The Line of Sight (LOS) required by each controller is shown in Figure 3.1-2 with and without the Northside Ground Control position staffed. The LOS was established by correlating viewing angle from the cab with area of responsibility. Also, shown in the figure, is the BRITE viewing area. The large "footprint" on the floor surrounding the local controllers represents the area within which an observer will be able to read the ARTS alphanumerics with 90-percent accuracy.

As seen in Figure 3.1-2, the controllers have good LOS to their area of responsibility. The only potential interference

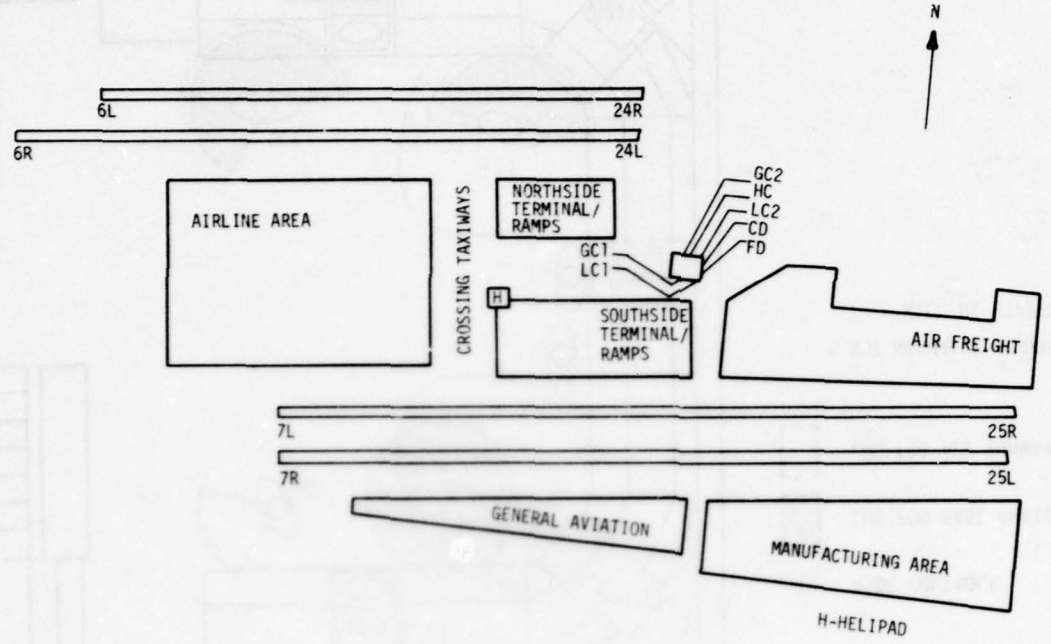


FIGURE 3.1-1. LOS ANGELES AIRPORT LAYOUT AND CAB LOCATION (CAB NOT TO SCALE)

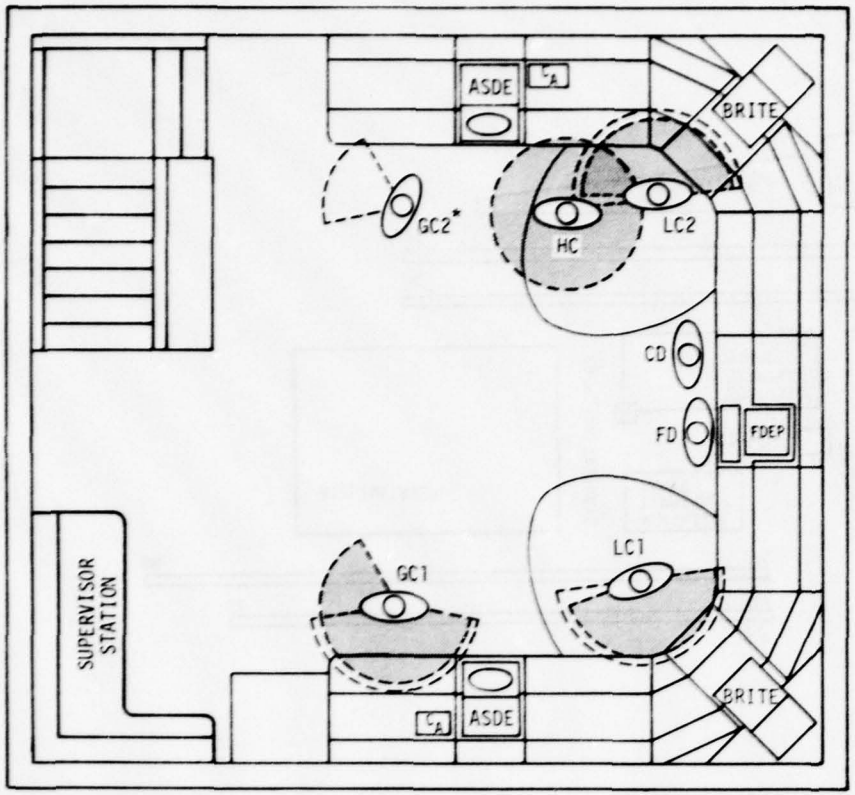


FIGURE 3.1-2. LOS ANGELES CAB LAYOUT AND VISUAL LINE-OF-SIGHT ASSUMPTIONS

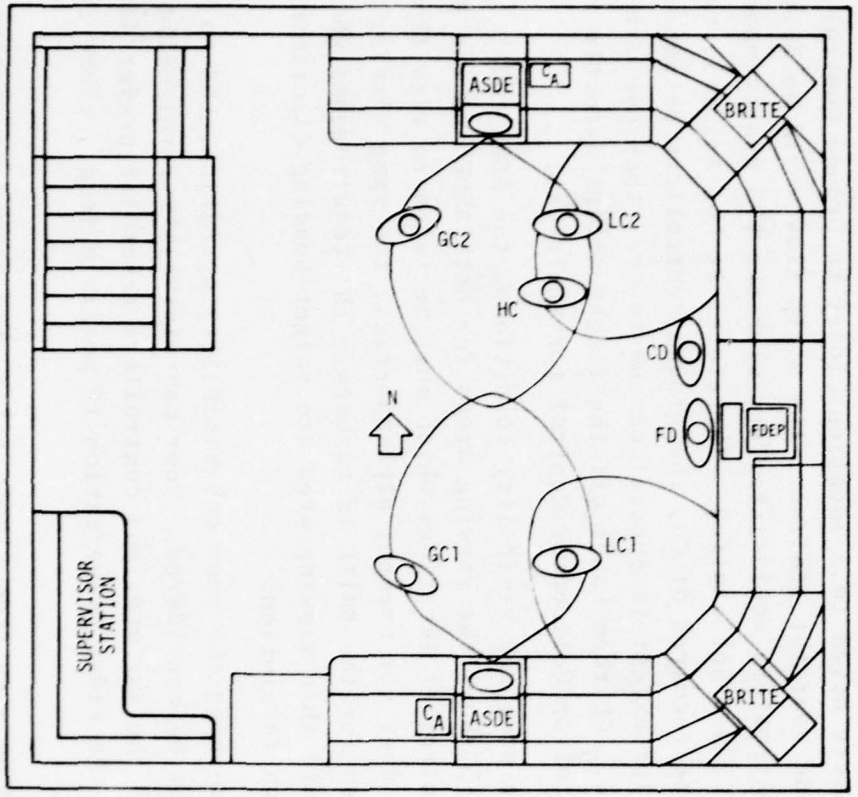
would involve Helicopter involve Helicopter Control (HC), particularly when the Northside Ground Control is staffed. HC will tend to block the view of LC2 when marking flight strips or scratch-pad, and LC2 will tend to block the HC view of the BRITE. Some movement to avoid this blockage is required, but its impact would be slight.

While LOS requirements look good, the flight-strip flow appears laborious. Due to the layout of the cab, there would be a great deal of movement required for Clearance Delivery (CD) to pass flight strips to Ground Control (GC1 and GC2). If CD and Flight Data (FD) were moved to a location closer to Ground Control, say at an island near the stairway, the strip flow would be better, but the controllers would interfere with the LOS requirements of GC1 when GC2 was not staffed. Therefore, at Los Angeles, to limit the movement required of CD, the ground controllers do not use flight strips except in special circumstances, they use only a scratch pad. CD then hands off the flight strips directly to Local Control or Helicopter Control for their use.

During poor cab-visibility conditions, the ASDE radar is used. Figure 3.1-3 shows the viewing areas for both ASDE and the BRITE and the controller locations which must be taken to view them. While ASDE does not present alphanumerics, the same viewing area that is used for the BRITE is assumed. The requirements which would dictate this viewing area are target-heading discrimination and position resolution.

In examining the poor cab-visibility operation, LOS to the surface must be considered. Poor cab-visibility rarely eliminates all view of the surface, and controllers generally prefer direct viewing to the radar presentation if possible (e.g., close in to the ramps).

As can be seen from Figure 3.1-3, the ground controllers (GC1 and GC2) must stand away from their station somewhat to see the ASDE at a good viewing angle. Some movement back and forth between their station and the radar would be expected to permit scratchpad marking and a good view of the ramps (if visible), but the impact



C_A ASDE CONTROLS

FIGURE 3.1-3. LOS ANGELES CAB LAYOUT AND CURRENT CONTROLLER LOCATIONS IN POOR-VISIBILITY IFR

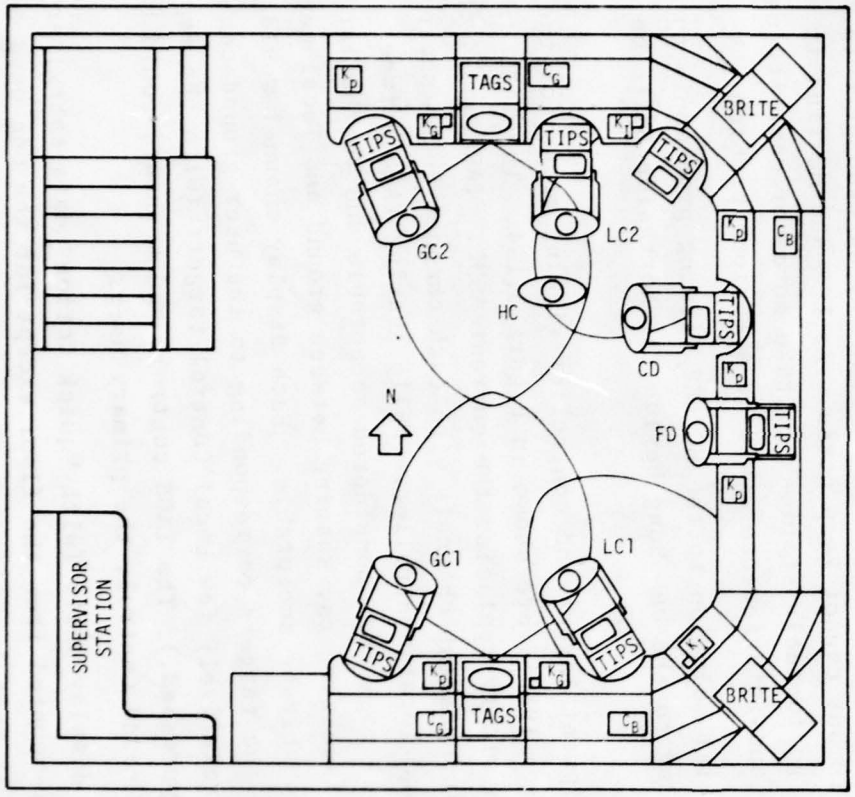
would be minor. Southside Local Control (LC1) must move back away from his station to see the ASDE. Since the viewing areas for the BRITE and ASDE intersect, the controller can view the ASDE without losing the use of the BRITE. However, when using his flight progress strips, he will have to leave the ASDE to return to his station as does Ground Control.

The most serious viewing problems appear to occur in the Northside between HC and LC2. The local controller has priority on the use of the surveillance equipment, and must move in to the HC station to see the ASDE. HC must either move close in to his station, precluding his use of ASDE, or out away from his station behind LC2. When out away from his station, he can see both the ASDE and BRITE but cannot keep notes. As LC2 and HC find it necessary to go to their stations to take notes or mark strips, viewing loss and interference could be a serious problem.

A potential solution to the HC/LC2 viewing problem is to add an ASDE display to the cab hung beside the Northside BRITE on a double yoke.

The equipment layout and controller-viewing areas for the LAX cab in the late 1980's are shown in Figure 3.1-4. The TAGS display is shown simply replacing the current ASDE. TAGS would then provide two independent channels with each channel being shared by a ground and local controller. While sharing TAGS between ground controllers is not considered acceptable due to the large number of surface targets, sharing between ground and local control would probably be acceptable. Each display channel would identify only the targets corresponding to the user ground controller plus relatively few Local Control targets (with the departure queue suppressed.) The TAGS controls and keyboard would be located near Ground Control, the primary user.

The TIPS display units (with "quick action" data entry) are shown pedestal-mounted from the floor except for the one used by Flight Data. At that location, the unit was console-mounted in the space left by the FDEP removal. The TIPS keyboard is assumed to be integrated with the BRITE keyboard for Local Control to reduce multiple keyboards.



C_B BRITE CONTROLS

C_G TAGS CONTROL

K_I INTEGRATED BRITE/TIPS KEYBOARD

K_p TIPS KEYBOARD

K_G TAGS KEYBOARD

FIGURE 3.1-4. LOS ANGELES IFR OPERATIONAL LAYOUT IN THE LATE 1980'S

The BRITE displays are located as they currently are. BRITE controls are added to the console in currently empty locations. BRITE keyboards are assumed integrated with TIPS keyboards, and are left on the counters near the displays.

The addition of the MSDP equipment has both positive and negative effects on the cab operation. These effects are listed as follows:

3.1.1 Positive Aspects

a) Flight identity is provided to Ground Control via TAGS to assist control under poor cab-visibility conditions.

b) Inter-controller handoff of flight data is facilitated by TIPS, permitting Ground Control full access to flight data.

c) The LC2/HC interference problem discussed previously with regard to ASDE and the BRITE is somewhat reduced with the introduction of TIPS.

3.1.2 Negative Aspects

a) When mounted on a floor pedestal, TIPS may interfere with access to console-mounted controls even if the floor mount is low. However, the controller can move around TIPS, and can rotate and tilt the unit up to facilitate reaching the console.

b) TIPS displays and the TAGS, TIPS, and BRITE keyboards take up considerable counter space. Writing space for note and recordkeeping is very limited for both ground controllers and for Helicopter Control.

c) The shared TAGS display while acceptable with respect to alphanumeric clutter, will compromise the "quick look" and "two-presentation" select options. When shared, these options will have to be set up so as not adversely to effect the local controller.

The equipment installation in a more or less add-on fashion appears acceptable under the following conditions:

1) The Northside Local Control and Helicopter Control positions should receive at least a TAGS repeater to relieve the

interference problem cited. This would even seem advisable now, with the ASDE system.

2) The TIPS, TAGS, and BRITE keyboards should be integrated to minimize their impact on the limited space available. Even under these conditions, equipment leaves very little counter space available for notetaking, etc., and alternative means for providing this may be required.

3.2 TAGS/VAS SENSOR INTEGRATION

The deployment of ASTC Surveillance and Vortex Advisory Systems (VAS) at the major airports adds two more systems to the airport surface already congested with terminal surveillance, communications, meteorological, lighting, ILS, and other systems. Because the siting criteria for both the multilateration TAGS sensors and the VAS ground-wind-sensing towers favor locations at the airport periphery (VAS near runway thresholds and TAGS to the outside of runways), at first glance, a collocation seems worth exploring. Possible benefits from such a collocation are a reduced number of new towers obstructing navigable airspace and installation cost savings. Installation cost savings are in the form of common cable runs, common access roads, and common site construction (grading, surveying, concrete foundations, etc.).

A preliminary plan for TAGS sensor-siting at O'Hare done previously resulted in a total of 8 sites, consisting of 5 interrogators and 3 receive-only sites. The locations chosen are shown in Figure 3.2-1. Some of the constraints applicable to TAGS sensor-siting are:

a. The maximum interrogation baseline is 9170 feet.

b. Interrogators can be no closer than 600 feet from the Airport Movement Area.

c. Line-of-sight visibility must be maintained between at least three receivers and the aircraft, and two interrogators and the aircraft.

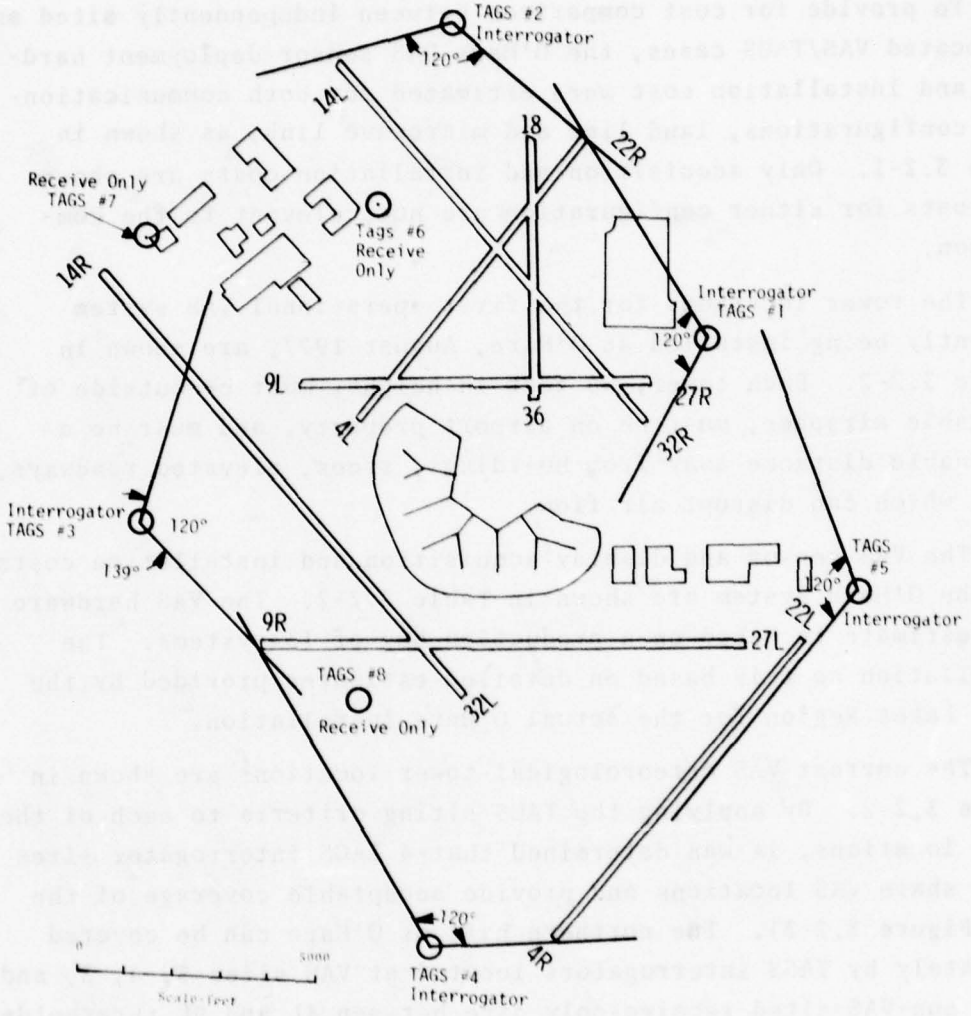


FIGURE 3.2-1. O'HARE TAGS DAS SITING (PRELIMINARY)

d. Obstacle clearance requirements for the navigable airspace around the airport must be met.

e. The TAGS DAS sites must be on airport property.

f. Interrogation stations must be within 15,000 feet of aircraft being interrogated.

To provide for cost comparison between independently sited and collocated VAS/TAGS cases, the O'Hare DAS sensor-deployment hardware and installation cost were estimated for both communication-link configurations, land line and microwave link, as shown in Table 3.2-1. Only acquisition and installation costs are shown. O&M costs for either configuration are not relevant to the comparison.

The tower locations for the first operational VAS system currently being installed at O'Hare, August 1977, are shown in Figure 3.2-2. Each tower, 50 feet in height, must be outside of navigable airspace, must be on airport property, and must be a reasonable distance away from buildings, trees, elevated roadways, etc., which can disrupt air flow.

The VAS sensor and display acquisition and installation costs for the O'Hare system are shown in Table 3.2-2. The VAS hardware cost estimate is based on a production buy of 13 systems. The installation cost is based on detailed estimates provided by the Great Lakes Region for the actual O'Hare installation.

The current VAS meteorological-tower locations are shown in Figure 3.2-2. By applying the TAGS siting criteria to each of the 7 VAS locations, it was determined that 4 TAGS interrogator sites could share VAS locations and provide acceptable coverage of the AMA (Figure 3.2-3). The northern half of O'Hare can be covered adequately by TAGS interrogators located at VAS sites 5, 4, 3, and 2. A non-VAS-sited receive-only site between 4L and 9L thresholds is required to eliminate blockages (TAGS$_Y$), ensuring that aircraft on the AMA always has 3 receivers in view. VAS 6 is not usable at its current location because the interrogation antenna 120 degree coverage limitation does not allow simultaneous coverage

TABLE 3.2-1. TAGS TRILATERATION SENSOR HARDWARE COST ESTIMATE (O'HARE)

	Microwave Link	Land Line*
1. 8 Site Hardware Acquisition Costs (based on buy of 9 TAGS Systems in 1980) 5 Interrogator Stations 3 Receive Stations 1 Central Control Station 1 Processor/Display	$1422 (includes $30K site for Microwave hardware)	$1206 (includes $24K cable costs)
2. 8 Site Installation Costs Foundations Tower/Shelter Erection Electrical Terminations Communication Installation Power Access Roads Civil Engineering/Supervision 30% Contingency	$400K	$473K
3. Total Costs (Acquisition & Installation)	$1822	$1679

*Assumes adequate buried twisted pair cable capacity exists at junction points within 2000 feet from each DAS site.

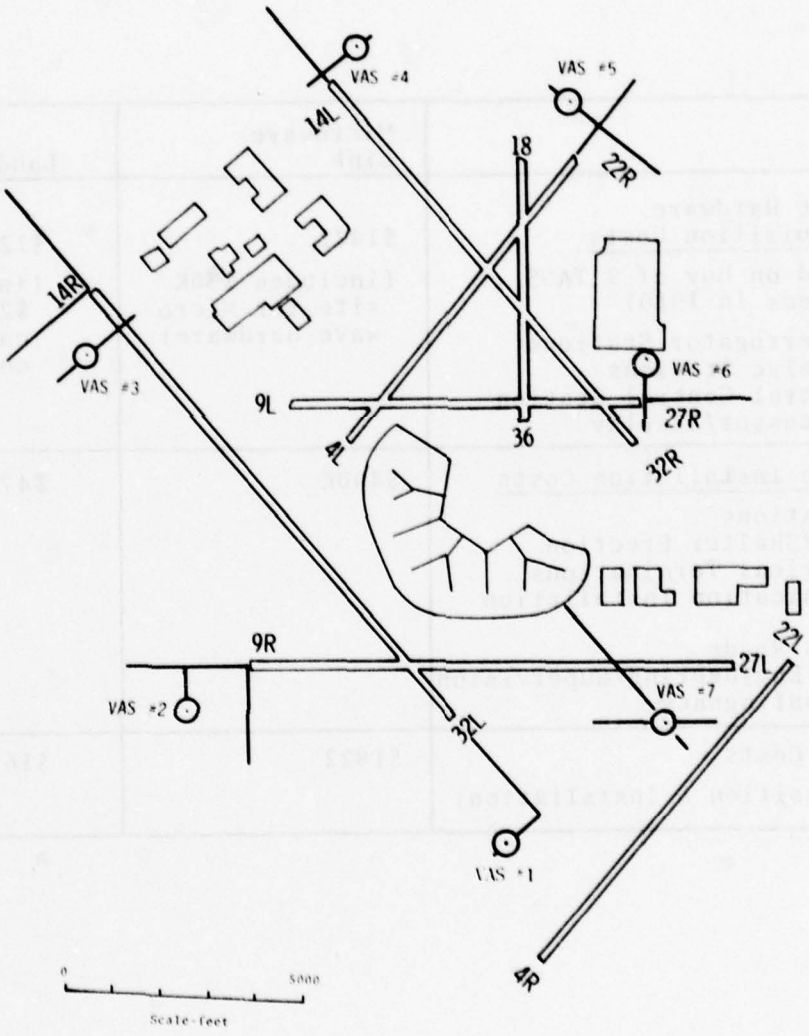


FIGURE 3.2-2. O'HARE VAS SITE LOCATIONS

TABLE 3.2-2. VAS O'HARE SENSOR INSTALLATION COSTS

1. Acquisition Costs	
Towers	
Sensors/Electronics	
Processor	
Display	$300K
2. Installation Cost	
Tower Foundations	
Tower Erection	
Electrical Terminations	
Underground Cabling	
Power	
Access Roads	
Civil Engr/Supervision	
30% Contingency	$186K
3. Total Cost (Acquisition & Installation)	$486K

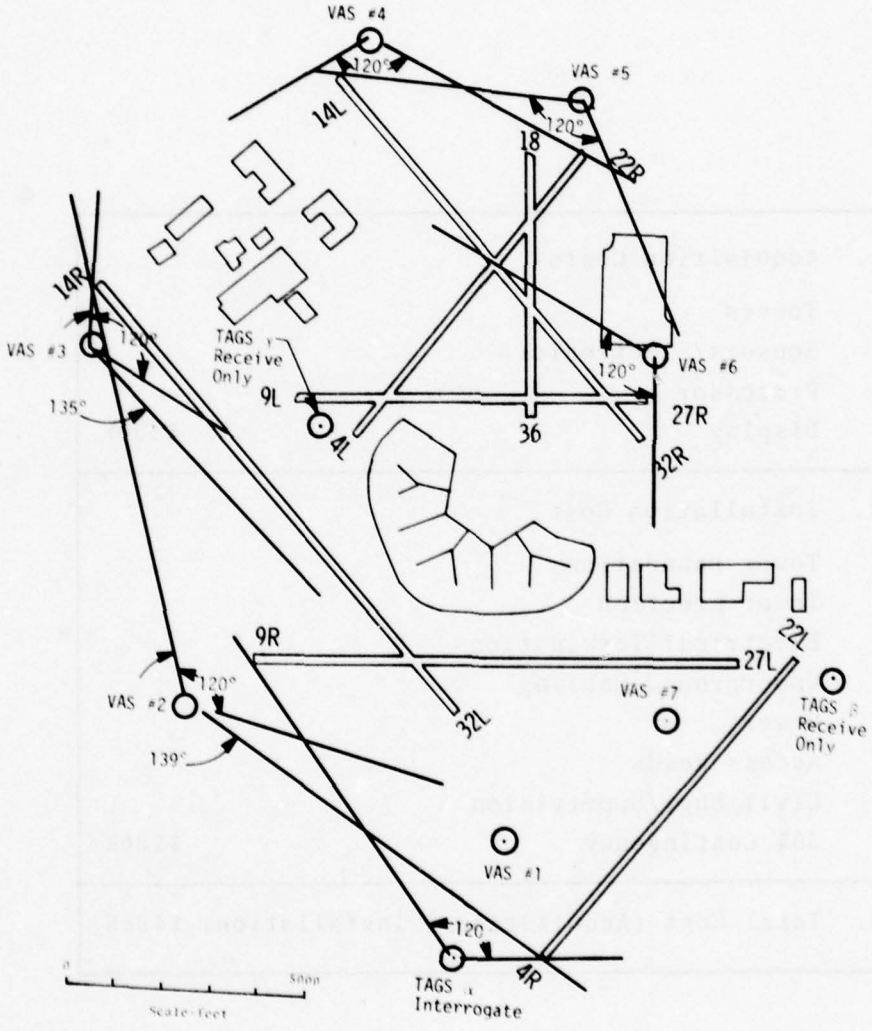


FIGURE 3.2-3. O'HARE VAS DAS SITE COLLOCATIONS

at the threshold end of 27R/32R and 22R. For VAS 2, 120-degree coverage angle must be placed to cover 14R threshold, sacrificing full view of 4R. The lack of full 4R coverage by VAS 2 is only one of several problems with TAGS/VAS collocation for the southern half of O'Hare.

Costs identified as being eliminated by the exact collocation of the VAS and the DAS towers are shown in Table 3.2-3. The $23K estimate per VAS site does not include, for example, VAS tower erection, electronics housing, and electrical hookup costs unique to VAS. New access-road construction at O'Hare is limited due to the nearness of existing airport roads; an average road length of 100 feet per site was estimated. The total cost savings for the 4-site collocation is estimated at $104K. As Table 3.2-4 shows, the 4-site collocation represents about 5 percent of total system acquisition and installation costs. If all VAS sites were located with DAS sensors, about 9 percent of total acquisition costs could be saved. This latter possibility would depend, in the case of the O'Hare installation, on the VAS sensors being moved to a TAGS location, not vice versa, as discussed previously.

Table 3.2-5 shows the savings expressed as a percentage of installation costs only, excluding system-hardware acquisitions except that data-link and cabling costs are included. The second and third table entires show savings as a percentage of the costs the regional Airway Facilities would incur, ranging from 14 to 22 percent for land line and microwave, respectively.

3.3 SUMMARY OF RESULTS AND RECOMMENDATIONS

3.3.1 Results

A summary of the major conclusions drawn from the cab-layout and sensor-integration studies follows. However, these conclusions are preliminary since they do not incorporate feedback from operational personnel.

a) The installation of the three large MSDP cab systems as additions to the current cab stations/equipment appears feasible. The TAGS displays will be located primarily where ASDE-2 displays

TABLE 3.2-3. VAS COST ITEMS ELIMINATED FOR COLLOCATION OF SENSORS

Item	Per Site Cost
Site Ground Preparation	$ 1K
Tower Pads (Concrete)	3K
New Cable Duct Runs @ 2000' ($5.50/ft. installed, cable included)	11K
Access Roads ($20/Ft) 100'/Site	2K
Civil Engineering 25 work-days @ $90/day	5K
Contract Supervision 12 work-days @ $190/day	2K
Accessholes/Junctions	2K
	$26K

TABLE 3.2-4. COST SAVINGS AS A PERCENTAGE OF TOTAL SYSTEM INSTALLATION COSTS - O'HARE (DOLLARS)

Collocation Config.	DAS* Costs	VAS* Costs	Collocated Total Costs	Cost Svgs.	Savings as % of Total
4 sites	$1679K	$486K	$2061K	$104K	5%
7 sites	$1679K	$486K	$1983K	$182K	9%

*Acquisition costs included are for 8 site TAGS configuration (see Tables 3.2-1 and 3.2-2).

TABLE 3.2-5. COST SAVINGS AS A PERCENTAGE OF INSTALLATION COSTS EXCLUSIVE OF ACQUISITION COSTS - O'HARE (DOLLARS X 10^3)

Configuration	DAS Alone	VAS Alone	Total Collocated*	Svgs.	% of Total
Microwave**	640	186	722	104	14%
Landline***	497	186	579	104	18%
Microwave (Installation costs only)	400	186	482	104	22%

*Assumes 4 sites collocated

**Includes $240K Microwave hardware costs

***Includes 24K cable costs

are now. Added ASDE-3 displays will primarily be hung from the ceiling on yokes to permit rotating and tipping to the best orientation. TIPS display and "quick action" data-entry units will primarily be pedestal-mounted from the floor in yokes to permit rotating and tipping to the best orientation.

b) The chief reservation regarding the simple addition of the MSDP cab systems concerns counter space, particularly at the Class A airport cabs. In installing the systems without reworking/integrating the individual stations, counter space has been drastically reduced. TIPS will probably not completely eliminate the need for note-taking.

c) The counter-space limitations occur despite the integration of the TIPS and BRITE keyboards. In the study, it was assumed that the TIPS and the BRITE keyboards would be integrated into one keyboard for Local Control. In this way, each controller would have only one keyboard at the Class B cabs and two keyboards at the Class A cabs.

d) The add-on-type installation does not depend on the sequence of the installation. As currently configured, ASTC equipments can precede or follow TIPS installation. Only new integrated system features might change this.

e) O'Hare, due to its configuration, readily accomodates VAS/TAGS sensor collocation with little compromise for 4 out of the 7 VAS locations. Three of the VAS locations are such that TAGS siting is not feasible even allowing minor VAS relocation. LAX presents a more difficult challenge, but, given the use of a control-tower-located interrogator, 3 of the 4 VAS site locations can be shared. The cost savings alone, possibly only 5 percent of total system costs, are probably not enough to justify program delays to effect collocation. However, the benefits for reducing obstructions to navigable airspace and efficiencies in site-contracting work through the Airway Facilities Regional Office may make the collocation worth considering at the time when TAGS and VAS production schedules become realities.

3.3.2 Recommendations

a) The two integration issues identified should be considered in some detail. They are the integration of keyboards and the movement of "quick look" controls (TAGS or BRITE Alphanumeric) and ASDE-3 "two-presentation" select "controls to the keyboard or TIPS "quick action" entry.

b) The studies done to date should be presented to both Air Traffic and Airway Facilities personnel at the airport cabs (or associated regions) for their review and input.

c) The studies should be extended to additional airports.

4. HUMAN FACTORS ASPECTS OF MSDP SYSTEMS INTEGRATION

4.1 BACKGROUND

Certain aspects of the design and integration of the MSDP systems assume particular importance when considered from the viewpoint of the people who must operate the ATC system. As a general background, some unique features of the control-tower operation should be noted.

a. High reliance on visual contact with aircraft.
b. Controller mobility.
c. Frequent standing operations.
d. Wide range of ambient lighting conditions.

Design of any equipment (for Local Control and Ground Control especially) must be compatible with a controller who frequently stands up, who must look out the window, and who may move about the cab to obtain favorable viewing conditions. Visual displays must be adjustable in brightness and contrast to compensate for both bright and dim ambient lighting and for frequent brightness adaptations between external and internal viewing.

Another general feature to be noted is that controllers may have one hand continually occupied with a press-to-talk switch (assuming continuation of current communications procedures); new equipment should, therefore, avoid requirements for two-handed operation.

The impact on controllers of the introduction of MSDP elements into tower cabs is summarized in Table 4.1-1. For each system element, the advantages and disadvantages are noted together with an indication if the new element requires additional equipment, or if it replaces equipment currently in use. Where particular duty positions are affected, the initials of the position are given in parentheses.

From the ADVANTAGES column of the table, it is evident that MSDP elements in general will not provide workload relief. Most elements are designed to permit the controllers to continue to do

TABLE 4.1-1. SUMMARY OF HUMAN FACTORS IMPACT ON TOWER CONTROLLERS OF MSDP SYSTEMS

MSDP ELEMENT	ADVANTAGE	DISADVANTAGE	ADDED EQUIPMENT	REPLACED EQUIPMENT
DABS	More reliable data (LC,GC)			
MLS	More reliable data (LC) Ability to handle more traffic	Increased Workload (LC). More IFR traffic More complex approach paths. More status panels to monitor. More data for ATIS (FD)	Status and control panels	ILS (some towers)
FSS Automation		Increased workload (FD). Weather observation (some towers)	Weather-observing equip. (some towers)	Weather-observing equip. (some towers)
VAS/WVAS	More information. Spacing decision provided (LC) Safer operations	Increased workload (LC). More displays to Monitor More information to relay. Closer arrival/ departure spacing More data for ATIS/ (FD). Crowding of workspace	Displays and controls	
Wind Shear	More information. Safer operations	Increased workload (LC). More displays to monitor More information to relay. More complex decisions More data for ATIS (FD). Crowding of workspace	Displays and controls	

TABLE 4.1-1 (Concl'd)

MSDP ELEMENT	ADVANTAGE	DISADVANTAGE	ADDED EQUIPMENT	REPLACED EQUIPMENT
ASTC/TAGS	More reliable data (GC, LC). More complete data (GC, LC) Integrated data (GC). Safer operations	Crowding of workspace (LC). More keying required (GC, LC)	Displays and keyboards	ASDE displays (GC)
TIPS	More information available. Faster information dissemination	More keying required. Inadequate provision for entry of flight-strip data (GC, LC) Crowding of workspace Inadequate failure mode	Displays and keyboards	Flight strips and bays FDEP Electrowriter/ Telautograph
ARTS III Enhancements	More information available. More reliable information Easier conflict monitoring (LC). Safer operations	Increased workload (LC). Increased arrival rates	BRITE display for remote locations (some towers)	

what they are presently doing with a greater degree of effectiveness--more accurate data, more available data for decisions, making and, more accessible data. This increase in effectiveness generally involves an increased workload -- more data to process, more aircraft to service, and more information to relay. The principal features that may unburden controllers somewhat include the determination of safe intervals by VAS and WVAS, the automatic identification of aircraft on the ground by TAGS, automatic runway assignment by TIPS, and automatic conflict warning by ARTS.

The DISADVANTAGES column shows again the increase in data to be processed and relayed and in aircraft to be serviced. It also shows an increase in display devices and status panels to be monitored. Some of the additional data will very likely be incorporated into ATIS messages, increasing the work and time involved in ATIS preparation and recording. The increase in amount and accessibility of information carries with it the need to perform additional keying and switching operations to retrieve desired data.

The complexity of information-processing by controllers is increased by some elements. VAS and wind-shear elements will increase the complexity of visualizing and evaluating wind-field patterns. The curved approach paths made possible by MLS will increase the difficulty of estimating threshold times from both visual observation and radar returns.

The automation of FSS's will add the job of weather observation to the duties of some towers.

The ADDED EQUIPMENT and REPLACED EQUIPMENT columns together show that introduction of MSDP elements will result in a net increase in tower equipment, with consequent crowding of already crowded workspace. Display devices for VAS and wind shear (not yet specified) will require yet more prime space.

TIPS, while acquiring, distributing, and displaying information much more effectively than is presently done, does not provide the data-recording and notepad capabilities of the flight strips that it will replace. Furthermore, if flight strips, flight strip bays, and flight strip printers are removed from the

tower, the manual backup procedure in the event of system failure will be wholly inadequate.

In summary, introduction of MSDP elements has the potential for creating three major problems for control tower personnel:

a. workload increase,
b. workspace crowding, and
c. loss of flight-strip capabilities.

4.2 DISCUSSION

4.2.1 Workload

Taken one element at a time, the controller-workload increments resulting from the introduction of MSDP elements into the tower cab do not appear important. It is easy to assume that the controllers can adapt to these new demands, and it seems desirable to gain the associated benefits. However, the aggregate increment in workload, when several of the elements are added, is more difficult to assess, and should not be overlooked. The increase in accident potential, when system operators adapt to an increased workload, is an evident problem; adaptation is accomplished by adopting shortcuts in procedure. Although this procedural streamlining is generally effective, on rare occasions when a chance combination of events occurs, it can be fatal.

There is ample evidence that controllers, in some towers at some time, are overloaded under present working conditions. Therefore, it is desirable, when introducing changes, to seek ways of exploiting these changes so as to reduce workload, or at the very least to avoid increasing it.

There are two general features of combined MSDP elements that have great potential for such exploitation: computing capability and the display capability inherent in CRT's. Thus, the computers associated with ARTS, TAGS, TIPS, and perhaps, the wind-evaluating systems might be used to relieve controllers of data-processing requirements. Also, the CRT displays of ARTS, TAGS, and TIPS might accommodate the increased display requirements generated by VAS,

WVAS, wind shear, and MLS. This process of system integration has great potential for alleviating the MSDP-workload problems.

For example, "time-to-threshold" could be computed for each approaching aircraft, and displayed on the local controller's situation display on demand, thus assisting the controller in information-processing and decisionmaking, and increasing the accuracy of decisions. In the display area, it has been proposed to represent wind-shear information symbolically at the geographical location where it applies on a situation display. Similarly, wherever it seems to be desirable, the system is asked to integrate information from various sources, and to present to the controller only what is needed, when it is needed, where it is needed, and in a format that requires a minimum of further processing by the controller.

4.2.2 Workspace

The crowding of controller's workspace by added MSDP equipment can also be alleviated by system integration. Collecting the outputs from several elements for display on a common surface, and consolidating various keyboard requirements into a single keyboard, can provide considerable relief of space requirements.

Minimizing display requirements should include the integration of current with future ones. Considerable space on present consoles is occupied by a few weather-related devices (altimeter setting, wind speed, wind direction, and RVV and RVR indicators). VAS, WVAS, and wind shear presently propose additional displays. Any approximation that can be made to the consolidated display of weather data on the situation display will release a considerable amount of prime space for the local controller. Similarly, using single buttons to call up sets of information can reduce control panel and keyboard requirements as well as simplify information retrieval by the controller.

Possible arrangements of idealized consoles for Local Control and for Clearance Delivery or Flight Data are given in Figures 4.2-1 and 4.2-2.

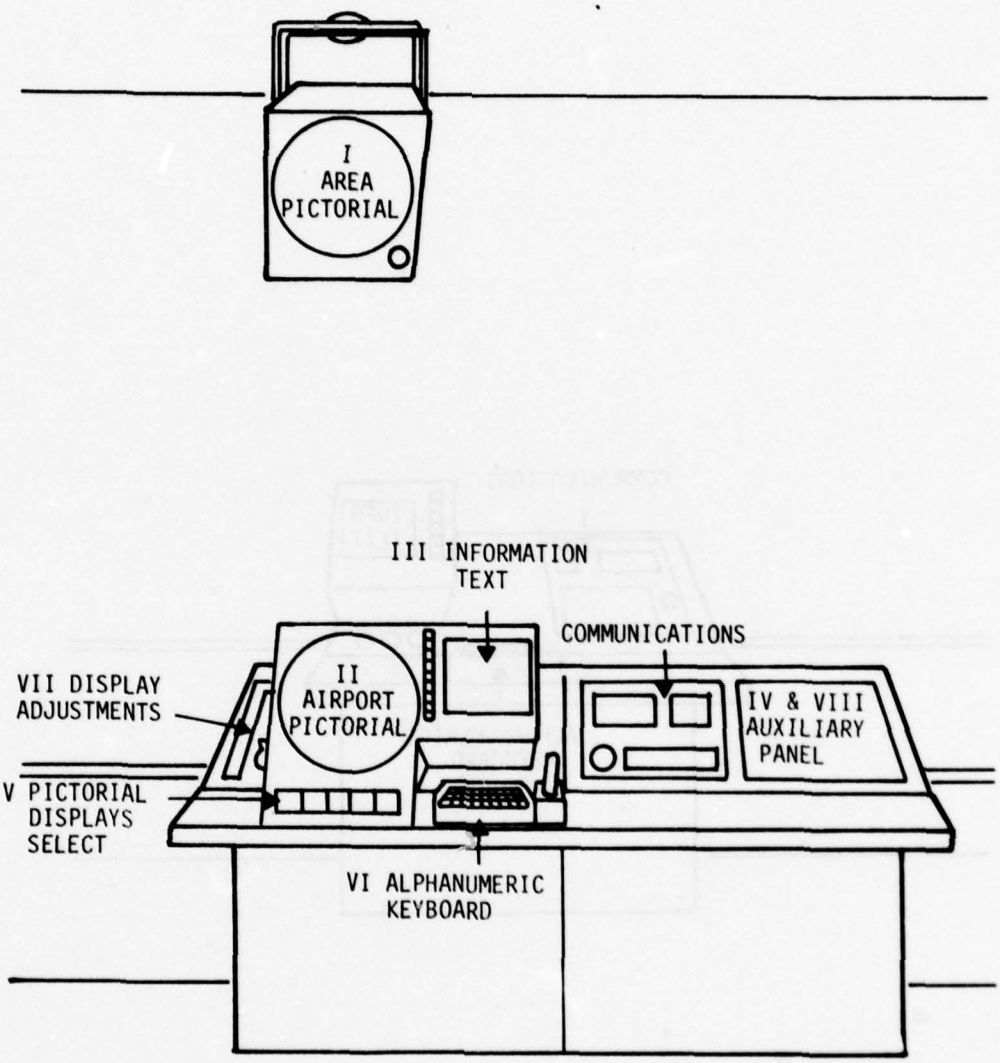


FIGURE 4.2-1. POSSIBLE ARRANGEMENT OF IDEALIZED LOCAL-CONTROL POSITION

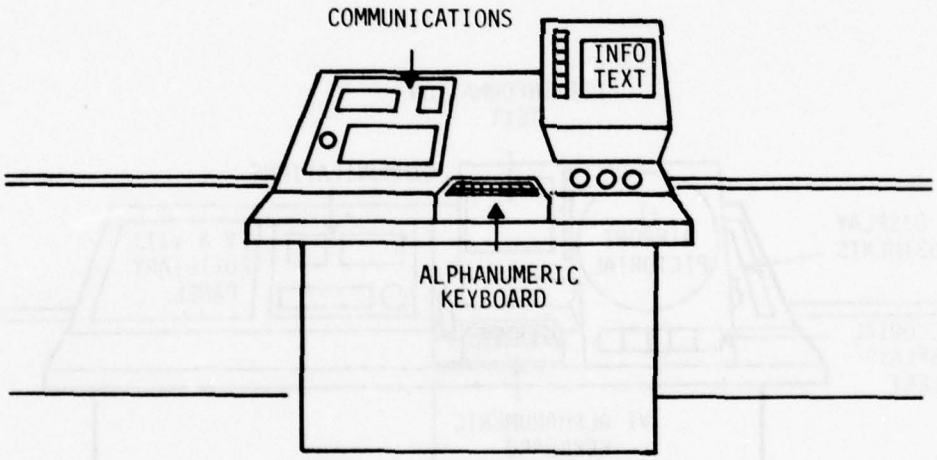


FIGURE 4.2-2. POSSIBLE ARRANGEMENT OF IDEALIZED CLEARANCE-DELIVERY OR FLIGHT-DATA POSITION

4.2.3 Flight-Strip Capabilities

The functions served by flight strips as surfaces for data-recording may be lost when the strips are replaced by TIPS. Some of these can be retained by programming TIPS to record certain action times (e.g., takeoff, and clearance delivered). Other functions could be retained by utilizing the keyboard for notetaking. Still other capabilities might be achieved by providing for special printouts at the input-output terminal.

Provision of a manual backup in the event of a TIPS failure appears to be a serious problem. Resorting to scratch pads and handwritten flight strips (without bays for organizing them) would result in an operation more primitive than the most poorly equipped current operations. Strip holders and portable bays could be kept in storage for use during a TIPS failure; however, it is doubtful that controllers trained and experienced in the use of TIPS could revert effectively to such a manual system. Certainly, the problem of TIPS failure modes should have some priority for further consideration.

4.2.4 Automatic Message Generation and Transmission

Because DABS is not expected to be deployed widely before 1985, its use as an uplink for transmission of digital messages has not been assumed in the present analysis. Implementation of DABS will permit the generation of command and information messages and their transmission to aircraft without controller intervention. This development will have profound effects on the roles of tower personnel in air traffic control, reducing workload requirements for almost every element of the future system. Completely new display concepts will be required, and the controller will be given a more passive role (monitoring and approving). New problems will involve keeping controllers alert and active enough to assure that they are prepared to intervene when the situation requires it. As DABS capabilities and utilization become more clearly specified, provision must be made for redefinition of controller roles and display requirements through detailed simulation studies.

5. FUNCTIONAL AND DATA-PROCESSING ASPECTS OF MSDP SYSTEMS INTEGRATION

The tower cab is one of the focal points of an extensive data gathering, processing, and display complex. This complex makes available to the controllers in the tower information they need to ensure the proper operation of air traffic in to, within, and out of the airport. The input data can be classified as:

surveillance data -- measurements of aircraft position, including altitude;

identification information -- codes transmitted by the aircraft which disclose identity or characteristic;

flight data -- identity, timing, and characteristic data which describe aircraft expected or known to be in the system;

meteorological data -- measurements and predictions of prevailing atmospheric conditions of various kinds in the surrounding airspace; and

system data -- certain fixed, semi-fixed, and regularly changing data describing the state of the ATC system and its environs.

The controller has the task of assimilating the subset of these data that are needed to carry out the particular duties; the subset required will vary, depending on the position. Occasionally, information will be received from an outside source which will have to be stored for later use.

Many of the MSDP systems will contribute to this flow of data in to and out of the cab. Insofar as is possible, the systems should be coordinated functionally to avoid confusion on the part of controllers faced with multiple sources of information, some of them possibly contradictory. Also, form a data-processing point of view, interfaces between systems and the interchange of data between systems should be designed in a comprehensive and consistent way rather than as ad hoc, uncoordinated solutions which could lead to inefficiencies and error.

In general, each of the MSDP systems has the three usual subsystems: sensor, processor, and output (display). This subsystem breakdown can be used to help identify common functions and/or common inputs and outputs among the systems.

The sensor subsystem has the job of providing the input surveillance, identification, and/or meteorological data to be used by the rest of the system.

The usual task set for the data-processing portion of the system is to display to the controller that portion of the airspace of interest with an indication of the traffic in that area, to keep a list of the aircraft in, or expected to be in, the area of interest, and to maintain and display the identities of the aircraft in the list. To maintain this correlation, the data-processing system must convert radar target-position measurements to its own coordinate system, must maintain the continuity of the tracking of the targets with less than perfect data, must keep the correspondence between target and aircraft identification (ACID), and must format and display the results to the proper controllers.

There are other subtasks which the data-processing system must accomplish in the course of doing its main task. They include accepting inputs from other data processors and from controllers via keyboards, modifying the data base and the display outputs to correspond.

In addition to the basic function, the DP system has been called upon to carry out other functions, such as conflict detection, metering and spacing, and minimum safe-altitude warning.

5.1 FUNCTIONAL DESCRIPTION OF TOWER CAB

A Class A tower cab is defined in this study as one which will be equipped with all of the major and minor MSDP systems. A block diagram of such a tower cab and its environs is given in Figure 5.1-1. The diagram is divided into six areas which represent the remote sensors, remote processors, the tower cab, remote tower cab,

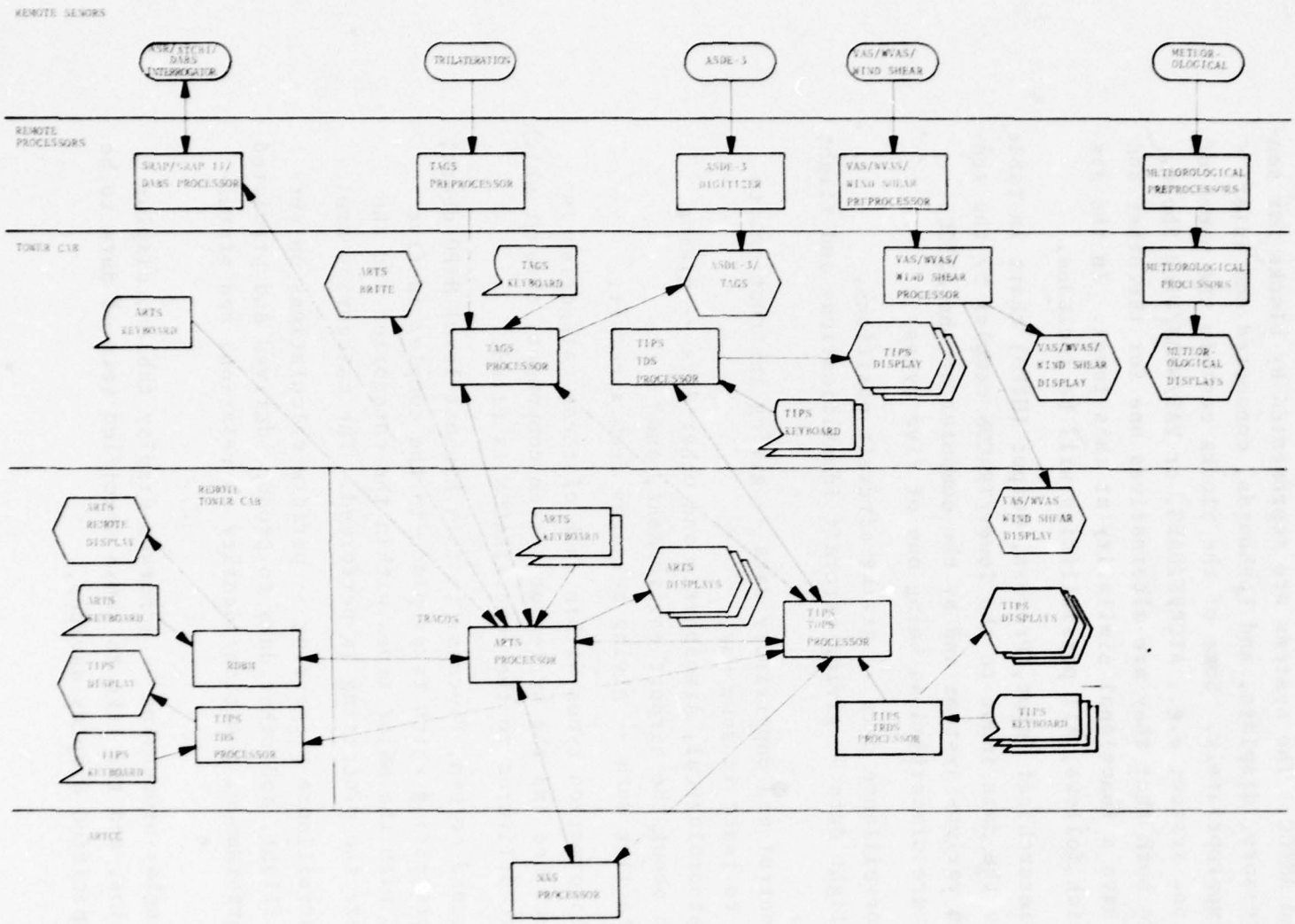


FIGURE 5.1-1. BLOCK DIAGRAM OF CLASS A EQUIPMENT

TRACON, and ARTCC. The systems are represented by blocks for sensors, processors, displays, and keyboards, connected and interconnected appropriately. Some of the blocks contain the names of more than one system; e.g., ATCRBS/DABS, or VAS/WVAS/Wind Shear, to indicate both that they are alternatives one for the other and that they have a functional similarity at this level. In the discussion which follows, all possibilities will be included.

The Hierarchical Input, Process, Output (HIPO) chart in Table 5.1-1 shows the data input to the Tower/TRACON complex by the sensors of the various systems and by the computer at the ARTCC. These data are classified as being one of five types:

a) Surveillance data -- giving aircraft positions,

b) Flight data -- giving aircraft identifications and flight intentions,

c) Control and Supervisory data -- giving instructions to the system to react in some way,

d) Meteorological, Atmospheric and other data -- giving information about the airport environment, and

e) Data link data -- giving messages from aircraft.

The major information types within each of these categories is briefly described and the system or system component, through which the data are delivered to the Tower/TRACON is cited.

The second column, Process, in this highest-level HIPO chart, lists the processing which takes place in the complex in five categories, with the major types within the categories and the systems where the processing is performed. The categories are:

1) Surveillance-processing -- perform calculations on surveillance, flight, and other data to produce derived and predicted aircraft performance, position/identity correlation, and status-monitoring,

2) Display-processing -- generate display tables, display command chains, and the like to cause specified sets of data to be output to specified display devices,

3) Flight-Data-processing -- maintain and modify as required flight-plan information for aircraft in or about to enter the controlled airspace,

4) Message-processing -- interpret and transmit to appropriate process or system messages input via keyboards or communications links, and

5) Other processing -- as the name implies.

Finally, the third column of the chart lists the data outputs from the complex grouped into three categories:

a) Displays -- output to controllers in tower cab and TRACON,

b) Messages to ARTCC -- control, supervisory, and flight data-information generated in the tower/TRACON, and

c) Data Link data -- messages to be transmitted to aircraft.

The key MSDP system, as far as the tower cab is concerned is TIPS, which was developed to replace the FDEP/flight-strip equipment in cab and TRACON. In the course of system design, the decision was made to make TIPS the repository for the terminal flight-data base, and to put the larger part of the TIPS data-processing capability in the TRACON. This led easily to the notion that TIPS should communicate with the NAS computer at ARTCC to obtain flight data, and further, that the ARTS-TIPS-NAS path should subsume the functions of the ARTS-NAS link. Thus, TIPS becomes both the flight-data manager and the communications center for messages among the tower, TRACON, and ARTCC.

These two delegations of function are presumed in the development to follow since they seem to be solidly backed by the analysis done by MITRE.

Besides TIPS, the systems to be considered here are TAGS, the WVAS/Wind Shear group, and the Meteorological group. The ARTS III display in the cab is assumed to be the Tower Cab Digital Display (TCDD) driven by an ARTS IIIA installation whose sensor data are processed by a Sensor Receiver and Processor (SRAP).

TABLE 5.1-1. HIPO CHART - OVERALL TOWER/TRACON

INPUT	PROCESS	OUTPUT
Surveillance Data	Surveillance Processing	Displays
. For each a/c within range 1 to 60 miles from radar: Range, aximuth (ASR)	. Accept and process surveillance data, track a/c, correlate with flight data. (ARTS, TAGS)	. Data blocks: ACID, altitude, speed, etc. (ARTS, TAGS)
. For each beacon a/c: Range, azimuth, altitude beacon code (ATCBI, DABS)	. Perform MSAW, M&S, Conflict Alert calculations (ARTS)	. Tabular lists: arrival, departure, ACID beacon code, etc. (ARTS, TAGS, TIPS)
. For each beacon a/c on airport surface: position, beacon code (TAGS)	Display Processing . Prepare displays of data blocks (ARTS, TAGS)	. Airport status, weather (ARTS, TAGS, TIPS)
. For cross-tell a/c: position, ACID, beacon code (ARTCC)	. Prepare displays of tabular lists (ARTS, TAGS, TIPS)	. Clearances (TIPS)
Flight Data	Flight Data Processing	. Vortex advisory or prediction (VAS/WVAS)
. For each a/c filing IFR flight plan or amendment: ACID, assigned beacon code, arrival/departure fix, ETA/PTD (ARTS/TIPS keyboard, ARTCC)	. Accept and process flight data (ARTS, TAGS, TIPS)	. Wind Shear warning (Wind Shear)
. Clearances (TIPS keyboard)	. Accept and process flight data modifications (ARTS, TAGS, TIPS)	. Temperature, visibility, etc. (meteorological)
		Messages to ARTCC
Control and Supervisory Data	Message Processing	. Flight plan submissions, changes and cancellations (ARTS, TIPS)
. For each a/c, as appropriate: handoffs, Delete messages (ARTS/TIPS keyboards, ARTCC)	. Accept and process keyboard inputs (ARTS, TAGS, TIPS)	. Cross-tell surveillance data (ARTS)
. As appropriate: Reconfiguration (ARTS/TIPS keyboards) Display format (ARTS/TIPS keyboards)	. Accept and process data link messages, prepare outgoing data link messages (ARTS)	. Hand-off messages (ARTS)

TABLE 5.1-1 (Cont.)

INPUT	PROCESS	OUTPUT
Meterological, Atmospheric and Other Data . NOTAMS, ATIS, Airport status (ARTS/TIPS keyboards) . Wind Measurements from selected locations (VAS/WVAS) . Wind and other measurements (Wind Shear) . Temperature, visibility, etc. (Meterological) Data Link Data . Messages from a/c (DABS)	Other Processing . Accept and process observations to produce vortex advisory or prediction, wind shear warning (VAS/WVAS/Wind Shear) . Prepare runway and beacon code assignments (ARTS, TAGS, TIPS) . Accept and process meterological data (Meterological)	Data Link Data . Messages for a/c (DABS)

5.2 FUNCTIONAL INTEGRATION OF TOWER SYSTEMS

The analysis of the functional performance of the future tower systems was based on certain assumptions about the course of the MSDP's.

a) It is assumed that the ARTS IIIA procurement will go as planned, and further, that certain equipment now in the prototype state -- namely, the Remote Display Buffer Memory (RDBM) and the Tower Cab Digital Display (TCDD) -- will be developed and procured in quantity.

b) The ASDE-3 will be developed and procured, and the TAGS which is developed and procured will be the hybrid system described earlier.

c) The TIPS will be developed and procured substantially as described in system documentation, and will act as a flight-data manager and communications center for the system.

d) It is desirable to distribute the outputs of the wake-vortex, wind-shear, and meteorological measurement systems to the controllers and ATC functions through some combination of TIPS, TAGS, ASDE-3, and ARTS.

The Class A Tower Cab and TRACON will have at least six new processing capabilities: three already identified with separate computers -- the TIPS Tower and TRACON Display Subsystem processors and Terminal Data-processing Subsystem processor -- and three new ones -- the TAGS, WVAS/Wind Shear, and Meteorological processors. It is suggested here that the last three be integrated in some way with the TIPS TDPS processors. A number of approaches to this integration are discussed below.

A major benefit of such integration is that the results of wake-vortex, wind-shear, and meteorological observations and calculations would be directly accessible by TIPS (and TAGS), and hence, by ARTS, NAS, and the tower and TRACON controllers. This will allow (1) wake-vortex and wind-shear information to be passed to the Metering and Spacing function in a timely fashion, (2) wake-vortex, wind-shear, and meteorological-information to be displayed

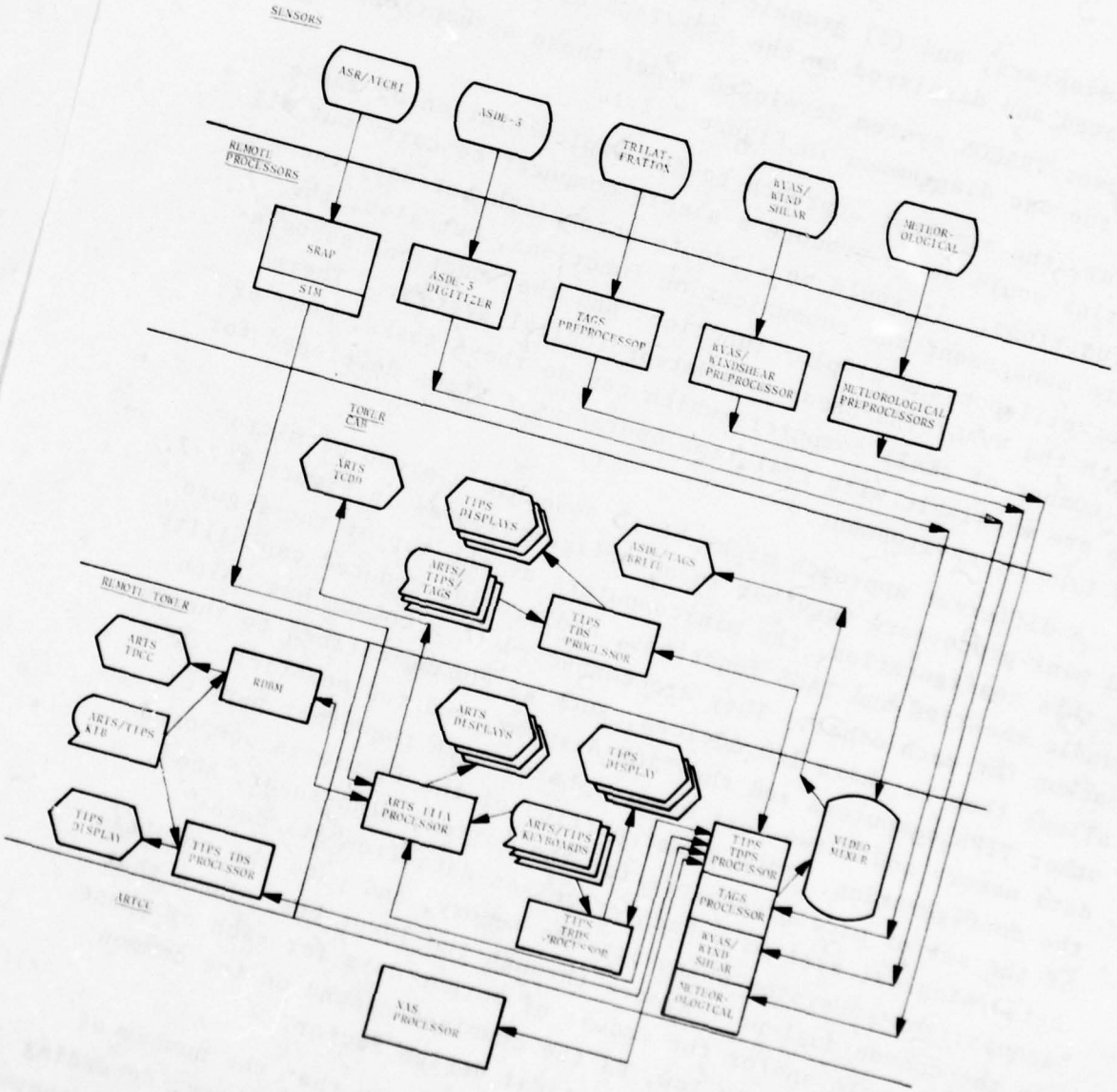
on the TIPS displays, and (3) graphic representations of these data to be generated and displayed on the ASDE/TAGS display.

The Tower/TRACON system developed under these assumptions resembles the one diagrammed in Figure 5.2.1.

By far, the simplest approach to the implementation of these capabilities would be to procure a single computer to carry out all of the functions. It would be sized to accomplish not only the TIPS data management and communication functions, but also, the TAGS surveillance and display functions and the functions associated with the WVAS/Wind-Shear and Meteorological systems. There are a number of small computers which can do these tasks, many of which are available with real-time operating systems developed for this type of environment.

A different approach might be to assemble a group of micro- and mini-processors together in a configuration as in Figure 5.2-2. In this configuration, the minicomputers at the top of the figure handle the TIPS and TAGS functions, and provide reduced capability backup for each other. They are connected to a common bus which allows them to share I/O devices, such as communications to the other TIPS computers and the TAGS display, and two memories: a data memory and a two-port memory shared with the other part of the configuration. This lower portion of the figure is composed of the set of microprocessors for the vortex, wind-shear, and meteorological systems. Each processes data from its data-acquisition subsystem using its own memory, and puts the results in the common dual-port memory through the lower bus. Note that the duty cycle and/or the amount of output data for each of these systems is relatively low, as the combined demand on the common memory is unlikely to be a critical design factor.

This configuration is quite flexible in that the number of microprocessors in the data-acquisition row is arbitary, depending only on the systems installed at the airport in question. Furthermore, the size, configuration, and programming of the mini-or microprocessors of the top row is independent of the lower, except to the extent of the data passed through the dual-port memory.


SENSORS
ASR/ATCRI
ASDE-3
TRILAT-ERATION
WAS/ WIND SHEAR
METEOR-OLOGICAL
REMOTE PROCESSORS
SRAP
SIM
ASDE-3 DIGITIZER
TAGS PREPROCESSOR
WAS/ WINDSHEAR PREPROCESSOR
METEOROLOGICAL PREPROCESSORS
TOWER CAB
ARTS TCDB
TPS DISPLAYS
ASDE/TAGS ORTHO
ARTS/ TPS/ TAGS
TPS TDS PROCESSOR
REMOTE TOWER
ARTS TDCC
RDBM
ARTS/TPS KEYB
ARTS DISPLAYS
TPS DISPLAY
TPS DISPLAY
ARTS IIIA PROCESSOR
ARTS/TPS KEYBOARDS
TPS TPDS PROCESSOR
VIDEO MIXER
TPS TDS PROCESSOR
TPS TPDS PROCESSOR
TAGS PROCESSOR
WAS/ WIND SHEAR
METEOR-OLOGICAL
WAS PROCESSOR
ARTCC

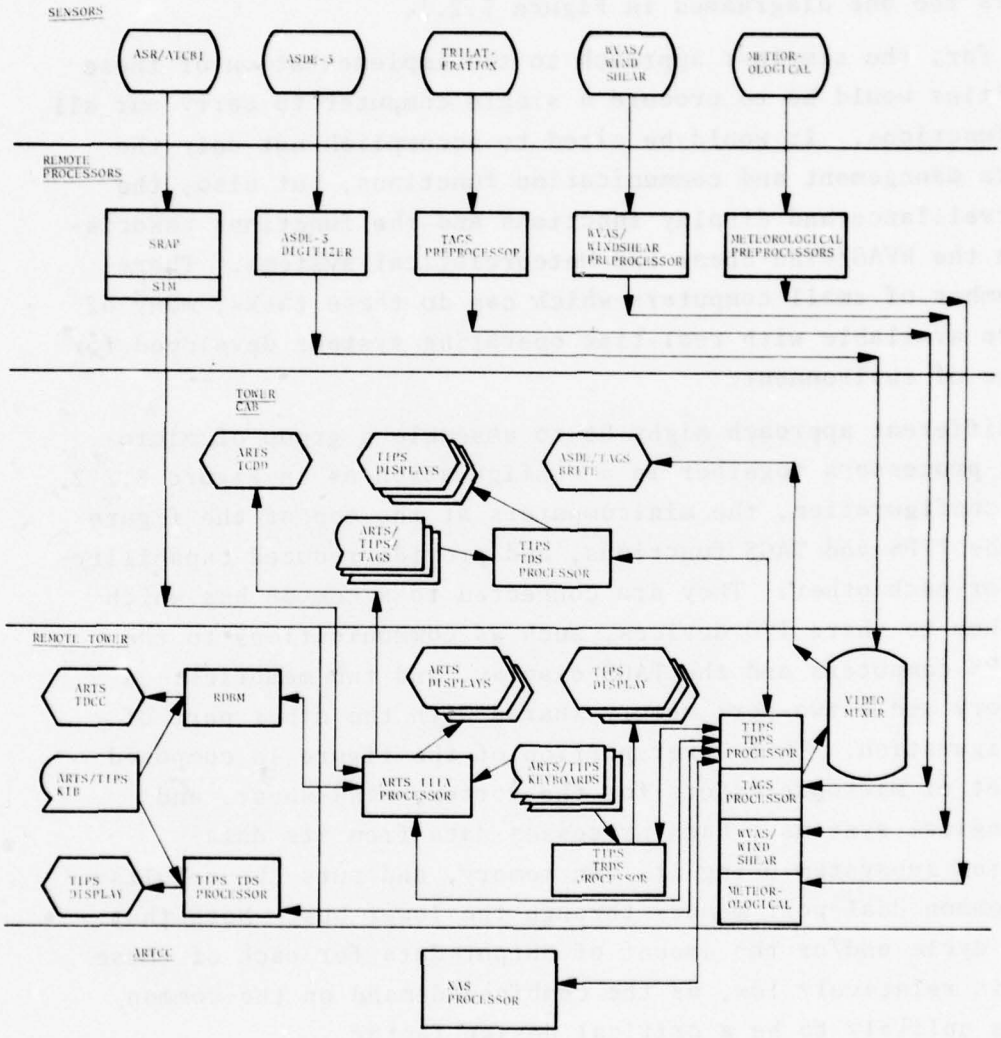


FIGURE 5.2-1. INTEGRATED CLASS A CAB -- COLLOCATED TRACON

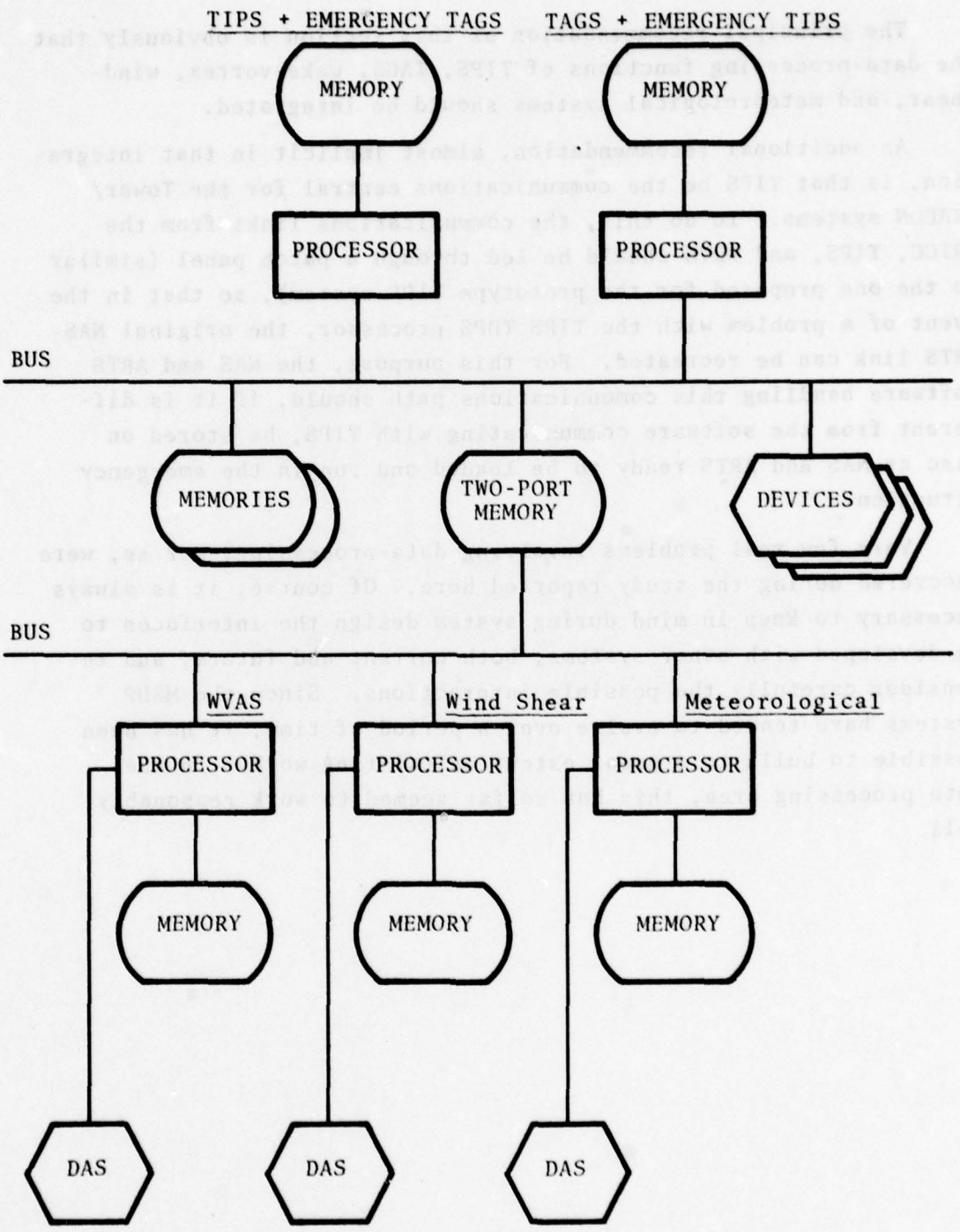


FIGURE 5.2-2. MINI/MICROPROCESSOR CONFIGURATION

The principal recommendation of this section is obviously that the data-processing functions of TIPS, TAGS, wake-vortex, wind-shear, and meteorological systems should be integrated.

An additional recommendation, almost implicit in that integration, is that TIPS be the communications central for the Tower/TRACON systems. To do this, the communications links from the ARTCC, TIPS, and ARTS should be led through a patch panel (similar to the one proposed for the prototype TIPS system), so that in the event of a problem with the TIPS TDPS processor, the original NAS-ARTS link can be recreated. For this purpose, the NAS and ARTS software handling this communications path should, if it is different from the software communicating with TIPS, be stored on disc at NAS and ARTS ready to be loaded and run in the emergency situation.

Very few real problems involving data-processing, per se, were uncovered during the study reported here. Of course, it is always necessary to keep in mind during system design the interfaces to be developed with other systems, both current and future, and to consider carefully the possible interactions. Since the MSDP systems have tended to evolve over a period of time, it has been possible to build to a great extent on existing work. In the data-processing area, this has so far seemed to work reasonably well.

6. SUMMARY OF FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

6.1 INTRODUCTION

The analysis of the integration of the MSDP systems into the tower cab environment described in this report is preliminary in nature. Because of the limited time that was available for the study, it was necessary to carry out various portions of the study in parallel with little opportunity for cross reference. As a result, many of the conclusions and recommendations are presented in the text together with unresolved counterarguments. This section consolidates those differing points of view.

For the purposes of this summary, the material has been grouped into six categories:

a. The physical integration of the equipment in the tower cab and on the airport surface,

b. The effect of the introduction of the new systems on the operations in the tower cab,

c. Human factors aspects of the integration,

d. The functional integration of the new systems,

e. Interfaces between the new systems and between the new and existing systems, and

f. Failure modes in the tower cab after the new systems have been introduced.

The depths of the analyses of the various MSDP systems varied widely depending principally on the degree to which the system in question has been developed.

6.2 PHYSICAL INTEGRATION IN THE CAB AND AIRPORT

6.2.1 Tower Cab Studies

The tower cabs of a representative sample of airports, six in number, were studied to determine physical (and operational)

ramifications of the integration of the MSDP systems. In each case, a configuration was proposed which included the MSDP systems appropriate to it. The systems considered were those which make use of large displays and are fairly well defined; namely, TAGS, ASDE-3, TIPS, remoted ARTS III and ARTS II.

Although no broadly applicable findings can be established through these efforts, both because of the unique nature of each tower cab and airport and because of the preliminary and unverified nature of the investigation, still the feasibility of installing the new systems as designed, with minimum integration of equipment has been shown for these six cases.

It is important to note, moreover, that these analyses have not been reviewed by the respective airports and until so verified and corrected, they should be considered quite preliminary.

Because airports and tower cabs differ among themselves so radically, the study should be extended to many more airports.

The following common principles were developed for fitting the MSDP systems equipment into the six representative tower-cab layouts presented in this report.

a. Wherever possible the TIPS displays were mounted on pedestals on the floor in front of the console, swiveling in cut-outs in the counter. This arrangement has advantages of flexibility and ease of use over the console-mounted positions.

The floor mount was possible at most LC and GC positions (except in Boston where space did not permit).

At most FD or CD positions, the TIPS displays replaced console- or counter-mounted FDEP or flight-strip equipment.

b. The TAGS display, where present, was put in place of the existing ASDE-2 display. In general, ASDE-3 displays were yoke-mounted from the ceiling.

Where an ASDE-3/TAGS display was shared by controller, it was between a GC and an LC, rather than two GC's. There are too many potential targets of interest to two GC's to fit well on a single display.

c. Display controls were mounted on the console, where possible, in spare space or in place of displaced equipment.

d. Keyboards were placed on counters and integrated with others wherever possible.

Some of the drawbacks of these layouts are:

The sharing of TAGS/ASDE-3 displays by two controllers prevents the use of the "quick-look" (TAGS) and "two-presentation select" (ASDE-3) features of the new equipment.

The floor-mounted TIPS display makes access to console-mounted controls somewhat awkward.

The keyboards and displays take up most of the available counter space.

The effect of these difficulties could be minimized by some additional or modified equipment.

The console-mounted controls could be moved to the keyboard or even made a part of the TIPS "quick-action entry" capability.

Keyboards for TAGS and TIPS could be integrated to save counter space.

Additional TAGS/ASDE-3 channels would allow better use of display features and would reduce interference between controllers.

6.2.2 Integration of Keyboards

The integration of the ARTS, TIPS and TAGS keyboards was the subject of a preliminary feasibility study.

The study concluded that it would be possible to attach relatively small supplementary keyboards onto the ARTS keyboard to produce combined ARTS/TIPS, ARTS/TAGS or ARTS/TIPS/TAGS units.

The concept is that the combined units are connected to both, or all three, system processors with switching of signals taking place in the add-on keyboard modules. Thus, in the ARTS mode, the TIPS and/or TAGS modules would be passive and simply pass the signals through to the ARTS processor. In the TIPS mode, the signals from the ARTS keyboard are added to those of the TIPS module and sent to the TIPS processor. A similar action takes

place in the TAGS module.

If all the MSDP systems are deployed as anticipated in this study, at least 79 controller positions will be supplied with multiple keyboards, 71 with ARTS and TIPS keyboards. Given the space limitations in the cabs, this may be enough to justify a keyboard integration effort.

6.2.3 Integration of Displays

Combining displays from two systems was suggested as another way to save space. This does not seem practicable for a number of reasons.

The ARTS BRITE display does not seem to be suitable for use by any other of the systems because it lacks certain characteristics or features described below.

The ASDE-3/TAGS display requires very high resolution, resulting in a very expensive unit which would not be suitable as the common, TIPS-alone display.

The TIPS display requires the "quick-action"data entry feature as an integral part of the display.

The information displayed by the TIPS and ASDE 3/TAGS is quite different in nature and would require an area almost equal to the sum of the individual areas (unless the area were time-shared, probably not a workable arrangement).

6.2.4 Idealized Controller Stations

The new systems, especially TIPS, will require a great deal of space, which must come from:

a) existing spare space

b) space created by removing excess or obsolete equipment, such as FDEP or flight-strip racks,

c) space created by combining or consolidating existing equipment in a more efficient arrangement, or

d) new tower cabs.

It would be desirable to have some rational way to minimize the demand for space on the part of the new systems and maximize the space made available from activities (b) and (c) above. An attempt was made to derive an idealized cab layout, or more precisely, a set of idealized controller stations, strictly from human engineering principles unconstrained by the actual physical sizes of specific projected equipment or the limitations of specific tower cabs.

The idealized configurations are based on a NAFEC controller station design developed earlier under another program.

While this station was a good basis on which to develop configurations derived from information needs, it is probably not practical for actual use because of its large size.

The basic arrangement developed for the LC station consists of an area pictorial display suspended above the controller's line of sight and an airport pictorial display in the console beside an alphanumeric display. Function-select keys are situated below the airport pictorial display and alphanumeric keyboard and PEM below the alphanumeric display.

The developed GC station is similar but without the area display, while the CD and FD have only the alphanumeric display and keyboard.

Communications and auxiliary equipment are provided at each station where needed.

6.2.5 Sensor Collocation

The possible collocation of TAGS and VAS sensors at Chicago and Los Angeles was studied to assess the cost and other advantages which might accrue.

It was concluded that because of some incompatible requirements, collocation was not always possible. Furthermore, when it was feasible, the resulting cost savings would probably be only on the order of 5 percent of the total system cost (or about 20 percent of the region's cost).

Other considerations, however, such as the reduction in the number of obstructions near the runways and efficiencies in site contracting work, may make collocation worth considering on a case-by-case basis.

6.3 THE EFFECT ON OPERATIONS IN THE CAB

The effect of the new systems on the operations in the tower cab can only be estimated since none of them have been operated under real conditions. However, the work on both the actual tower cabs and the idealized controller stations, as well as consideration of what the various new systems are expected to include, has led to some general conclusions.

There will have to be some adjustments in the way controllers operate because of the lack of space around some of the displays, especially those that must be shared by more than one position. On the other hand, since flight strips will no longer be passed from position to position, the locations of the stations in the cab may be selected on the basis of operational convenience rather than flight-strip passing.

Unless there is a marked change in the TIPS concept; viz., to make provision for extensive scratch-pad operations, the controllers will have to develop more retentive memories or supplement the system with scratch pads of their own. There seems to be evidence that controllers need and use the scratch-pad capability of the flight strips; whether they can adapt to a TIPS environment without scratch pad should be the subject of experiment during the TIPS engineering test phase.

The length and complexity of weather and weather-related messages in the system will increase with the advent of the wake vortex, wind shear and automated meteorological systems. Provisions for handling these data and conveying the information to the controllers and pilots are at the moment fragmented among the various new systems. A concerted effort to standardize and combine the TIPS, ATIS, AV-AWOS, WVAS and wind shear aspects of weather and status messages should be mounted to ensure that controller workloads are not unduly increased and that information flow is not impeded by incompatible formats or processing requirements.

6.4 HUMAN FACTORS ASPECTS OF SYSTEM INTEGRATION

Controller operations in control towers exhibit certain charateristics which are not found in operations in other ATC facilities, namely:

a. high reliance on visual contact with aircraft,
b. controller mobility,
c. frequent standing operations and
d. wide range of ambient lighting conditions.

The design of systems and equipment to be used in the cab must take these factors into account.

Another general feature to be noted is that controllers may have one hand continually occupied with a press-to-talk switch; new equipment should avoid requirements for two-handed operation.

The new systems will not, in general, provide workload relief to the controller in the cab; most of the elements are designed to permit the controllers to do what they are doing now but with a greater degree of effectiveness. They provide more accurate data, make the data more accessible or provide new types of data. This increase in effectiveness generally involves an increased workload - more data to process more aircraft to service and more information to relay.

The introduction of the new systems will also, in general, add equipment to already crowded towers, making the controllers' environment less conducive to efficient operation. New displays and keyboards are called for which could more than fill the available counter space; requiring measures such as the floor-mounting of displays. This would force controllers back away from windows, reducing their, in some cases already restricted, visibility.

To alleviate these two conditions -- controller workload and work-area crowding -- the new systems to be introduced into the cabs should be integrated where possible. The effect of the integration should be:

1) to provide increased processing of data to relieve the controller of the need to estimate or calculate mentally; an example is "time to threshold" for approaching aircraft, and

2) to combine display output in a way which provides information conveniently and efficiently; for example, time-of-day and meteorological readings on a display such as TIPS.

To the extent that the controllers can handle increased workload effectively and safely, their productivity will be increased. The human

factors evaluations and recommendations of this study are all aimed at increasing the assurance that, given these system improvements, controllers will be able to achieve increased system throughput. However, increased controller productivity can not be guaranteed from design studies; hence, the emphasis in the recommendations that simulation studies be initiated as early as is feasible.

6.5 FUNCTIONAL INTEGRATION OF THE SYSTEM

As a general rule, each of the systems being developed under the Major System Development Programs has been designed to act independently of the others. It is appropriate at this time, when deployment plans are being prepared, to think about ways in which TIPS, TAGS, ASDE-3, WVAS, etc. could be implemented in an integrated, cooperative manner. Two areas of possible cooperation suggest themselves.

TIPS should be regarded by all of the other systems as the central communication path in the tower/TRACON complex. This is a natural extension of the current TIPS/ARTS/NAS communications concept and would serve to rationalize and standardize the communications process in the complex.

The data-processing functions of TIPS, TAGS, WVAS, wind shear, and meteorological systems should be integrated in one fashion or another. Both a single minicomputer and a configuration of microcomputers were put forward as possibilities. The advantage of such an approach is that data derived from the sensors of all of the systems would be available for use and for display by any of them. In particular, the weather and weather-related data, from WVAS, wind shear, and meteorological systems, would be available for display on TAGS and/or TIPS and WVAS data would be available to the ARTS metering and spacing function.

6.6 INTERFACES AMONG TOWER CAB SYSTEMS

The interfaces between the controllers and the tower-cab systems, both old and new, and between the systems themselves are a matter of great concern. The matrix in Table 18.6.1 shows the

interfaces between the controller and the ten systems considered in this report. The spaces marked '0' indicate that there will probably be no important interface across which information or control will flow. The spaces marked 'I' indicate that any interface is indirect, as for example; NAS/ARTS, which will exchange information via TIPS. Note in the case of the controller and MLS that a status-only interface is indicated, which is meant to imply that the controller will have the responsibility for monitoring

TABLE 6.6-1 MSDP TOWER SYSTEM INTERFACES

	Controller	NAS	ARTS	TIPS	TAGS	WVAS	Wind Shear	Meteoro-logical	MLS	FSS	DABS
Controller	X	-	-	-	-	-	-	-	-	-	-
NAS	I	X	-	-	-	-	-	-	-	-	-
ARTS	*	*	X	-	-	-	-	-	-	-	-
TIPS	*	*	*	X	-	-	-	-	-	-	-
TAGS	*	I	I	*	X	-	-	-	-	-	-
WVAS	*	I	*	*	I	X	-	-	-	-	-
Wind Shear	*	I	I	*	I	0	X	-	-	-	-
Meteorological	*	I	I	*	I	0	0	X			
MLS	S	0	0	*	I	0	0	0	X	-	-
FSS	0	*	I	*	0	0	0	I	0	X	-
DABS	I	*	*	I	I	0	0	0	0	0	X

0 = no interface

I = indirect interface

S = status only

* = interface discussed in the text

equipment performance but will not get information from MLS with respect to the air traffic situation.

The interfaces marked with asterisks will be discussed in the paragraphs below, with the discussion of the indirect interfaces interpolated where appropriate.

Controller/ARTS

For the most part, the interface between the controller and ARTS will be unchanged, at least externally, when the new systems are introduced. This will be both because the interface already exists and is in use and because there is a need to maintain continuity of operations for benefit of the controllers. If, however, TIPS is made the communications central exchange among the automation systems as has been suggested, this interface may disappear in favor of the controller/TIPS interface. Careful system design could make the changeover very simple by retaining to a large degree the outward form of the interaction -- making similar actions produce similar reactions in the two situations.

Controller/TIPS

The interface between the controller and TIPS has been the subject of much design effort and probably could be improved only after considerable experimentation or simulation. The only areas of concern which have been noted in this study are the use of TIPS to replace the flight strip without providing a replacement for the extensively used "scratch-pad" function of the strip, and the possibility that the physical placement of the display/data entry devices might be inconvenient or awkward.

Controller/TAGS

The TAGS input and output devices will resemble closely the ARTS and ASDE keyboards and BRITE displays already in use. The interface with the controller does not appear critical at this stage.

Controller/WVAS

The interface between the controller and WVAS is straightforward -- the single display device described earlier. It has been suggested that a more integrated approach be followed by providing WVAS information on the TIPS, TAGS or ASDE-3 display, thus reducing in number the array of devices

confronting the controller. This, of course, has implications for the data-processing activities in the tower, as described above.

Controller/Wind Shear

The remarks above on WVAS hold equally for the interface between the controller and the wind shear system.

Controller/Meteorological

The various meteorological systems in use provide output to the controller via conventional dials and gauges. Much-needed space could be saved, however, if the digitized outputs of the sensors were provided to the TIPS computer for display on the TIPS output device. This would also make the measurements available for distribution to the ARTS and NAS computers as well.

TIPS/NAS

The interface between TIPS and NAS is a major one which has been the subject of much thought on the part of system developers. All of the flight data used in the terminal will pass from NAS to TIPS through this interface. In addition, it is planned that data interchange between ARTS and NAS will pass through TIPS via the same interface. If TIPS is established as communications manager for the tower/TRACON complex, then this interface will be quite busy, serving not only the TIPS needs, but indirectly those of TAGS, WVAS, wind shear and meteorological systems.

FSS/NAS

This FSS/NAS interface exists now and probably will become more automated and more active as VFR flight plans in computer form are made available.

DABS/NAS

The DABS/NAS interface is not defined at present although its general characteristics seem to be known. It is really outside of the scope of this work and is included only for completeness.

TIPS/ARTS

As with the TIPS/NAS interface, the TIPS/ARTS interface has been described in detail for the prototype installation but not for any production system

Again, the interface could serve TAGS, WVAS, wind shear and meteorological systems indirectly.

If arrival separation standards are ever reduced to three miles or less, departure gaps would be eliminated under saturation conditions. Inter-arrival gaps will have to be created (or detected) by M&S and departures will have to be synchronized precisely with these gaps. Departure schedules will have to be sent to M&S and gap times sent to the CD, GC and LC positions, ideally through the TIPS/ARTS interface.

WVAS/ARTS

The interface between WVAS and ARTS will exist for the purpose of passing wake vortex or spacing information to the metering and spacing functions of ARTS. It is recommended elsewhere in this report that the actual message transfer be carried out through the TIPS as a common communications facility; if WVAS precedes TIPS in the field, however, a direct interface, if only temporary, will have to be provided.

The time between changes in meteorological conditions sufficient to produce changes in WVAS indications is estimated to be of the same order of magnitude as the time during which aircraft would be in the approach path, 15 to 30 minutes. Therefore, the dynamic characteristics of the meteorological phenomena will have an effect on the M&S computations and should be taken into account during M&S development.

DABS/ARTS

Except for the possible use by tower operations of the data-link capability of DABS, the interface is not germane to this document. The data link may prove to be an important adjunct to the TIPS and TAGS operation however. Automatic delivery of clearance through TIPS and transmission of MLS-derived position data to TAGS are examples of possible data-link uses.

TAGS/TIPS

The TAGS and TIPS systems will have need to exchange information, such as flight data from TIPS and actual time of arrival from TAGS. If the systems are implemented with separate computers, then a message-exchange capability, hardware and software, must be provided. If, as is suggested earlier in this document, the processing facilities of the two systems

are integrated, then the information transfer will be possible using whatever interprocess communications techniques are provided by the operating system used.

WVAS, Wind Shear, Meteorological/TIPS

These interfaces; i.e., WVAS, Wind Shear and Meteorological/TIPS, are similar to each other in that they will exist only to the extent that the integration suggestions presented earlier are actually implemented. If it is assumed that there will be a microprocessor associated with each sensor to digitize and preprocess the data, then the outputs can be provided to the controller either through separate microprocessors and displays or integrated with TIPS (and indirectly with TAGS) for processing and display. In the first case, no interfaces exist; and in the second case, the interfaces are the hardware and software facilities for accepting the data for processing.

If the interface between WVAS and TIPS is implemented, it can serve to convey wake vortex information to the metering and spacing function of ARTS.

MLS/TIPS

Provision has been made in the MLS design for ground-to-air transmission of such data as condition of runway operational status of the guidance system and weather data. If such data are to be provided to MLS, they should come from TIPS (assuming the integration mentioned above takes place). The interface would be a rather straightforward message - transfer facility.

FSS/TIPS

There is currently no plan for an interface between FSS/TIPS. It is conceivable that allowing flight plans filed at Flight Service Stations to be entered directly into the TIPS data files might prove useful. If so, the interface would presumably be via a phone line and standard hardware/software modules.

If the meteorological data collected at the airport is available in the TIPS processor, then this interface could be used to convey such data to the Flight Service Station, if desired.

6.7 FAILURE MODES IN THE TOWER CAB

There are two aspects of system/failure that have been addressed to some extent in this study: reliability and backup. The first concerns efforts to prevent failures while the second involves the reaction to failures if and when they do occur.

Failure considerations have not really been addressed in the design of the new systems (other than ARTS IIIA) since they are for the most part still in the experimental phase of their development. When the principal characteristics of the new systems are known with some certainty and the deployment plans are relatively fixed, considerable thought must be given to the tradeoffs among costs, individual system reliability and backup operations.

Some relatively simple provisions for continued operation in the event of partial system failure have been considered for the TIPS tower subsystem. The tower supervisor has the capability to reconfigure (through the input-output terminal) the positions served by the various displays. Hence, if a display is disabled, a spare unit can be assigned to that position, or the position can be combined with another to share the same display. A failure in the tower-display processor, while leaving the displays with their last data presentation visible, disables the tower subsystem.

The TAGS/ASDE-3 system will achieve a certain amount of reliability by supplying high-risk components, such as the transmitter/receiver section of ASDE-3, in duplicate. The hybrid system will also provide some duplication of function which will allow the controller to keep working if part of the system goes down. For example, if the ASDE sensor fails, the ATCRBS sensor will still maintain position and identification of all beacon-equipped targets; if the ATCRBS sensor fails, the ASDE sensor will supply at least position information for all targets.

In spite of these efforts, the tower operation will suffer when problems occur in one of the systems because the systems are interrelated in one way or another and hence cannot be protected by measures which affect only individual systems. There must be an inclusive plan which makes the proper tradeoffs, mentioned above. It should insist on high-reliability components or redundant equipment where cost-effective and must make provision for replacement or back-up functions on a systematic basis.

Provision of manual backup in the event of failure would seem to be a serious mistake. The new equipment will replace such things as printed flight strips and stripholders; resorting to scratch pads and handwritten flight strips (without bays for organizing them) would result in an operation more primitive than the most poorly equipped current operations.

A systematic, integrated plan for reliable, continuous operation is needed before any production system is procured.

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