Ground Control Stations for Unmanned Air Vehicles

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ABSTRACT

During the last five decades, the world has witnessed tremendous growth in the military aircraft technology and the air defence weapons technology. Use of manned aircraft for routine reconnaissance/ surveillance missions has become a less preferred option due to possible high attrition rate. Currently, the high political cost of human life has practically earmarked the roles of reconnaissance and surveillance missions to the unmanned air vehicles (UAVs). Almost every major country has a UAV program of its own and this interest has spawned intensive research in the field of UAVs. Presently, the UAVs come in all shapes and sizes, from palm top micro UAVs to giant strategic UAVs that can loiter over targets for extended periods of time. Though UAVs are capable of operating at different levels of autonomy, these are generally controlled from a ground control station (GCS). The GCS is the nerve centre of activity during UAV missions and provides necessary capability to plan and execute UAV missions. The GCS incorporates facilities, such as communication, displays, mission planning and data exploitation. The GCS architecture is highly processor-oriented and hence the computer hardware and software technologies play a major role in the realisation of this vital system. This paper gives an overview of the GCS, its architecture and the current state-of-the-art in various subsystem technologies.

Keywords: Unmanned air vehicle, ground control station, mission planning, data link, surveillance, reconnaissance, military intelligence gathering

1. INTRODUCTION

Battlefields in early 1970s witnessed a new genre of unmanned air vehicles (UAVs) making debut in providing real-time battlefield surveillance information. These UAVs ushered in a new operational doctrine of military intelligence gathering and exploitation. Advances in aeronautics, electronics and sensors, coupled with the user understanding of UAVs potential, provided the required impetus to the proliferation of different kinds of UAVs. At present, there is a wide spectrum of UAVs developed all over the world that can be grouped under various categories based on size, range, mission type, altitude, endurance, wing-type, speed, engine-type, control systems and fuel-type. These UAVs have endurance up to 72 hr and can carry a wide variety of sensors, from a TV camera to the most advanced synthetic aperture radar (SAR) and the hyperspectral imaging system.

UAVs, in spite of their capability to operate at different levels of autonomy, are controlled remotely from ground. This remote control centre or the ground control station (GCS) facilitates the control and monitoring of the UAV and the exploitation of the information provided by the UAV. The GCS technology also witnessed a great deal of advancement over the years to match the performance of the UAVs. From the simple GCS of target drones with minimal information

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feedback to the controller, the presentday UAV GCS incorporates features, such as mission planning, digital maps, satellite communication links and image processing capabilities.

2. FUNCTIONAL REQUIREMENTS FOR GROUND CONTROL STATIONS

The design of a GCS for UAVs should address certain basic functional requirements[1] as enumerated below:

2.1 Air Vehicle Control

This function refers to the capability to effectively control and fly the UAV during its mission. It implies the availability of suitable data links to communicate with the UAV with ability to localise its position and command/display stations for the UAV controller.

2.2 Payload Control

The UAVs carry a variety of sensors that need to be operated from ground and their outputs need to be acquired and utilised. This would call for various controls specific to the payloads carried, suitable data link to acquire the data, display devices and storage media for utilisation of the information obtained.

2.3 Mission Planning

The GCS shall aid the UAV controller in planning the mission taking into account the capabilities and the limitations of the UAV systems. This function provides the controller the required knowledge-based inputs to arrive at an optimum mission profile without jeopardising the safety of the UAV.

2.4 Payload Data Analysis & Dissemination

In general, the image information obtained by payloads needs processing to compensate for external conditions, such as visibility, camouflaging, etc. In addition, specific information, such as location and dimensions of targets of interest, need to be computed from the images. These capabilities are provided by an image processing subsystem (with necessary communication capability) that analyses and extracts information and disseminates the data to the eventual users.

2.5 System/Air Vehicle Diagnostics

In view of the functionalities provided by the UAV system, both the GCS and the UAV tend to be complex systems requiring automatic test facility for their effective maintenance and deployment.

2.6 Operator Training

Facility to train the air vehicle controller in handling the aircraft, practicing the proposed mission plans and emergency procedures is required. As regards the payload operator, facility for training to identify and acquire the targets under realistic flight conditions is needed.

2.7 Post-Flight Analysis

Capability to store flight data and payload data and to analyse the same after the flight is an essential requirement of an UAV GCS.

3. OPERATIONAL REQUIREMENTS OF GROUND CONTROL STATIONS

The UAV GCS is required to meet the following operational requirements to maximise their utility.

3.1 Joint Operations Capability

The GCS architecture shall permit the operation of the UAV system in an integrated mode with other platforms, such as manned aircraft, satellites, etc.

3.2 Interoperability

When more than one type of UAV is in service, capability to use the same GCS (through software reconfiguration) with different types of UAVs is highly desirable, to derive advantages wrt system cost and operator training[2].

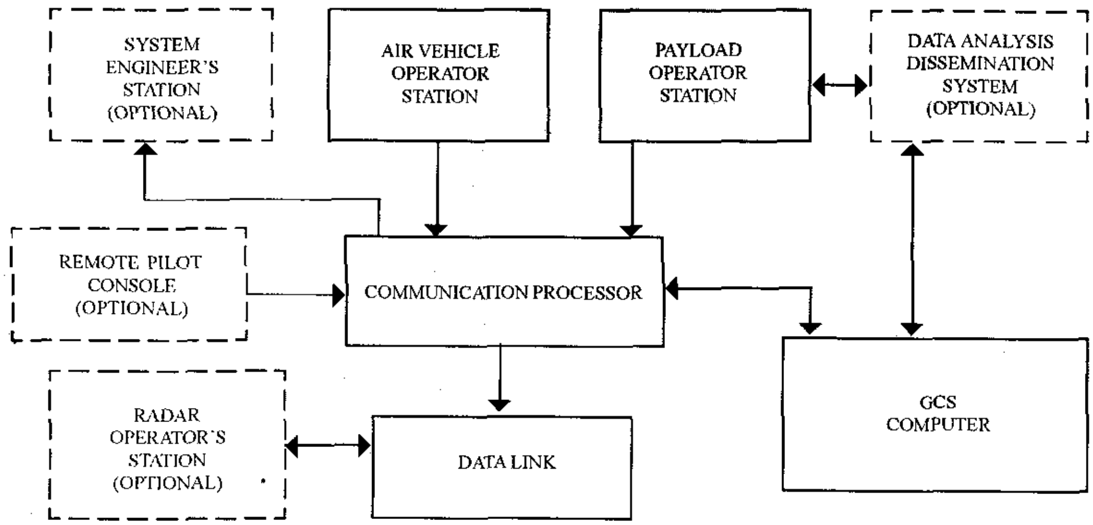

Figure 1. Block schematic of UAV ground control station

3.3 Open Architecture

The GCS system shall incorporate subsystems that have industry standard modules and interfaces. This approach can handle issues, such as technological obsolescence and permits incremental enhancement of individual subsystems without affecting other parts of GCS, thereby safeguarding the investments made earlier.

3.4 COTS Technology

The GCS should be configured using commercial off the shelf items, thereby making the system affordable.

4. CONFIGURATION OF GROUND CONTROL STATION

A typical UAV GCS incorporates one or more operator stations for air vehicle control,

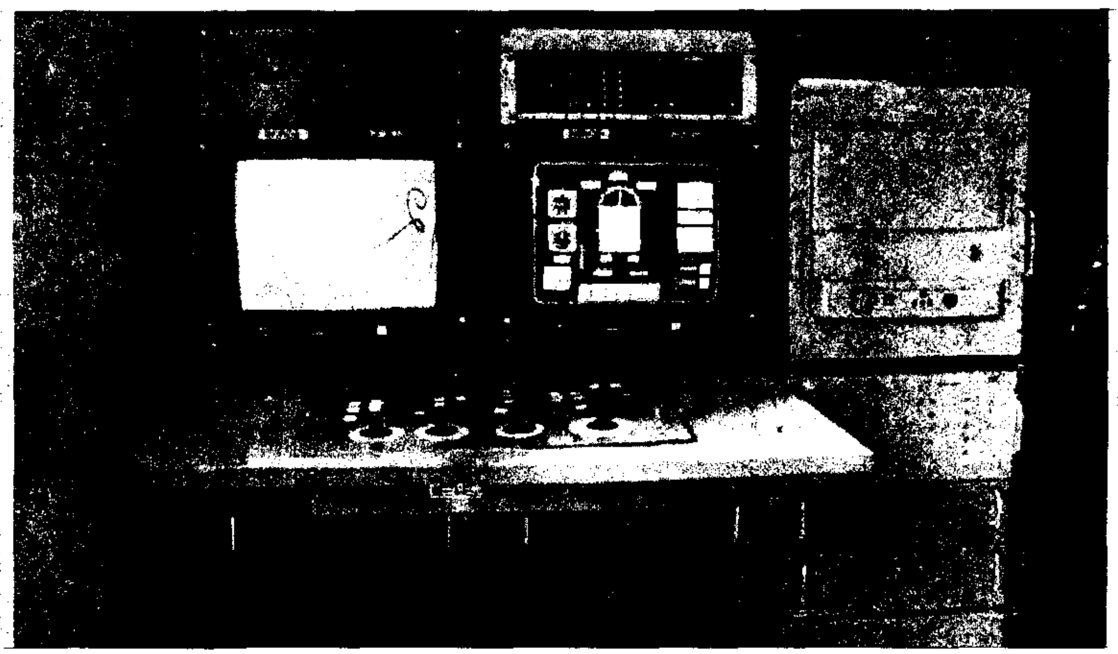

Figure 2. Air vehicle operator station

radar operation, mission control, payload operation, payload data analysis and system maintenance. The block diagram of a typical UAV GCS is shown in Fig. 1.

In addition to the operator stations, the GCS incorporates the data link and the GCS central computer, which handles data and display management[3].

4.1 Air Vehicle Operator Station

This station provides man-machine interface for the air vehicle controller to control and fly the UAV. It consists of an air vehicle command console, UAV flight parameter display, UAV trajectory display and an optional video (payload) data display. A typical air vehicle controller's station is shown in Fig. 2.

The air vehicle command console in corporates necessary controls needed to operate various UAV systems, such as joysticks/ potentiometers and switches. While command consoles incorporating conventional control devices are in vogue, virtual command console (on computer screen) through GUI is gaining acceptance. For UAVs employing conventional take-off and landing, the provision of an external pilot's console becomes mandatory. Suitable connectivity between the external console and the GCS by means of copper or fibre-optic cable is provided.

The UAV parameter display provides the pilot all the relevant flight data, such as aircraft attitude, altitude, heading, speed and engine parameters, etc. This display is designed in conjunction with the command panel, satisfying laid out human factors engineering considerations. While many of the contemporary systems incorporate aircraft-type meters, the current trend is to employ glass cockpit similar to the manned aircraft with suitable modifications.

The trajectory display provides the air vehicle controller information about the position of the UAV. Presently, the trajectory display with digital map background has become the industry standard.

4.2 Payload Operator Station

This station provides features necessary for controlling the payloads carried by the UAV. The controls include joysticks for operating the gimbal assembly, controls for TV/FLIR, video tracker, and other UAV sensors. This station incorporates one or more video monitors and video recorders to monitor incoming video and to record the video with suitable data annotation. A separate spatial information display indicating the area being viewed through the sensor is provided. Ideally, an independent map display with features, such as sensor line of sight, sensor footprint on the map and sensor orientation wrt UAV are needed for effective payload operation.

4.3 Mission Commander's Station

The mission commander's station provides facilities to edit/validate the mission plan and to monitor the system operation during the UAV missions. Facility to monitor and operate the RF systems is provided in this station

4.4 Radar Operator's Station

This station incorporates controls for operating the tracking antenna systems and the RF packages, such as transmitter and the receiver. In some GCS configurations, these controls are also duplicated in the mission commander's station for remote operation.

4.5 Data Interpreter's Station

This station is meant for analysing and interpreting the images obtained through the UAV. This station consists of image processing systems that provide features, such as image enhancement, video snap shot, hard copy printout of video frame and photogrammetry capability, etc.

4.6 System Engineer's Station

The UAV GCS incorporates a separate system called system engineer's station capable of online monitoring some specific system related parameters online. This system helps to determine the health of the airborne systems during the UAV missions. The features of this station include display of flight data in engineering units/graphs and warning displays.

4.7 Connectivity Among Operator Consoles

The various GCS operator consoles are processor-based subsystems and are usually connected by high speed communication links to the communication processor and the GCS computer in a star topology. Ethernet connections are currently employed to link these subsystems in a GCS.

5. DATA LINK

The data link provides the vital communication among the various operators' stations on ground and airborne systems. The main design equirements relating to the UAV data link are:

(a) Reliable and robust command transmission from GCS to air vehicle (commonly referred to as UPLINK) and the telemetry data from UAV to GCS(DOWNLINK)

(b) Accurate UAV tracking in range and azimuth to locate the UAV

(c) The data links for target drones are generally simple CLEAR data links that operate in UHF, L and C bands. Tactical UAVs incorporate secure data links employing either direct sequence-spread spectrum modulation (DS-SSM) or frequency hopping techniques to avoid susceptibility to any intended or unintended interference. For most of the reconnaissance/surveillance roles, UAV systems incorporate secure data links. As for downlink, the telemetry data and the video information are generally sent on a single carrier. Encryption of the downlink data is also adopted. In some UAV systems, the downlink data and video information are sent on different carriers.

(d) In the tactical UAV scenario, the increased operational range (typically 200 km) is achieved using an airborne relay and/or a relay ground station.In high altitude and strategic UAVs, due to large range involved, conventional line of sight links used in the tactical UAVs are no longer viable. In these UAVs, satellite communication links are used to communicate with the GCS. Satellite communication links, besides providing the extra range offer stealth features. Currently, many UAV systems incorporate satellite communication links and claim an operational range of about 5000 km.

(e) Multiple UAV control is resorted to in a situation where a UAV is used as an airborne relay to increase the operational range of the UAV or when there is a requirement to keep an aircraft aloft over an area without break for extended periods of time. The data links for such an application would need frequency division multiplexed access (FDMA) and code division multiplexed access (CDMA) capability. At any point of time, only one UAV would be in direct control.

(f) The need for continuous command link to the UAV is more for control the payloads than for UAV control, as the air vehicles have autonomous flying capability. However in the case of UAVs using conventional take-off and landing methodology, the presence of a command link during these phases is mandatory and the GCSs incorporate a backup command link in the form of an UHF (clear) data link.

(g) The data links should be capable of operating with different UAV systems.

(h) To provide integrated operational capability, the UAV data links are required to operate with other aerial platforms, such as manned aircraft and satellites through common data link concept[4,5]

6. COMMUNICATION PROCESSOR

The data flow between the GCS and the UAV is managed by a set of dedicated communication processor systems at either end. The primary

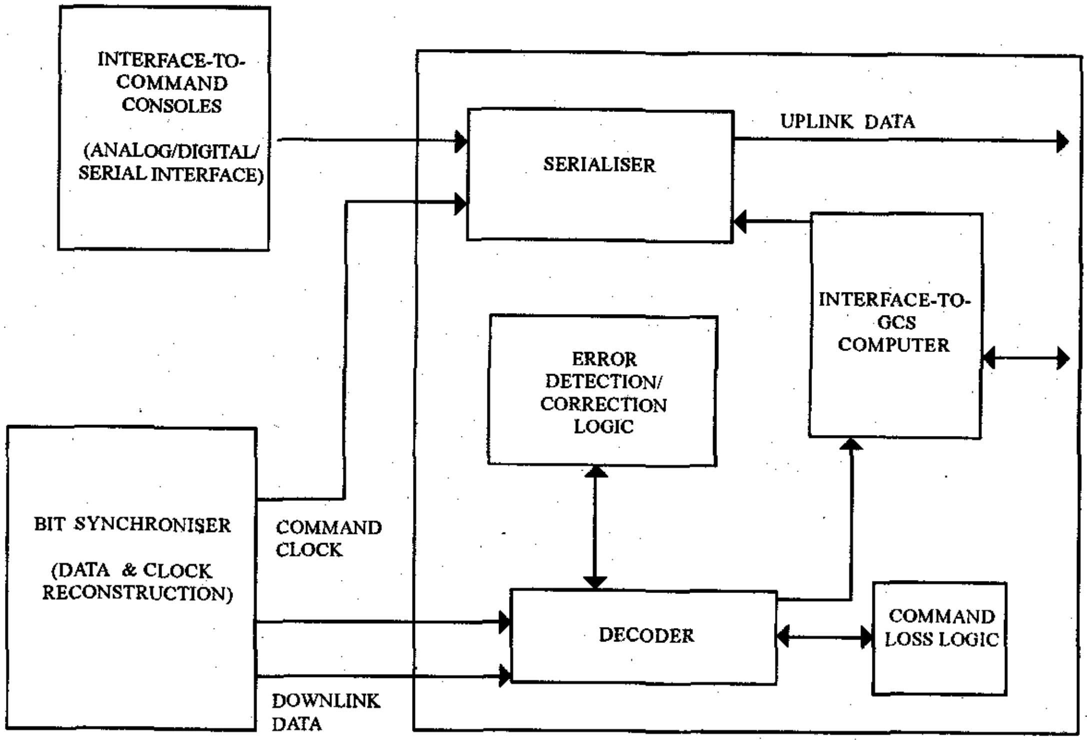

Figure 3. Block schematic of GCS communication processor

functions of the communication processor are:

- Encoding of commands as per the sampling rate specified
- Error-free decoding of downlink data
- Capability to handle errors in an unambiguous manner
- Validation of data before it is sent for further processing.

The communication processor incorporates two functional units, namely encoder and decoder. The encoder subsystem has the data acquisition hardware and channel serialiser. The decoder subsystem has a bit synchroniser to extract clock and data, a de-commutation system to decode the individual data and a suitable interface to the airborne/GCS processor for exchange of information. The decoder system has the necessary logic to identify the link-loss conditions. The communication processor can be a hard-wired system or a processor-based system. The processor-based system provides message/file-handling capability required for uploading mission plans to the UAV. The block diagram of a UAV GCS communication processor is shown in Fig. 3.

7. GROUND CONTROL STATION COMPUTER ARCHITECTURE

The UAV GCS functions are provided by a powerful computer system. The functions performed by this computer are:

- Acquisition and processing of data from UAV in real-time
- Display management
- Mission planning, validation and uploading the plan to UAV
- Electronic map
- Data dissemination through C^3I links
- Post-flight analysis
- System diagnostics.

Since the GCS functions are both computation and I/O intensive, distributed computing system is the preferred architecture for GCS computer system. Computer systems built on industry standard bus, such as VME or MULTIBUS II are suitable for this application[6]. Such an approach permits incremental enhancement of the system without affecting other functionalities. A typical

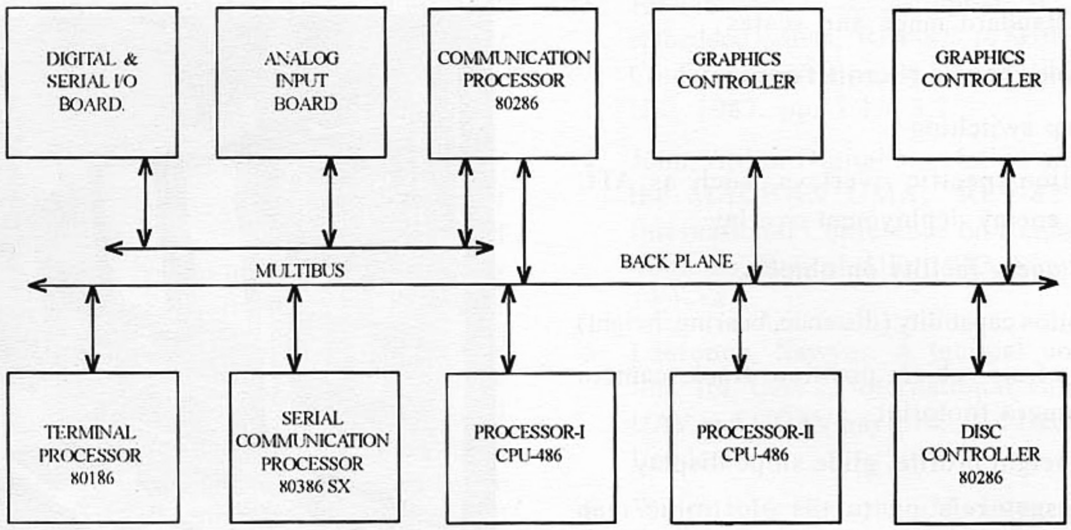

Figure 4. Block schematic of ground control station computer

GCS computer system incorporates one or more CPU modules, graphic processor modules (with video data acquisition capability) to handle the required number of display heads, communication processor modules for communicating with various operator stations and for C^3I needs. The communication processor with its interfaces to different consoles is usually integrated in the same hardware. The communication with the GCS computer is achieved through the system back plane. Advances in the LAN technology permits the communication processor to be separated from the GCS computer system.

A block diagram of a multiprocessor-based UAV GCS computer system is given in Fig. 4. Distributed computer system architecture with network connectivity opens new vistas for realising higher performance in GCS. Systems having fault-tolerance features and live insertion hardware components are candidates for high availability GCS systems needed for long-endurance UAVs. While many UAV GCS systems include IBM/PCs as main computing platform, systems based on networked symmetric multiple processors providing fault-tolerant capability are also available

8. GCS SOFTWARE

GCS software contains modules, which lend themselves well to concurrent execution. Data acquisition (from different consoles and the UAV) and data logging are primarily I/O intensive functions, while processing and display functions are computation intensive. The mission planning and the electronic map display modules though computation intensive, have significant amount of user interaction.

In a typical GCS computer system, the real-time functions, such as processing and display are embedded in one CPU in a real-time environment, while another CPU manages the non real-time functions like mission planning in a general operating system environment, such as Unix[7]. While Aeronautical Development Establishment's GCS development activities are centred on C/C^{++} development environment, elsewhere GCS Systems have been developed on ADA.

8.1 Electronic Map Display Software

To provide the air vehicle controller information about the position of the UAV and to indicate to the payload operator the exact area under surveillance, the display of the map in the electronic display is essential. Availability of GIS software packages and the digital map database enable very powerful electronic map systems for UAV GCS. Systems based on vector database and scanned-map databases are currently available. The features (specific to UAV GCS) that are incorporated in the electronic map software are:

- Use of standard maps and scales
- Map zoom, pan-and-scroll feature
- Auto map switching
- Application-specific overlays, such as ATC overlay, enemy deployment overlay
- Limited query facility on objects
- Mensuration capability (distance, bearing, height)
- Display of air vehicle position, track, camera LOS, camera footprint
- Terrain height profile, glide slope display

Other issues relating to the electronic map display software are the ease of generating the map database and its storage. Recent advances in the scanner and digital storage media technologies have made scanned map systems more attractive.

8.1.1 *Mission Planning Software*

The mission planning is one of the primary functions of the GCS. The mission planning module provides the mission controller to plan (edit), validate and then upload the mission plan to the UAV.

8.1.1.1 *Mission Plan Validation*

This requirement refers to the capability to provide the mission commander knowledge-based inputs to effectively plan the mission that would have higher probability of success. This module would apply certain UAV system-based rules to verify that the mission planned is within the ambit of the UAV system capabilities. In case of any violation, this module prompts the user of limitations, and in some cases denies permission to go ahead with the planning exercise. Ability to reach a way point, endurance, ability to return to base, safety of flight taking into account the terrain profile, LOS availability are some of the constraints applied to the way point specification during validation. The validation of mission plan is performed, whenever the mission plan is modified.

8.1.1.2 *Mission Plan Uploading*

The mission plan, after creating and validating, needs to be automatically transferred to the

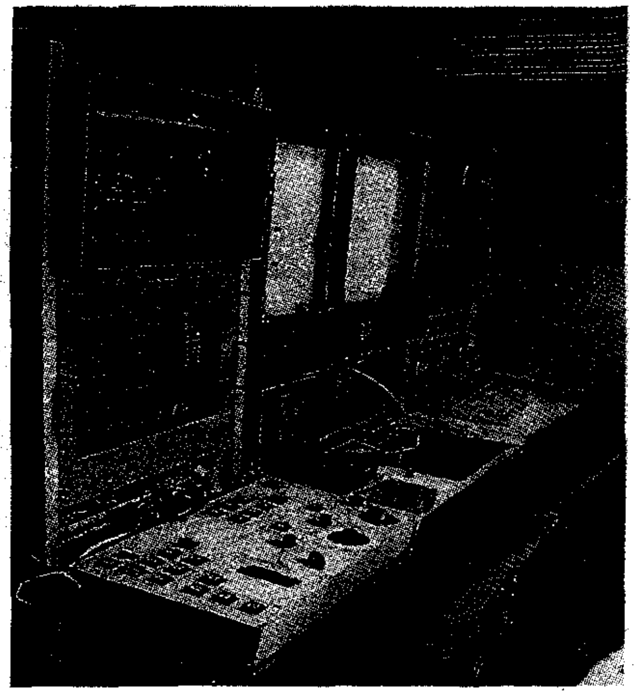

Figure 5. Ground control station (*Nishant*)

UAV, either through the cable or RF link. Facility to load full or part (modified) file is needed. This software modifies the mission plan to a format required by the UAV and transfers the same through a suitable file transfer protocol. Ability to verify the data stored in the UAV is also provided as part of this module. All these features provide the mission commander the ability to create, validate and upload the mission plan without any error.

9. EXPERIENCE AT AERONAUTICAL DEVELOPMENT ESTABLISHMENT

ADE has developed GCSs for its UAV programmes that yielded valuable experience in this field. A two-operator ground station with integral RF system housed in a transportable shelter has been developed for *Lakshya* unmanned aircraft system. This station is built around an indigenous MULTIBUS II compatible IBM/PC AT (80486) with two display heads required for air vehicle controller. The GCS for *Nishant* UAV is configured as a three-operator station with separate RF system enclosure interlinked by fibre-optic interface. This system incorporates an indigenous 80486-based multiprocessor computer system that provides all major features of an UAV GCS. Figure 5 provides the inside view of *Nishant* UAV GCS.

10. CONCLUSION

The GCS of UAV is the nerve centre of activity during the planning, and execution of UAV missions. This system incorporates a number of technologies, such as communication, computer hardware, software, system engineering and human factor engineering. Each of these technologies is critical to the overall success of the GCS development and operation. Burgeoning power of open architecture computer hardware with industry standard operating systems and software, versatile display devices, fault-tolerant, network capability and common data link compatibility would be the driving forces for the future high availability GCSs for UAVs.

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