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SPACE DIRECTORATE RESEARCH AND TECHNOLOGY ACCOMPLISHMENTS FOR FY 1987

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SUMMARY

The purpose of this report is to present the major accomplishments and test highlights for FY 1987 that occurred in the Space Directorate. Accomplishments and test highlights are presented by Division and Branch. The presented information will be useful in program coordination with government organizations, universities, and industry in areas of mutual interest.

ORGANIZATION

The Langley Research Center is organized by directorates as shown on figure 1. Directorates are organized by divisions and offices. The Space Directorate consists of two divisions (Atmospheric Sciences Division, Space Systems Division) and one office (Space Station Office) as shown in figure 2. The Atmospheric Sciences Divisions consists of 92 NASA civil servants who are divided into five branches and one office. The Space Systems Division consists of 97 NASA civil servants who are divided into five branches and one office. The Space Station Office consists of 30 NASA civil servants who are divided into three offices. Figure 2 lists the key people in the Divisions.

The Space Directorate conducts research in atmospheric and Earth sciences, identifies and develops technology for advanced transportation systems, conducts research in energy conversion techniques for space applications, and provides the focal point for conceptual design activities for both large space systems technology and Space Station activities.

FACILITIES

The Hypersonic Facilities Complex consists of several hypersonic wind tunnels located at four Langley sites. They are considered as a complex because these facilities represent a major unique national resource for wind tunnel testing. The complex currently includes the Hypersonic CF_4 (tetrafluoromethane) Tunnel ($M = 6$), the High Reynolds Number Mach 6 Tunnel, the 20-Inch Mach 6 Tunnel, the Mach 8 Variable-Density Tunnel, the 31-Inch Mach 10 Tunnel, the Hypersonic Nitrogen Tunnel ($M = 17$), and the Hypersonic Helium Tunnel and its open jet leg ($M = 20$). (See figure 3.) These facilities are used to study the aerodynamic and aerothermodynamic phenomena associated with the development of advanced space transportation systems, including future orbital-transfer and launch vehicles; to support the development of advanced military spacecraft capability; to support the development of future planetary entry probes; to support the development of hypersonic missiles and transports; to perform basic fluid mechanics studies, to establish data bases for verification of computer codes, and to develop measurement and testing techniques.

This complex of facilities provides an unparalleled capability at a single installation to study the effects of Mach number, Reynolds number, test gas, and viscous interactions on the hypersonic characteristics of aerospace vehicles. Approximately half the current testing in these facilities is classified, thus restricting the amount and content of test results that can be reported in the open literature. Facility descriptions follow.

Hypersonic CF_4 Tunnel:

The CF_4 tunnel was converted from the Langley 20-Inch Hypersonic Arc-Heated Tunnel in the early 1970's. The basic components include a CF_4 storage trailer, high-pressure CF_4 storage field, pressure regulator, lead-bath heaters, nozzle, test section, diffuser, vacuum system, and CF_4 reclaimer. The CF_4 test gas is heated to a maximum temperature of approximately 1530°R by two lead-bath heaters operated in parallel. Each heater contains 20,000 lb of molten lead that is heated by 18 3-kW heating elements: the test gas flows through 44 spirally wound tubes immersed in the molten-lead container. The high pressure (up to 2500 psi) heated CF_4 flows from the heater, through an in-line filter designed to trap particles greater than 10 microns in diameter, and into a settling chamber which consists of a pressure vessel, diffusing cone, and fine-mesh screens.

Flow is expanded along a contoured, axisymmetric nozzle having a throat diameter of 0.446 in., and exit diameter of 20 in., and designed to produce Mach 6 at the exit. The settling chamber and nozzle were designed for a maximum pressure of 3000 psia and a temperature of 1600°R.

The flow exhausts from the nozzle into an open-jet test section. Models are supported at the nozzle exit by a pneumatically driven injection mechanism and the angle of attack may be varied over a range from -10° to 50°, but is not variable during a run (i.e., the system lacks pitch-pause capability). The injection time is variable from approximately 0.3 to 1 sec. Windows are located on opposite sides of the test section for flow visualization.

Following the establishment of steady flow in the nozzle, which requires about 3 sec, the model is injected into the flow. After desired data are obtained, the model is retracted and the tunnel is shut down. The nominal run time is 10 sec; however, a maximum run time of approximately 30 sec is possible. Presently, the reclaimer operates at an efficiency of 70 to 75 percent. This operational efficiency coupled to the high cost of CF_4 (approximately $10/lb) dictates that the run be as brief as possible.

High Reynolds Number Mach 6 Tunnel:

This facility is an intermittent blowdown tunnel which became operational in 1958. The air-test medium is heated by electrical heaters, passes through a settling chamber, a contoured axisymmetric nozzle, a test section, a diffuser, and exhausts into a 41-ft-diameter vacuum sphere. The same air supply and vacuum systems are used for this facility and for the Mach Variable Density Tunnel discussed earlier. The stagnation temperature range is 700°-1060°R and the stagnation pressure range is 50-3200 psia giving a Reynolds number range from $1.8 - 50 \times 10^6$ per ft. The test section diameter is 12 in. There are two interchangeable test sections: one has Schlieren windows and a model injection system (angle of attack not variable during a run) while the other test section is for tunnel-wall boundary-layer studies over a length of 12 ft and length Reynolds number up to 1200 million. The maximum run time is approximately 5 minutes.

20-Inch Mach 6 Tunnel:

The Langley 20-Inch Mach 6 Tunnel, which became operational in 1958, is a blowdown wind tunnel that uses dry air as the test gas. Air is supplied from a 600 psi reservior with a storage capacity of 42,000 ft^3 and heated to a maximum temperature of 1000°R by an electrical resistance heater. Air for this reservoir is transferred from either 3000 psi or 4250 psi tank fields. An activated alumina dryer provides a dewpoint temperature equal to 419°R at a pressure of 600 psi. The settling chamber contains a perforated conical baffle at the entrance and screens; the maximum pressure is 525 psia. A fixed-geometry, two-dimensional contoured nozzle is used; that is, the top and bottom walls of the nozzle are contoured and the sides are parallel. The test section is 20.5 in. by 20 in., and the nozzle length from the throat to the test section window center is 7.45 ft. This tunnel is equipped with an adjustable second minimum and exhausts either into combined 41-ft-diameter and 60-ft-diameter vacuum spheres, a 100-ft-diameter vacuum sphere, or to the atmosphere through an annular air ejector. The maximum run time is 1.5 minutes with the two spheres, 10-15 minutes with the single large sphere, and 20 minutes with the ejector.

The Mach 6 tunnel has an upper and a lower injection system at the test section. The upper system is generally used to insert a pitot pressure probe into the flow. Models are mounted on the lower injection system located in a housing below the test section. This system includes a manually operated, remotely-controlled, sting support system capable of moving the model through an angle-of-attack range from -5° to +55° for angles of sideslip of 0° to -10°. Injection time of the model can be as rapid as 0.5 sec, covering the last 10 in. of travel in approximately 0.3 sec with a maximum acceleration of 6g for heat-transfer tests. For force and moment tests, the injection time for the last 10 in. is adjusted to 0.9 sec with maximum acceleration of 2g.

Mach 8 Variable Density Tunnel:

The Mach 8 Variable Density Tunnel is an intermittent blowdown tunnel which became operational in 1960. It consists basically of a heater, settling chamber, contoured axisymmetric nozzle, test section, fixed second minimum, and vacuum system. Dry air is transferred from a 4250 psi tank field and regulated from 30 to 3000 psi. The air is heated by an electric resistance heater that is shared with three other wind tunnels (not members of the HFC), to temperatures between 1160°R and 1510°R. The heated air flows into a settling chamber having an inside diameter of 14 in., length of 4.75 ft, and containing a perforated conical baffle at the entrance and a set of screens. The nozzle throat diameter is 0.58 in., the test section diameter is 18 in., and the length from the throat to the test section is 8.9 ft. Windows are located on both sides and the top of the test section.

A model injection system beneath the test section allows models up to 27 in. in length to be rapidly injected at fixed angles of attack and sideslip; a variable angle strut exists for the force tests. Flow is exhausted into two vacuum spheres, 41 ft and 60 ft in diameter, which provides a run time of 90 seconds.

31-Inch Mach 10 Tunnel:

The 31-Inch Mach 10 Tunnel, formerly known as the Continuous Flow Hypersonic Tunnel, was designed as a blowdown start, continuous running facility. Constructed in 1959 to 1962, the first blowdown run was made in 1962 and the first continuous run was made in 1964. Due to energy conservation measures instituted in the mid 1970's, this facility is presently operated only in the blowdown mode. It consists of a high pressure air storage system having an internal volume of 875 ft^3 and rated at 5000 psi maximum, a 15-MW electrical resistance heater located in a vertical pressure vessel, a 12-in.-diameter settling chamber, nozzle, test section, adjustable second minimum, after cooler, vacuum spheres, and vacuum pumps. The settling chamber, nozzle throat section, test section, adjustable second minimum, and subsonic diffuser are all water cooled. The settling chamber is equipped with screens at the upstream end and is faired into the upstream end of a square nozzle which is 1.07 in. by 1.07 in. at the throat. The throat section was machined undersized from four beryllium copper segments with copper cooling tubes placed in slots bonded with silver solder, flame sprayed with nickel aluminide and zirconia to provide a layer of insulation, and hand worked to the final contour. This throat section has its own high pressure cooling water system that operates at 1600 psi.

Models are supported on a hydraulically operated injection system contained within a housing on the side of the test section. This housing rotates about a vertical axis to provide access to the model and is isolated from the test section by a sliding door. This arrangement allows access to the model without opening the test section to the atmosphere; hence, model changes could be made without having to shut the tunnel down when it was operated in the continuous mode. Models can be injected to the nozzle centerline in less than 0.5 sec and the angle of attack varied +90° (useful angle-of-attack range with straight sting is from -45° to 45°) at 5° per sec; the sideslip range is +5° at 2° per sec and both angle of attack and yaw are remotely controlled by a computer. With the second minimum closed to about 25 percent of the maximum test section cross section area and the use of two 41-ft-diameter vacuum spheres, run times of approximately 60 sec are achieved.

Although presently operated only in the blowdown mode, the five multistage, centrifugal compressors in series with a 24,500 hp drive system remain on site. Also worthy of note is the fact that a smaller Mach 10 tunnel, referred to as the Langley 15-Inch Hypersonic Flow Apparatus, is on site. This facility is used exclusively for Schlieren studies, since the Schlieren system for the 31-Inch Mach 10 Tunnel was dismantled when the model assess housing was installed on the side of the test section.

Hypersonic Nitrogen Tunnel:

The Hypersonic Nitrogen Tunnel is a blowdown tunnel that was placed into operation in 1964. High purity liquid nitrogen flows from a 4000-gallon storage vessel to a liquid nitrogen conversion unit which pumps the LN_2 to high pressures (up to 8000 psi). The nitrogen exits the conversion unit as a gas, passes into four surge tanks and through a turbine-type flowmeter which continuously records the rate of mass flow through the system. The gas next passes through a high-pressure flow control valve that regulates the rate of mass flow necessary to produce the desired stagnation pressure.

The test gas enters the downstream portion of a pressure case designed to withstand an internal pressure of 20,000 psi, and flows around the outside surface of the refractory metallic throat to cool the throat region. After it passes around the throat assembly, it enters the portion of the pressure chamber which contains the heater assembly. The basic components of the assembly are three concentric radiation shields and a highly porous, woven screen tungsten heater element powered by a 2-MW dc power source. The route that the gas takes around the radiation shields is essentially a triple pass system. Since tungsten oxidizes readily, precautions are exercised to minimize the amount of oxygen in the system, particularly the pressure case and associated upstream piping.

The heated nitrogen is expanded through a nitrogen cooled nozzle throat section with a throat diameter of 0.111 in. and a 10.5 ft long, water-cooled, axisymmetric, contoured nozzle with a 16-in. exit diameter; that is, this facility has an open jet test section. The facility is equipped with a quick injection model support system (injection time less than 0.3 sec) having an angle-of-attack range from 30° to -15° and angle-of-sideslip range from 15° to -15°. The range of angular motion is adjustable for 4° to 20° per second and a pitch-pause mode is available. The test section is equipped with Schlieren windows. From the test section, the gas passes through a water-cooled, straight pipe diffuser with a length-to-diameter ratio equal to 10 and into a 100-ft-diameter vacuum sphere which can be evacuated to a pressure of less than 1 micron. From the sphere, the nitrogen is exhausted to atmosphere and thus not reclaimed. Nominal run time for this facility is 90 minutes.

Hypersonic Helium Tunnel (Aerodynamic Leg):

This helium tunnel is an intermittent, closed-cycle, blowdown tunnel that became operational in 1960. It is capable of operating over a large Mach number range by means of interchangeable throat sections in conjunction with a contoured nozzle. High purity helium (less than 40 parts per million impurities at purchase) flows from a high pressure storage system designed for 5000 psi, through an in-line, 67 kW electrical resistance heater capable of heating the gas to a maximum temperature of 869°R and into a settling chamber. In the present configuration, the flow is expanded through a 0.622-in.-diameter throat and along a contoured nozzle into a contoured test section having a length of 11.6 ft and a maximum diameter of 22 in.; the test section is equipped with a top, bottom, and side windows. Five nozzles were fabricated for this facility; three contoured nozzles designed to produce Mach 18, 22, and 26 flows and two conical nozzles to produce Mach 20 and 40 flows.

The flow is decelerated by means of a two-dimensional constant-area supersonic and subsonic diffuser before entering two interconnected 60-ft-diameter vacuum spheres. Typical run time is 30 sec, but run times of 120 sec have been achieved using two additional 60-ft-diameter spheres. The helium collected in the spheres is recompressed to 5000 psi and is passed through molecular sieve filter beds, LN_2 cold traps, and a purifier using silica-gel dryer maintained at 140°R to reduce the contaminating agents to less than 0.02 percent by volume. After purification, the helium is stored in high pressure tanks for reuse.

Angle of attack may be varied from -18° to 18° with a hydraulically actuated support mechanism and using a straight sting. This mechanism, which has pitch-pause capability, is mounted vertically downstream of the test section; thus, models are mounted in the tunnel during nozzle flow establishment and not injected into the flow. A starting cone is generally used to shield the model during flow startup and is retracted after steady flow is achieved.

Hypersonic Helium Tunnel (Open Jet Leg):

The open jet leg (OJL) was added to the 22-Inch Helium Tunnel System around 1970 and uses the same high pressure helium supply, heater, vacuum spheres, vacuum system, compressors, and purifier. This facility has two axisymmetric contoured nozzles. One nozzle was designed to produce Mach 22 flow at its 22-in.-diameter exit and the other to produce Mach 40 flow at its 36-in.-diameter exit. Models are installed on a system that swings the model from a sheltered position to the nozzle centerline; thus, steady flow is obtained prior to insertion of the model. This support system provides a range of angle of attack from -20° to 20° and has pitch-pause capability.

Because of the very low liquefaction temperature of helium, heating is not required for Mach 20. The helium test gas for the 22-Inch Hypersonic Helium Tunnel and the Mach 22 OJL is seldom heated, since only heat transfer studies require the gas to be heated and only a few such studies have been performed in helium. However, the heater is required for the Mach 40 OJL to prevent liquifaction.

Test Highlights

Demonstration of Two-Color Phosphor Thermography System in Hypersonic Wind Tunnel:

A study was initiated to develop a method for obtaining simultaneous heat-transfer measurements and aerodynamic force and moment measurements on hypersonic and wind tunnel models. The study approach was to develop a thermal imaging system using an appropriate optical measurement technique providing quantitative surface temperature data. A technique for quantitative thermal imaging was developed using two-color thermographic phosphors.

The thermal imaging technique is based on the ratio of measured blue to green (450, 520 nm) emission from a phosphor coating excited by an ultraviolet (365 nm) source. Separately filtered images are recorded from a three-tube color camera, utilizing off-the-shelf front-end video optics to discriminate wavelengths. Digital processing is used to calculate surface temperature profiles from video image data. The technique provides ideal surface temperature-time data necessary in calculating heat-transfer coefficients.

Tests demonstrating the thermal imaging system (TIS) were performed in the 31-Inch Mach 10 Tunnel using phosphor-coated cast ceramic models. Models tested included a 12.84/7 degree straight biconic with a 3-in. base, an 11-in. strake/wing transatmospheric vehicle, and a 9.5-in. slender blunted cone. Cone models were cast around stainless balance insertion sleeves, although force and moment measurements were not conducted for this TIS demonstration test. Image data were recorded on 3/4-in. video tape and processed at Langley's Image Processing Laboratory. Work is currently under way to develop a dedicated digital acquisition/image processing system.

G. M. Buck
RTOP: 505-61-31-05

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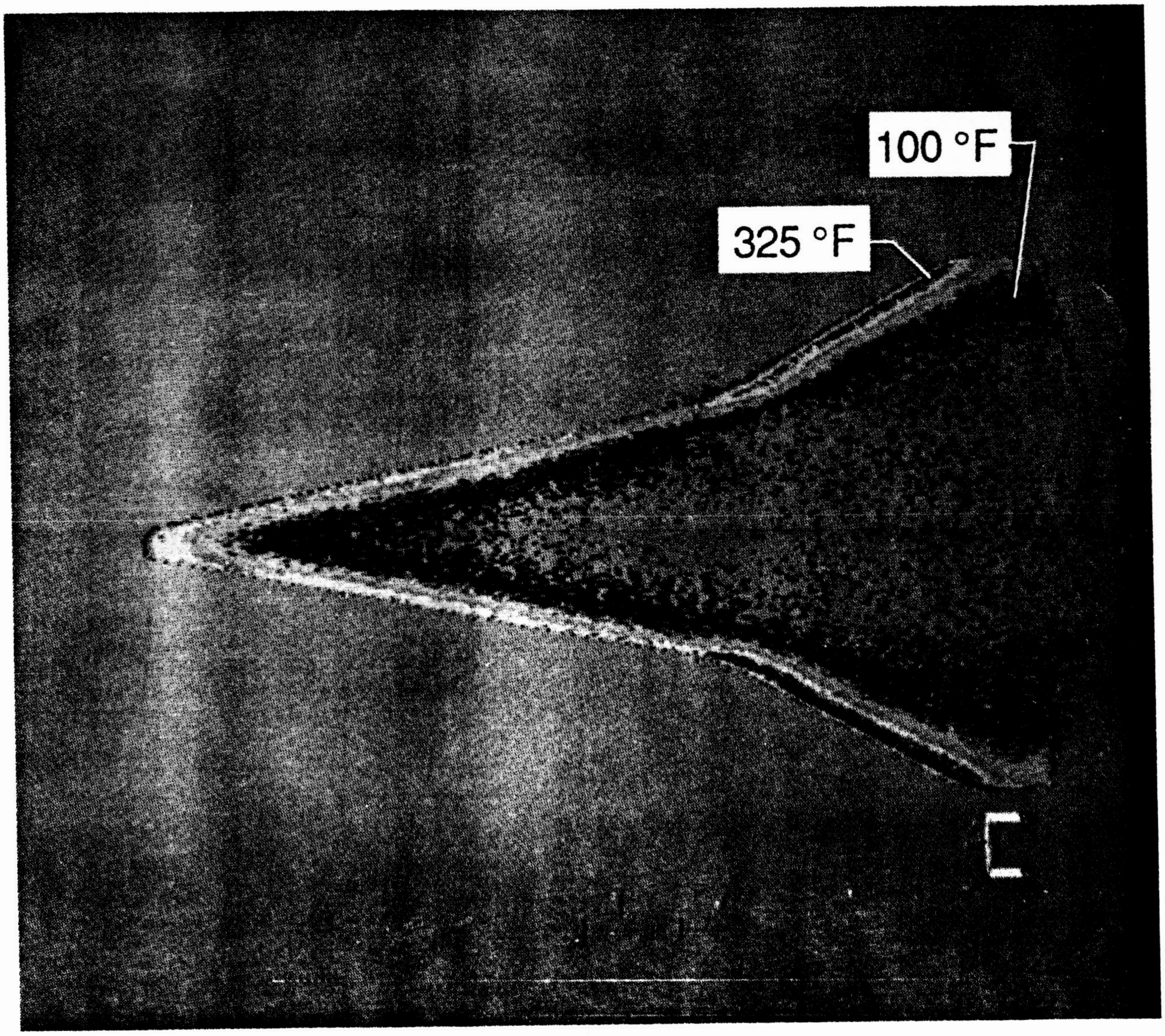


Windward surface temperature mapping on a transatmospheric model in 31-Inch Mach 10 Tunnel.

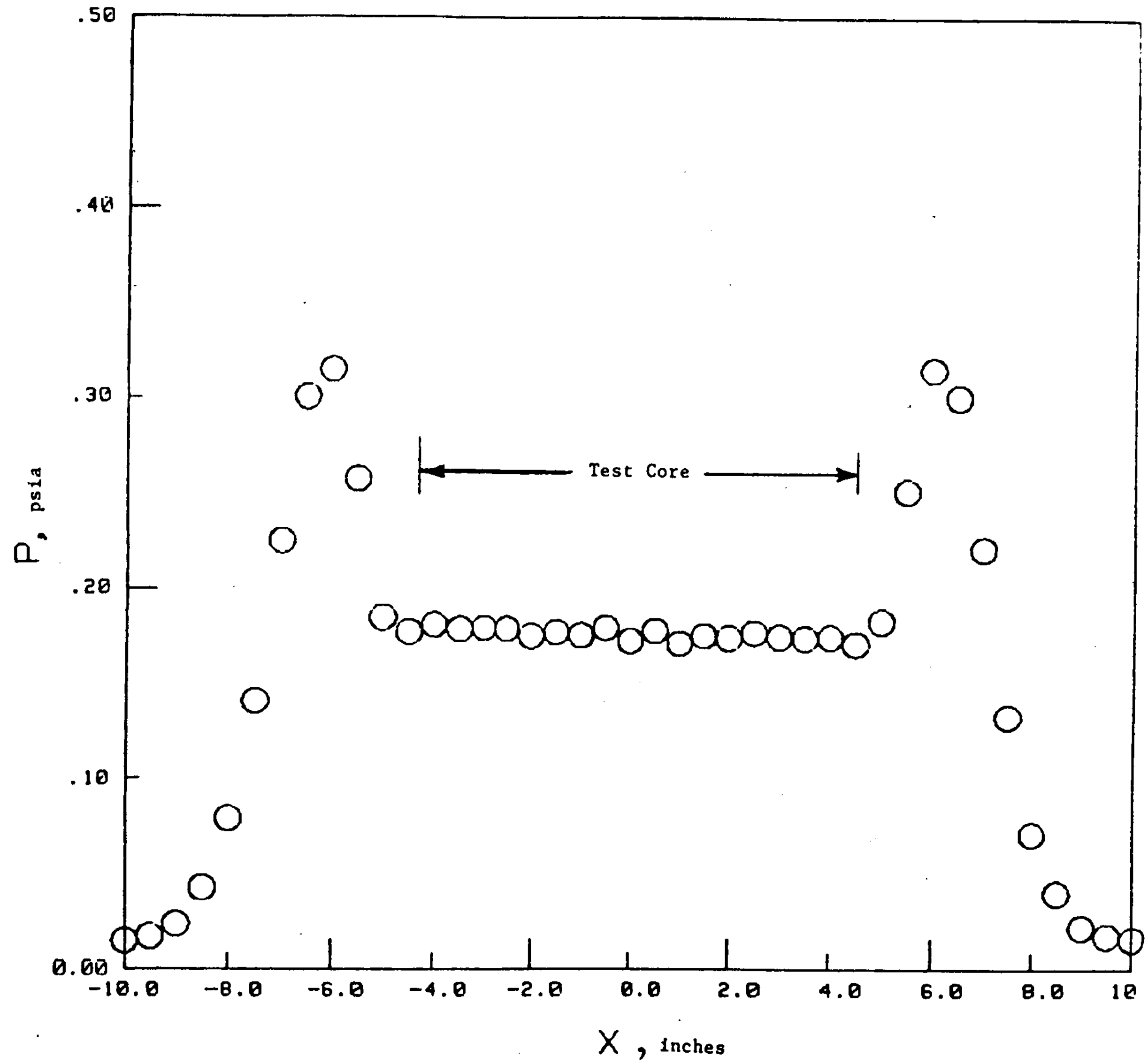
Low-Density Flow in the Langley Hypersonic CF_4 Tunnel:

Some of the aerodynamic effects of air dissociation ("real-gas effects") between the shock and body of an entry vehicle during flight can be simulated by reproducing the density ratio across the normal shock in a wind tunnel. The Langley Hypersonic CF_4 Tunnel uses tetrafluoromethane (CF_4) as a test gas, which allows a partial simulation of real-gas effects by producing a normal shock density ratio of approximately 12, which is closer to the flight value (approximately 17) than the ratio obtainable in an air or nitrogen tunnel (approximately 6). Some vehicles not only fly at very high velocity, which results in shock-induced dissociation, but at very high altitude as well. This high-altitude flight occurs in a low-density flow field that is not generally available as a test condition in this nation's hypersonic facilities. These low-density effects can change vehicle aerodynamic characteristics dramatically, particularly for blunt-body configurations. (An example of a class of high-velocity, high-altitude flight vehicles with blunt configurations is the Aeroassisted Orbital Transfer Vehicle, AOTV.)

Recently in an attempt to better simulate the high-altitude, low-density flight conditions, the Langley Hypersonic CF_4 Tunnel has been successfully operated at a reservoir pressure as low as 100 psi. The normal reservoir operating pressure is in the range from 1500 to 2000 psi. Measurement with a pitot rake at the low-pressure condition indicated a nearly constant pitot pressure distribution over an 8-in.-diameter core, which is comparable to the high-pressure test core size.

Much work will be required to assure that flow conditions are correctly calculated and that all types of wind-tunnel testing can be carried out in this low-density environment. However, results obtained so far suggest that the effects of a high value of normal shock density ratio and low test stream density may be obtained in the same test environment.

R. E. Midden/W. L. Wells
RTOP: 506-40-41-01 (FY 88)



Test stream pitot pressure profile in the Langley Hypersonic CF_4 Tunnel at a reservoir pressure of 133 psi.

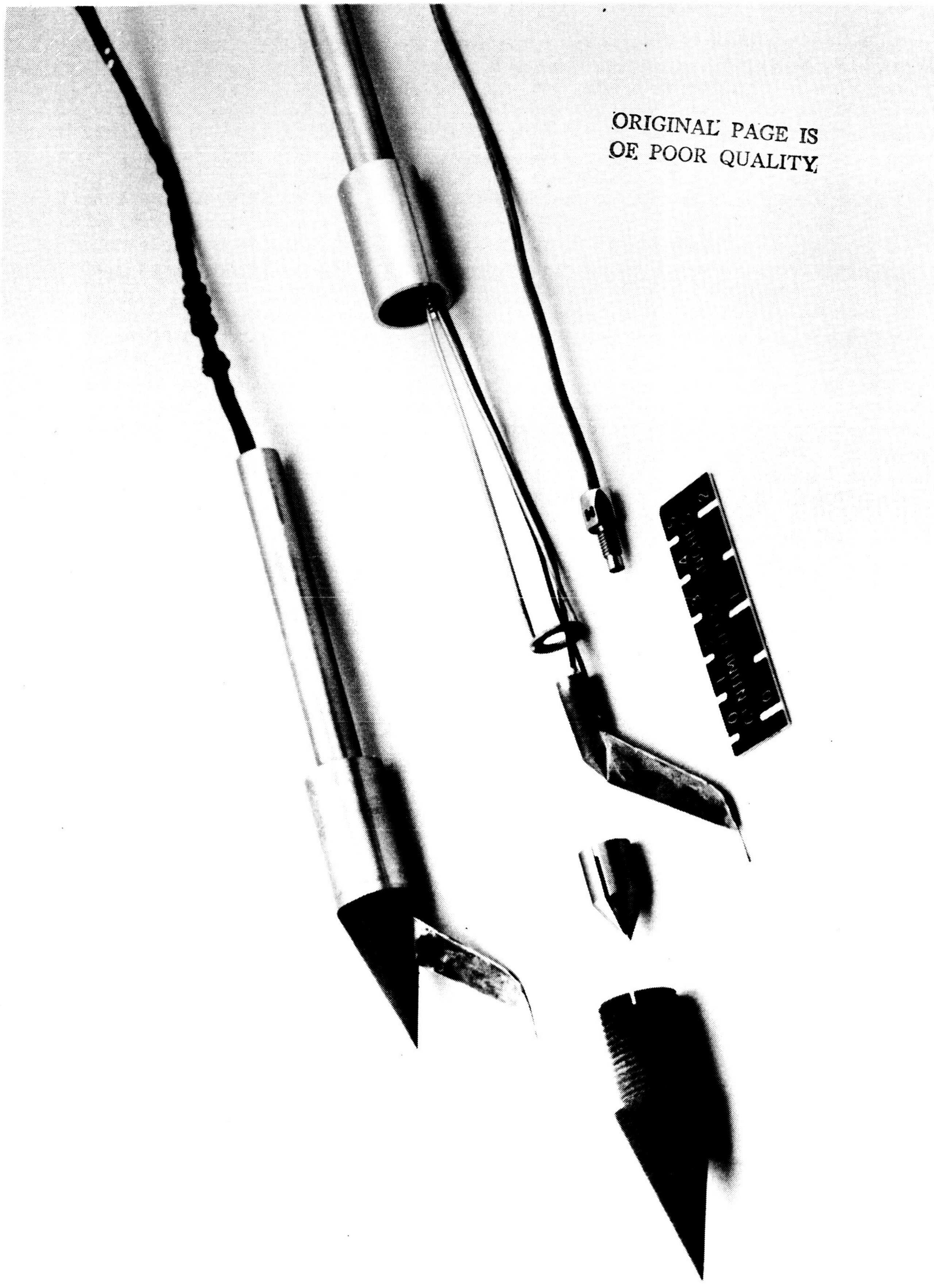
Miniaturized Water-Cooled Pitot-Pressure Probe for Flow-Field Surveys in Hypersonic Wind Tunnels:

A relatively fast response (less than 0.3 sec), miniaturized pitot-pressure probe has been designed, fabricated, and successfully demonstrated in the flow field about a 2 to 1 elliptical cone in the Langley 20-Inch Mach 6 Tunnel.

The probe, which has a 0.013-in. outside diameter, has the pressure transducer located within the probe body approximately 2-1/2 in. from the probe top and is surrounded by a water jacket. The water cooling reduced the temperature at the transducer during the tunnel tests from 325°F to 103°F, which is normally low enough to avoid thermal effects on the accuracy of the transducer.

During the tunnel tests, the probe was also shown to be small enough to eliminate the intrusive interference that occurred between a larger probe and the laminar boundary layer on the cone model.

George C. Ashby, Jr.
RTOP: 506-40-41-02 (FY 88)



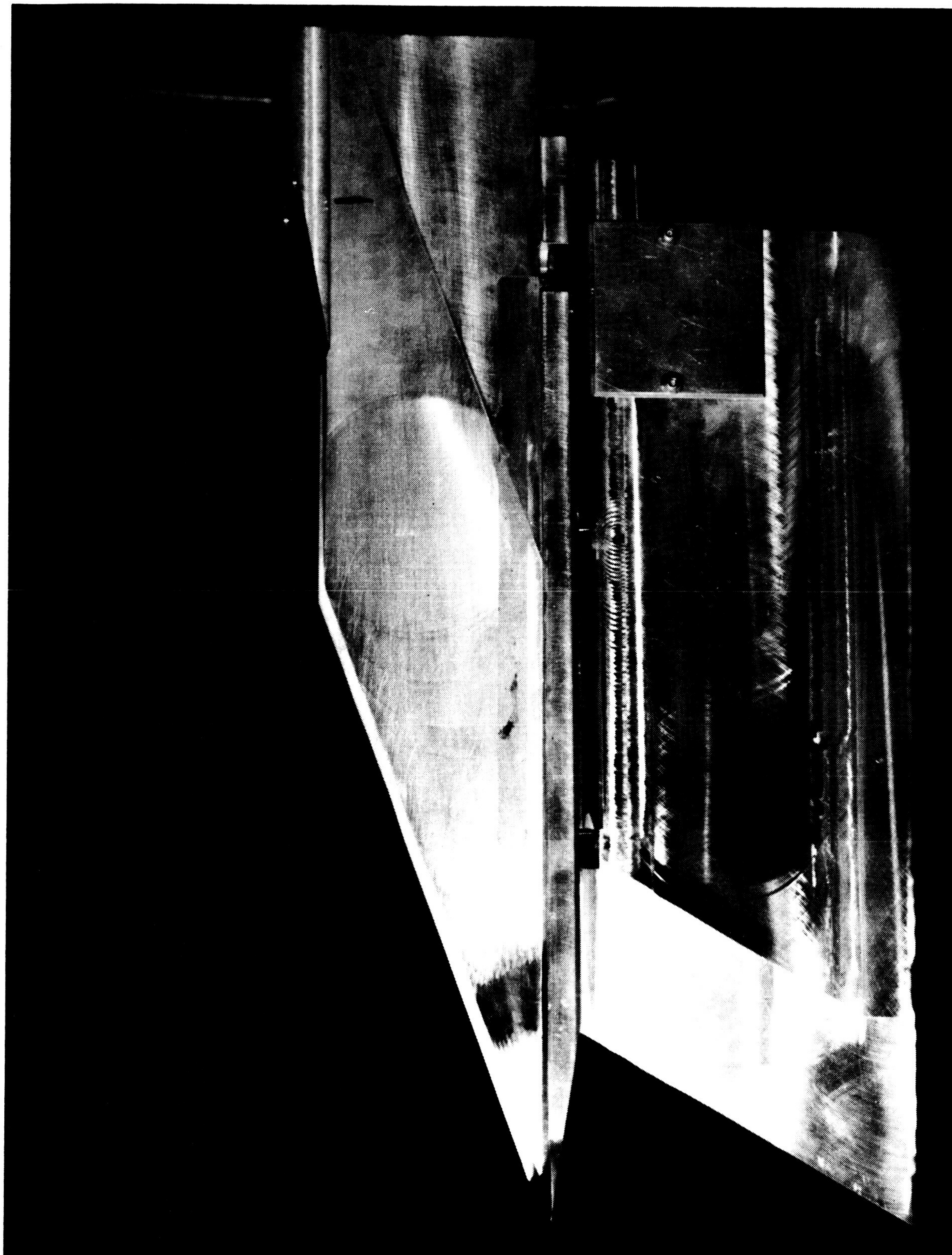
L-87-8455

Exploratory Hypersonic Helium Tests on an Inlet:

The emphasis on the National Aero-Space Plane (NASP) has generated the need to extend simple inlet testing to high Mach numbers. A variety of simple inlet models tested at M = 4 in air existed. One was adapted for installation in the LaRC Hypersonic Helium Tunnel with modifications to provide for additional parametric variations. Contraction ratio, cowl position and sweep, and Reynolds number were among the test variables considered. Measured data included pressures on the centerline and at two locations on the side walls. Flow visualization was provided by the electron beam technique. Concerns included the possibility of an unstarted tunnel or inlet because there was no previous test experience either in this facility or others at these high Mach numbers (M = 20). Test objectives included determining our ability to test reasonably sized inlets at M = 20 in helium and to generate sufficient data for computational fluid dynamics (CFD) calibration.

Tunnel flow conditions were fully established for the extremes of tunnel operation (M = 18 to 22, Reynolds number = 2×10^6 to 12×10^6). Measured pressures and flow visualization data were obtained for both started and unstarted inlets, depending on inlet configuration and test conditions. Both 30° and 70° swept inlets appeared to start at contraction ratios of 4 and 5 with the cowl at the throat. Moving the cowl forward produced unstarted flow for the 30° inlet, but the 70° inlet remained started at the lower contraction ratio. All configurations exhibited possible corner flow effects and flow separation. Results confirm our ability to determine internal pressure, shock structure, surface flow structure, and mass flow of a variety of inlet configurations at M = 20 for CFD calibration.

W. C. Woods
RTOP: 763-01-31-17



L-87-7809

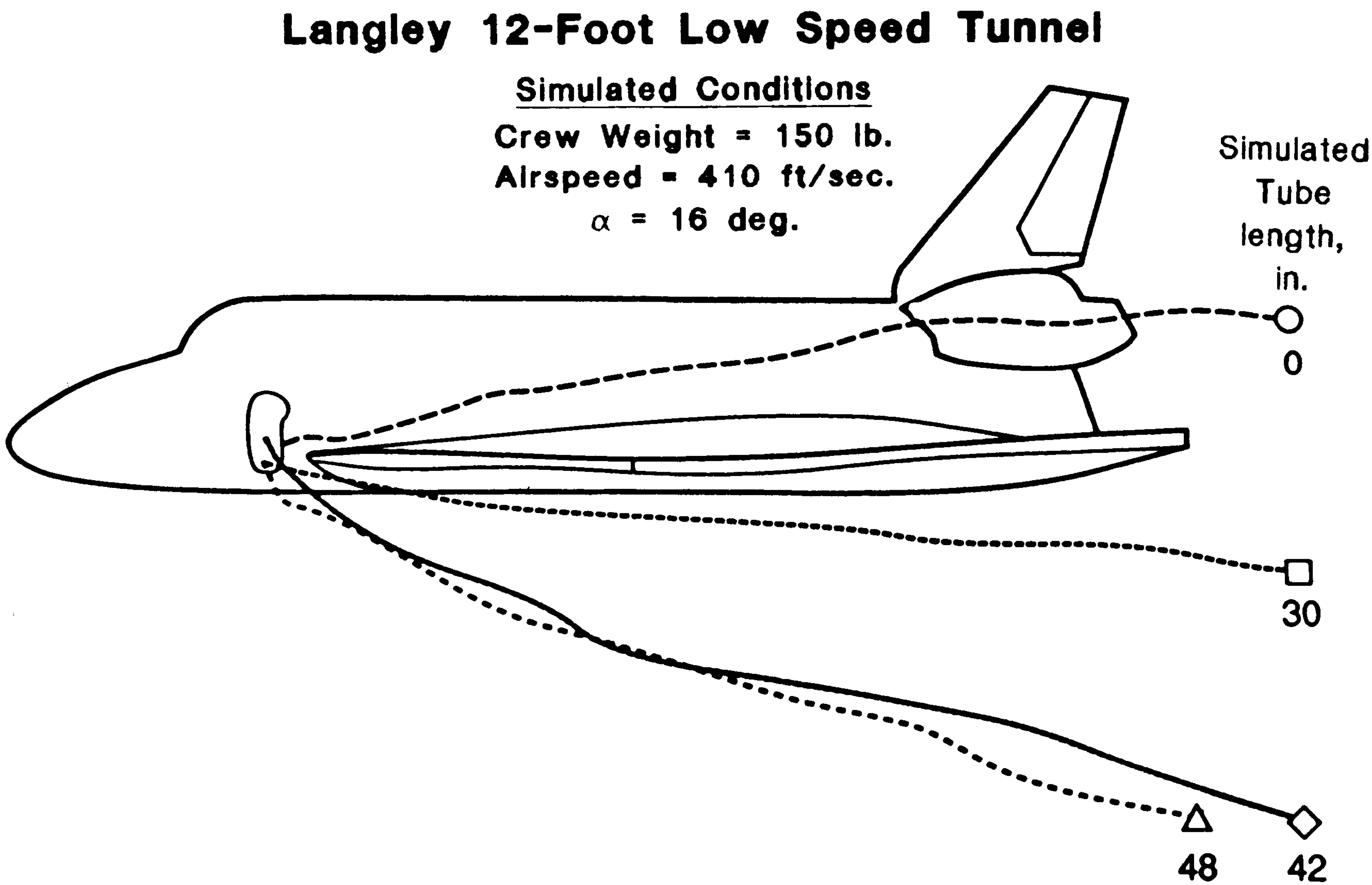
Shuttle Crew Escape Tube Study:

The National Aeronautics and Space Administration is investigating means of safe crew escape during the subsonic phase of Shuttle flight. This situation could occur during an abort on ascent where the Orbiter has safely separated from the external tank and solid rocket boosters, has slowed to low subsonic speeds, and is in stable gliding flight, but cannot reach a suitable landing site. It may also exist during entry if a guidance or other malfunction has made a safe landing impossible. A previous investigation conducted at the Langley Research Center indicated that unassisted crew bailout from the Orbiter main side hatch would be extremely dangerous even at low speeds. Therefore, current work has concentrated on augmenting crew egress. Several schemes to aid crew bailout are under consideration. The study made at Langley considered a method that utilizes a deployable tube extending out of the main hatch and down the side of the vehicle. This would allow the crew to slide down the tube and exit below the wing.

The investigation consisted of an engineering design feasibility study and wind-tunnel tests. Two Langley wind-tunnel tests were conducted; one with a 0.03-scale Orbiter model in the 12-Foot Low-Speed Tunnel to determine the length of the tube necessary to allow the crew figure models to exit safely, and a second with a 0.015-scale model in the Low-Turbulence Pressure Tunnel to determine the effect of the deployed tube on the stability and control characteristics of the Orbiter. In addition, measurements were made to determine the aerodynamic loads on the tube for design purposes.

The investigation revealed that the crew could exit safely if the escape tube extended 1 ft below the leading edge of the wing (about 42 in. below the bottom of the side hatch opening). The loads on the tube were found to be in the range that could be handled by current air-mat (an inflatable rubber/fabric material) technology, and the tube could be packaged and deployed from the Orbiter.

George M. Ware
RTOP: 551-12-02-05



Effect of escape tube length on crew bailout trajectory.

Supersonic Characteristics of Modified
Circular Body Vehicles:

One concept now under study as an advanced space transportation system is based on the requirement of full reusability. This results in a single-stage-to-orbit vehicle that carries the propellant internally, is launched vertically, and lands horizontally. The basic configuration consists of a fuselage having a circular cross section, a cropped delta wing, and a large vertical tail. The circular body vehicle is 197 ft long, which is about twice the size of the Space Shuttle orbiter. This study has been expanded to ascertain the effects of two alternate versions on the aerodynamic characteristics. One version employed wing tip fins instead of the vertical tail, whereas the second version used a small nose-mounted dorsal fin with fuselage side brakes. Force and moment tests were conducted in the Unitary Plan Wind Tunnel at Mach numbers of 2.3, 2.96, 3.9, and 4.6. Data on the basic vehicle and the two alternate versions were obtained over an angle-of-attack range of 0° to 22° at a Reynolds number of 4.3 million, based on fuselage length.

For all three models, stable trim conditions were obtained at M = 3.9 and 4.6 by using elevon controls. The vertical tail model yielded stable trim at the two lower Mach numbers. The tip fin and dorsal versions generally had only neutral stability for M = 2.96. At M = 2.3, the dorsal model indicated stable conditions at the operational angle of attack of 10°, whereas the tip fin model was unstable. With the center of gravity located at 72 percent of the fuselage length, the tip fin and dorsal versions were directionally unstable. Directional stability existed for the vertical tail model, but only at angles of attack below about 10°. Positive effective dihedral was obtained over the angle-of-attack range of 0° to 22° for the vertical tail model. For the other two versions, positive dihedral was indicated at angles of attack above about 10°. In general, it appears the basic model with the large vertical tail yielded better longitudinal and directional stability characteristics when compared with the alternate versions.

P. T. Bernot
RTOP: 506-40-11 (FY 87)
506-40-41 (FY 88)

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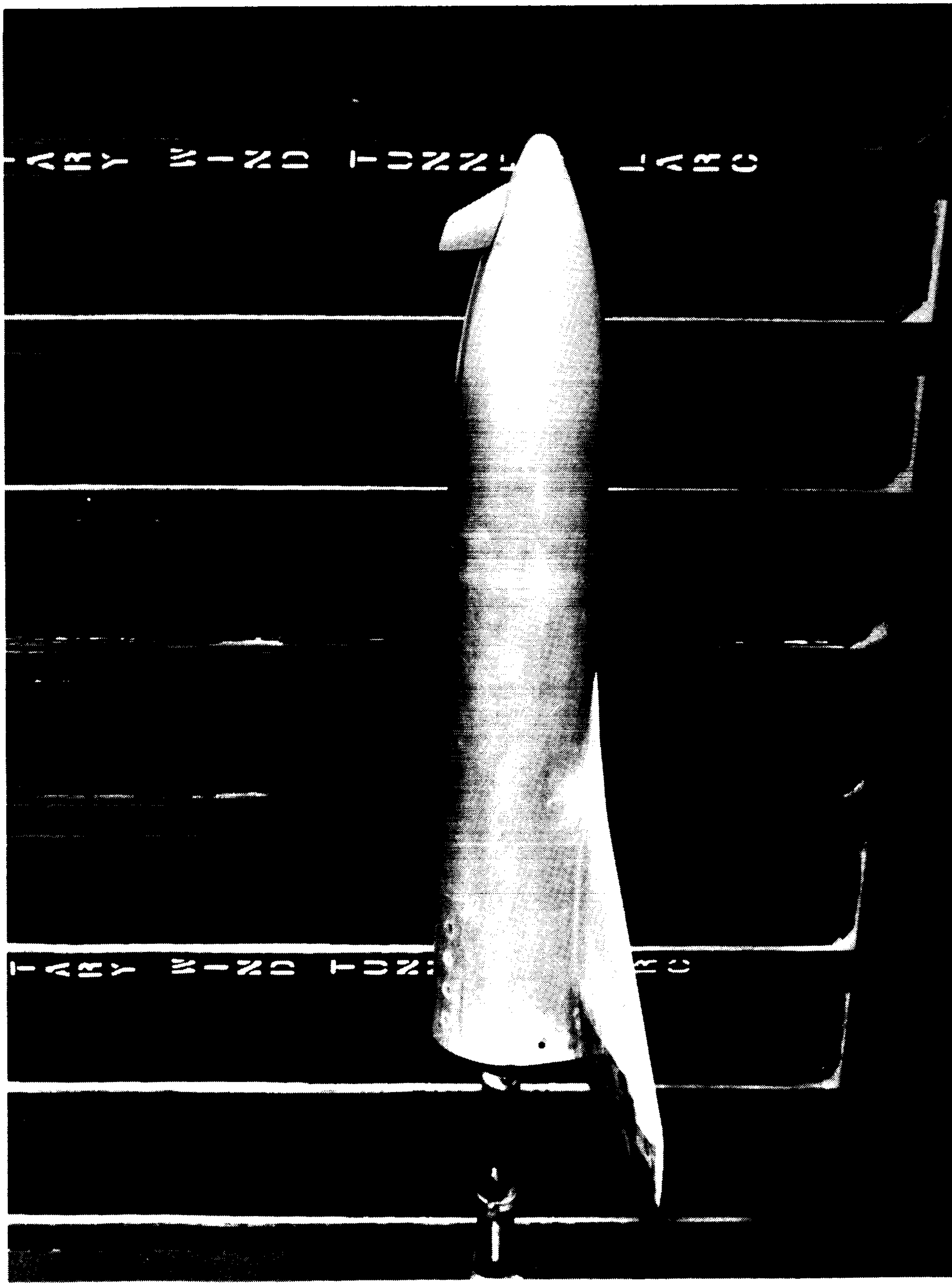

L-87-4420

FY 87 ACCOMPLISHMENTS

Atmospheric Sciences Division

The Atmospheric Sciences Division is a leader in the area of atmospheric sciences. Its researchers are involved in seeking a more detailed understanding of the origins, distributions, chemistry, and transport mechanisms that govern the regional and global distributions, chemistry, and transport mechanisms that govern the regional and global distributions of tropospheric and stratospheric gases and aerosols, and in the study of the Earth radiation budget and its effect on climate processes. The research seeks to better understand both natural and anthropogenic processes and covers a wide spectrum of activities, including the development of theoretical and empirical medals; collection of experimental data from in situ and remote sensing instruments designed, developed, and fabricated at NASA Langley; organization of extended field experiments; and development of data management systems for the efficient processing and interpretation of data derived from airborne and satellite instruments. (An organization chart for the Atmospheric Sciences Division is shown in fig. 4.) Major accomplishments for FY 1987 follow.

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Atmospheric Studies Office

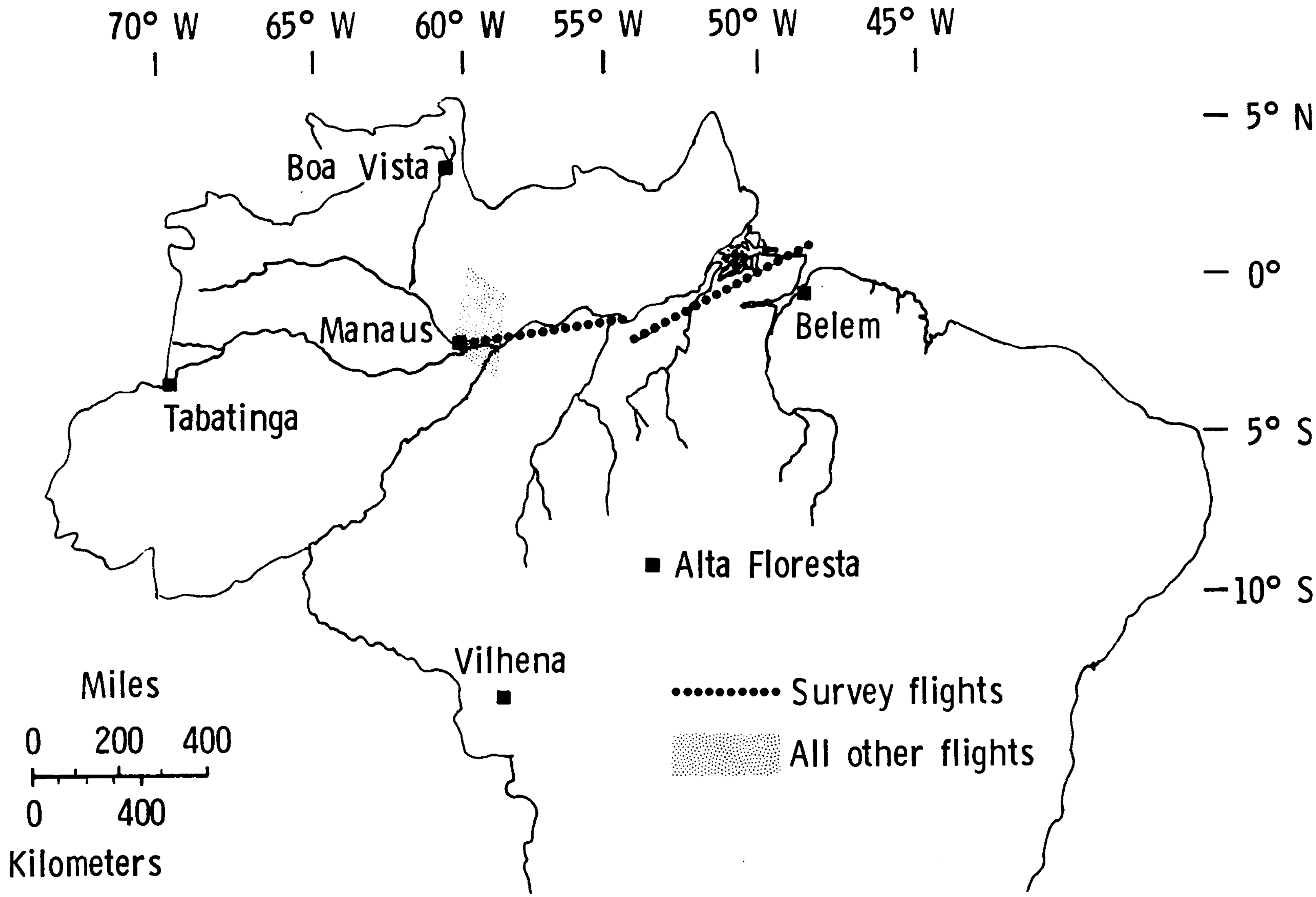
The Amazon Boundary Layer Experiment:

The Amazon Boundary Layer Experiment (ABLE) focused on assessing the role of biosphere-atmosphere interactions on the chemistry of the atmosphere over pristine tropical forests and wetlands. ABLE-2A was conducted in July and August 1985 during the dry season to characterize the chemistry of the undisturbed (non-precipitating) atmospheric boundary layer. ABLE-2B in April and May 1987, during the wet season, investigated the chemistry and transport of gases and particles influenced by large-scale storm systems. The design and execution of ABLE-2 was a collaboration of U.S. and Brazilian scientists sponsored by the National Aeronautics and Space Administration (NASA) and the Instituto Nacional de Pesquisas Espaciais (INPE), the Brazilian space agency. Important facilities and logistical support were also provided by the Instituto Nacional de Pesquisas da Amazonia (INPA), Manaus, Brazil. These experiments are parts of a longer term study of the chemistry of the atmospheric boundary layer supported by the Global Tropospheric Experiment (GTE) component of the NASA Tropospheric Chemistry Program.

Several key results have confirmed the theoretical studies of the importance of these tropical ecosystems to global trace gas chemistry and budgets. Amazonian soils and vegetation are significant sources of methane (CH_4), nitric oxide (NO), and isoprene (C_5H_8). During the dry season, NO levels exceed those required for photochemical processes to produce ozone (O_3) over the undisturbed rain forests of the Amazon. During the wet season, NO levels are lower and photochemical processes destroy O_3. Other biogenic emissions are also present in the boundary layer where they and their chemical products are subject to vertical transport upward to the free troposphere by thunderstorms. These mechanisms couple the tropical biosphere to the global atmosphere, with subsequent effects on the Earth's air quality and heat budget. Gas phase formic and acetic acids were also measured with indications that these organic acids were derived from direct vegetation emissions and from photochemical reactions involving isoprene. In rain water, these organic acids are the primary source of the acid rain of natural origin in the Amazon Basin. Particulates over the region were primarily composed of organic carbon, suggesting a biogenic origin. The Amazon aerosol was also acid-base neutral, in contrast to the acidic aerosol found over Northern Hemisphere industrialized regions. ABLE-2 documented land-clearing fires as an important source of carbon monoxide, nitrous oxide, and ozone in the atmosphere over the Central Amazon Basin.

The ABLE-2 expedition was an initial step toward understanding how the tropical rain forests of the world influence global atmospheric chemistry and climate. The development of new technologically sophisticated airborne and satellite measurement systems made the experiment possible. The expedition demonstrated how ground, aircraft, and space technologies must be integrated with theoretical studies to resolve issues of global habitability.

J. M. Hoell, Jr.
R. C. Harriss
RTOP: 176-20-09-70



Map of the Amazon basin region of Brazil showing the locations of the ABLE-2B studies.

Data Management Office

Evaluation of an Optical Disk System for Archiving Data from the Earth Radiation Budget Experiment:

The Earth Radiation Budget Experiment (ERBE) is a three-satellite experiment designed to monitor the Earth's radiation budget. The first satellite was launched on October 5, 1984, by Space Shuttle Challenger. The second and third satellites were launched by the National Oceanic and Atmospheric Administration on December 12, 1984, and September 17, 1986. The data from these satellites are being reduced at the Langley Research Center into science data products. Approximately 40 magnetic tapes are needed to store the data from each satellite. After validation by the ERBE science team, the data product will be archived for use by the scientific community.

An optical disk system is being evaluated for storing ERBE archival data. One month of ERBE data can be stored on a single optical disk, which is considerably more compact than the 120 magnetic tapes. Each 12-in.-diameter write-once, read-many platter stores 1 gigabyte of digital data on each side. Optical disks have an expected lifetime of 10 years with no maintenance requirement, while magnetic tapes have to be re-tensioned and copied to new tapes every 2 years. This archival technique promises to substantially reduce the cost and logistical problems associated with distributing large volumes of satellite data.

Michelle T. Ferebee
RTOP: 665-45-20-01

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Near Global Distribution of Carbon Monoxide as Measured from the Space Shuttle Platform:

The Measurement of Air Pollution from Satellites (MAPS) experiment was flown aboard the Space Shuttle during November 1981 and again during October 1984. The purpose of the experiment was to measure the distribution of carbon monoxide in the atmosphere between the altitudes of 3 and 15 kilometers. Carbon monoxide is an air pollutant that is emitted both as a result of man's industrial and agricultural activities and as a result of natural processes. At the present time, it is felt that man's emissions are about equal to the natural emissions. Because carbon monoxide can perturb the global scale chemistry and, thereby, possibly affect the climate of the Earth, it is extremely important that we understand both the sources and the distribution of the gas.

The MAPS data have shown that the amount of carbon monoxide in the atmosphere is highly variable over the Earth. As can be seen in the figure, which shows the data from the 1984 flight, the amount of carbon monoxide in the atmosphere is relatively low and uniform over the tropical Pacific Ocean. In constrast, the atmosphere over Europe, northern Asia, South America, and southern Africa all show enhanced mixing ratios. Examination of shuttle-borne photographs and eyewitness reports from the astronauts indicate that there were many agricultural ground fires burning during the mission in both South America and southern Africa. These fires are thought to be the source of the carbon monoxide measured over those areas, and they represent a significant source on the global scale. Further, they are a large source of carbon monoxide in the Southern Hemisphere, an area previously thought to be free of significant carbon monoxide sources.

Henry G. Reichle, Jr.
RTOP: 618-22-31-02

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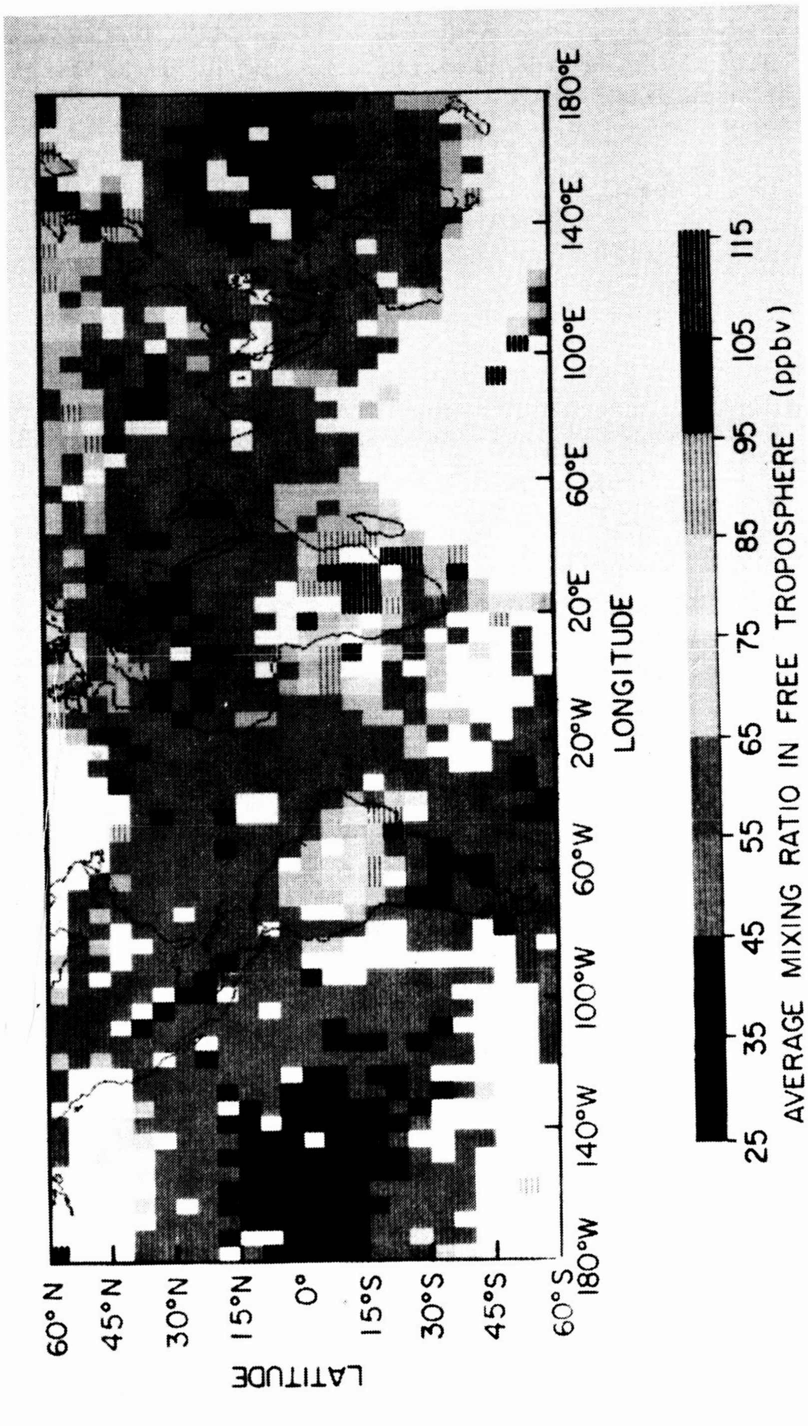


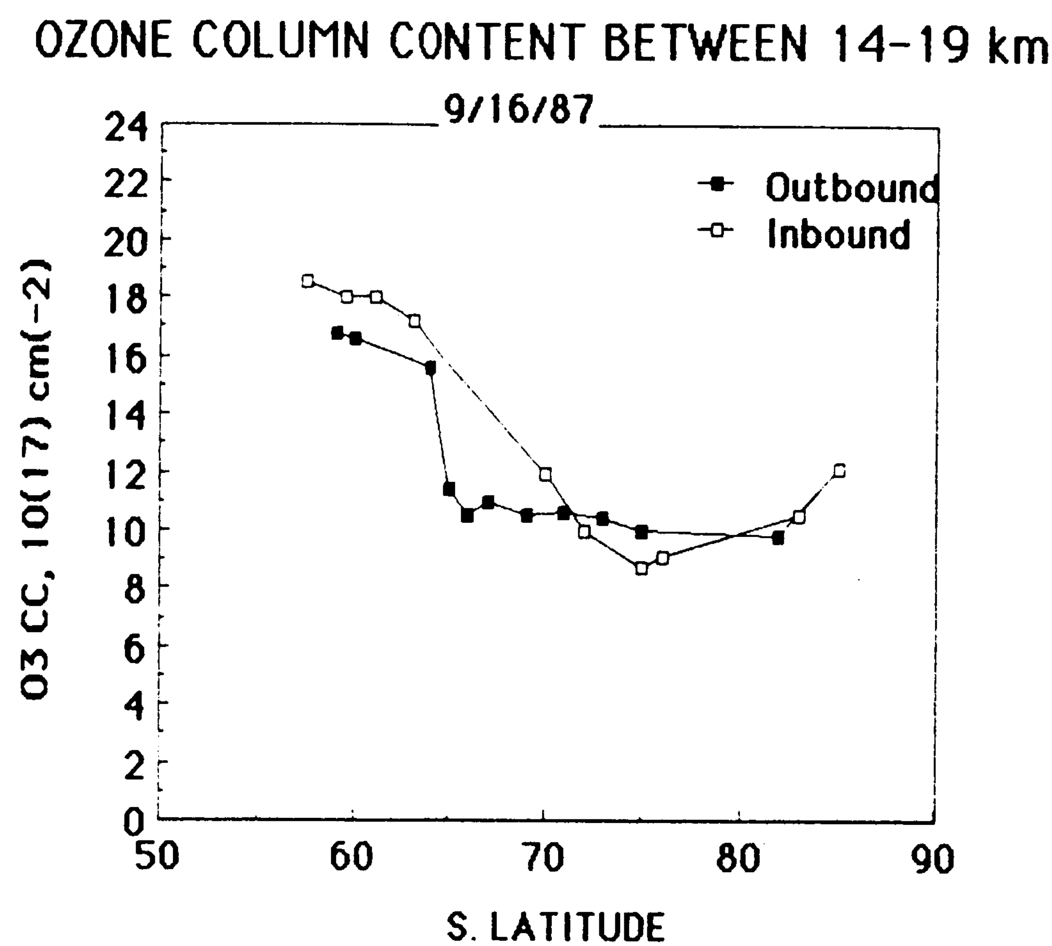
The distribution of carbon monoxide as measured by the MAPS experiment during October 1984.

Airborne Dial Investigations During 1987 Airborne Antarctic Ozone Experiment:

A joint field experiment between NASA and the National Oceanic and Atmospheric Adminstration was conducted during August-September 1987 to investigate the distribution of key gases and aerosols during the formation of the ozone hole over Antarctica. The NASA LaRC airborne system was operated from the NASA ARC DC-8 to make remote measurements of ozone and aerosol profiles in the lower stratosphere during flights into the polar vortex. The DIAL system transmitted simultaneously four laser wavelengths (300, 310, 600, and 1064 nm) above the DC-8 for measurements of ozone and aerosol profiles between 10-23 km altitude on 13 DC-18 flights over Antarctica from August 28 to September 29.

Polar stratospheric clouds (PSC's) were detected in thin layers up to an altitude of 21 km, and the scattering ratios for these clouds were consistent with those expected for nitric acid aerosols. The PSC's were found in regions of low temperatures (below -80°C) with spatial continuity in some of the PSC's to lower altitude clouds. Large-scale cross sections of ozone distributions were obtained from 10-20 km during the formation of the ozone hole, and trends seen in the DIAL data compare well with the TOMS data. At high latitudes, ozone did not change below 14 km, while between 14-19 km, the column amount of ozone decreased by over 50 percent from August 28 to September 24. These data provide the first information on the large-scale variability of ozone and aerosol profiles during the formation of the ozone hole over Antarctica.

Edward V. Browell
RTOP: 147-14-34

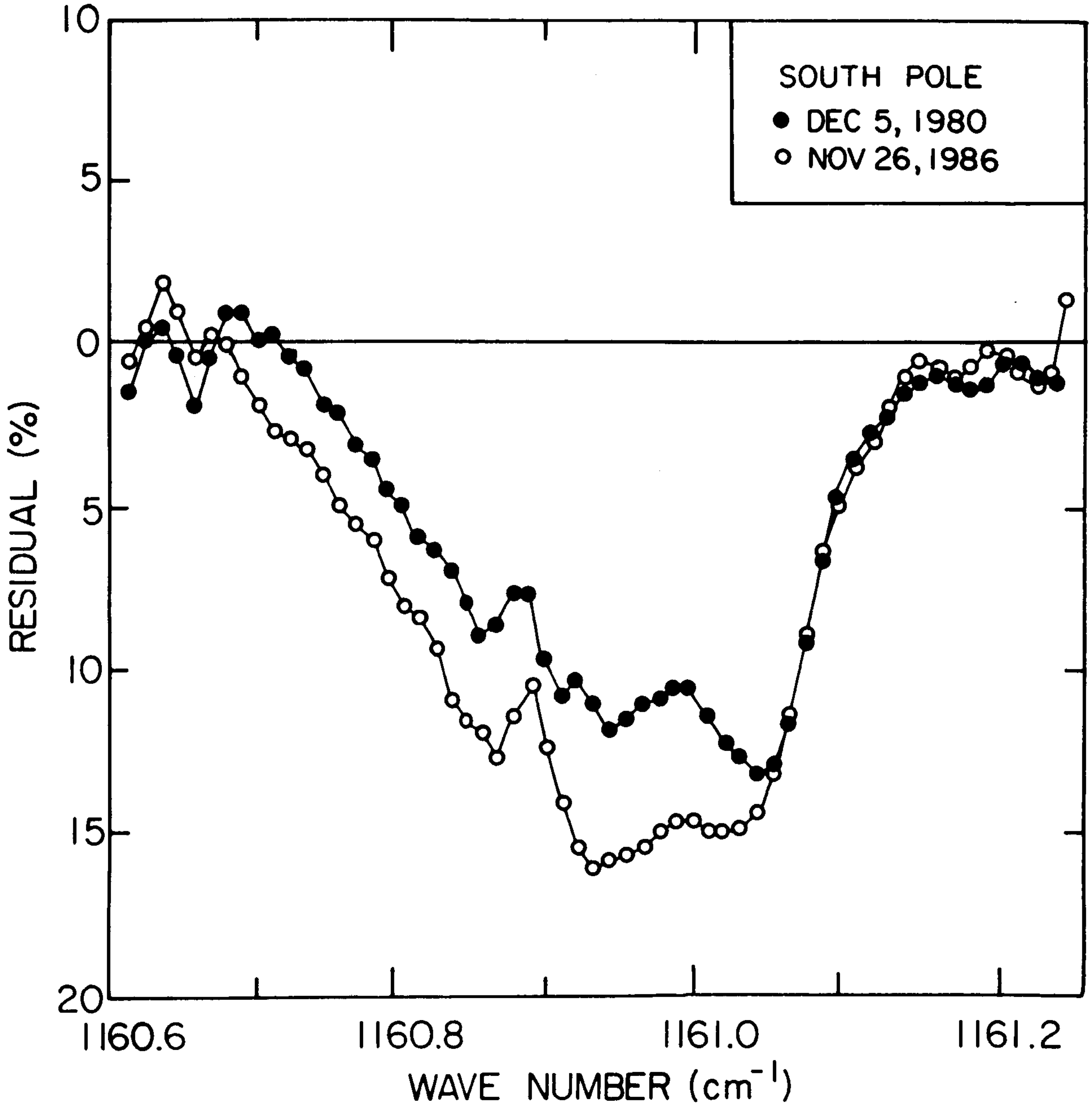


Ozone column content between 14-19 km derived from airborne DIAL data on September 16, 1977. Note significant decrease in ozone at high altitudes (>65°S) over Antarctica. In this ozone hole region, the ozone decreased by more than 50 percent in this region from August 28 to September 24.

Infrared Measurements of Atmospheric Gases Above the South Pole:

High-resolution infrared solar spectra recorded by the University of Denver atmospheric spectroscopy group from the Amundsen-Scott South Pole station shortly after the time of the Antarctic spring ozone hole in 1980 and 1986 have been analyzed at NASA Langley and the University of Denver, resulting in simultaneous measurements of a large number of atmospheric gases, several of which are thought to be key to understanding the chemistry producing the Antarctic ozone hole. The measurements define, for the first time, the levels of these species immediately following the breakup of the polar vortex. The retrieved amounts for several important gases are different than extrapolations of measurements made at lower latitudes. For example, the total HCl column above the South Pole is considerably larger than would be expected on the basis of earlier Northern and Southern Hemisphere latitudinal surveys. Because the same instrument was used for the 1980 and 1986 measurements and the same spectral line parameters and analysis method were used in analyzing both data sets, the precision in comparing the measurements from these two dates is rather high. For these reasons, it has been possible to quantify or determine meaningful upper limits for differences between the 1980 and 1986 total atmospheric amounts of a number of species. As illustrated in the figure below, an increase in the absorption by CF_2Cl_2, the most abundant chlorofluorocarbon in the atmosphere, has been detected. Analysis of these measurements has yielded an estimate of 3.6 ± 2.1 percent per year for the average rate of increase in the total amount of CF_2Cl_2 above the South Pole between 1980 and 1986.

Curtis P. Rinsland
RTOP: 147-44-02-70



Comparison of absorption by CF_2Cl_2 in South Pole solar spectra recorded in 1980 and 1986.

Electronic Data Base for Stratospheric Trace Gases:

Rapid, effective access to the increasing volume of information on stratospheric trace gas concentrations is an important factor in advancing our knowledge of the Earth's atmosphere and its potential for change. These data originate from diverse sources, including both measurements and model calculations, and are found in a variety of locations and in a wide range of formats. The ability to easily obtain and use a wide range of such data sets is recognized as a key element in addressing many of the issues in stratospheric research.

A pilot electronic data base, the Upper Atmosphere Data Pilot (UADP), has been implemented at NASA Langley to provide the research community with easy access to data on stratospheric trace gases. The prototype system, now operational on a dedicated VAX 8200 computer, incorporates measurements from several major satellite experiments and from individual balloon experiments along with calculations from two-dimensional atmospheric models. Capabilities for browsing, retrieving, and displaying data are provided. A user can access the UADP from a remote site over normal telephone lines, via Telenet, or over the Space Physics Analysis Network (SPAN). During 1987, the UADP was used to support a two-dimensional intercomparison workshop. Utilizing a specialized set of model calculations from five two-dimensional modeling groups, the abilities to easily intercompare specific outputs from the various models and to access data from the workshop site were successfully demonstrated. As the data sets in the UADP grow with the addition of further available satellite and balloon measurements and model results, it will provide an increasingly effective tool for research and for periodic assessment and intercomparison efforts.

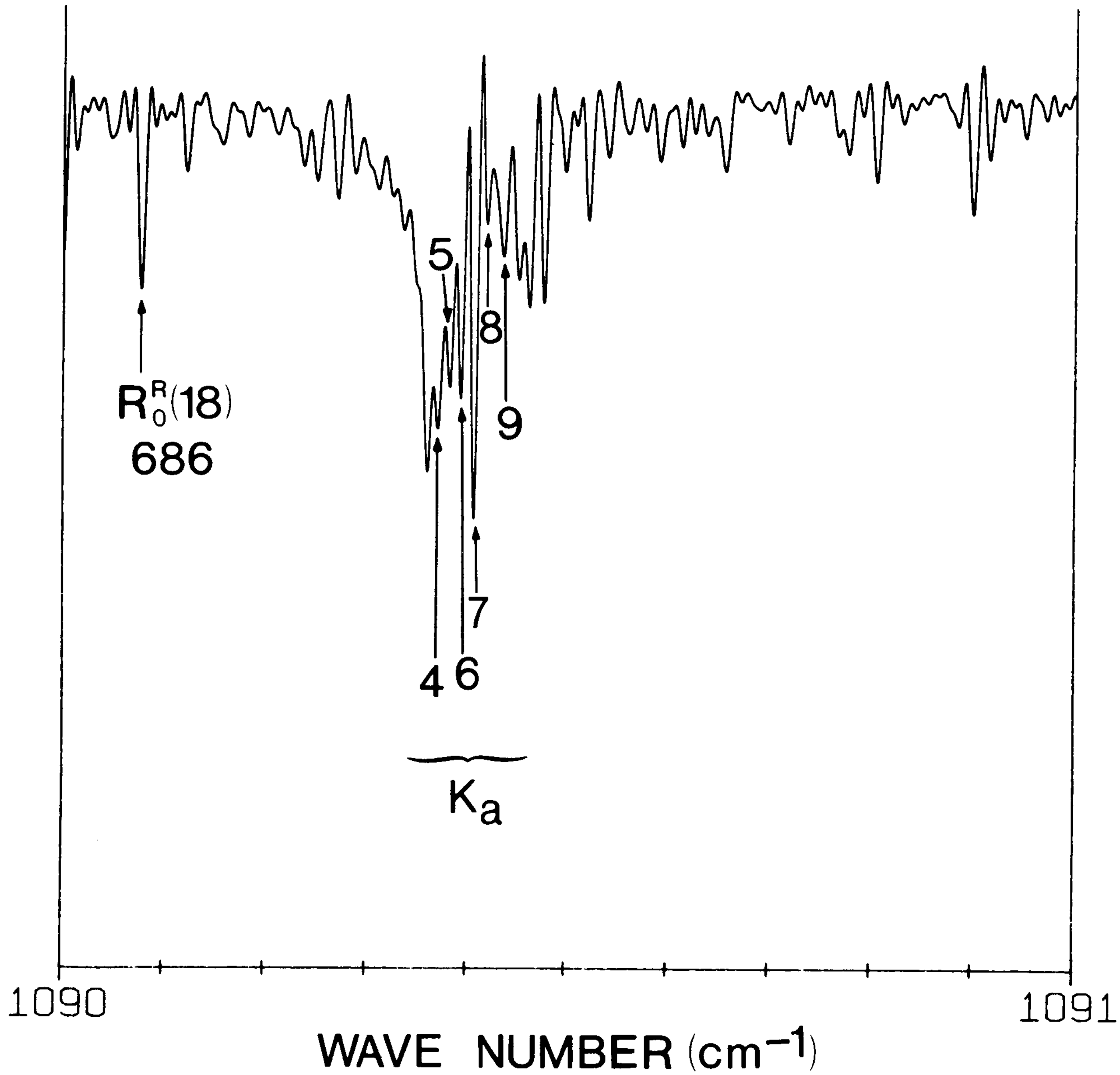
Robert K. Seals, Jr.
RTOP: 673-56-02-70

Laboratory Measurements of the Infrared Spectrum of Ozone:

Detailed knowledge of the infrared spectrum of ozone is needed for accurate calculation of atmospheric heating and cooling rates due to changes in the stratospheric ozone layer. Recent remote sensing experiments have shown that space-based measurements of infrared absorption or emission can be used to accurately determine the concentration and distribution of stratospheric ozone on a global scale. Laboratory investigations have been performed to improve our knowledge of the ozone spectrum at wavelengths between 5 and 15 μm. These measurements utilized both the McMath high-resolution Fourier Transform Spectrometer (FTS) at the National Solar Observatory on Kitt Peak, Arizona, and the tunable diode laser (TDL) spectrometer laboratory at Langley Research Center. Data analysis was performed at Langley Research Center, and the theoretical interpretation of the results was done in collaboration with investigators at several other institutions, including the Jet Propulsion Laboratory, the University of Denver, and two universities in France.

Results of this work have improved line positions and relative intensities for eight fundamental vibration-rotation bands of the most abundant isotopic form of the ozone molecule ($^{16}O_3$), and have, for the first time, allowed the scaling of line intensities in these bands to a consistent standard. Analyses of spectra of ^{18}O-enhanced ozone in the 9- to 11-μm region have resulted in new parameters for the strongest fundamental bands which are substantially improved over those which have previously been available. These laboratory results have already been applied in an investigation of the isotopic composition of stratospheric ozone. Detailed studies of the broadening of ozone absorption lines by air and by nitrogen, using both FTS and TDL measurements, have resulted in precise broadening coefficients for over 50 spectral lines not previously measured and the first measurements of pressure-induced line shifts for ozone.

Mary Ann H. Smith
RTOP: 147-23-11-70



FTS spectrum of isotopically heavy ozone showing a strong absorption feature (Q-branch) of $^{16}O^{16}O^{18}O$.

Airborne Lidar Measurements of Ozone and Aerosols Over the Amazon Basin During the Wet Season:

Extensive ozone and aerosol data were obtained by the NASA airborne differential absorption lidar (DIAL) system over the tropical rain forest of Brazil during April-May 1987 as part of the NASA Global Tropospheric Experiment (GTE) Amazon Boundary Layer Experiment (ABLE-2B). The objective of our airborne DIAL investigation was to study the sources and sinks for ozone aerosols in the boundary layer and free troposphere across the Amazon Basin during the wet season. These data were contrasted to results found during the ABLE-2A field experiment, which was conducted over the tropical rain forest during the dry season (July-August 1985). The new capability of the airborne DIAL system to simultaneously make measurements above and below the aircraft permitted the mapping of ozone and aerosol variability from the top of the forest canopy to the upper troposphere. Investigations of ozone and aerosol distributions and atmospheric structure and dynamics were conducted in a broad range of atmospheric conditions over the rain forest near Manaus, Brazil.

In contrast to the data obtained during the dry season over the Amazon Basin, the ozone levels in the mixed layer were low (generally less than 10 ppbv) with no evidence of remnants of biomass burning or photochemical ozone production. Ozone removal processes in the experiment appeared to be much more efficient at the surface than during the dry season, and substantial mixing throughout the lower troposphere resulted in generally homogeneous vertical profiles at ozone mixing ratios of 16-22 ppbv, which is about 10 ppbv lower than in the dry season. The rate of growth of the mixed layer was found to be about the same in both seasons (5-10 cm/s); however, the strong trade wind inversion that was seen during the dry season was not present during the wet season. Because of the frequent wet season precipitation, the aerosol loading in the lower troposphere was generally reduced compared to the dry season. Results from this experiment are being interpreted in relation to the chemistry and dynamics of the atmosphere over the tropical rain forest of Brazil during the wet season.

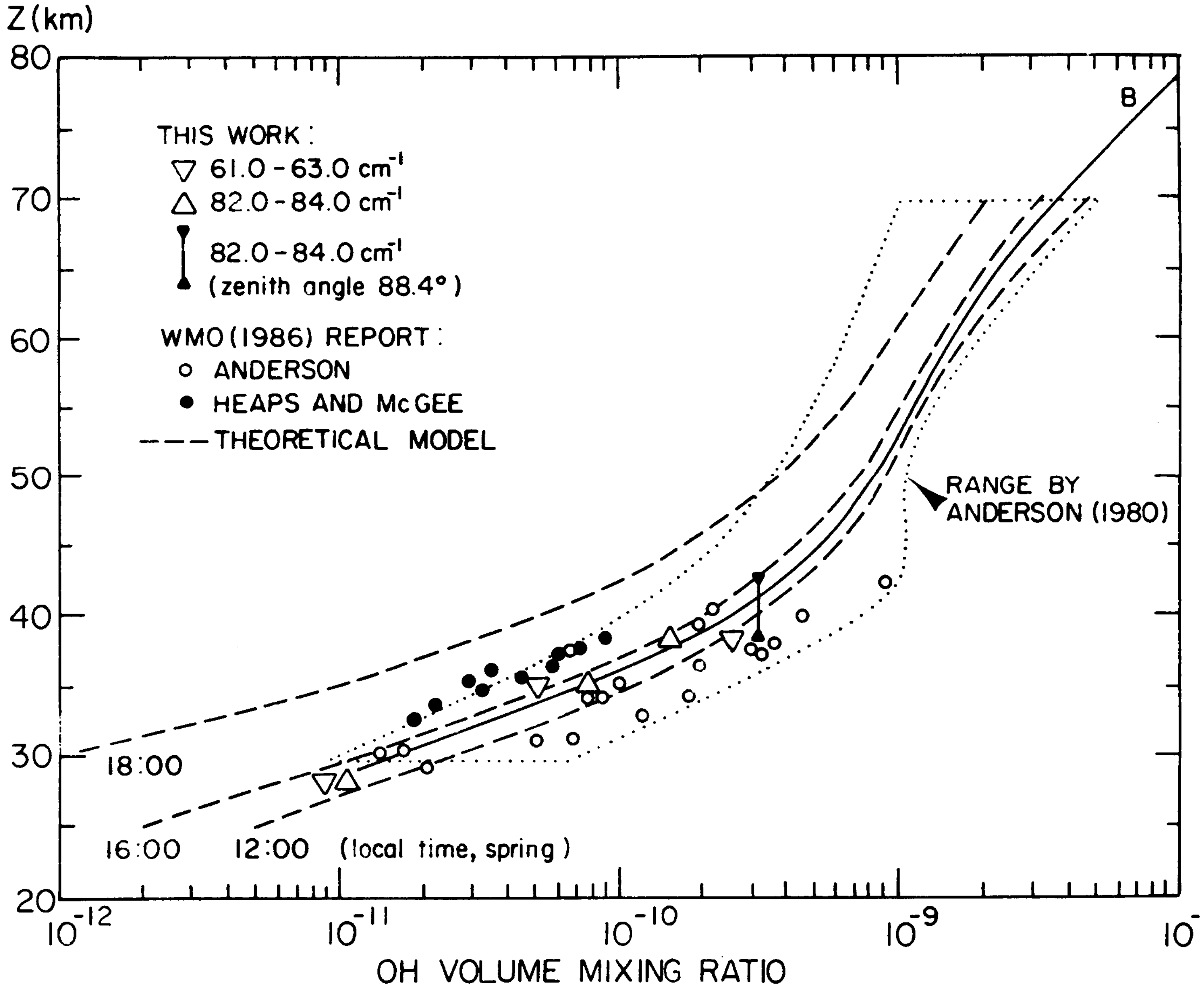
Edward V. Browell
RTOP: 176-40-04-70

Stratospheric Remote Sensing Using Emission Far Infrared Spectroscopy:

The vertical mixing ratio profiles of H_2O, HDO, O_3, heavy ozone, HF, HCl, HCN, and OH in the stratosphere are retrieved from high-resolution far infrared emission spectra. These spectra were obtained with a balloon-borne Fourier transform spectrometer in the spring of 1979 at 32°N. The nonlinear least-squares fit method is used in the analysis. The results are obtained relative to the O_2 mixing ratio whose emission features can be found in the same spectra. The retrieval of OH together with other species should be particularly significant for the study of upper stratospheric photochemistry, although the errors are relatively large--30-35 percent for OH and 20-28 percent for other species. The OH mixing ratio distributions retrieved from two spectral intervals (i.e., 61 and 83 cm^{-1}) are shown in the figure. Other profiles are taken from the World Meteorological Organization (1986) report.

In a subsequent balloon flight in the summer of 1983, much stronger emission features of OH have been measured. These data are being analyzed to obtain more accurate vertical profiles as well as the diurnal variation of OH mixing ratio.

Jae H. Park
RTOP: 147-44-02-70



The OH mixing ratios retrieved from far infrared emission spectra. The other reported profiles are from WMO (1986), Atmospheric Ozone 1985; Global Ozone Research and Monitoring Project Report No. 165, World Meteorological Organization.

Microbial Activity, Atmospheric Gases, and Life on Mars:

Nitrous oxide (N_2O) is a trace gas in the atmosphere of Earth with a mixing ratio of only 0.33 parts per million by volume. Nitrous oxide in the middle atmosphere controls the global chemical destruction of ozone, which protects us from solar ultraviolet radiation. In addition, nitrous oxide is a greenhouse gas which impacts the thermal balance of our planet. Even though its concentration is only a fraction of a part per million by volume, it is more than 10 orders of magnitude greater than would be expected from theoretical thermodynamic equilibrium calculations. This paradox can be explained by the overwhelming production of atmospheric nitrous oxide by microbial activity in soils. Microbial metabolic activity is an important disequilibrium chemical process that significantly impacts the trace gas composition of the atmosphere. The processes and parameters that control the production of nitrous oxide and other biogenic gases in soil have been studied in controlled laboratory experiments and in experiments conducted in the field. Methane, ammonia, and hydrogen sulfide are other important trace atmospheric gases produced by microbial activity.

The existence of these gases in the atmosphere of Mars may indicate the existence of an active microbial biosphere on the Martian surface. Thermodynamic equilibrium calculations indicate that these gases should not be present in the atmosphere of Mars; our photochemical calculations indicate that the lifetime of these gases should be extremely short, if they exist at all. An experiment has been designed to search for these biogenic gases involving high-resolution spectroscopic measurements of the atmosphere of Mars from an orbiter and/or in situ measurements from a Mars lander or rover. We believe that the detection of trace gases of biogenic origin in the atmosphere of Mars would be an unambiguous indication of the presence of an active microbial biosphere.

Joel S. Levine
RTOP: 199-52-26-01

Mars as photographed during the Viking 2 approach in August 1976. The Viking Project, managed at NASA Langley, included a search for life at both Lander sites. The next Mars Mission is an orbiter, the Mars Observer Mission, scheduled for a 1992 launch.

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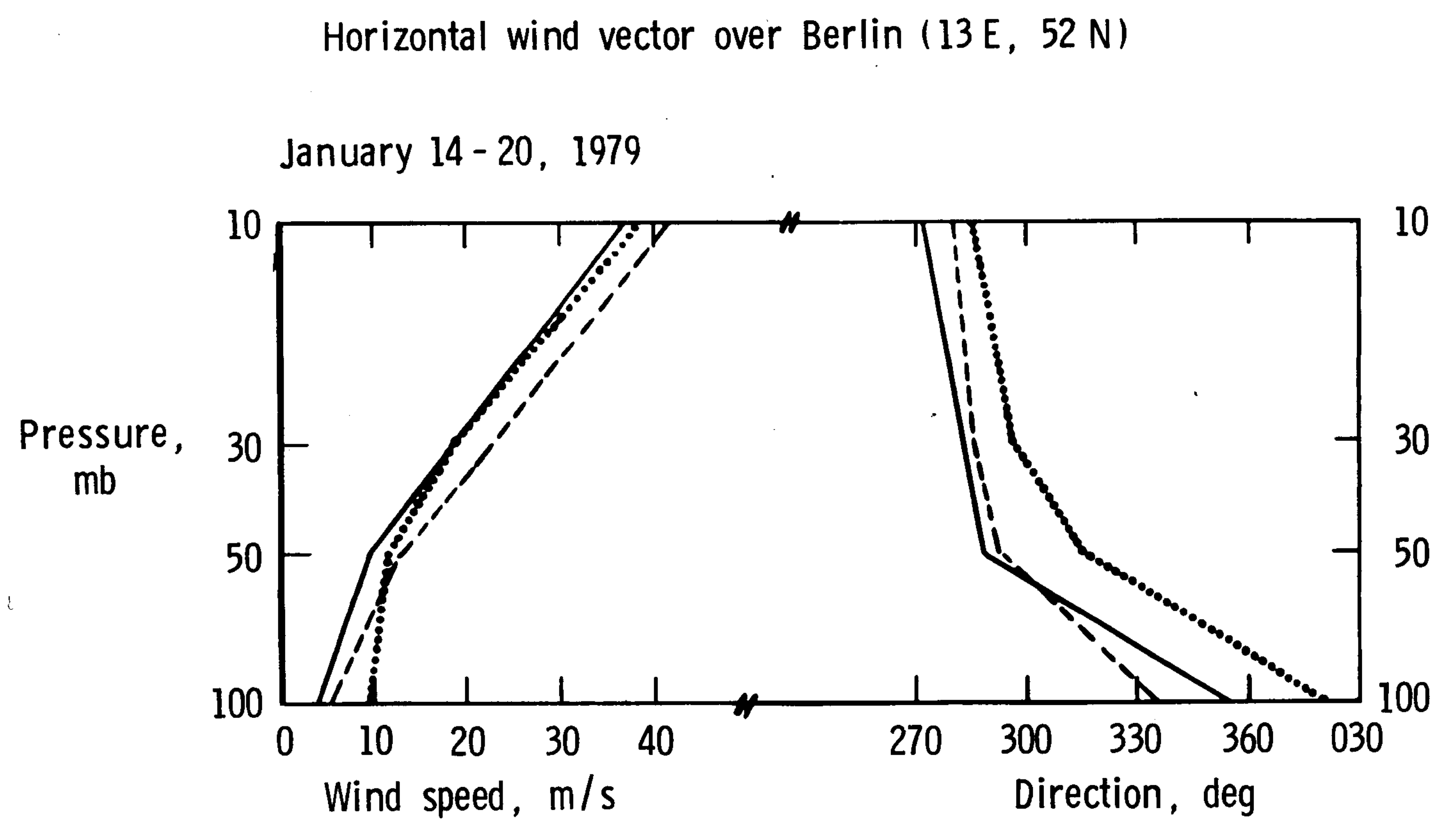
Validation of Stratospheric Satellite Wind Analyses:

The traditional approach in determining horizontal winds in observational studies of stratospheric dynamics is to utilize the geostrophic equation, which represents a balance between horizontal pressure gradient and Coriolis forces. Geostrophic winds can be calculated using layer thicknesses derived from satellite temperature soundings which in turn are added to the height of a radiosonde reference-level pressure surface (≈100 mb). Model simulations have recently suggested that nongeostrophic wind components may exert a substantial influence on the winter polar night jet.

This hypothesis has been examined using geopotential height data from the Nimbus 7 LIMS (Limb Infrared Monitor of the Stratosphere) experiment. Iterative solutions of the nonlinear balance equation were obtained with a successive under-relaxation procedure applied to a 4° × 10° latitude-longitude grid at 18 pressue levels (100 to 0.05 mbar). Spatial smoothing and enforcement of the appropriate criterion for the LIMS height analyses were required to achieve satisfactory convergence of the numerical solutions. The accompanying figure compares LIMS geostrophic and nonlinear balanced winds versus Berlin radiosonde measurements for January 14-20, 1979. The satellite and radiosonde wind profiles exhibit generally close qualitative agreement, both in terms of vertical wind shear in wind strength and the backing of wind direction with decreasing pressure. The balanced wind formulation appears to provide more accurate wind direction. These intercomparisons underline the usefulness of the satellite-derived wind analyses for application in stratospheric transport and dynamics investigations.

Thomas Miles
RTOP: 673-64-02-70

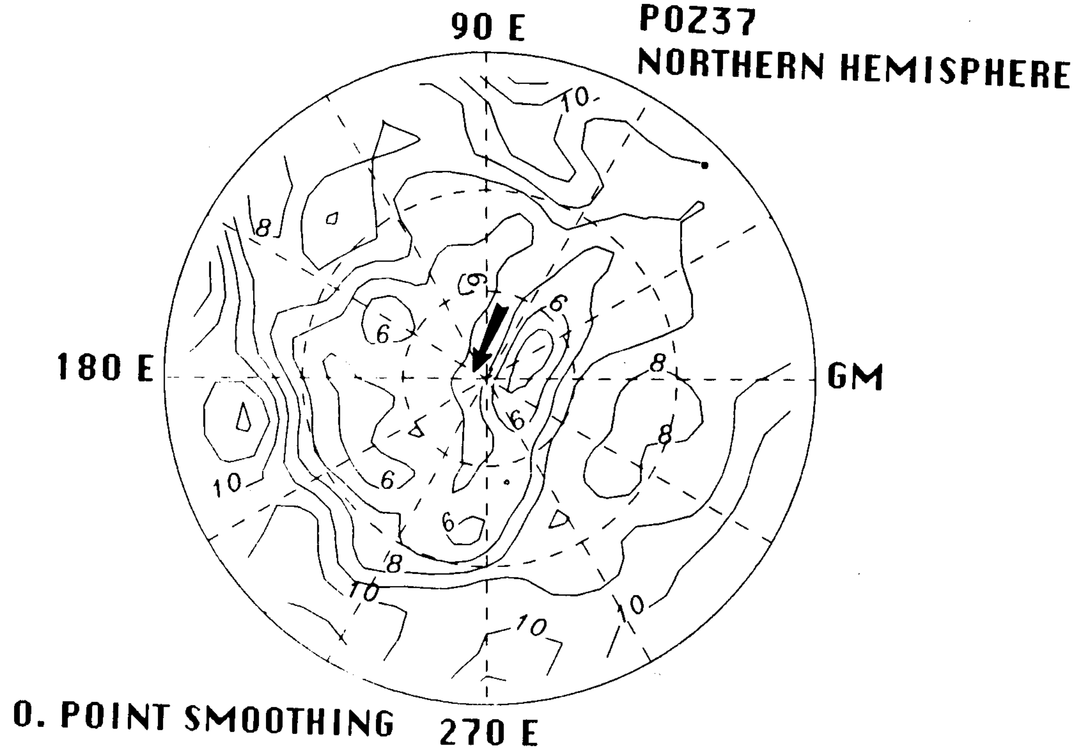


Comparison of horizontal windflow over Berlin (13E,52N) between radiosonde (solid curves) and LIMS geostrophic (dotted curves) and balanced analysis (dashed curves).

Modeling Dynamics and Transport Processes in the Middle Atmosphere:

During the last decade and a half, the potential for ozone depletion in the stratosphere as a result of aircraft emissions, halocarbons, fertilizers, and various other chemicals has stimulated the requirement to understand the complex processes which determine the spatial and temporal distribution of ozone and other important trace constituents in the Earth's atmosphere. A three-dimensional atmospheric circulation/transport model incorporating comprehensive chemistry has been developed at LaRC to simulate the distribution of constituents from the surface to 60 km altitude. Comparisons of simulated distributions with data from satellite experiments demonstrate good agreement. The model has been particularly successful in simulating the transport of ozone during highly disturbed conditions such as during mid-winter stratospheric warmings. Of particular interest are incursions or "tongues" (denoted by bold arrows in the figure) of ozone-rich air parcels from lower latitudes into the polar cap region associated with a strong cross-polar jet and a displaced polar vortex during the warming event. The simulation exhibits erosion of the vortex and irreversible mixing consistent with the concept of wave-breaking inferred from satellite data. The model has also successfully simulated the observed evolution of the high-latitude spring maximum in total column ozone. Applications of the model will be focused on Upper Atmosphere Research Satellite model/data interaction studies.

William L. Grose
RTOP: 673-64-02-70

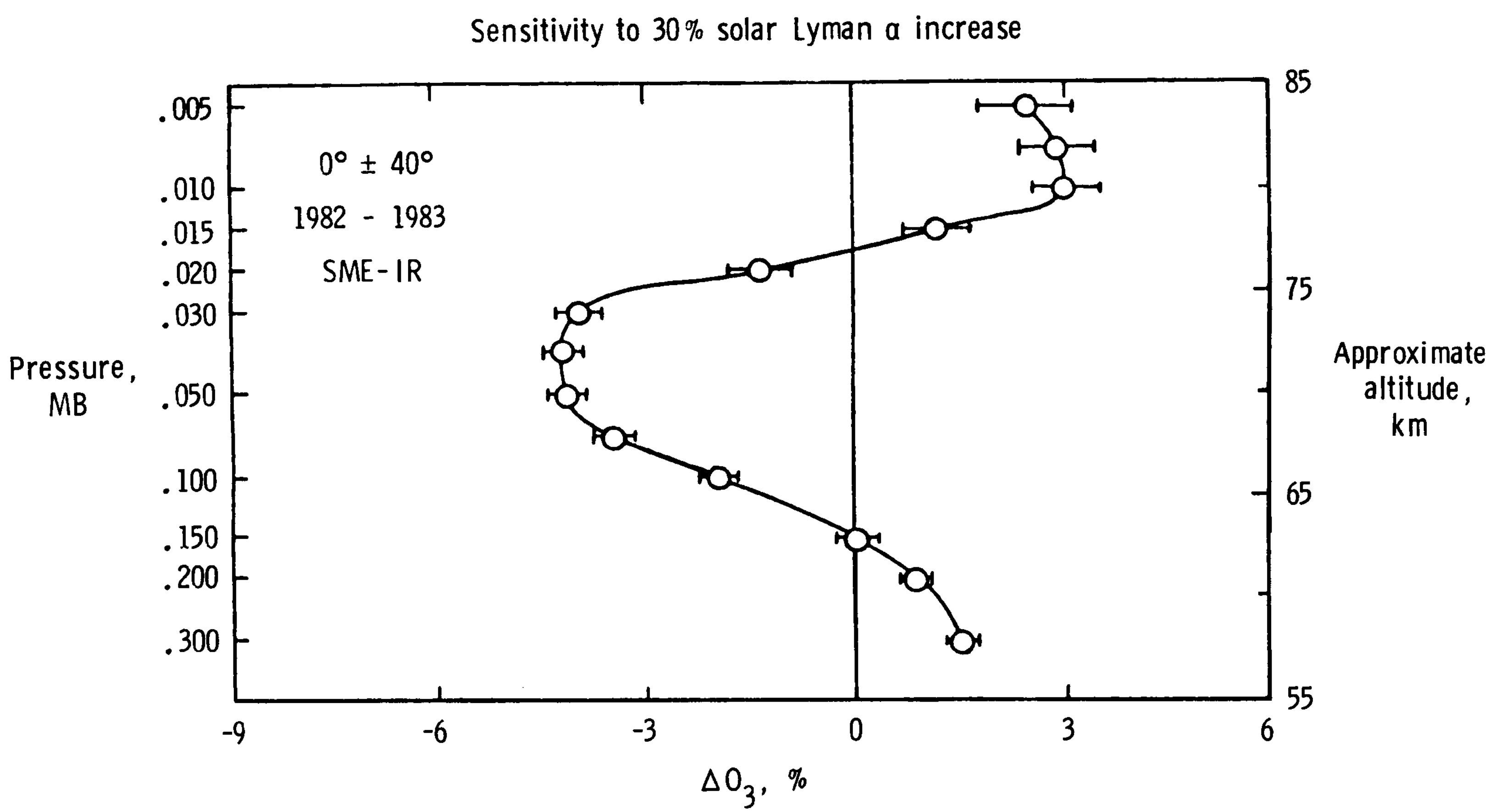


Simulated ozone mixing ratio (parts per million by volume) on the 10 millibar pressure surface (≈30 km altitude) of the Northern Hemisphere for model day February 7. The outermost circle is the Equator, and the dashed inner circles correspond to 30°N and 60°N, respectively.

Ozone Depletion Via Solar Lyman Alpha Radiation Detected:

A study of 3 years of ozone measurements from the Solar Mesosphere Explorer satellite's 1.27μ experiment has resulted in the detection of the response of mesospheric ozone to solar variations. The study was conducted relating short-term variations in solar Lyman alpha (Lα) radiation (121.6 nm) to short-term ozone variations. Over the 27-day solar rotation period, the solar Lα variations were found to be as large as 30 percent. In order to achieve the precision necessary to detect the corresponding ozone response, a vast amount of ozone was combined from low and mid latitudes. Shown in the accompanying figure is the ozone response to 30-percent solar Lα variations as a function of pressure and altitude. A strong ozone depletion is observed which maximizes near 70 km altitude. This depletion is thought to result from solar Lα radiation photodissociating water vapor near 70 km, with the resulting HO_x acting as a catalyst for the destruction of ozone. This systematic destruction of mesospheric ozone by HO_x has been hypothesized, but the ozone depletion via solar Lα had not been previously detected. This discovery should provide a stringent test of HO_x/O_x chemistry in the middle atmosphere which is crucial to understanding the Earth's ozone budget. Once the HO_x/O_x chemistry is validated, a study of the ozone depletion as a function of latitude and season may allow a mesospheric water vapor climatology to be formulated.

Gerald M. Keating
RTOP: 673-41-07-70



Mean mesospheric ozone response to short-term solar UV variability.

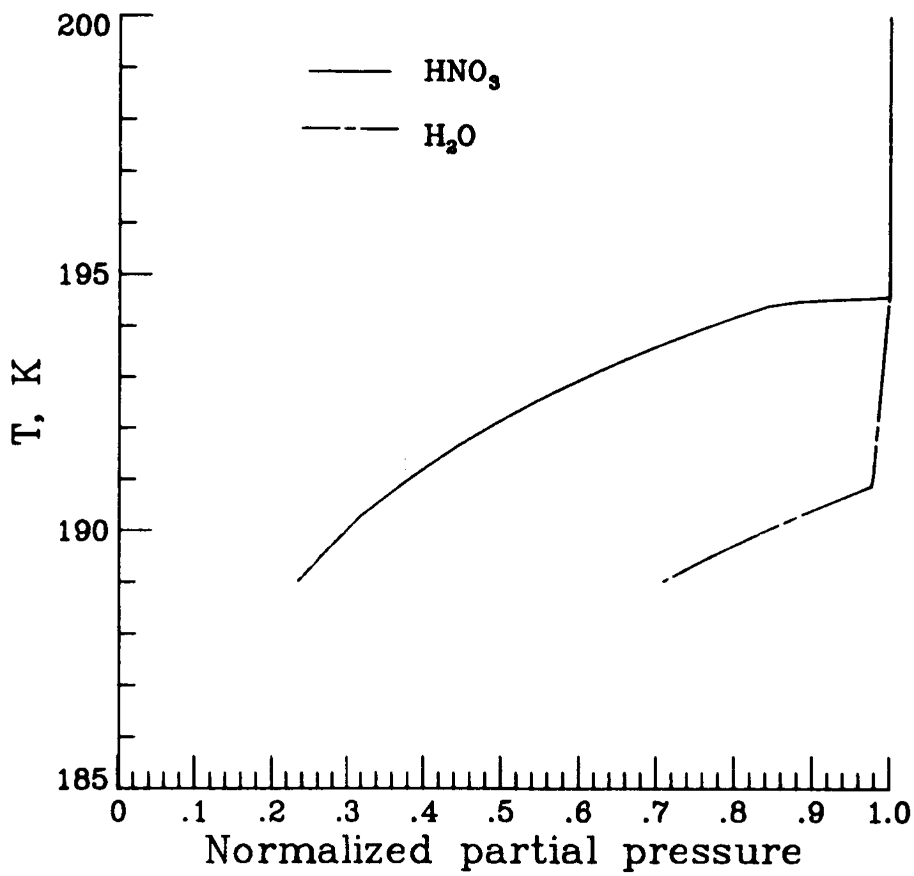
Aerosol Research Branch

Polar Stratospheric Clouds and the Antarctic Ozone Hole:

One of the most controversial and important topics in atmospheric sciences today is the dramatic decrease in stratospheric ozone observed in Antarctica during recent Southern Hemisphere spring seasons (September-October). Although other theories have been proposed for the development of this "ozone hole," many scientists feel that man-made chlorofluorocarbons (CFC's) are involved. These CFC's release halogen atoms and molecules when dissociated by sunlight in the springtime Antarctic stratosphere; the halogens, in turn, can catalytically destroy ozone if the supply of gaseous odd nitrogen (NO_x) compounds is insufficient to retard the catalytic cycles. Several recent publications have suggested that a large fraction of the gaseous NO_x supply may be removed (in the form of nitric acid, HNO_3) from the Antarctic stratosphere by the formation of polar stratospheric clouds (PSC's), which have been identified as recurring Antarctic phenomena through measurements by the orbiting SAM II (Stratospheric Aerosol Measurement II) sensor.

A new theoretical model of PSC formation and growth which incorporates a stage of HNO_3 vapor deposition has been developed. Recent calculations tailored to the altitude regime in which Antarctic ozone depletion is observed to be most severe (near 17 km) suggest that up to 80 percent of the ambient HNO_3 vapor (and 30 percent of the ambient H_2O vapor) may be consumed by PSC formation if the temperature should fall to 189°K. More importantly, the cloud particles may grow to a radius of 4-5 μm and then fall quickly from the region in which they were formed, thereby depleting the formation region of gaseous NO_x.

L. R. Poole
RTOP: 665-10-40-04



Depletion of HNO_3 and H_2O vapor supplies by the formation of Antarctic polar stratospheric clouds.

Satellite Measurements of Stratospheric Polar Aerosols:

In October 1978 the Stratospheric Aerosol Measurement (SAM) II experiment was launched on-board the Nimbus 7 spacecraft to obtain detailed information about the high-latitude stratospheric aerosol layer. The SAM II instrument remains fully operational, and a large and unique data set has been assembled for examining the characteristics of polar stratospheric aerosols as well as providing information on the long-term variation of the aerosol layer.

The weekly averaged stratospheric aerosol optical depth is presented in the figure for the period October 1978 to October 1986. This record shows that the overall yearly values in the two polar regions are influenced by seasonal variations and controlled by volcanic perturbations. The impact of volcanic eruptions is much more apparent in the northern high latitudes, partly because of the greater number of eruptions in the Northern Hemisphere and partly because of the more favorable seasonal circulation patterns following these eruptions. The eruption of El Chichon in April 1982 created the largest enhancement in optical depth recorded in both hemispheres.

Pronounced enhancements are also visible yearly, especially in the southern high latitude observations each mid-winter. These episodes are due to the formation of Polar Stratospheric Clouds (PSC's) when temperatures descend below about -80°C. Antarctic PSC's are present for periods of about 3-4 months, from early June until late September. Arctic PSC's are also observed in each Northern Hemisphere winter season, but are much less frequent because of generally warmer stratospheric conditions.

Another recurring feature in the data is the depression in optical depth observed in late September and early October in the Southern Hemisphere immediately following the disappearance of PSC's at the latitudes measured by SAM II. It is believed that this relative minimum is produced by the loss of aerosols within the vortex by both gravitational settling of the PSC particles during the coldest segment of winter and the general subsidence of air induced by the mean diabatic circulation. Changes in the aerosol structure that take place within the vortex by these processes are maintained until the vortex breaks up, usually about November, when increases in aerosol optical depth are observed as aerosol from lower latitudes moves into these higher latitudes. This period of low optical depth agrees well with the observed low total ozone at similar latitudes.

M. P. McCormick
RTOP: 665-10-40-04

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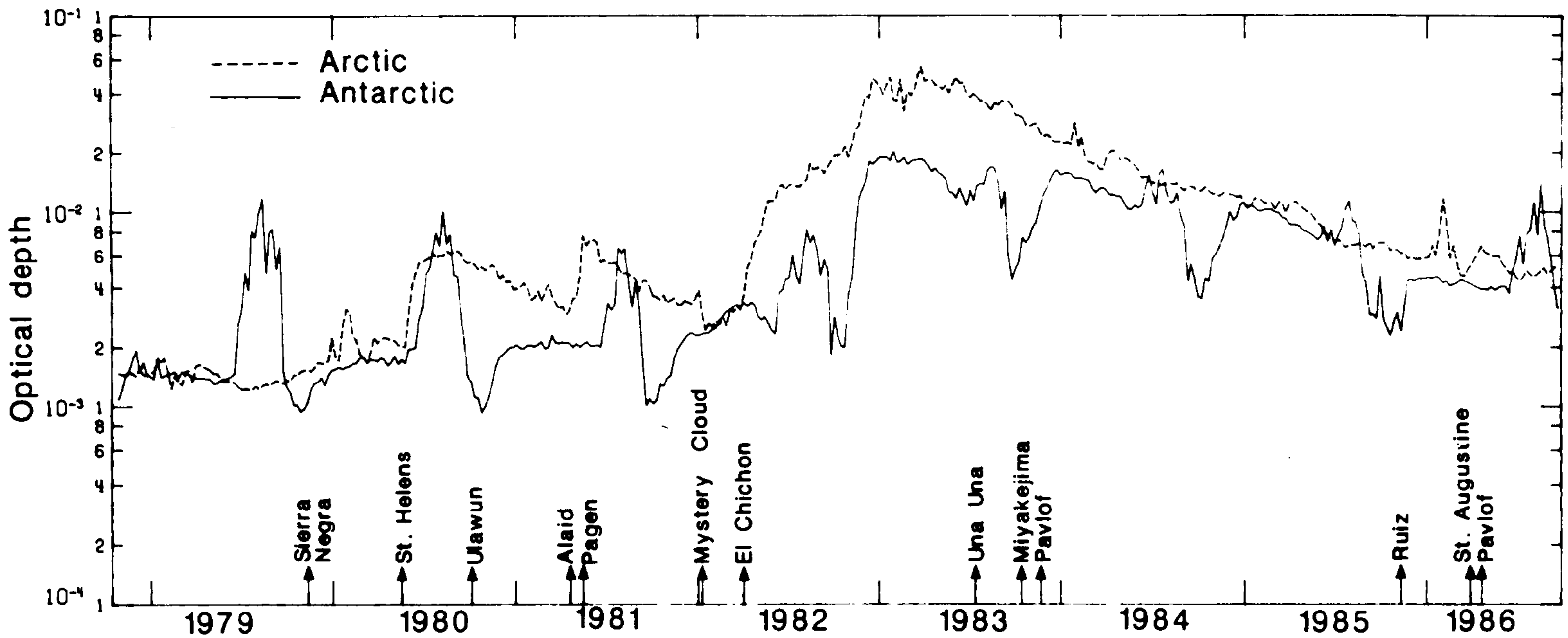


SAM II stratospheric aerosol optical depth record. The dashed and solid lines represent measurements made in the Arctic and Antarctic region, respectively. Dates of significant volcanic eruptions are indicated.

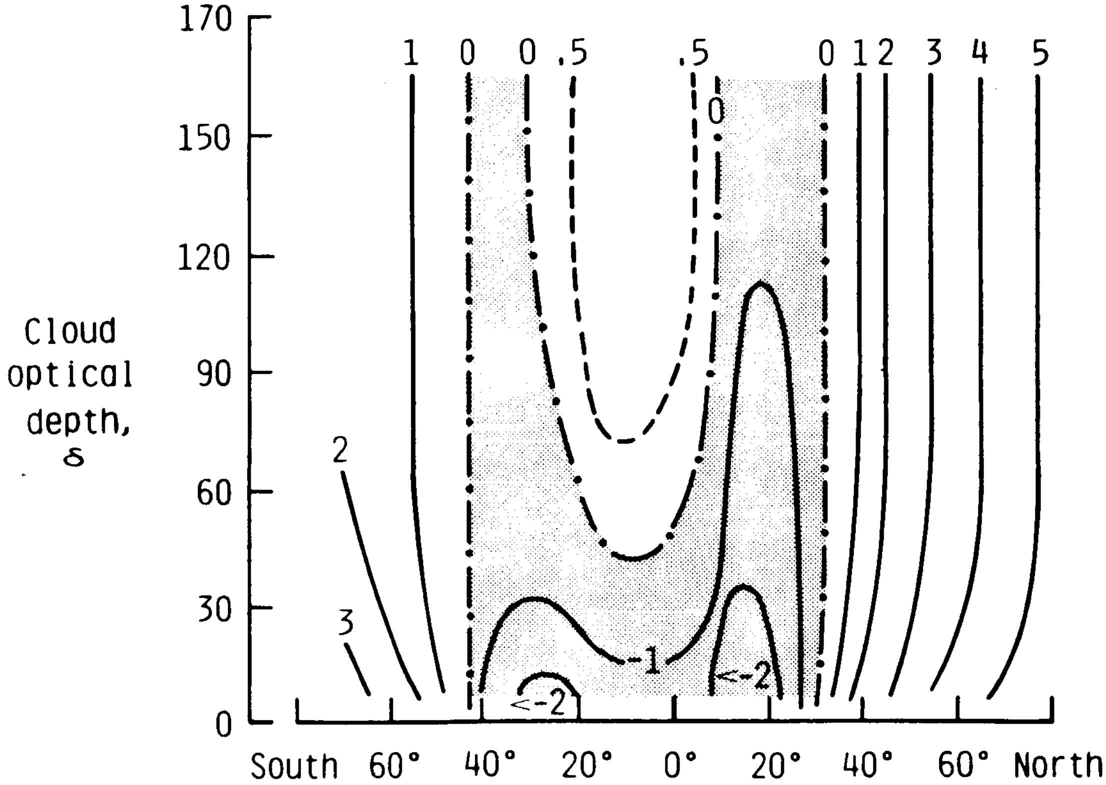
Clouds, Radiation, and Atmospheric Energy:

Clouds change the radiation from the Sun that is absorbed by the atmosphere and the Earth's surface and that the Earth's surface and atmosphere emit into space. A method was developed and implemented for evaluating the effects of these changes in radiation on the available potential energy (APE) of the atmosphere. Computations were performed using a detailed radiative transfer computer code and statistics for clouds. The APE is important in understanding the interaction of energy releasing and dissipating processes, such as radiation, with the dynamics of the atmosphere. Computations were done for January zonal mean atmospheric conditions.

The effects of clouds in cooling and heating the atmosphere were found as a function of cloud top height, optical thickness, and latitude. The effects of low clouds on APE are shown in the figure. In terms of the effects of clouds on the general circulation, the globe can be divided into two regimes. One regime is the belt between 40°S and 30°N, i.e., the Tropics and subtropics. The other is the remainder of the Earth. In the Tropics and subtropics, a change in optical thickness will significantly contribute to APE, intensifying the Hadley circulation and thereby linking tropical sea surface temperature to changes in extratropical circulation.

A mechanism is described whereby the interaction of clouds with radiation produces a strong feedback effect on the development of sea surface temperature anomalies in the tropical oceans, as during an El Niño event. Changes in the cloud pattern over the east Pacific Ocean during the onset of an El Niño results in a strong increase in radiative heating at least as large as the latent heat release.

S. L. Smith
RTOP: 672-40-05-70



Effect of clouds on zonal available potential energy due to radiation.

Infrared Radiation Studies From Nimbus Satellite Data Sets:

Two atlases of monthly mean outgoing longwave radiation global contour maps and associated spherical harmonic coefficients have recently been published. The first atlas contains 3 years of continuous data from July 1975 to June 1978 from the wide field-of-view sensor on the Earth Radiation Budget (ERB) experiment aboard the Nimbus 6 satellite. The second atlas contains 7 years of continuous data from November 1978 to October 1985 from the ERB experiment aboard the Nimbus 7 satellite. Together these two atlases give a data set covering a 10-year time period and will be very valuable in studying different aspects of our changing climate over monthly, annual, and interannual scales in the time domain and over regional, zonal, and global scales in the spatial domain.

The figure shows a contour map of the change in regional longwave radiation of January 1983 from the 7-year average January as derived from Nimbus 7 measurements. Low areas of outgoing radiation caused by large amounts of cloudiness are denoted by dashed contours. High areas of outgoing radiation are denoted by solid contours. A prominent low of -66 watts per square meter in the equatorial region of the western Pacific was caused by the 1983 El Niño which peaked in January of 1983. At the same time, a prominent high region of radiation was evident over Indonesia. For normal conditions (non El Niño years), these two regions of high and low radiation would be reversed.

T. D. Bess
RTOP: 672-40-05-70

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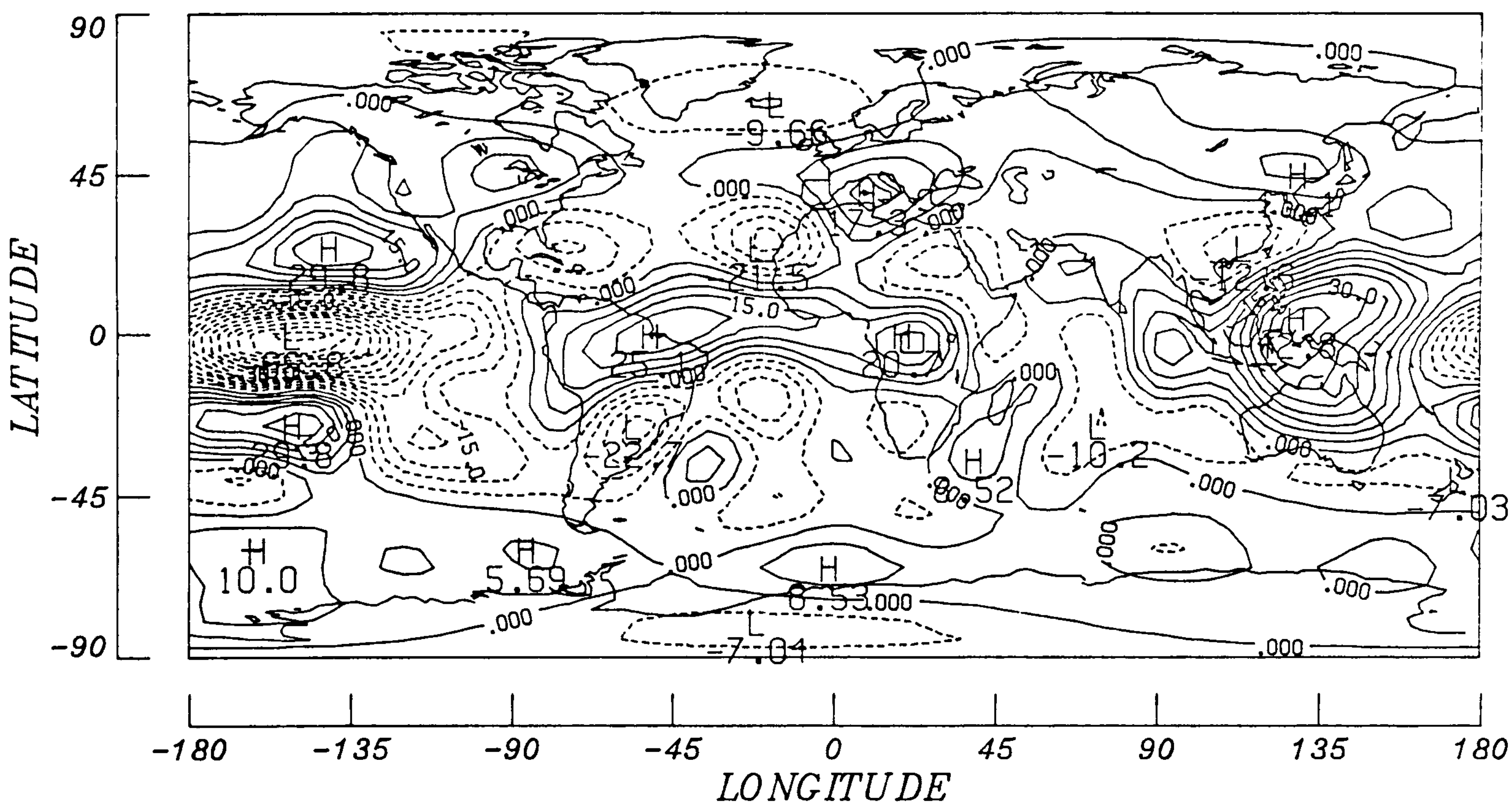


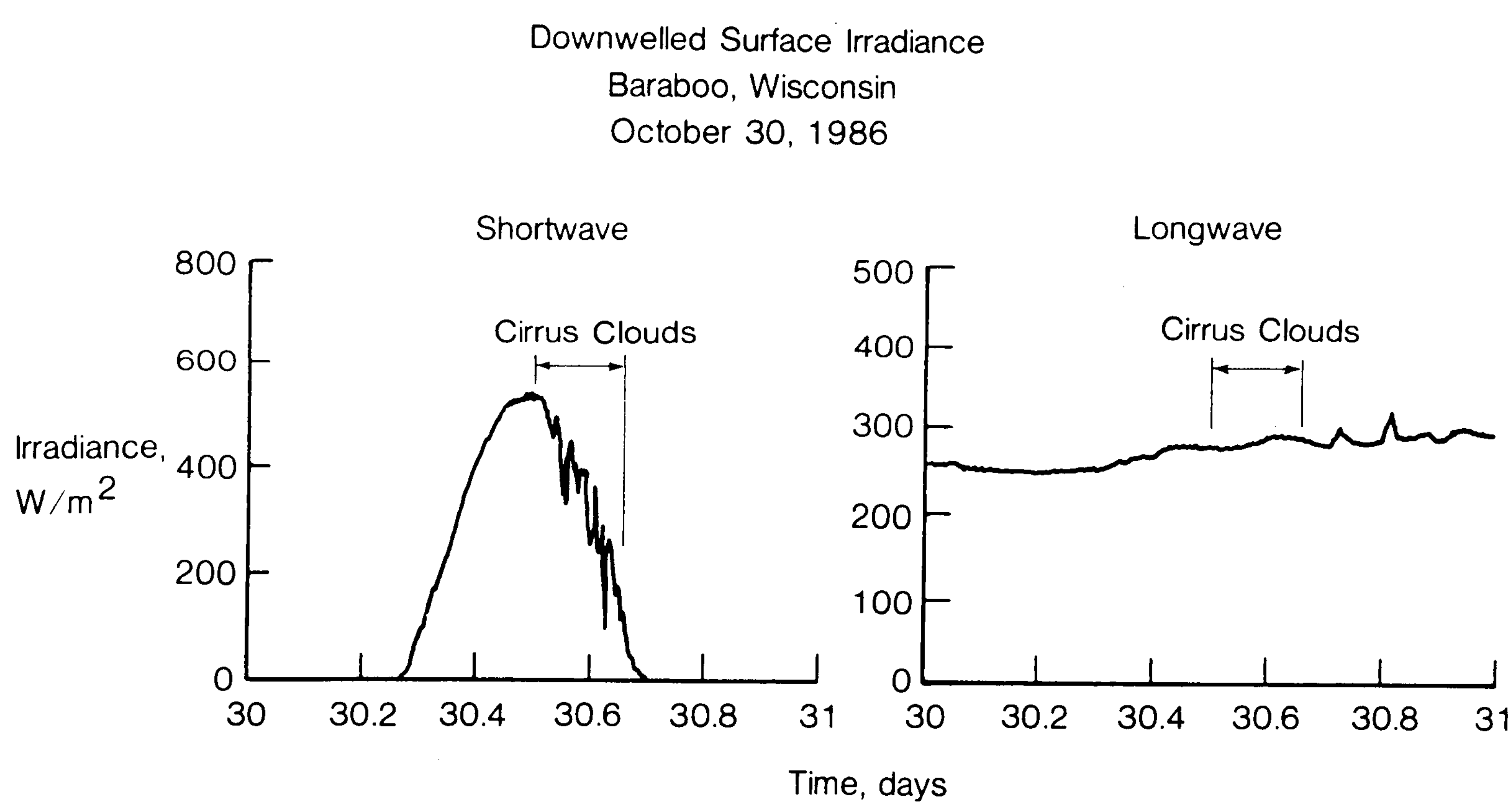
Change in regional longwave radiation.

Surface Radiation Measurements for Satellite Algorithm Studies:

NASA has recently established an SRB (Surface Radiation Budget) Satellite Data Analysis Project at the Langley Research Center. Objectives are to plan and implement algorithm intercomparison and validation studies prior to computing a global, long-term data set. The strategy is to conduct ground-based experiments to establish data sets for satellite algorithm validation studies. Satellite data are available from operational systems and special experiments such as ERBE (Earth Radiation Budget Experiment). Surface measurements are needed for a variety of climatologically important land and ocean areas. However, with the exception of shortwave measurements for some mid-latitude land areas, these measurements are virtually nonexistent.

A major experiment of the SRB Satellite Data Analysis Project was completed this year. This month-long campaign was conducted in cooperation with the FIRE (First International Satellite Cloud Climatology Project [ISCCP] Regional Experiment) cirrus cloud experiment in Wisconsin. SRB measurements were conducted at 18 ground sites, and aircraft observations were made for calibration of satellite measurements. The figure gives an example of results which show the effect of cirrus clouds on the radiation fluxes hitting the Earth's surface. The large shortwave and small longwave changes agree with effects predicted by models. The experimental results are providing the basis for improvements to satellite algorithms for deriving surface radiation fluxes.

Charles H. Whitlock
RTOP: 672-22-20-70



Effect of cirrus clouds on shortwave and longwave radiation fluxes at the Earth's surface.

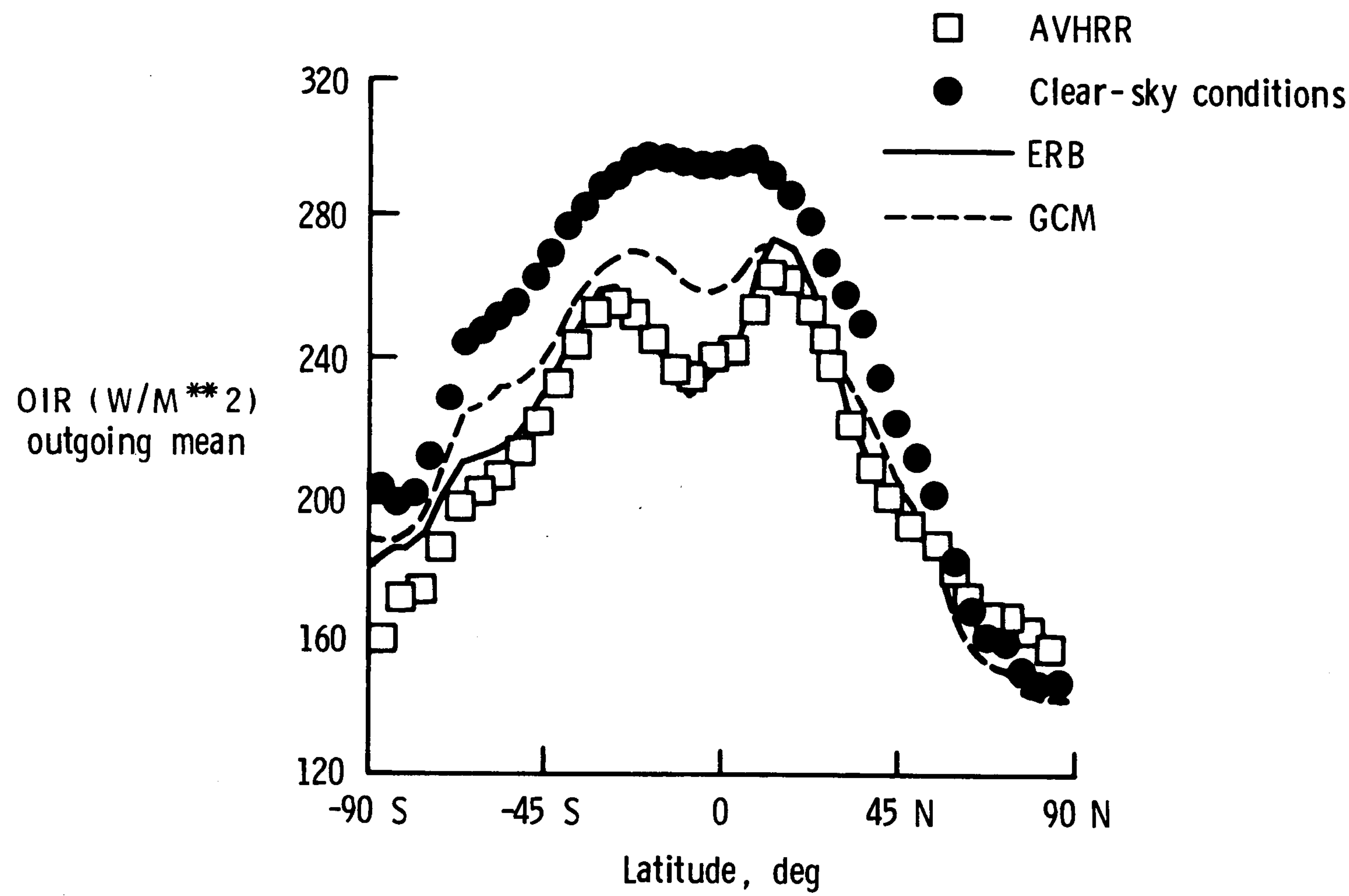
Comparison of Climate Model Simulations With
Satellite Observations:

Climatic changes such as those anticipated for increases in the concentrations of carbon dioxide can be simulated with general circulation models (GCM's). The accuracy of the GCM climate predictions is a crucial issue in modern atmospheric science.

In both a GCM and in nature, the outgoing thermal infrared radiation (IR) balances the incoming solar radiation on a global, annual average. Short-term geographical imbalances in solar heating and IR cooling drive the global weather. The IR is determined by the distribution of temperature, water vapor, traces gases, and cloudiness. The modeled (GCM) and observed (Nimbus 7 Earth Radiation Budget and Advanced Very High Resolution Radiometer [AVHRR]) fields of IR for January have been averaged about each latitude belt and are plotted on the figure.

The GCM (dashed line) has a separate field of IR for the model clear-sky condition (circles). The model cloud fields have brought the GCM into close agreement with the Nimbus 7 ERB (solid line) and AVHRR (squares) satellite observations over much of the globe. Time series analysis of the GCM and satellite IR are being compared to suggest physical processes which should be included in succeeding generations of the model.

Thomas P. Charlock
RTOP: 146-74-04-70



Zonally averaged outgoing thermal infrared radiation (IR) is a model and in satellite observations.

Field Experiments Branch

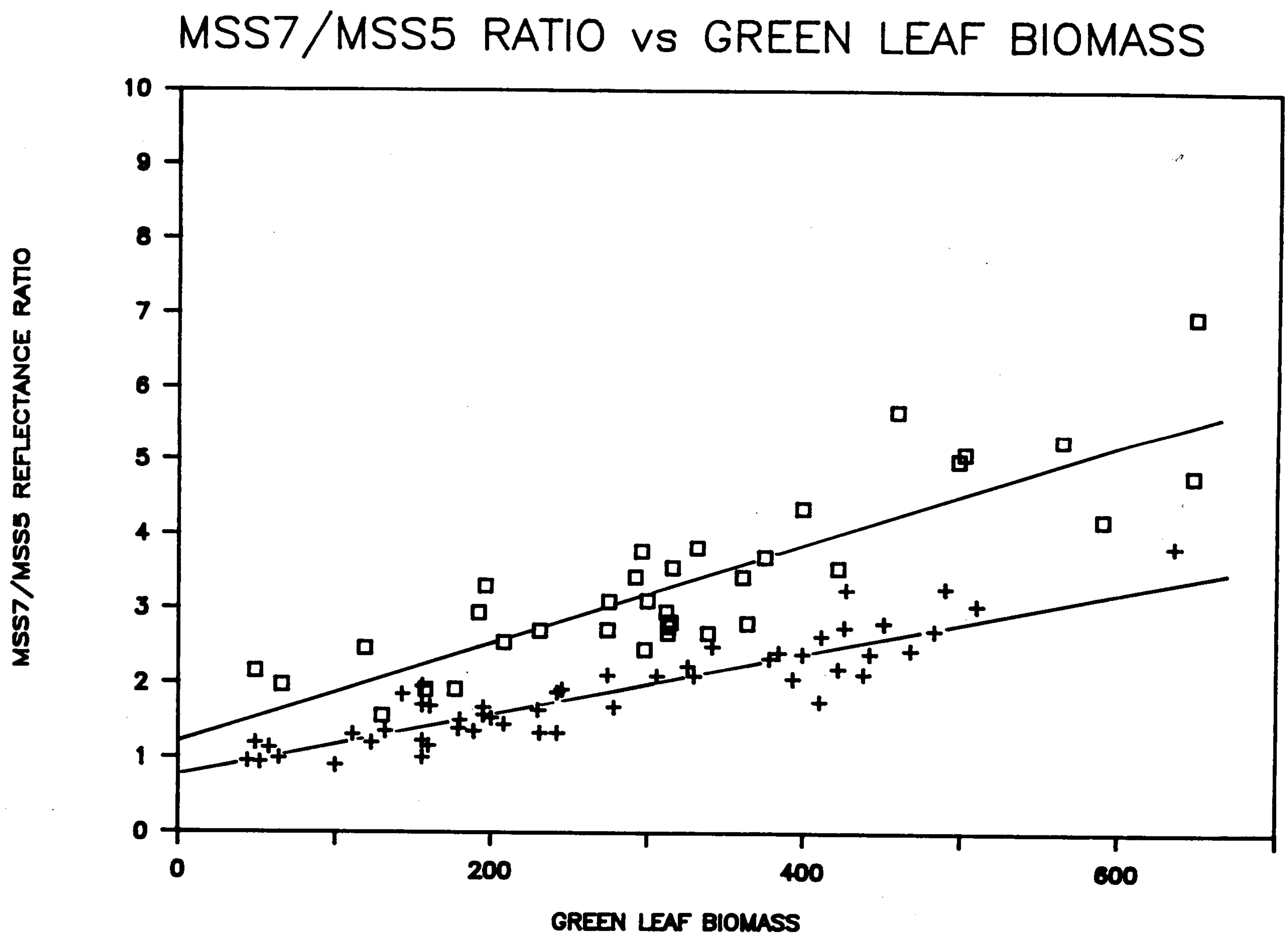
Analysis of Vegetation Growth/Carbon Cycling at Continental-Sized Geographic Scales:

Global models of the cycling of carbon and its impact on atmospheric chemistry and climate require accurate assessment of terrestrial plant growth (transforming atmospheric CO_2 into organic material) and decay (releasing CO_2 and CH_4 into the atmosphere) over large areas. Experimental studies have found correlations of remotely sensed spectral indices with the mass of living vegetation per unit ground area ("biomass"), the area of leaves per unit ground area ("leaf area index"-LAI), and the amount of light absorbed by the canopy for use in photosynthesis ("absorbed photosynthetically active radiation"-APAR). All of these parameters can be related to the dynamics of plant growth and decay. However, it is not known what impacts the application to data covering very large areas of the globe may have on the utility of the relationships. We have conducted an experiment in which field measurements of canopy spectral characteristics, biomass, and LAI were made in plots scattered throughout the range of a single, widely distributed wetland plant.

We found that important, systematic changes in the spectral reflectance characteristics of this plant occurred within its 17° latitudinal range. Mean near-infrared reflectances of canopies in the northern half of the range are nearly double those of the southern half. The transition from one regional canopy type to the other occurs quite abruptly near the center of the plant's latitudinal range (at approximately 37°30'N). Reflectance at visible wavelengths is unaffected. The result is that continental assessment of biomass using the common near-infrared/visible spectral indices would be severely affected (see figure).

Use of spectral indices to assess more fundamental radiative transfer properties of the canopy is not subject to the observed latitudinal changes, suggesting that large area studies can more reliably address canopy parameters such as APAR. The observed changes in canopy geometry also have potential functional consequences for the plant which would be of considerable interest if similar trends are found for other plants and regions. We conclude that orbital assessment of vegetation over large geographic areas will be most consistent and useful if directed at the radiative transfer (e.g., APAR) rather than structural (e.g., biomass) characteristics of plant canopies.

David S. Bartlett
RTOP: 199-30-86-03



The relationship of a commonly used remote spectral index (MSS7/MSS5 reflectance ratio) to green leaf biomass (g/m^2) in widely dispersed plots of a North American coastal plant. There is significant divergence of plots north of 37°30'N( ) from plots south (+) of this latitude, which would result in ambiguous interpretation of continental scale orbital data.

Space Systems Division

The Space Systems Division conducts research on and systems analysis of advanced transportation systems, large space systems, and space station concepts, as well as basic research on energy conversion techniques for potential space application. The division is a leader in the development of highly interactive and user-friendly computer-aided design (CAD) tools that enable the rapid evaluation of system concepts and the identification of technologies necessary for the development of space transportation systems, large space systems, and the Space Station. The evaluation of advanced space transportation systems covers a wide range of capability, including Earth-to-orbit vehicles, Shuttle II, orbit-on-demand launches, services vehicles, and orbital transfer vehicles.

The development of orbiter experiments that utilize the Shuttle as a reentry research vehicle to study aerothermodynamic and aerodynamic characteristics has been a key activity and one which will provide the data base required for the development of advanced vehicle systems.

An organization chart of the Space Systems Division is shown in figure 5. Major accomplishments for FY 1987 follow.

Experimental Aerodynamics Branch

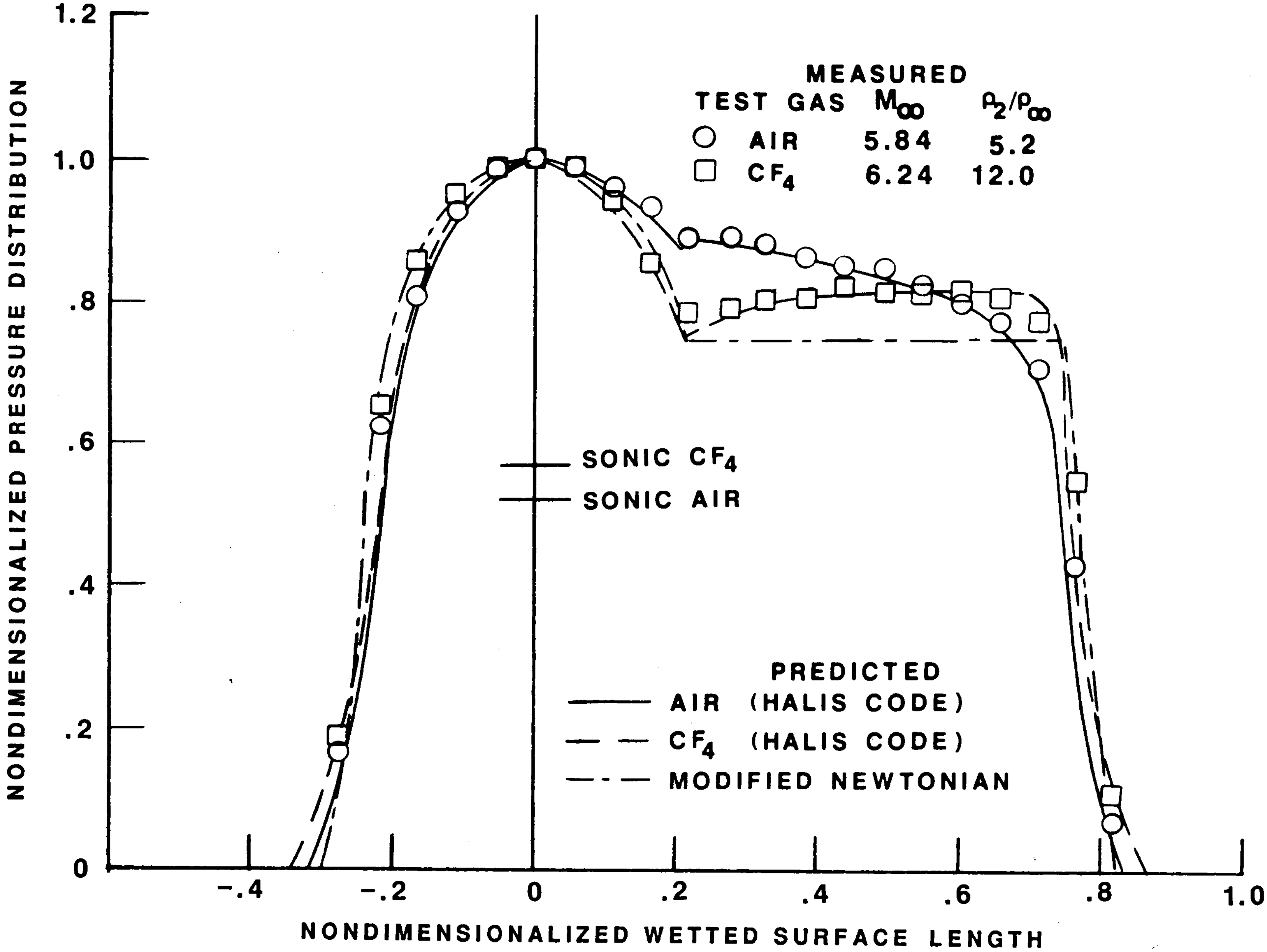
Simulation of Real Gas Effects on Aeroassist Flight Experiment Vehicle:

An important phase of future space transportation operations is the transfer of cargo and personnel from low to high Earth orbit. A class of vehicles known as aeroassisted orbital transfer vehicles (AOTV's) have been proposed for this task. By using the vehicle's aerodynamic lift and drag forces to capture an orbit, payloads would be increased over an all-propulsion braking orbital transfer vehicle (OTV). Because of the lack of flight data at the high altitudes and velocities of the AOTV's, a precursor flight experiment referred to as the Aeroassist Flight Experiment (AFE) will be performed. Development of an extensive aerodynamic/aerothermodynamic data base for the AFE configuration has been initiated at Langley. This data base will provide a better understanding of AFE vehicle performance and will be used to calibrate computational fluid dynamics (CFD) codes for use in future AOTV designs.

Tests in hypersonic wind tunnels to determine the effects of angle of attack, Reynolds number, and normal shock density ratio on AFE pressure distributions have been performed. A significant effect of density ratio (a real-gas simulation parameter) in the nose/cone expansion region of the configuration was observed, and the magnitude of this effect decreased with increasing angle of attack. A negligible effect of Reynolds number was observed for the present test conditions. Predictions from an inviscid flow-field code developed at Langley and known as HALIS (High ALpha Inviscid Solution) were in good agreement with the experimental data.

Pressure distributions predicted with modified Newtonian theory were in good agreement with experiment over the nose and skirt of the configuration but in poor agreement over the cone section.

John R. Micol
RTOP: 506-40-11



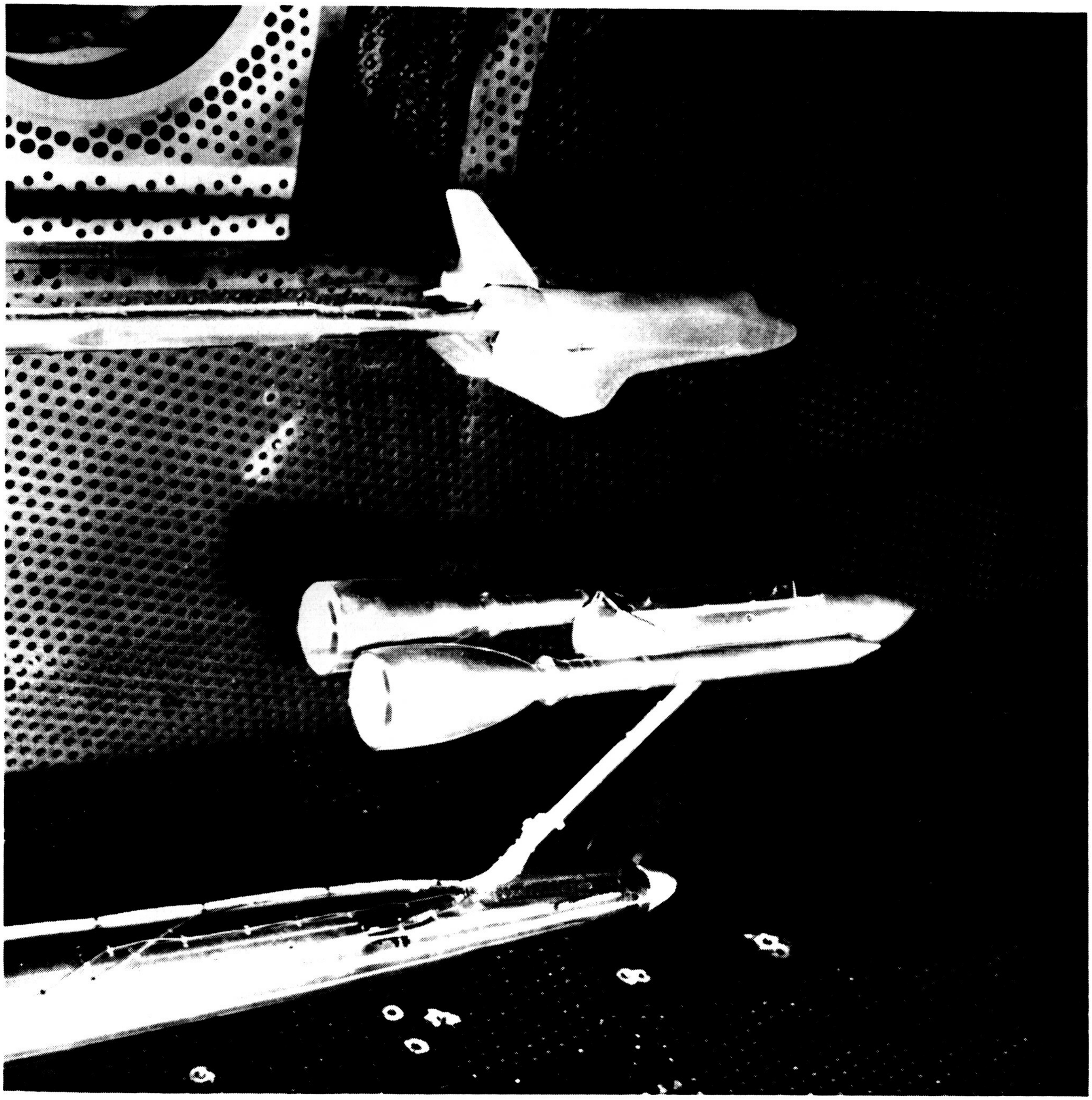
Effect of normal shock density ratio (ρ_2/ρ_∞) on pressure distributions for the AFE vehicle at $\alpha = 0°$ and Mach = 6.

Experimental Investigation of Shuttle Orbiter Ascent Separation:

In response to The Presidential Commission on the Space Shuttle Challenger Accident, the Langley Research Center is investigating means of safe crew escape during launch abort. One phase of this investigation concentrated on examining the possibility of aerodynamic separation of the Orbiter from the external tank and solid rocket boosters (lower stack) during ascent while the boosters were firing. This required detailed wind-tunnel studies at vehicle abort attitudes in and out of the presence of the lower stack (studies that were not investigated during Shuttle development). The tests were made at subsonic and transonic speeds in the Calspan 8-ft Transonic Wind Tunnel and at supersonic speeds in the LTV High Speed Wind Tunnel. These facilities were selected because each had the special equipment to test two independent bodies in the presence of the other while moving them remotely through a predetermined trajectory.

Two 0.01-scale Shuttle ascent models were designed specifically for tests in these tunnels. The rocket exhaust plumes from the solid rocket boosters were simulated by solid bodies sized for each Mach number. Aerodynamic characteristics (and interference effects) were measured over a test area extending from the normal Orbiter-attachment position to the lower stack in the mated configuration to about one Orbiter length (1290 inches full-scale) in the Z-direction (vertical or perpendicular to the relative wind) and one Orbiter length extending in the X-direction (aligned with the relative wind). Tests were also made with the Orbiter alone to obtain interference-free data. Analysis of the data from these tests indicates that the aerodynamic forces on the Orbiter in the presence of the lower stack are in a direction to aid natural separation. The pitching moments on the Orbiter taken about the aft attachment strut are in the nose-up direction. It may be possible, therefore, to release the forward attachment, allow the Orbiter to rotate to a higher angle of attack (which increases the Orbiter's lift), and then at the desired lift, release the aft attachment to provide a clean separation. When the aft attachment is released, the point of rotation for the Orbiter reverts back to its own center of gravity, which should stabilize the vehicle. Thus, these data suggest that an aerodynamic separation of the Orbiter intact from the lower stack during ascent may be possible.

George M. Ware
RTOP: 506-40-11



Shuttle ascent model mounted for wind-tunnel tests.

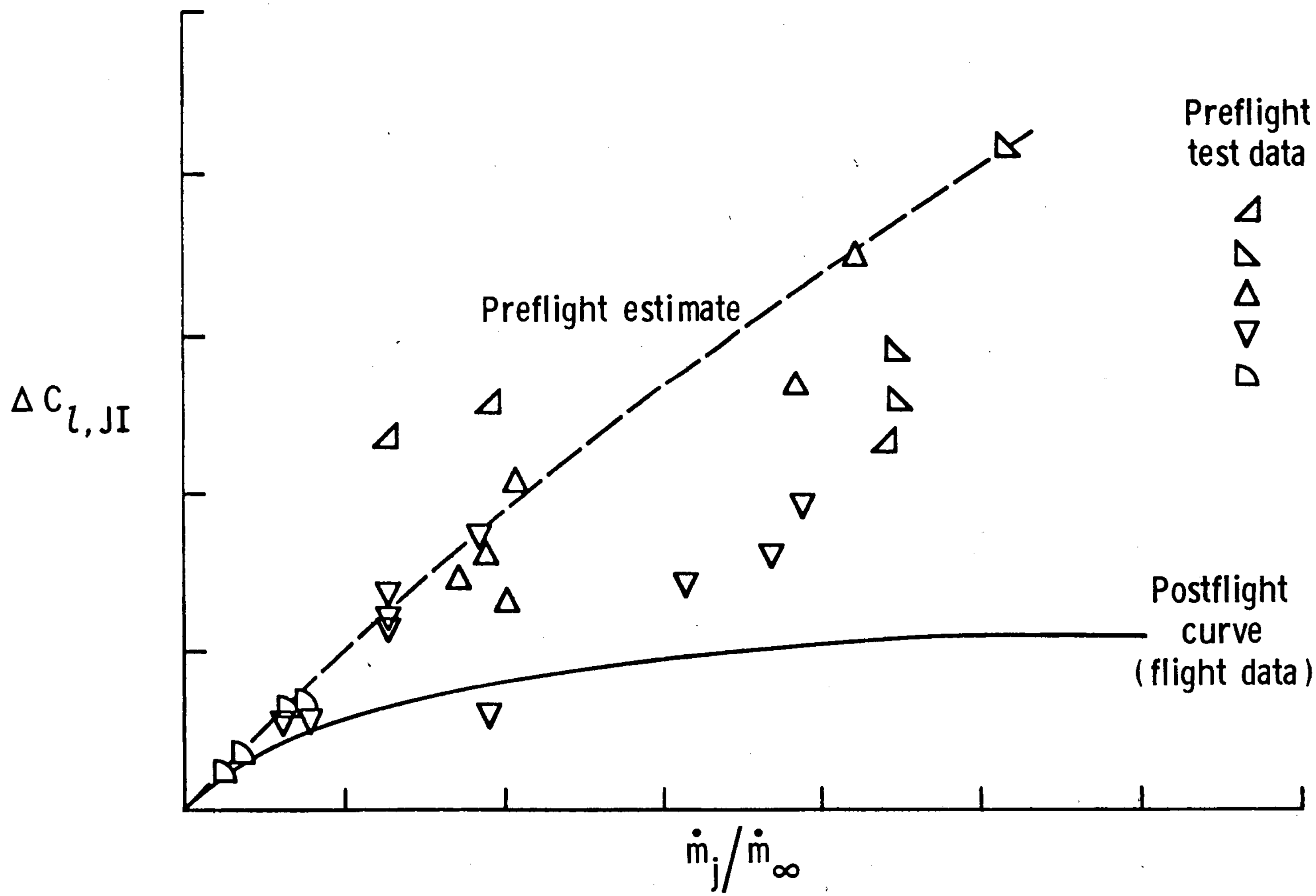
Reaction Control System Plume/Flow-Field Interaction:

The first entry flight of the Space Shuttle orbiter Columbia revealed that the effect of the interaction between the reaction control system (RCS) rocket plumes and the leeside flow field on the rolling moment of the orbiter was greatly overpredicted. Large disagreement between the pre-flight wind-tunnel data and the post-flight curve, shown in the figure, resulted in noticeable excursions in the vehicle attitude during the first navigation bank maneuver at high altitude. Because of this discrepancy, an RCS plume/flow-field interaction technology study was initiated to establish improved ground-to-flight test correlations and flight prediction techniques applicable to future space vehicles. The Space Shuttle orbiter was chosen to be modeled because of the opportunity to obtain ground and flight data on the same configuration.

An 0.0125-scale model was tested in the Langley Unitary Plan Wind Tunnel at Mach 2.5, 3.5, and 4.5, and in the Arnold Engineering Development Center (AEDC) Tunnel C at Mach 10. Surface pressure measurements were obtained on the upper surface of the wing, fuselage side, and vertical tail with the model RCS on and off for various test conditions. These are the first wind-tunnel measurements that demonstrate the response of the wing upper surface pressures to the plumes from the RCS yaw thrusters. Differences in surface pressures between RCS on and off were integrated over the affected areas to determine the increments in moment resulting from the RCS plume/flow-field interaction. Tests at Mach 10 indicate that (1) the new wind-tunnel data (which are classified) are in better agreement than the original data with flight results taken from the onboard inertial measurements and (2) for a given momentum ratio, the interactions are insensitive to plume shape or number of thrusters fired.

A flight program with additional pressure sensors installed on the wing, fuselage, and vertical tail surfaces of Columbia would permit highly valuable correlation and potential extrapolation of wind-tunnel measurements to flight conditions.

William I. Scallion
RTOP: 506-40-11



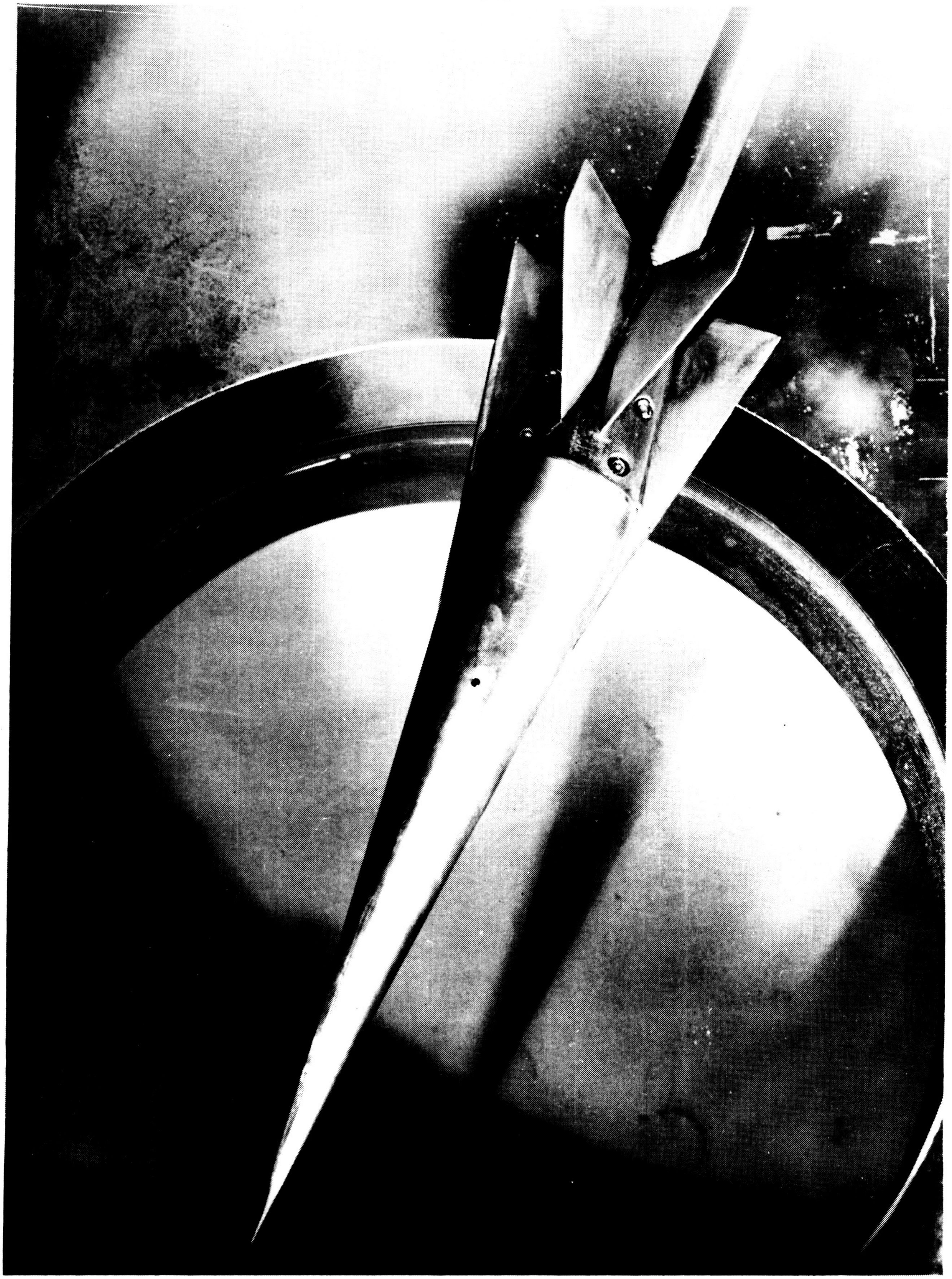
Predicted and post-flight rolling-moment interaction coefficient ($\Delta C_{l,JI}$) as a function of mass-flow ratio, $\dot{m}_j/\dot{m}_\infty$.

Aerodynamic Characteristics of Transatmospheric Vehicle Concept Over Wide Speed Range:

Transatmospheric vehicles (TAV's) proposed for the 1990's would routinely take off from a conventional runway, accelerate using air-breathing propulsion to achieve low-Earth orbit, reenter, and land horizontally. One generic TAV concept of interest is a winged-cone configuration which offers design advantages in efficient vehicle packaging and the orientation of multiple engines. An experimental investigation of aerodynamic characteristics for a winged-cone configuration without engines has been performed over the approximate flight Mach number range of the vehicle ($0.6 < \text{Mach} < 20$). The primary purpose of this study was twofold: (1) to establish a timely aerodynamic data base for this class of TAV's and (2) to compare predictions made with engineering codes (e.g., the Hypersonic Arbitrary Body Program) with measurements.

The variation of the measured drag coefficient at zero lift, C_{D_o}, with Mach number is shown by the circular symbols in the figure. These data reveal a steep transonic drag rise followed by a more gradual decline in drag levels supersonically. Engineering code predictions of C_{D_o} at the present supersonic and hypersonic flow conditions and model scale (shown by the solid and dashed lines) are generally in good agreement with measurement. A large travel in the longitudinal center of pressure (approximately 23 percent of the vehicle length) was observed to accompany an increase in Mach number from 1.5 to 20. Such a large center of pressure variation with Mach number will dictate the need for large, effective control surfaces to facilitate flight at low angles of attack.

W. Pelham Phillips
RTOP: 506-40-11



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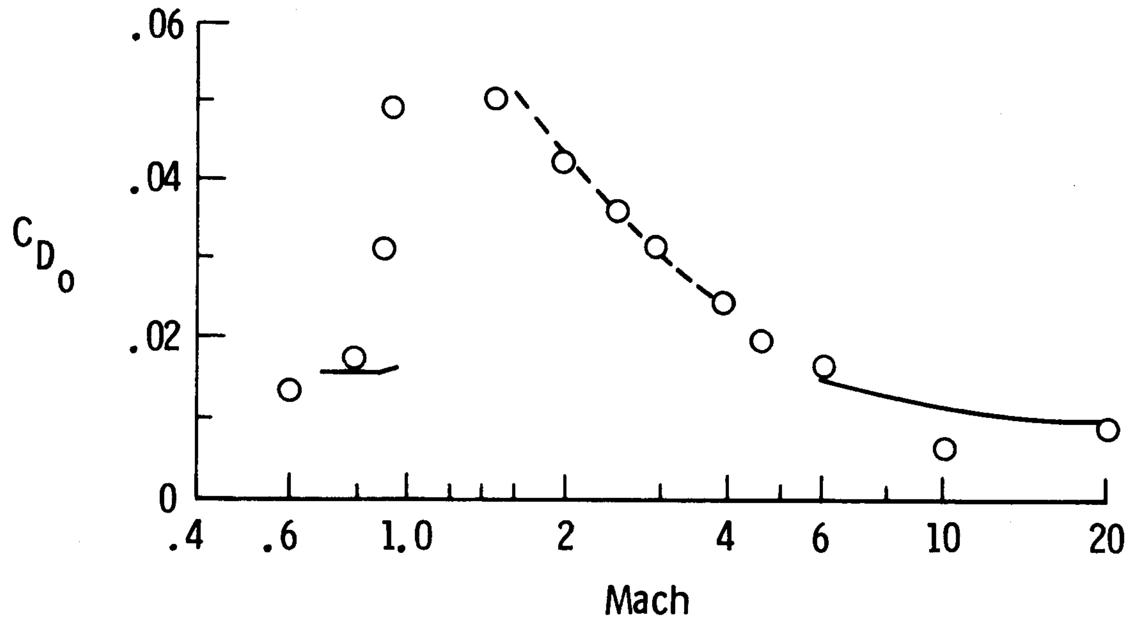
Transatmospheric vehicle concept.



Variation in zero-lift drag with Mach number.

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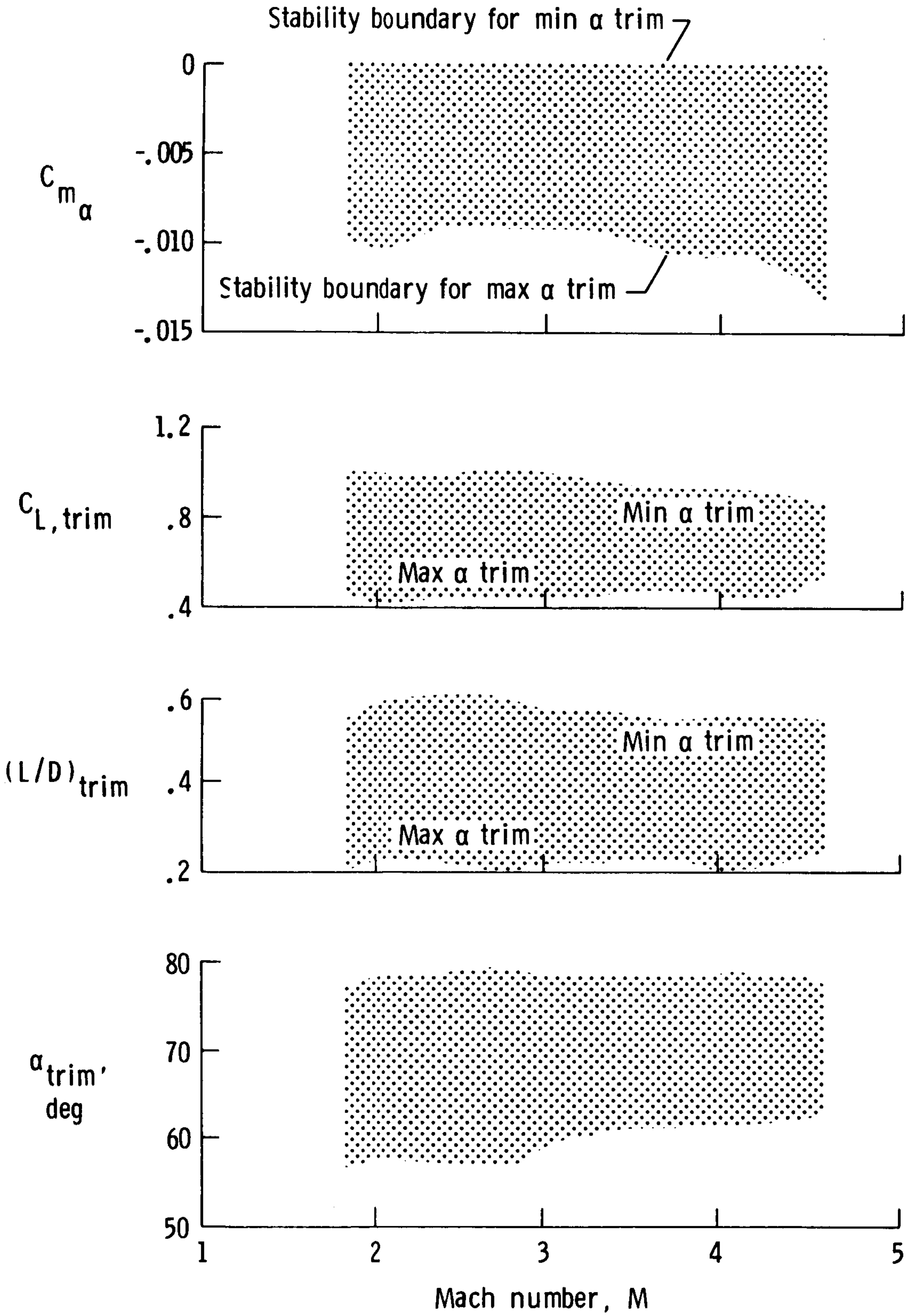
Space Shuttle Orbiter Stability and Control Characteristics at High Angles of Attack:

Langley Research Center is continuing to support the refinement and updating of the aerodynamic data base of the Space Shuttle orbiter. One area recently under study addresses an alternate means of crew escape during an ascent abort. The orbiter, however, has only one entrance, the side hatch. Previous tests have shown that unassisted bailout from the side hatch during steady gliding subsonic flight at normal flight attitudes is very risky. The current series of tests were conducted with the thought that if the orbiter could be safely trimmed at very high angles of attack (α) a slower descent rate might be achieved and more benign bailout conditions might exist. It might also be possible to exit the vehicle from the upper cabin windows located on top of the fuselage.

Tests were conducted in the Langley Low-Turbulence Pressure Tunnel, the Langley Unitary Plan Wind Tunnel, and the Calspan 8-Ft Transonic Tunnel over a Mach range from 4.6 to 0.30 to determine the high-angle-of-attack characteristics of the orbiter. Even though bailout was considered only at the slowest speeds, the study was carried to the high Mach numbers because it may be advantageous to trim the orbiter to high angles of attack early in the gliding return at high Mach numbers and allow the vehicle to slow down while in that attitude. The results of the tests are summarized in the accompanying figure, which shows that the orbiter is longitudinally stable and trimmable over a wide range of lift (C_L) and lift-drag (L/D) values, producing a more favorable environment for bailout.

B. Spencer, Jr.
RTOP: 506-40-11



Summary of orbiter model high-angle-of-attack stable trimmed characteristics. C_{m_α} is the change in pitching moment with respect to α.

Crew Emergency Rescue Vehicle:

For a permanently manned Space Station, some type of crew emergency rescue vehicle (CERV) is needed. Dependability, speed of recovery, ride quality, risk, and cost are all considerations. Many alternatives are being considered, from ballistic shapes to vehicles that can fly and land like airplanes. The objective of this study was to evaluate a lifting body as a potential CERV.

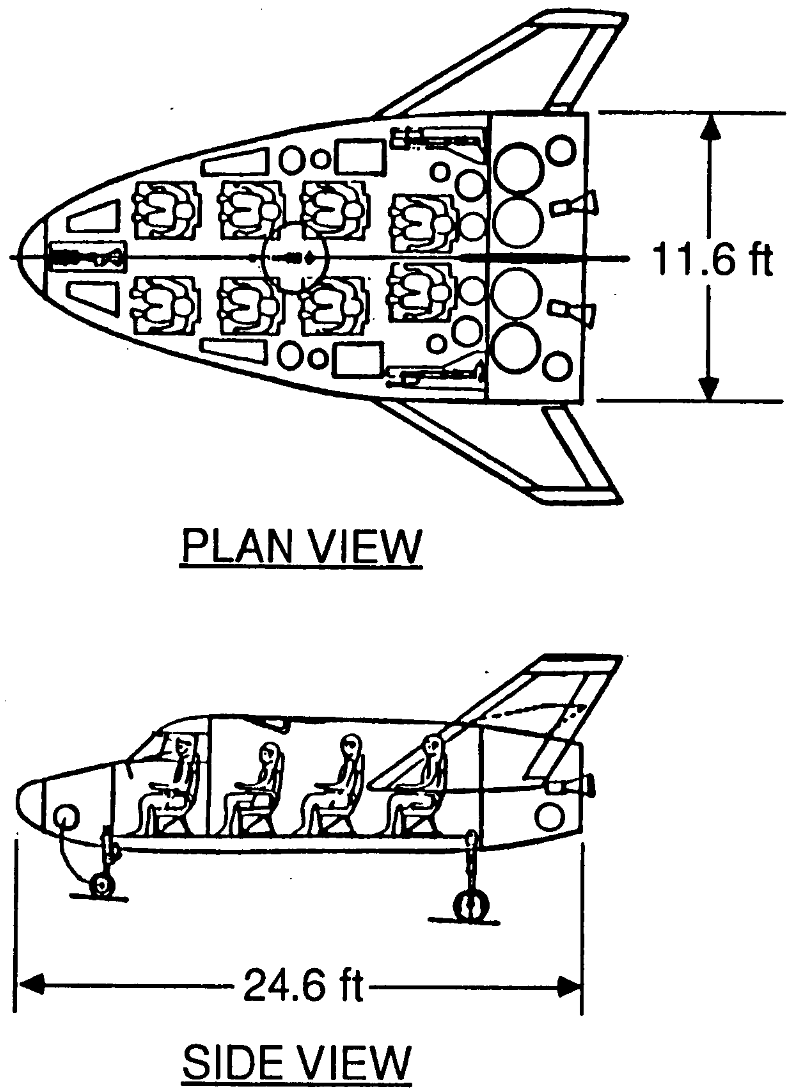
The guidelines for the study included the accommodation of up to eight persons, delivery to orbit in the Space Shuttle, ability to stay docked at the Space Station in a ready state for at least 180 days without resupply, and ability to loiter on orbit for up to 24 hours after separation from the Space Station. Because of an additional guideline that there may not be a trained or healthy pilot on board, the necessary architecture for the avionics to provide for an automated entry and landing is proposed.

Trajectory calculations starting over Cape Kennedy show that the vehicle has enough crossrange to land at either Kennedy Space Center or Edwards Air Force Base on the first four orbits, or at Edwards on the fifth orbit. When Kennedy, Edwards, Hawaii, Guam, and Dakar (West Africa) are considered as landing sites, a return from the Space Station is possible on every orbit.

An analysis of the entry heating indicates that the peak surface temperature (in the nose stagnation region) is about 30 percent higher than that for the Shuttle but is considered to be within the present capabilities of existing thermal protection materials. (The higher temperature is due principally to the smaller nose radius of the CERV when compared with the Shuttle.)

Some other characteristics of the vehicle include titanium structure, a durable thermal protection system, a battery power system, all electric actuators for control surfaces, and hinged wings so that the vehicle can be accommodated in the Space Shuttle cargo bay. The study resulted in the inclusion of a lifting body as a viable candidate in the Space Station contractual activities for a rescue vehicle.

I. O. MacConochie
RTOP: 506-40-11-05



The 8 man CERV inboard layout.

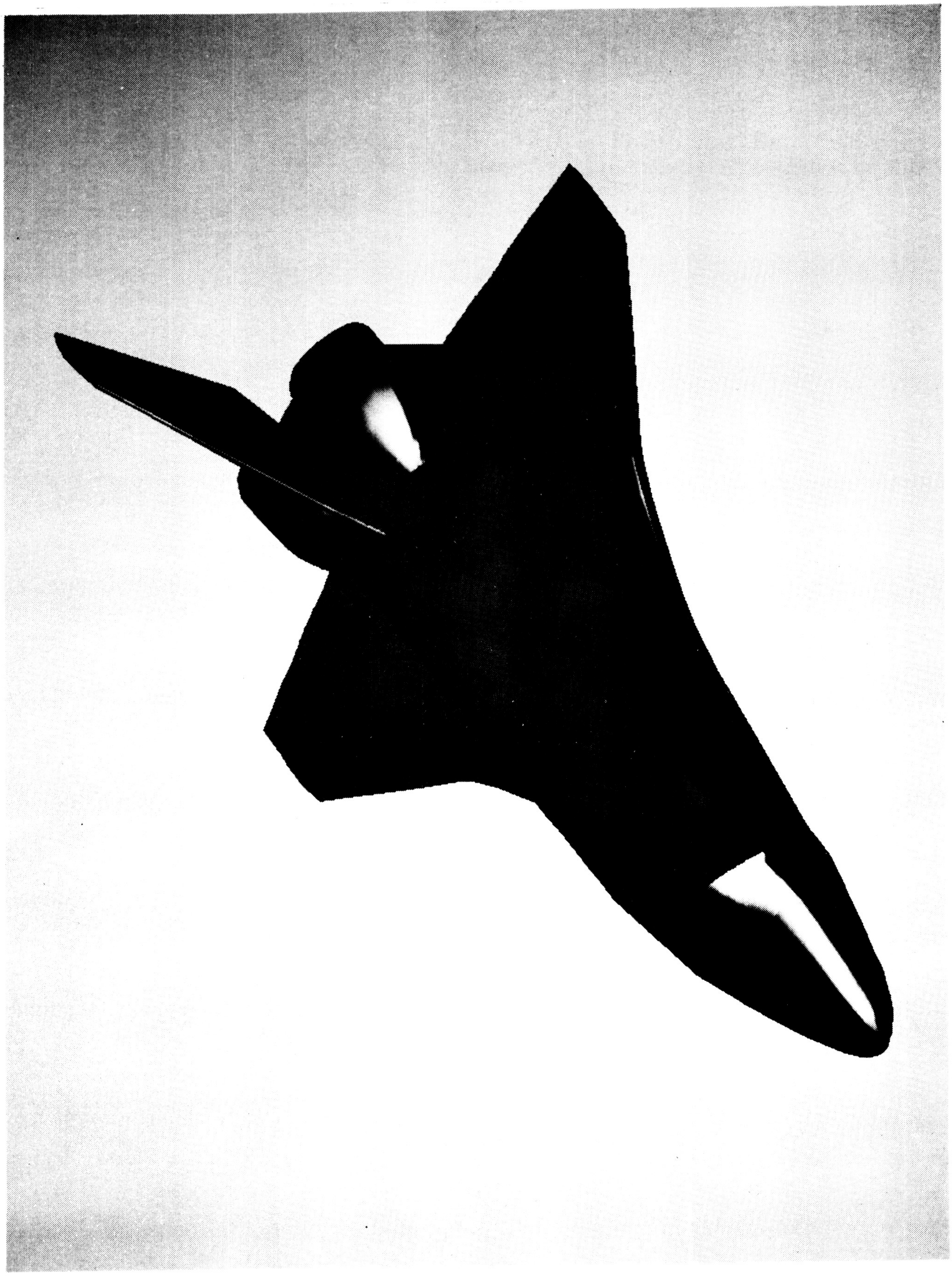
Solid Modeling Aerospace Research Tool:

A new geometry modeler has been developed for the second generation AVID (Aerospace Vehicle Interactive Design) system. The new modeling program, called SMART (Solid Modeling Aerospace Research Tool), takes advantage of state-of-the-art computer graphics hardware to substantially increase the productivity of the design engineer. Complex configurations can now be quickly and accurately generated and, through interfaces, can be sent to applications programs, such as aerodynamics and structures for detailed analyses. Realistic color pictures of configurations can be generated. For example, the figure shows a Shuttle orbiter produced by the SMART program.

To provide this capability, SMART was developed with the following features: analytical surface descriptions, bicubic Bezier patches, are used to provide accuracy and completeness; an effective user interface makes the system easy to learn and convenient to use; geometry generation techniques tailored to aerospace applications are provided; and interface to other analysis programs through the LaWGS (Langley Wire-frame Graphics Standard) system is available; and the advanced graphics hardware of the Silicon Graphic IRIS workstation allows geometry generation, modification, and manipulation in real time.

After 1 1/2 years of development, SMART has entered production use. It has been applied with great success to the National Aero-Space Plane (NASP) Program. A number of complex configurations have been generated. The geometries for these configurations have been successfully transferred from SMART to structural analysis and computational fluid dynamics program.

J. J. Rehder
RTOP: 506-49-11-01



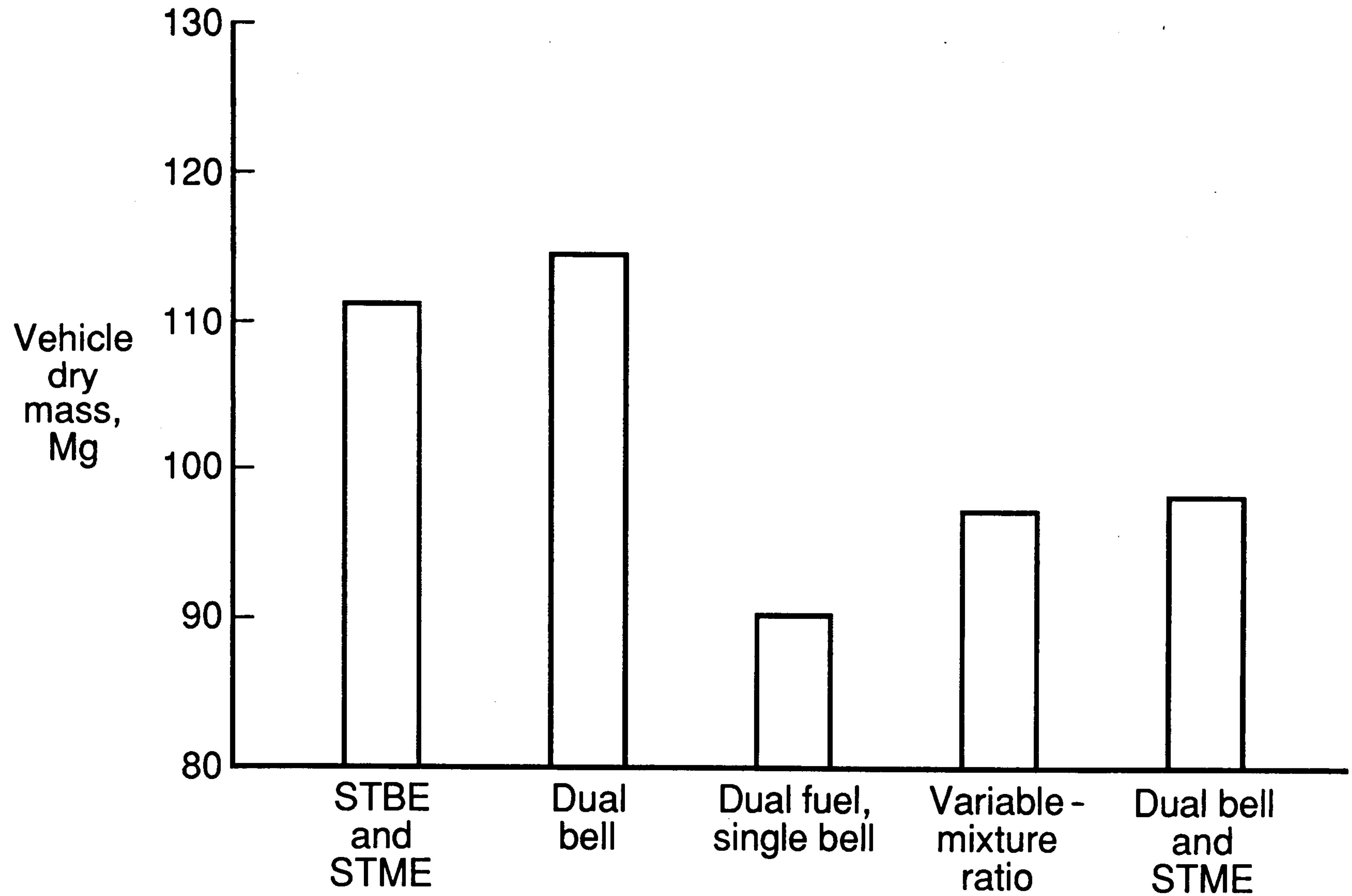
Shuttle orbiter produced by the SMART program.

Engine Selection for Advanced Earth-to-Orbit Vehicles:

Studies are currently under way at major rocket engine companies that could lead to the development of new engines for the next generation of Earth-to-orbit vehicles. These vehicles include unmanned heavy-lift vehicles that might be partly reusable as well as fully reusable Shuttle II concepts. The baseline efforts are directed toward a hydrocarbon engine for the boosters called the Space Transportation Booster Engine (STBE) and a hydrogen engine for the upper stages called the Space Transportation Main Engine (STME). These baseline engines (STBE and STME) have been selected such that they can be developed relatively quickly with existing technology. In addition to the baseline engines, other designs are being considered which might improve the vehicle even though they might require some technology development. The conceptual design analyses performed at Langley Research Center have incorporated results from these studies (directed by Marshall Space Flight Center) to show the effect of these advanced engines on single-stage vehicles with vertical takeoff and horizontal landing.

The figure shows that the baseline engines can be used in a parallel-burn dual fuel vehicle, and theresulting vehicle dry mass would be 111 Mg for a payload of 13.6 Mg. The best advanced engine, called the dual fuel, single bell engine, could reduce the vehicle dry mass about 20 percent, to 90 Mg. In addition, only one engine would need to be developed. Another concept, the variable mixture ratio engine, could reduce the vehicle dry mass and also simplify the operations because only one fuel, hydrogen, would be needed. A third concept, the dual bell engine, could be used by itself, but the results showed that the vehicle dry mass would be increased with this approach. Using this engine with the STME provided some improvement. The dual bell concept could also be applied to the STME for additional improvement, or it could be applied to the dual fuel, single bell engine. Overall, these results have shown that there are improved engine concepts that should be considered before beginning full-scale development of the next generation of rocket engines.

J. A. Martin
RTOP: 506-49-11-02



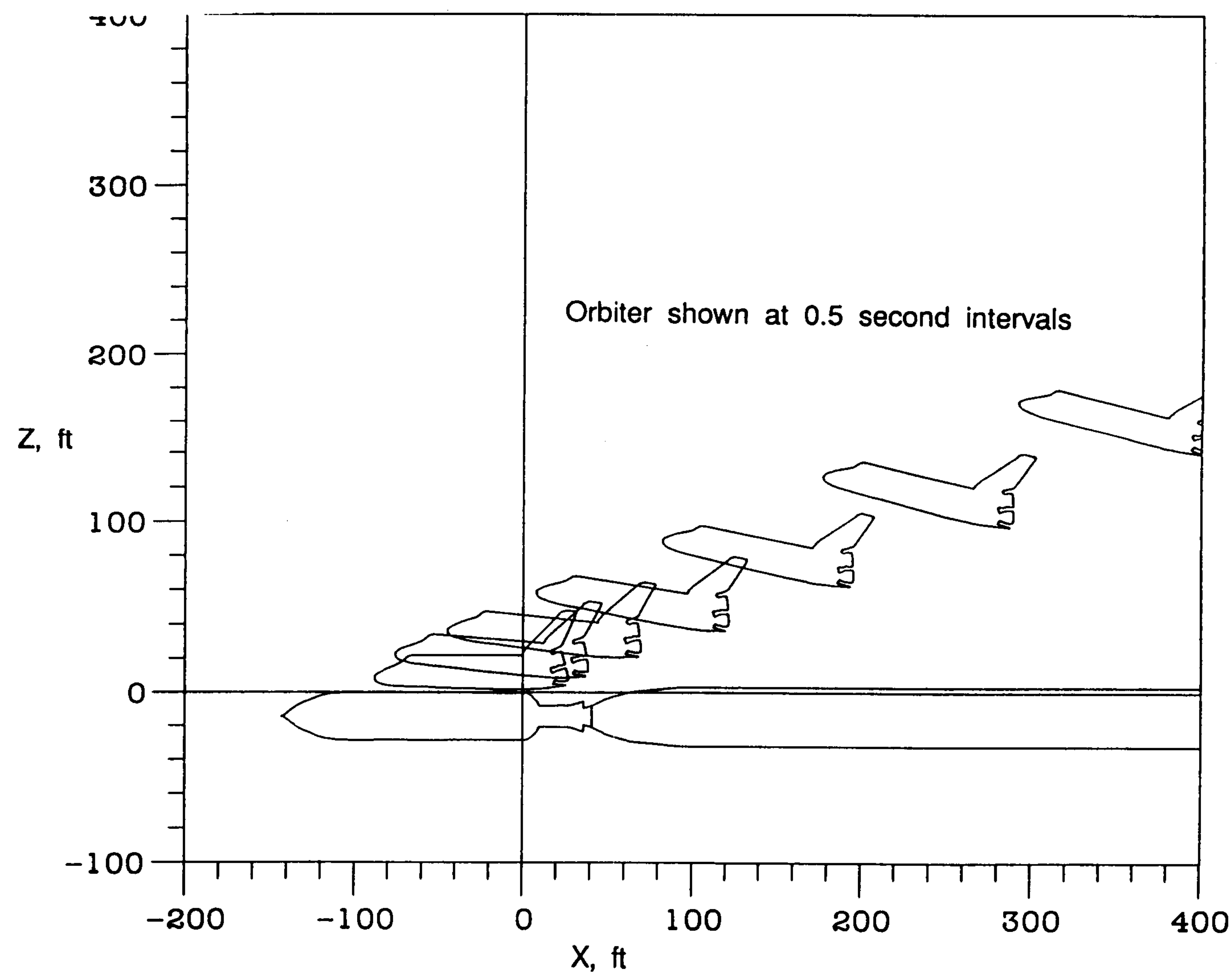
Effect of engine selection on dry mass of single-stage-to-orbit rocket vehicle.

Shuttle Abort Simulations:

A study has been conducted to evaluate the feasibility of aerodynamic separation of the Shuttle orbiter from the external tank (ET) and solid rocket boosters (SRB's) while the SRB's are thrusting. Separation trajectories were modeled using starting points from a nominal ascent trajectory. A multibody, six-degree-of-freedom computer program was used to simulate the trajectories. This computer program was originally developed in 1969 for use on Space Shuttle configuration studies and had been archived in the early 1970's. The program required many modifications before it was suitable for this separation study. Two of the major modifications involved the addition of a control algorithm for the orbiter and the addition of an aerodynamic data base consisting of wind-tunnel data. The initial wind-tunnel data incorporated into the separation simulation were from the Calspan 8-Foot Tunnel tests and covered the Mach number range of 0.6 to 1.25. A wind-tunnel test in the Marshall Space Flight Center (MSFC) 14-Inch Tri-Sonic Tunnel yielded data that were used to assess the orbiter wing loads during the separation maneuvers and to establish angle-of-attack limits.

Analysis of results from Mach numbers of 0.6 to 1.25 indicates that aerodynamic separation may be feasible, but hardware and software modifications would be required. In this Mach number range, the Shuttle is at negative angles of attack. For favorable separation forces to occur, the forward strut must be released first, and then after the orbiter has rotated to a positive angle of attack, the aft strut is released. The figure demonstrates a separation trajectory at maximum ascent dynamic pressure. In this case, the orbiter has rotated approximately 5° about the aft strut before release. The orbiter then separates from the ET/SRB combination without violating the angle-of-attack constraints set by the wing load limits. Both the forward and aft struts, as well as the orbiter control system, would have to be modified. (Additional studies are underway and must be completed before a final recommendation can be made.)

J. C. Naftel
RTOP: 551-15-01-04



Mach 1.25 separation trajectory.

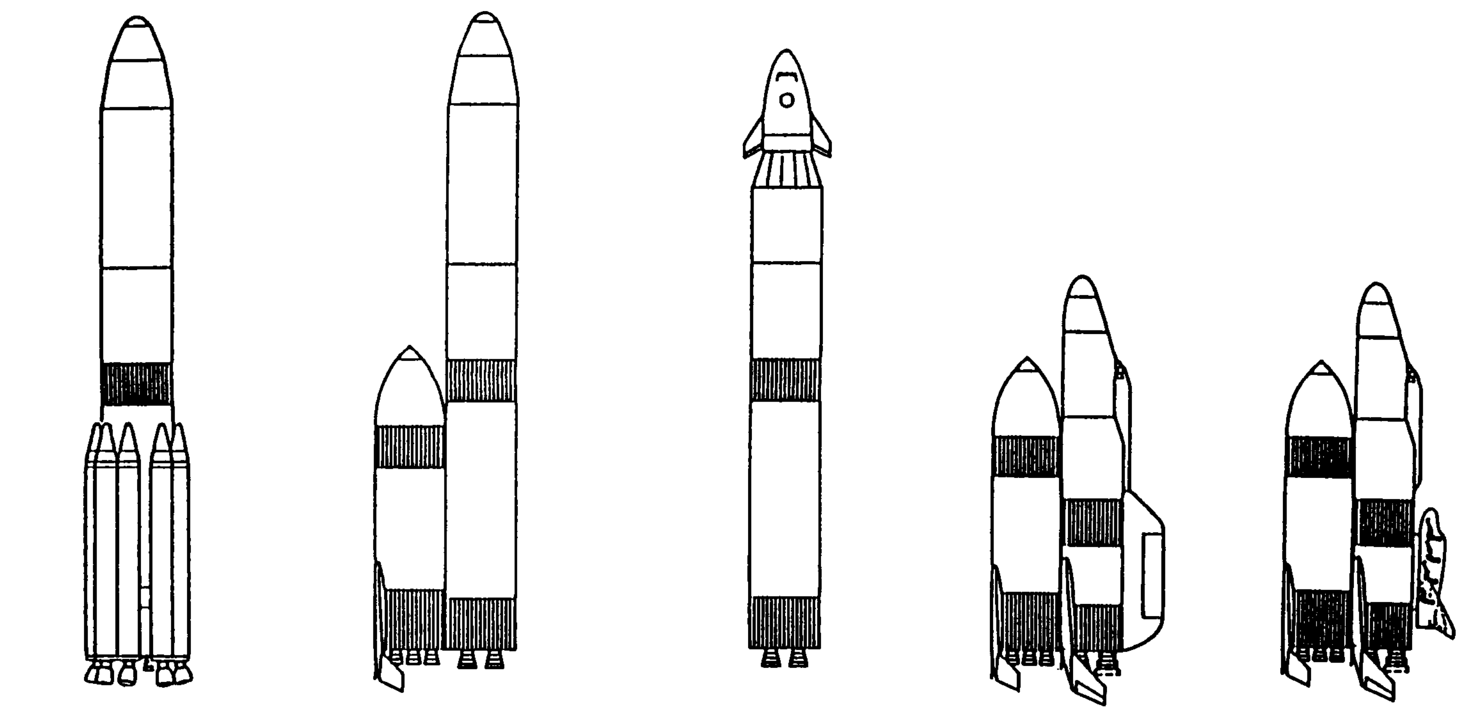
Launch Vehicle Architecture Study:

Expansion of man's activities into space over the next several decades will require routine, low-cost, reliable space transportation. In the future, a multi-vehicle approach will be used whereby unmanned cargo vehicles deliver heavy payloads to orbit, and small manned vehicles perform the man-critical missions. The challenge is to develop a set of vehicles, or architecture, that is not only effective from a life-cycle cost viewpoint but can also enhance this nation's launch capabilities in a timely manner.

The NASA Langley Shuttle II Study has examined characteristics and technologies associated with a future-generation manned launch system. Assuming a development cycle initiated in the early 1990's and evolutionary technology advancements, a two-stage vertical take-off rocket system was selected for further in-depth studies. This concept, with its unmanned booster element, lends itself well to the multi-vehicle phased-approach architecture pictured.

Under study is a liquid hydrogen (LH2)/liquid oxygen (LOX) propelled core stage which, combined with solid rocket augmentation, can lift payloads of up to 100,000 lb to orbit. Later incorporation of the Shuttle II glideback booster element, using methane propulsion, increases the core-stage lift capacity to 150,000 lb and reduces launch costs. Manned access to space in the early years of the Space Station is assured with a small, interim manned vehicle that complements the Space Shuttle and is also flown on the core stage. The fully resuable Shuttle II orbiter would become available around 2005 and carry payloads in easily processed canisters. For passenger transport, the interim manned vehicle would replace the canisters and provide the added advantage of an independent launch escape capability.

T. A. Talay
RTOP: 906-65-01-01



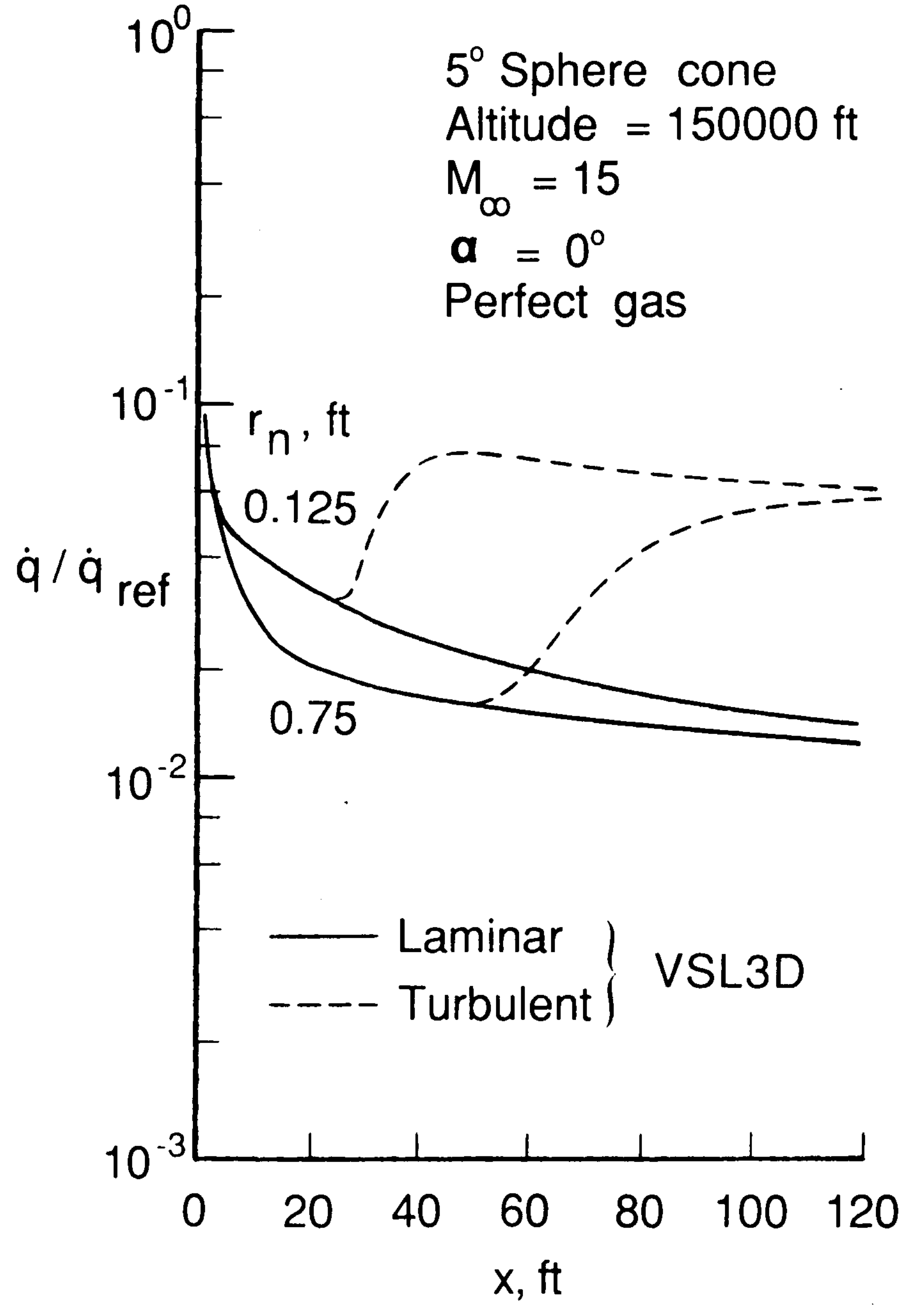
Space transportation architecture phased approach.

Aerothermodynamic Study of Slender Conical Vehicles:

Recent interest in transatmospheric vehicles and the National Aero-Space Plane (NASP) has renewed the need for development and verification of prediction techniques which may be used to analyze the viscous hypersonic flow over slender vehicles. Consequently, a study was initiated to investigate the applicability of several existing techniques for the slender body aerothermal problem. These techniques ranged in complexity from finite-difference solution of the three-dimensional viscous-shock-layer equations (VSL3D) to approximate "engineering" type analyses. Using these techniques, comparisons were made between predicted results and flight and wind-tunnel data, for both laminar and turbulent flow and perfect gas and equilibrium air chemistry. Comparisons of the predicted heat-transfer rates with flight data from the Reentry F vehicle showed the method to be generally accurate; however, some deficiencies in the engineering techniques were noted, particularly at angle-of-attack conditions.

As a second part of this study, these codes were used to illustrate the effects of nose bluntness and angle of attack on the heat transfer, transition onset, and zero-lift drag coefficients for a slender cone at a free-stream Mach number (M_∞) of 15. Those results showed the quantitative benefits of increased nose bluntness, which resulted in decreased local heat transfer rates and overall heat loads, and delayed boundary-layer transition. Total vehicle drag was not adversely affected by increasing nose radius (r_n) for the laminar case and was decreased for the turbulent condition, using the given transition model. The figure shows the nondimensional heat-transfer rates ($\dot{q}/\dot{q}_{ref}$) versus axial distance from the nosetip (x) at 0° angle of attack (x) for bodies with different nose radii (r_n) for both laminar and turbulent flow.

R. A. Thompson
RTOP: 506-40-11-01



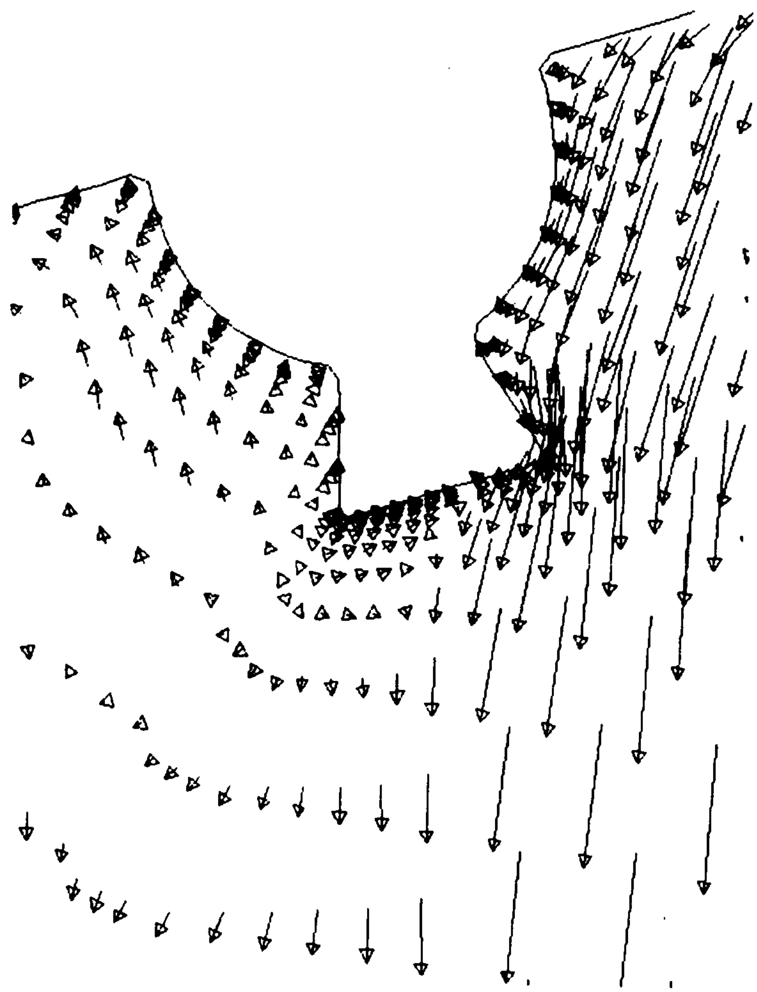
Nose radius effects on heat transfer to slender cones in hypersonic flow.

Near-Wake Flow Field Over Aeroassist Flight Experiment (AFE) Vehicle:

Program LAURA (Langley Aerothermodynamic Upwind Relaxation Algorithm) has been used to calculate the complete flow field about the Aeroassist Flight Experiment (AFE) vehicle at a single trajectory point. This study is the first attempt at defining the near wake flow field over a close approximation to the actual AFE geometry. Both perfect-gas and chemical nonequilibrium (single temperature, no species dissipation) assumptions have been used. The results demonstrate the present capabilities and limitations of the LAURA algorithm.

The Symmetric Total Variation Diminishing (STVD) algorithm used in LAURA has been demonstrated to be robust for the simulation of the near wake flow field behind the AFE at a flight trajectory point using perfect-gas assumptions. Calculations on two different grids at the same trajectory point have given consistent predictions of flow field phenomena. Calculations at two different Reynolds numbers exhibit the correct phenomenological trends. Of particular interest is the prediction of a strong flow impingement on the lip of the AFE rocket nozzle and of the correspondingly high heating rates at that location. This impingement is evident in the symmetry-plane mapping of velocity vectors computed for a flight condition of Mach number (M_∞) equal to 32 and Reynolds number ($Re_{\infty,D}$) equal to 79000, at the design angle of attack (see figure). A survey of local Knudsen number throughout the flow field indicates that a continuum analysis is generally well founded, but there are isolated regions in the near wake close to the body where, at a minimum, slip conditions should be imposed, and possibly continuum results are in error at the maximum dynamic pressure trajectory point. The higher densities associated with real-gas flows relax this restriction on the continuum analysis.

P. A. Gnoffo
RTOP: 506-40-11-02



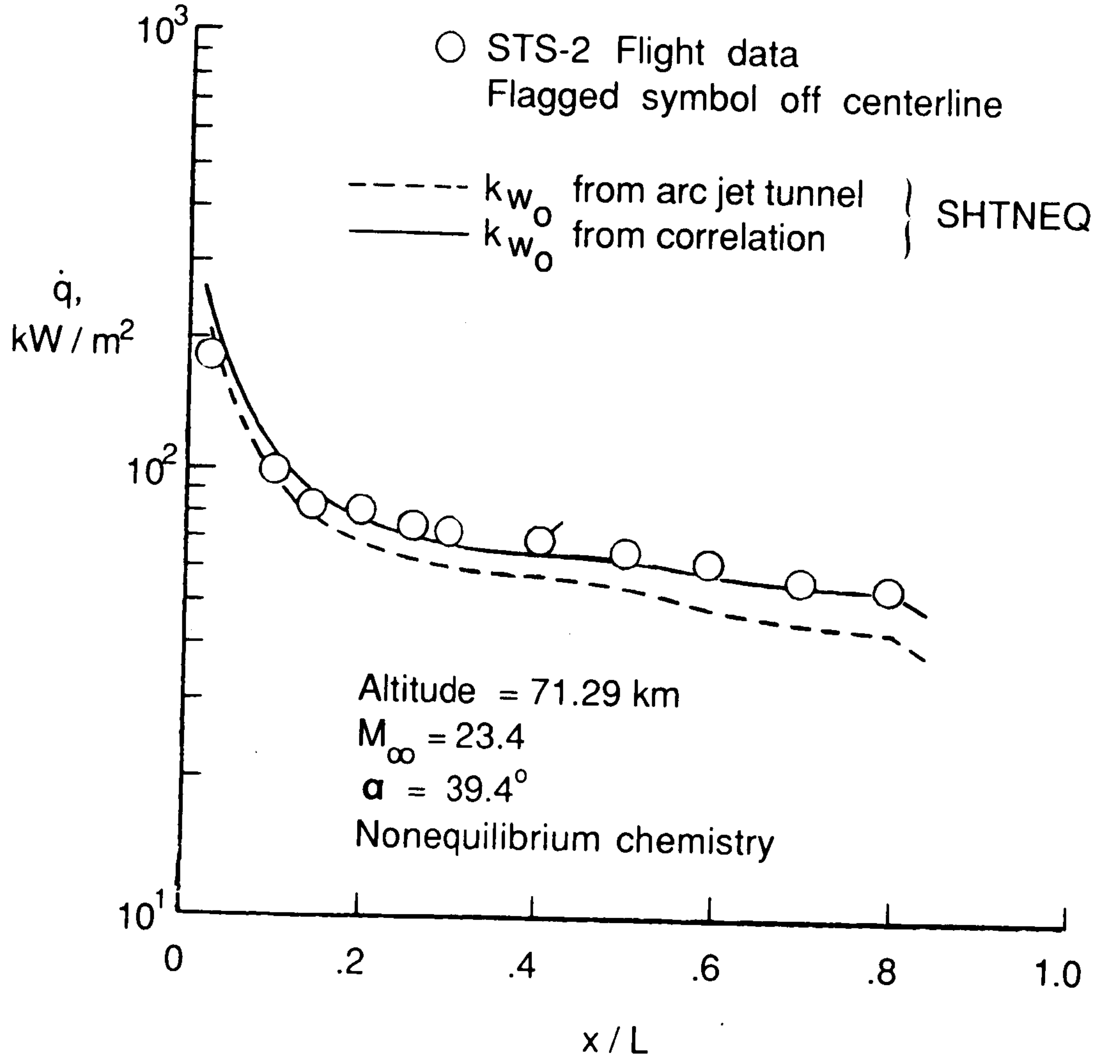
Velocity vectors in the near-wake plane of symmetry of the AFE vehicle.

Calculation of Three-Dimensional Nonequilibrium Viscous Flow Over Shuttle Windward Surface:

A three-dimensional viscous-shock-layer code has been used to compute the nonequilibrium flow field over the windward surface of the Shuttle orbiter for reentry conditions between 75 and 60 km. The computer code used for this work (SHTNEQ) was originally developed under grant from Langley and solves the full set of viscous-shock-layer equations and coupled reaction equations to model the nonequilibrium chemically reacting flow of air over the Shuttle surface. Modifications made to the program have been found to significantly improve its accuracy and applicability. Comparisons of present predictions of surface heat transfer with previous results show differences of 30 percent, and the new results demonstrate that three-dimensional effects on the Shuttle windward centerline heat-transfer distribution are not as significant as previously reported.

Windward symmetry plane and off-centerline heating predictions obtained with the code have been compared with experimental data from flights STS-2 and STS-3. Different surface recombination rates for oxygen, to account for the catalyticity of the Shuttle tile surface, have been considered in the predictions. Those results show that a recent correlation for oxygen recombination provides good agreement between predicted heat transfer and that measured in flight. Typical results for heat-transfer distribution ($\dot{q}$) as a function of normalized distance (x/L) along the Shuttle windward centerline are shown for an altitude of 71.29 km and free-stream Mach number (M_∞) of 23.4. Angle of attack (α) for this case was 39.4°. The two predicted heat-transfer distributions were obtained using the different oxygen recombination rates (k_{w_O}) as noted. Comparisons of heating predictions with flight data in the crossflow direction have also been made and show good agreement for the regions computed. Trends in the measured crossflow heating distributions are generally predicted with the three-dimensional viscous-shock-layer code.

R. A. Thompson
RTOP: 506-40-11-03



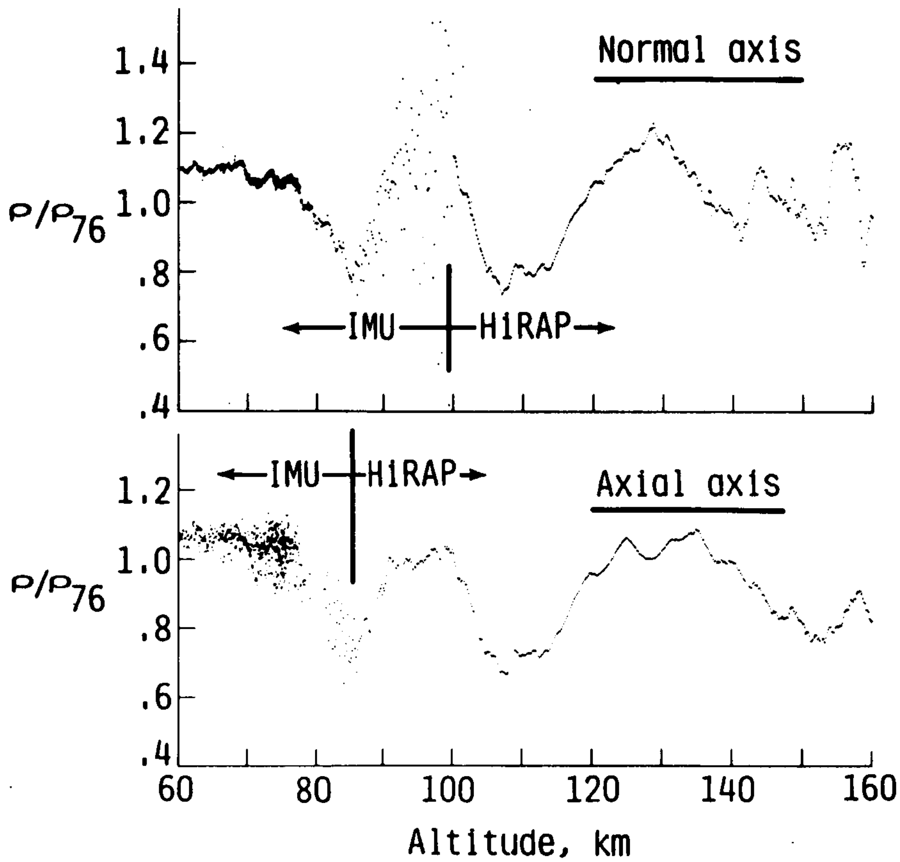
Measured and computed heat-transfer rates in the windward symmetry plane of the Shuttle orbiter.

In Situ Upper Altitude Density Measurement
From Shuttle Orbiter Accelerometry:

A Shuttle orbiter experiment, the High Resolution Accelerometer Package (HiRAP), provides a new and unique source of measurements of atmospheric density. The HiRAP experiment is a triaxial set of high-resolution accelerometers which measure the aerodynamic deceleration rates of the orbiter during the high-altitude portion of its atmospheric entry. By comparing these measured vehicle responses to aerodynamic forces with the aerodynamic characteristics of the orbiter, the atmospheric density may be inferred. Aerodynamic models for both the normal and axial aerodynamic components are used in the density extraction process. Data taken on 10 flights of two instrumented Shuttle orbiters (OV-102 and OV-099) have provided density measurements of unusual character. The uniqueness of the measurements resides in the fact that the orbiter enters the atmosphere nearly horizontally because of its shallow reentry flight path angle. The ratio of the orbiter's ground-track distance to descent distance is about 80:1 for each mission. This horizontal component of the atmosphere is rarely, if ever, obtained by sounding rockets, since they traverse relatively short down track distances and are essentially limited to taking vertical atmospheric soundings. Orbiting satellites, on the other hand, can provide the same type of measurements but cannot enter the region of the atmosphere from 80 km to 130 km.

The inferred density data shown are normalized to the 1976 U.S. Standard Atmosphere so that deviations can be readily observed. The HiRAP data have been merged with data derived from the orbiter's Inertial Measurement Unit (IMU) to extend measurements to lower altitudes. As seen from the figure, undulations in density on the order of 30 percent appear in both channels of data and are typical for all 10 flights examined to date. It is believed that this wave-like feature is atmospheric in origin. Unlike the orbiter, future vehicles (e.g., aeroassisted orbital transfer vehicles and the National Aero-Space Plane) which will spend more time in the upper atmosphere may have to account for these density variations in various subsystems design, such as guidance and control.

R. C. Blanchard
RTOP: 506-40-11-03



Atmospheric density derived from STS-6 Shuttle orbiter accelerometry.

Modeling Space Radiation Effects:

In the approaching era of career astronauts and space workers who may spend significant periods of time in space, knowledge of galactic cosmic ray (GCR) interaction and transport in bulk matter is needed to accurately analyze requirements for shielding astronauts and spacecraft components from this radiation. Of particular interest is the high-energy heavy ion (HZE) component of the incident space radiation spectrum. As these high-velocity nuclei strike the spacecraft, they undergo nuclear fragmentation (breakup), and these fragmented particles may then undergo further interactions with the vehicle structure and components and also with the bodies of the astronauts. Accurate methods to describe the transport of these HZE particles through bulk matter are under development at NASA Langley.

Solution of the HZE transport problem requires solution of many (~100) coupled, partial differential-integral equations in six-dimensional space. Ultimately, one faces the task of assuring the accuracy and validity of both the equation coefficients and the solution techniques. Ideally, validation should be accomplished using detailed transport data obtained from carefully planned and controlled experiments; unfortunately, only a paucity of such data exists and the actual conditions are almost impossible to model experimentally. Although useful for comparison purposes, the atmospheric propagation measurements used previously are clearly not definitive since they consist of integral fluences of as many as 10 different nuclear species represented by a single datum. Although limited quantities of HZE dosimetry measurements from manned space missions (e.g., Skylab) are also available, numerous assumptions concerning the relationships between dosimeter locations and spacecraft shield thicknesses and geometry must be made in order to estimate astronaut doses using GCR codes. Since many of these assumptions involve inherently large uncertainties (a factor of two or greater), it becomes difficult to attribute sources of any comparison differences to particular assumptions or approximations which may have been used in the analyses. In the absence of definitive GCR transport measurements with which to compare code predictions, other methods of validation must be considered.

There are several different versions of HZE transport codes available. When used with the same input spectra, interaction parameters, and boundary conditions, all should yield comparable results. The history of transport code development, however, suggests otherwise. For this reason, Langley has developed a realistic, nontrivial, exact, analytic solution to the simplified Boltzmann equation used to describe HZE transport. This solution will serve as an absolute standard for code comparison purposes. Comparison between the analytic solution and the LaRC transport code is given in Table 1. The agreement is everywhere within 1 percent.

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TABLE 1

Comparison of the Benchmark Numerical Simulation to the Analytic Solution for Secondary Manganese Ions as a Function of Ion Energy and Depth into the Aluminum Absorber.

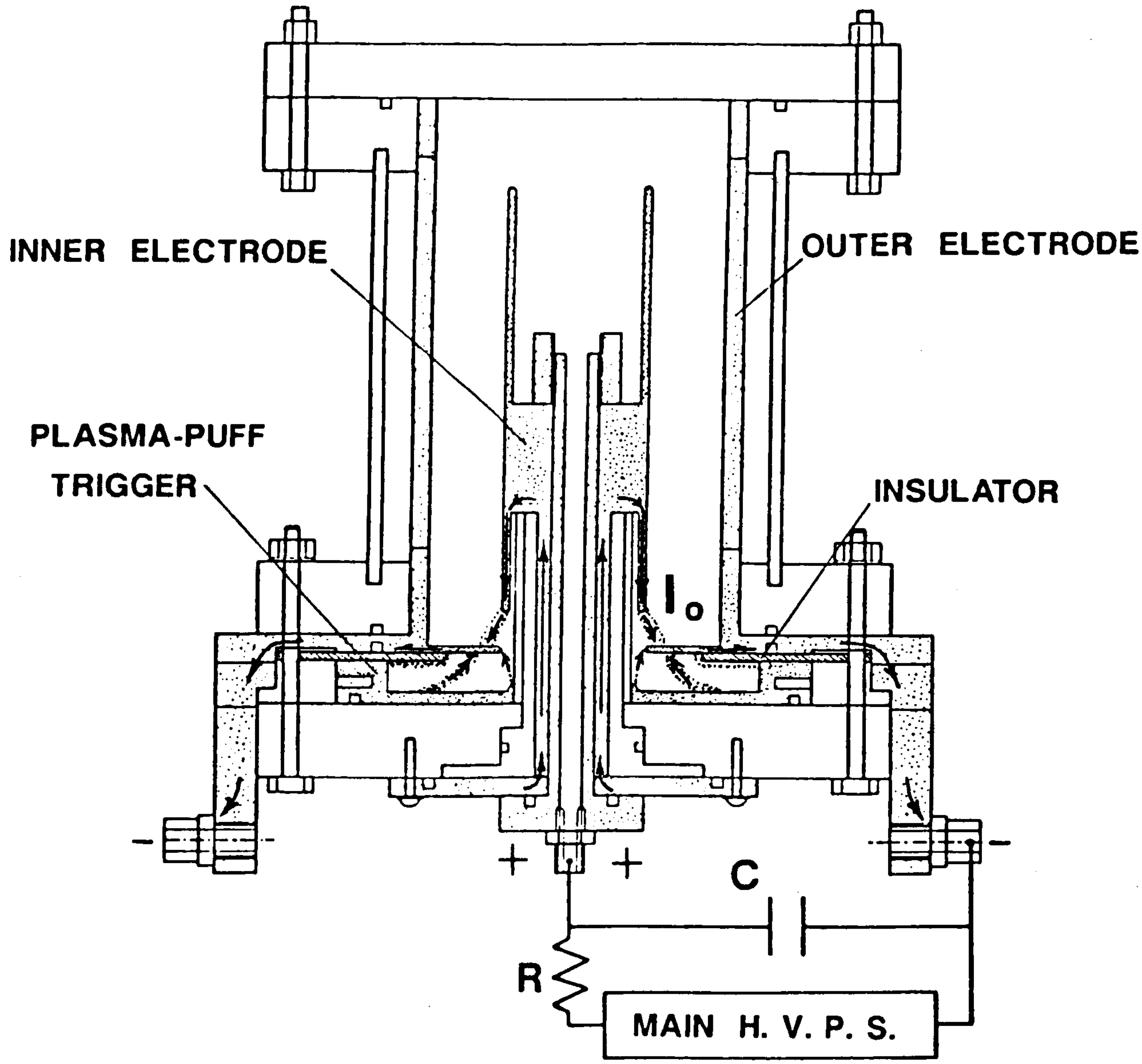
Energy, MeV/amu	Mn Flux at 10 g/cm^2		Mn Flux at 20 g/cm^2	
	Numerical	Analytic	Numerical	Analytic
.0198	1.772E-6	1.780E-6	5.704E-7	5.768E-7
.1147	1.772E-6	1.7780-6	5.704E-7	5.768E-7
1.090	1.772E-6	1.779E-6	5.704E-7	5.767E-7
10.07	1.767E-6	1.771E-6	5.696E-7	5.753E-7
100.1	1.504E-6	1.503E-6	5.242E-7	5.291E-7
1059.	7.797E-8	7.806E-8	6.880E-8	6.918E-8
10490.	7.004E-10	7.004E-10	8.728E-10	8.728E-10

A Long-Life, High-Power Plasma Switch:

The requirements for a high-power plasma switch are, in general, fast risetime, high-current handling capability, fast recovery time (which affects the repetition rate), fast thermal energy dissipation, reduction of component damage, and high hold-off voltage. In addition, a switch requires a long duty cycle with consistent switching action.

A novel inverse-pinch plasma switch for closing has been designed and tested with respect to the above requirements. An azimuthally uniform initiation of breakdown is a key factor that is necessary to realize the inverse-pinch current path. Recently this has been successfully achieved by injection of a plasma ring (plasma puff) which is produced separately in a hypocycloidal-pinch geometry. The figure shows the cross section of the plasma switch with the plasma-puff trigger. The plasma-puff trigger electrode placed under the cathode (-) is energized by a secondary power supply which is not shown. The arrows show the paths of the currents at switch closing. The results show that the local charge density transfer is significantly reduced, and thus damage to the electrodes and insulator surfaces is minimized. With a typical peak current achieved in the experiment of 333 kA at a hold-off voltage of 14 kV and a fill gas pressure of 1.3 Pa, charge density transfer on the electrode surface was approximately 34 coulombs/m^2. For a conventional spark-gap switch with the same operating conditions, the charge density transfer would have been 7×10^5 coulombs/m^2. Therefore, the electron bombardment on the inverse-pinch electrode is four orders of magnitude less than that of the spark-gap switch. Since the local heating is approximately proportional to the charge density transfer for a given time, the heating of the electrode of the inverse-pinch switch is also four orders of magnitude less than that of a conventional spark-gap switch. This translates directly to a long switch life ($>10^9$ pulses). Indeed, a few thousand shots with the peak currents over a mega-ampere level and a hold-off voltage up to 20 kV have been conducted without showing measurable damages on the electrodes. The long useful life projected from these results indicates the plasma switch is suitable for high pulse-power delivery systems in space. Potential applications include timed-pulsed power delivery to a hypersonic real-gas test facility for spacecraft entry studies, powering magnetoplasmadynamic thrusters, powering electromagnetic launches for advanced aerospace transportation, and components in pulsed-power systems for airborne and spaceborne high-power lasers.

J. H. Lee
RTOP: 506-41-41-02



Inverse-pinch switch with plasma-puff trigger.

Atomic Oxygen Beam Generator:

The combination of a spacecraft's orbital velocity with the composition of the atmosphere at orbital altitude (200 to 1000 km) results in hyperthermal atomic oxygen (O) impinging on the spacecraft surfaces with a flux of 10^{15} cm^{-2}-sec^{-1} and a kinetic energy (E) of approximately 5 eV. The high chemical reactivity of this O-atom flux has caused substantial degradation of organic materials aboard the Space Shuttle and suggests that materials on the proposed Space Station, composites used in large space structures, exterior coatings on the optics of the Hubble Space Telescope, proposed ultraviolet telescopes, and future laser communications systems may have substantially reduced lifetimes. It is therefore essential to study the reactivity of these materials toward atomic oxygen in ground-based laboratories.

A promising approach for developing a laboratory atomic oxygen gun to simulate the orbital condition involves the use of two unique phenomena: the unusally high permeability of oxygen through silver and electron stimulated desorption (ESD). Normally, when the O atoms arrive at the vacuum interface, surface diffusion occurs and results in coverage of the surface with a chemisorbed layer of atoms (<500°C). By using an incident flux of low-energy electrons (100 to 500 eV) upon this surface, the O atoms are excited to antibonding states and desorb predominantly as hyperthermal O neutrals with energies $2 < E < 6$ eV.

Results of laboratory experiments have demonstrated proof of this concept and have shown that oxygen transport through the silver membrane proceeds via the grain boundaries. Present research efforts are centered around minimizing the silver grain size to increase the atomic oxygen flux levels to 1×10^{15} cm^{-2}-sec^{-1}, thus providing a close approximation to orbital conditions. Applications of this technique include mass spectrometer calibration, surface physics, chemical kinetics, as well as materials degradation.

R. A. Outlaw
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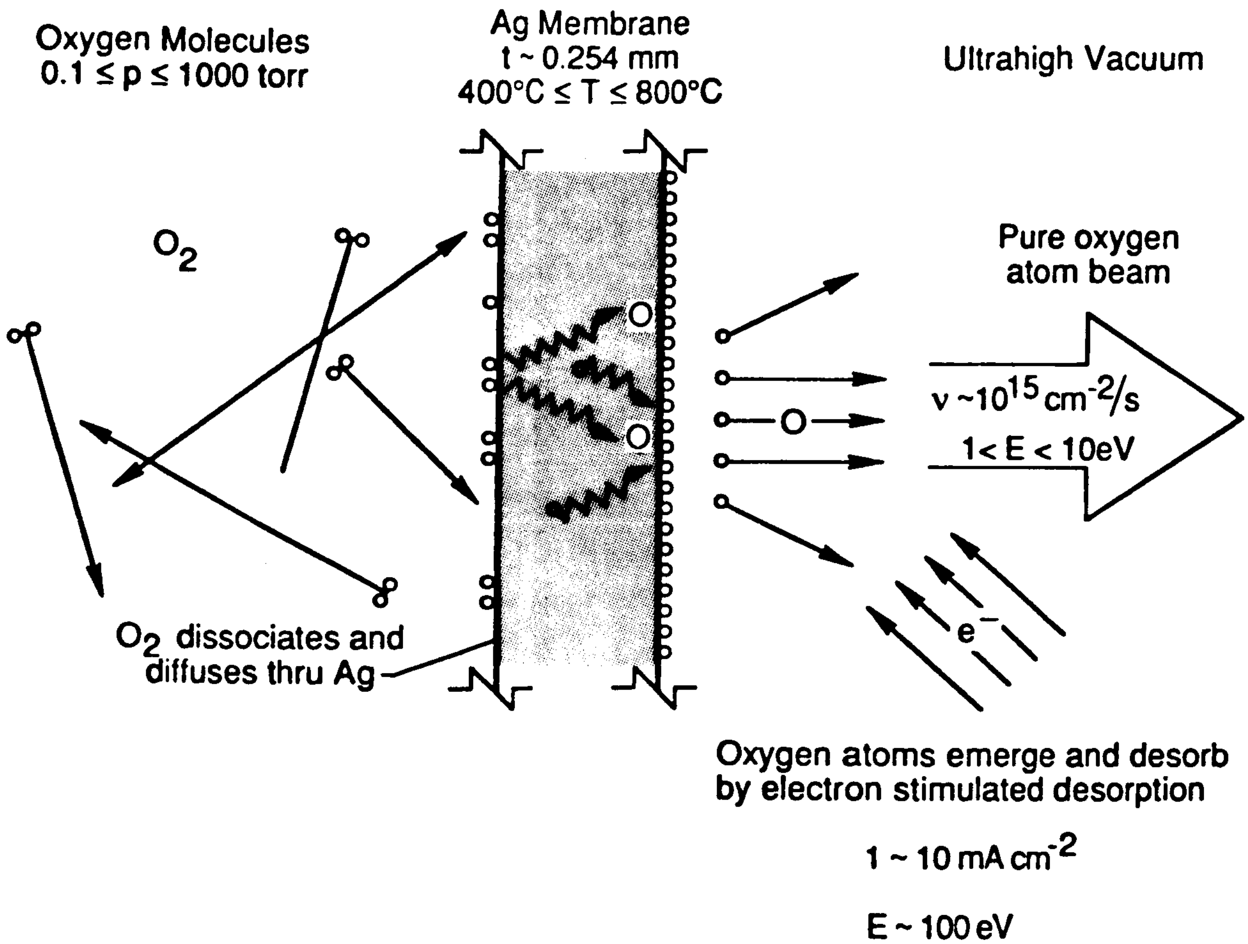

Oxygen dissolves in the silver, permeates the membrane, and is desorbed by electron stimulated desorption to produce the atomic oxygen beam.

Q-Switched Solar-Pumped Iodine Lasers:

Research on solar-pumped lasers was initiated in 1980 for the purpose of evaluating their feasibility as space-to-space power transmitters. For example, space laser power transmitters placed on a high-altitude orbiting power station can transmit power to a low-altitude satellite with space manufacturing factories. Such transmitters require at least 1 MW output to be practical. Most laser power receivers are designed for continuous wave (CW) power reception; however, other important applications (including laser propulsion) are better suited for pulsed power sources.

One pivotal technology receiving detailed study involves the use of sunlight to directly pump a gas laser. Significant progress was achieved over several years with photodissociation iodine lasers using an organic-iodine lasant and a solar-simulator. Since the first solar-pumped lasing was achieved in 1980, the output power levels of iodine lasers increased from less than 1 MW pulsed to 10 W CW, which is the highest CW power ever achieved with photodissociation iodine lasers (reported in Langley R&T 1986).

Recently the peak laser power was boosted by more than an order of magnitude by adapting a Q-switching technique to the CW system. Q-switching is a method for generating high-power laser pulses at high repetition rates by depositing large quantities of energy in very short time increments before loss mechanisms can begin to operate. For this experiment, Q-switching was accomplished by placing a fast mechanical chopper in the laser cavity. The popular Q-switching method, Pockels cell, cannot be used because of the intolerable insertion loss at the 1.3 micrometer laser wavelength. A train of high power (up to 150 W) laser pulses was continuously produced at various repetition rates while the solar simulator, a Vortek argon arc, pumped the laser medium at steady optical power. This is the first reported Q-switching of CW iodine lasers. By this method, the highest-ever laser power for solar-pumped gas lasers was achieved. The flow of the laser medium, n-C_3F_7I vapor, was longitudinal and maintained by the pressure differential between an evaporator and a liquid-nitrogen-cooled condenser. The dependence of CW and Q-switched laser power on parameters such as iodine vapor pressure, gas flow rate, and chopping speed was determined and analyzed.

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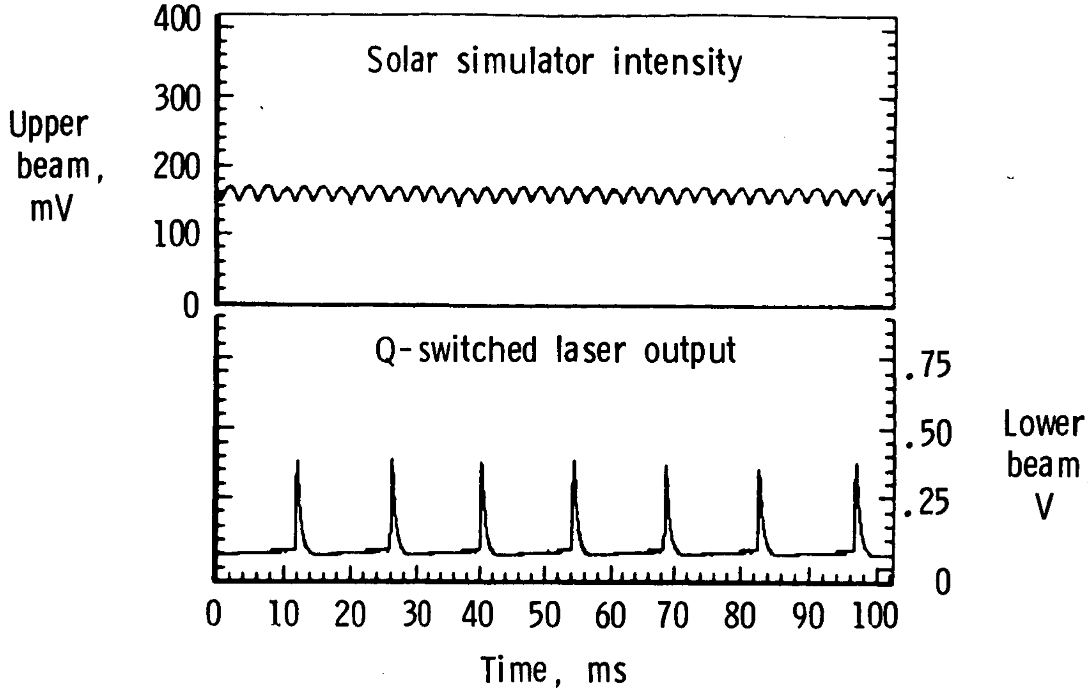
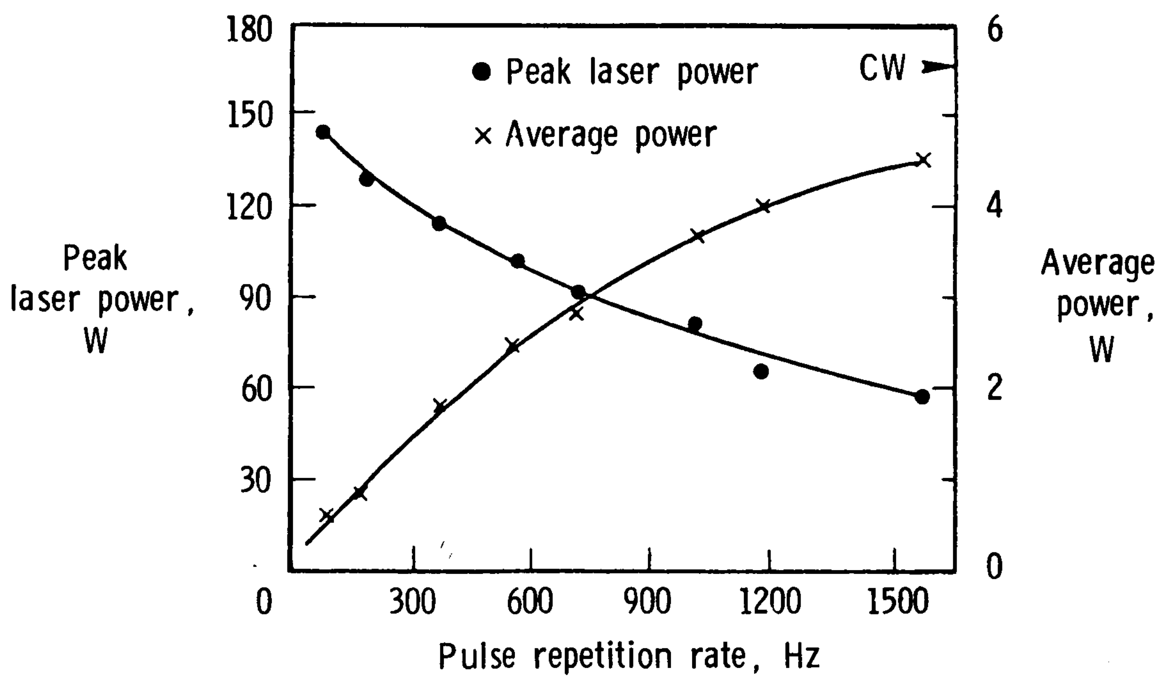
RTOP: 506-41-41-01





Solar-simulator pumping intensity and Q-switching iodine laser output signals (top), and peak laser power versus pulse repetition rate.

A Transportation Base Space Station for 2025:

The current Space Station reference configuration, scheduled for service in 1994, will be required to function in many capacities, including orbiting laboratory, satellite servicing facility, experiment platform, orbiting construction site, and orbital maneuvering vehicle (OMV) and orbital transfer vehicle (OTV) base. Future transportation demands, however, would quickly overwhelm the Space Station as Shuttle, Shuttle-derived vehicle, and OTV traffic increases. A fully dedicated transportation base Space Station would be the most efficient method to meet the transportation needs of the 21st century.

The figure shown is one concept of a fully dedicated transportation base Space Station operating in low Earth orbit. The concept has been developed with the IDEAS[2] conceptual design software and features four docking ports for Shuttle-type vehicles as well as four large enclosed hangars. These hangars would support OTV servicing, repairs, and storage as well as satellite servicing and repair, including refueling operations. The large truss structure would serve as a bay for the construction of large space structures and for the assembly of Mars, lunar, and interplanetary vehicles, thereby adding the function of a staging base to the station.

With the development of this concept, additional studies will be initiated, such as interfaces with current and future transportation concepts and associated propellant requirements. The various subsystems will be sized and a mission scenario will be developed. On-orbit performance will be evaluated and technology advancement requirements will be defined. Alternate concepts may also be developed in order to assess the relative merits of each.

A. Don Scott
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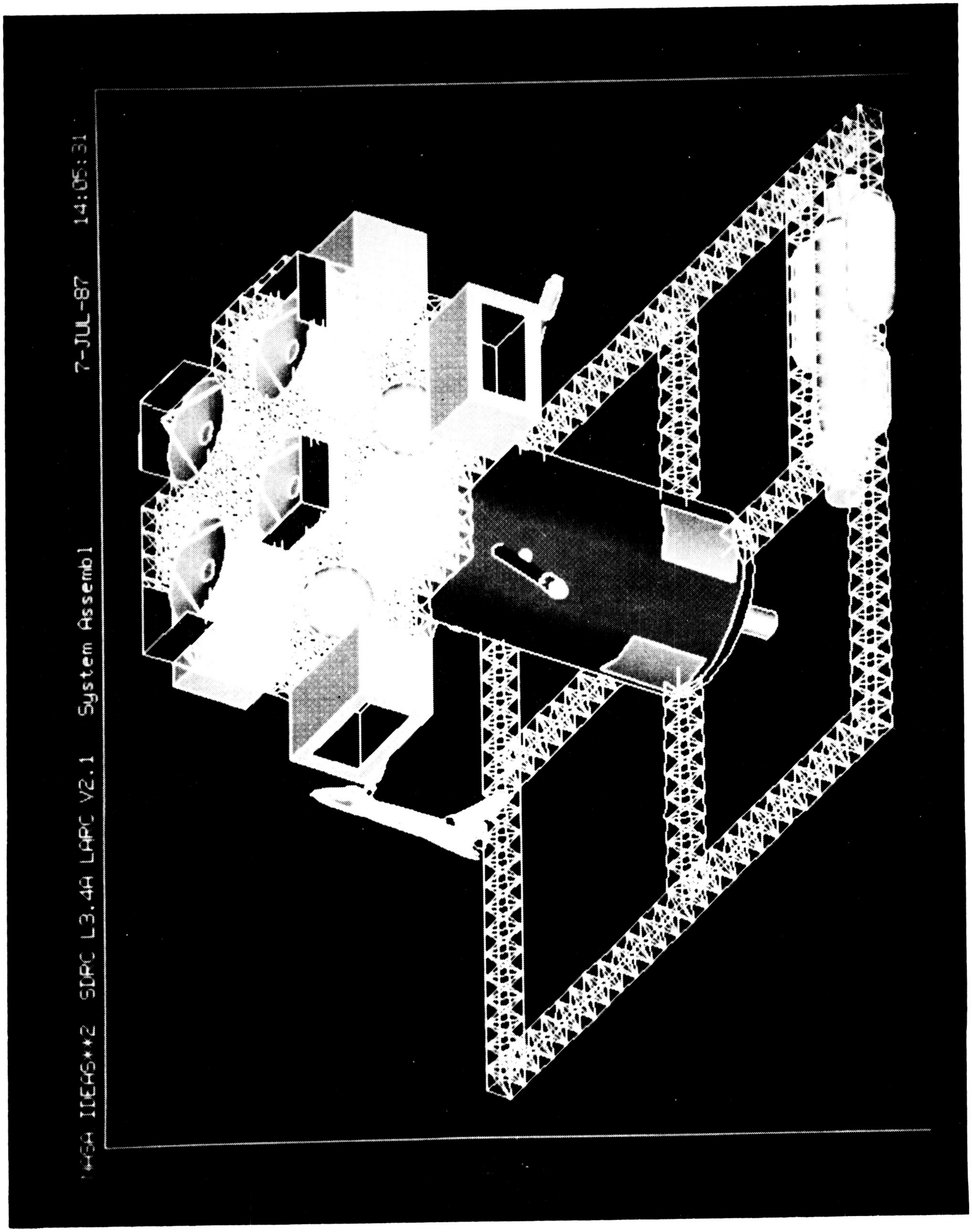

A transportation base Space Station concept.

Conceptual Design of a Lunar Base Thermal Control System:

Space Station and advanced development thermal control technologies were evaluated for lunar base applications. The Space Station technologies consisted of single-phase pumped water loops for heat removal from the internal environment of the manned section and two-phase ammonia loops to transport and reject these heat loads to the external environment. Alternate advanced technologies were identified for those areas where Space Station technologies proved to be incompatible with the lunar environment. Areas were also identified where lunar resources could enhance the thermal control system. The internal acquisition subsystem essentially remained the same, but modifications were needed for the transport and rejection subsystems because of the extreme temperature variations on the lunar surface.

The alternate technologies examined to accommodate the high daytime temperatures incorporated lunar surface insulting blankets, refrigeration systems, shading, and lunar soil. Other heat management techniques, such as louvers, were examined to prevent the radiators from freezing during the low lunar nighttime temperatures. The impact of the geographic location of the lunar base and the orientation of the radiators was also examined. Trade studies were performed to generate an optimum baseline design which minimizes weight, power, volume, and maintainability.

Using lunar soil as insulation can greatly simplify the passive thermal control, and permanently shaded regions greatly simplify the transportation and rejection of heat. However, the extreme temperature variations at the equatorial and mid-to-upper latitudinal regions of the moon complicate the thermal rejection design.

L. C. Simonsen
M. J. DeBarro
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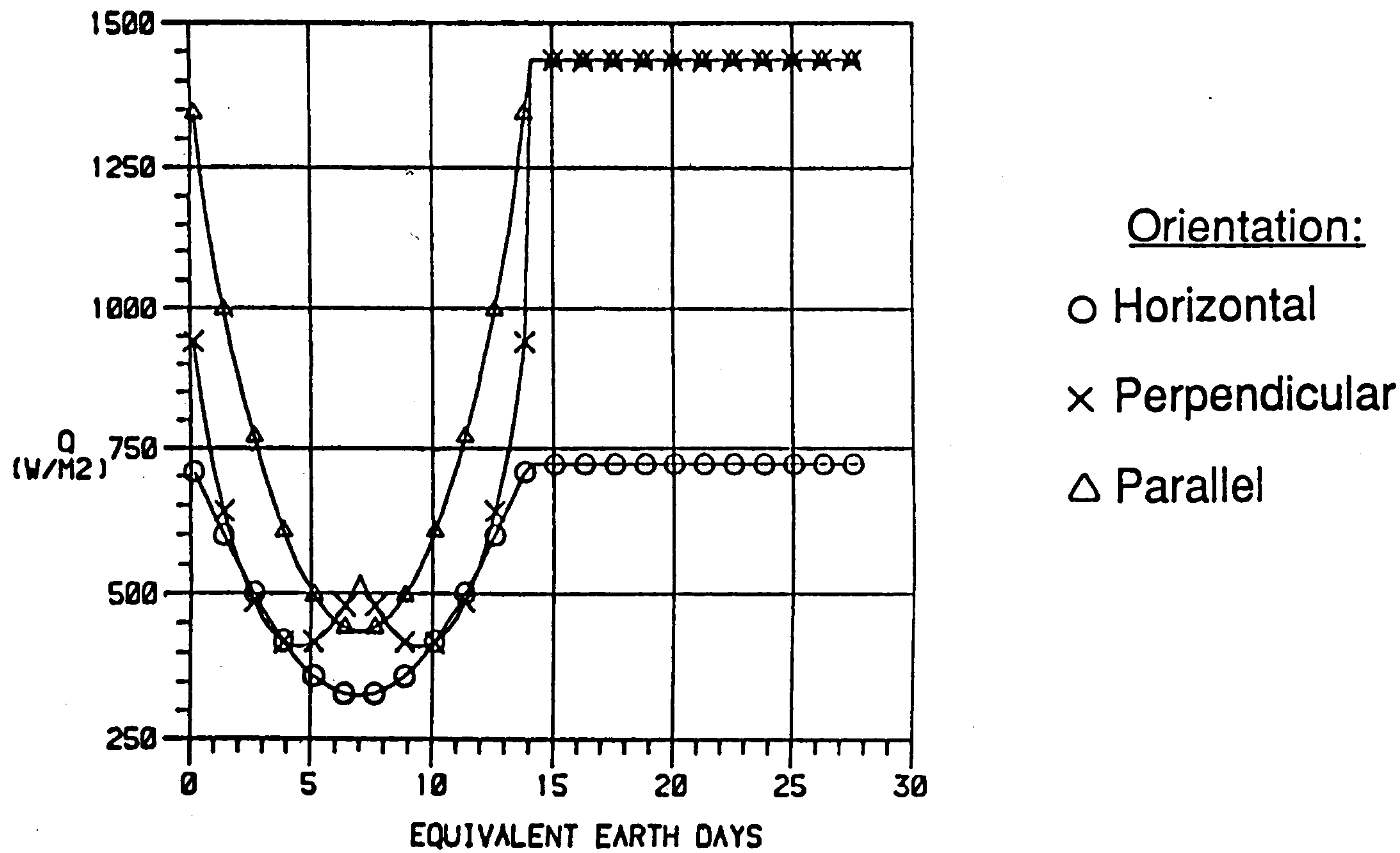
- Absorptivity = 0.30
- Emissivity = 0.85
- Latitude 13.5°
- Radiator Wall Temperature = 350 K (170° F)



Effect of radiator orientation on lunar base radiator heat flux (Q).

C-2

Conceptual Analysis of a Lunar Base Transportation System:

Construction and maintenance of a lunar base will place a tremendous burden on any space transportation system. The initial developmental phase of the lunar base will require three to four million pounds of total weight to be placed in low-Earth-orbit (LEO) by 20 to 30 launches of a 150,000-lb-payload heavy-lift launch vehicle. Even with the most optimistic Earth-to-orbit (ETO) turnaround scenarios, this translates into several years of dedicated lunar missions. As part of an overall lunar base systems assessment, a parametric trade-off study was performed to define the requirements for an optimum lunar base transportation system. Variables in the study included manned versus unmanned systems, the operational mode (i.e., expendable versus reusable, and single-stage versus two-stage orbital transfer vehicle (OTV)), cryogenic propulsion system specific impulse reflecting different levels of engine technology, and aerobraking versus all-propulsive return to Earth orbit. The use of lunar-derived liquid oxygen (LOX) was also examined for its general impact.

Results of the analysis showed that aerobraking is a critical if not enabling technology. Over the course of 16 lunar missions, it can reduce ETO weight requirements on the order of 1.5 million pounds. Aerobraking is also critical in making a reusable OTV advantageous. Using a two-stage OTV yields no significant advantage in weight savings. In terms of operational logistics, then, a one-stage OTV is preferable. Utilizing lunar-derived oxygen for lunar landing, ascent from the lunar surface, and return to Earth orbit can reduce mission initial weight to one-half to one-sixth that for missions using Earth-produced oxygen.

T. D. Hoy
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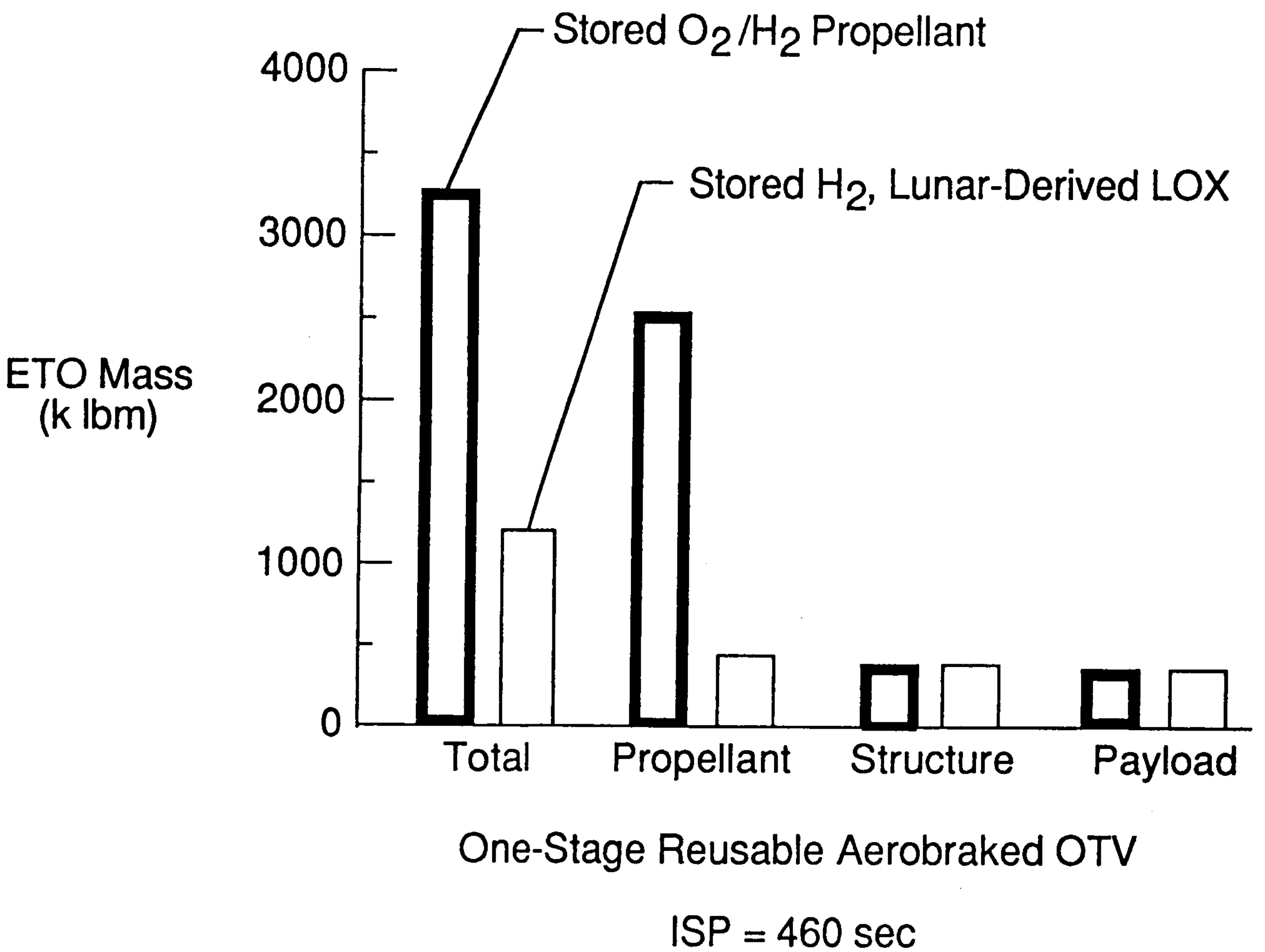

Comparison of ETO mass and manned module mass for reusable, aerobraked mission using lunar and Earth LOX.

Baseline ECLS System for a Lunar Base:

A baseline environmental control and life support (ECLS) system has been defined for a lunar base initially manned intermittently by four crew persons and later permanently occupied by eight crew persons. The ECLS subsystems were selected on the basis of technologies and systems developed for the space station. These systems were integrated and quantified with the use of ECLS assessment and integration computer models developed at the NASA Langley Research Center. The ECLS system is regenerative except for the food loop; however, makeup water and gases must be resupplied to the water and air loops because 100 percent closure is not feasible. Whole body bathing and reusable clothing are included, and both have an impact on the water balance.

Physical characteristics for the intermittently manned ECLS system include a launch weight of 10,589 lb, launch volume of 955 cu ft, 90-day resupply weight of 5,971 lb, 90-day resupply volume of 346 cu ft, and peak power requirement of 10.5 kW. After the evolution into a continuously manned base, ECLS system requirements include a launch weight of 31,471 lb, launch volume of 2174 cu ft, 90-day resupply weight of 13,558 lb, resupply volume of 751 cu ft, and peak power of 21.2 kW. These values include those of the intermittently manned base. Both the intermittently and continuously manned bases feature an ECLS system distributed within a common, reproducible node/module/node core assembly.

Pressurizing the three nonhabitat structures (observatory, laboratory, and liquid oxygen (LOX) pilot plant), initially assumed to be unpressurized, would increase the initial launch weight by 9 percent and the resupply weight by 13 percent. Use of lunar-derived LOX for metabolism and makeup in the continuously manned base would decrease the resupply weight by 10 percent, the resupply volume by 3 percent, and the power required by 12 percent.

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W. B. Hypes
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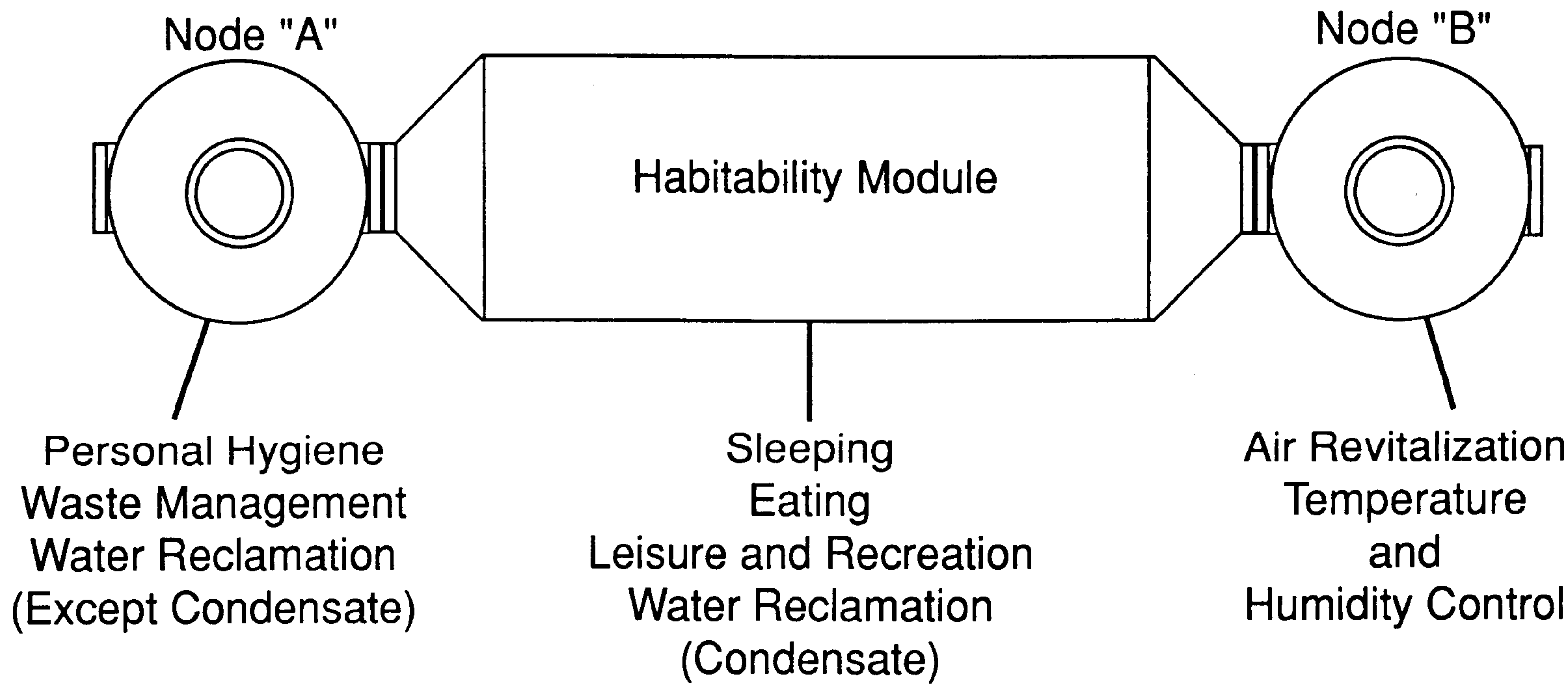


Advantages:

- Supports Growth by Adding Core Assemblies
- Groups Like Functions for Efficiency
- Removes Odors and Noise From Living Area

Reproducible node/module/node core assembly for lunar base.

Concept for a Low-Gravity Research Facility:

One of the biggest payoffs of space technology in the future is expected to be in the area of low-gravity research. Advances in a variety of disciplines such as materials science, electronics, fluids, astrophysics, and medicine are expected as laboratories in space become available. Spacecraft specialized to meet this demand are being studied and unmanned free-flyers have emerged as a promising concept. The figure shows an early configuration developed with the IDEAS^2 computer program.

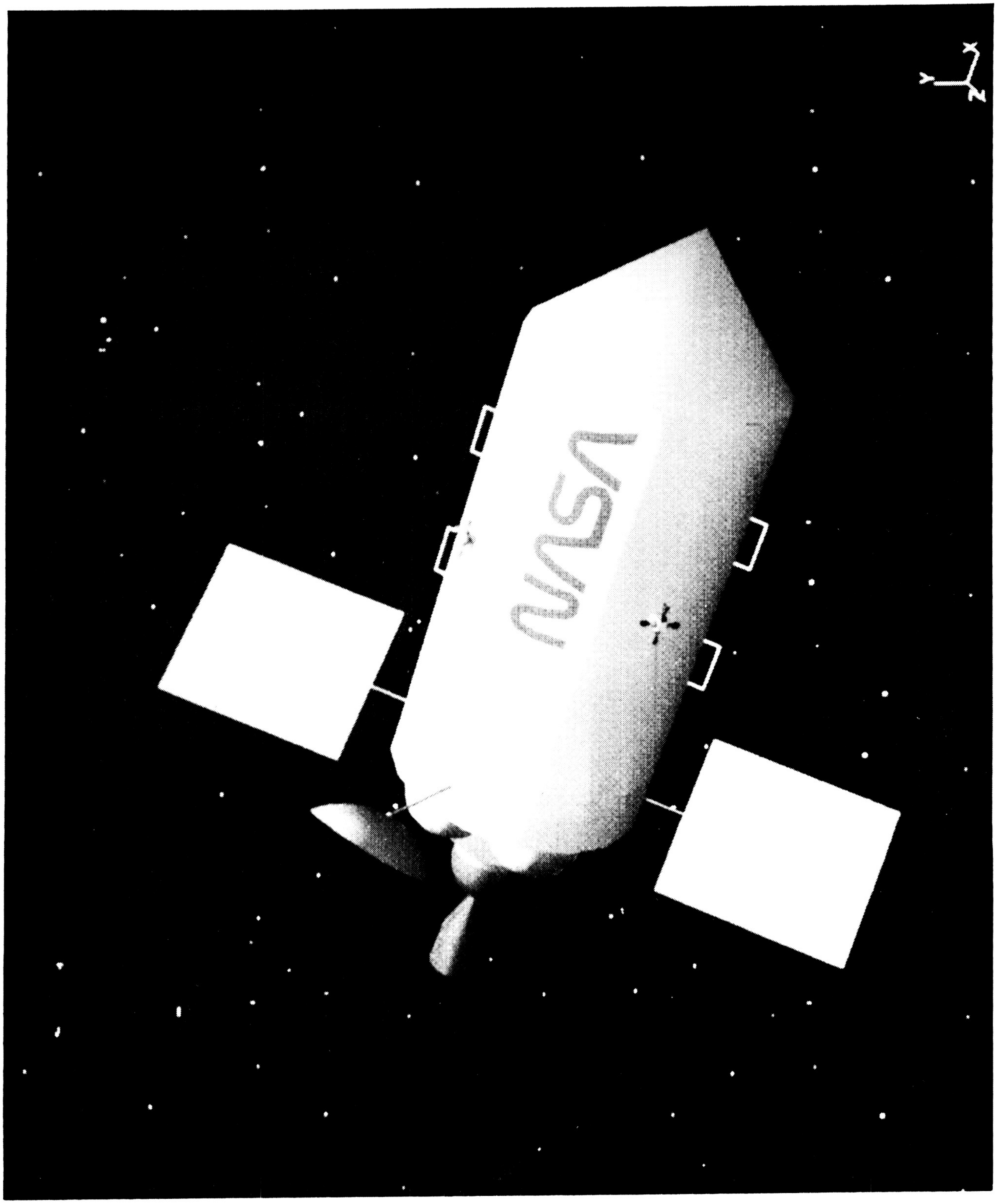
Unmanned free-flyers can be utilized to maintain low acceleration environments for long periods of time. Concepts involving free-flyers composed of an outer shell separated from the inner Low Gravity Module (LGM) are currently under study. The standardized outer shell flies around the LGM during periods when a low acceleration environment is needed and acts as a platform for the subsystems needed to support the experiment. These subsystems include power, propulsion, thermal control, guidance, navigation, and control.

The low gravity module is completely surrounded by the outer shell and is separated from it by an evacuated gap. The acceleration environment of the LGM is dominated only by altitude dependent gravity gradient accelerations and those accelerations caused by moving portions of the experiment itself. The LGM will be experiment dependent but also must be of a fixed configuration in order to mate correctly with the shell. The LGM will remain in free-fall at all times during the experiments. Accelerations due to atmospheric drag, charge buildup, solar and albedo pressures as well as those caused by normal subsystem function such as antenna and radiator movement are all isolated from the LGM by the gap.

A fleet of these free-flyers could be serviced either by the Space Station or by a specialized "tender" spacecraft. Since the gravity gradient accelerations decrease with altitude, engines mounted on the shell will be used to boost the spacecraft to the desired orbit and then bring it back after the experiment is over. At the Space Station the LGM will be pulled out and be replaced by a new one while the shell is refurbished for another mission. Since many free-flyers could be orbiting simultaneously at different altitudes and for different durations, many varied experiments could take place in a short amount of time. This concept would also be well suited for a continuous manufacturing process in which the shells and modules may be serviced by a specialized spacecraft.

New technology issues include artificial intelligence, since the experiments would have to run autonomously, design of apparatus with few or no moving parts for the LGM, advanced accelerometers and sensors to monitor the LGM environment, and precision control to fly the shell around the experiment. Advancements are also needed in materials and propulsion.

Gary Martin
RTOP: 506-49-31-01



Low-gravity research facility concept.

Advanced Satellite Servicing Facility:

As the population of active polar-orbiting and near-polar Sun-synchronous satellites increases, the need to effectively manage the satellites in this group of orbits may eventually require an on-orbit manned facility dedicated to serving their needs. The presence of such a facility could significantly reduce the cost of high-inclination space operations by providing a number of common services from a permanently manned platform. Technology requirements of such a facility in the year 2025 are being examined. The prime technology drivers are crew and facility safety, a large satellite servicing capacity with a quick turnaround, the reduction or elimination of extravehicular activity in all operations, and minimizing the frequency of launches needed to support facility operations.

One candidate for a satellite servicing facility is the concept shown in the figure. This configuration was developed using IDEAS[2], an interactive computer program for conceptual design.

The mission areas being examined are (1) facility-based satellite assembly, checkout, and deployment, (2) retrieval and redeployment for satellite refueling, repair, or systems upgrade, (3) remote satellite refueling, repair, or systems upgrade, (4) ferrying materials and consumables to and from manufacturing platforms, (5) the deorbit, removal, repositioning, or salvage of satellites and debris, and (6) crew rescue of other manned vehicles in high inclination orbits. The technology issues identified to date include easily used and maintained expert systems capable of controlling many facility operations, telerobotic and autonomous systems capable of performing a large number of varied tasks from rendezvous/docking to component changeout and refueling, closed-loop life support systems, and methods of lessening or arresting the physiological effects of long stays in orbit.

Garry Qualls
RTOP: 506-49-31-01

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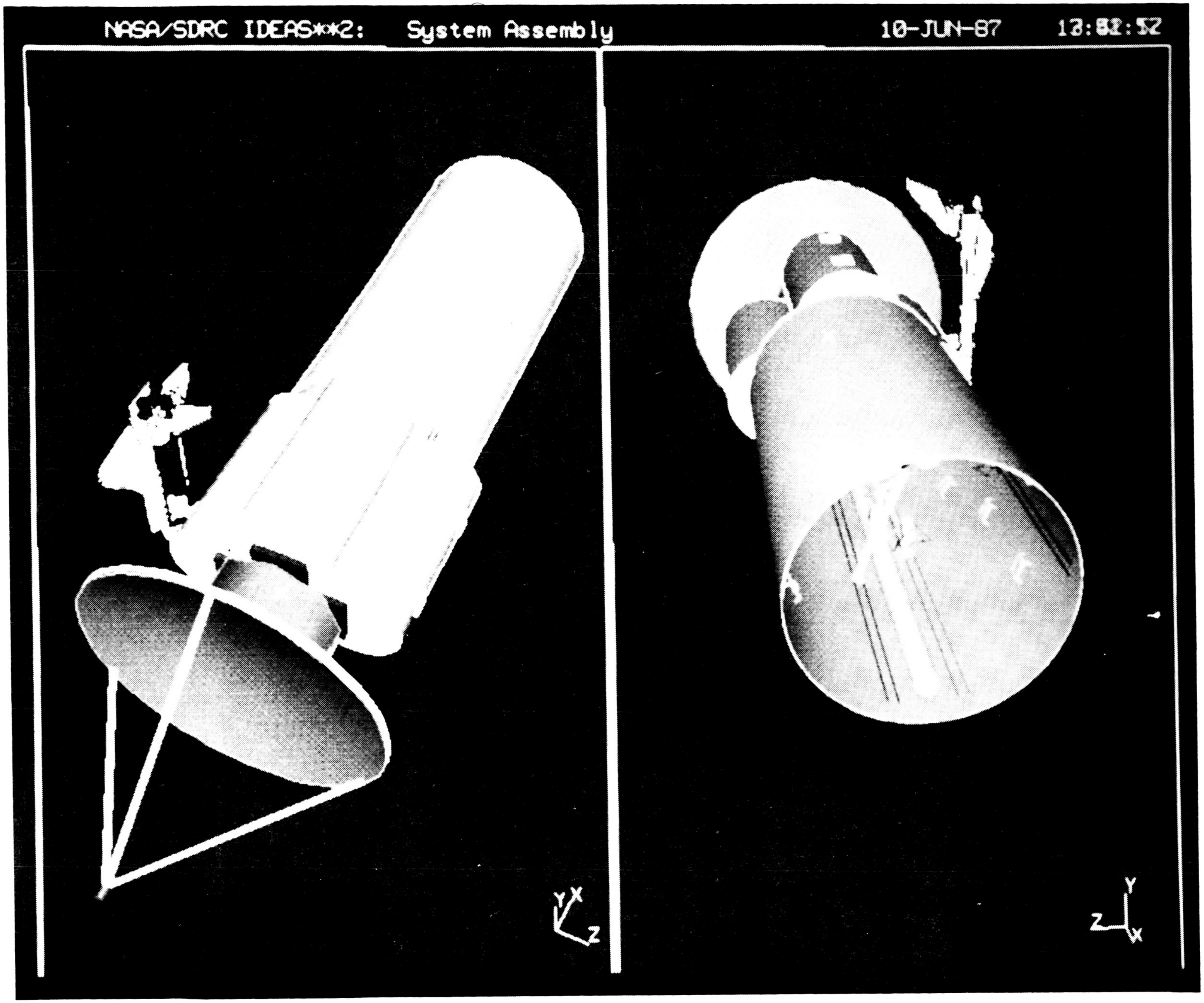

Concept for an advanced satellite servicing facility.

Space Station On-Orbit Operation Model:

The operations area of NASA space programs is an essential element requiring substantial resources during program lifetime. The current Space Station effort addresses one of the most complex concepts proposed to date. In addition to the usual requirements of spacecraft design and the added complexity of manned presence, the very long mission duration (15-20 years) increases the emphasis on operational cost. Within the on-orbit operations area, crew time has been identified as a most valuable and limited resource for the Space Station. The objective of this effort is to provide NASA with a state-of-the-art computer modeling technique for on-orbit operations modeling and assessment.

Langley and Computer Sciences Corporation have developed an operations model (OPSMODEL) which permits a user to assess the impact on crew time of system/subsystem designs, technologies, and operational philosophies for a given station design. The basic concept for this model is presented in the figure. OPSMODEL employs discrete event simulation to model crew activities and keeps track of all consumables and resources. The simulation model is composed of a data base manager and an operations simulator. The data base manager is programmed in R:BASE 5000, and the operations simulator uses a general-purpose simulation programming language, SIMSCRIPT II.5.

Crew activity is modeled using "tasks" which can be represented at any level of detail. Tasks are linked together to form operations or complete segments of work. By using these principles, total crew activities can be modeled over the desired mission time. Model output includes crew "busy," "waiting," and "idle" times, resource profiles, and cost reports. Event and crew member traces assist the user in problem resolution. The menu-driven model runs on an IBM-PC-AT or XT computer requiring no programming, recompiling, or special computer skills of the user. OPSMODEL is intended to improve NASA's capability to expose operations areas in which there may be increases in Space Station productivity or reductions in cost.

William R. Jones
RTOP: 506-49-31-01

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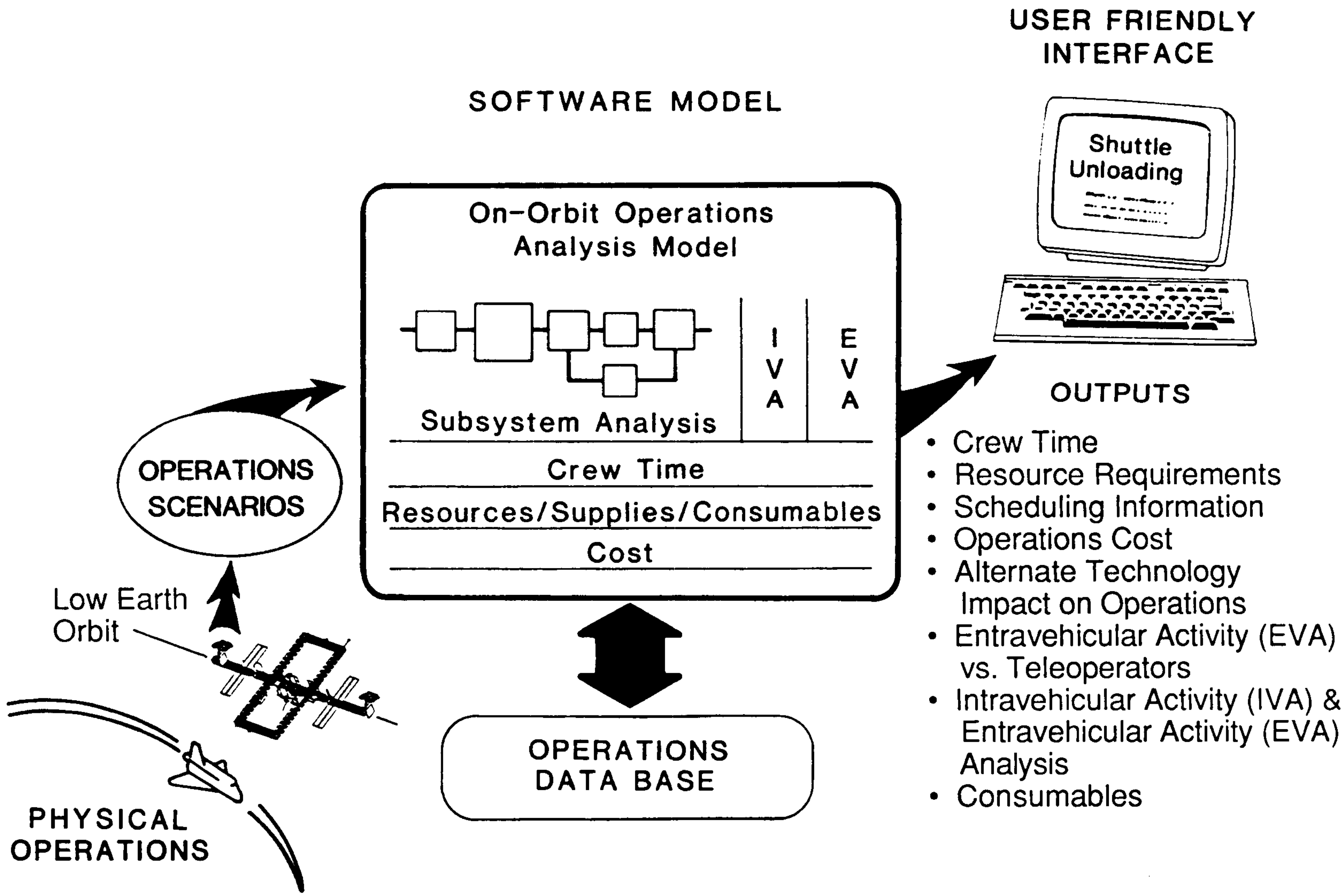

OPSMODEL concept.

Space Station Office

The Space Station Office is the focal point for NASA Langley involvement in the Agency-Wide Space Station Program and is responsible for the implementation and/or coordination of NASA Langley's direct support of this program. The Space Station Office is the NASA lead for the identification, definition, and evaluation of the Evolutionary Space Station capabilities and for the identification of technology and advanced development required for long-term evolutionary development. The office represents the engineering community as technology users of the Space Station. It also advocates flight experiments on future Space Shuttle flights which contribute to Space Station technology use as well as flight experiments from technology programs which can contribute to both the initial operational capability and the evolutionary station. The office provides NASA Langley support to the NASA-wide in-house Space Station systems engineering and integration in areas consistent with demonstrated NASA Langley capabilities and expertise.

An organization chart for the Space Station Office is shown in figure 6. Major accomplishments for FY 1987 follow.

Space Station Accommodation of Lunar Base and Humans to Mars Initiatives:

The Space Station must be capable of meeting the needs of future U.S. space initiatives. For the Lunar Base and Humans to Mars Mission, these needs include Life Science Research, System and Subsystem Technology development and verification, and vehicle assembly, checkout, servicing and maintenance (the latter two relate only to reusable elements of the infrastructure).

A study was conducted to determine the feasibility of Space Station evolution to a facility in Low Earth Orbit which could meet the requirements of the two manned space initiatives. A comprehensive life sciences research program was defined to develop countermeasures to the deleterious effects of long-term exposure to the zero g environment on human physiology for the Mars mission. After establishing space vehicle requirements for both missions, technology development and verification programs were defined for those activities which require in-space experiments or demonstration. Functional requirements for vehicle assembly and checkout were developed and Space Station resource requirements were estimated.

Space Station crew requirements for accommodation of the Mars Sprint Mission are shown in the figure. If we make the fundamental assumption that we must minimize the impact of accommodating the Manned Mars Mission on the basic research program at the station, we will maintain the baseline crew resources at 8. The crew required to carry out the Mars Mission life science program varies from 2.9 down to 1.5. After examination of the baseline life science program as defined by SAAX307, 307A, and 311, we concluded that 1.5 crew persons in the baseline program were conducting life science research directly applicable to the Mars program. Thus the total has been adjusted accordingly. On orbit technology development while at times crew and EVA intensive is, on the average over a 6-month period, one crew person. Depending on the degree of automation and the level of robotic assistance available to the crew, the crew required for the assembly and checkout function can vary considerably. It appears that a crew of three to six is the minimum required to accomplish this function.

With a crew requirement that varies from none to eleven +, it is clear that one additional Hab module is required at the station to accommodate the Mars Mission. The life science program results in the need for an additional lab module plus a pocket lab containing a four meter centrifuge. Results of this study demonstrate that the current Space Station can evolve to meet the needs of the Lunar Base and Humans to Mars initiatives.

E. B. Pritchard
RTOP: 488-10-00-01

	'94	'95		'96		'97		'98		'99		'00		'01		'02	
BASELINE CREW [1]	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
LIFE SCIENCE	2.9	2.9	2.9	2.9	1.5	1.5	1.5	1.5	1.5	3.5	3.5	3.5	1.5	1.5	1.5	1.5	1.5
ON-ORBIT TECH. DEVELOPMENT	--	--	1	1	1	1	1	1	0.7	0.7	0.7	0.7	0.7	--	--	--	--
VEHICLE ASSEMBLY / C/O	--	--	--	--	--	--	--	--	--	--	--	--	--	3	3	6	6
TOTALS	10.9	10.9	11.9	11.9	10.5	10.5	10.5	10.5	10.2	10.2	11.3	11.3	11.3	12.5	12.5	15.5	15.5
TOTAL CREW AFTER ADJUSTMENT [2] FOR BASELINE LIFE SCIENCES	9.4		10.4		9				8.7		9.8			11		14	

1 - RESERVED FOR COEXISTING SCIENCE, COMMERCIAL AND TECHNOLOGY ACTIVITIES

2 - 1.5 CREW FOR LIFE SCIENCE MISSIONS EMBEDDED IN BASELINE CREW OF 8 (SAAX 307, 307A, 311).

Mars sprint mission average crew requirements.

Growth of the Multidiscipline, R&D Station Constrained by Earth-to-Orbit Transportation Capability:

The Earth-orbiting, Space Station will provide a permanently manned facility for conducting scientific research and pursuing commercial activities in space, beginning in the mid-1990's. The Phase I Station must be capable of evolving over its 30-year lifetime to accommodate advances in technology and to enable growth in capability for research, commercial production, and space exploration. The Space Station Office at LaRC is investigating the impact of selected evolution options or "paths" for the Station consistent with potential U.S. objectives in space. Evolution analyses are conducted to derive requirements and identify design provisions or "scars" which enable and/or facilitate the on-orbit evolution of Space Station.

One such task had the objective of deriving realistic requirements for the growth of the Station as a multidiscipline, research and development facility for microgravity research and materials production, observational sciences (astrophysics and Earth observations), life sciences and technology development. Since Earth-to-orbit transportation will be the major limitation to Space Station evolution, conservative and aggressive transportation models were developed and their corresponding lift capabilities were employed as constraining parameters. The models consisted of a mixed fleet of shuttles and expendable launch vehicles (ELV's). An evolution mission model was developed as an input to the multidiscipline growth study. This model is a subject of the Space Station Mission Requirements Data Base (MRDB) containing revised data entries and post-phase I missions which have been endorsed by their sponsoring organizations. Three separate analyses were conducted each assuming a strong emphasis on Station of a specific discipline. Resources were allocated such that the emphasized mission category received power, lift, crew, and volume on Station until 100 percent accommodation was achieved while all other missions were held to their initial or phase I accommodation level. The discipline emphases for the study were microgravity research and materials processing, observational sciences, and life sciences.

The analysis results indicated that the largest growth resource requirements occur when materials processing is the principal growth path onboard the Space Station. For the aggressive transportation model (8 Space Transportation System (STS) launches per year plus ELV's and Shuttle C heavy lift support), the requirements grew to 325 kilowatts of power, a crew of 26, 4 habitation modules, and 5 laboratory modules. Another product of the analysis is the conceptual development of candidate growth configurations for the Space Station. One such configuration is shown in the adjacent figure. It features solar dynamic power generation systems, facilities for servicing free-flying satellites, added habitation and laboratory modules, and a large hanger at the base of the Station for accommodating the Orbital Transfer Vehicle (OTV) which can be used for servicing visits to platforms in geosynchronous orbit. The results derived from the growth analysis will be used at the Space Station Program, Preliminary Requirements Review (PRR) to establish evolution requirements and provide supporting rationale.

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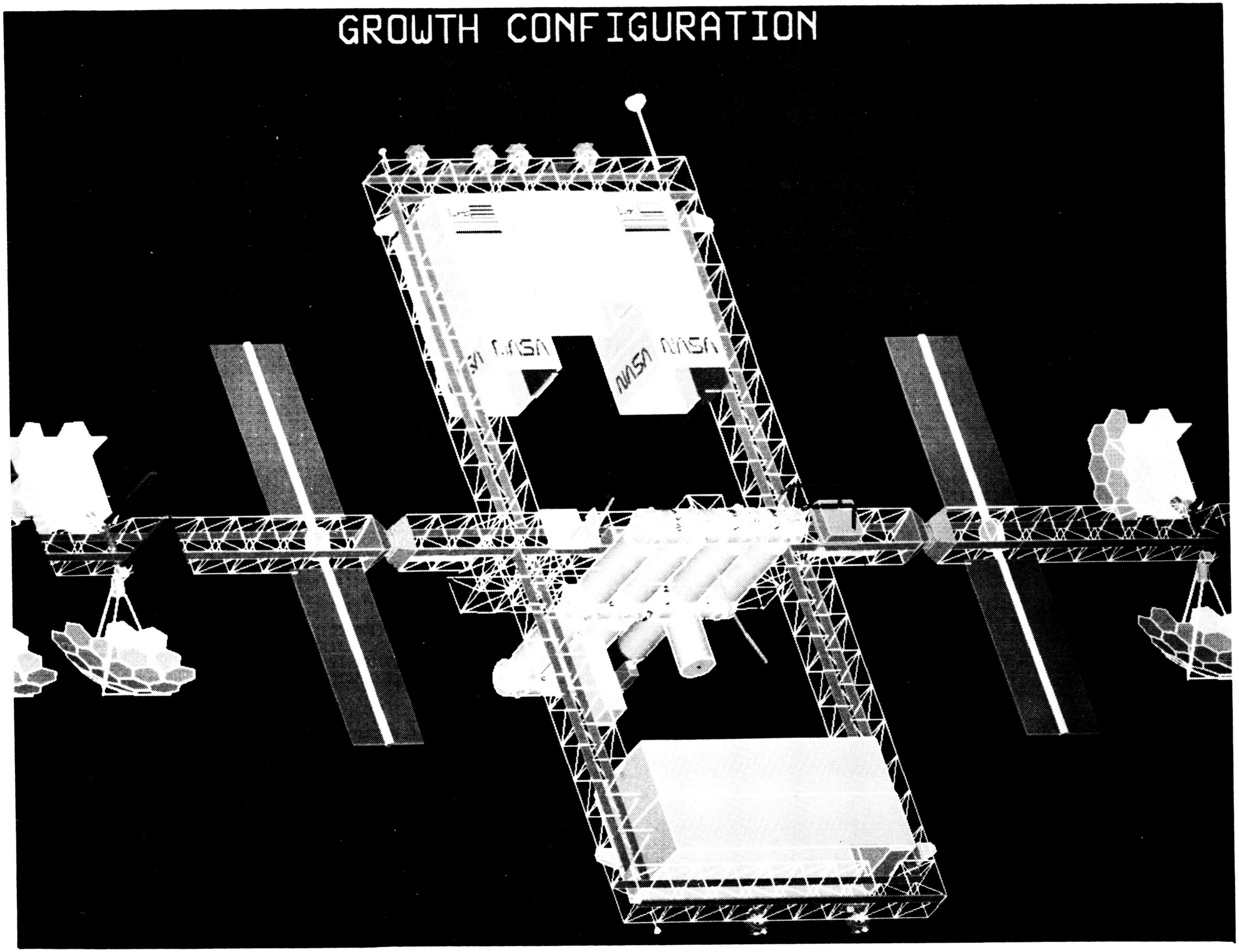
RTOP: 488-10-00-01



Growth of the multidiscipline, R&D Space Station.

Heavy Lift Launch Vehicle Utilization Study:

The Space Station Preliminary Design Definition is based on dedicated use of the Space Transportation System (STS) for assembly, verification, outfitting, logistics, resupply, crew rotation, and return of experiments and refuse to ground. Since the 51-L accident, however, a large number of postponed Shuttle flights has created a mission planning backlog of non-Space Station missions. The Shuttle's performance with respect to payload delivery to orbit has also been downrated. Therefore, the need for additional launch vehicles has become apparent to accommodate national needs during the 1990's when Space Station launch demands must compete with those of both science missions and national defense.

The 1986 NASA Mixed Fleet Study, which compared requirements with capabilities, showed that a combination of Shuttle flights with missions flown by other launch vehicles would reduce Shuttle demands and minimize the shortfall caused by use of the Shuttle alone. The larger lift capacity (both weight and volume) offered by Heavy Lift Launch Vehicles (HLLVs) is attractive to consider with respect to Space Station assembly because it presents the ability to launch more fully integrated and outfitted subsystems, modules, and servicing facilities. Study objectives have been defined which examine in detail the use of HLLVs and assess their utility for Space Station (SS) assembly/deployment, logistics, and resupply.

Several potential HLLVs have been considered, including those based on the Titan ELV, proprietary designs from private industry, and Shuttle-derived vehicles (SDVs). The SS assembly options made possible through the use of HLLVs are compared with the baseline Critical Evaluation Task Force (CETF) SS assembly sequence, both in terms of schedule and of risk. The issues of cost, dual compatibility with the STS, comanifesting of SS payloads with other science missions, cargo return, and ground handling and launch facilities are also considered.

The main advantages of HLLV utilization that have been identified are simplification of assembly procedures, added resupply capability, and increased assured access to space. The major disadvantages are increased orbital flight operations complexity, higher logistics costs, and additional ground handling/launch facility requirements. Also, HLLVs will not provide for any improvement in return cargo capacity nor for any additional crew transport capabilities. Another aspect of unmanned launch vehicle use studied was the development and testing of an Orbital Maneuvering Vehicle (OMV). It was found that development of both the HLLV and OMV would have to be concurrent with SS design. Finally, it was determined that dual STS/HLLV compatibility should be maintained to minimize space station program risk.

L. J. DeRyder
RTOP: 483-32-03-01

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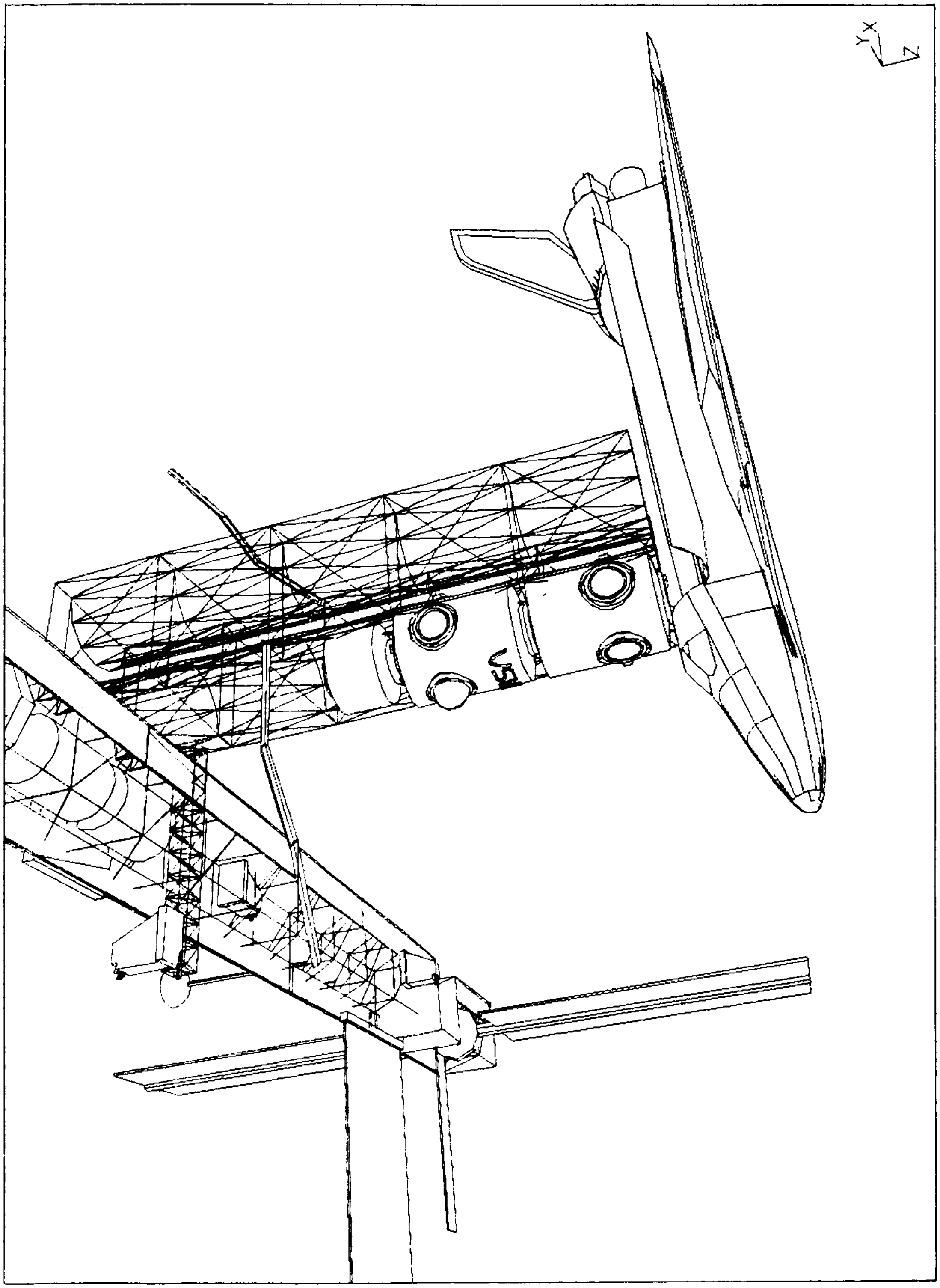

Heavy lift launch vehicle study - pre PMC utilization option.

Space Station Articular Dynamics Analysis Capability:

Various Space Station system studies have identified the need for an articular dynamics analysis capability which could be used to perform system dynamic studies of Space Station operations such as orbiter docking, payload deployment/retrieval, Space Station assembly, robotic applications, and extravehicular activity (EVA). In addition, the articular dynamics capability require the ability to model orbital environments, Sun tracking and anti-tracking mechanisms, and attitude control systems.

The commercially available Automatic Dynamic Analysis of Mechanical Systems (ADAMS) software package has been integrated into Integrated Design and Engineering Systems (IDEAS**2) to meet the spacecraft articular dynamics systems analysis need. ADAMS is capable of solving both the kinematic and dynamic behavior of systems undergoing large displacements. Spacecraft mechanism definition is performed with the IDEAS**2 solid modeler, which allows the creation of bodies, joints, reference triads (coordinate systems), constraints, and load sets. Mechanism configuration data are transferred to ADAMS via a project relational data base. Customized spacecraft analysis software accessible to ADAMS is used to model orbital environment disturbances (gravity, gravity gradient, aerodynamic, and solar pressure), Sun racking and anti-tracking mechanisms such as solar arrays and radiations and attitude jet control systems. ADAMS results are transferred to the data base and made available for output plotting postprocessing and animation. As an example, a Space Station Remote Manipulator System (SSRMS) is shown reaching for a payload located in the Shuttle cargo bay. The applied torques required of the joint actuators are illustrated in the figure.

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RTOP: 483-32-03-04

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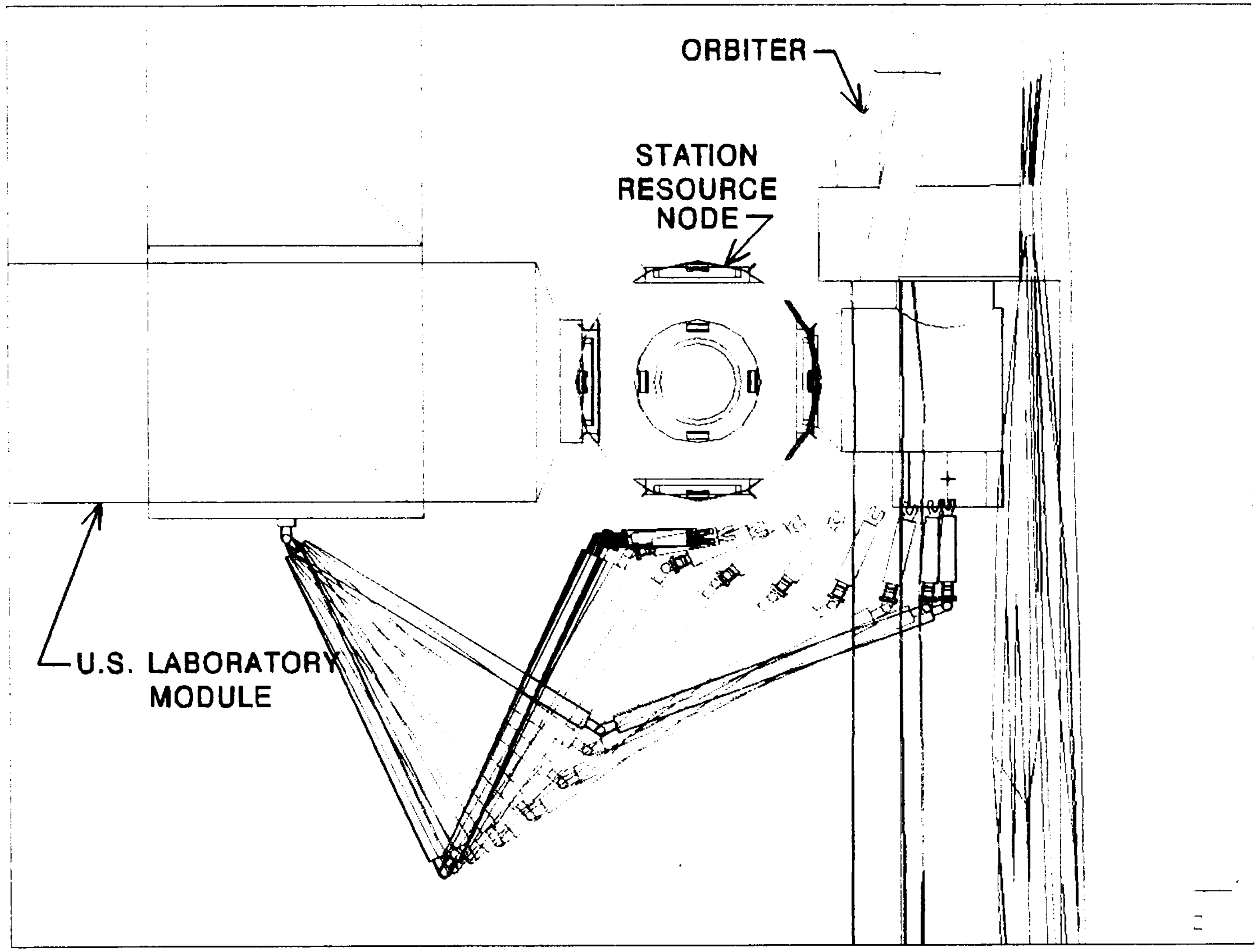
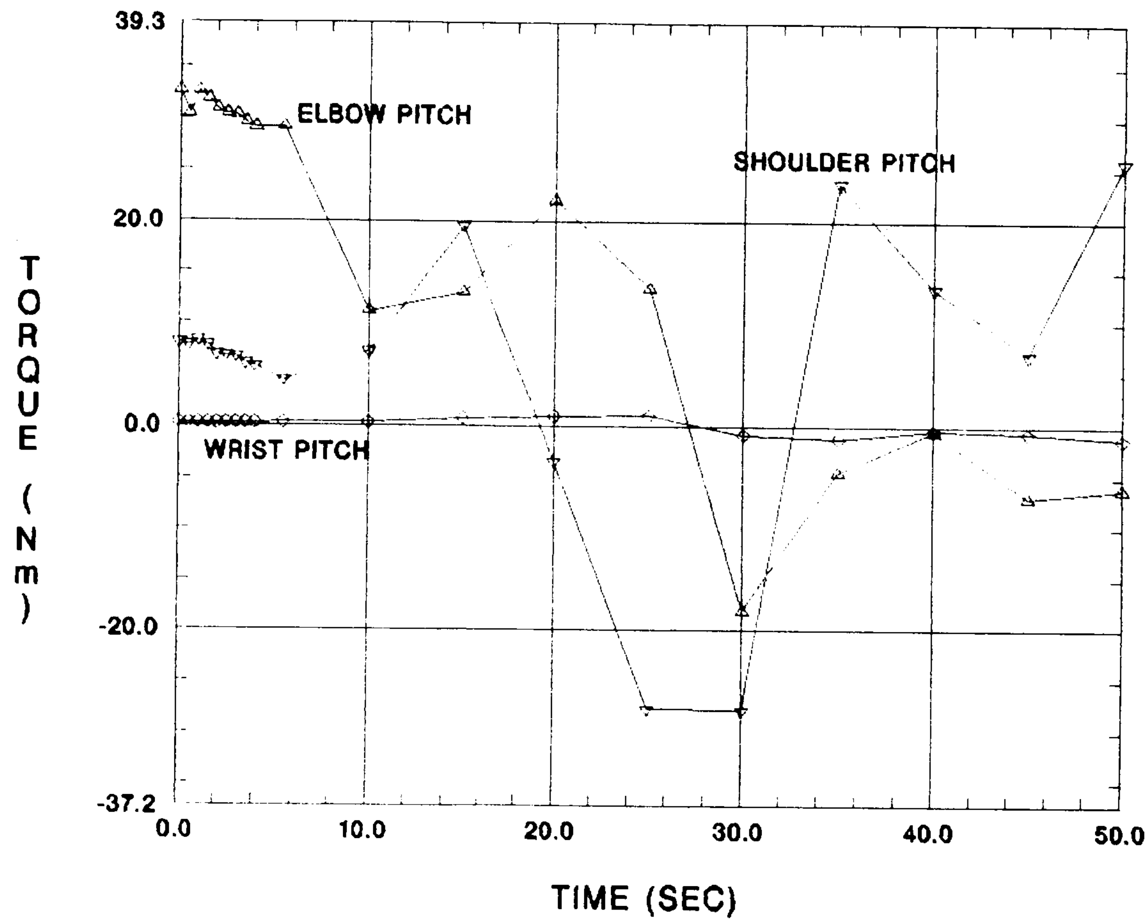


SSRMS kinematics for shuttle payload retrieval.



SSRMS applied joint torque for shuttle payload retrieval.

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Space Station Phased Program Definition:

The Space Station Phased Program Task Force (PPTF) study was initiated after Congressional review of the Critical Evaluation Task Force (CETF) recommendations which resulted in a NASA Headquarters Program management funding re-phasing definition to maintain established cost guidelines favorable to governmental Executive and Legislative Fiscal Year 1988 budget deliberations. The Space Station Reference Configuration as established by CETF was redefined at Program Management direction to consist of two phases of implementation where Phase I would fall within desired funding guidelines and Phase II would define the remaining configuration elements necessary to maintain the CETF recommended reference configuration.

The PPTF was tasked to define a configuration and flight assembly sequence that provided for permanent manned presence in space with full international partner participation utilizing a photovoltaic power system with a 75 KW capability. Starting with the CETF Reference Configuration the LaRC based PPTF, consisting of representatives from NASA Headquarters, MSFC, JSC, GSFC, LeRC, KSC, and the international partners, analyzed and assessed key assembly sequence drivers which included Shuttle up and down cargo limitations, total number of Shuttle flights per year, power system options, assembly altitude and reboost requirements, Flight Telerobotic Servicer (FTS) availability and weight, resupply logistics, and user resource optimization. The Study results recommended major deferrals of key station elements to Phase II which included the Solar Dynamic Power System, the Vertical Truss Structure Keels and Booms, the Satellite Servicing Facilities, and the Co-Orbiting Platform. At Phase II completion the Station configuration would consist of full boom and keel structure, servicing facilities and 125 KW of total power which is a 37.5 KW increase from the CETF configuration definition.

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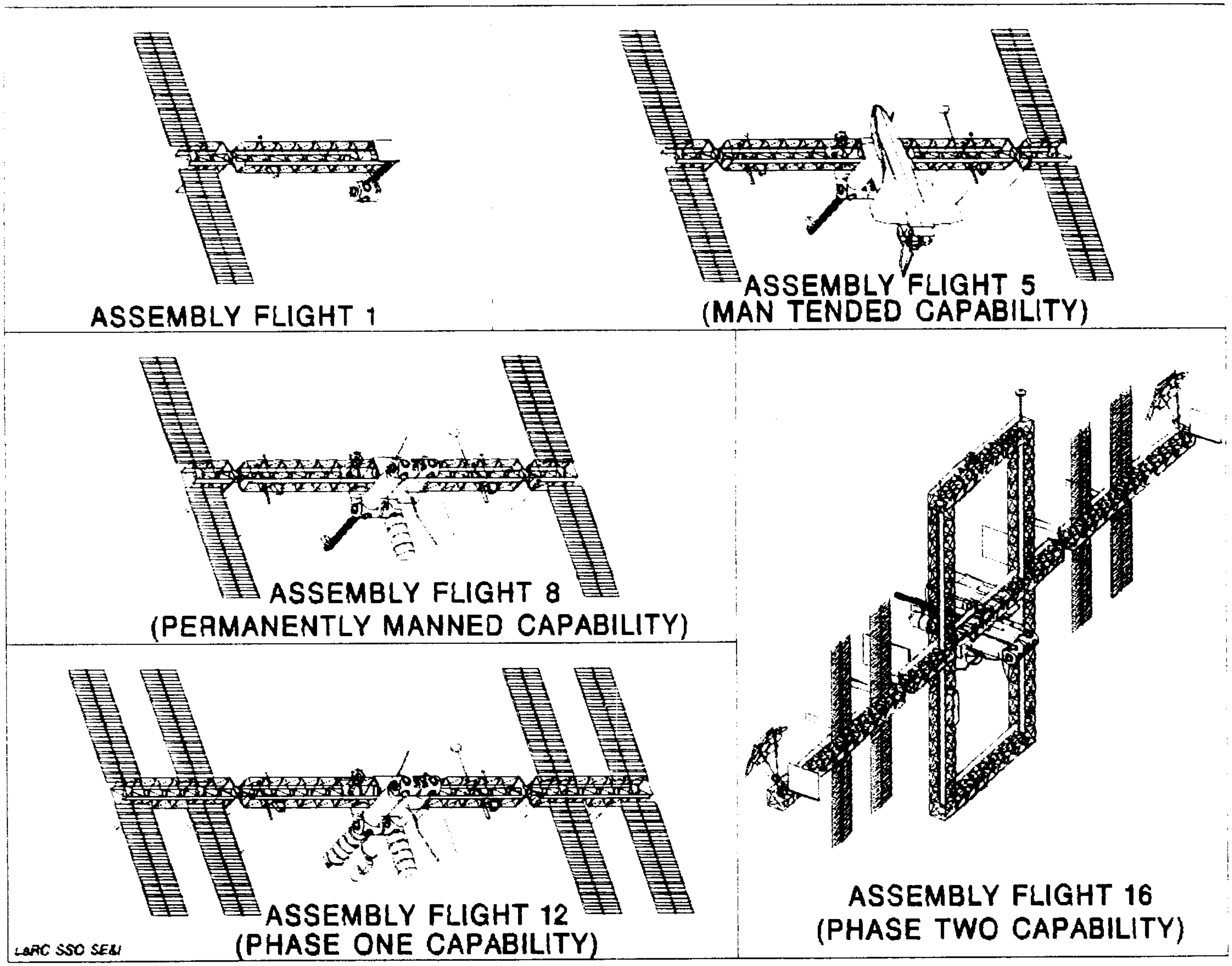

Phased program flight assembly highlights.

NRC Space Station Transportation Study:

The NASA Space Station Transportation Study for the National Research Council was performed to assess the impact of reducing Space Station Shuttle flights to five per year, the use of alternate launch vehicles, Shuttle performance improvements, decreasing the risk of on-orbit module outfitting, and the effect of a launch package loss or failure to operate. Impact assessments were made utilizing post-Challenge Shuttle performance specifications assent performance, landing load, and crew carrying definitions. In accomplishing these objectives, options under consideration had to maintain the current functional capability sequence and dual compatibility of Station design to transportation system.

A number of transportation scenarios were analyzed with respect to their effects on orbital assembly sequences, launch package integration, end-items requiring on-orbit integration, and risk implications for reboost factors and element loss recovery. In a variety of combinations, options employed the baseline Shuttle and a version with enhanced performance, both with and without support of Heavy Lift Launch Vehicle (HLLV). Additional scenarios considered the effects of different pressurized module lengths, preintegrated space station resource nodes, delayed nodes, truss structure modifications, EVA (Extravehicular Activity) extensions, additional Shuttle performance from an advanced solid rocket booster, and utilization of several different HLLV configurations.

Options are compared on the basis of number of NSTS flights needed for assembly, the Station's orbital life between reboost and resupply opportunities, and the percent of module outfitting deferred to later flights. Beyond the assembly phase analyses, attention was paid to the effect of the five NSTS fights per year limit on logistics support of the operational Space Station. These considerations involved reassessment of basic resupply requirements and methods, crew factors (delivery, duty tours, numbers of astronauts, and rotation periods), and alternate trash disposal scenarios. The recommended configuration holds to the NSTS flight limit, uses both EVA and IVA (Intravehicular Activity) for assembly, maintains program margins (weight per flight, altitude, EVA), incorporates needed back-up flight hardware, and accommodates users and Station growth.

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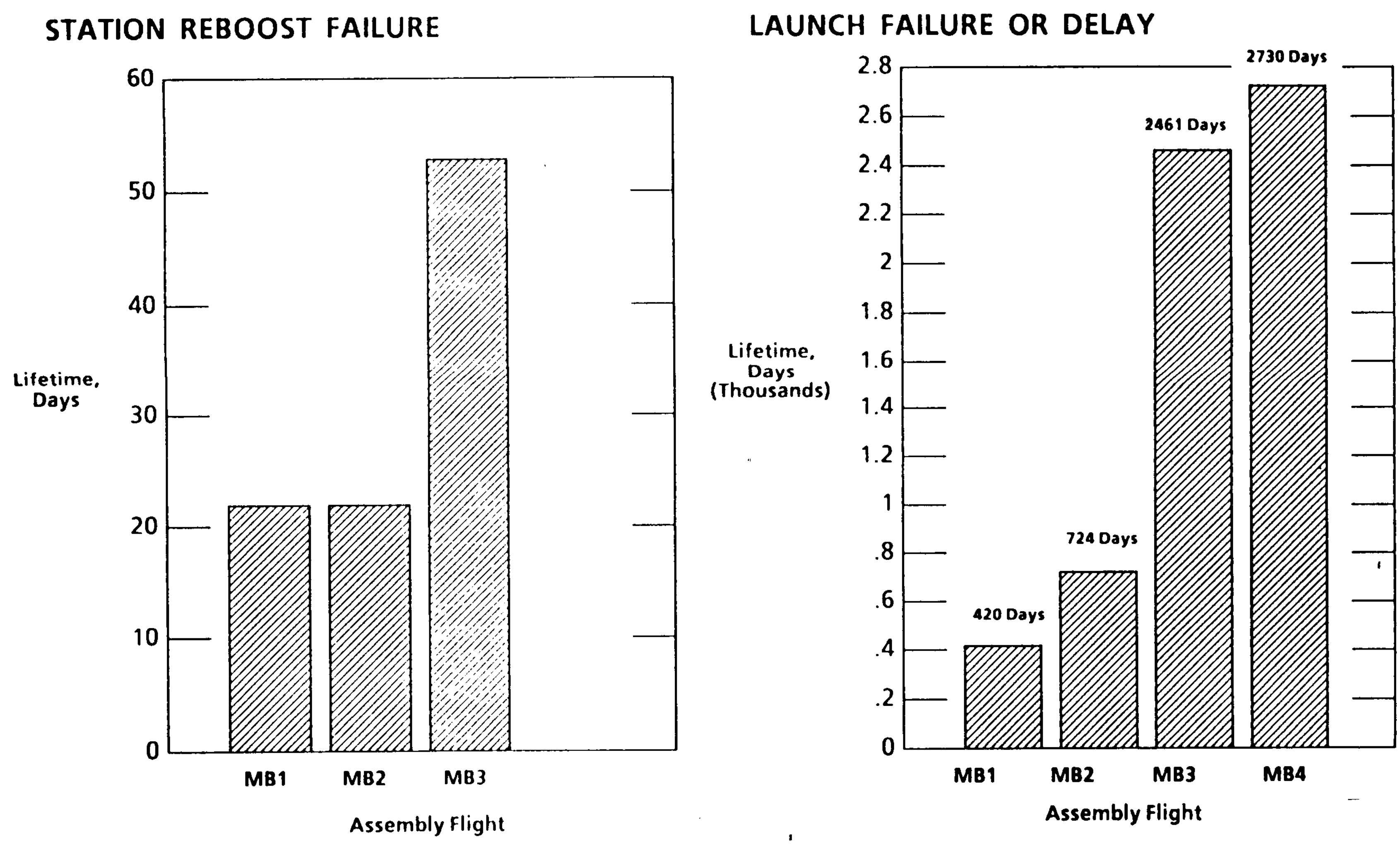
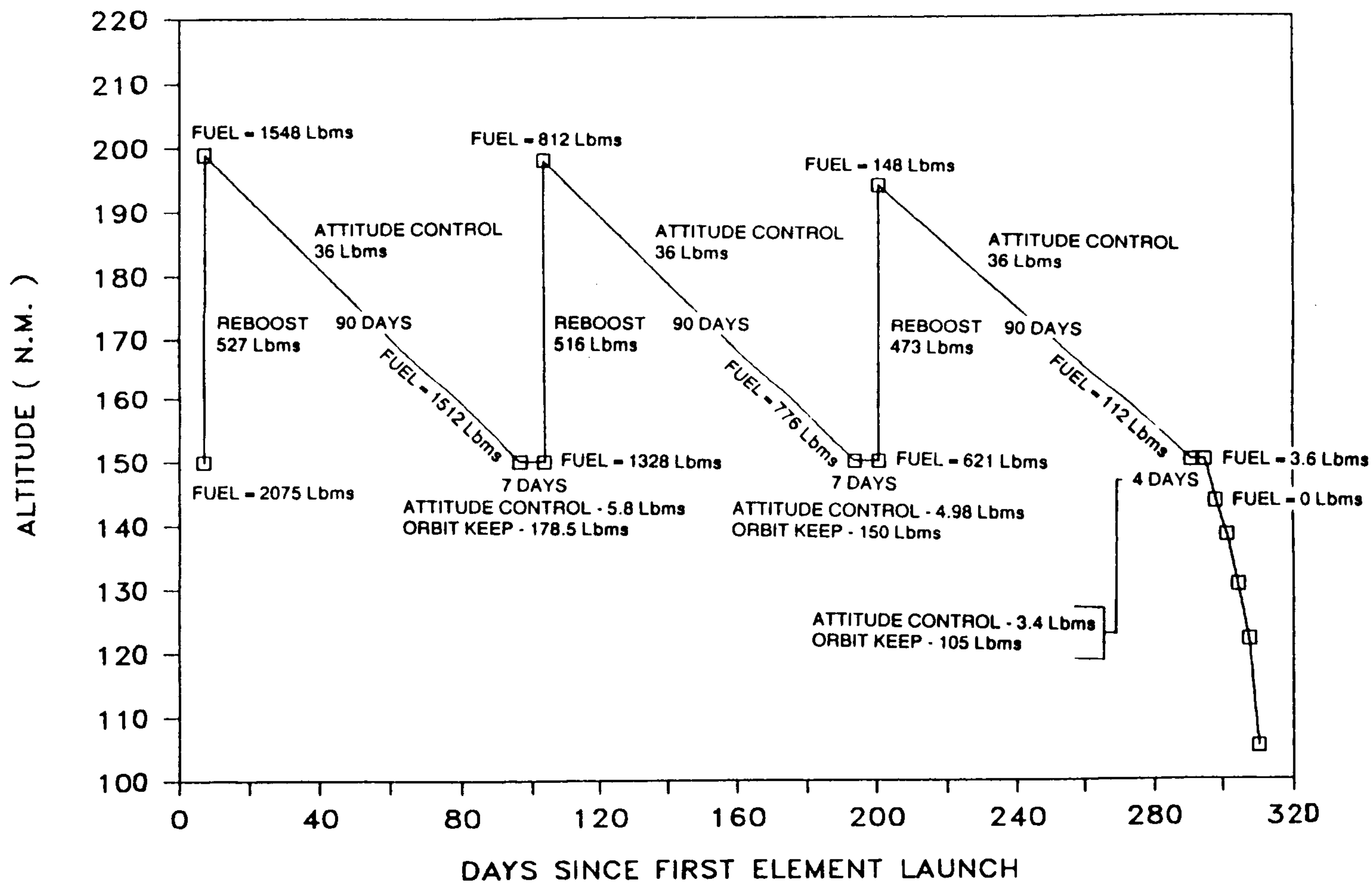


Orbital lifetime of flight 1(MB-1) baseline STS.

MB1 CONFIGURATION



Ninety day contingency scenario.

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PUBLICATIONS

The FY 1987 accomplishments of the Space Directorate resulted in a number of publications. The publications are listed below by organization and are identified by the categories of journal publications, formal NASA reports, conference presentations, contractor reports, tech briefs, and patents.

Atmospheric Sciences Division

Conference Presentations:

1. Harriss, R. C.; Garstang, M.; Wofsy, S.; and McNeal, R. J.: Chemical Studies of the Global Troposphere: The Atmospheric Boundary Layer Experiments. Presented at 2nd Airborne Science Workshop, Miami, Florida, February 3-6, 1987.

2. Harriss, R. C.; Sebacher, D. .F: Bartlett, K. B.; and Bartlett, D. S.: Methane Flux From Florida Everglades. Presented at American Chemical Society, Denver, Colorado, April 5-10, 1987.

3. Boston, Penelope J.: Are Human Investigators Needed on Mars to Study the Life Sciences. Presented at Case for Mars III, Boulder, Colorado, July 18-22, 1987.

4. Harriss, R. C.: Atmospheric Methane: An Indicator of Global Climatic Change Presented at 6th International Symposium of the Commission for Atmospheric Chemistry and Global Pollution on Global Atmospheric Chemistry, IAMAP, Ontario, Canada, August 23-29, 1987.

Journals:

1. Beck, S. M.; Bendura, R. J.; McDougal, D. S.; Hoell, J. M., Jr.; Gregory, G. L.; et al.: Operational Overview of NASA GTE/CITE-1 Airborne Instrument Intercomparisons: Carbon Monoxide, Nitric Oxide, and Hydroxyl Instrumentation. Journal of Geophysical Research, vol. 92, no. D2, pp. 1977-1985, February 27, 1987.

2. Hoell, James M., Jr.; Gregory, Gerald L.; McDougal, David S.; et al.: Airborne Intercomparison of Nitric Oxide Measurement Techniques. Journal of Geophysical Research, vol. 92, no. D2, pp. 1995-2008, February 27, 1987.

3. Hoell, J. M.; Gregory, G. L.; McDougal, D. S.; et al.: Airborne Intercomparison of Carbon Monoxide Measurement Techniques. Journal of Geophysical Research, vol. 92, no. D2, pp. 2009-2019, February 27, 1987.

Data Management Office

Journals:

1. Ferebee, Michelle T.: Color Contouring for Atmospheric Data Sets. Journal of the National Technical Association, vol. 60, no. 4, pp. 15-17, April 1987.

Conference Presentations:

1. Ferebee, Michelle T.; and Kibler, James F.: Evaluation of an Optical Disk System for Storing Archival Satellite Data. Presented at 59th Annual Conference of the National Technical Association, Norfolk, Virginia, July 8-11, 1987.

Chemistry and Dynamics Branch

Journals:

1. Park, Jae H.; and Carli, Bruno: Analysis of Far Infrared Emission Fourier Transform Spectra. Applied Optics, vol. 25, no. 19, pp. 3490-3501, October 1, 1986.

2. Cofer, W. R., III; Connors, Vickie S.; Levine, Joel S.; and Edahl, Robert A., Jr.: Day and Night Profiles of Tropospheric Nitrous Oxide. Journal of Geophysical Research, vol. 91, no. D11, pp. 11,911-11,914, October 20, 1986.

3. Thakur, K. B.; Rinsland, C. P.; Smith, M. A. H.; Benner, D. C.; and Devi, V. M.: Absolute Line Intensity Measurements in the ν_2 Bands of HDO and D_2O Using a Tunable Diode Laser Spectrometer. Journal of Molecular Spectroscopy, vol. 120, pp. 239-245, 1986.

4. Fishman, Jack; Minnis, Patrick; and Reichle, Henry G., Jr.: Use of Satellite Data to Study Tropospheric Ozone in the Tropics. Journal of Geophysical Research, vol. 91, no. D13, pp. 14,451-14,465, December 20, 1986.

5. Devi, V. M.; Benner, D. C.; Rinsland, C. P.; Smith, M. A. H.; and Thakur, K. B.: Diode Laser Measurements of Intensities and Halfwidths in the ν_6 Band of $^{12}CH_3D$. Journal of Molecular Spectroscopy, vol. 122, pp. 182-189, 1986.

6. Rinsland, C. P.; and Levine, J. S.: Identification and Measurement of Atmospheric Ethane (C_2H_6) From a 1951 Infrared Solar Spectrum. Applied Optics, vol. 25, no. 24, pp. 4522-4525, December 15, 1986.

7. Flaud, J. M.; Camy-Peyret, C.; Devi, V. Malathy; Rinsland, C. P.; and Smith, M. A. H.: The ν_1 and ν_3 Bands of $^{18}O_3$ and $^{18}O^{16}O^{18}O$: Line Positions and Intensities. Accepted 9/26/86 for publication in Journal of Molecular Spectroscopy, vol. 122, pp. 221-228, 1986.

8. Browell, E. V.; Danielsen, E. F.; Ismail, S.; Gregory, G. L.; and Beck, S. M.: Tropopause Fold Structure Determined From Airborne Lidar and In Situ Measurements. Journal of Geophysical Research, vol. 92, no. D2, pp. 2112-2120, February 27, 1987.

9. Grossmann, B. E.; Singh, U. N.; Higdon, N. S.; Wilkerson, T. D.; and Browell, E. V.: Raman-Shifted Dye Laser for Water Vapor DIAL Measurements. Applied Optics, vol. 26, no. 9, pp. 1617-1621, May 1, 1987.

10. Thakur, K. B.; Rao, K. N.; Friedl, R. R.; Rinsland, C. P.; and Devi, V. M.: Analysis of the ν_6 Band of Carbonyl Fluoride. Journal of Molecular Spectroscopy, vol. 123, pp. 255-266, 1987.

11. Zander, R.; Rinsland, C. P.; Farmer, C. B.; and Norton, R. H.: Infrared Spectroscopic Measurements of Halogenated Source Gases in the Stratosphere With the ATMOS Instrument. Journal of Geophysical Research, vol. 92, no. D8, pp. 9836-9850, August 1987.

12. Flaud, J.-M.; Camy-Peyret, C.; Devi, V. M.; Rinsland, C. P.; and Smith, M. A. H.: The ν_1 and ν_3 Bands of $^{16}O_3$: Line Positions and Intensities. Journal of Molecular Spectroscopy, vol. 124, pp. 209-217, 1987.

13. Devi, V. M.; Flaud, J.-M.; Camy-Peyret, C.; Rinsland, C. P.; and Smith, M. A. H.: Line Positions and Intensities for the $\nu_1 + \nu_2$ and $\nu_2 + \nu_3$ Bands of $^{16}O_3$. Journal of Molecular Spectroscopy, vol. 125, pp. 174-183, 1987.

Conference Presentations:

1. Park, J. H.; and Carli, B.: NLSF Analysis of Emission FT Spectra From Balloon Altitude. Presented at 11th International Conference on Infrared and Millimeter Waves, Tirrenia, Pisa, Italy, October 20-24, 1986.

2. Baldecchi, etc., Park, J.: High Resolution Spectra of the Far-Infrared Stratospheric Emission. Presented at 11th International Conference on Infrared and Millimeter Waves, Tirrenia, Pisa, Italy, October 20-24, 1986.

3. Wallio, H. Andrew; and Gormsen, Barbara B.: An Ancillary Enhanced Measurement To Improve the Data Reduction and Interpretation of GFR Trace Gas Measurements. Presented at Fall AGU Meeting, San Francisco, California, December 8-12, 1986.

4. Reichle, H. G., Jr.: The Distribution of Tropospheric Carbon Monoxide During October 1984 as Measured by a Satellite-Borne Remote Sensor. Presented at Fall AGU Meeting, San Francisco, California, December 8-12, 1986.

5. Garstang, Michael; Greco, Steve; Scala, John; Harriss, Robert; Browell, Edward; Sachse, Glenn; Simpson, Joanne; Tao, Wei-Kuo; and Torres, Arnold: Trace Gas Exchanges and Transports Over the Amazonian Rain Forest. Presented at Second International Conference on Southern Hemisphere Meteorology, Wellington, New Zealand, December 1-5, 1986.

6. Connors, V. S.; Reichle, H. G., Jr.; Sullivan, K. D.; and Helfert, M. R.: Global Observations of Biomass Burning From Space. Presented at Fall AGU Meeting, San Francisco, California, December 8-12, 1986.

7. Reichle, Henry G., Jr.: The Distribution of Tropospheric Carbon Monoxide as Measured by the Space Shuttle Borne MAPS Experiment. Presented at AIAA 25th Aerospace Sciences Meeting, Reno, Nevada, January 12-15, 1987.

8. Wallio, H. A.; Gormsen, B. B.; and Reichle, H. G.: Results of an Aircraft Correlative Flight Experiment for the Support of the MAPS Gas Filter Radiometer Experiment. Presented at 2nd Airborne Science Workshop, Miami, Florida, February 3-6, 1987.

9. Browell, E. V.: Airborne Lidar Measurements of Ozone and Aerosols During NASA Global Tropospheric Field Experiments. Presented at 2nd Airborne Science Workshop, Miami, Florida, February 3-6, 1987.

10. Browell, E. V.; Vaughan, W. R.; Hall, W. M.; et al.: Development of High-Altitude Airborne Differential Absorption Lidar System--The Lidar Atmospheric Sensing Experiment (LASE). Presented at 2nd Airborne Science Workshop, Miami, Florida, February 3-6, 1987.

11. Barrick, J. D.; Gormsen, B. B.; and Wallio, H. A.: The MAPS Airborne Correlative Measurement System: Instrumentation, Integration, and Flight Operation. Presented at 2nd Airborne Science Workshop, Miami, Florida, February 3-6, 1987.

12. Ismail, Syed; and Browell, Edward V.: Sensitivity Analysis for Airborne and Spaceborne DIAL Measurements of H_2O Profiles. Presented at SPIE 1987 Technical Symposium Southeast, Orlando, Florida, May 20, 1987.

13. Devi, V. M.; Flaud, J.-M.; Camy-Peyret, C.; Rinsland, C. P.; and Smith, M. A. H.: Intensities and Analysis of the $\nu_1 + \nu_2$ and $\nu_2 + \nu_3$ Bands of $^{16}O^3$ Near 5.7 μm. Presented at Ohio State University 42nd Symposium on Molecular Spectroscopy, Columbus, Ohio, June 15-19, 1987.

14. Rinsland, C. P.; Devi, V. M.; Smith, M. A. H.; and Benner, D. C.: Air-Broadened and Nitrogen-Broadened Width Coefficients and Pressure Shifts in the ν_4 and ν_2 Bands of $^{12}CH_4$. Presented at Ohio State University 42nd Symposium on Molecular Spectroscopy, Columbus, Ohio, June 15-19, 1987.

15. Smith, M. A. H.; Devi, V. M.; Rinsland, C. P.; and Benner, D. C.: Pressure-Induced Line Shifts and Widths of O_3 Broadened by N_2 and by Air. Presented at Ohio State University 42nd Symposium on Molecular Spectroscopy, Columbus, Ohio, June 15-19, 1987.

16. Pickett, H. M.; Cohen, E. A.; Brown, L. R.; Rinsland, C. P.; Smith, M. A. H.; et al.: The Vibrational and Rotational Spectra of Ozone for the (0,1,0) and (0,2,0) States. Presented at Ohio State University 42nd Symposium on Molecular Spectroscopy, Columbus, Ohio, June 15-19, 1987.

17. Devi, V. M.; Rinsland, C. P.: Smith, M. A. H.; and Benner, D. C.: Air-Broadened Lorentz Halfwidths in the ν_4 Band of $^{13}CH_4$ Using a Fourier Transform Spectrometer. Presented at Ohio State University 42nd Symposium on Molecular Spectroscopy, Columbus, Ohio, June 15-19, 1987.

18. Grossmann, B.; and Browell, E. V.: High-Resolution Water Vapor Spectroscopic Measurements in the 720-nm Region for Lidar Meteorological Application. Presented at International Conference on Laser Spectroscopy, International Union of Pure and Applied Physics, Are, Sweden, June 22-26, 1987.

19. Goldman, A.; Murcray, F. H.; Murcray, D. G.; and Rinsland, C. P.: Quantification of Several Atmospheric Gases From High Resolution Infrared Solar Spectra Obtained at the South Pole in 1980 and 1986. Presented at Sixth FTS Conference 1987, Vienna, Austria, August 24-28, 1987.

20. Rinsland, C. P.; Devi, V. M.; Smith, M. A. H.; and Benner, D. C.: Halfwidth and Pressure Shift Measurements in the ν_4 and ν_2 Bands of $^{12}CH_4$ and the ν_4 Band of $^{13}CH_4$. Presented at Atmospheric Spectroscopy Applications Workshop, Rutherford Appleton Lab., England, September 1-3, 1987.

Theoretical Studies Branch

Journals:

1. Cofer, W. R., III; Connors, Vickie S.; Levine, Joel S.; and Edahl, Robert A., Jr.: Day and Night Profiles of Tropospheric Nitrous Oxide. Journal of Geophysical Research, vol. 91, no. D11, pp. 11,911-11,914, October 20, 1986.

2. Callis, L. B.; and Natarajan, M.: Ozone and Nitrogen Dioxide Changes in the Stratosphere During 1979-1984. Nature, vol. 323, no. 6091, pp. 772-777, October 30, 1986.

3. Austin, J.; Remsberg, E. E.; Jones, R. L.; and Tuck, A. F.: Polar Stratospheric Clouds Inferred From Satellite Data. Geophysical Research Letters, vol. 13, no. 12, pp. 1256-1259, November 1986.

4. Boughner, Robert E.: A Rapid and Accurate Method for Calculation of Stratospheric Photolysis Rates With Molecular Scattering. Journal of Geophysical Research, vol. 91, no. D12, pp. 13,187-13,194, November 20, 1986.

5. Vukovich, Fred M.; and Fishman, Jack: The Climatology of Summertime O_3 and SO_2 (1977-1981). Atmospheric Environment, vol. 20, no. 12, pp. 2423-2433, 1986.

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CONCLUDING REMARKS

This publication documents the FY 1987 accomplishments, research and technical highlights for the Space Directorate.

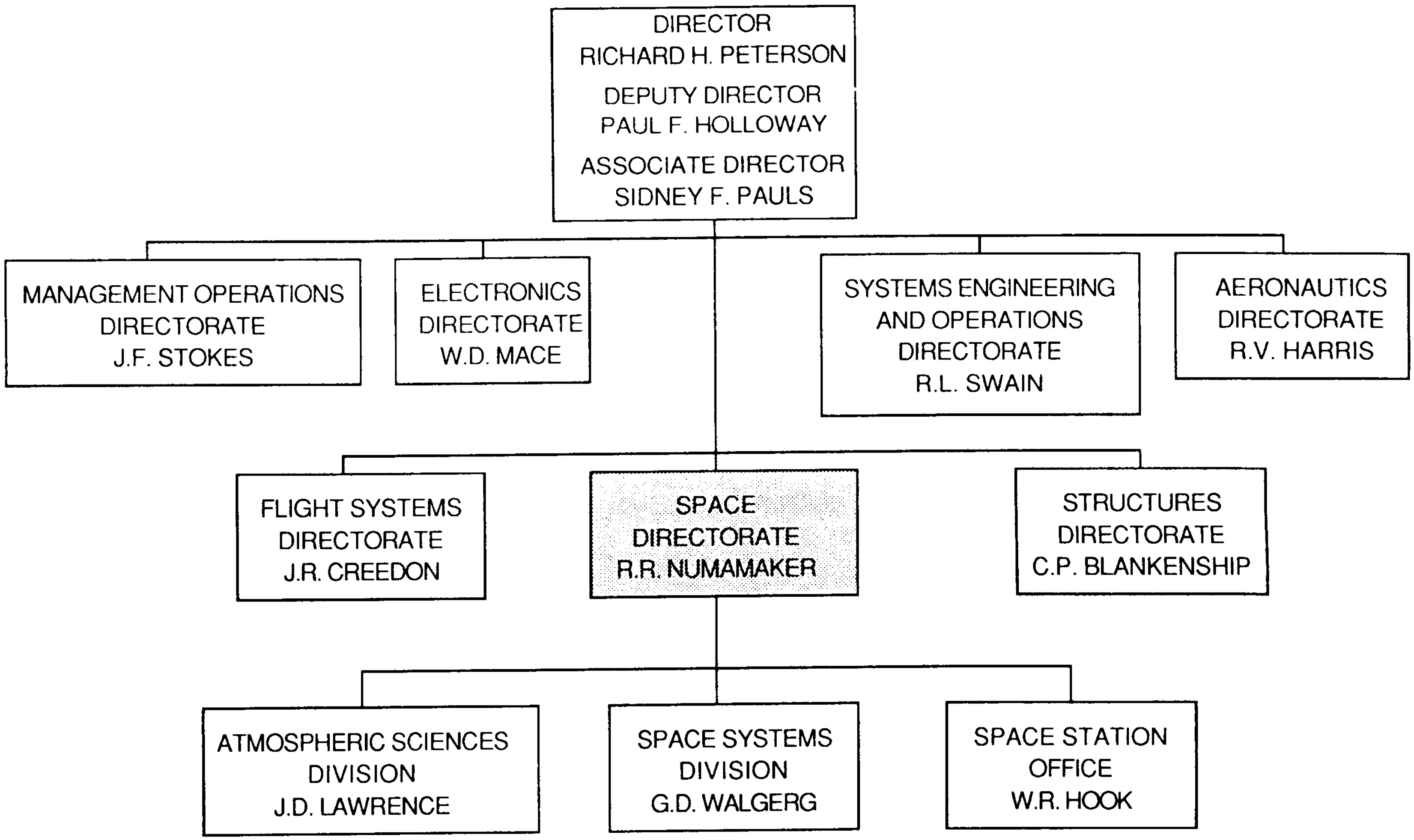

Figure 1.- Langley Research Center.

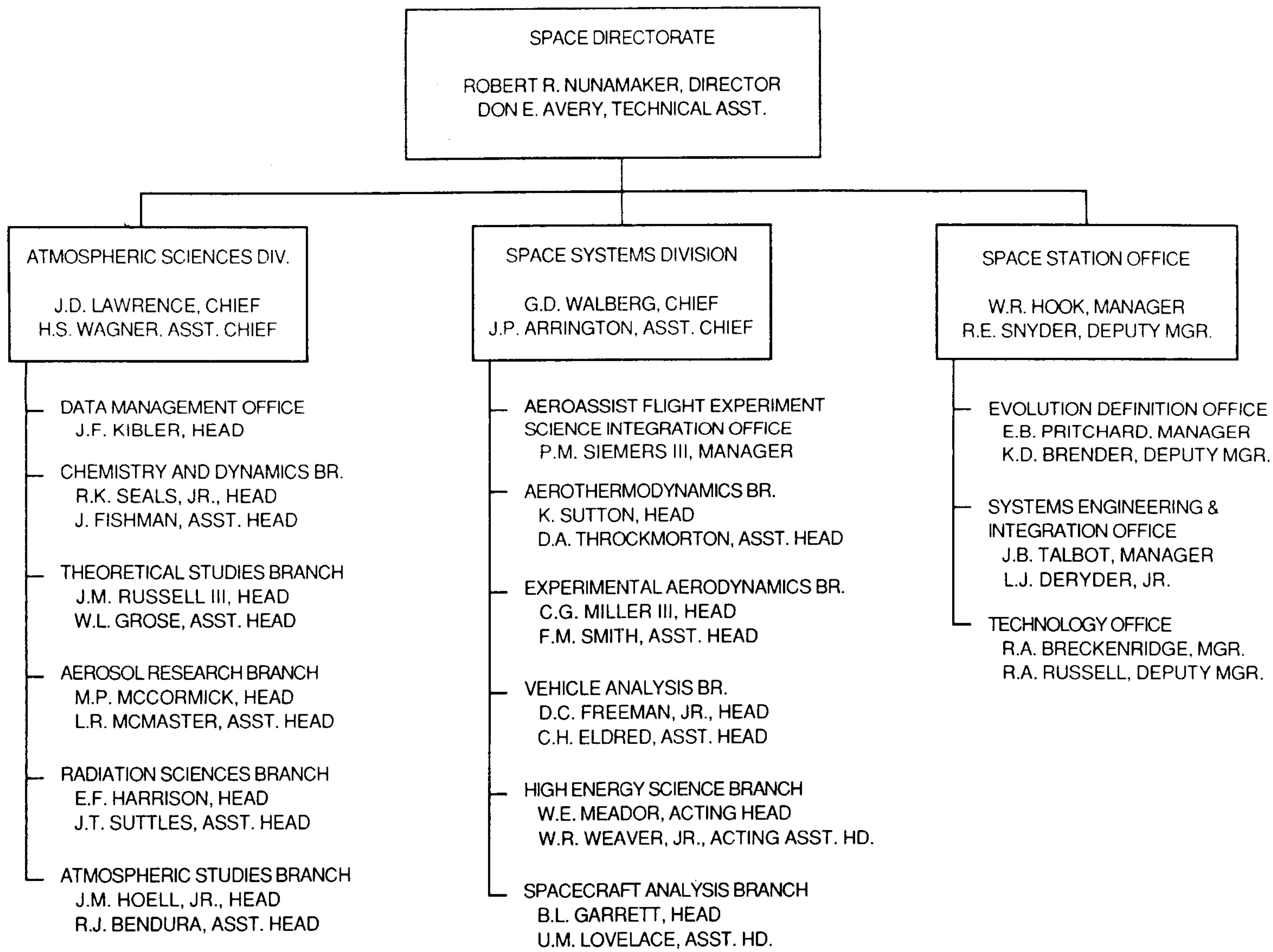

Figure 2.- Space Directorate.

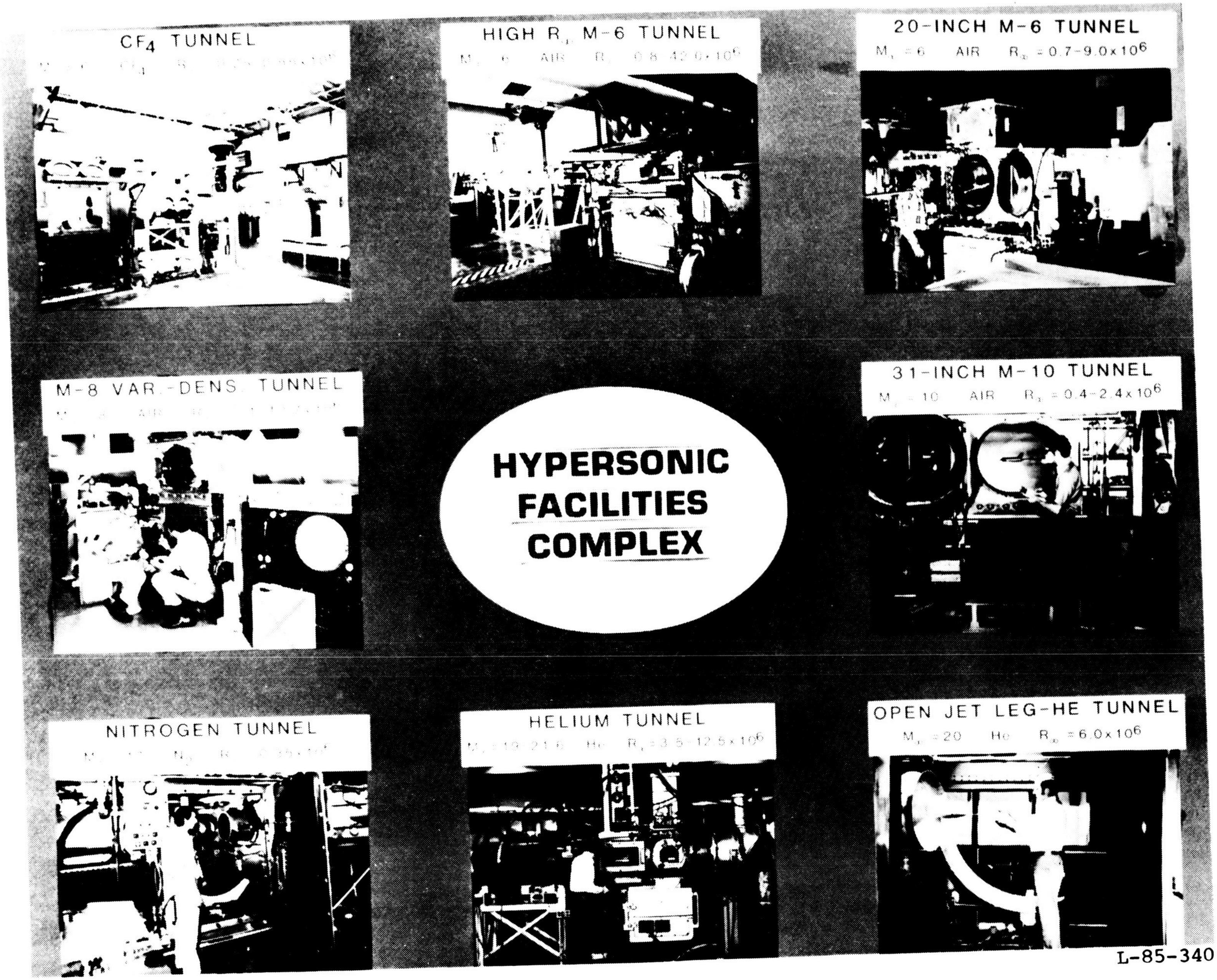

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Figure 3.- Hypersonic Facilities Complex.

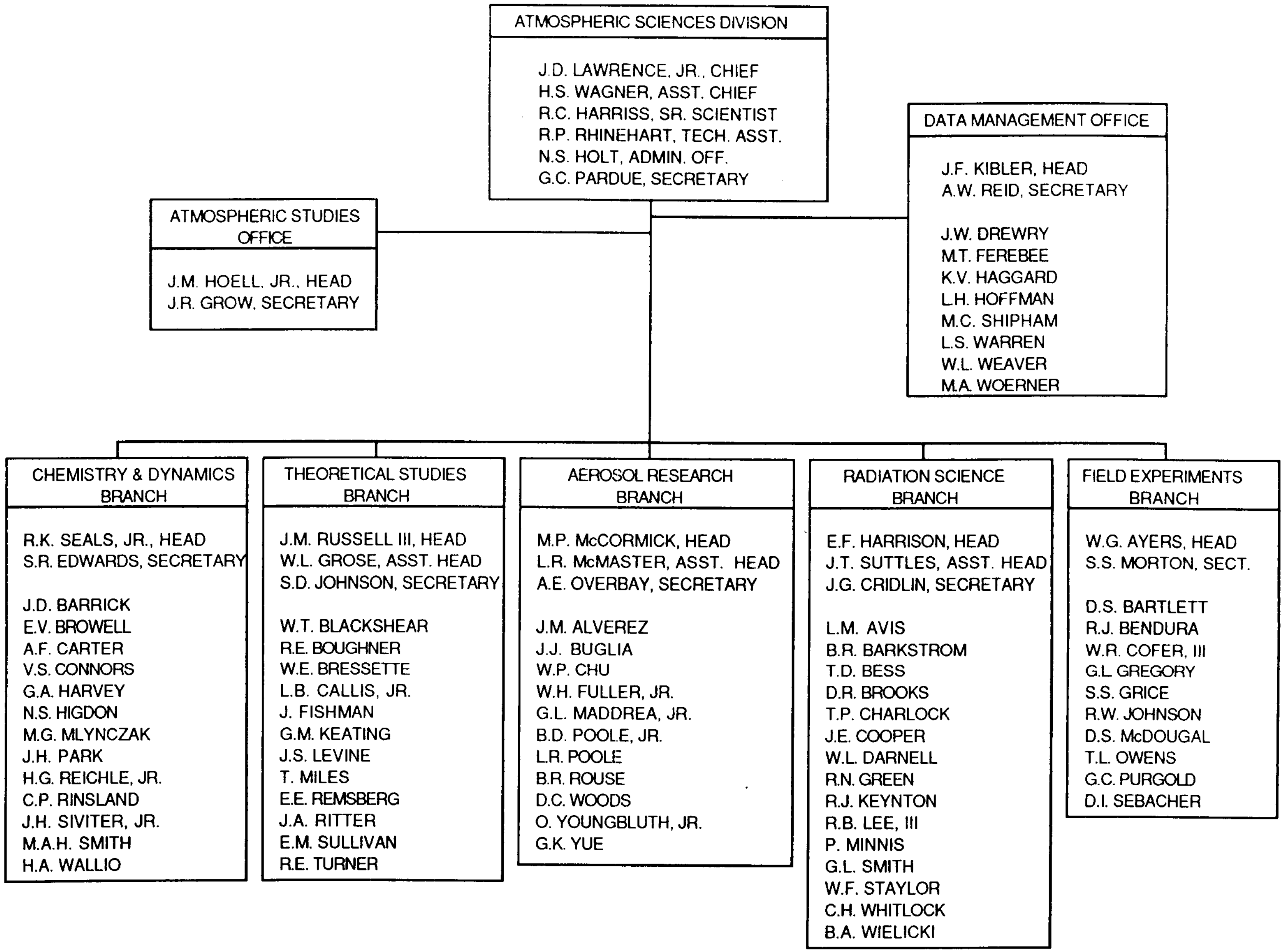

Figure 4.- Atmospheric Sciences Division Organization.

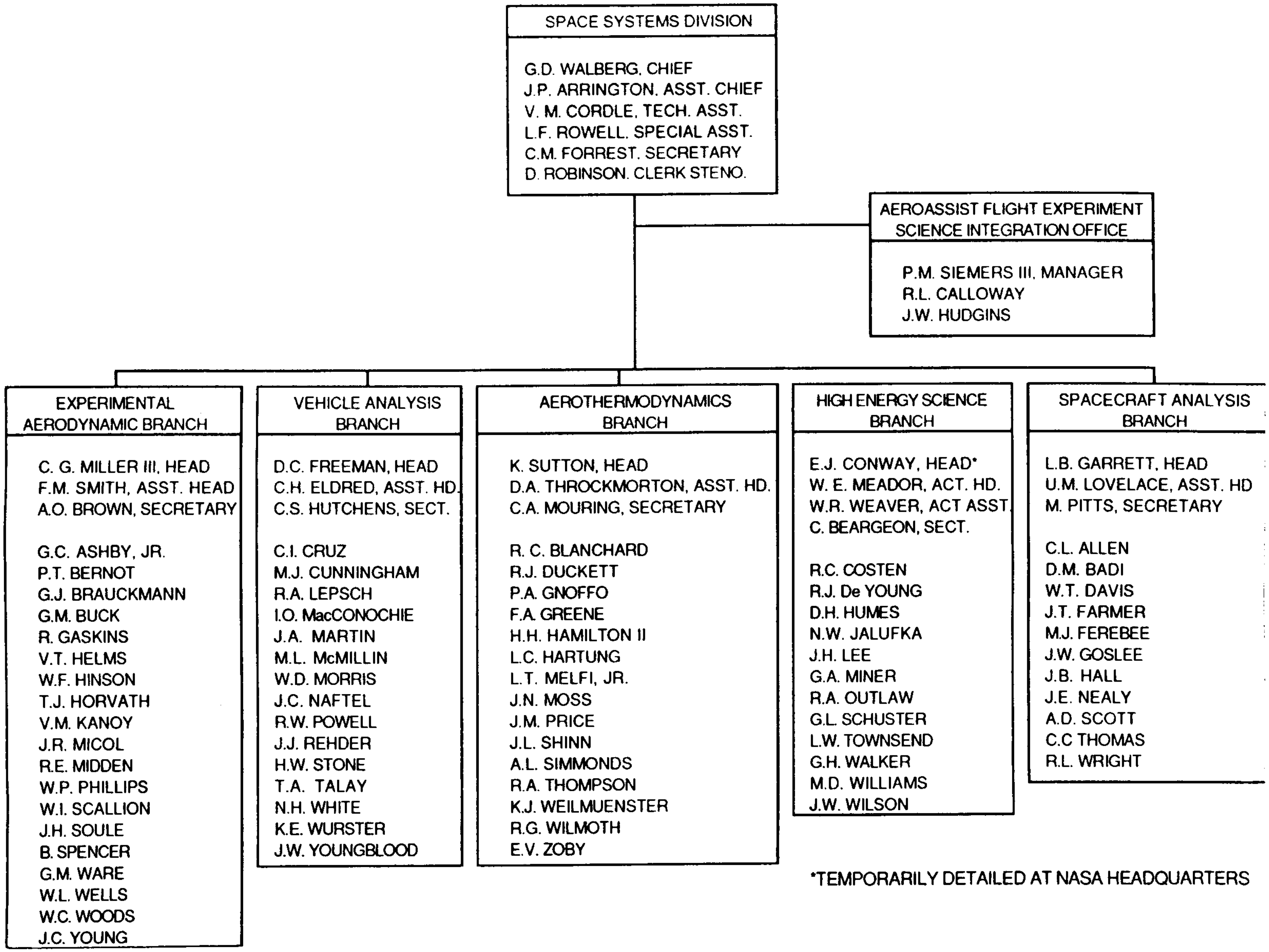

Figure 5.- Space Systems Division Organization.

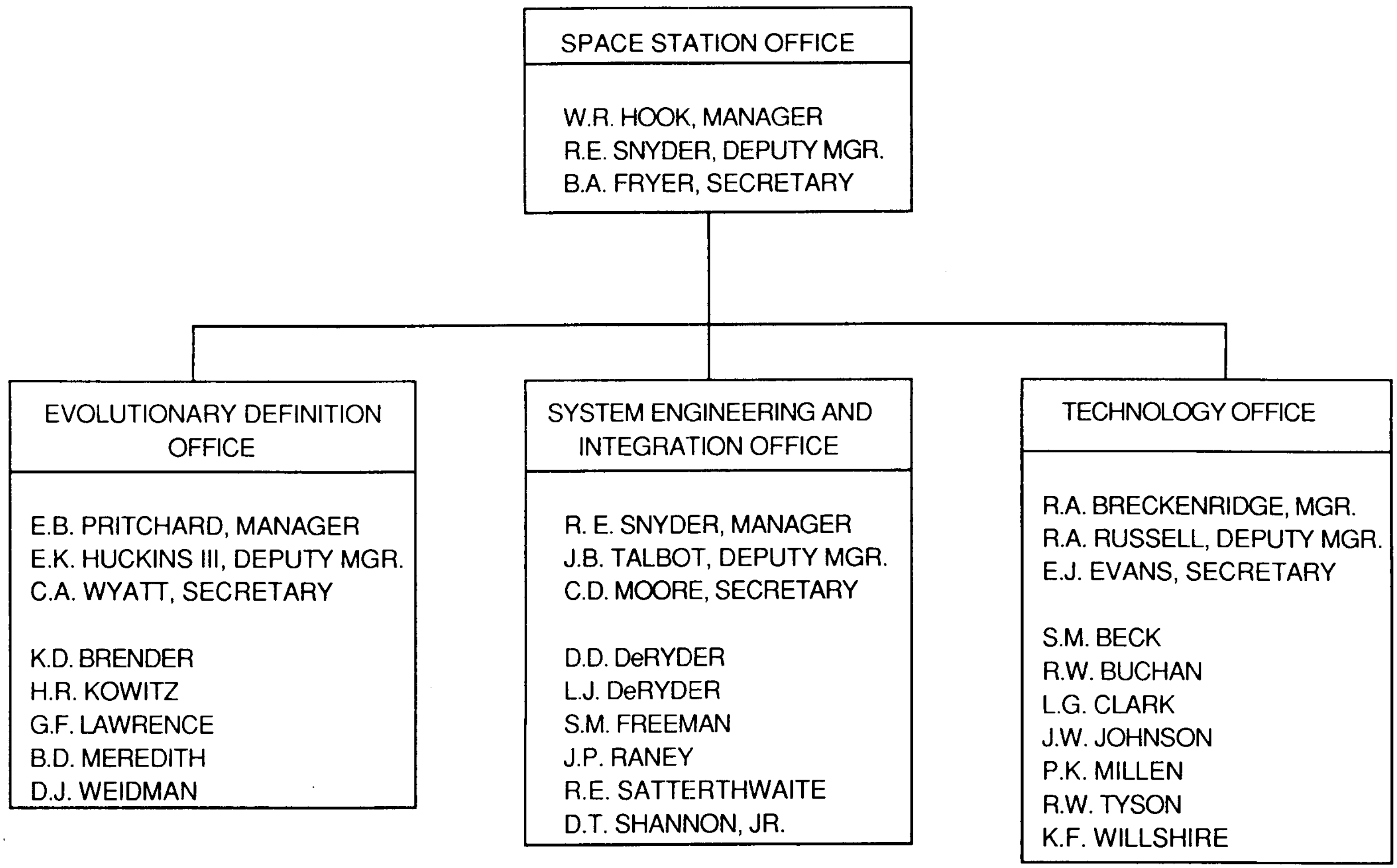

Figure 6.- Space Station Office Organization.

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15. Supplementary Notes

16. Abstract

The purpose of this report is to present the major accomplishments and test highlights for FY 1987 that occurred in the Space Directorate. Accomplishments and test highlights are presented by Division and Branch. The presented information will be useful in program coordination with government organizations, universities, and industry in areas of mutual interest.

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