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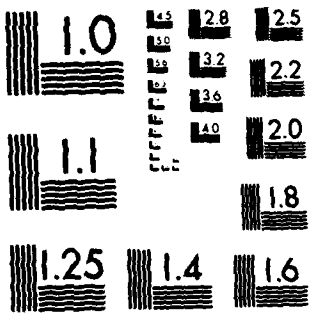

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AN ANDROID RESEARCH AND DEVELOPMENT PROGRAM

THESIS

AFIT/GE/EE/83M-3

Roslyn J. Taylor
Captain USAF

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY (ATC)
AIR FORCE INSTITUTE OF TECHNOLOGY
Wright-Patterson Air Force Base, Ohio

AFIT/GE/EE/83M-3

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THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

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Roslyn J. Taylor, B.S., B.S.E.E.

Captain USAF

Graduate Electrical Engineer

January 1983

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Preface

This thesis is dedicated to the memory of my father, Raymond Oliver Solander (26 November 1917 to 27 October 1982).

Robotics is a rapidly growing field. Interest has grown worldwide as well as within the Department of Defense. This project deals with an extension of robotics: a very sophisticated mechanism termed, herein, an android.

Acknowledgements

It is impossible to acknowledge everyone's help, individually. Although, special thanks must go to my thesis sponsor, Dr. Ints Kaleps of the Air Force Aerospace Medical Research Laboratory. And, I must thank Dr. Jones, who became my thesis advisor after my original advisor was transferred. And, last but not least, Dr. Hartrum, I thank you for acting as my assistant thesis advisor.

My deepest, most heartfelt thanks must go to my new husband, Richard, and my new four-year old son, Andrew, for their unfailing support during the past fifteen months. Without their help, sanity retention would have been impossible. And last, but certainly not least, I must thank my mother, Ruth Solander, for coming to my rescue during her own period of personal tragedy. When my husband was transferred to Korea, and my babysitter moved with only two weeks left to finish writing this thesis, mom arrived and took over everything <u>except</u> (unfortunately) writing my thesis. She proofread, pulled carbons, burst perforated pages, and collated all of my rough drafts after her arrival (not to mention such mundane things as cooking, cleaning, nursing, babysitting, etc!) Without her help and support, this work could not have been finished. Thank you, all of you, again.

Roslyn J. Taylor

Contents

	Page
Preface	ii
Acknowledgements	iii
List of Figures	vi
Abstract	vii
I. Introduction	1
Background	1
Problem and Scope	5
Definitions	5
Objectives	7
Assumptions	10
Approach	11
Organization	11
II. User Requirements	13
Requirements Description	13
Basic Maintenance Tasks Summary	20
III. Android Requirements	23
Desired Capabilities	23
Current State of the Art	33
IV. Areas Requiring Further Research	46
Background	46
Areas Requiring Further Research	50
Common Steps	50
IC2	50
Perception	52
Manipulators	52
Mobility	53
What Can Air Force Agencies Do?	54
AFIT	54
AFAMRL	56
Other Air Force Agencies	57
V. Mobile Platform Project	59
VI. Conclusions and Recommendations	67
Discussion	67
Conclusions	68
Recommendations	69

Contents

	Page
Further Recommendations for R2P2	70
Description of a Robotic Clearing House	72
Bibliography	76
Related Sources Bibliography (Annotated)	82
Appendix A: Analysis Diagrams	92
Appendix B: Data Definitions	116
Appendix C: Audio Cassette Recorder Programs	120
Appendix D: List of Contacts and Suggested Contacts	131
Appendix E: DC Gearmotor Specifications	135
Vita	139

List of Figures

Figure		Page
1	A-0, Maintain Aircraft	15
2	A0, Make Aircraft Flyable	16
3	Motor Controller	63
4	Input Signal Controller	64
5	Clearing House Relationships	73
6	Information Exchange within Clearing House	74
7	A-0, Maintain Aircraft	93
8	A0, Make Aircraft Flyable	95
9	A2, Identify Aircraft	97
10	A3, Accomplish Post-Flight Check	98
11	A31, Direct Aircraft	100
12	A32, Secure Aircraft	102
13	A4, Accomplish Ground Maintenance	106
14	A44, Determine Component Condition	108
15	A45, Fix Bad Component	109
16	A5, Pre-Flight Check	111
17	A51, Accomplish Refuel/Rearm	114

Abstract

This report identifies areas requiring further research to develop a detailed research and development plan for an aircraft maintenance android. The general user requirements are defined and the desired android capabilities are addressed to meet the defined user requirements. The user requirements are defined independently of aircraft type. Structured analysis diagrams are used to describe the functional requirements. Specific recommendations are made.

AN ANDROID RESEARCH AND DEVELOPMENT PROGRAM

I. Introduction

Background

Robots and androids bring varied images and definitions to mind. Some of these images and definitions stem from fictional literature associations, others from practical involvement with industry. The history and definitions presented in the background section of this introduction provide a common basis of knowledge between the author and the readers. The remaining sections of the introduction provide a transition from these definitions and history into the work accomplished by this thesis.

Joseph F. Engelberger, president and founder of Unimation, Inc. (of Danbury, Connecticut, the first U.S. robot manufacturer), claimed his interest in robots started in the 1940s while an undergraduate physics-major at Columbia University. He read the robot stories of his fellow Columbian, Isaac Asimov (Asimov, 1982a: xiii). Many of us can say the same thing--our interest in a particular scientific area (robots for example) stemmed from reading the fiction and speculations of others. It is easy, once the imagination is captured, to expend energy and effort to see if our dreams can be realized.

Asimov and robots are almost always thought of together; however, Isaac Asimov did not write the first robot story. In 1942, he did invent the term 'robotics'. The robots he envisioned were more like the 'industrial robots' of today--manipulators "created by engineers to do specific jobs and with safety features built in (Asimov, 1982a: xiii)". The first story about a robot (although not called a robot) was mentioned in legend--during the Middle Ages! This was the Golem, brought to life by Rabbi Loew of Prague in the Middle Ages. This robot was formed of clay (Asimov, 1982a: 57; Raphael, 1976: 253).

> Karel Capek's play 'R.U.R.', introduced the term 'robot' to the world in 1920. But it did not involve robots in the strictest sense of the word. The robots manufactured by Rossum's Universal Robots (the 'R.U.R.' of the title) were androids (Asimov, 1982a: 153).

So much for the past of robots and robotics; but where are they now?

> Portia Isaacson predicts that we will soon see robot stores in addition to our current computer stores and software stores...Jerome Hamlin constructed a robot 'butler' at home. He named it Comro I and persuaded Neiman-Marcus to feature the robot, priced at $15,000, in its [1981] Christmas catalog. The store sold three. Hamlin is now working on a robot kit that he plans to sell for under $2000. Heath has already demonstrated a prototype robot kit that it plans to introduce either later this year or next year for between $1500 and $3000. Several companies are already selling computer controlled arms and bodies in kit form that range in price from $700 to $2500, and there are rumors that some toy companies have

> developed prototypes of true robotic toys that will sell in the $300 to $500 price range. So far, the personal robotics products and projects that have been built are awkward and not very useful, reminiscent of the early personal computers. But more and more experimenters are getting involved in robotics projects, and the likelihood is that we will soon see the fruits of these labors translated into a mushrooming new market (Libes, 1982: 446, 449).

With predictions of robot stores and promises of robot kits both by individuals and companies, it appears that robots have caught the imagination and the minds of laymen. But currently, the people who have the largest demand for robots are the industrialists.

Industry, however, has its own definition of a robot. Jack Lohr, the vice-president of Robotics International, provided an official industry definition:

> A robot is a reprogrammable multifunctional manipulator designed to move material, parts, tools, or special devices, through variable programmed motions for the performance of a variety of tasks (Seminar, 1982).

Industry first used industrial robots (built by Unimation, Inc.) for die casting in the 1960s (Calahan, 1982: 130). So far, industry is the largest robotics user, with the automotive industry as the largest single user (Freedman, 1982). As such, research and development has been conducted primarily to meet industry's needs. Since industry provided the funding and impetus for the research, that is only natural.

However, "the Pentagon is calling for a supportive role fostering the U.S. development of robotics technology (Military, 1982: 4)." With this increased Department of

Defense (DOD) interest in robotics, an evaluation of where, how, and what impact robots will have on DOD is necessary. A very brief overview of the DOD Research Program in Robotics was published in 1980. This overview included the future, as well as the present, impact of robots on DOD.

> DOD has all of the cost/productivity/worker morale problems of industry plus a few special problems of its own. Not only must DOD manufacture systems, it must also support and maintain these systems across a far-flung theater of operations in frequently hostile operating environments, using a largely unskilled labor force that has a high turnover rate. Thus, the demand for intelligent, flexible automation (robots) is obvious....Robots will be developed for DOD field uses to assist combat and support forces. These field applications will place still greater requirements on robots to be more flexible, intelligent and to have sensory capabilities (Vranish, 1980: 5, 7).

In fact, with the variety of possible DOD applications, several classes or kinds of robots to meet these needs would probably be most advantageous. This thesis does not deal with an overall DOD evaluation and research recommendation, but with one particular goal of interest to the United States Air Force (USAF).

This goal was described by Dr. Ints Kaleps, Branch Chief of the Mathematics and Analysis Branch of the Air Force Aerospace Medical Research Laboratory (AFAMRL), in August 1981. This goal was

> a robot capable of repairing and refueling aircraft in a hostile environment without direct human intervention or supervision (Kaleps, 1981a).

'Hostile environment' included space and hazardous radioactive or chemical areas. In September 1981, he also expressed a need for a systematic definition of robotic research intitiatives with applications to the Air Force and particularly the AFAMRL missions (Kaleps, 1981b).

To meet the need for a systematic definition of robotic research initiatives, AFAMRL sponsored and supported this thesis.

This thesis defines a set of robotic research initiatives which if followed, implemented, and carried through to some natural conclusion, could result in a robot capable of repairing and refueling aircraft in a hostile environment without direct human intervention or supervision. The required technology to construct such a robot does not presently exist. Research continues on the various components, such as artificial intelligence, manipulators, sensors, controls, and pattern recognition. Unfortunately, according to Feldman, little or no communication has occured among researchers in these separate areas (Feldman, 1980: 244).

Problem and Scope

Definitions. Not only has communication among the different research areas been limited, but no standard set of definitions has existed (Weinstein, 1980: 37; Seminar, 1982). So far, in this thesis, the term robot has been used rather loosely. This term has been commonly and easily recognized by scientists and laymen alike. However, many definitions of 'robot' exist, all of which are dependent upon who does the defining. Since neither scientists, nor the dictionary (representing laymen) can agree on a standard definition of robot, the following definitions will be used in this thesis:

> 1. An 'industrial robot' is a [mechanized,] reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialized devices, through variable programmed motions for the performance of a variety of tasks (Seminar, 1982).
>
> 2. A 'robot' is a mechanism, fixed or mobile, possessing the ability to manipulate objects external to itself under the constant control of a human being, a computer, or some other external intelligence (Weinstein, 1980: 37).
>
> 3. An 'android' is a mobile mechanism possessing the ability to manipulate objects external to itself under the constant control of its own resident intelligence, operating within guidelines initially established and occasionally updated by a human being, a computer, or some other external intelligence (Weinstein, 1980: 38).
>
> 4. 'Holistic' means of or relating to <u>the theory that</u> a being [or thing] has an identity other than and exceeding the total or sum of its parts (Grolier, 1976: 458). [This is more than just mere synergistic cooperation.] In the context of this thesis, 'total systems concept' will be used interchangeably with 'holistic'.

Although both robot and android tend to suggest humanoid shapes, notice the definitions, given above, do <u>NOT</u> say that either one is or must be humanoid in appearance. These definitions show the conceptual difference among the different types or classes of the mechanisms defined. These mechanisms are all frequently and casually termed 'robot'!

Since Dr. Kaleps specified a robot functioning without direct human intervention and supervision, the definition best fitting that description was an android. Thus the term 'android', rather than 'robot', is used in conjunction with

Dr. Kaleps' goal. As a result, the R&D program defined by this thesis (if carried through) should produce an android able to repair and refuel an aircraft in a hazardous environment.

It must be noted at this time, the term android is not an agreed upon term in the scientific community. Of those terms defined in this thesis, the only commonly agreed upon term is the definition of an industrial robot. Mr. Lohr in his discussion about the history of this definition made it quite clear that it took considerable time and effort to get agreement on this one definition (Seminar, 1982; Electronics, 1982: 39). However, the sophisticated mechanism desired by Dr. Kaleps' requirement is not an industrial robot and should not be confused with one. Thus, the term android is used to denote this difference. One could say that 'robot' was the generic term while 'android' was a specific subclass.

Objectives. Specifically, the objectives addressed by this thesis were:

1. Determine the user requirements for aircraft maintenance.

2. Define the research and development requirements for a program to achieve the android described by Dr. Kaleps. More specifically, this program is to be used by AFAMRL and other USAF agencies to develop and realize a detailed R&D plan. This thesis sets guidelines for the proposed research and development.

3. Construct a mobile platform for future use and development by AFIT students and faculty for testing various concepts of the R&D program. By definition, this platform by itself is not a robot, but is a mobile base on which the features of a robot, and then an android, may be designed, built, and tested. More specifically, the mobile platform associated with this thesis's hardware project will: a) be self-contained, that is, it will have its own 'on board' power system; and b) the platform and motors will support about 100 pounds. (This weight includes the platform's structure, wheels, motors, power supply, and other equipment.)

4. Based on 1. and 2., recommend futher AFIT efforts.

The R&D program establishes a general program identifying functional areas requiring further research and development. This thesis also shows where primary governmental support is needed: the general areas of R&D in which AFIT, AFAMRL, and other agencies could participate. This participation could be through support of industrial and academic research as well as conducting their own in-house research. Further support and participation should be through conference sponsorship and by enhancing communication among the different robotic/android disciplines.

Once a detailed R&D plan is established, a seven year time frame is suggested as sufficient time for the results of the plan to be realized. This time period was arrived at based on discussions with Lt Mayer of the Materials Laboratory (Mayer, 1981). Also, examination of the literature made this period appear to be a reasonable length of time, since reports of an existing generalized household robot prototype were found. The reports expected this prototype to be field tested in 1985 (Asimov, 1982b: 10, 13).

The hardware project provided a moveable platform and a means for using microcomputer generated signals to control the platform motors. This platform could provide the basis for future AFIT projects and theses addressing the control, manipulator, intelligence, and other android/robotic functions. In past robotics efforts conducted by AFIT, great interest was expessed in the artificial intelligence areas, such as motion algorithms, pattern recognition (both verbal and visual), as well as sensor controls and simulations. No interest could be generated in the motors and motor controllers. This work was important because without movement, the platform could not be used to test and evaluate possible android functions as they were developed. Thus, initially, the platform must be made to move, even without intelligence. The hardware project associated with this thesis accomplished this, and provided the necessary access to the motors for computer control (for expandable intelligence).

Due to resource restrictions at this time, the majority of the effort was expended in defining goals, and getting individuals interested in working on these concepts, ideas, and proposed improvements. This included capturing the interest of the students and faculty of AFIT, as well as the interest of researchers in other USAF agencies. Another great need at this time was the organization of the materials on hand from previous AFIT efforts. This organization was needed because much of the documentation on previous efforts had been lost or was incomplete. Furthermore, the hardware project was made as modular as possible, providing minimal upgrade effort as improved resources became available.

Assumptions

This thesis was based on these assumptions:

1. Future AFIT students and faculty would continue the research suggested by this thesis.

2. Those research areas and projects requiring more manhours and resources than AFIT students and faculty can provide would be supported and/or accomplished by AFAMRL, the Air Force, and other government agencies.

3. Funds and/or manpower would be provided to accomplish the necessary research and development.

4. Industry would continue its research in this field and advance the state of the art in its own areas of interest.

Approach

The methods which achieved these objectives were:

The R&D Program. The R&D program was developed by reviewing the literature, and contacting other scientists and roboticists. This contact consisted of interviews, letters, and phone calls. The areas for future research were established through projections based on the current knowledge in the given area. The user requirements were defined through interviews with USAF officers and enlisted personnel including both maintenance and flying personnel. These requirements were further defined by observation of a flight-maintenance crew during typical pre- and post-flight operations.

The Platform. The platform project was accomplished by reviewing and evaluating previous AFIT efforts. The platform design was based on these experiences and incorporating newly available concepts. Some of these designs, decisions, and concepts were implemented, tested, evaluated, and redesigned (as necessary). The limit here rested with resource availability. Suggestions for future efforts to improve and expand the capabilities of this basic platform were made.

Organization

This chapter briefly introduces the reader to robotics and its terms through a brief history, and by defining the main terms of interest: industrial robot, robot, and android. These definitions and history leads into a summary of the objectives of this thesis and the assumptions necessary to accomplish those objectives. Finally, the approach used to accomplish the thesis objectives is briefly described.

Chapter Two describes the user requirements in more detail. These requirements resulted from structured analysis diagrams and a literature review. Chapter Three discusses the desired state of the art and the current state of the art as related to the user requirements presented in Chapter Two. Chapter Four presents the proposed research and development program. Chapter Five presents the results of the mobile platform project. Chapter Six presents a short discussion, and the recommendations and conclusions. An annotated supplemental bibliography is provided in addition to the standard reference bibliography. The analysis diagrams, for Chapter Two, are provided in Appendix A with the data definitions in Appendix B. The 8080-based assembly language code generated by the mobile platform project, described in Chapter Five, is given in Appendix C. Appendix D is a list of contacts and suggested contacts which, with the annotated supplemental bibliography, provides a list of additional reference material for those interested in the follow on work for this thesis. Appendix E gives the specifications for the motors used in the mobile platform project.

II. User Requirements

Requirements Description

These user requirements were the analytical results of direct observations, interviews, and discussions with 4950th Test Wing Organizational Maintenance Squadron (4950th TW/OMS) and AFIT students who were Navigators, Radar Navigators, Pilots, Chiefs of Maintenance, Flight Engineers, Maintenance Personnel, and so on. (*The names of the* individual interviewees are given in the bibliography.) The two planes directly observed were a T-39B, and a T-37 from the 4950th TW. The discussions and comments covered aircraft such as B-52s, F-4s, C-141s, KC-135s, and others. Those comments and suggestions which do not bear directly on this thesis topic, but are considered to have merit, for consideration have been included in the recommendations section. Again, the issue at hand is the definition of android research initiatives resulting in: "an android capable of repairing and refueling aircraft in a hostile environment without direct human intervention or supervision" (Kaleps, 1981).

Two primary scenarios of interest to the USAF were a wartime environment and a peacetime environment. The major differences between the two were the existence of hazardous atmospheric conditions, the requirements for rapid turn-around times for combatant aircraft, and a decision of which risks were acceptable or not. Hazardous atmospheric conditions would be primarily due to chemical/biological warfare tactics and the use of small, tactical nuclear weapons. For whichever aircraft were involved in warfare (regardless of whether they were tankers, fighters, bombers, or other aircraft), minimal ground/down time is desired. During wartime, some risks would be acceptable which would not be during peacetime.

The wartime situation would consist of doing whatever had to be done to keep the planes flying. The user requirements addressed that situation directly. Those additional duties which could be done during peacetime will be addressed as recommendations. Basically, the following duties are accomplished for all aircraft either during post-flight, pre-flight, and/or ground maintenance:

1. Physically inspect the aircraft.
2. Hook/unhook mobile power plants to the aircraft.
3. Refuel the aircraft.
4. Initiate safety procedures for the aircraft.
5. Repair the aircraft.
6. Replenish armaments onboard the aircraft.
7. Decontaminate the aircraft.
8. Follow-me/Park-on-me/Marshall guidance for the aircraft.
9. Secure the aircraft.

All of the above are done on an as needed, per aircraft basis.

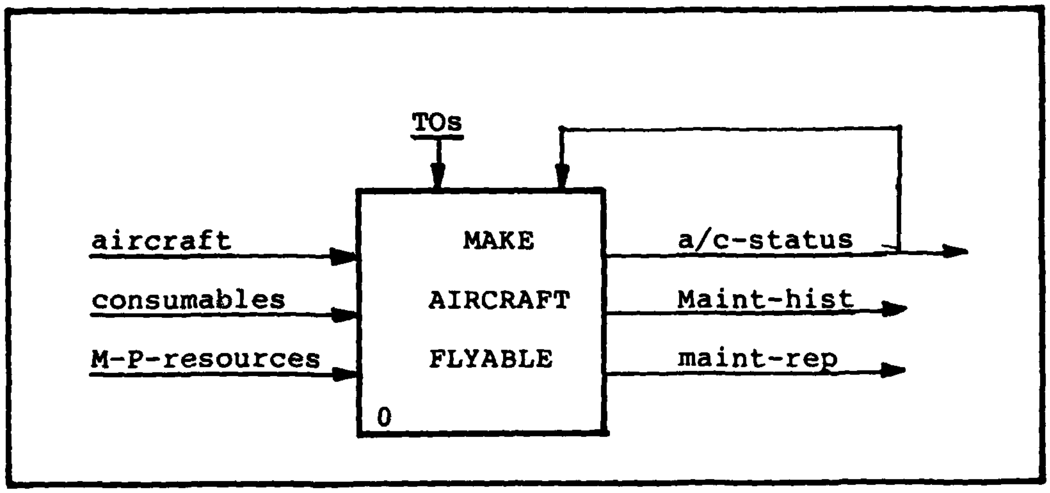

Figure 1. A-0, Maintain aircraft

To define and describe the activities of the aircraft maintenance people, analysis diagrams similar to SADT diagrams were constructed. SADT stands for Structured Analysis Design Technique (Ross, 1977: 13). The information base for these diagrams was derived from the various interviews of flight and maintenance personnel. Figures 1 and 2 show the overall and general concepts dealt with; the remaining diagrams were placed in Appendix A. The data dictionary associated with these diagrams was placed in Appendix B (Peters, 1981: 76).

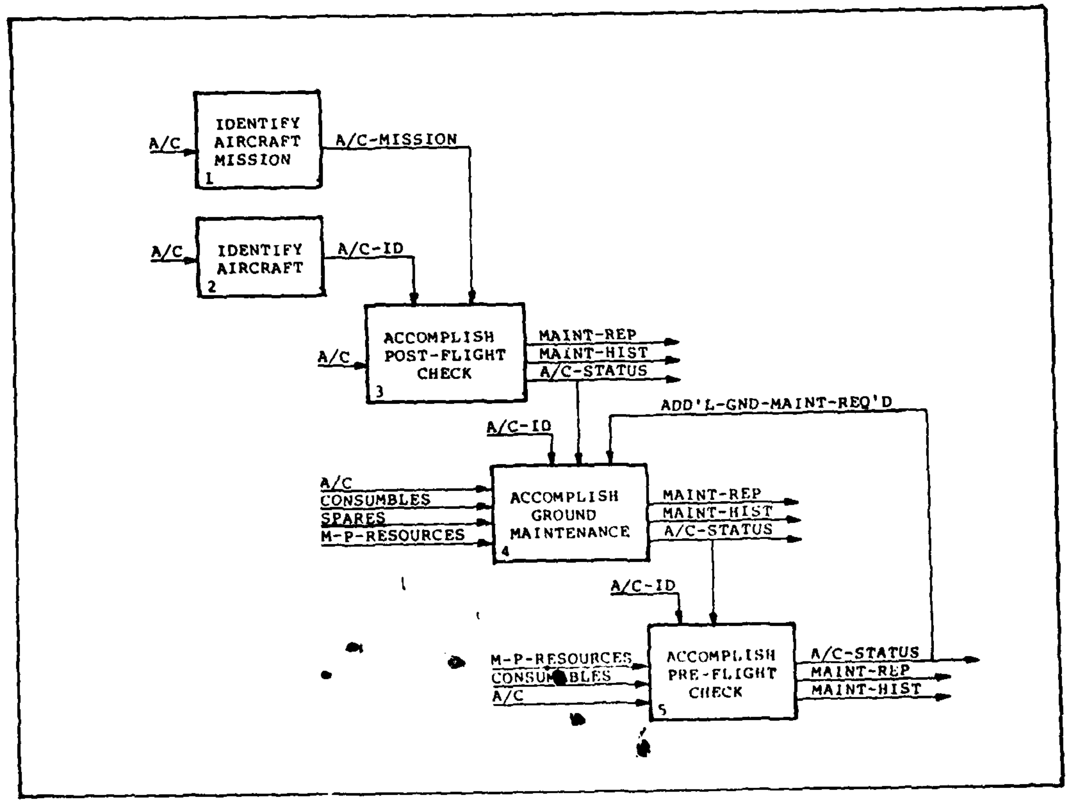

Figure 2. A0, Make Aircraft Flyable

Examining these diagrams, several common themes were noticeable. These were identification, reports and histories, and status. Identification included identify aircraft, identify location, identify component and so on. People usually accomplished these identifications visually. The histories were written data compilations. The written reports were required by Air Force Maintenance Regulations. The status was an immediate data evaluation of a given activity and frequently changing. A status could be written or verbal.

Among the activities performed by maintenance people were: seeing (vision), walking, climbing, carrying, grasping, hearing, driving, pushing, pulling, inserting, clamping, twisting, lifting, and precision inserting or matching. The implied activities were such things as memory, a knowledge of duties and how to accomplish them, and a knowledge of required materials and how to get them (be it a replacement from bench stock, armaments from munitions, or special ordering an item from supply). These were the duties which people did while maintaining aircraft.

Visual activities included locating and checking the aircraft components. Aircraft components included flight controls, hydraulics, landing gear, engines, black boxes, and air frames. Checking component tolerances involved reading TO specifications and comparing those values with the current component values as indicated, visibly, by meters and other devices. Diagnosing bad components and their repair or replacement were also usually performed visually. Checking the surroundings (for both safety and security reasons) included looking for and remov- unauthorized personnel, foreign objects, and any equipment out of place. Directing aircraft involved visually locating and leading the aircraft to the desired location. Locating objects and physical locations were also normally visual activities. Again, these were people oriented activities.

But what could an android do, and how? The duties won't change. The same activities are required to keep an aircraft flying whether a person or an android does the maintaining. However, the mechanism needed to accomplish a task may not be the same for both. For example, a person would identify an aircraft's type by using vision (most often); an android could use vision, an identity signal, or a combination of both. An identity signal could be used to identify people, places, objects, locations, or even aircraft components. To facilitate android maintenance, some additional modifications to the aircraft and its components, as well as to flight line facilities will probably need to be done.

Since the android was expected to work during hazardous conditions, it was not expected to enter any area occupied by people unless those people were wearing proper protective gear. An android working in a hazardous environment must be assumed to be contaminated. If an android entered the aircraft, from the hazardous environment, it then could contaminate the area it entered. This did not preclude rearming since rearming could be done from the exterior or through hatches away from the crew areas. For example, bombs, on planes that carry them internally, are loaded through open bomb bay doors. This eliminated the need for this research and development program to address the climbing function.

Since aircraft must have relatively smooth areas for taxi-ways, take offs, and landings, the android could move by using wheels or tank type tracks. However, a hole with a radius approximately 1/2 the aircraft's wheel radius, and approximately 1/4 radius deep will cause the aircraft difficulty--if the aircraft were unable to avoid the hole. If the android had wheels, it could experience similar difficulties. A tracked vehicle could minimize those difficulties, enabling the android to go places where the aircraft would not. During war, it is not unreasonable to expect holes in taxi-ways and aprons.

Tracks on the android would also enable the android to cross hangar door tracks, door jams, and other similar low (height) obstacles more easily. Bench stock is usually located within the appropriate hangar or hangar area, usually on ground level or else up one or two steps. A few steps could be replaced by a ramp which could be easily navigated by the android. Bench stock, if located upstairs, would have to be accessed through an elevator or ramp to facilitate movement of heavy equipment or components by maintenance people (or an android).

The android would need a carrying capability which includes the ability to grasp or hold items such as test equipment, fuel hoses, and/or aircraft components. Frequently used tools such as certain screwdrivers and wrenches could be part of the android manipulator and alternate with a grasping end effector. An android could have one or more arms and end effectors. There should be no need to duplicate human functional appearance unless psychology demanded it. However, this thesis did not deal with the psychological aspects.

Basic Maintenance Tasks Summary

Each analysis diagram in Appendix A is accompanied by descriptive text. The following summarizes the commonly required tasks for aircraft maintenance.

1. Identify aircraft mission.
2. Form aircraft-ID,
    - 2a. from: Aircraft type identificaton, and
    - 2b. from: Specific aircraft identification.
3. Lead and direct aircraft
4. Make pre- and post-arrival security check.
5. Perform ground safety check.
6. Decontaminate aircraft.
7. Inspect aircraft (post-flight check requirement); the same as #19.
8. Implement aircraft component check list.

9. Follow up crew debriefing comments.

10. Physically locate next component on list.

11. Check component tolerances.

12. Replenish consumables.

13. Diagnose bad component problem.

14. Repair or replace bad component.

15. Determine rearm/refuel sequence.

16. Rearm aircraft.

17. Refuel aircraft.

18. Apply external power to aircraft.

19. Inspect aircraft (pre-flight check requirement); the same as #7.

20. Perform air safety check.

21. Generate data:

21a. Statuses (aircraft statuses and component conditions)

21b. Reports

21c. Histories

21d. Identifiers (aircraft ID and component ID)

21e. Diagnoses.

22. Other items used:

22a. TOs

22b. Checklists

22c. Data generated

22d. Tools and equipment as required

22e. Various "controls".

This list of tasks was derived from the lowest level of the analysis diagram boxes. The android capabilities needed to meet these tasks is discussed in Chapter Three as the "desired state of the art".

III. Android Requirements

Desired Capabilities

The android capabilities needed to accomplish those tasks defined in Chapter II are discussed here. It is important to recall that mimicking human actions is not necessarily the best way to accomplish a task. However, if a better methodology is not available, and the task must be accomplished, then mimicry is an acceptable interim solution.

> It is extremely important to realize that the human system performs its function because of unsurpassed hand-eye coordination. Nonetheless, the human system is probably a very poor model for performing precision operations under load....Note that no human hand is capable of precision measurement or is capable of precision machining operations under load. Because this is true, the human model for robotic manipulators is adequate for simple repetive tasks such as: Pick-and-Place, Spot Welding, Spray Painting, Surveillance, Unloaded Assembly, etc. (Tesar, 1982: 14).

The android needs perception, mobility, manipulators, and IC2 (intelligence, control, and communication) as general capabilities. Perception covers the sensory aspects. Mobility covers the android's own movements, while the manipulators deal with the android moving objects other than itself. For the purpose of this thesis, IC2 is defined as the intelligence, control and communication function(s) combined. These three are grouped together because of their strong interweaving and interaction. IC2 includes the feedback control loops required for manipulation and perception, the communication between the android's own systems, the communication with the world, and the individual computer control aspects. Additionally, communication and sensing tend to overlap when one considers robotic sensing as being divided into two parts. These two parts could be classed as

> 1) internal robotic sensing, which monitors the state of the robot's system, and 2) external robotic sensing, which monitors the state of the robot's environment (Nitzan, 1980: 182).

Internal robotic sensing will be considered part of IC2, while external sensing will be considered as the previously mentioned perception. In order to accomplish those tasks currently done by aircraft maintenance personnel, the android must be able to sense both its internal state and its environment's state. Not only must it sense these two states, but it must be able to coordinate the two data sets and then arrive at the proper actions. It must be remembered that not all of the sensors need to be physically present on the android, as long as it has some method of receiving the necessary remote sensor data (Nitzan, 1980: 191).

IC2 also includes the hardware and software which allows judgement, decision making, and the interfacing of the android's systems to itself and to the world. These areas overlap and interact with each other in providing the desired results.

Some of the tasks developed in Chapter II require that the android locate, identify, inspect, and move. These four activities involve varying amounts of perception. Primary candidates for these perception requirements are primitive sight mechanisms (PSM), and primitive hearing mechanisms (PHM). These two perceptions account for most of the sensory information required to carry out aircraft maintenance. If a need for 'taste' or 'smell' is required at a later date, then these areas could be developed at that time. They will not be considered here. Touch is discussed in the discussion involved with manipulators and control, where it is employed more often, rather than here.

The primitive hearing mechanisms use acoustic transmitters and receivers. Military aircraft already possess a transponder system which provides a radio 'identification-friend-or-foe' (IFF) signal. This is a query system, where the identification signal is only sent in response to a request for aircraft "verification". A similar, acoustic version of this could be used on major aircraft components, ground equipment, buildings, personnel identification tags, and other obstacles.

This IFF signal would be backed up by a visible identification code (VIC) which would employ a primitive sight mechanism. [Since the Air Force has stock numbers for virtually everything it uses, <u>what</u> to use as the identification code, initially, is not dealt with here.] This code is similar in concept to those codes which various stores and the railroad use. The android either knows where to look for the VIC or else a marker, such as an LED, would denote where the VIC was. The VIC would be a permanent part of each component and each aircraft. Each aircraft would have VICs at various points on the aircraft to allow the android to know where it was with respect to the aircraft and the aircraft components. These latter VICs would facilitate finding various components and recepticles on the aircraft. Each aircraft would have a VIC which designates the aircraft type and which particular aircraft it was. Just as the VICs would be used on aircraft to back up the IFF, they would be used on ground equipment, buildings, personnel identification tags, and other obstacles. Together, the PSM and PHM provide reliable identification.

Motion perception deals primarily with collision avoidance. An android avoids collisions by gathering and manipulating data, and then making decisions based on that data. Acoustic sensors would warn the android of objects, their distance, and relative motion and speed. Additionally, primitive 1-D or 2-D vision would be coupled with the acoustic sensors. By coupling it with the acoustic sensors, vision need not be the sole means of identification. The vision system would show the android where a potential object or obstacle is, then the android would direct its acoustic sensors toward the object to determine whether or not it was really there, its distance, and its relative speed. The sonar sensors, presently available, are of two general types: 1) pin point, and 2) broad beam. Not only would the basic sonar sensors be used, but the IFF subsystem would be used simultaneously to provide additional information and confirmation as well. These data sets would become the database for decision making. Thus no one single sense is used to identify items or objects. If an object could be certainly identified by just one sense, using a judgement algorithm would speed up the identification procedure, and thus the decisions necessary to avoid collisions, or to locate components and other objects.

Permanently stationary objects could transmit their location and identification either upon query or continuously. The continuous identification versus query initiated identification would depend upon the hazard which the obstacle or object presented as well as the desired level of security. A transmitted location implies either a reference map within the android or that the android has access to a reference map, so that the location information is meaningful.

Inspection of an aircraft, its components, or the flight line requires evaluation as well as perception. The android can identify and find various components and objects through primitive sight mechanisms and primitive hearing mechanisms, but inspection also requires determining whether or not the component or object of interest is acceptable or allowable. This determination is based on test results, and their comparison to the TO specifications. Judgement will be addressed with intelligence and in the recommendations, not here. Specially designed test equipment, developed for an android, will be needed as well as the modification of existing test equipment to allow direct access to the test equipment for the android's data gathering. Further modifications, other than to the test equipment, may be required to facilitate android maintenance.

One such potential modification would allow the android direct access to the on board aircraft computer systems. Many aircraft components have built in computer systems and computer diagnostics. With a lead or plug directly attached to the android, these would be used by the android for data gathering and testing. If these self-diagnostics were on all major aircraft components, then the need for separate, android specialized test equipment would be minimized.

By judiciously modifying existing aircraft components, the android could use manipulators with primitive end effectors. Two feasible modifications require 1) an aircraft component modification which allows easier access by a non-human hand, and 2) the relocation of aircraft components [if necessary] to facilitate access by an android. The android need not grasp a wrench or other tool exactly in the way a person would. The android would have several manipulators, each with a set of rotating, interchangeable, self-locking end effectors. [Remember, the android is not limited to <u>two</u> arms.] Each end effector would be a different tool. At least two manipulators would have several matched tools to facilitate moving or removing larger components and items. Screwdrivers, wrenches, test leads or plugs, and other commonly used tools would be part of the end effector. To handle the grasping of aircraft components or other items, a threaded receptacle in the component with a matching threaded extrusion as an end effector could replace the need for an end effector with the ability to use human door handles or human component 'pullers'.

Allowing the android to have several manipulators facilitates the use of different classes of manipulators. These various classes of manipulators and their related end effectors are based on the requirements which they fullfill, such as low torque, precise force measurements, precision matching or inserting, high torque, and amount of mass it is able to manipulate. Those manipulators requiring precise force measurements would have end effectors capable of such precision. Those manipulators able to do precise matching and insertion would have end effectors to make computer outlet connections, test equipment lead connections, and such. There could be combinations of these, and others to meet the needs of aircraft maintenance by an android. This does require a sense of touch, however. The sense of touch, or a recognition of the amount of force applied, is really more of a control function.

Previously, the perception aspects of mobility were emphasized. The scenario under discussion is a hazardous environment due to warfare. One consequence of war is damage to the ground from various weapons. In the textual portion of Appendix A, it is noted that some holes in the ground would not interfere with an aircraft on takeoff, landing, or taxying. This was because either the larger holes are avoidable or else the holes are small enough that the aircraft wheels can safely cross them.

Because of the possible ground damage, wheels are not necessarily the best means of movement for the android. [Although there are tired vehicles which can navigate marshy country, the primary candidate for mobility, as addressed here, is the tracked vehicle.] Tank-type tracks provide a more effective method of movement. Even in a non-war environment, the tracks are more effective on the flight line because of the inclement weather, crossing doorsills or hangar door tracks, and similar obstacles. The tracks minimize the need for circumventing holes and other obstacles in the terrain. The tracks also provide a more stable base from which the android may work.

The final, general android capability to be discussed here is 'IC2'. Intelligence, communication, and control [in conjunction with mobility] are what make the android an android and not simply a robot. Control combines with intelligence and enables the android to do what it 'should do' at each level. These levels include the overall, 'gross' concept of aircraft maintenance; the level which deals with how much torque or pressure is required to screw down a particular screw or where and how to insert a plug to carry out a diagnostic procedure; and even lower to the level which deals with each sensor or microcomputer and their priority to interrupt during an in-progress function or routine.

One aspect of control, without a direct linkage to intelligence, is the feedback control loop. [It must be noted however, that closed loop feedback is, in one sense, limited intelligence.] In digital control, computer hardware and software are combined, with and without mechanistic control techniques, to provide the controlling functions and factors. One extension of this is the use of pattern recognition as the sensory input factor for the feedback control loops. The more advanced the feedback control technique is, in general, the more complex the computer requirements. It is closed, feedback control loops which will help give the android its sense of touch and its ability to have precise perception. This aspect of control uses internal communication and interfaces.

Another communication aspect might be the networking of the various modules (with or without digital or analog processors) connected to and located within the android. It is also the exchange of information between the android and another android or robot, or a person, or its required reporting 'official' (the computerized maintenance system or the chief of maintenance, for example), or even aircraft components. One form or another of communication results in all the gathered, stored, and generated data.

Most people prefer use speech, rather than having to punch buttons, pull levers, punch and insert computer cards, or type out instructions. Thus the android must be able to speak to people and understand what the people are saying. Part of speaking to people, is having the android respond in some manner to whomever spoke to it, such as a special blinking light or a verbal response. People who are not used to machines, especially quasi-intelligent machines, need to know their command was heard. Especially if there is a time lag between hearing the command and an active response by the android. This time lag would be the android's "thinking" or deciding time. [Do remember that people take thinking time, also.] This is a form of communication. Understanding speech is a function of pattern recognition, while speaking is a result of either preprogrammed responses or artificial intelligence.

Several of suggested methods (primary candidates), both directly and indirectly, require a large data storage capability. If these methods are used, then this implies the android might need to supply this capability. To some extent, this is true. However, if the computerized maintenance system (CMS) continues to be developed and implemented, then a working 'scratch' memory area combined with the android's direct access to the CMS would minimize how much data must be stored at <u>all</u> times within the android. For example, once the aircraft is identified, the android communicates with the CMS, and loads the information and directions pertinent to that particular aircraft including the report and history formats. As work progresses, the data is stored in these formats by the android. Thus, when a job or report is completed, or the memory constraints require it, the appropriate data is off-loaded into the CMS. Easy access to the CMS aircraft diagrams and maps provide the additional data necessary for decision making without having to maintain a large database on board the android at all times.

IC2 is the hardware, firmware, and software which enables the android to make decisions, exercise judgement, to communicate with itself and others, and to control itself and what it does. This is what the android needs, but what is currently available?

Current State of the Art

The functions discussed here are the same general capabilities discussed previously, that is, IC2, mobility, manipulators, and perception. Vision and hearing were the two major areas of perception discussed.

Some of the available primitive sight mechanisms can be seen daily in grocery and department stores. These readers require a relatively precise orientation of the reading head over, and a particular distance from, the code to be read. Once these two conditions are met, the code is read. One and two dimensional (1-D and 2-D) vision capabilities are available as well. The National Bureau of Standards has been working in the control area of robotics for some time. One area of control, has been real time vision. This vision system uses a camera, strobe type of light source, and an 8-bit microprocessor. It is limited to a distance of one meter and has a 36 degree field of view (VanderBrug, 1979: 213-231).

> Of course, the 128 points which represent the function do not give information about the entire object. They only contain information about a particular cross section of the object. However, in some robot vision applications, such as alignment and feature inspection, this may be sufficient. In other applications where it is not sufficient, the control system can decide that additional images from other perspectives (such as closer in, higher, lower, from the other side) are required (VanderBrug, 1979: 216).

Not only should the control system decide if additional images from the camera were needed, but also decide if additional information from the other sensors available would resolve the deficiency.

One possibility is the combination of the information from both a 1-D and a 2-D vision system. The Jet Propulsion Laboratory was working on a visual tracking system. This system assumes the tracker has acquired the object and must follow it around a scene. This particular paper deals with feature extraction for visual tracking and the principles involved with the tracking algorithm. To deduce the internal model's errors, an inverse Jacobean matrix is used (Saund, 1979: WP-2E).

Most vision systems are very limited in their pattern recognition abilities, because of the processing requirements. But as previously pointed out, that would not be a current limitation if combined with data from other sensors, and with the current progress being made in microprocessor capabilities. Additionally, a backup method, similar to that used with the Air Force's Communication Center's OCR Message reader and sender should be used until vision or the combination of vision and other senses is completely reliable and available. The OCR Message Reader, when it is not sure of a character it is supposed to read and then send, sounds an alarm. The operator then goes to the reader, looks at the character on display, determines the character, and then tells the reader what character it should have recognized. Then both the operator and the reader return to their normal functioning modes (Tour, 1982). Thus, the android would transmit its video to the maintenance shop, and sound an alarm when it could not decide. Then one of the on-duty maintenance persons could look at the picture in question and tell the android what it needs to know. However, as perception systems become more reliable, this will occur less often. According to Joseph Engelberger,

> We all know that human vision serves its possessors in a spectrum that ranges from the near-blind to 20/20 vision. A combination of 20/20 vision and 20/20 ability to analyze scenes is not in the cards for robots in this century, if ever (Electronic, 1982: 55).

The overwhelming shortfalls in the area of vision are the equipment required, the space needed to house the equipment, and the limited portability of the equipment while in use.

The available primitive hearing mechanisms are acoustic sensors. These sensors primarily transmit and/or receive, such as the military aircraft transponders. To use these transponders in the manner described previously, they need to be miniaturized and remain functional. Acoustic sensors exist now with pin point and broad beam capabilities. The phased array radar technology provides pin point sensing capabilities at long distances. But phased array radars tend to be large, fixed units. Thus to be useful for an android, the phased array type of radar would have to be miniaturized and made mobile.

The mobility area has mixed requirements involving physical implementations and control considerations. The tracked vehicle technology ranges from moving toy tanks to large military tanks. The track movements are primarily mechanical. The need here is for appropriate computer interfaces which allow computer control of the tracks. In fact

> vehicular mobility over smooth surfaces can be regarded as a solved problem. Moreover...it is evident that conventional wheels or tracks when coupled with appropriately designed passive suspension systems afford effective means of transport over moderately irregular surfaces (McGhee, 1980: 167).

According to McGhee, most of the work done for vehicles with wheels or tracks was done for the Mars Rover project which was not complete at the time the above paper was written.

This maintenance android is not expected to climb, but to work from the ground (actually the flight line surface), a ramp, or a platform when available. These are relatively smooth surfaces due to the requirements for a surface on which an aircraft can travel while on the ground. Ramps and platforms could easily be constructed which the android could travel over, as well. A ramp, or a platform was decided as a highly probable necessity to facilitate android maintenance from the ground. With each new aircraft type, the relocation of its components is feasible; but the relocation on existing aircraft is limited. Some relocation will be required to facilitate android maintenance.

The android's manipulators are of the same class as industrial robots. Good manipulators are available today, and industry continues to improve them. Some manipulators have limited feedback which allows more precise force and movement measurements. Industrial robots are available which accomplish pick and place, as well as the insertion of one object into another. This is possible because the items to be picked or inserted have a known orientation and position, and the place or object waiting for insertion is also well defined in space. These manipulators are currently in use in the automobile industry, and two were were demonstrated by Kohol Systems, Inc. after the Robotics Seminar held in Dayton, Ohio on 17 April 1982. This ability can be used with a known end effector for some aircraft maintenance requirements.

Joseph Engelberger in his article on "Robotics in

Practice: Future capabilities" discussed a new invention in touch sensing:

> The second most important frontier is tactile sensing and here invention has already occurred. Draper Labs, in its efforts to computer control the interaction between parts that must be mated, came upon a serendipitous conclusion that such parts-mating can be eased by a completely mechanical passive accommodation. The device known as the Remote Center Compliance (RCC) is .... already being used experimentally by researchers attacking the problem of programmable assembly (Electronic, 1982: 55).

The RCC was described by Whitney and Nevins as

> a controlled, documented, reproducible source of multi-axis compliance or float which allow easy interfacing of mechanical mating parts in spite of intial lateral and angular misalignments. Its greatest potentials lie in accomplishing difficult insertions and in providing a valuable margin of error in constructing and maintaining many kinds of machines (Whitney, 1979: 143).

This device as part of a wrist would accomplish many inserting and matching requirements for aircraft maintenance. Using software-controllable compliances and saturation levels for a five-degree-of-freedom wrist as a means for active force feedback, more precise manipulator activites could be accomplished. This 'active adaptive compliance wrist' was described in the literature in 1979. It was reported that work was to continue to improve the wrist by using stochastic methods to provide certain learning functions. The paper claimed that this active adaptive compliance wrist will

> allow the use of inaccurate general purpose industrial robots for precision assembly tasks (Van Brussel, 1979: 176).

More recently, Shin and Malin discussed an adaptive feedback control algorithm for a multiple degree-of-freedom manipulator which they claim is well suited to real-time microprocessor application. The crux of this is the use of a microprocessor for each degree-of-freedom within the manipulator (Shin, 1981b: 420-427).

But very delicate, precise work, such as inspecting surface tolerances, requires an even more sophisticated touch sense. 'Active touch sensing' research has been conducted at the Artificial Intelligence Laboratory at the Massachusetts Institute of Technology and in France by Briot. Both use a planar array or matrix sensor. Briot described his technique in 1979, as an 'artificial skin' sensor (Briot, 1979: 529). The MIT AI Lab's active touch sensing method attached its array of tactile sensors to a mechanical finger. The finger then identified "commonly used fastening devices- nuts, bolts, flat washers, lock washers, dowel pins, cotterpins, and set screws" by pressing and probing the object with the finger. The finger and sensor combination were controlled by a tactile recognition program. The paper's description of the active versus classical sensing approach was the "choice of top-down versus bottom-up". The classical approach was "sense, analyze, and abstract" while the active approach was "hypothesize, measure, analyze, debug," and repeat until done (Hillis, 1981: 23-24). However, the author of the paper remarked that

> one should not be too impressed by a program that distinguishes between six objects on the basis of

> three parameters. If only a single bit of information was derived from each parameter, it should be enough to recognize at least eight objects (Hillis, 1981: 32).

The remarks continued with three suggested improvements which (in Hillis' estimation) were not too far in the future. These were texture recognition, thermal conductivity sensing, and coordination of multiple tactile images into a global picture (Hillis, 1981: 33).

Thus the major android manipulator needs were 1) the ability to work from a mobile platform, 2) the interfaces between the manipulators and sensors, 3) improved closed loop feedback control, and 4) faster data processing to produce the desired capabilities. It must be remembered that most industrial robots are bolted to the floor in the areas they work or are only mobile in a limited sense. Thus a mobile base for a manipulator introduces additional system control problems or, at least, the possibility of additional problems.

In fact, these problems would be dealt with as part of the 'manipulator strategy'. Manipulation strategy, a subfunction of IC2, determines how a manipulator will do a given task. In general, "manipulation strategy is in a low state of development. This is very task dependent. Can strategies be developed which apply to a class of tasks?" (Whitney, 1980: 156). Again, the last area of discussion is IC2. Part of IC2 is communication. Communication is both internal and external.

To accomplish part of the external communication, human speech recognition is needed. Lt. Jerry Montgomery wrote an algorithm which took the output of an acoustic analyzer and determined what word was spoken. The analyzer had a set of 71 phonets, of which two were noise representations, based on the words zero, one, two three, four, five, six, seven, eight, nine. The recognition rate was greater than ninety per cent, and a few additional words outside of those original ten words were correctly identified as well. The recognition was both speaker and acoustic analyzer independent, and single words were recognized rather than sentences (Montgomery, 1982). As long as human speech to the android is limited to a few single word commands, then Lt Montgomery's recognition algorithm should be a primary candidate. It does need some improvements in terms of processing time, computer size, and memory requirements to run the algorithm. This algorithm used fuzzy set theory in its decision making process.

Fuzzy set theory and its related disciplines, such as possibility distributions, fuzzy logic, fuzzy programming, and fuzzy production, are frequently used to provide robots with the ability to make judgemental decisions. Much development and research is needed in this area to provide the level of judgement required in this maintenance android. For example, the fuzzy production system described by Whalen and Schott was a direct application to financial investments. But the concept of a fuzzy production system

> is promising because it provides a direct model of human-like qualitative reasoning about variables

> over a broad spectrum from exact concepts...to very vague and diffuse concepts, all within a unified system of approximate reasoning....fuzzy logic is tolerant of situations which would be considered paradoxical in the Aristotelian logic...the process of judgemental interaction with a fuzzy production system is well-suited to the area of decision support systems... (Whelan, 1981: 653).

These decision support systems are to be implemented on microprocessors and microcomputers which will be on board the android or will be accessible to the android. As such, these decision processes will in part be programmed algorithms. Prade and Vaina defined 'Fuzzy HOS' as the fuzzy extension of Higher Order Software (HOS) methodology and discussed the notion of fuzzy data types and the concept of fuzzy reliability. These appear as one means of specifying fuzzy systems (Prade, 1980: 850-857). If fuzzy mathematics are to be used to give the android judgemental capability, then fuzzy data types and fuzzy reliability are concepts to be dealt with. Fuzzy mathematics deserve thorough investigation),

In direct connnection with the software requirements for decision making is a need for determining probabilities (in the stochastic sense). However, when dealing with imprecise variables such as those used with and introduced by fuzzy set theory, a better descriptive term is 'possibility distribution'. Zadeh continued his work in fuzzy sets with a discussion of the theory of possibility distribution defined as "the fuzzy set of all possible vaules of a variable" (Zadeh, 1980: 242). This possibility distribution may also come to be known as 'fuzzy distribution'.

Overall, IC2 is the major 'frontier' area. Work is being done in control, artificial intelligence, pattern recognition, networking, and so on. Most of the current work uses large main frame computers or minicomputers. As computer technology advances, so does the switch to microcomputers. The current limitations of the microcomputers is their capacity, and speed. But these barriers are challenged daily. The needs here are faster algorthms, accurate pattern recognition with less required input data, the ability to work while moving, and so on. Graupe and Saridis in their paper on intelligent controls, defined intelligent contols, thusly:

> Significant results have been accomplished in Speech Recognition, Image Analysis and Perception, Data Base Analysis and Decision Making, Learning, Theorem Proving and Gains, Autonomous Robots, etc. The discipline that couples these advanced methodologies with the system theoretic approaches necessary for the solution of the current technological problems of our societies is called "Intelligent Controls". Intelligent Controls utilize the powerful high-level decision making of the digital computer with advanced mathematical modeling and synthesis techniques of system theory to produce a unified approach suitable for the engineering needs of the future (Graupe, 1980: 80-81).

Graupe and Saridis discussed a "Hierarchical Intelligent Control approach" which consisted of three levels of controls: 1) the organization level, 2) the coordination level, and 3) the hardware control level. They propsed this approach as a "unified theoretic approach of cognitive and control systems methodologies" (Graupe, 1980: 83). The authors later explained that this method was

> successfully applied to the control of a general

purpose manipulator with visual feedback and voice inputs, and traffic control system for an integrated urban and highway environment (Graupe, 1980: 84).

Increased interest in the demands which robotic systems have placed on control theory is shown by the increasing amount of research being conducted on robotic system control and the related papers discussing it. Bejczy, in 1980, discussed control theory and robotics in a generalized manner. The robotics areas discussed were robot arms, robot hands, and robot locomotion systems, without reference to a specific model. He summarized the control issues involved with multi-level robot control systems into two groups: 1) hierarchical control schemes, and 2) control logic systems.

> 1) In general, the possiblity of controlling multivariable systems efficiently requires the development of hierarchical control schemes. The information content associated with the different hierarchical control levels creates several control system design problems (Bejczy, 1980: 59).
>
> 2) Pattern recognition schemes, decision networks and logic calculations are entering into the feedback paths of advanced robot control systems. This has a profound effect on the stability and other performance characteristics of robot controls....The central issue is now to design control logic systems that provide stable and optimal performance in the domain of relevant events [vice the classical time domain] (Bejczy, 1980: 64).

Much of what Bejczy says is directly applicable to or extendable to the android control problem. He also recognized the need "to study and develop theoretical frames for the analysis and synthesis of pattern-referenced robot control systems (Bejczy, 1980: 65).

For now, the desired control system approach is that of a hierarchical control system. This is the literature's most commonly chosen method of overall robot control. Shin and Malin described a hierarchically distributed robot control system which is supposed to be flexible enough to accomodate the integration of visual and tactile sensing. However, the paper stated these two aspects had not yet been implemented (Shin, 1980: 814). James Albus, the National Bureau of Standards, has co-authored several papers on hierarchical control in robots, as well.

> The next generation of robot systems will be distinguished from present second generation systems by the fact that the operator will communicate to the robot the goals that are to be achieved, rather than defining the sequence of operations to be performed. From a description of the desired goal, the robot will automatically formulate the required plan of action. In order to generate these plans, robots will have to be instilled not only with much greater intelligence, but also much more knowledge about the objects to be manipulated. Work to develop such systems is already underway [Will, Lozano-Perez] (Shimano, 1980: 211).

In summary, primitive sight and hearing mechanisms are currently available to give the android those perceptive abilities. Also currently available are the remote center compliance devices and active touch sensing devices which are primitive touch mechanisms. Manipulators of greatly varying sizes, shapes, and capabilities are available. The technology for tracked vehicles is sufficient to meet the android's mobility needs. The limited availabilities lie with the IC2 area. And <u>that</u>, is where the current state of the art for androids and robots is at this time.

IV. Areas Requiring Further Research

Background

The approach to the recommended areas requiring further research (frequently referred to, in this thesis, as the R&D program) is broken down into functional areas, just as Chapter Three is. This is necessary since an expert in one field would not necessarily be an expert in another field, let alone be an expert in every field involved in android development. However, communication and understanding must be emphasized. When one field impinges on another, each field must know what the other has and has not done. This does not guarantee a successful interfacing of the technologies, but does make success more probable. This requires a "central" overseer who provides coordination, impetus, encouragement, and, on occasion, a 'shove' to the various groups and agencies for cooperation and communication.

Several aspects of research and development are common, regardless of the area or field of work involved. This program is no different. The current state of the art must be assessed. Items available off the shelf must be evaluated. The needs required to meet the desired goals must be defined.

Once these three aspects are assessed and compared, voids can be clearly identified. Research initiatives are then defined to fill the voids. Those shelf items requiring modification must be evaluated for cost effectiveness. Shelf items not requiring modifications, and other needed supplies or items must be procured.

As important as these aspects are, for a successful android or robotic project, the three "C's" (3Cs) must be adhered to, religiously! Communicate, cooperate, and coordinate are the 3Cs referred to by this thesis. No one area should be developed in isolation from the others. A functional android requires parts which interact, interface, and communicate efficiently together. Thus, an android should be thought of as a holistic mechanism. That is, the parts which work well separately, work even better once they are joined together to form a whole mechanism. In fact, due to the multiple interfacings, interactions, and extended communications the joined parts work at a level which is above the improvement due to just the parts cooperating.

This is why it is so important for the interaction, interfacing, and communication not to be haphazard. Each part grows and develops somewhat on its own. But even so, the other android parts and the overall goals must be considered during that growth period as well. Then as these parts eventually become the whole android, the whole android will be a holistic mechanism.

This subject, generically called robotics, and the interest it generates, is growing significantly each day. By the time this thesis is published, and the follow on work begun, a new survey of the state of the art and of the off the shelf items will have to be made for each area to be investigated because of these rapid advances. Thus, each functional area will have to have its own literature review prior to beginning actual research in that area. In addition to the literature review, some items may be obtainable directly from robotic parts sources. These parts sources are also rapidly becoming more plentiful. A few are listed in Appendix E, 'List of Contacts and Suggested Contacts'.

The items available in this manner will have to be reviewed and evaluated for their applicability to the given area of interest. Based on the information gathered by these two surveys, the decision can then be made as to whether or not the desired capabilities exist or if further research is required to achieve those capabilities.

A thorough study of the various aircrafts within, and proposed for, the Air Force inventory must be made to define the classes or types of robots and androids required. This study would include precisely <u>what</u> maintenance is done and <u>how</u> it is done for each aircraft. Studies based on related fields are needed for their descriptions as well, such as the bioengineering functional descriptions of perception, processes, and manipulations.

These studies are based on how people do the work. The results of these studies are then analyzed and transformed into what and how a mechanism efficiently and effectively accomplishes them. The results, of the analyses and transformations, determine what type, and how many androids or robots will be built. Another outgrowth of these studies would be the recommended aircraft component design and placement modifications to aid android maintenance.

These studies and analyses will require personnel who are expert electrical engineers, digital engineers, mechanical engineers, computer engineers, computer scientists, bioengineers, roboticists, aircraft maintenance personnel, and so on. Not only do they need to be experts in their own areas but they should have an interest or capability in robotics. This is necessary to allow the 3Cs to work.

Some duties or categories of duties are common from aircraft to aircraft. Thus, the idea of classes or types of maintenance robots and androids is very feasible. This idea also has the direct side benefit of robots doing simple, menial tasks in maintenance shops relatively soon. This early implementation, in turn, allows the maintenace personnel to get used to having an android or robot around, while the designers get some early field testing and much needed feedback from the maintenance personnel.

One expected outgrowth of these studies is an android or robot which is independent of aircraft type. For example, a mobile robot could fetch forgotten tools or tool boxes, check the grounds for foreign matter and remove it, and make routine security checks for unauthorized personnel or objects, or even do snow removal around hangar doors. If it never touches the aircraft, but merely gathers information such as the aircraft type, mission, and identification in addition to those other duties just listed, then the robot or android is aircraft independent. It then does menial but necessary labor, provides communication and information for other robots, androids, and people while allowing maintenance personnel and more sophisticated robots and androids to do other work more effectively, efficiently, and safely. It would also minimize the duties a more sophisticated android or robot would have.

Areas Requiring Further Research

At this time, the program is based on the android capabilities and the current state of the art as discussed in Chapter Three. The steps common to all research efforts are listed first, then each functional area is presented. This program assumes that all of the aircraft maintenance procedures for all of the Air Force's inventory were studied, and that the classes of robots and androids have been defined.

Common Steps. As each functional area is chosen by someone for research, the following questions must be answered.

1. Are the goals given in this thesis still valid?
    a. What are the changes?
    b. Are the changes significant?

2. What is the current state of the art?

3. What is available as shelf stock?

4. Comparing 1. with 2. and 3., what are the current needs?

a. Are there still voids requiring research?

b. How much research effort will be required?

c. Is the shelf stock suitable?

d. Is modification of shelf stock cost effective?

e. Should a special manufacturing requirement be made, instead of modifying shelf stock?

f. Is the shelf stock easily interfaced to other components?

g. Can other components be easily designed or redesigned to interface better with the shelf stock to be used?

h. At this time, are further changes in the current model cost effective, or would incorporating the innovations in a later model be more cost effective?

i. Have you continuously applied the 3Cs?

5. What are the wartime hazards?

a. What about bullets and schrapnel, blast and thermal radiation?

b. What about radiation effects, both direct and indirect?

c. What about the chemicals used in both chemical warfare and in defense (from fire extinguishers to anti-chemical warfare chemicals)?

IC2. IC2 requires the most work. It has the highest priority of the functional areas. IC2 affects all of the functional areas and is the single most critical area of all, for the android. Control theory and practice will have to be extended and developed. Sturdier and more mobile hardware will have to be developed. Internal sensing and communications will have to be improved in speed, sturdiness, and compactness.

More specifically, smaller, faster, more durable processors are needed. The algorithms which allow experts to pass on their judgemental capabilities to the android, as well as those algorithms which provide the artificial intelligence, control and communication must be improved and, in some cases, developed from scratch. This is the first frontier for androids. Without resounding success here, success in the other areas is limited. IC2 must do all of this, and meet the common research needs stated previously.

Perception. Perception is the second most important functional area. The needs of IC2 overlap the perception needs. These needs in perception are limited to the sensors and sensory applications, rather than applied to the whole android. [IC2 is applied to the whole android.] Again, the processors and algorithms associated with the sensors need to be faster, more compact, and able to meet the common research requirements described earlier.

The pattern recognition capabilities need to be improved. The sensors need to supply accurate data while moving. Also, if remote sensors are needed, then the means to receive data from these remote sensors in a timely manner must also be developed. Sensors need to be miniaturized and reliable. The data output by the sensors needs to be easily useable by the pattern recognition algorithms. The types of perception, in their order of priority, are speech, touch, and vision. This is also the order based on the amount of work needed in that area for success. [Remember, human type vision is not considered feasible in the foreseeable future.]

Manipulators. As listed above for IC2 and perception, manipulators have some common needs: good algorithms, the ability to function from a non-fixed base, fast and compact processors, interfacing capabilities, and the ability to meet the common research requirements described previously. The development of interchangeable end effectors and the resulting IC2 interfaces (could be a problem) has need of the most effort in this area. Within the functional area of manipulators, the interchangeable end effector and its interfaces has top priority.

Mobility. As listed for the three previous functional areas, mobility's greatest need is for work on the mobility applications of IC2. This area was given the lowest priority because the desired technology is primarily available. The algorithms which provide the intelligence and control functions are actually part of IC2. Ensuring

IC2 for mobility is accomplished and meeting the common research requirements described previously, is all that is left to be done in this functional area.

What Can Air Force Agencies Do?

The Air Force agencies discussed here are AFIT, and AFAMRL with general recommendations for other Air Force agencies. The discussions are kept at a general level, with specific recommendations made in Chapter Six, 'Conclusions and Recommendations'.

AFIT. AFIT is a tremendous, and frequently untapped, source of manpower. All three schools have access to large numbers of 'free labor'. The Engineering School and the school of Systems and Logistics have students in residence for relatively long periods of time. Their thesis students have curriculums ranging from 12 to 18 months. For robotics, the Engineering School will provide the most resources, although the Log School does have Engineering Management students who could easily have the background and interest to work in some areas. Another school, commonly forgotten, is the School of Civil Engineering. The School of Civil Engineering's resident students are primarily short course students. However, some of the courses require students do special projects as a group. Thus, it is possible that some small managerial or technical design problems could be done by a group of Civil Engineering students, such as a physical requirements definition.

Thus students could easily tackle and solve small problems requiring one man-month to one man-year of work. Students are well able to do literature surveys and reviews with constructive comments and thoughts. The same is true for checking what is available as off the shelf items. Students are willing to do special projects as part of a laboratory class, or as a one or two term special study, or even as a full thesis effort. Most students want to do work which is interesting and which challenges and stimulates their imaginations. Probably most important, students are willing to 'break their backs' if they truly believe the work they are doing is useful, and not just an academic exercise!

The 'management' of AFIT can encourage this. The Engineering School should offer courses in robotics and its related fields, and establish a program in this area, as well. This should be a resident program and a continuing education program. With a resident robotics program, students would have a better robtics background from which to do thesis work. The continuing education program would allow the training and familiarization of Air Force personnel in robotics. This is needed if the Air Force is going to work in, or monitor contracts which make the robots or androids, or if the Air Force is going to use the robots or androids once they are developed. AFIT and its students could do very valuable research and development for the Air Force in robotics with some financial backing for research, for instructors, and for classes. Once an agency decides to be involved with robotics, it defines what it will do. It then has to break that definition into smaller, more workable pieces. Some of these pieces and subpieces, AFIT could do for the agency. Thus the agency involved would sponsor and support (with money, manpower, material, etc) special projects and thesis efforts.

Just as AFIT has a continuing pattern recognition research laboratory, there could be other continuing efforts in robotic control research, artificial intelligence research, and so on throughout the functional areas needed for robotics. But this requires manpower and funding for the school to do this.

AFAMRL. The Air Force Aerospace Medical Research Laboratory and its Modeling and Analysis Branch

> had a program in areas of bionics, cybernetics, artificial intelligence, pattern recognition and, to some extent, robotics a number of years ago. These programs, by specific directives, were discontinued, with total technical withdrawal occurring in the mid-70s. Recent Air Force top-level guidance, however, has revived these technological areas and encouraged new program initiatives. In response to these, our laboratory has sought to define its role within these technological areas as well as to simultaneously focus on a specific applications scenario. This latter being the development of robotic techniques for servicing aircraft in hazardous environments (Kaleps, 1982).

Assuming the Air Force supports AFAMRL's mission, it can resume its previous efforts as applicable to the desired goal described in Chapters Two and Three. As these efforts are resumed, there will be areas which would fall under the capabilities of AFIT. Since AFAMRL and AFIT are physically located near each other, AFAMRL could easily support projects done at AFIT with personal guidance, resources, and money for those projects of interest to AFAMRL.

On the broader scene, work will have to be done at AFAMRL to evaluate what can be done by themselves, in house, and what would have to be contracted out. Additionally, AFAMRL needs to maintain contact with private industry and other Air Force agencies as to what is being done, by whom, and where. This is done of course, by attending conferences, reading the literature, and through personal contacts. But, AFAMRL can also sponsor workshops, meetings, and conferences bringing the experts from the various disciplines together. As the different disciplines come together frequently, then the intercommunication becomes easier. Thus, the 3Cs could be implemented more easily, as well.

Wright Patterson AFB has many agencies involved in robotics and related areas such as ICAM (Integrated Computer-Aided Manufacturing) and CAD-CAM (Computer-Aided Design Computer-Aided Manufacturing). It is surprising just how many different offices are involved. Some of these are listed in Appendix D. A monthly luncheon seminar with local speakers or discussions of non-classified material would also help the 3Cs to grow and be implemented, at least on the local base level.

<u>Other Air Force Agencies</u>. In as much as their current or revised mission statements allow, other agencies should

think of what they are doing which could contribute to the growth of robotics. Those agencies not research oriented, should think in terms of what could be done by a robot or an android and what would be 'nice' for a person not to have to do. Managers should not think of robots or androids as replacing people in the sense that people will be lost. But they should think of robots and androids as a means of protecting their people from harm in dangerous situations, or of relieving them of drudgery that no one really likes or wants to do. Those are the situations and times that robots or androids are needed, not to replace humans at what they enjoy doing!

Not only that, but in war, if robots can do what people do, and do it well, then by combining people and robots or androids would allow needed resources to be dispersed. Dispersed resources are more costly for the enemy to destroy. For example, assume an airfield requires 20 maintenance troops to be on hand to handle the wartime aircraft maintenance, and assume that one android can do the work of one person. Then, if 20 androids were available, by putting 10 people and 10 androids together, there would be enough maintenance 'personnel' to man two airfields. The second set of personnel could be sent to one of Civil Engineering's 'portable' airstrips. This provides additional places for the aircraft to be, forcing the enemy to expend more energy and resources to destroy our resources.

V. Mobile Platform Project

Over the past several years at AFIT, various short-term, robotics oriented projects were tackled. The time spent on each project varied from weeks to several months. Many aspects and results of these efforts were sucessful. Some were directly applicable to this mobile platform project while others were peripheral. Inititally, the physical results and documentation of these previous efforts were gathered. Once gathered, it was obvious that some organization and sorting was required to determine what was of value to the immediate project and goal.

Some of the documentation was very useful and informative. Unfortunately, most had little direct bearing or else required much work to discover what was or was not useful. As part of a previous effort the mobile platform had been constructed. Since an economical mobile platform could not be found in time for this project, it was decided to continue using this platform. An MMD-1 microcomputer had been associated with this platform in a previous project, and considering the resource constraints its use was continued also. The MMD-1 executes 8080 code. Thus, if an upgrade to a better microcomputer chip at a later date included this capability then all the existing computer code would be useable with the new microcomputer. With an appropriate compiler, code could be developed in a higher order language such as FORTRAN or PASCAL.

The AFIT MMD-1/MI configuration had 2.5K of user accessible "on board" memory. This configuration also allowed the use of an ADM-3 CRT terminal, and cassette recorder for nonvolatile memory. This nonvolatile memory was necessary when working with an MMD-1, since loss of power meant a loss of memory. The MMD-1 also required hand keying in of programs, since downloading from a higher order machine was not avaliable. The tape recorder allowed long programs to be stored on tape, and then reloaded into memory from tape. Maj Borky, a past professor at AFIT, had used the CRT terminal and cassette recorder with an MMD-1 while at AFIT. However, little documentation was available on how he was able to get the setup working. All that was known was that he had used the three pieces of equipment together.

Many hours were spent discovering how to get these three major pieces of hardware communicating properly with each other. As a result, the code given in Appendix C was generated. These programs included a bootstrap loader routine, a write to the cassette recorder (from the MMD-1 memory) routine, and a read from cassette recorder (to the MMD-1 memory) routine. The bootstrap loader was the minimal code hand keyed into the MMD-1 which, when executed, loaded code from the tape into the MMD-1 memory. Thus, it works similarly to a disk bootstrap loader. Several other useful routines were written or modified which helped to implement the above mentioned routines. Some of these other routines were a time delay routine, a display routine (which displayed the memory contents on the MMD-1 LEDs), and a return to the CRT monitor control routine.

Additionally, extra copies of the MMD-1/MI and EID-1 operating manuals and EID-1 laboratory experiments were collected and annotated to reflect the special AFIT configuration and the special data collected while accomplishing this project. The manuals were not included in this thesis since they reflect a system unique to AFIT. However, they do exist at AFIT for future reference by those doing follow on work at AFIT.

Once communication was established between the MMD-1 and its peripherals, work progressed on making the platform move. The first movement goal was to find motors which would turn the wheels while attached to the platform. The wheels were acceptable (vice the recommended tank tracks for the 'ultimate' android) since the platform's current and near future movement will be restricted to building corridors and rooms which have level, smooth floors.

The previous effort tried stepper motors, since it was felt they would be easier to interface to a digital computer for computer control. However, the specification sheet for the stepper motors stated that the torque (per motor) was a maximum of 43 oz.-in. The suggested uses for these motors were chart drives, X-Y plotters and paper feed drives. Needless to say, the motors could not move the mass combination of the platform, motors, and wheels. The estimated combined weight was 35 pounds.

Extensive searching (via letters and telephone calls) discovered a small DC motor with a starting torque of 75.0 in.-lbs. and a running torque of 21.0 in.-lbs at 16.0 RPM. No specification sheet came with the motors, this data was provided in the catalog where the motors were found. A copy of this catalog page was provided in Appendix F. Two motors were purchased, one for each wheel. The motors were mounted on the platform and attached to the wheels. Each motor was connected directly to the DC-power source to test the motors. One motor turned the platform in a circle using the stationary wheel as a pivot point. Maj Ross then sat on the platform and repeated the test. The single motor again turned the platform in a circle, pivoting around the stationary wheel. The current measurements were not taken at this time, but were taken later, in July 1982 to determine the current drawn. The power source used for these tests was not a battery, but a constant DC power source which used a normal 120-volt AC socket.

The estimated weight of Maj Ross, and the platform was two hundred pounds. Since one motor could move two hundred pounds (with the AC-powered DC power source), it was felt that the platform should be able to carry the weight needed with both motors running. While waiting for the 12-volt DC (car type) battery to be found and charged, a simple motor controller was designed (by Dr. Jones) and built. The motor controller design was based on gross current measurements made in July 1982. The current was 1.2 amps (approximate) while running and 3.5 amps (approximate) when stalled. The actual current readings were not steady, but were always less than the values reported above. The motor controller diagram was presented in Figure 3.

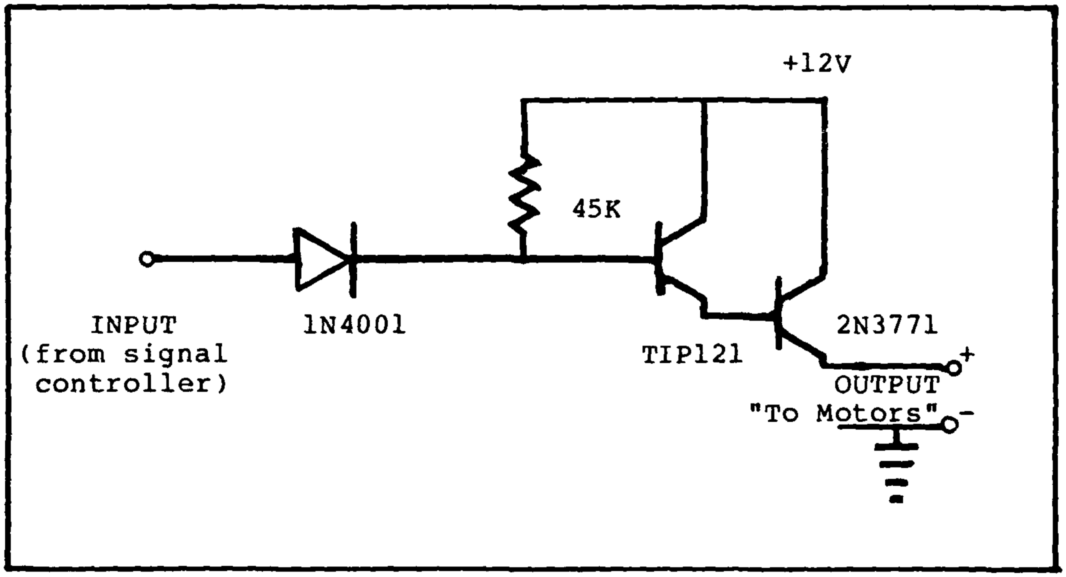

Figure 3. Motor Controller

The normal tolerance in color coded resistor values was used to balance the two motors' voltage output through the motor controller. This resistor tolerance was five per cent. The motors were not identically matched. The drift introduced by this slight mismatching of the motors was acceptable during these initial stages. Both motors were operated from the same power source, with the voltage passing through a motor controller for each motor. These motor controllers minimized the inherent differences between the two motors.

(Later, the drift was minimized even more by use of a second input signal controller, i.e. each motor had its own input control).

A variable speed was desired, so a simple input signal controller was designed (by Dr. Jones) and constructed as shown in Figure 4.

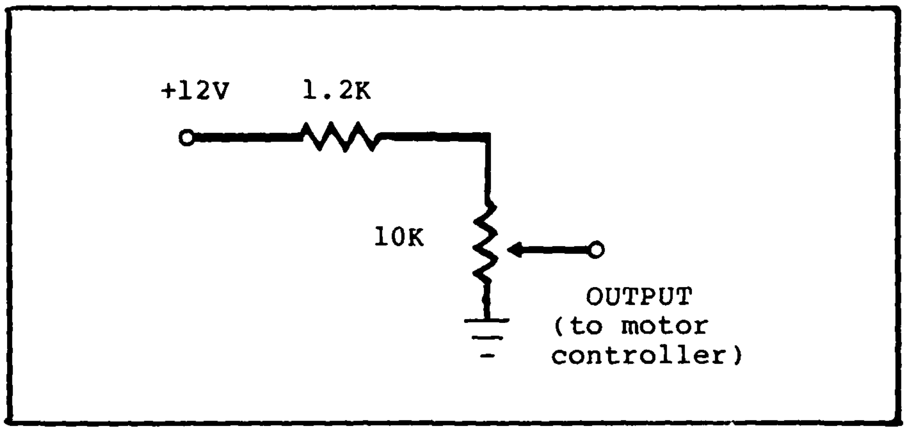

Figure 4. Input Signal Controller

This allowed the motor controller output to be varied depending upon the output of the input signal controller. This control was manual by using a variable resistor, but this was the "hook" to allow the MMD-1 to control the motor speed. By replacing the circuit of Figure 4 with a D/A signal converter, the MMD-1 could control the motor speed. The output voltage of this controller was 0 -> 9 volts. Initially one input signal controller was constructed and used to control both motors simultaneously. Once one input signal controller worked, a second was built and installed, so each motor was controlled independently. The dual input signal controllers minimized the drift due to unmatched motors even more.

The motors worked and were controllable while receiving power from the constant DC-power source. Next the motors and controllers were tested with the battery as the power source. Thus, the platform was independently powered and by replacing Figure 4 with the appropriate D/A signal converter, the platform could be connected to the MMD-1 for computer control. A previous effort had established the means for operating the MMD-1 from a 12-Volt battery (Meisner, 1981). This operability was not verified as part of this project. The next task verified whether the battery operated platform could support the weight of an individual. As currently configured, with the controllers shown in Figures 3 and 4, the platform would not move.

The capability to carry an individual was not required, however, the requirement was for the platform to move with 100 pounds of equipment and related devices attached to it. This 100 pounds represented the additional features which might be added and tested at a future date, such as manipulators, visual sensors, additional communication, control and intelligence features, and so on. Since it was difficult and inconvenient to find and weigh objects to a total weight of 100 pounds, a 'quick and dirty' test using an individual was tried. The conclusion was that if the platform could move with an individual (at least 100 pounds) then, the platform would suffice for the future equipment testing expansion requirement.

Not only would the platform not move with the individual on top, but when the individual got off, the platform still would not run. When directly connected to the battery, the motors still worked. Apparently, the current required for such a load was too much for the input signal controllers as designed. Since the input signal controllers were to be replaced by D/A signal converters, the controllers were not improved to handle the current requirements. This will be of significance to whoever designs the D/A signal converter, however.

The AFIT School of Engineering had a graduate student who designed an electric vehicle power controller as his thesis (Frazier, 1981). Captains Clark Briggs and Aaron DeWispelare (Astro/Aeronautical Engineering Department) brought this thesis document to my attention. At this stage, this controller was more elaborate than necessary. However, as the platform develops more and more in capabilities, improved motors, or both, this controller (with or without modifications) may prove very worthwhile.

Thus, the platform moves on its own and can have the computer "brain" added as a later project. Other features could be added as they are developed or become available. The following chapter, "Recommendations and Conclusions", provides more detail.

VI. Recommendations and Conclusions

Discussion

This thesis consists of two parts, a theoretical portion which results in the recommended areas for further research program as presented in Chapter IV, and a practical hardware project, presented in Chapter V. The theoretical problem studied was the development of a program from which a detailed R&D plan could be prepared. This R&D plan, if carried through, would result in a mechanism which would provide aircraft maintenance in a hostile or hazardous environment without direct human supervision.

The initial work was a literature survey to see if this had been done previously and whether or not it had been documented. Various people involved with the robotics field were interviewed. The literature in the four main functional areas: 1) mobility, 2) perception, 3) manipulators, and 4) IC2 was surveyed. Each area, in itself, could use an in depth literature search and study of approximately six months. There was not sufficient time for that, although each area was reviewed sufficiently to recommend the most likely areas to give the desired results. In addition to reading and interviewing, several seminars on robotics were attended to keep abreast of current efforts and to make additional contacts within the field.

Armed with some knowledge of what was available in the field, the 4950th TW/OMS was visited. The maintenance personnel were observed and interviewed to define general maintenance duties. The R&D program addressed these general duties, not specifically how the duties were done. To fully implement this program, a thorough study of all Air Force aircraft must be done to define the how (with respect to the android), and the previously mentioned in depth literature search and study must be done, also. The program did not discuss maintenance of the android, that is, whether the android would maintain itself and/or others, or whether human maintenance would be required.

To provide AFIT with a means of assisting in this R&D effort, a hardware project was undertaken. This project consisted of consolidating past AFIT efforts (both successful and unsuccessful) at building a working mobile platform. This was done, and is ready for follow on work as small projects and/or thesis efforts.

Conclusions

1. When examined logically, the R&D program should provide the desired results if appropriate funding and manpower are provided.

2. The platform moves and is ready to have various devices attached and interfaced to it, such as sensors, manipulators, artificial intelligence, and IC2 in general.

3. Based on the literature, a central clearing house is needed to help provide coordination, cooperation, and

communication among the various disciplines involved in this field. This would help the various disciplines to approach robots and androids from a holistic point of view.

Recommendations

1. It is suggested that the R&D program as outlined in Chapter IV be supported and carried through.

2. It is suggested that coordination, cooperation, and communication among the various disciplines in the robotics field be supported and encouraged.

3. It is suggested that a 'Central Clearing House' on robotics be considered and established. A description is given later.

4. It is suggested that robotic efforts in academia, industry, and DOD be supported and encouraged through meetings, workshops, seminars, classes, research, and sponsorship.

5. It is suggested that Air Force personnel be trained at various levels in this field, to meet the Air Force's current and <u>future</u> needs as managers, researchers, technicians, implementors, and maintainers.

6. It is suggested that AFIT, via the School of Engineering and the Civilian Institution Program, establish an accepted curiculum in robotics and its related fields.

7. It is suggested that the AFIT staff and students conduct research in these fields with Air Force goals in mind.

8. It is suggested that AFIT teach short courses and continuing education courses to train Air Force managers and other DOD personnel in the basic robotic disciplines to facillitate better management of robot related requirements.

9. It is suggested that the AFIT platform (also known as 'R2P2', Roz's Research Platform Project) continue to be used as a mobile research test base.

10. It is suggested that the computerized maintenance system currently being tested be further evaluated and possibly expanded to provide a data base access for the maintenance android.

Further Recommendations for R2P2

1. It is suggested that the input signal controller be replaced by a microcomputer and appropriate D/A signal converter.

2. It is suggested that reevaluation of the motors and motor controllers if R2P2 should ever weigh more than 100 pounds with all of its equipment on board.

3. It is suggested that the sensors and related IC2 be added to R2P2 in stages:

a. To what is now available, add a hole sensor to prevent R2P2 from wandering into open stairwells or elevator shafts;

b. Add, to a., side sensors and a forward sensor to allow R2P2 to detect stationary objects and respond, including box canyon type of situations;

c. Add, to b., sonar sensors to detect stationary versus moving obstacles, inclines, and holes while using the sensors in b. as a failsafe measure:

1) Minimally, using those sensors found in self-focusing cameras;

2) Preferably, using one of the more advanced sonic or ultrasonic sensing devices;

4. It is suggested that the previously accomplished battery supplied voltage for the MMD-1 be evaluated.

5. It is suggested that artificial intelligence work be designed and implemented on R2P2.

6. It is suggested that speech and speech recognition be implemented on R2P2 once Dr. Kabrisky's laboratory feels it is ready to test mobilized speech, speech recognition, and response.

7. It is suggested that vision and vision recognition be implemented on R2P2 once Dr. Kabrisky's laboratory feels it is ready to test mobilized vision, vision recognition, and response.

8. It is suggested that AFIT evaluate and buy two manipulators for use and testing:

a. One for bench use and testing;

b. One for R2P2 (mobile) use and testing.

9. It is suggested that AFIT consider, evaluate, and buy one of the whole robot kits currently available, such as Heath's HEROI.

10. It is suggested that the current microcomputer

technology be evaluated to determine if a better microcomputer chip is available to be used in R2P2 as part of, and to form, an overall IC2 network.

Description of a Robotic Clearing House

There should be one government backed group to serve as a central clearing house for robotic android research and development. This could be privately run, i.e. a foundation supported by the government. In part, this is contrary to the opinion expressed by DOD Deputy undersecretary, Edith Martin.

> Instead of a central administration for a robotics program, Martin suggested an information exchange system using data base technology. A program to assess the impact and development of robots across the entire spectrum of technology to take place every two years, is also under discussion (Military, 1982: 4).

However, the final results of Martin's suggestion would parallel those espoused here.

The new group would function as a clearing house for all government funded research. It is needed to serve as coordinator, communicator, and cooperator. It would also dissemenate unclassified/classified information resulting from the sponsored research. (Of course classified information would only be passed on after meeting the then current requirements for receiving classified information.) This relationship is illustrated in Figures 5 and 6.

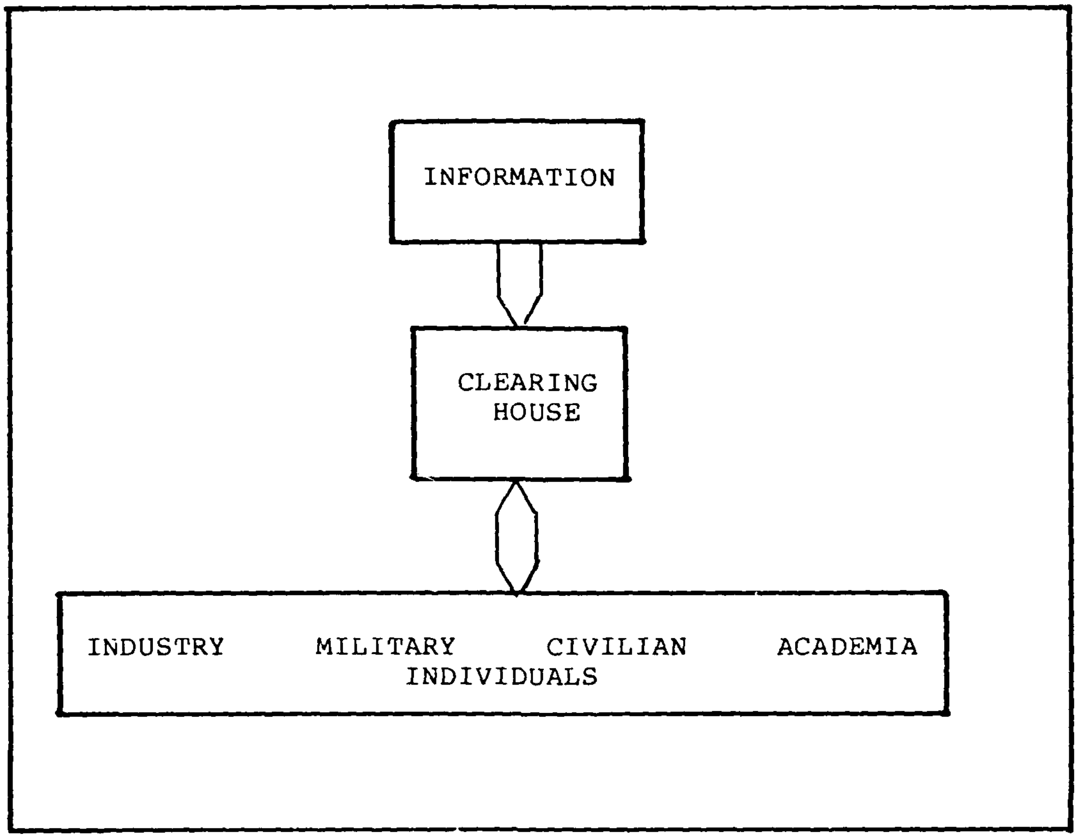

Figure 5. Clearing House Relationships

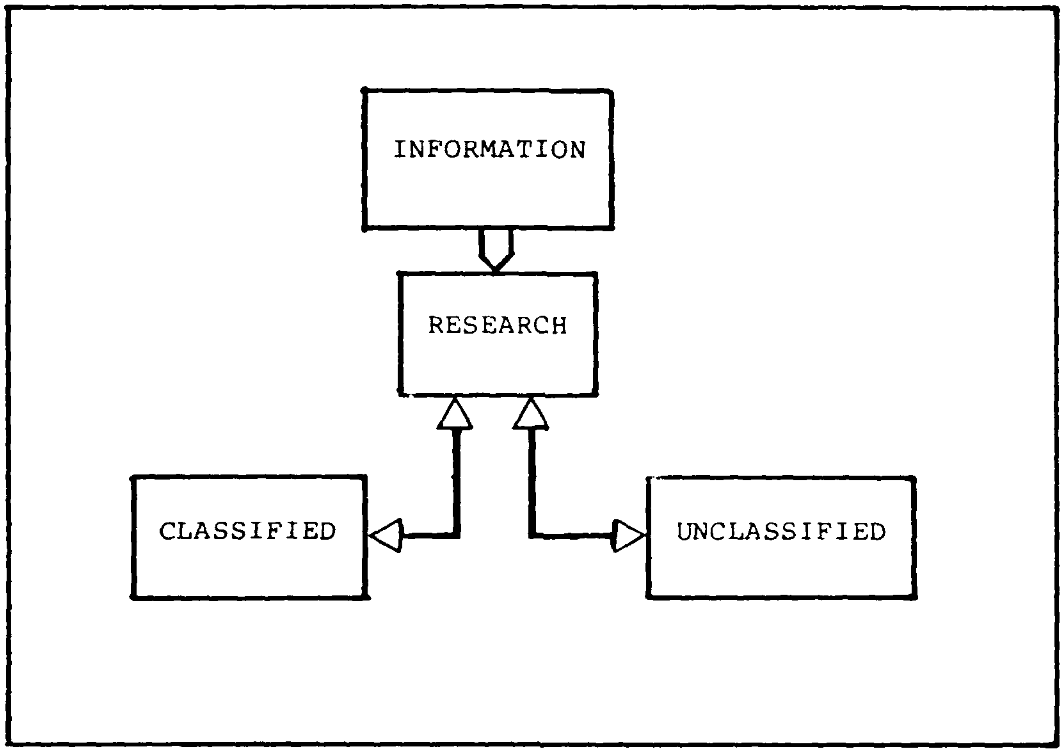

Figure 6. Information Exchange within Clearing House

Since processes, inventions, information, and such resulting from government funded research are generally considered 'public domain', this information sharing should really pose no problems whatsoever! Anyone using government money for research normally agrees to this.

As a clearing house for robotics related information, it could reduce redundancy somewhat, thus saving money and time. In scientific efforts, some duplication of effort is necessary to ensure that the first occurrence was not a 'fluke' of nature or wishfull thinking. This duplication of results is usually accomplished by using a different approach from previous efforts. As a central location for information in this field, it could coordinate research efforts nationwide and provide better communications among all the researchers. With the increased communication, a possible outgrowth is standardization of terms and information.

The information pool would help minimize the unnecessary duplication of efforts in areas already explored, possibly provide points for future research and/or investigation, and most importantly, open the way for better communication among the various researchers working on robotics. These different areas are so diverse and many, that for one person to be expert or even understand them all is nearly impossible. A group would have at least one expert in each area, and interface people would be needed to serve as 'interpreters' among the different experts to enhance these communications.

The group should have a central site, representatives who are co-located with major research and development participants (both academic and industrial), and Roving representatives to work with and visit those places which would not qualify for a permanent representative. The group could conduct its own research as well (with all of those experts in one place, working together on research seems reasonable). The education with industry and military research associate programs would benefit heavily from this as well.

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Interviews. Several AFIT students were interviewed for their opinions and suggestions with respect to the topic of the thesis. These students were USAF officers in either test engineering, aircraft maintenance, navigator, pilot, or radar-navigator career fields. One officer had prior enlisted time as a flight engineer. The officers interviewed included: Capt Geno Cuomo, Capt Dick Maul, 1Lt Craig Hazelton, Capt Rick Taylor. Capt Drew Peterson of the 4950th TW was briefly interviewed as well. These interviews were conducted throughout the 1982 calender year.

Kaleps, Ints. Interview. (20 August 1981), Wright-Patterson AFB, Ohio. Dr. Kaleps is the Branch Chief for the Mathematics and Analysis Branch of the Air Force Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio. The interview was to determine whether or not Roz Taylor (thesis student) would be sponsored by Dr. Kaleps and AFAMRL. Dr. Kaleps outlined what he was interested in sponsoring and discussed Capt Taylor's thesis interests.

Kaleps, Ints. Letter. (18 September 1981b), Wright-Patterson AFB, Ohio. Dr. Kaleps is the Branch Chief for the Mathematics and Analysis Branch of the Air Force Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio. Dr. Kaleps stated his interest in supporting Capt Taylor's thesis.

Kaleps, Ints. AFIT Research Assessment Comments. (December 1982), Wright-Patterson AFB, Ohio. Those individuals and agencies which sponsor and/or support AFIT thesis efforts are required to evaluate the value and/or contribution of the research accomplished by the student.

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Mayer, Lt Gordon E. Interview. 5 November 1981, Wright-Patterson AFB, Ohio. Lt Mayer is the Projects Manager, Materials Laboratory, Wright-Patterson AFB, Ohio. He has his M.S. in robotics from Purdue University (1979). His thesis was on the Kinematic Design/Control of Manipulators. He worked most of 1979 for Unimation prior to coming on active duty (Air Force).

McGhee, R. B. "Robot Locomotion with Active Terrain Accomodation", Proceedings of the Workshop on the Research Needed to Advance the State of Knowledge in Robotics, 15-17 April 1980. The workshop was supported under NSF Grant #ENG79-21587. pp 167-177.

Meisner, Capt Robert, Lt Andrew Gravin, Lt Todd. The Robot Users Manual. An unpublished laboratory report on an unsuccessful mobile platform project. School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, 25 March 1981.

Military Electronics/Countermeasures, "Washington Perspective" 8 (8): 4 (August 1982).

Montgomery, Jerry Lt. Notes from guest lectures given by Lt. Montgomery to EE 8.17 class in November 1982, on his MSEE thesis. Presented at the Air Force Institute of Technology, Wright-Patterson AFB, Ohio.

Nitzan, David. "Assessment of Robotic Sensors", Proceedings of the Workshop on the Research Needed to Advance the State of Knowledge in Robotics, 15-17 April 1980. The workshop was supported under NSF Grant #ENG79-21587. pp 182-194.

Peters, Lawrence J. SOFTWARE DESIGN: Methods & Techniques. New York: Yourdon Press, 1981.

Prade, Henri, and Lucia Vaina. "What 'Fuzzy HOS' May Mean", Proceedings of the IEEE Computer Society's Fourth International Computer Software and Applications Conference. Chicago, Palmer House: 1980. pp 850-857.

Raphael, Bertram. THE THINKING COMPUTER: Mind Inside Matter. San Francisco: W.H. Freeman and Company, 1976.

"Recent Selections of the Library of Computer and Information Sciences", published approximately 14 times per year by the book club entitled The Library of Computer and Information Sciences, a subsidary of Macmillan Book Clubs, Inc. They review published books of possible interest to people in the computer and information sciences fields. The selections bulletins quoted in the supplemental bibliography are to help would be readers evaluate whether or not a book is of interest. The bulletins were all printed in 1982.

Rosenfeld, Azriel. "Rapporteur for Sensing Systems", Proceedings of the Workshop on the Research Needed to Advance the State of Knowledge in Robotics, 15-17 April 1980. The workshop was supported under NSF Grant #ENG79-21587. pp 198-205.

Ross, T. Douglas. "Structured Analysis (SA): A Language for Communicating Ideas", IEEE Transactions on Software Engineering, SE-3 (1): 15-35 (January 1977).

Saridis, George N. "Intelligent Robotic Control", Proceedings of the 1981 Joint Automatic Control Conference, 17-19 June 1981. Volume 1. American Automatic Control Council, 1981. pp TA-2E.

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Seminar. "Robotics: Productivity Tool for Today". A one-day seminar presented by the AIIE, IEEE, and the AES-S. Held at the Dayton Marriot Hotel, Dayton, Ohio: 17 April 1982. No proceedings published.

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Shin, Kang G., and Stuart B. Malin. "A Hierarchically Distributed Robot Control System", Proceedings of the IEEE Computer Society's Fourth International Computer Software and Applications Conference. Chicago, Palmer House: 1980. pp 814-820.

Shin, Kang G., and Stuart B. Malin. "Dynamic Adaptation of Robot Kinematic Control to its Actual Behavior", Proceedings of the International Conference on Cybernetics and Society, 26-28 October 1981. Sponsored by the IEEE Systems, Man and Cybernetics Society. New York, IEEE: 1981b. pp 420-427.

Tesar, Delbert. TESTIMONY on HEARING FOR ROBOTICS, Presented to The Subcommittee on Investigations and Oversights of the House Committee on Science and Technology, 2 June 1982. Professor, Mechanical Engineering, Director of the Center for Intelligent Machines and Robotics (CIMAR), University of Florida, Gainesville, Florida 32611.

Tour. EE 8.17 class visited the WPAFB Area B Communications Center run by the 2046th Communications Squadron, to see the OCR Message reader and sender operate. Additionally, information about some of the other communications equipment used, was explained.

Van Brussel, H., and J. Simons. "The adaptable Compliance Concept and its use for Automatic Assembly by Active Force Feedback Accommodations", Proceedings of the IEEE Computer Society's Fourth International Computer Software and Applications Conference. Chicago, Palmer House: 1980. pp 167-181.

VanderBrug, G. J., J. S. Albus, and E. Barkmeyer. "A Vision System for Real Time Control of Robots", Proceedings of the 9th International Symposium on Industrial Robots, 13-15 March 1979. Dearborn, Michigan, Society of Manufacturing Engineers: 1979. pp 213-230. This work was done while at the National Bureau of Standards.

Vranish, John M. DOD Research Program in Robotics. NSWC TR 80-325 brief overview of the DOD Research Program in Robotics. Sponsored by Naval Surface Weapons Center, Silver Spring, Maryland 20910: 10 September 1980. DTIC #AD A100744.

Weinstein, Martin Bradley. "Design your own android", Radio-Electronics, 37-40 (January 1980). NOTE: I was supplied a copy of this article, without full referencing available. Searching the periodical literature guides did not produce a volume number or issue number.

Whelan, Thomas, and Brian Schott. "Fuzzy Production Systems for Decision Support", Proceedings of the International Conference on Cybernetics and Society, 26-28 October 1981. Sponsored by the IEEE Systems, Man and Cybernetics Society. New York, IEEE: 1981. pp 649-653.

Whitney, D. E., and J. L. Nevins. "What is the Remote Center Compliance (RCC) and What Can It Do?", Proceedings of the 9th International Symposium on Industrial Robots, 13-15 March 1979. Dearborn, Michigan, Society of Manufacturing Engineers: 1979. pp 135-152.

Whitney, D. E. "Rapporteur for Manipulation", Proceedings of the Workshop on the Research Needed to Advance the State of Knowledge in Robotics, 15-17 April 1980. The workshop was supported under NSF Grant #ENG79-21587. 1980b: pp 156-161.

Zadeh, L. A. "Possibility Theory as a Basis for Information Processing and Knowledge Representation", Proceedings of the IEEE Computer Society's Fourth International Computer Software and Applications Conference. Chicago, Palmer House: 1980. pp 842-849.

Related Sources Bibliography (Annotated)

This bibliography contains material of possible interest to those continuing the research and work suggested by this thesis. This information and that contained in Appendix E were discovered while preparing this thesis. The information was not directly pertinent to this thesis but could be valuable to those whose work follows.

Several of the electronics trade type magazines (for technicians and repairmen) discuss parts, and components suitable for robotic/android usage.

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Ballard, Dana H. and Christopher M. Brown. Computer Vision. "Explores the technical and theoretical aspects of computer-based systems of vision. From image scanning to frame theory, from programming for coordinates to problems of image definition and recognition, covers important topics as optical flow, templates and image geometry, control stategies and control mechanisms and more" (Recent, 1982). I had purchased this book, but before I reviewed it thoroughly, I loaned it to Dr. Kabrisky (this is one of his areas). Unfortunately, at this time, he still has the book so I am unable to provide the full bibliographic information. The copywrite date should be 1982 or 1981.

Barr, Avron, Paul R. Cohn, and Edward A. Feigenbaum. Handbook of Artificial Intelligence, Volumes I and II. RE: Vol I, "Outstanding collection of articles on AI research, produced at Stanford University. How computers exhibit near-human intelligence" (Recent, 1982). RE: Vol II, "This comprehensive collection of papers and articles inquires into areas like programming languages for AI research...data structures and control structures for the AI environment...AI research for scientific application...database storage and retrieval techniques for the AI environment...and more" (Recent, 1982).

Bejczy, A. K. Advanced Robot Control: A Tutorial Workshop. Bejczy was the organizer of this workshop at the 20th IEEE Conference on Decision and Control, held in San Diego, CA on 16-18 December 1981. The three sessions were 1) Robot mechanisms, sensors and control, 2) The mathematics of robot control, and 3) visual sensing for robot conntrol. The flyer summarized the workshop as follows:

The development of advanced robots calls for the study and implementation of advanced feedback control systems. This tutorial workshop (i) will provide an

introduction to robot control problems and to robotics in general, and (ii) will outline the technical meaning of "advanced feedback control" within the context of advanced robot control. Robot modeling for control, the mathematics of robot control and sensor-referenced robot control systems/tehcniques will be discussed.

If this was published as other IEEE tutorials have been, this would probably be worthwhile to have in the library and for those working in the areas discussed.

Chang, S. K. The Translation of Fuzzy Queries. This was a paper scheduled to be given at the 1980 IEEE COMPSAC, but was not included in the proceedings for the 1980 COMPSAC. Only the abstract was included, and described the paper as dealing with the translation of fuzzy, or imprecise, queries for a relational data base system. Examples were to be presented for fuzz translation, and extension to pictorial fuzzy query translation was also to be discussed. Knowledge Systems Laboratory, University of Illinois at Chicago, Chicago, Illinois was the affiliation given for the author. This paper might be worthwhile to someone working with fuzzy set theory and the android's decision making capabilities.

Electronic Products. Special Reference Issue on "Controls, Drives, and Switches". Volume 24 Number 8, 30 November 1981. Some article titles include "The Encoder/Controller Interface", "I/O Modules Refine Industrial Control", "Source List: Motors", "Don't Confuse Pressure Sensors and Transducers", "Source List: Pressure Transducers", and "Source List: Temperature Transducers".

Freedman, M. David, and Lansing B. Evans. DESIGNING SYSTEMS WITH MICROCOMPUTERS: a systematic approach. This is a forthcoming book from Prentice-Hall: 1983. Excerpts from this book were used as course notes for a seminar sponsored by the Engineering Society of Detroit, Detroit, Michigan, 20-21 September 1982. Dr. Freedman has developed an English programming design language (not just a 'pseudo-English' design language). He also has a translator which takes his design language (85%) to PL/M. He either has or plans to extend this to an additional HOL such as FORTRAN or PASCAL. His design language is presented in his book. This design language is much easier for the customer to understand, and minimizes the programmer's natural tendancy to jump into coding. The machine translation of the design language to code, provides a more standard approach to coding which makes maintenance a little easier since the code for most of the routines is consistent.

Geschke, Clifford Calvin. A System for Programming and Controlling Sensor-Based Robot Manipulators. The thesis was submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Electrical Engineering in the Graduate College of the University of Illinois at Urbana-Champaign, 1979. DTIC #AD a077224. The thesis advisor was Professor R. T. Chien. The literature reveiwed and remarked upon is pre-1978. This is primarily a feedback control thesis, research and bibliography. Even though it is not what I had in mind for android implementation, it could provide good background and thought stimulus for people doing future work on feedback control for the android. If it is not too far into the future when the feedback control work is done, this thesis should be worth several hours of reading and thought. When the Conference was advertised, the person to contact was:

Professor D. Pierre, Chairman
IEEE CSS Education Committee
Department of Electrical Engineering and Computer Science,
Montana State University,
Bozeman, Montana 59717

Hobby Robot Co. Robots and modules for sale. They have a catalog with complete robots and robot parts. See appendix E for address.

IEEE. Computer, 15 (12): December 1982. The whole issue discusses robotic topics. "In this issue: Robotics & Automation, 1982 Annual Index"--quoted from cover of magazine.

"INFOWORLD: The Newsweekly for Microcomputer Users." Toll free subscription line: 800-343-6474 (Massachusetts 617-879-0700). Is available on 35mm microfilm through University Microfilm, Periodical Entry Dept, 300 North Zeeb Road, Ann Arbor, MI 48106 (313) 761-4700. According to the 8 November 1982 issue, "in upcoming issues of InfoWorld, you will find coverage of developments in the field of industrial robotics. We will look at the kinds of jobs that robots are doing right now, the size and nature of the factory-robotics market, the burgeoning Japanese robotics industry and the social costs and benefits of factory automation. The steel-collar revolution in factory automation is not all there is to robotics. We will also monitor garage laboratories where hobbyists, in a rough parallel with the early days of the personal-computer industry, are breaking new ground in what could be a personal robotics industry. We will examine their homebrew systems while keeping you current with the state of the art in robot vision, locomotion and manipulation. In this issue, to kick off our coverage of robotics, we focus on the emerging hobby-robotics movement." Hobby robotics movement is covered on pages 25-29 of 8 November 1982

issue. The 29 November 1982 issue has a follow-on article on hobby robotics (RB5X) on page 16.

Jain, Ramesh and Susan Haynes. "Imprecision in Computer Vision", Computer, 15 (8): 39-48 (August 1982). IEEE number is 0018-9162/82/0800-0039$00.75. One of four articles on fuzzy set theory provided by Lt Jerry Montgomery as part of his lecture on fuzzy set theory and his thesis. It discusses fuzzy set theory and its application to computer vision. It has 28 references, some on fuzzy set theory and others related to the application.

Jarvis, R. A. "A Computer Vision and Robotics Laboratory", Computer, 15 (6): 8-24 (June 1982). The author is a reader in computer science at the Australian National University, Canberra. He has a PhD in electrical engineering and his current research interests include digital computing technology, pattern recognition,image processing, computer vision, and robotics. This article has 34 references. The IEEE number is 0018-9126/82/0600-0008$00.75.

Kent, Ernest W. The Brains of Men and Machines. BYTE/McGraw Hill, Peterborough, N. H.: 1981. This book talks about the human brain, its organization, its structure and functional characteristics and how they could be applied to the development of intelligent robotic systems. The bibliography is by subject and has some annotations. Good starting place for those interested in android control systems, those working on the hardware, and those working on the software. Interesting point of view, and starts with the basic principles and works up from there.
Malvania, Nikhil. The Design of a Modular Laboratory for Control Robotics. Thesis for MS degree at Massachusetts Institute of Technology, September 1976. MIT/LCS/TM-74. Supported by the Advanced Research Projects Agency of the Department of Defense and monitored by the Office of Naval Research under contract no. N00014-75-C-0661. DTIC # AD-A030418. Although this is old, too, it starts out with classical, digital, and computer control introduction. It discusses the Daemonized approach to computer control, and controlling power of a processor. It was not what I had hoped it would be when I requested the copy of the document. At the time of the thesis' publication, the laboratory had not been implemented and was not expected to be implemented.

Naedel, R. G. "Intelligent Associative Memory (IAM) Architecture". A report of work done by Intellimac, Inc. 6001 Montrose Road, Rockville, MD 20852. The work was done under U.S. Government contract, so a copy of the report should be available, somewhere. For those working on associate memories, this may be helpful, Lt Montgomery did not think so. But, it may have been that it was not what he was looking for.

Nevatia, Ramakant. Machine Perception. Englewood Cliffs, New Jersey, Prentice-Hall, Inc.: 1982. "Detailed exploration of the problems encountered and the techniques employed to develop machines that can 'see' the world around them. The book covers everything from a brief discussion of pattern classification methods to three-dimensional scenes, from the relationship of veiwing angle to perspective, to complex segmented models" (Recent, 1982). This book has at least two pages of references for most chapters. The chapter titles are "Introduction, Pattern Classification Methods; Simple Polyhedral Scenes; Complex Scenes of Polyhedra; Shape Analysis and Recognition; Perception of Brightness and Color; Edge and Curve Detection; Region Segmentation and Texture Analysis; Depth Measurement Analysis; Knowledge Based Systems and Applications."

Proceedings of the Fifth International Symposium on Industrial Robots. IIT Research Institute, Chicago, Illinois, September 22-24, 1975. Sponsored by the Society of Manufacturing Engineers, IIT Research Institute, and the Robot Institute of America; others involved were The Charles Stark Draper Laboratory, Inc., Stanford Reserach Institute (Aritificial Intelligence Center), National Bureau of Standards, and the Office of Developmental Automation and Control Technology. Published by the Society of Manufacturing Engineers, Dearborn, Michigan, 1975. (Received on Inter-Library Loan from Clemson University.) The various papers deal with industrial robots primarily, however, the information on vision, manipulators, "computer-aided robot operation systems design", control (algorithmic and adaptive), and so on. Information which is applicable to industrial robots may be adaptable for use with an android.

Proceedings of the International Joint Conference on Pattern Recognition. Mentioned in the 1982 Publications Catalog of the IEEE Computer Society Press, pg 24. "With the growing interest in robotics and manmade interaction, the discipline of pattern recognition is coming into its own." The fifth conference was held in December 1980 and has two volumes. The descriptive quote from the catalog implies the fifth and/or future proceedings of this conference would bear watching for papers of possible interest to roboticists.

Proceedings of the Joint Automatic Control Conference (JACC), 1981. In Robotics Age, I found a reference to

"Control of a Robotic Exercise Machine" by Wayne Book and David Ruise. Unforturnately, the article and/or proceedings could not be found. If the conference were held late in the year, publication of the proceedings does take quite a while.

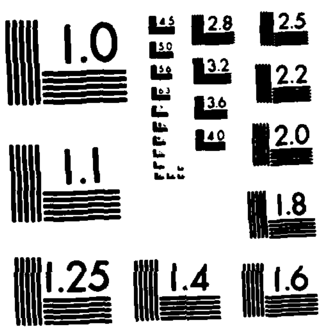
Proceedings of the Pattern Recognition and Image Processing. "At this conference practitioners discuss approaches to flexible and intelligent human interface to pattern and pictorial data. Topics have included user-oriented graphics, industrial applications, remote sensing and image processing, speech understanding and sound analysis, and data definition and conversion." Mentioned in the 1982 Publications Catalog of the IEEE Computer Society Press, pg 25. Titles read "19XX Conference on Pattern Recognition and Image Processing". Apparently the conference is held every two years.

Proceedings of the Sixth International Joint Conference on Artifical Intelligence, Tokyo, August 20-23, 1979, Volumes I and II. (A.K.A. IJCAI-79) Has several papers directly written on and related to robotics. The areas include image anaylsis, robotics, vision, object detection, and problem solving.

Proceedings of the Third Symposium on Theory and Practice of Robots and Manipulators, Udine, Italy, 1978. Good for seeing what is being done in robotics, internationally. Nearly six hundred pages of papers presented. Published in 1980 by Elsevier Scientific Publishing Company, Amsterdam - Oxford - New York; and Polish Scientific Publishers, Warszawa.

Robotics Age: The Journal of Intelligent Machines. Interesting magazine, geared primarily for the hobbist. The articles range from image processing, artificial intelligence, to how to build your own "backyard" robot. The advertisements are interesting and could provide leads to track down parts or supplies of interest as well as books on the subject. Regular features include "New Products", "Media Sensors", "Organizations", and "Books".

Robotron 4201 Minicomputer System Summary. This is an old document but is a translation of work done in East Germany. The DTIC copy I received is an "edited Translation" with FTD-ID(RS)T-1269-77 dated 29 November 1977. The DTIC #ADB 025595L. "The present system summary corresponds to the status as of November 1975. The right to make changes resulting from further technical development is reserved. Reprinting, reproduction of these documents and excerpts therefrom are unauthorized". I remember seeing several articles on Robotron 4201 when I was doing my literature search,



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

mostly untranslated except for the abstract and reference I was reading. Although this is out of date, it would answer some questions about the work being done in East Germany, as well as raising other questions.

Safford, Edward L., Jr. The Complete Handbook of Robotics. Tab Books, Blue Ridge Summit4, PA: 1978. This is geared more for the robot hobbyist, but helps to get the mind moving and thinking, even when you disagree with what is said and done. It is fairly easy to read and hits most every area of interest to a roboticist or androidist. It is worth looking at in pieces for an overview, almost lay-type of view, of the area of interest, such as sensors, servomechanisms, radio control, etc.

Sembi, B.S. and E. H. Mamdani. Linguistic Rule-Based Decision Making Using Fuzzy Logic. This was to be a paper presented at the 1980 IEEE COMPSAC. All that appeared in the proceedings was the abstract. The abstract states that the decision making in this case was to be applied to process control systems but using a general technique. For those contemplating fuzzy logic for decision making in the android, this paper might be worth running down.

Spegel, Marjan. Programming of Mechanism Motion. Technical Report CRL-43, November 1975. A thesis prepared for Information Systems Program, Office of Naval Research, Department of the Navy. Contract No. N00014-75-C-0572, NR 049-274.w DTIC # AD-A023 171. Again, this is an older publication. It provides a motion description in 1-D, uses FORTRAN as its HOL, but the motion description could be expanded by hand to any other HOL. If a special language were needed to be developed for the android's motion programming, looking at what Spegel did here would be good to see what one approach was. The developer could use this as a basis for deciding how he or she would develop the android's motion descriptive language. Some times it is easier to look at someone else's approach and say no, that was the wrong approach there, I think this is a better way; than to come up with something "out of whole cloth", as it were. One of the recommendations was to extend this to 3-D, so it is possible that someone is or has done that.

Tesar, Delbert. Trip Report: Visits to Major Research Centers in Robotics in Europe and Russia, 8-30 June 1981. Discusses some of the work being done abroad; their interests; and provides some interesting statistics and comments. Report was dated 24 July 1981. For further information on Dr. Tesar, see bibliography entry (Tesar).

Toepperwein, L. L., M. T. Blackmon, et al. ICAM Robotics Application Guide (RAG). Final Report, dated September 1978 - March 1980 by General Dynamics, Fort Worth Division, P. O. Box 748, Fort Worth, Texas for the Materials Laboratory (AFWAL/MLTC), Air Force Wright Aeronautical Laboratories, WPAFB, Ohio 45433. Project Number 812-8, April 1980. AFWAL-TR-80-4042, Volume II. This document has a large current literature list, listed by topic.

Whitney, D. Applying Stochastic Control Theory to Robot Sensing, Teaching and Long Term Control. This was to be a paper presented at the 1981 "Joint Automatic Control Conference, but was not included. Whitney's affiliation was given as Charles Stark Draper Laboratory, Cambridge, MA. The control people might be interested in this work.

Yager, Ronald R. "Multiple objective decision-making using fuzzy sets", Int. J. Man-Machine Studies (1977) 9, 375-382. One of four articles on fuzzy set theory provided by Lt Jerry Montgomery as part of his lecture on fuzzy set theory and his thesis. Has a brief review of fuzzy sets and shows an example of using fuzzy sets to make decisions, and the importance "function" use in fuzzy set theory. (The last page was missing on the copy which I received, so unable to state the number of references given.)

Yager, Ronald R. "Possibilistic Decisionmaking", IEEE Transactions on Systems, Man, and Cybernetics, SMC-9 (7): 388-392 (July 1979). One of four articles on fuzzy set theory provided by Lt Jerry Montgomery as part of his lecture on fuzzy set theory and his thesis. There are 22 references.

Zadeh, Lotfi A. "Outline of a New Approach to the Analysis of Complex Systems and Decision Processes", IEEE Transactions on Systems, Man, and Cybernetics, January 1973: 28-44. One of four articles on fuzzy set theory provided by Lt Jerry Montgomery as part of his lecture on fuzzy set theory and his thesis. It has 20 references. This article is rated "fantastic" by Lt. Montgomery and has three references circled. The three references, by Zadeh, which follow this entry are those circled references.

Zadeh, Lotfi A. "Quantitative fuzzy semantics", Inform. Sci., vol. 3, Pp 159-176, 1971.

Zadeh, Lotfi A. "Fuzzy languages and their relation to human and machine intelligence", In Proc. Conf. Man and Computer, 1970; also Electron. Res. Lab., Univ. California, Berkeley, Memo. M-302, 1971.

Zadeh, Lotfi A. "A fuzzy set theoretic interpretation of hedges", Electron. Res. Lab., Univ. California, Berkeley, Memo. M-335, 1972.

Zobrist, Albert I., and William B. Thompson. Building a Distance Function for Gestalt Grouping. DTIC #ADA015435. This work is related to image processing and may be of interest. However, the copy I received from DTIC was illegible. Apparently, it was printed in the IEEE Transactions on Computers, Vol ?-4, No. 7, July 1975; Anals No. 507??00?. Since it was "older" and did not bear directly on my thesis, I did not pursue a better copy.

APPENDICES

Appendix A

Analysis Diagrams

The following ten diagrams organize the data presented in chapter II. Each diagram is followed by descriptive text. The Data Dictionary which describes the terms used in the diagrams, is included in Appendix B. The ten diagrams are numbered and titled in accordance with standard SADT practices. I.e., the first diagram is "A-0", the next diagram in sequence is "A0", the third diagram is labeled "A1", and so on.

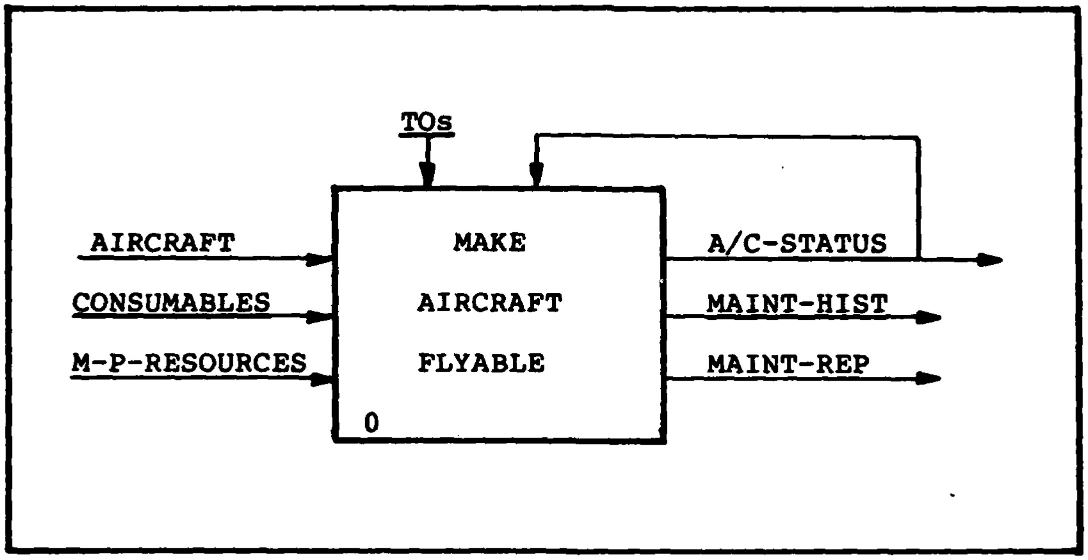


Figure 7. A-0, Maintain Aircraft

A-0, Maintain Aircraft

This is the simplest view of the aircraft maintenance system. The activity box representing "make aircraft flyable" is simply what aircraft maintenance does. The inputs needed are the actual aircraft, those items which are consumable (and always needed for every aircraft for every mission), those spares needed to repair or replace items on the aircraft which are within maintenance's realm of responsibility, and those resources which are mission-particular (i.e. mission dependent). The outputs are the required maintenance histories, maintenance reports, and the aircraft status. All three of these may be oral, written, or both. As indicated by the diagram, the technical orders (TOs) and the current status of the aircraft control the aircraft maintenance procedure.

It is not unusual for flight crew members to talk to maintenance personnel about the aircraft assigned for a particular mission. This exchange allows maintenance to request that the crew member(s) make specific observations under specified conditions. This could help maintenance pinpoint an elusive malfunction. This exchange also enables the flight crew to be forewarned of possible equipment failure or malfunction. For example, if for the last six months every flight shows a particular failure occurring during flight, the crew might reasonably expect that failure to recur. This is especially true, if the same repair technique is noted in the maintenance history for that component!

Alternately, if a piece of equipment (such as one of the navigation aids) has run perfectly for six or more months, the navigator frequently refreshes his memory on how to do that particular navigation aid's work manually. Similarly, other interested personnel, on a need to know basis, request written and/or oral reports on particular aircraft. These reports enable scheduling to schedule particular aircraft for particular missions.

When USAF personnel describe the Air Force's mission as 'To Fly and Fight', the status of an aircraft becomes very important and of interest to many individuals. When an aircraft is ready to fly (according to maintenance standards), the aircraft status reflects that, and the aircraft is held in its appropriate area or hangar.

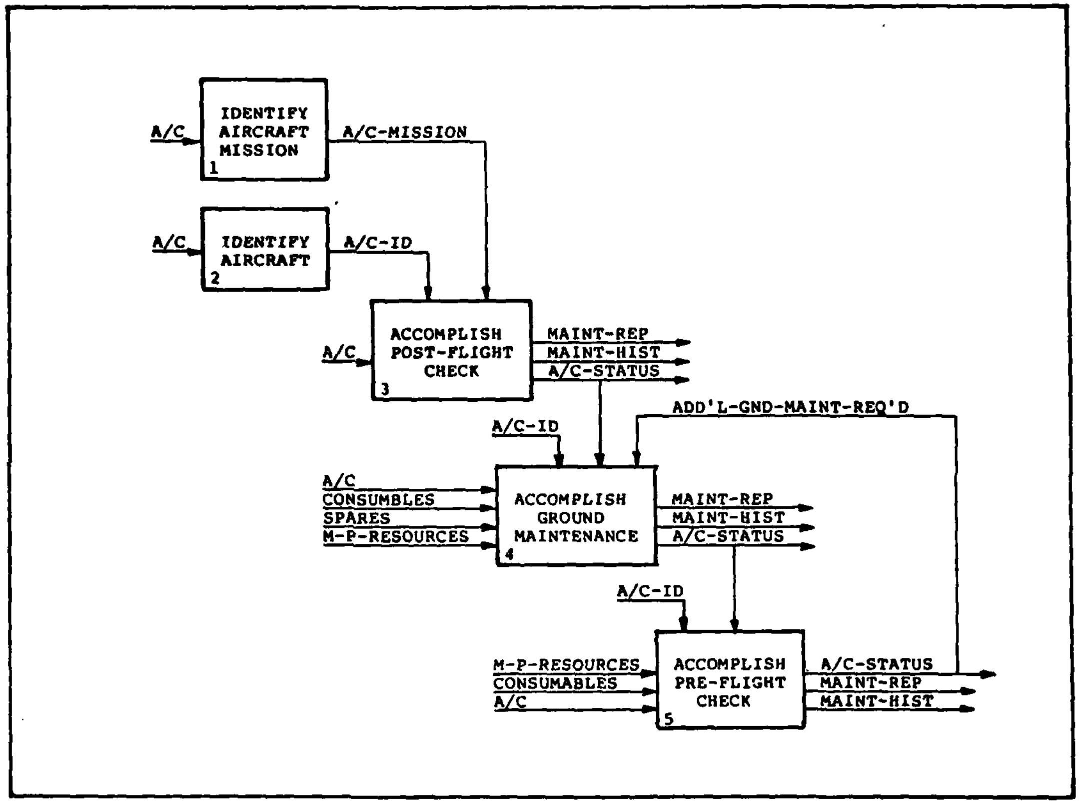


Figure 8. A0, Make Aircraft Flyable

A0, Make aircraft Flyable.

The three aircraft maintenance phases are post-flight check, ground maintenance, and pre-flight check. But, before maintenance personnel can do these, the specific aircraft has to be identified as well as its mission. These two identifications and the aircraft itself are necessary to begin the aircraft maintenance procedure. Preparation for maintenance can begin prior to the actual arrival of the aircraft, once identification is complete.

Each phase of maintenance generates its own histories, reports, and aircraft status. The aircraft status determines what maintenance is done and when. Some of the maintenance procedures of one phase can overlap those of another phase, assuming all necessary controls and inputs are available.

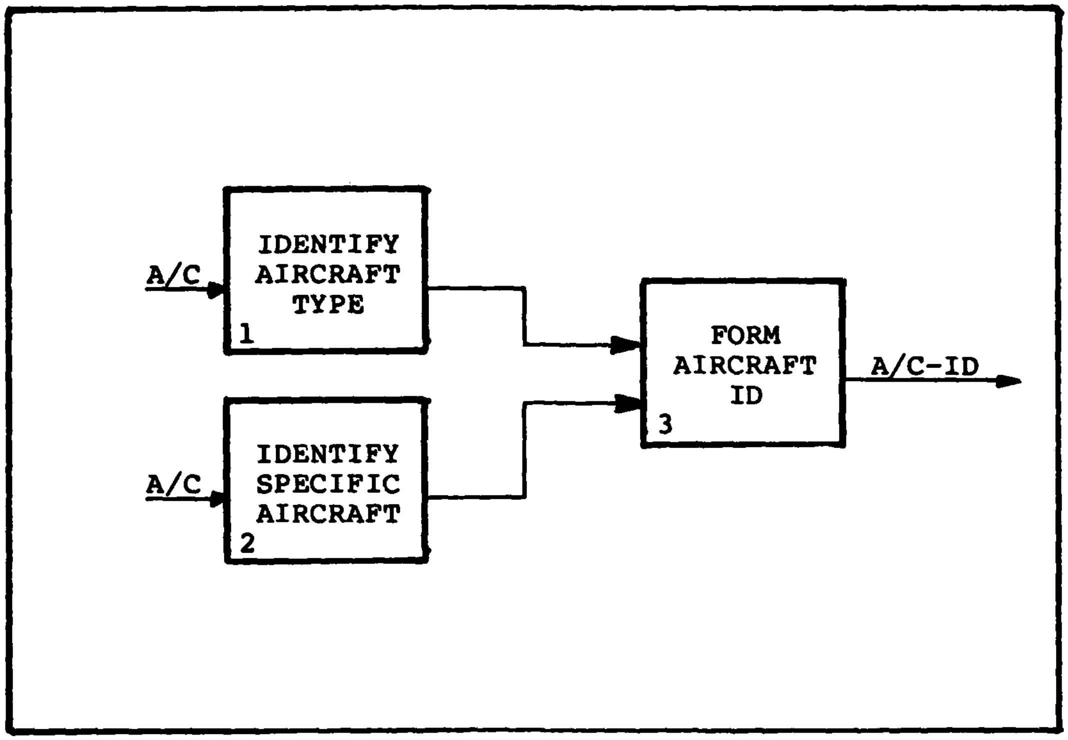


Figure 9. A2, Identify Aircraft

A2, Identify Aircraft.

The aircraft identification is constructed from two pieces of information. This information comes directly from the aircraft itself. The first piece is the aircraft type such as B-52 bomber or F-4 fighter. The second piece is the specific aircraft identity denoted by the tail number. These two pieces of information form the specific aircraft identification for maintenance purposes.

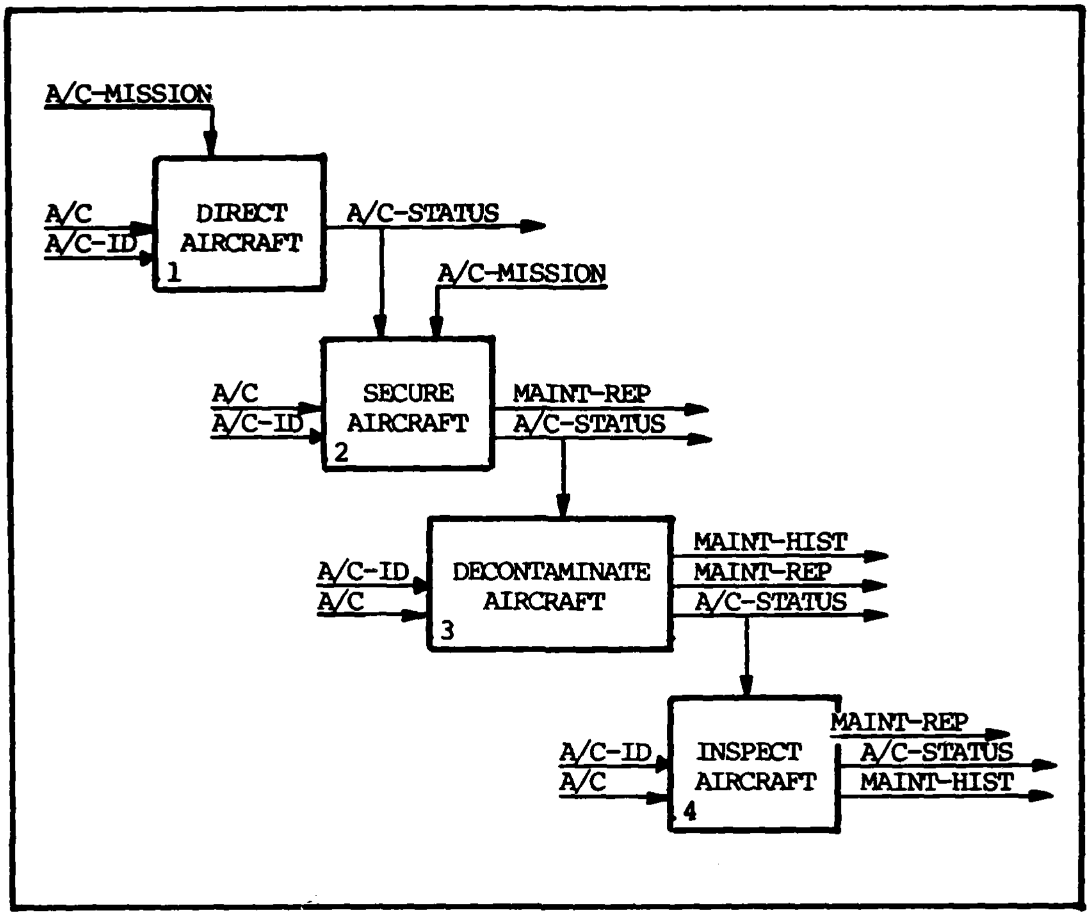


Figure 10. A3, Accomplish Post-Flight Check

A3, Accomplish Post-Flight Check.

The post-flight check consists of directing the aircraft, securing the aircraft, decontamination of the aircraft (if necessary), and physically inspecting the aircraft. Part of securing the aircraft can be accomplished prior to the aircraft's arrival. Once the aircraft is parked, it is made secure and safe, so that the ground maintenance personnel can work. Then, decontamination starts and the physical inspection continues since the inspection starts while the aircraft is being secured. (I.e. as the maintenance personnel work on or around the aircraft they contninually watch for physical damage or anything out of the ordinary.)

Once the aircraft is safe, physical inspection continues and/or decontamination begins. Physical inspection of an aircraft includes examining all surfaces for damage, loose screws and bolts, checking engines and blades (internal and external) for damage and foreign debris, checking gauges, ensuring landing gear and flight controls are within tolerances, and checking cables for tension and damage.

Decontamination is generally accomplished by hand, by personnel in the appropriate protective gear. The aircraft is literally scrubbed down with burshes, soap and water, or whatever is required to remove the contaminants. The general consensus is that these protective suits are cumbersome, awkward, and dangerous in their own right. However, they are better than nothing! Even though this is a robot/android scenario, decontamination is necessary if the crew is to deplane, if the contaminate would damage the aircraft, or if people must do the repairs on the aircraft.

Once the aircraft is safe for the ground maintenance crew to start work, and the aircraft status indicates the need, the ground maintenance work begins.

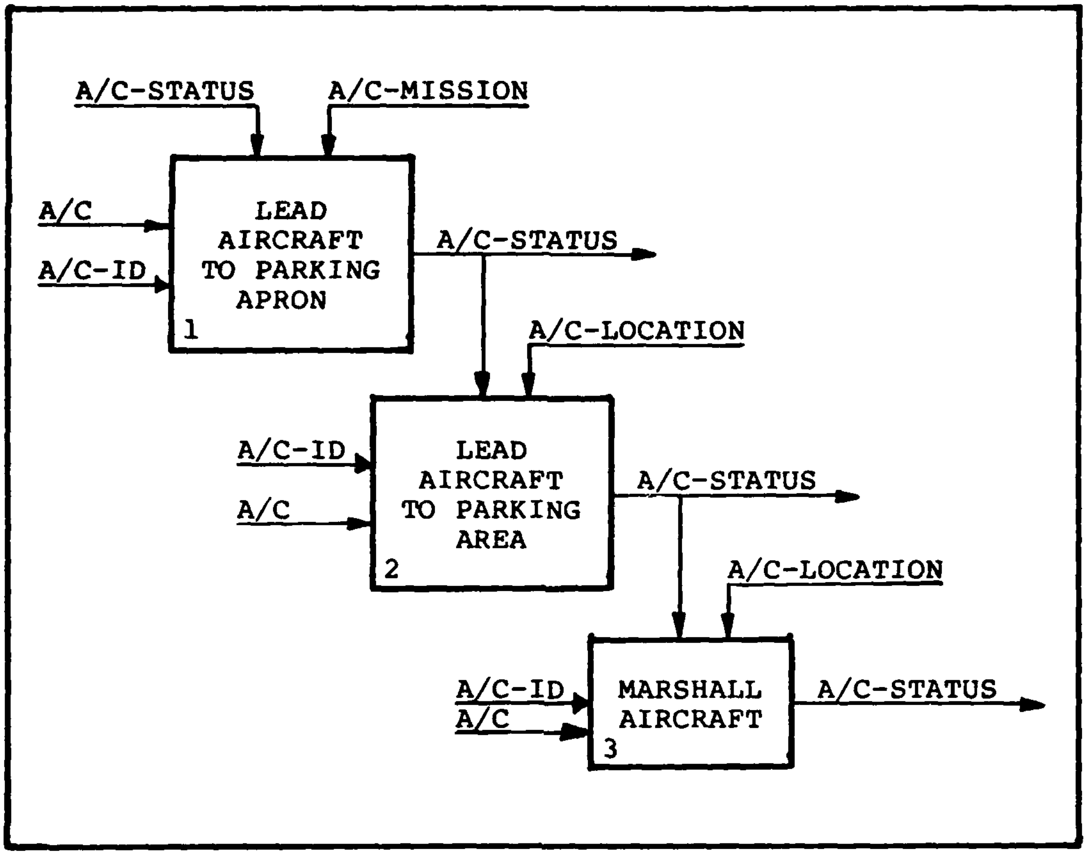


Figure 11. A31, Direct Aircraft

A31, Direct Aircraft. If an aircraft's crew were unfamiliar with an airfield, the aircraft would be directed from its landing point to the appropirate taxiway, and parking aprons. The follow-me or park-on-me normally uses a vehicle with lights and the appropriate label to lead the aircraft. All aircraft are directed into their final parking place since obstacles are usually nearby which can damage the aircraft or be damaged by the aircraft. This is called marshalling. Marshalling is accomplished by one or more individuals with hand-held signal lights used to guide the aircraft into its final parking place. This requires the status of the aircraft with respect to its current location and its desired location. The final parking place is reached by following the arm signals of one or more ground maintenace crew members who compare the distance between the aircraft, any nearby objects, and the aircraft's final desired position.

Thus blocks 1 and 2 of A31 would not be required for every aircraft. The mission of the aircraft could have a bearing on where an aircraft is serviced. For example, if both a test wing and a SAC unit are co-located on the same base, each would generally have its own maintenance facilities.

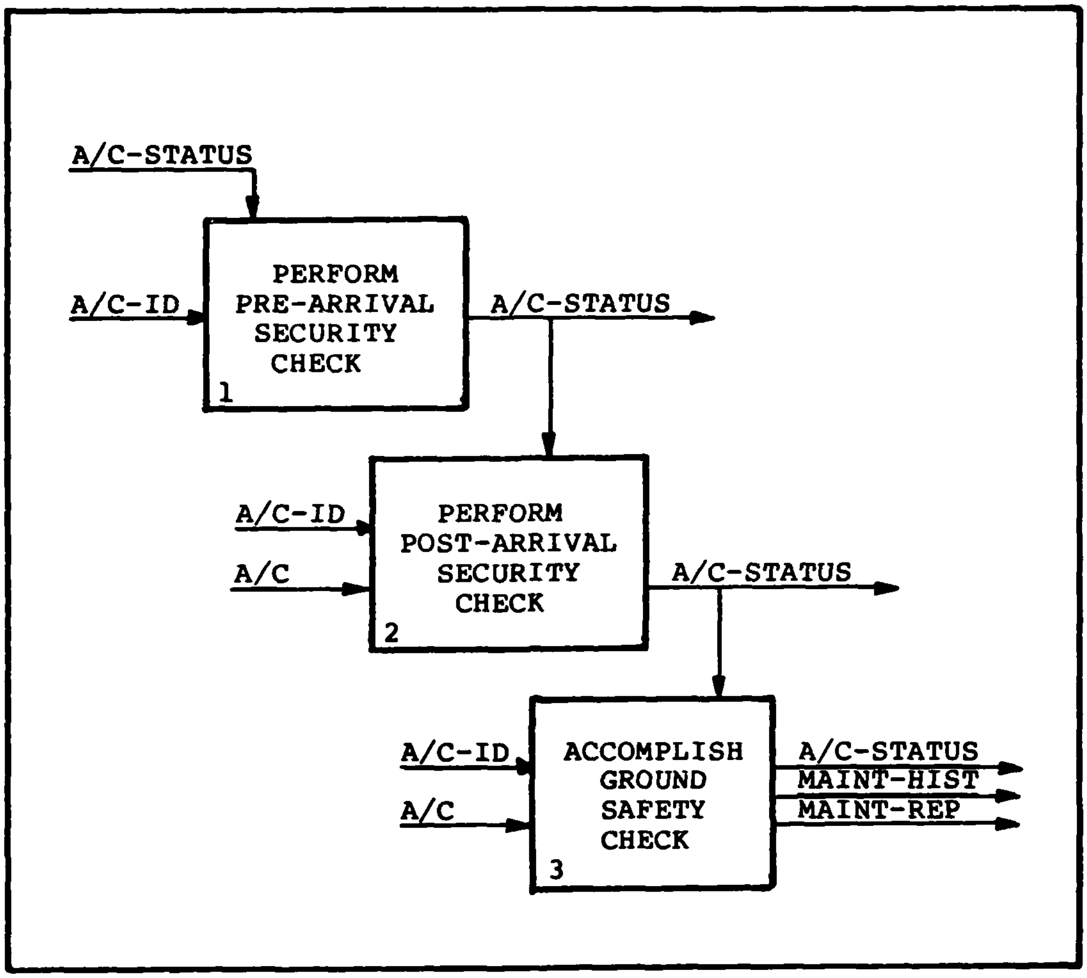


Figure 12. A32, Secure Aircraft

A32, Secure Aircraft. Before an aircraft is parked in its final maintenance parking place, the parking area must have a security check. Once the parking place meets the security requirements, the aircraft could be parked, the final security check is made, and the safety check is initiated. The initial security check can begin while the aircraft is still in the air; it must be completed before the aircraft can be parked. The final security check can not be finished until the aircraft is parked.

Flight lines are always restricted areas, both for safety and for security reasons. In wartime, security would be even more imperative since resources would be dwindling and must be preserved. Maintenance personnel are expected to challenge unauthorized personnel (those without the proper badges) when encountered on the flight line at any time. This involves communication with people, and manipulation of objects, or equipment. When necessary, maintenance personnel notify the security police or area guards of unusual circumstances or request assistance.

Once the aircraft is secure, the maintenance crew begins the safety check. Certain safety precautions must be done before others. Safety pins are re-installed in munitions and external fuel tanks (which have not been dropped) as soon as the plane lands, prior to entering the apron/parking areas. Once parked, safety pins are re-installed in the landing gear to prevent the gear from collapsing; and chocks are placed around the wheels. Additional safety pins are installed for the canopies and ejection seats (as needed). Other safety precautions may need to be taken, depending upon the aircraft and its condition (such as fuel leaks or hot brakes), and whether or not the crew or munitions are still on board. Since the physical inspection begins during the safety check, one result is a report of discrepancies or possible damage for further investigation. Part of the safety check determines whether or not the aicraft requires decontamination at this time. The aircraft status reflects this requirement.

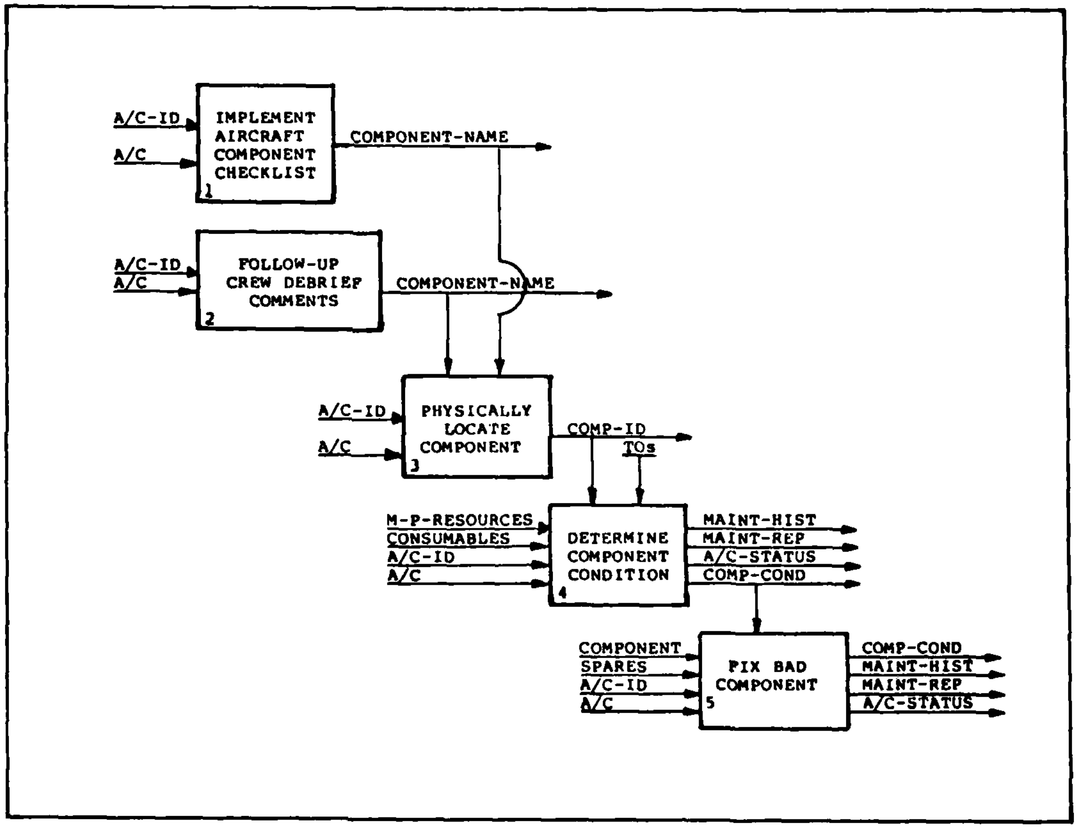


Figure 13. A4, Accomplish Ground Maintenance

A4, Accomplish Ground Maintenance.

Ground maintenance identifies any component which needs repair or replacement (including consumables, as required). A component is an item or subpart of an item which constitutes part of the aircraft, such as flight controls, hydraulics, landing gear, engines, black boxes, or air frames. To accomplish this, ground maintenance personnel debrief the flight crew members for their comments on the aircraft and its equipment. This debriefing frequently occurs while the post-flight check is conducted. Sometimes, if a problem is elusive, the maintenance crew requests the flight crew make special observations during the next flight. These observations are then given to maintenance during the debriefing. In addition to the flight crew's comments, the TOs define maintenance checklists for each aircraft and its components. Once the maintenance crew receives the above information and has the aircraft available, each component is located and checked to see if it meets specifications. This determines the condition of the component. Then, as required, the components not meeting specifications are replaced or repaired. Before certifying the component fixed, it is rechecked to ensure it meets specifications. If the repaired/replaced component meets specifications, then the next component is checked and the cycle is repeated. If the fixed component does not meet specifications, then it is rediagnosed to determine the problem and the requirements to fix it. This procedure generates both maintenance reports and histories. Informal reports are updated "continuously", while the written reports and histories are accomplished later. The status of the aircraft is dependent upon the status of its components.

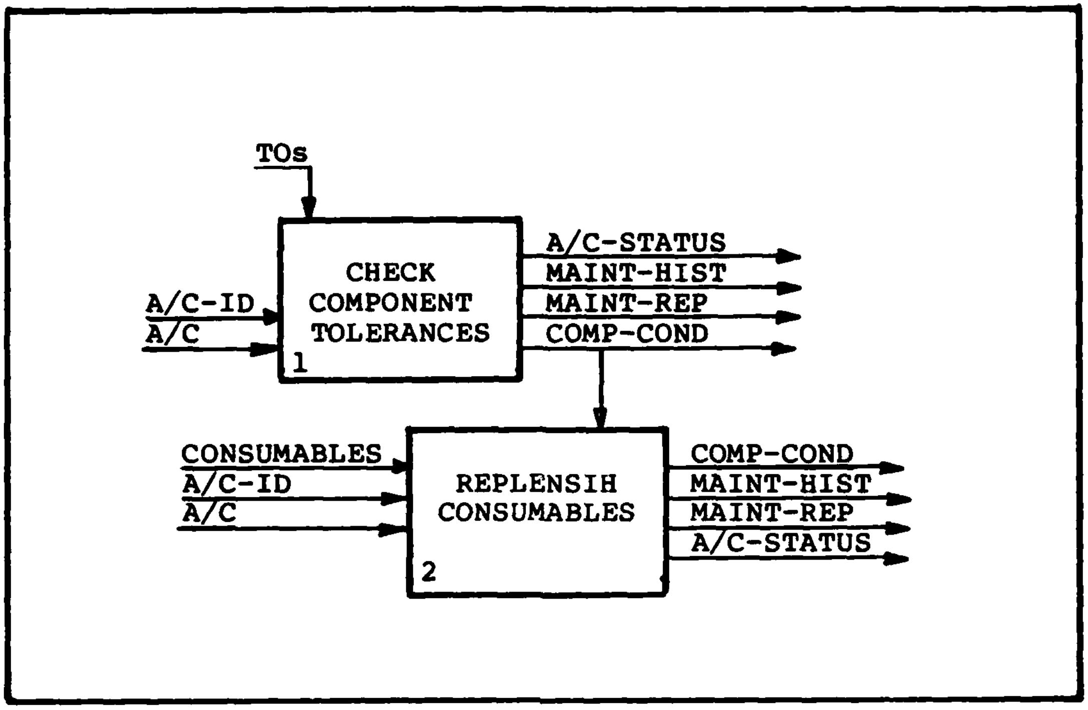


Figure 14. A44, Determine Component Condition

A44, Determine Component Condition. The current condition of the component must be compared to the TO's specifications. If the aircraft component matches the TO specification (within the acceptable variance), then the component is 'good'. If the component meets the TO specifications, but containes consumables which require replenishing, then the consumables are replenished. If the component does not meet the TO specifications, then it is 'bad' and must be repaired or replaced. If the mission of the aircraft requires additional equipment or supplies from maintenance which are not usually needed but are needed for this particular mission, these would be supplied now. This thesis defined These as mission particular resources.

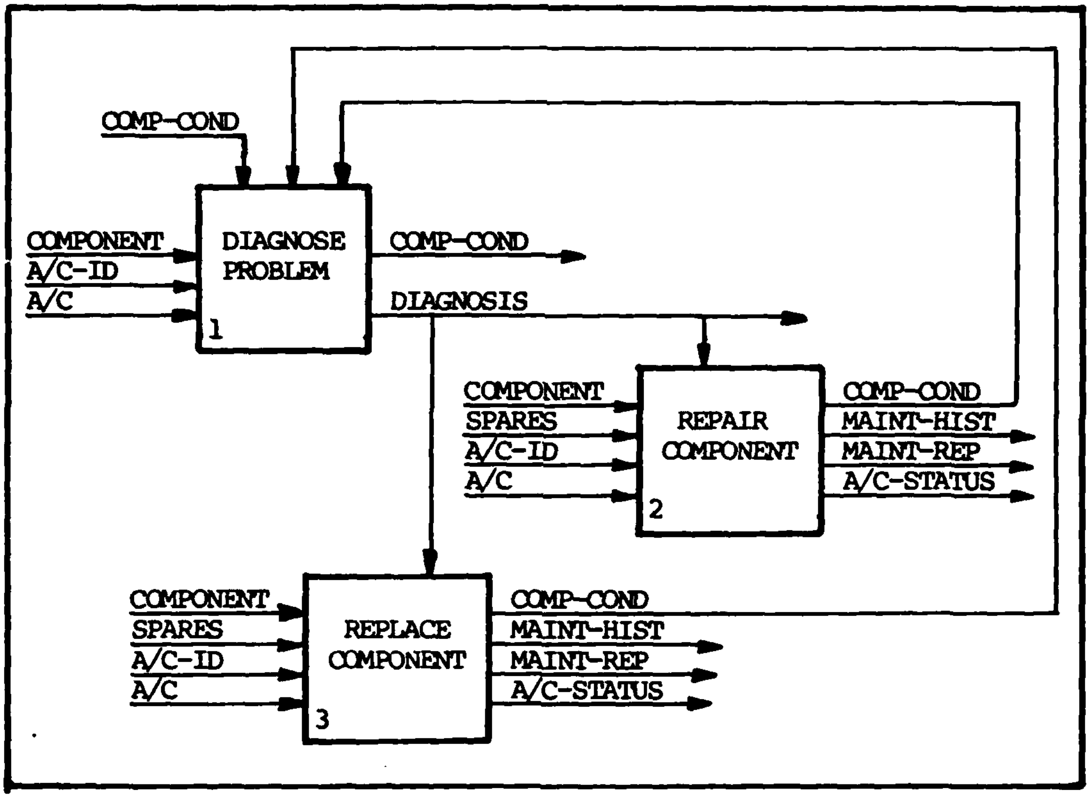


Figure 15. A45, Fix Bad Component

A45, Fix Bad Component. Fixing a bad component consists of either replacing or repairing it. Once a component is labeled as 'bad', the cause has to be diagnosed in order to fix the component. Whether the component can be repaired on-site, or must be replaced is determined. Then, once the component is thought to be fixed, it again has to be checked against the TO specifications. A replacement could be faulty, or the cause of the bad component might be due to compound causes. If the fixed component meets the TO specifications, then the next component is checked. If that is the last component to be checked, then the reports and status are updated as required.

Repairs are done as necessary. While some repairs may be temporarily postponed, such as a small brake fluid leak (found during a pre-flight check); others must be made immediately, such as fuel leaks (anytime), or hot brakes (normally occur during post-flight check). The danger of a fuel leak should be obvious to everyone--an explosion and/or fire. Hot brakes can be just as dangerous because of explosion and possible fire as well.

Many repairs are modular, that is, a malfunctioning box of equipment can be pulled out (also called 'unplugged') of the aircraft and be replaced with one functioning properly. This is referred to as 'black box' maintenance by the maintenance personnel. Some are not, such as repairing a flat tire. A flat tire must be repaired because an aircraft cannot safely take off with a flat tire. An aircraft can be landed safely with a flat tire, however. Maintenance personnel know (via TOs, training, and experience) the location of the components to be checked and how often to check them for damage.

Once ground maintenance clears an aircraft as ready to fly, the next stage before an actual flight is the pre-flight check. This can occur right after ground maintenance was done, or may be days later. The pre-flight check is accomplished just prior to the aircraft's flight.

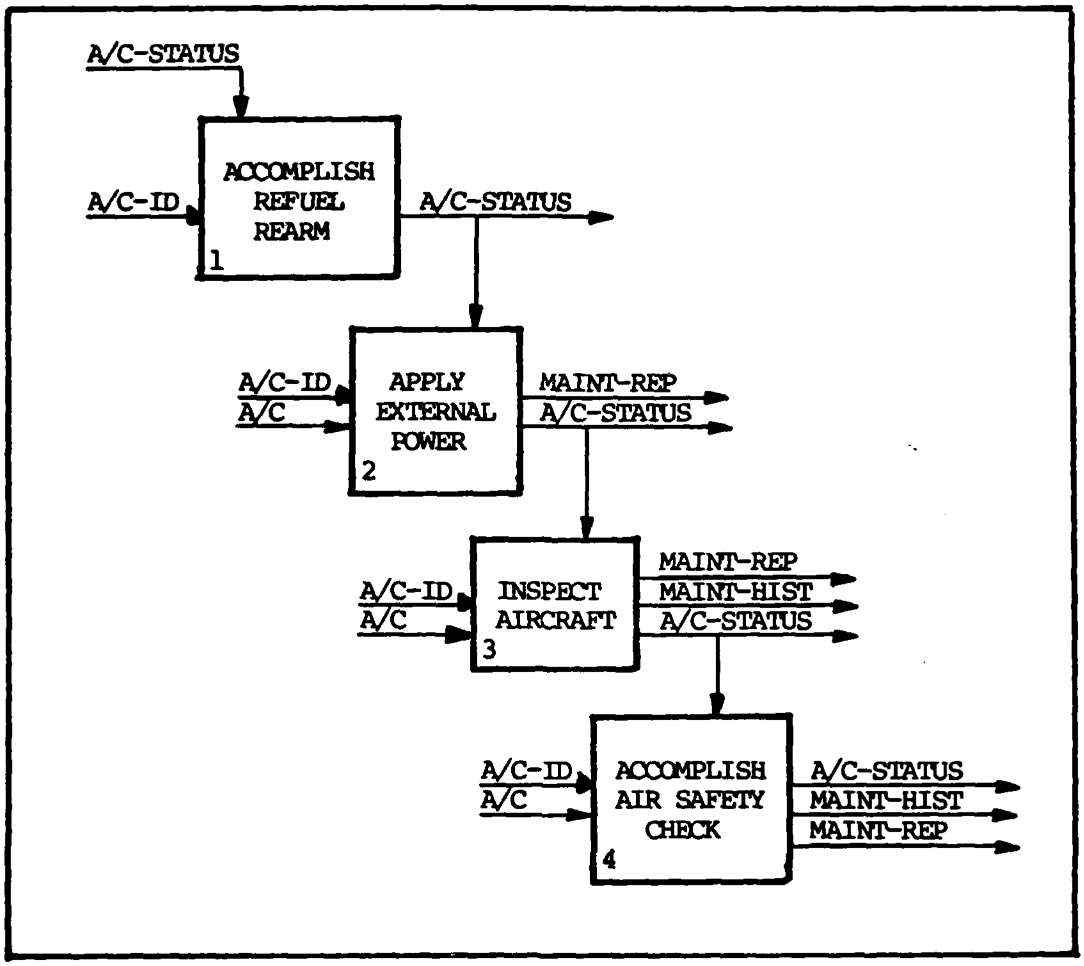


Figure 16. A5, Pre-Flight Check

A5, Accomplish Pre-Flight Check

The refuel and rearm sequence must be determined for each aircraft, and the aircraft must be physically inspected, external power applied to the aircraft, and the aircraft must be made safe for flight. These are the major duties accomplished during the pre-flight check. The physical inspection, the external power hookup, and parts of the pre-flight safety check can be accomplished before, during, or after refueling or rearming and in any convenient sequence.

Prior to take-off, a portable power plant is hooked up to the aircraft. This supplies electric power for the aircraft until the engines are running. An 'air pusher' may be required to be hooked up to some fighter engines as well as the electric power. Once the engines are started and running under their own power, the power plant is disconnected. At least one cable runs from the power plant to the aircraft. The attachment point on the aircraft is similar in appearance to a power outlet/wall socket. The 'air pusher' has a large flexible tube which attaches to the engine, so that air can be forced into the engine. Maintenance personnel know what the power and engine starting requirements are for an aircraft. Then, using the proper power plant, the power cables are plugged into the correct recepticles, and the proper engine starter mechanisms are attached.

The physical inspection is the same as during the post-flight check as discussed in A3. If damage is found or suspected which can not be remedied immediately, the aircraft returns to the "ground maintenance required" status. The air safety check is just the reverse of the ground safety check. Primarily, the landing gear pins, engine covers, and chocks must be removed. The canopy and ejection seat pins must be removed. The munitions pins and fuel tank pins are removed, as well, but not until just before the plane takes off (to prevent any accidents on the landing apron or parking area). Thus, the maintenance personnel ensure the aircraft is ready (and safe for flight) by removing the ground-required safeguards. Once the maintenance crew signals the flight crew that maintenance is complete and the flight crew takes control, the aircraft's mission is considered started--even before the aircraft physically takes off. Thus, if the aircraft's mission is aborted after the flight crew takes command, the aircraft reverts to the post-flight check. This is true, even if the aircraft never leaves the ground.

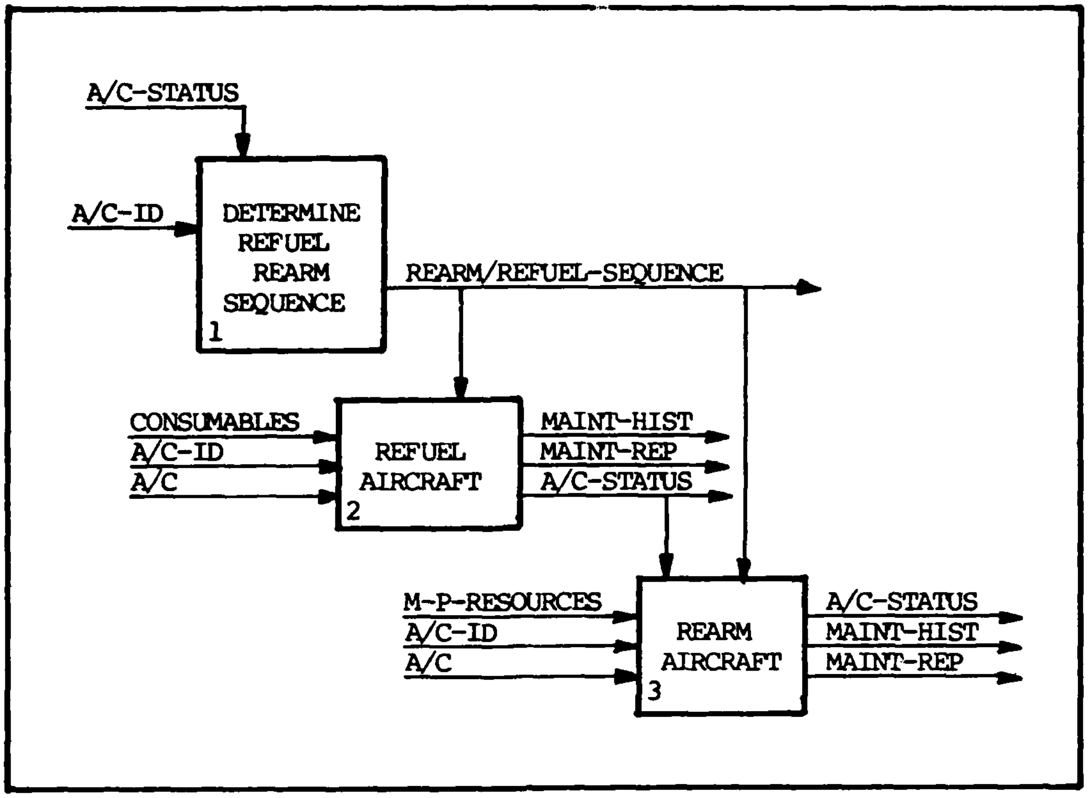


Figure 17. A51, Accomplish Refuel/Rearm

A51, Determine Refuel/Rearm Sequence. Since these are generally mutually exclusive activities, the rearm, refuel sequence must be determined before starting either to rearm or to refuel. If only refueling or rearming are required then this determination step may be skipped. The determination is based on the availability of the refuel trucks, rearmament personnel and equipment.

For ground refueling, two methods are primarily used. On larger aircraft, a single point refueling receptacle is the usual refueling method. This method refuels all fuel tanks on the aircraft from a single access point. However, smaller aircraft are filled, using a fuel hose with a nozzle, in a manner similar to that used to refuel automobiles. Each fuel tank must be filled separately, through separate access points. The larger aircraft are able to use this second method when the single point refueling method is not available. This can be accomplished since each fuel tank on the larger aircraft has individual access points, as well as the single access point. Maintenance personnel know the method for refueling, and the type of fuel for each aircraft serviced (this information is learned from the TOs and technical training).

In wartime, as long as bombs, other munitions, and the aircraft to carry them are available, the aircraft has to be resupplied. Thus, based on the particular aircraft, and its mission, the maintenance personnel know whether or not to contact the munitions personnel for the armaments required.

Appendix B

Data Dictionary

a/c	= A/C = aircraft
aircraft	= the physical, individual aircraft. Alias: a/c, A/C
aircraft-identification	= a/c-type + specific-a/c. Alias: a/c-ID, A/C-ID
aircraft-location	= the physical location of the aircraft including its location with respect to nearby objects of interest. Alias: a/c-location, A/C-location, a/c-loc, A/C-loc
aircraft-mission	= what the aircraft is scheduled to do next. Alias: a/c-mission, A/C-mission
aircraft-status	= current state (status) of the aircraft. Possible values (not all inclusive): in-ground-maintenance, in-post-flight-check, flyable-a/c, aircraft-parked, aircraft-location,

additional-ground-maintenance required, aircraft-secure, pre-flight-check-complete. Alias: a/c-status, A/C-status

aircraft-type = the type of aircraft. Possible values (not all inclusive): B52 bomber, F4 fighter, KC135 tanker. Alias: a/c-type, A/C-type

component = a physical item or part on or removable from the aircraft. Alias: comp

component-condition = the current state of each component after comparison to the technical order requirements. Alias: comp-cond

component-identification = a unique identifier for each component which denotes which specific aircraft and which particular component on that aircraft. Alias: comp-ID

component-name = the name of the component as it appears on checklists and the inventory lists. Alias: comp-name

consumables	=	those items which are needed for each and every aircraft, each and every mission.
diagnosis	=	what is thought to be wrong with a component.
maintenance-history	=	the record of maintenance by part and malfunction or intolerance of each component and aircraft. <u>Alias:</u> maint-hist, Maint-Hist
maintenance-reports	=	those reports which maintenance is both required and requested to make orally or written. <u>Alias:</u> maint-rep, Maint-Rep
mission-particular-resources	=	those items which are needed by an aircraft to accomplish its particular mission. <u>Alias:</u> M-P-Resources
refuel/rearm-sequence	=	the sequence in which rearmming and refueling will be accomplished; since, one may only be done after the other is complete. The order does not matter. <u>Alias:</u> refuel/rearm-sequence, refuel/rearm-seq

spares	=	those items required by maintenace to bring the aircraft and its components to flyable status.
specific-aircraft	=	the unique aircraft as identified by tail number. Alias: spec-a/c, spec-A/C, Spec-a/c, Spec-A/C
TO(s)	=	Air Force Technical Order(s)

Appendix C

Audio Cassette Recorder Programs

(13 July 1982: Version 2.4)

These programs were modified by Roz Taylor; based on the original programs as provided in the MMD-1/MI Operating Manual by E&L Instruments, Inc. The modifications were necessary to use the MMD-1/MI as configured at AFIT.

The following routines were used with the MMD-1 configured with the Memory Interface Board. Each section of code starts with an even "octet". When the code is finalized, the trailing NOPs should be removed and the total code made more compact. This would result in addresses being changed within the code. It was deemed at this time, unnecessary to accomplish these changes prior to finalizing the code. The code which follows works, but may not be the most efficient method.

RAM LOAD/DUMP PROGRAM

This is a listing of the Loader/Dump Program which when resident, is located in the main board RAM (RAM PR"2"). The PROM LOAD/DUMP PROGRAM exists, however it was not used because the PROM location interfered with the special programming installed in this particular version of the MMD-1/MI.

****

<u>READ FROM CASSETTE ROUTINE (RCAS)</u>: This routine reads the data from the cassette tape and stores it in sucessive memory locations starting with 030 000. As the data is input, it is displayed on the MMD-1 LEDs (port 2). The address is displayed on the MMD-1 LEDs via ports 1 and 0. Control is returned to the CRT monitor when transfer is complete. START CASSETTE RECORDER <u>BEFORE</u> USING THIS ROUTINE. Modification suggestion: add the ability for user to specify number of blocks of code to be moved into memory, as in the write to cassette routine.

==

```
MEMORY       CODE       LABEL      MNEMONIC      COMMENTS
LOCATION
002 000     041        RCAS:      LXIH        Initialize the mem-
002 001     000                               ory pointer:  H=030
002 002     030                               and L=000.
002 003     315                   CALL
002 004     170                   INPUT
002 005     002
     002 006    Thru    002 010    000     NOP  (This was where
                a  previous  bit of code was--but eliminated,
                later)
002 011     333                   IN          Clear flags if
002 012     022                               necessary.
002 013     315       NEXTIN:     CALL        Input a byte of
002 014     100                   CASIN       data into the
002 015     002                               accumulator from
002 016     167                               the cassette tape.
002 017     315                   CALL
002 020     220                   DISPLAY
002 021     002
002 022     043                   INXH        Increment the mem-
002 023     174                   MOVAH       ory pointer, load
002 024     272                   CMPD        new high address
002 025     302                   JNZ         value and check for
002 026     013                   NEXTIN      end of loop. If not
002 027     002                               end, get next byte.
002 030     303                   JMP         When done loading
002 031     240                   CRT         return to the CRT
002 032     002                               monitor.
    002 033    thru    002 037    000    NOP
```

****

<u>WRITE ONTO CASSETTE TAPE ROUTINE (WCAS)</u>: This routine stores the data on cassette tape. The user selects from 1 to 8 blocks of data. Each block consists of 377 (octal) bytes of memory, starting at 030 000. Once the routine starts, the desired number of blocks is entered by the user via the HEX pad on the MMD-1. Use 0 to indicate 8 blocks. After a 22 second delay, the data is written onto the cassette. Once the data is written to tape, control is returned to the CRT monitor. START THE CASSETTE RECORDER <u>BEFORE</u> USING THIS ROUTINE.

==

```
002 040    041        WCAS:     LXIH       Initialize the mem-
002 041    000                             ory point to H=030
002 042    030                             and L=000.
002 043    315                  CALL       Wait for user to
002 044    170                  INPUT      input number of
002 045    002                             bytes to be trans-
002 046    315                  CALL       ferred.  Delays
002 047    140                  DELAY      the start of the
002 050    002                             data transfer.
    002    051  Thru   002 053   000    NOP (Unnecessary code
                removed)
002 054    176        MORE:                Get data from mem-
002 055    315                  CALL       ory (accumulator)
002 056    120                  CASIN      output and load to
002 057    002                             cassette tape.
002 060    315                  CALL       Display each byte
002 061    220                  DISPLAY    data and its add-
002 062    002                             ress on ports #2,
                                           1, and 0
002 063    043                  INXH       respectively.
002 064    174                  MOVAH      Increment the high
002 065    272                  CMPD       address byte and
002 066    302                  JNZ        check for end of
002 067    054                  MORE       data.  If not end,
002 070    002                             get more data.  If
002 071    303                  JMP        end, return to CRT
002 072    240                  CRT        monitor routine.
002 073    002
    002 074     Thru   002 077   000    NOP
```

****

CASSETTE INPUT ROUTINE (CASIN): This routine waits for data to be received by the cassette recorder UART, and inputs the data into the accumulator.

==

```
002 100   333        CASIN:   IN       Check the cassette
002 101   023                          UART status bits.
002 102   037                 RAR
002 103   322                 JNC      Recheck the cassette
002 104   100                 CASIN    UART status bits
002 105   002                          until data is avail.
002 106   333                 IN       Input data to the
002 107   022                          accumulator.
002 110   311                 RET     Go back to where
002 111   000                 NOP     CASIN was called.
    002 112   Thru   002 117   000     NOP
```

****

<u>CASSETTE OUTPUT ROUTINE (CASOUT)</u>: This routine waits for the transmitter holding register to say it is ready for the next data byte. The routine then outputs the data to the cassette.

==

```
002 120    365     CASOUT:   PUSHPSW    Save the data.
002 121    333               IN         Check the transmit-
002 122    023                          ter status bits.
002 123    346               ANI
002 124    004
002 125    312               JZ         Recheck the trans-
002 126    121               CASOUT+1   mitter status bits.
002 127    002                          (But do NOT try to
002 130    361               POPPSW     "resave" the prog
002 131    323               OUT        status word.)
002 132    022                          Once the transmitter
002 133    311               RET        status says it is
002 134    000               NOP        ready, return the
002 135    000               NOP        data to the ouput
002 136    000               NOP        port to send to the
002 137    000               NOP        cassette recorder.
```

****

<u>DELAY</u> <u>PROGRAM</u> <u>CONTINUATION</u> <u>ROUTINE</u> <u>(DELAY)</u>: This is a time delay. As programmed, the delay is for about 22 seconds. If the value ("001") in location 002 144 is changed to "000", then the time delay is only about 12.2 seconds (not quite a drop by half).

==

```
002 140   365      DELAY:  PUSHPSW     Save the registers.
002 141   305              PUSHB
002 142   001              LXIB        Load the following
002 143   364                          value into Reg. B.
002 144   001                          This value changes
002 145   315              CALL        the time duration.
002 146   277              KTS         KTS=THE KEX TIMEOUT
002 147   000                          SUBROUTINE (comes
002 150   013              DCXB        with the MMD-1).
002 151   170              MOVAB       When count is not
002 152   261              ORAC        zero, recall the
002 153   302              JNZ         KTS.  (Do NOT do
002 154   145              DELAY+5     all those saves/
002 155   002                          loads again!)
002 156   301              POPB        When time is up,
002 157   361              POPPSW      restore all saved
                                       registers.
002 160   311              RET
     002 161   thru   002 167   000        NOP
```

****

INPUT NUMBER OF DATA BLOCKS TO BE MOVED ROUTINE (INPUT): This routine allows the user to enter a single digit number from the HEX keyboard on the MMD-1/MI. Only the numbers from 1 -> 8 are accepted. Use a "0" to denote the number 8. If more than 8 blocks of data are to be loaded via this method, the loading routine will have to be repeated for each set of 8 or less blocks with appropriate changes in the load routine to allow for the memory location differences.

==

```
002 170   315        INPUT:    CALL
002 171   315                  KEX
002 172   000
002 173   376                  CPI        Check for a number
002 174   010                             from 0 -> 7, input
002 175   322                  JNC        by the user.
002 176   170                  INPUT      If not, go back and
002 177   002                  .          try again.
002 200   267                  ORAA       Set flags.
002 201   302                  JNZ
002 202   206                  NOT0
002 203   002
002 204   306                  ADI         Add 8, if the zero
002 205   010                              key were input.
002 206   204        NOT0:     ADDH        Compute stopping
002 207   127                  MOVDA       address; save it
002 210   311                  RET         in Reg. D.  Go
002 211   000                  NOP         back to where
002 212   000                  NOP         called from.
     002 213   Thru   002 217   000    NOP
```

****

<u>DISPLAY CONTENTS OF MEMORY ON LEDS ROUTINE (DISPLAY)</u>: This routine assumes the data of interest (shown by contents of H & L) is located in the accumulator when it is called, and displays it on Port 2. It takes the address given in H & L and displays them on Ports 1 & 0. (Ports 2, 1, & 0 are LEDs on the MMD-1.)

==

```
002 220   323      DISPLAY:  OUT      Move the contents of
002 221   002             (Port 2)   the accumulator to
002 222   175               MOVAL    the output Port, #2.
002 223   323               OUT      Move the low byte of
002 224   000             (Port 0)   the address to output
002 225   174               MOVAH    port, #0, and the high
002 226   323               OUT      byte of the address to
002 227   001                        output port, #1.
002 230   311               RET      Go back to who called.
     002 231   Thru   002 237   000   NOP
```

****

RETURN CONTROL TO THE CRT MONITOR ROUTINE (CRT): This routine initializes the stack pointer, resets he MMD-1, and returns control to the CRT monitor routine. If user is concerned about resetting to the beginning of the Audio Cassette Recorder Programs, change program contents for 002 244 and 002 245 to the starting address of "free" memory. 002 244 is the low byte and 002 245 is the high byte of the address.

==

```
002 240   061        CRT:  LXI        Give the stack pointer
002 241   000              SP         the value 4.  (i.e.
002 242   004                         initialize the "SP".)
002 243   041              LXIH       Load the starting add-
002 244   000                         ress of user access-
002 245   002                         ible memory into H&L.
                                      This is equivalent to
                                      using the RESET button
                                      on the hex pad of the
                                      MMD-1.
002 246   176              MOVAM      Move the contents of
                                      the addressed memory
                                      location into the
                                      accumulator.
002 247   315              CALL       Display the contents
                                      of memory on the MMD-1
002 250   220              DISPLAY    LEDs.
002 251   002
002 252   303              JMP        Go to the CRT monitor
002 253   000                         routine (found in KEX
002 254   001                         routines in MMD-1).
     002 255   Thru   002 257   000    NOP
```

****

<u>BOOTSTRAP</u> <u>ROUTINE</u> <u>(BOOT)</u>: This routine loads the previous code (already on tape) from tape into the memory addresses given above. This routine must be entered, by hand, each time the MMD-1/MI unit loses power. Unfortunately, the MMD-1 does NOT have continuous memory. NOTICE: THIS ROUTINE IS LOADed and executed from <u>HIGH</u> MEMORY!!!!! Do not tell how many bytes you want to transfer. When all MMD-1 LED lights go dark for more than 5 seconds or all are lit for more than 5 seconds, the tape is through loading.

==

```
030 000   041     BOOT:    LXIH     Initialize the memory
030 001   000                       pointer to starting
030 002   002                       address of audio cas-
                                    sette Recorder
                                    Programs.
030 003   333              IN       Clear flags, if
030 004   022                       necessary.
030 005   333     NEXTIN:  IN       Input status bits.
030 006   023
030 007   037              RAR
030 010   322              JNC      Jump back if no data
030 011   005              NEXTIN   available, yet.
030 012   030
030 013   333              IN       Input data.
030 014   022
030 015   167              MOVMA    Store the data
030 016   323              OUT      Output the data and
030 017   002                       address to Port #2.
030 020   175              MOVAL    Move the low address
030 021   323              OUT      byte to accumulator
030 022   000                       and output to Port #0.
030 023   174              MOVAH    Move the high address
030 024   323              OUT      byte to the accumula-
030 025   001                       tor and display on
                                    Port #1.
030 026   043              INXH     Increment the memory
030 027   303              JMP      pointer and then get
030 030   005              NEXTIN   more data.
030 031   030
```

The MMD-1/MI Operating Manual lists the code for three routines which were part of the AFIT KEX/MONITOR adaptation. These routines were TTYIN, TTYOUT, and RDRIN. These were at 000 164, and 000 201 respectively. Since RDRIN was for a paper tape reader input subroutine and was omitted from this work as unneeded. It was not included in the AFIT modification of the KEX/MONITOR program, as well.

Appendix D

List of Contacts and Suggested Contacts

Anderson, Timothy. He works at the Air Force Aerospace Medical Research Laboratory (AFAMRL), WPAFB, Ohio. He is a scientist/mathematician interested in robotics. Extension: 513-255-4244.

Bejczy, Antal. Manager, Teleoperator Laboratory, NASA/JPL, Pasadena, California.

Braswell, Robert N (Ph.D.). Deputy for Armament Systems, Armament Division, (AD/CZ), Eglin AFB, FL 32542. AUTOVON: 872-5315.

Brooks, Fred (Mr). ASD/AIM, WPAFB, Ohio. Required to assess robotics and its impact on the Air Force. I believe he had to write a statement of work as well.

Chu, Yee-yeen. Senior Scientist, Perceptronics, Inc., Woodland Hills, California.

CIMAR: The Center for Intelligent Machines and Robotics. This is Dr. Tesar's group. University of Florida, 300 MEB, Gainesville, Florida 32611.

Fielding, Michael. Program Manager, Airborne-Remotely-Operated Devices, Naval Ocean Systems Center, Kailua, Hawaii.

Freedy, Amos. Executive Vice President, Perceptronics, Inc., Woodland Hills, California.

FTD (Foreign Technology Division). The personnel stationed at FTD, WPAFB can fill (some) requests for information searches such as Unclassified memorandums. These memorandums could be translations of "Moscow Broadcast" taken from BBC Summary of World Broadcasts. I discovered this prosepective source of information through Mr. Tim Anderson (AFAMRL). He had requested a search by FTD of unclassified information relating to robotics.

Herbach and Rademan, Inc. 401 East Erie Avenue, Philadelphia, PA 19134 (215-426-1700). This was where the motors' information came from.

Hobby Robot Co., Inc., P.O. Box 997, Lilburn, GA 30247.

Johnson, R. T. Professor at University of Missouri-Rolla (was the Missouri School of Mines). He is involved with the fledgling robotics program at UM-R. His phone number is 314-341-4614. The Department of Mechanical and Aerospace Engineering Chairman's phone number is 314-341-4662, while the general faculty phone number is 314-341-4661. The address is:

Department of Mechanical and Aerospace Engineering
Mechanical Engineering Building
Rolla, MO 65401

Dr. Johnson noted in a letter (to me) that if his "limited" experience would benefit me, to call.

Kessler, Bill. A Ph.D. working at WPAFB, Ohio which Dr. Tesar suggested as someone locally to talk to about robotics, the U of F, and Dr. Tesar's work. I got the impression that Dr. Tesar has had "dealings" with Dr. Kessler, previously.

Langendorf, Lt. Col. Henry. Chief, AI/Robotics Division, TRADOC, Fort Benjamin-Harison, Indiana.

Lyman, John. Professor and Chairman, Engineering Systems Department, School of Engineering and Applied Science, UCLA. "Professor Lyman has participated in research, development and application of high-technology robotic sysstems, including teleoperator andd limb prosthetics, for more than 25 years. His special interest is in the human-equipment interface for complex, addaptive machines."

Madni, Azad. Director, Robotics and Automation Systems, Perceptronics, Inc., Woodland Hills, California. "Dr. Madni is currently principal investigator on a Navy Robotics R&D program directed toward the design and development of an intelligent robotic platform for U.S. Marine Corps reconnaissance and surveillance needs. He also serves as an advisor to the U.S. Army Research Institute Robotics/Artificial Intelligence Program. Dr. Madni has been principal investigator over the last four years on several DARPA projects in man-machine relations, user models in information prioritization and selection tasks, advanced methods for information display, and videodisc-based low-cost portable training systems."

Mayer, Lt Gordon E. Lt Mayer is the Projects Manager, Materials Laboratory, Wright-Patterson AFB, Ohio. He has his M.S. in robotics from Purdue University (1979). His thesis was on the Kinematic Design/Control of Manipulators. He worked most of 1979 for Unimation prior to coming on active duty (Air Force).

Montgomery, Jerry g. Lt, USAF. Currently assigned to ASD at WPAFB, Ohio. Was an M.S.E.E. student in pattern recognition under Dr. Matthew Kabrisky at AFIT. He is "local expert" on fuzzy set theory and fuzzy statistics. ASD/B1LE, 513-255-4044.

Motors (6-12V-DC). These motors were found in a Brevel Stock Motors catalog. These were purchased from:
Reserve Electric,
(Mike Evans, Sales Engineer)
2090 E. 19th Ave,
Cleveland, Ohio
216-771-5764

RB Robot Corporation. Produces the RB5X robot (with batteries for $1195. "The company expects computer and electronics engineers and hobbyists to buy the robot as a starter system for further robotics development. For $1195, the robot you get is blind, deaf and dumb. Its only sensory apparatuses are feely bumpers that tell it when it has run into an object. They provide tactile input for the robot's learning programs....[it] has a standard RS-232 serial interfface....[it has] an option package with sonar, pulsating light and extra memory, for $295" (Infoworld, 1982). The company is located in Golden, Colorado.

Roboticon. Name of seminar "series" on robotics. Can be offerred "in-house". For more information, contact:
Registrar, Roboticon
157 East Valley Parkway, Suite 2B
Escondido, CA 92025

Saveriano, Jerry W. President, Saveriano & Associates, Huntington Beach, California.

Tallen, Norman. A Ph.D. working at WPAFB, Ohio which Dr. Tesar suggested as someone locally to talk to about robotics, the U of F, and Dr. Tesar's work. I got the impression that Dr. Tesar has had "dealings" with Dr. Tallen, previously.

Tesar, Delbert. Director of CIMAR, University of Florida, 300 MEB, Gainesville, Florida 32611. Dr. Tesar will usually provide copies of his material upon request. 904-392-0814 (He was also quite good about returning my telephone calls; but, I tried not to abuse that either!)

UCLA Extension. A short course program was offerred at UCLA on 11-14 January 1983, entitled "Smart Systems and Human Factors in Battlefield Robotics". The coordinators and lecturers were John Lyman (PhD) and Azad Madni (PhD). Other lecturers were Antal Bejczy (PhD), Yee-yeen Chu (PhD), Michael Fielding (MS), Amos Freedy (PhD), Lt Col.

Henry Langendorf, and Jerry W. Saveriano (MS). Each of these lecturers and their "addresses" are listed separately. This was a four day course, EDP No. E4719V, Course No. Engineering 839.42, 2.4 CEU. Mailing list address is:

Mailing Lists, UCLA Extensions
P.O. Box 24901
Los Angeles, CA 90024

Perhaps lecture notes or other information would be available, if requested. The intent (quoted from the mailing list brochure) was "for managers of robotics/automation programs, developers of advanced weapon systems, researchers in the field of intelligent automation, C3 system designers and human factors engineers." The purpose "provides new concepts, methodologies, and specific technologies which are directly applicable to the development and realization of smart weapon systems for 1990-2000 time frame. It introduces generic approaches that should allow system developers to meaningfully apply state-of-the-art techniques in human factors engineering and man-machine interface design, advanced automation and expert systems, user models and information management aids to various current and projected application areas in battlefield robotics.

Appendix E

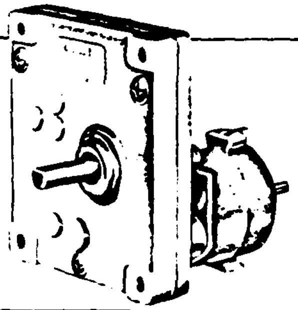
DC Gearmotor Specifications

BREVEL MOTORS

Engineering Bulletin No. 50

D.C. GEARMOTORS

SERIES 14R



The 14R D C Gearmotor is used where low to medium speed operation and high torque are desired. It is particularly suited to applications requiring high starting torque, infinitely variable speed control and/or reversibility. Typical applications include amusement games, business machines, micro film transports, tape drives, door or drawer openers, vending machines, and many others. Where other features or performance are required, we will design to suit the application and furnish a quotation after complete specifications are received.

MECHANICAL CONSTRUCTION

GEAR CASE Gears fully enclosed in heavily reinforced, closely fitting zinc-alloy die castings

BEARINGS Output and Armature Bearings are pre-oiled, sintered metal. Armature Bearings are self aligning with large oil reservoirs. Intermediate gears turn on hardened and ground steel pins securely held in die castings

GEARING Helical rotor pinion and helical linen base phenolic first gear for noise reduction is standard. Spur gears and pinions are used in other stages. Gears and Pinions are hardened to suit the application. Number of stages between rotor pinion and final gear will vary according to output speed.

OUTPUT SHAFT Case hardened cold rolled steel, ¼" dia., ⅝" long is standard

BRUSHES Copper-Graphite with Coil Springs is standard. Brush replaceable without disassembling motor.

FAN SHAFT: Rear motor extension of .1818" Dia

MOUNTING Four #8 32 Tap thru holes standard

All specifications subject to change without notice.

ENGINEERING DATA

SPEED RANGE 0.5 to 400 R P M

TORQUE: Up to 75 lb in., higher available depending upon duty cycle

ELECTRICAL SPECIFICATIONS:

SUPPLY VOLTAGE 6.0 to 48 Volts

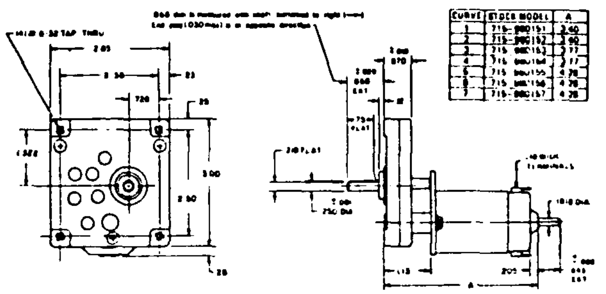
TERMINALS 3/16 Male Quick Connectors

OPTIONAL FEATURES

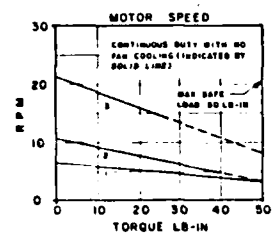
- Mounting Configuration Four Holes 10-32, 1/4 20 Tap or .170 Thru
- Electrical Terminations .110 Wide Male Quick Connect Terminals or Leads to Suit.
- Tachometer Output D.C. Voltage Proportional to Speed.
- Output Shaft Configuration. Up to 3/8" O.D. with Flats, Crossdrilled Holes, Internal or External Threads, Rear Extension, or Other Features to Suit. Stainless Steel Material and Other Corrosion Protection Available
- Refer to Engineering Bulletin No. 40 for additional features available on the drive motor.

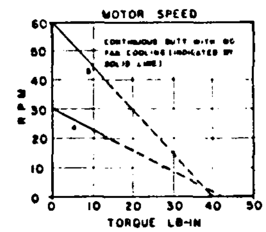
THE DESIGNS SHOWN ON THIS PAGE ARE READILY AVAILABLE FROM STOCK.

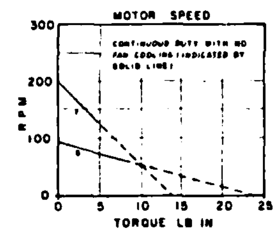
SPECIAL DESIGNS CAN BE ENGINEERED TO MEET YOUR SPECIFIC APPLICATION.

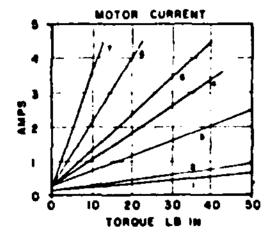


CURVE	STOCK MODEL	A
1	715-[illegible]151	2.40
2	715-[illegible]152	2.60
3	715-[illegible]153	2.77
4	716-[illegible]	2.77
6	715-[illegible]155	4.78
8	715-[illegible]156	4.78
7	715-[illegible]157	4.78









BREVEL MOTORS INC.

a subsidiary of

VERNITRON CORPORATION

BROAD AND 16th STREETS
CARLSTADT, NEW JERSEY 07072
TELEPHONE (201) 933 0220
TELEX 642-606

Model Z

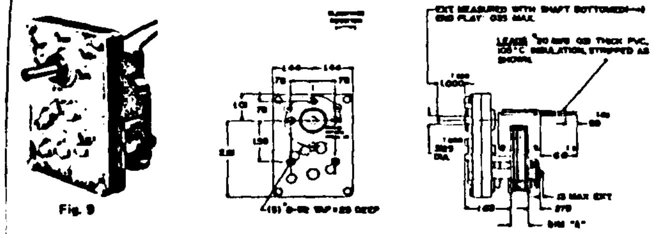


Fig. 9

D.C. Motors

These motors utilize permanent magnets and the recommended operating speeds established for maximum efficiency. A .545" long, rear shaft extension is standard for a cooling fan, if required. The armature stack is seven-slot with a seven bar commutator turned for minimum runout. The unit is mounted to a die-cast aluminum or Zamac end cap with #6-32 tapped holes. These motors are equipped with copper graphite brushes and coil springs located in the rear end cap. All bearings are self aligning, sintered bronze with accurate retention for maximum life. Standard stock motors operate from a nominal of 12 VDC and are equipped with combination solder and 3/16" tab terminals. The brush and spring assembly may be replaced without disassembling the motor.

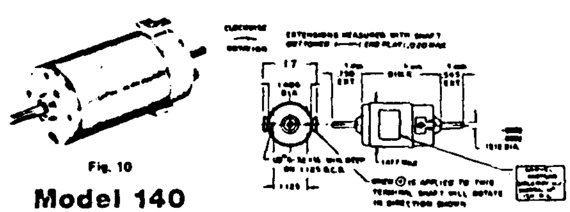


Fig. 10

Model 140

Stock No.	Fig. No.	No Load RPM	Starting Torque (oz-in)	Running Torque @RPM	Dim. "A"
724-980141	10	3700	6.5	2.0 – 2500	2.315
724-980142	10	4000	13.0	4.1 – 2700	2.690
724-980143	10	3200	20.0	6.5 – 2100	3.195

D.C. Gearmotors

In this group, the model R gear case is combined with one of the Model 140 D.C. motors for nominal operation at 12 VDC. A .545"-long, high-speed shaft extension is provided for a cooling fan, if required, or to obtain maximum motor life. Each gear case is fully enclosed in heavily reinforced, closely fitting, zinc alloy die castings with preoiled, sintered, porous metal bearings. The first or highest speed gearing stage consists of a helical rotor pinion and helical gear for maximum noise reduction. In other stages, spur gears and pinions are used.

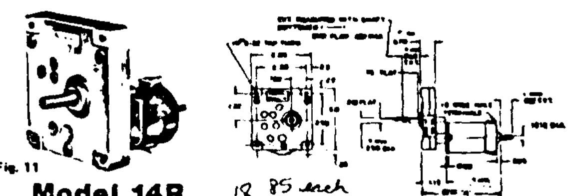


Fig. 11

Model 14R

18 85 each ORDER 2

Stock No.	Fig. No.	No Load RPM	Starting Torque (lb-in)	Running Torque @RPM	Dim. "A"
715-980151	11	7.3	100.0	30.0 – 4.8	3.40
715-980152	11	11.7	65.0	18.0 – 7.8	3.40
→ 715-980153	11	27.0	75.0	21.0 – 16.0	3.77
715-980154	11	30.0	47.0	14.0 – 20.0	3.77
715-980155	11	60.0	40.0	13.0 – 40.0	4.28
715-980156	11	90.0	25.0	10.0 – 60.0	4.28
715-980157	11	200.0	13.0	5.0 – 132.0	4.28

Vita

Roslyn J. Taylor was born on 8 August 1949 in San Francisco, California. She graduated from high school in Lebanon, Oregon in 1967 and attended Oregon State University from which she received the degree of Bachelor of Science in Chemistry in June 1973. In 1977, she entered Officer Training School and received her commission in the USAF. Upon receiving her commission, she attended the basic Communications-Electronics Officer Course at Keesler AFB, Mississippi. Upon graduation from technical school, she became the Chief of Quality Assurance for the 2046 Communication and Installation Group at Wright-Patterson AFB, Ohio, and then the Communications-Electronics Plans and Programs Officer for the 2046th CIG. In August 1979, she entered the newly organized Electrical Engineering Conversion Program offerred in residence at AFIT. In June 1981, she received the degree of Bachelor of Science in Electrical Engineering, whereupon she remained at AFIT to continue her studies in electrical engineering.

Permanent address:
34133 Tennessee Road
Lebanon, Oregon 97355

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7 APR 1983

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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Research, Development,
Clearing House

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report identifies areas requiring further research to develop a detailed research and development plan for an aircraft maintenance android. The general user requirements are defined and the desired android capabilities are addressed to meet the defined user requirements. The user requirements are defined independently of aircraft type. Structured analysis diagrams are used to describe the functional requirements. Specific recommendations are made.

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