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Apr 1st, 8:00 AM

## A Review of the Canadian Space Program

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## A REVIEW OF CANADIAN SPACE ACTIVITIES

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### ABSTRACT

This paper reviews the history of Canadian activities in space from the early Alouette I satellite to Canada's present involvement in the Space Shuttle Remote Manipulator System (SRMS) program. The SRMS program is being executed by Spar Aerospace Limited, through, an international agreement between the National Aeronautics and Space Administration (NASA) and the National Research Council of Canada (NRCC).

As the first flight SRMS reaches completion at Spar, the program is reviewed. The SRMS is described in terms of its subsystems, its modes of control and performance requirements and the current status of the hardware is examined. Delivery to NASA JSC of the first flight system is scheduled in 1980.

In conclusion, the paper highlights the benefits which accrue from international cooperation at the industrial level in space programs and makes a case for the continuance of such arrangements.

### INTRODUCTION

In a country whose size and population distribution makes communication land lines prohibitively expensive and who until 1951 had accurately mapped only 1 million of its 3.8 million squares miles, Canada is an ideal country to use satellites for survey and communication.

Canada has a population of 23.5 million, nearly 90% of whom reside within a handfull of southern cities in a corridor some 200 miles wide and 3,700 miles long. The remainder of the population are widely scattered throughout an area which extends northwards from the U.S. border some 3,000 miles to the Arctic.

The need to communicate efficiently as a means towards resource development has been a prime motivator in Canadian development. From the earliest times, therefore Canada has been at the forefront of communication research and development. In 1846, Canada's first electric commercial telegraph system was introduced between Toronto and Niagara, a distance of 37 miles to be followed some 28 years later by Graham Bell who on a journey between Boston and his home in Brampton, Ontario, prepared the first diagrams and notes for his invention of the telephone.

From such a beginning, Canada has developed a world class space industry and a satellite and ground station communications system that is one of the most advanced and efficient in the world.

In 1962, Canada became the third country in the world to place a satellite in orbit. Since that time, it has been Canadian government policy to engage in international space projects and for Canadian industry to play a vital role in the space programs of the world. That first Canadian launch has been followed by a further eight satellites and our industry has participated in many international space programs.

### CANADIAN ACTIVITIES IN SPACE

From the earliest days of Canada's involvement in space, the country has advanced in both space and earth sector systems. The design and construction of earth stations began as an evolutionary extension of RCA's experience in wideband microwave technology, coupled with its expertise in cassegrainian microwave-optics antenna feed systems. As early as 1959, Canada (RCA) collaborated with NASA in employing this type of antenna feed on deep-space probes in the Mojave Desert.

To improve long distance radio communications, Canada initiated development in 1955 of a family of sounding rockets called BLACK BRANT to measure the characteristics of the ionosphere.

ALOUETTE As a natural extension to this work, a Canadian satellite program of top side ionospheric research started in 1962 with the launch of ALOUETTE I. This satellite manufactured in Canada, sounded and mapped the ionosphere using radio waves. The information collected contributed the first global information about the upper region of the ionosphere. The sounding equipment developed included four Canadian designed and built STEM devices which formed the long sounding dipole antennas.

The STEM (Storable Tubular Extendible Member) is essentially a thin tape which assumes a tubular shape of high strength when extended. It is stored coiled on a drum. This Canadian invention has become an important multipurpose space mechanism and has subsequently been used on many space vehicles.

At a time when most satellites had a design life of only a few months, ALOUETTE had a design life of one year, but exceeding expectations, the satellite continued to send back useful information for almost eleven. Three years after the launch of ALOUETTE I, it was joined on-orbit by ALOUETTE II.

ISIS Following the success of ALOUETTE, an agreement was reached whereby Canada should design and build and the U.S. launch a series of International Satellites for Ionospheric Study (ISIS). The primary objective of the program was the comprehensive measurement of the ionosphere over a range of heights and latitudes. ISIS I was launched in 1969 and 1971 saw the launch of ISIS II with all of the program objectives being achieved.

EARTH STATIONS In concert with these activities, in 1963, RCA built Canada's first 4/6 GHz satellite ground station at Mill Village, Nova Scotia. This became the eastern terminal for Canadian overseas satellite communication via the INTELSAT system. The station was built for Teleglobe Canada, a Crown corporation. Teleglobe furthered the Canadian earth station capability by establishing three more earth stations; Mill Village II in 1969, Lake Cowichan, in 1971 and a station in the Laurentians currently being commissioned.

ANIK In 1969, the Canadian Government incorporated TELESAT to operate a commercial system of satellite communication to cover Canada. As a result, 1972 marked the western world's first domestic geosynchronous

communications satellite with the launch of ANIK A1. The satellite operates in the 4/6 GHz band and provides twelve radio frequency channels.

Communication with ANIK is accomplished by a network of 35 ground stations which includes 3 tracking stations and transportable earth stations called ANIKOM, these have been developed for remote locations. ANIKOM have antennas as small as 1 m diameter, are lightweight and they can be moved by aircraft, train or truck and assembled in a few hours.

The primary structure and the entire electronics payload of ANIK A was manufactured in Canada. The structure was manufactured by Spar Aerospace Limited and the electronics by Northern Electric (now Spar Aerospace) under contract to the Hughes Aircraft Company; the prime contractor to TELESAT Canada. The completion of this design led to similar contract arrangements for some 15 additional satellites that are derivatives of the Anik system. In the ANIK A series, three satellites were launched.

HERMES In January 1976, Canada's eighth satellite, and the world's most powerful communications satellite HERMES was launched. Originally called the Communications Technology Satellite, HERMES was the culmination of a five year program that had begun with the signing of a Memorandum of Understanding (MOU) in April 1971 between the Canadian Department of Communications (DOC) and NASA. Industrial contracts for the program were signed one year later in March 1972. A further agreement was reached in 1972 between DOC and the European Space Research Organization (ESRO) now ESA. Under this agreement, ESA contracted to provide the solar array blanket for the satellite. The blanket was manufactured by AEG-Telefunken.

The program blended several high technology elements including three unique subsystems. Two were developed in Canada; these being the lightweight, extendible, flexible substrate solar array system, and the 3 axis stabilization system which maintained the antenna earth pointing, whilst the solar arrays tracked the sun. This was the first 3 axis stabilization system in a geosynchronous communication satellite with flexible arrays.

The USA provided the travelling wave tube amplifier, which had an efficiency greater than 50% and gave a saturated power output of 200 watts. In addition, the U.S. contribution included the Thor-Delta launch vehicle; the test and launch preparation and launch.

Spar Aerospace Limited was responsible for the design, development, fabrication and testing of the spacecraft structure and executed the overall configuration design, mechanical subsystems design and the design and manufacture of the solar array and thermal control systems. As well, RCA Canada (now Spar Aerospace) supplied the electronics payload including antenna, telemetry, tracking, command, power conditioning and transponders. The transponders have four 85 MHz pass bands, two for receiving in the 14 GHz region and two for transmitting in the 12 GHz region. An essential part of the CTS system was the ground stations which RCA built. In all eighteen terminals, ten with 3 ft. diameter dish antenna and eight with 8 ft. diameter dish antenna were supplied.

HERMES is considered to be the forerunner of a generation of direct broadcast satellites that will be used to beam signals directly to home receivers. The satellite conducted communications experiments with the U.S. and Canada, sharing experiment time equally. The Canadian experiments were aimed at identifying and solving the country's communications needs for the 1980's. Other experiments included telemedicine, community interaction, government administration, radio wave propagation and evaluation of satellite earth terminals.

The satellite performed so well during its scheduled two years life that additional third and fourth years of experiments were possible, doubling its life span. At the request of the Australian government, HERMES was stationed over that country and used in a variety of tests and demonstrations including rain attenuation tests during 1979. When HERMES finally ceased functioning in December 1979, the program was hailed as a magnificent achievement.

ANIK B Canada's ninth satellite, ANIK B was launched by a Delta vehicle in 1978 and became Canada's fifth geosynchronous communications satellite on-orbit. The satellite has a multipurpose payload providing twelve color T.V. channels in the 4/6 GHz band plus four channels which operate in the 12/14 GHz band. The 12/14 GHz capability allows ANIK B to transmit and receive from crowded city areas with antennas placed on the roofs of buildings. This has a distinct advantage over the 4/6 GHz channel broadcasting which can interfere with existing ground-based communications, requiring the ground stations to be located some distance from city centres.

SHUTTLE RMS In accordance with a Memorandum of Understanding (MOU), NASA and NRCC are conducting a cooperative program for the Design Development, Test and Evaluation

(DDT&E) and Follow-On Production (FOP) of the Shuttle Remote Manipulator System (SRMS). For the DDT&E program, funding is provided by the Canadian Government. The DDT&E program requires Canada to build three complete systems plus associated Ground Support Equipment (GSE). For the FOP program, NASA is procuring from Canadian Industry, additional RMS's to fulfill the space shuttle production requirements, initially this involves the delivery of three systems.

The Remote Manipulator System (RMS) is the anthropomorphic, man-machine, payload handling system of the Space Transportation System. The system's requirements are for a manipulator capability to deploy payloads from the orbiter cargo bay, retrieve them from orbit and return them to the cargo bay for refurbishment or earth return.

Typical baseline payloads are the Space Telescope, the Inertial Upper Stage, and the Long Duration Exposure Facility. However, the RMS is capable of supporting many other space activities including spacecraft construction, inspection and repair, orbiter inspection, astronaut EVA activities and rescue operations (Figure 1).

The SRMS program had its genesis in 1969 with NASA's offer to the Canadian Government to "join the shuttle program". In 1970/71, the concept that RMS could form the element for Canada's participation in the shuttle program came independently to two companies; Spar Aerospace Limited and Dilworth, Secord, Meagher Associates Ltd. Circumstances brought the companies together in a teaming situation in 1971 and NASA's interest in cooperating with Canada in this area was obtained at an unofficial level. 1974 saw the forming of a Canadian Industrial team with the addition of CAE Electronics Ltd. and RCA Canada Ltd. (now Spar Aerospace) both of Montreal. Later that year, this consortium was placed under contract to NRCC to initiate preliminary work. A rigorous source selection process ensued with NASA concluding that Canada could successfully build this mission critical man-in-the-loop system. With these essential ingredients in place, formal negotiations with NASA started in May 1974, leading to the signing of the MOU in July 1975.

The SRMS development program has been conducted by Canadian engineers and technologists without technology transfer from other countries. The result of this is that a world class capability now exists in Canada for remote manipulator systems. This includes a unique simulation facility capable of very accurate real-time simulation of remote manipulator systems and payload handling tasks.

The space programs discussed so far constitute the principal activities in Canada's space program. However, Canadian Industry has participated in many international programs. Over 500 STEM devices have been flown on a wide variety of satellites including UK4, ISS, EXPLORER, DODGE, OGO, ATS, IMP and EOLE, where they were used as antennas, gravity gradient booms and solar panel actuators.

MERCURY Canada's flight experience on manned programs started in 1962 with the MERCURY program where Spar Aerospace designed and supplied the high-frequency antennas used for orbital communication. The booms were STEM devices 15 feet in length x 0.5 inches diameter. These were incorporated in pairs in the retro-pack to form a 30 foot tip-to-tip dipole.

GEMINI Spar has formed a close association with the U.S. manned space program and participated in the developmental programs of GEMINI. The principal system supplied was the HF orbital and the recovery antennas, used to locate the spacecraft after splash-down. Other systems included docking booms and astronaut grapple tools, the AGENA's transponder boom on the rendezvous flights, magnetometer booms, altitude sensing devices and the UHF quarter wave antennas.

APOLLO During the last three APOLLO missions, the "J missions", Spar provided several antenna and deployment devices. For Apollo 15 and 16, part of Canada's contribution were two booms that extended 25 feet, one of which deployed a mass spectrometer; the other deployed a gamma ray spectrometer. These conducted mapping of the radioactive sources on the surface of the moon.

One of the prime experiments for Apollo 17 was the Lunar Sounder experiment. The combined HF and VHF rigid yaggi antenna array which pivoted into position from the rear of the Service Module was supplied by Spar and permitted probing of the moon's surface and subsurface to a depth of 1.0 kilometer for a survey of physical properties including mascons (mass concentrations).

SKYLAB Spar developed a proof of principle model of an actuation device for the transfer of film packs between the APOLLO telescope mount and the workshop of SKYLAB. Extensive neutral buoyancy tests concluded with the endorsement of the unit as a means of film transfer.

## SRMS SYSTEM DESCRIPTION

The SRMS comprises 3 major elements; a 6 degree-of-freedom, 50 ft. long arm attached to the port longeron of the shuttle orbiter cargo bay, a display and control system and the payload interface, (Figure 2). Control of the arm is effected by the use of hand controllers, a dedicated RMS display and control panel and CRT monitors located in the orbiter crew compartment. This is augmented by the orbiter CCTV monitors, and General Purpose Computer (GPC).

The operator has direct vision of the RMS and payload through four windows, two located on the cargo bay aft bulkhead and two located overhead. The operator monitors RMS and payload activity on TV monitors located adjacent to his control panel. These receive signals from the RMS wrist mounted camera and from cameras variously located in the cargo bay.

The standard payload interface of the RMS is the "snare" End Effector attached to the wrist at the tip of the arm. This interfaces with a grapple fixture mounted to the payload.

The arm is capable of deploying on-orbit a 60 ft. long 15 ft. diameter payload with a maximum mass of 65,000 lb. The system can retrieve a payload of the same dimensions and has the capability for contingency retrieval of the same mass, however, retrieval of 32,000 lb. payload is baseline. With a 32,000 lb. payload, the maximum tip velocity of the arm is 0.2 ft/sec. while the unloaded arm tip speed is 2.0 ft/sec. The arm can release payloads with an attitude error of less than +5 degrees and +2 inches positional tolerance relative to the orbiter. Linear tip off motions of less than 0.1 ft/sec. and angular tip off rates less than 0.015 degree/sec. relative to the orbiter are baseline features.

For payload capture, the RMS control system is designed so that the operator can place the End Effector's longitudinal axis within a circle of uncertainty of  $\pm 1.5$  inches.

The End Effector is capable of reacting up to 230 ft.lb. torque and can apply a force at the End Effector, tangential to the arm of between 15 lb. and 80 lb. depending on arm geometry. The system is designed for a 10 year, 100 mission life.

The RMS is comprised of four major subsystems:

- o MECHANICAL ARM SUBSYSTEM,
- o DISPLAY AND CONTROL SUBSYSTEM,
- o ELECTRICAL SUBSYSTEM,
- o SOFTWARE SUBSYSTEM.

**MECHANICAL ARM SUBSYSTEM** The Mechanical Arm subsystem consists of the MANIPULATOR ARM, the PAYLOAD INTERFACE, the THERMAL PROTECTION SYSTEM, and the CCTV AND LIGHTING ASSEMBLY.

The general configuration of the MANIPULATOR ARM is shown in Figure 3. The manipulator is a 6 degree-of-freedom arm comprising six electro-mechanical rotary joints connected by structural members.

The sequence of joints starting from the orbiter interface are, shoulder yaw, shoulder pitch, elbow pitch, wrist pitch, wrist yaw and wrist roll. The arm booms are made of graphite/epoxy thin-walled tubular sections with internal stabilization rings. A 21 ft. arm boom connects the shoulder joint to the elbow joint. A second arm boom 23 ft. long attaches to the elbow joint and terminates at the wrist pitch joint, a further 6 ft. segment terminates at the wrist roll joint. The End Effector is bolted onto this section.

The space environment and weight considerations favoured the selection of an electro-mechanical drive system, the joint design being modular to minimize repair time and inventory costs. Housed within the joint structure, each joint contains a brushless dc servo-motor and gearbox. The drive systems are similar for all joints with the gear trains designed with forward and backdrive capability.

The standard RMS/PAYLOAD INTERFACE is the snare type End Effector which mates with a grapple fixture attached to the payload. The grapple fixture carries a target for visual alignment. Using direct vision and the wrist camera, the operator manoeuvres the arm to align the End Effector with the payload grapple target.

The End Effector and arm control system allow capture of a payload which has an initial angular misalignment with the grapple fixture of up to  $15^\circ$  in all axes, orthogonal misalignment can be up to  $\pm 2$  inches in the X axis and  $\pm 4$  inches the Y and Z axes. Three guide ramp cams on the grapple fixture mate with the compatible key ways in the End Effector and take out any misalignment during the capture sequence. At this time, joint motors implement zero current to allow the arm to reconfigure for this misalignment.

Capture of the payload is achieved by three "snare" wires which are mounted to a retractable carriage within the End Effector closing around the shaft on the grapple fixture and forming a soft dock (Figure 4 shows the grappling sequence). The snare wires are then retracted into the End Effector to rigidize the interface. The final allowable misalignment between end effector and grapple

fixture is  $\pm 0.015$  degrees and  $\pm 0.1$  inches in the X, Y and Z axes. Electrical connection between the End Effector and payload may be made after rigidization to provide dedicated hardwired connection for power and data.

The RMS poses a unique problem in THERMAL PROTECTION as the system is of highly variable geometry. It is used in a variety of operational sequences and the thermal environment alternates from sun facing to sun shielded. The factors that primarily affect the temperature and consequently, the on-orbit operating time of the arm are solar flux, steady state temperature prior to operation, power dissipation during operation and the thermal inertia of the system. The RMS thermal control maintains all of the elements of the RMS in operation within their temperature limits essentially by passive thermal control, using insulating blankets. White paint is also selectively used to ensure acceptable cooldown rates and to minimize solar absorption from areas that cannot be insulated. However, the system is supplemented by electrical resistance heaters to maintain minimum temperature levels under non-operating cold case environment conditions. Insulating blankets are used mainly to minimize both the magnitude and specular content of the solar energy reflected from the surface of the arm. The blankets cover the entire exterior of the arm, other than the white painted areas. Each blanket is multilayer and consists of layers of single and double goldized Kapton which are separated by dacron scrim cloth. The outer layer of the blanket is a teflon coated, Beta fibreglass fabric. All of the metallized layers are grounded by flying leads to the arm structure, to which the blanket itself is affixed by velcro tape.

On-orbit temperature monitoring is accomplished by sensors located in the thermally most critical components. The data thus obtained is multiplexed to the on-board computer where absolute temperatures are compared against the specified allowable levels. The operator is alerted via the display and control panel for any over temperature conditions and the corrective action to reposition the manipulator arm or to switch the power off, is taken.

The orbiter/RMS CLOSED CIRCUIT TELEVISION (CCTV) system consists of television cameras and lights located on the RMS and in the Orbiter cargo bay which give black and white pictures. The capability exists to transmit these pictures to the ground. The RMS contains as baseline, one light and camera

located on the wrist for payload capture. An option exists for a second CCTV and light assembly and a pan and tilt unit to assist in payload stowage. This is mounted to the elbow.

The cargo bay has locations for six lights outside the payload envelope and eight camera locations. This includes two camera locations on each of the forward and aft bulkheads and four on the keel. These input to the two split-screen monitors in the crew station. Facilities exist within the cargo bay to connect a color television camera for use by an astronaut in EVA.

DISPLAY AND CONTROL SUBSYSTEM. The dedicated RMS display and control system in conjunction with the orbiter CRT monitors and keyboard input to the GPC, provide the interface between the operator and the manipulator system. This system provides the necessary information to operate the RMS during check-out and on-orbit operations including, selection of primary control modes, safing, brakes on/off, End Effector control, and back-up channel drive modes.

DISPLAY. The RMS display system monitors and announces the system's mode and health, by audio warning and by the use of two CCTV monitors with split screen capability. Extensive Built-In Test Equipment (BITE) circuits perform self testing functions which are displayed.

CONTROL. The majority of RMS operations require man-in-the-loop control. For this reason, control of the RMS has been made "instinctive". This enables the operator to consider only the end point coordinates required of the End Effector/Payload, rather than controlling the joints serially to achieve the position. Primary control commands are implemented by two 3 degree-of-freedom hand controllers. The left hand controller permits the operator to command the three translational velocity components of the End Effector. The right hand controller allows the command of the three rotational velocity components of the End Effector, rate selection functions are provided by thumb and finger switches built into the handle. Secondary control is by switches on the D&C panel. Commands from the controller are routed through the Manipulator Controller Interface Unit (MCIU). This is the main interface between the orbiter GPC, the control and display panel, the electrical subsystem and the End Effector. The MCIU collects all the data, reformats it and transmits it to the appropriate part of the

system. To minimize weight, subsystem complexity and to retain flexibility, the MCIU utilizes microprocessor and bi-directional serial digital data buses across the various RMS interfaces.

Modes of Control As with all manned space activities, crew safety is an overriding factor in system design. The RMS modes of control recognize this and implement a double back-up system to the primary modes of operation; both bypass the primary chain of command through the GPC and utilize hardwired commands to the joint drive systems. The RMS can be controlled in any one of the following modes:

- o Manual Augmented,
- o Automatic - commanded auto sequence,  
- preprogrammed auto sequence.
- o Single joint drive,
- o Direct drive,
- o Back-up drive channels.

MANUAL AUGMENTED MODE, this is the normal mode of operation with the operator in the control loop. The operator commands rotational and translational velocities by use of the hand controllers. These are resolved into the corresponding joint rate commands based on the resolved rate algorithm in the RMS software and fed to the joint servos via the MCIU. This produces a motion that is speed and vectorially proportional to the deflection of the control stick and allows end point control.

AUTOMATIC MODES, there are two types of automatic control; COMMANDED AUTO SEQUENCE and PREPROGRAMMED AUTO SEQUENCE. The operator COMMANDED AUTO SEQUENCE drives the arm along a "straight line" trajectory from the initial to the final position by inputting the required data to the GPC through the keyboard. The RMS software checks final coordinates and orientation for reachability prior to execution of the trajectory. The PREPROGRAMMED AUTO SEQUENCE trajectories are composed of straight line elements stored in the GPC. The operator can select the required trajectory from the D&C panel. Any of the end points of the straight line elements can be selected as a pause point where the arm can stop until the operator requests it to complete the trajectory.

SINGLE JOINT DRIVE, this enables the operator to control the arm on a joint-by-joint basis with full GPC support. The operator selects the desired joint and commands it via the D&C panel. The software via the MCIU supplies the rate demands to the selected joint. The remaining joints maintain hold position.



DIRECT DRIVE MODE, this is the first contingency mode of operation and contains display support but the control bypasses the MCIU, the GPC and the data buses and gives a hard-wired command to the joint motor drive. The control inputs are from the D&C panel, driving a single joint. The other joints are de-activated and held with brakes.

BACK-UP DRIVE CHANNEL, the second contingency drive mode is used when no prime drive channel modes are available. It bypasses the MCIU, GPC, prime channel electronics, power supply and data bus. The mode allows joint-by-joint control of the arm from a dedicated section of the D&C panel.

The END EFFECTOR prime control mode for payload capture and release is via the D&C panel, and the system incorporates a back-up payload release function in series with the prime channel.

ELECTRICAL SUBSYSTEM The electrical subsystem controls the electrical power to the arm joints and End Effector in response to control commands. It also relays status information to the D&C panel and GPC and serves a self testing and verification function for critical control signals. The subsystem consists of the MCIU and the Arm Based Electronics (ABE). The ABE are mounted adjacent to the joints in the electronics housing. The ABE is comprised of 5 electronics units; these being the Servo Power Amplifiers for servo rate control, Signal Conditioning Units to precondition the output of the tachometer, and an End Effector Electronics Unit to control and monitor the End Effector. Joint Power Conditioners are used to regulate the voltage and provide primary and secondary voltages. A Back-Up Drive Amplifier is incorporated; the main function of which is to provide drive to any one joint in the event of failure.

SOFTWARE SUBSYSTEM The RMS software which is used for all primary control modes translates operator commands into servo commands for controlling the arm. Operator commands are transferred from the control station to the MCIU and then the GPC and RMS software. The software controls and monitors the arm for the following functions:

- o Operation initialization,
- o Control,
- o Signal conditioning,
- o Coordinate transformation,
- o System health monitoring,
- o Singularity warnings.

RMS software parameters may be changed to support each mission by changing the mission specific data, prior to the mission.

Typical parameters might be payload translational and rotational velocities, maximum joint angle rates and payload mass properties.

#### RMS UPDATE

DDT&E PROGRAM Two major milestones of the DDT&E program have been completed; the Preliminary Design Review held in the fall of 1976 and the Critical Design Review held in July 1978. Currently, we plan to be "on dock" at JSC with the first flight system about six months from now. The GSE and engineering model are complete and the qualification and flight hardware are in the final stages of integration and verification testing. The SRMS verification activities have included analysis, real time and non-real time simulation, inspection, design reviews and development, qualification and acceptance testing and they have demonstrated that the system meets the design and performance requirements.

SYSTEM TESTING In 1977, Spar built a 100 ft. long by 75 ft. wide, high bay 100,000 class clean room INTEGRATION AND TEST area. This area contains a level flat floor which allows the manipulator arm to be manoeuvred on an air bearing test rig (Figure 5).

Use of the rig allows system tests to be conducted under room temperature conditions, as a demonstration of the capability of the arm to meet performance requirements. Parameters such as rate control, positional accuracy, acceleration characteristics and response to hand controller inputs being evaluated. The test set-up also acts to confirm the analytical data of the real and non-real time simulations.

The test rig supports the arm in a manner that imposes the least risk of introducing extraneous or uncontrolled loading of the joints, and simulates zero g in one plane (2 axes) by supporting the arm on air bearing pads. By so doing, the rig helps to overcome the major constraint of zero g system testing in a one g environment. Arm movement is initiated from the arm joints. The shoulder is rigidly fixed to the floor and control is via an MCIU, D&C panel and associated hand controllers working in conjunction with a computer system simulating the orbiter GPC.

The test rig will be used for system level acceptance tests of the flight model. The qualification hardware does not undergo this system test, and after certification testing, will remain in readiness and stored for future disposition.



For the flight system acceptance test the flight MCIU D&C panel and hand controllers will be used. These will be connected after the manipulator arm has been integrated and mounted on the air bearing rig. The use of the system test set-up has validated the SRMS design and demonstrably increases the confidence in the system for on-orbit performance.

System level Electromagnetic Compatibility (EMC) tests are conducted on the completed FLIGHT MANIPULATOR ARM after integration of the ABE, EEEU and CCTV system. For these tests, the elbow/lower arm boom interface is disconnected to allow the simultaneous motion of the 6 joints. Via the software, the joint commands are set to implement zero rate and by inputting RF signals, conducted susceptibility tests are carried out.

The ENGINEERING MODEL ARM has undergone extensive conducted emission and susceptibility tests at the system level, as well as radiated susceptibility tests on the assembly of the Shoulder, Upper Arm Boom and Elbow.

Qualification level tests on the QUALIFICATION SHOULDER have included radiated susceptibility, conducted susceptibility, conducted emission and radiated emission tests.

Radiated Susceptibility Characterization tests are scheduled for the QUALIFICATION WRIST in the July/August time frame. These will determine the arm RF threshold levels.

ENGINEERING MODEL In 1978, the ENGINEERING MODEL was integrated and has since been used on the test rig for system level performance evaluation. The engineering model is equivalent in fit form and function to the flight and qualification units and in many areas, has undergone qualification level testing.

Development of this model has required the testing of materials and processes where documented evidence of prior space application did not exist, such as the carbon composite material for the arm booms, the dry film lubricant and the joint brake material.

SIMULATION In the one g environment of earth, accurate analysis, modelling and simulation are the principal means of performance evaluation and system verification for systems, such as the RMS, which are required to operate in a zero g environment. Consequently, an extensive simulation program has been carried out for verification of the overall SRMS system performance and also to permit the development of crew operating procedures.

The VERIFICATION PROGRAM uses both real and non-real time simulation. Spar uses a non-real time FORTRAN program ASAD (All Singing All Dancing) to simulate in NRT the dynamics of the SRMS by using five basic modules, ARM DYNAMICS, JOINT SERVO and GEARBOX, ARM CONTROL ALGORITHM, ORBITER ACS and DISPLAY. ASAD is a detailed ORBITER/RMS/PAYLOAD model which incorporates up to thirty selectable flexible modes and addresses the detailed design, development and performance verification issues of the SRMS in QUANTITATIVE terms (such as magnitude of variables e.g. speed). The NRT simulation program provided complete information regarding the systems modes of operation such as deployment and retrieval of payloads, singularly management auto mode trajectories, and arm positioning capability. These simulations have demonstrated that the system as designed, is stable and meets the performance requirements.

For conducting the real time simulation, Spar used the facility SIMFAC which is based on ASAD and is suitably restructured to permit real-time processing. SIMFAC addresses the man-in-the-loop QUALITATIVE elements of the system, such as operational capabilities. The SIMFAC orbiter complex, with part of the simulation subsystem in the background is shown in Figure 6a.

In SIMFAC, the operator is totally enclosed in a replica of the orbiter RMS control station (Figure 6b) where operator commands are generated through hand controllers and the D&C panel. The simulator generates four views in real time depicting the outline of the orbiter cargo bay, payload and manipulator arm on vector-type CRT monitors (Figure 6c). These views are created from an internal data base that defines the shape of the payload structure and manipulator arm as seen from the orbiter windows.

Both real and non-real time simulation is required to support the program up to the delivery of the flight system and later to support the early STS flights. There have been three critical simulation milestones to date. Phase III which supported the SRMS CDR concluded in 1978 and used RT and NRT simulations. The RT activity simulated payload deployment and retrieval and acted as a training tool for SRMS operators. It confirmed many operating procedures and allowed an evaluation of the D&C functions of the system. Phase III also demonstrated live simulations successfully and displayed the high performance of the system.

Phase IV RT and NRT simulations supported disposition of RID's raised at the CDR and served to update the model elements based on hardware tests. In addition, this phase continued work on normal and malfunction operating procedures and successfully showed system performance in various degraded modes.

Phase V simulations began in October 1979 using SIMFAC and ASAD. The major objective of the simulation was to support the formal SRMS verification, with ASAD addressing the system's detailed quantitative requirements and SIMFAC primarily addressing the qualitative man-in-the-loop requirements.

Throughout the DDT&E program, on-going work has validated and reconfirmed the validation of both SIMFAC and ASAD. This activity required updating the format and interaction protocol to conform to the current flight baseline. ASAD validation has included the use of analysis, comparison with test results, development hardware and non-real time simulation programs. The NRT simulation included the use of such programs as STARDYNE, NASTRAN, Spar programs such as SPARMS and ONEJNT and also confirmatory checks with other independent simulation programs such as the NASA, SES (Shuttle Engineering Simulator) and PDRSS (Payload Deployment and Retrieval Simulation System). The NRT verification simulation runs included payload deployment, retrieval, berthing, velocity limiting, stopping, torque capability and singularity handling tasks for a variety of payload, size mass and control modes.

The run data was recorded in printout and plot form and where appropriate, operator observations.

ASAD is the principal non-real time program for the shuttle RMS and is used to validate SIMFAC with respect to flexible dynamics, control modes and operations in the neighborhood of arm singularities. This ensures that SIMFAC can adequately perform it's primary function which is that of providing an accurate visual representation of the arm performance and behaviour to an operator such that the operator reactions to these displays, in terms of control, will be realistic.

The real time simulation verification was performed by four operators, three of whom were astronauts and required the system to meet a number of Flight Operations Directorate requirements which included:

- o Evaluation of criticality for some classes of malfunction,
- o Identification of hardware/software interface problems,

- o Investigation of malfunction and post malfunction operation,
- o Evaluation of system health check,
- o Identification of potential product improvements,
- o Refinement to operating techniques and procedures.

Each operator completed 27 runs of 9 task types, using payloads of typical size and mass. The data runs required the operators to track and capture free flying payloads. One operator performed an additional seven runs designed to test arm rate accuracies and singularity handling. Unknown to the operator, eight malfunctions were inserted in the simulation at predetermined points; each malfunction being representative of a particular class of criticality 1 failure (possible loss of crew) and included unannounced joint and arm runaways, and tachometer and position encoder failure. Post malfunction runs demonstrated that the contingency modes of control could be successfully used to place the arm/payload in a safe configuration.

The real and non-real time verification simulations were completed in November 1979 and concluded with the complete endorsement of the remote manipulator system.

SRMS INTEGRATION AND TEST Consistent with VERIFICATION, INTEGRATION and MAINTAINABILITY requirements, the SRMS is composed of a hierarchy of subassemblies. This allows the Integration and Test (I&T) of the system on a building block basis. The arm contains eight top level subassemblies, LINE REPLACEABLE UNITS (LRU's); these being the MCIU, ROTATIONAL HAND CONTROLLER, TRANSLATIONAL HAND CONTROLLER, CCTV and LIGHT BRACKETS, D&C PANEL, MECHANICAL ARM ASSEMBLY, STANDARD END EFFECTOR and the ARM THERMAL PROTECTION KIT. Of these LRU's, the mechanical arm assembly, end effector, arm thermal protection and CCTV and light brackets are composed of lower level SRU's (SHOP REPLACEABLE UNIT). Acceptance tests are conducted on the Flight System at both LRU and SRU level.

A status review of the major LRU and SRU for the qualification and flight units follows.

A major common component is the motor module. This element is the nucleus of the joint drive system and has undergone extensive testing which consisted of environmental testing plus, torque, stiction, friction, electrical interface compatibility, continuity. Testing has shown that this unit performs in accordance with the system requirements.

Assembly of the mechanical arm will commence with the integration of the shoulder and upper arm boom during the second week of May. The qualification booms and two sets of flight booms are complete and are awaiting integration. The flight booms have the wiring harnesses and velcro thermal blanket attachments in place and are presently in the I&T area at Spar.

The FLIGHT SHOULDER will complete acceptance vibration and thermal testing during the first week in May. The QUALIFICATION SHOULDER is scheduled to complete its structural load tests and instrument and set-up checkouts at the same time having completed vibration, thermal vacuum and humidity testing.

Following integration of the flight shoulder and upper boom, the ELBOW JOINT is integrated, the latter having completed its acceptance testing on schedule in mid-February. There is no qual elbow joint as the flight unit was qualified by similarity to the shoulder.

The FLIGHT WRIST is next to be integrated, the acceptance testing of which will be completed by the second week in May. The flight wrist has successfully undergone vibration and thermal testing and the unit will enter integration this month. The QUALIFICATION WRIST entered test during March for vibration shock and thermal vacuum test and will complete testing during the third week in June.

Both the QUALIFICATION and FLIGHT END EFFECTOR are in the final stages of assembly. The flight end effector will enter thermal vacuum and vibration acceptance testing in June and will be ready for integration on schedule in July. The qualification end effector will undergo an extensive test sequence of some four months duration including humidity, vibration, thermal vacuum and endurance testing. This will be completed in September.

The thermal protection blankets for the system are complete and where they are not integrated as part of the joint assembly, they will form the last part of the system integration.

The MCIU, Rotational Hand Controller (RHC), Translational Hand Controller (THC) and the D&C panel completed acceptance testing during April and will be integrated by the end of June.

The CCTV camera and flood light were delivered to Spar during the last week of March in readiness for the CCTV system integration and test during July.

The GSE is complete and will be used for integration during June through to September.

FOP The Follow-On Production (FOP) program is a natural outgrowth of the DDT&E program and uses the same industrial team and suppliers. A letter contract was signed between NASA JSC, the Canadian Commercial Corporation and Spar effective May 1, 1979, and a definitive contract agreement for the FOP program was reached in January 1980 and the contract signed in early April 1980.

The program as currently contracted will be of some five years duration and is on schedule. It embraces the supply of three complete flight systems currently projected for delivery in May 1982, November 1983 and November 1984 and an Integrated Logistics Support (ILS) program. The three manipulator systems to be supplied are currently baselined to the first flight system for the DDT&E program.

The ILS program encompasses PRODUCT SUPPORT, GROUND SUPPORT EQUIPMENT, TECHNICAL MANUALS and SPARES PROVISIONING conferences. The ILS program covers the period from May 1979 to December 1984.

PRODUCT SUPPORT activity will be in response to task orders initiated by NASA and carried out at Spar Canada. Typically, the studies would be special design and trade-off studies, analysis and simulation tasks aimed at product improvement.

Spar will be providing OPERATIONAL FLIGHT SUPPORT at NASA JSC. The assignments cover such areas as mission support, establishment of operational and malfunction procedures and support of spacecraft and other hardware reviews.

SPARES PROVISIONING lists will be compiled for the first Spares Provisioning Conference scheduled for the last quarter of 1980. The list will contain candidate spares for both the SRMS and associated GSE identified over the initial first five year period of orbiter operation at JSC and the Vandenberg Air Force Base (VAFB).

TECHNICAL MANUALS will be supplied to cover the maintenance procedures to an intermediate depot level covering the exchange of joints, end effector and arm booms. Also covered will be depot repair and overhaul of Spar supplied LRU's and SRU's. The manuals are scheduled for delivery in the first quarter of 1983. GROUND SUPPORT EQUIPMENT (GSE) adequate to support the FOP program is being provided and includes such items as joint and

boom shipping containers, strongbacks, handling dollies and electrical checkout equipment. The GSE is scheduled to be in place at VAFB in time for the delivery of the second FOP RMS flight system in 1983.

#### FUTURE CANADIAN PROGRAMS

Following on the success of the ANIK B satellite and the SRMS, Canada is now moving forward with a balanced space program on a number of fronts. These programs can be broadly categorized into R&D INTENSIVE and OPERATIONS ORIENTED. The former including both ground and spaceborne studies/experiments in Remote Sensing, Space Science and Communications, the latter covering remote sensing operations such as receiving data from Landsat satellites and communications operations such as ANIK.

COMMUNICATION Since the establishment of TELESAT in 1969, four Canadian communications satellites have been placed in orbit and a further launch, ANIK C1 (TELESAT E) is planned during 1982. For all of these, it was necessary for Canada to rely on a U.S. prime contractor.

However, the next Canadian communication satellite to be launched, ANIK D1 (TELESAT F on STS-11) in November 1982, will be built in Canada with Spar Aerospace as the prime contractor. For this and future satellites, the David Florida Laboratory in Ottawa is being upgraded as the integration, assembly and environmental test facility.

ANIK C will form the backbone of east-west telecommunication in Canada during the 1980's. It will replace the ANIK A satellites which will be nearing the end of their life span. ANIK D1 will be followed by ANIK C2, (TELESAT G on STS-17) in March 1983 and ANIK D2, (TELESAT H) in the first quarter of 1985.

Canada's proposed MUSAT Multipurpose Satellite program is both R&D and operations-oriented. Initially it is a study which could lead to the construction of a satellite during the 1981/84 time period. The satellite would be built in Canada and provide "press-to-talk" voice communication with ships, aircraft and field parties in the Canadian north. Baseline for the ground stations is that they will be small, economical and easy to operate. The total system will offer a flexibility and cost efficiency not attainable by other means.

REMOTE SENSING/METEOROLOGICAL Involvement in two major remote sensing programs is planned for the period 1980-1985; these being LANDSAT and SEASAT. LANDSAT is primarily an operational-oriented program that is proving

to be increasingly valuable for crop inventory, forest, wildlife and water resource management, land use mapping, ice reconnaissance and mineral and petroleum exploration. LANDSAT D will be launched by NASA in 1981 and will use the upgraded Canadian data reception and processing earth stations facilities at Price Albert, Saskatoon and Shoe Cove, Newfoundland, to provide better colour and spatial resolution and improved identification of the earth's surface. Data from LANDSAT is received in Canada under terms of the Canada-USA Earth Resources Surveys (ERTS/LANDSAT) Agreement.

The U.S. SEASAT program uses satellites to monitor the oceans and to provide continuously updated reports on weather and sea conditions. Participation in this program is part of a Canadian project SURSAT which is a program aimed at defining the feasibility of using satellites to assist in surveillance and forecast needs for the 1980-2000 time frame.

ESA Canada entered into an Agreement of Cooperation with the European Space Agency (ESA) in December 1978 allowing for participation in the basic ESA program and other optional applications programs on a case-by-case basis. In the latter area, the Canadian Government has allocated funds for participation in the project definition studies on two projects; L-SAT and PERSSP. L-SAT is a demonstration satellite carrying a telecommunications payload and is expected to be launched in late 1983. Canadian participation is expected to include spacecraft platform subsystems and/or payload elements.

Canada's contribution to the PERSSP (Preparatory European Remote Sensing Satellite Program) is expected to involve work on the development of technology related to Synthetic Aperture Radar (SAR).

SPACE SCIENCE A new cooperative SPACE SCIENCE PROGRAM has been negotiated with NASA. It's objectives are to sustain and improve Canadian research competence in space science and provide knowledge on which to base future space programs. The program will consist of three separate contributions to the Shuttle/Spacelab missions and two ground based observational systems in support of a NASA study of the origin of plasma in the earth's neighborhood.

Additional space ventures for Canada in the next five years include a series of studies for an operational Direct Broadcast Satellite (DBS) system that would increase the coverage and the number of television and voice channels available to remote areas of Canada. As well, Canadian Industry hopes to

participate in selected international programs such as the Australian DBS system and earth stations, the European NORDSAT broadcast system, and possibly French and German domestic systems.

Looking further into the future, Canada may consider a successor to the HERMES communications technology satellite. Such a satellite with direct broadcast capability, launched as part of an international program (possibly Canada/USA) could be used to demonstrate the potential of satellite communication to developing nations and thereby enable them to develop their operational requirements for a domestic system. Further programs of research and development will be embarked upon to enable the improved use of meteorological data and further the knowledge of the composition and characteristics of the upper atmosphere.

#### THE BENEFITS OF INTERNATIONAL COOPERATION

Most countries now recognize that space is here to stay particularly in the area of communications and earth observation. Indeed many large countries such as India, island nations such as Indonesia and the Philippines and undeveloped nations are moving directly from regional networks to satellite communications bypassing the expensive and inflexible terrestrial microwave feed or landline systems.

These countries have found that for future development and economic needs, it is a necessity to become involved in a global space program. The cost and complexity of such programs, however, is so large that it necessitates international cooperation at both the financial and technical levels. Canada's Space Program shows a history of such international cooperation.

In 1964, Canada joined ten other nations in the first agreement for an international communications system employing satellite technology (INTELSAT). The organization was created to own and operate a global commercial communications network using satellites positioned over the Atlantic, Pacific and Indian Oceans. INTELSAT now has 101 member nations, 163 earth stations in 88 countries and some 25 satellites launched.

Since 1963, Canada and the U.S. have cooperated in meteorological programs whereby Canada has acquired cloud pictures and other data from U.S. satellites, using its own earth stations. Many other nations participate in such programs and along with the World Meteorological Organization provide data acquisition, communications and processing networks which allow a truly global system for meteorological information.

Since 1972, space receiving stations have been operated on Canadian soil to retrieve data from the U.S. LANDSAT remote sensing satellites for use by federal and provincial governments and the private sector in monitoring and managing the resources, crops and environment.

During 1979, Canada's involvement in international programs counted LANDSAT, SEASAT, ISIS, ESA programs, ANIK B, SARSAT, SRMS, ANIKS C AND D amongst its ventures.

Canada has recently joined with the U.S.A. and France in a Search and Rescue Satellites program SARSAT to test and demonstrate the use of satellites to detect and locate aircraft and marine disasters. The experiment will be carried aboard three U.S. weather satellites. The 15 month evaluation is scheduled to begin with the first launch in 1982. The USSR is also participating in SARSAT with Japan pressing to participate.

Amongst the gains of international cooperation is the contribution that is made to the world's scientific and demographic knowledge and the subsequent economic and social dividends that accrue. Also the achievement of national aims such as sovereignty, international recognition, employment for underdeveloped areas, resource exploration and management, education and community health programs can be realistically advanced by the use of spaceborne systems.

Canada's participation in international satellite programs has demonstrated that peoples of many nationalities can work together towards common objectives and in so doing, promote understanding on a man-to-man basis that helps to withdraw the barriers causing isolation between nations.

Advanced social and economic entities such as Canada, U.S.A, USSR need to maintain their standards and economic position relative to other nations in order to satisfy the aspirations of their population. Space programs at a price the countries can afford helps to maintain such standards and provides a means to enhance their high technology needs.

Man's imagination and spirit of adventure have always caused him to reach out for the unattainable. Space travel itself, once the symbol of the unattainable is now being conquered and man's inquiring mind is causing him to search further afield to achieve new goals.

The "space age" which may have started as a race or competition between nations is now becoming a cooperative effort with many nations sharing the program costs and knowledge gained.

The benefit to mankind of inventive space activities are legion and range from the use of solar energy, the better control of earth resources and environmental pollution, to seeking knowledge of the earth's formation and ultimately perhaps, to a greater understanding of the evolution of the universe itself.

International Cooperation in world space programs provide stimulating and challenging opportunities for future scientists and engineers, and from such endeavors, the industrial and national teaming can go beyond the immediate project and further objectives in other areas of world concern.

#### ACKNOWLEDGEMENTS

The author wishes to thank Spar Aerospace Limited for permission to present and publish this paper and the staff of Spar for assisting in it's preparation.

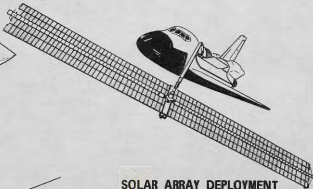
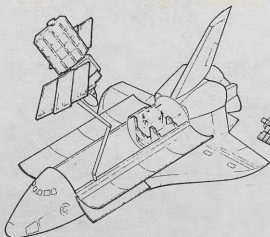
#### REFERENCES

1. Space Manipulators Present Capability and Future Potential, J.D. Graham, Dr. R. Ravindran, Dr. K. Knapp, May 1979, AIAA/NASA Conference on Advanced Technology for Future Space programs, Hampton, Virginia.
2. The Thermal Design, Analysis and Testing of the SRMS, A.M. Gray, A.S. Jones, A. Kong, June 1979, AIAA 14th Thermophysics Conference, Orlando, Florida.
3. The Canadian Space Program Five-Year Plan (80/81-84/85) Discussion paper published by Department of Communications, Government of Canada, January 1980.

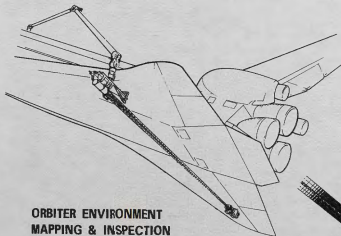
# Fig.1 TYPICAL RMS USES

**PAYLOAD DEPLOYMENT AND RETRIEVAL**

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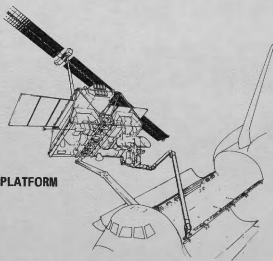
**SOLAR ARRAY DEPLOYMENT**



**ORBITER ENVIRONMENT  
MAPPING & INSPECTION**

**ON-ORBIT SATELLITE & PLATFORM**

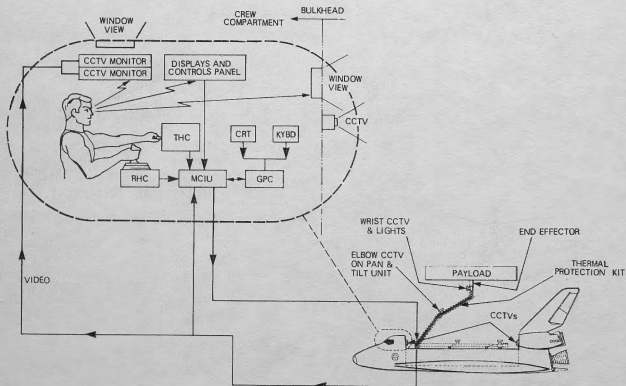
- CONSTRUCTION
- SERVICING
- ASTRONAUT EVA



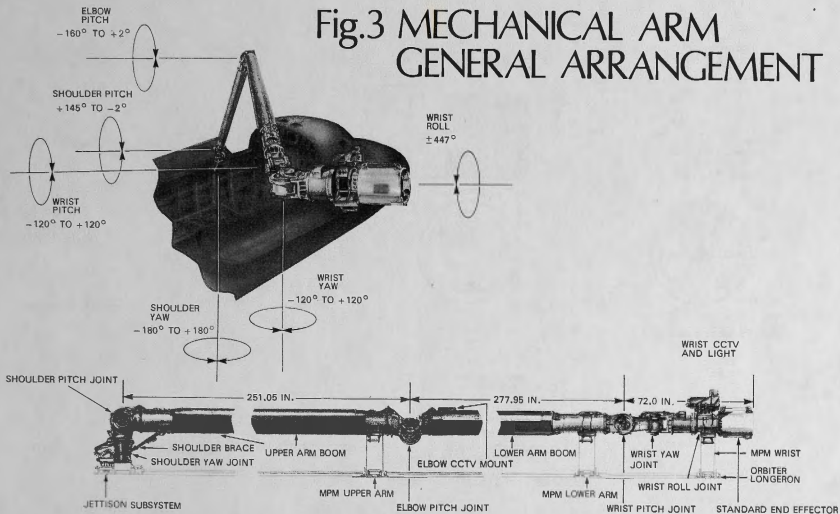


# Fig.2 SHUTTLE RMS

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# Fig.3 MECHANICAL ARM GENERAL ARRANGEMENT



# Fig.4 RMS END EFFECTOR CAPTURE & RIGIDIZE SEQUENCE

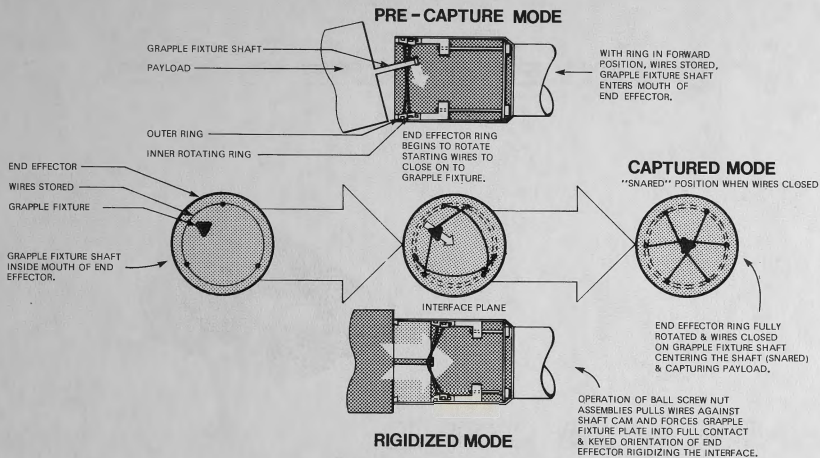
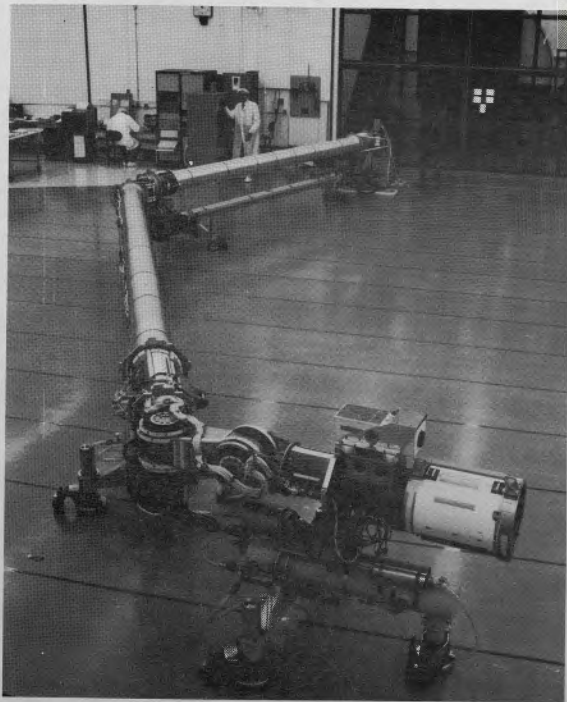


Fig.5 ENGINEERING MODEL ARM ON  
AIR BEARING TEST RIG

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SPAR I&T AREA 100,000 CLASS CLEAN ROOM

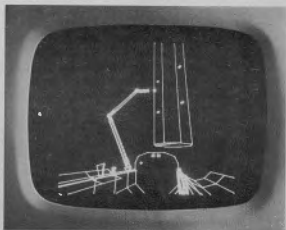
## Fig.6 SIMFAC SIMULATOR



a SHUTTLE ORBITER OPERATOR COMPLEX



b OPERATOR COMPLEX INTERIOR  
CONFIGURED AS THE AFT  
FLIGHT DECK OF THE NASA  
SHUTTLE ORBITER



c SCENE GENERATION MONITOR