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SEMI-ANNUAL PROGRESS REPORT PART I - OART PROGRAM SUPPORTING RESEARCH PROJECTS (U)

(JULY 1, 1964 TO JANUARY 1, 1965)

Research Projects Laboratory

NASA

George C. Marshall Space Flight Center, Huntsville, Alabama

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SEMI-ANNUAL PROGRESS REPORT

PART I
OART PROGRAM

SUPPORTING RESEARCH PROJECTS (U)

ABSTRACT

This Progress Report presents the Office of Advanced Research and Technology Program of Supporting Research and is Part I of a three-part series which describes the George C. Marshall Space Flight Center's Supporting Research Program for the reporting period July 1, 1964 through January 1, 1965.

OART tasks are submitted in their respective program areas of Space Power Technology, Space Vehicle Systems, Electronic Systems, and Research. Within the framework of Sub-Program and Task Area, both in-house and out-of-house work units convey in condensed form, the purpose, status, accomplishments, problems, and future plans of each study with appropriate illustrations. Finally, an introductory summary gives the highlights of the entire report in reduced form.

It should be noted that some of the studies found in this report have not been sponsored by the OART Program, but are included because they are identified with the OART mission.

Additional copies of this report may be obtained from the MSFC Technical Library, MS-IL.

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SEMI-ANNUAL PROGRESS REPORT

PART I

OART PROGRAM

SUPPORTING RESEARCH PROJECTS

(July 1, 1964 to January 1, 1965)

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RESEARCH AND DEVELOPMENT OPERATIONS
RESEARCH PROJECTS LABORATORY

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FOREWORD

The George C. Marshall Space Flight Center's Supporting Research Semi-Annual Progress Report was initiated July 1, 1961 in order to facilitate the exchange and dissemination of technical information and research results by providing a qualitative document for the reference of personnel engaged in the promotion of research activities.

This issue, Part I, Part II, and Part III, presents the status of individual work units under the cognizance of the Research Projects Laboratory during the period between July 1, 1964 and January 1, 1965.

This Center is justifiably proud of the effective utilization of research funds as demonstrated by accomplishments such as those found in this issue of the Report.

C. G. Miles, Jr., Chief
Supporting Research Office

Ernst Stuhlinger, Director
Research Projects Laboratory

ACKNOWLEDGEMENTS

Specific individuals, whose cooperative efforts assisted in the publication of this Report include Mr. Ledbetter (editorial assistance) and Mr. Ziak and Staff, Management Services Office; Mr. Smith, Quality and Reliability Assurance Laboratory; Mr. W. Murphree and Mr. J. Cauthen, Aero-Astrodynamics Laboratory; Mr. Daussman, Astrionics Laboratory; Mr. Holland, Manufacturing Engineering Laboratory; Mr. Rodman, Propulsion and Vehicle Engineering Laboratory; Mr. Hill, Test Laboratory; Mr. Doherty, Research Projects Laboratory; and Mr. Bean, Computation Laboratory.

TABLE OF CONTENTS

Page

SECTION I. SPACE POWER TECHNOLOGY PROGRAM 17

CHEMICAL POWER GENERATION 17

Fuel Cells 17

A. Fuel Cell Systems 17

B. Study of Energy Conversion Systems 20

Batteries 22

A. Research and Development of Primary Zinc-Silver Oxide Battery with Long Stand Capabilities 22

Electrical Power Distribution and Control 24

A. Development of 100 Ampere Silicon Transistor 24

B. Integrated Circuit Semiconductor Preamplifier 25

C. Integrated Circuit Power Amplifier 26

D. High Current Switching Devices 28

E. Bifilar-Wound Relays 31

SECTION II. SPACE VEHICLE SYSTEMS PROGRAM 33

SPACE VEHICLE AND ENVIRONMENTAL FACTORS 33

High Energy Radiation Effects and Shielding 33

A. Evaluation of Simulated Radiation Shielding 33

B. Data Compilation and Evaluation 34

C. Transport of Neutrons Induced by Space Radiation 35

TABLE OF CONTENTS (Cont'd)

Page

D. Evaluation of Nuclear Rocket Shield Calculation Methods 36

E. Compilation and Summary of Space Radiation and Shielding Data 37

F. Electron Shielding Studies 39

G. Experimental Simulation of Large, High Field Superconducting Magnet Operation 40

H. Experimental Investigation of Advanced Superconducting Magnets 42

I. Investigation of the Current Degradation Phenomenon in Superconducting Solenoids 44

J. Investigation of Mechanisms of Superconductivity by Nuclear Irradiation 45

K. Study of Properties of High Field Superconductors at Elevated Temperatures 49

L. Theoretical Investigation of Mu-Capture Ratio and Properties of Comparable Beta Transitions 54

M. Investigation of the Combined Effects of Nuclear Radiation, Cryogenic Temperature, and Vacuum on Engineering Materials 56

Meteoroid Environmental and Impact Hazard 59

A. Meteoroid Impact Simulation by Magnetic Gradient Particle Acceleration Techniques 59

B. Meteoroid Distributed Transducer 60

C. Feasibility Study for A Hypervelocity Rail Gun 61

TABLE OF CONTENTS (Cont'd)

Page

Thermal Radiation Effects and Temperature 62

A. Study of the Effects of Ultraviolet Radiation 62

B. Theoretical Study of the Radiative Emissivity of Materials 64

C. Emittance of Materials at Very High Temperatures 65

D. Emission Properties of Materials at Cryogenic Temperatures 66

E. Study of Micrometeoriod Damage to Thermal Control Materials 70

F. Directionally Reflective Surface Study 74

G. Research on Thermal Control Surfaces for the Extraterrestrial Environment 75

H. Solar Wind Damage to Spacecraft Thermal Control Surfaces 77

I. Electromagnetic Irradiation Effects on Thermal Control Surfaces 78

J. Thermal Similitude 79

K. Study of Interface Thermal Contact Conductance 86

L. Thermal Control by Use of Fusible Material 88

M. Development of Space-Stable Thermal-Control Coatings (Paints with Low Solar Absorptance/ Emittance Ratios) 89

N. Use of Thermal Models for Environmental Testing 96

TABLE OF CONTENTS (Cont'd)

Page

O. A Mathematical Expression for the Radiation Intensity and Reflectivity of the Lunar Surface 96

P. Development and Construction of an Infrared Radiometer 97

LAUNCH VEHICLE AEROTHERMODYNAMICS 99

Vehicle and Base Heating 99

A. Experimental Investigation of Combustion Phenomena in the Base Region of Vehicles Caused by Upstream Injection of Fuels 99

B. Base Heating and Separation Studies 101

C. Research on Base Heating of Rocket Motor Vehicles Using Shock Tube Techniques 104

D. Radiation from Gases 137

E. Study of Heating by Radiation From Exhaust Gases 138

F. Rocket Mainjet Radiation 141

Aerodynamic Forces, Steady Loads, Stability and Control 143

A. Experimental and Theoretical Investigation of the Dynamics of Separated Flow over Blunt Bodies 143

Acoustic Noise Propagation 144

A. Investigation of Noise Generated by Internal and External Rocket Combustion Phenomena 144

B. Development of Data Analysis Methods for High-Intensity Sound Propagation 145

TABLE OF CONTENTS (Cont'd)

Page

C. Establishment of Contingency Tables for Sound Propagation Forecasting 148

D. Absorption of Low Frequency Acoustic Energy in the Atmospheric Media 150

E. Aerodynamic Noise Research 151

LAUNCH VEHICLE STRUCTURES 152

Structural Loads 152

A. Wind Induced Oscillations 152

B. Evaluation of Spherical Balloon Aerodynamically Induced Motions 154

C. Engineering Development of JIMSPHERE Wind Sensor 155

D. Critical Evaluation of Methods for Making High Resolution Wind Measurements 156

E. Analysis of Variance with Correlated Variables and its Significance for Meteorological Statistics 157

Structural Dynamics 158

A. Sound Transmission Loss of Structures and Materials at Low Frequency 158

B. Axial Transmissibility Characteristics of Typical Rocket Vehicle Structures 159

C. Correlation of Random and Sinusoidal Vibrations 160

D. Study on the Failure of Equipment Due to Vibrations . . . 161

TABLE OF CONTENTS (Cont'd)

Page

E. Exploratory Studies and Analysis of the Problem of Buckling of Cylindrical Shells with Inclined Stiffeners 162

F. Monocoque Bulkhead Hoop Compression 163

G. Theoretical Research on the Pressure Distribution on Non-Spinning Multi-Stage Spacecraft Performing Bending Oscillations 166

H. Environmental Research 167

I. Fuel Sloshing Studies 168

J. Study of the Natural Vibration Modes and Frequencies of Space Vehicles 169

K. The Investigation of the Effects of Longitudinal Vibrations on the Structural Performance of Large Rocket Boosters 171

Structural Mechanics 172

A. Study of the Stability of Reinforced Cylindrical and Conical Shells Subjected to Various Types and Combinations of Loads 172

B. Elastic Behavior of Sandwich Shells 173

Structural Fabrication Techniques 175

A. Development of Technology Using Composite Sandwich Structures 175

SPACE VEHICLE DESIGN CRITERIA 175

Environmental Criteria 175

TABLE OF CONTENTS (Cont'd)

Page

A. Design Criteria for Theoretical and Experimental Dynamic Analysis 175

B. Environmental Design Criteria 177

C. Formulation of Space Environment Criteria 178

D. Collection of Material Property Data and Presentation of Said Data in the Form of Material Data Handbooks . . . 179

E. Formulation of Structural Analysis Criteria 180

SECTION III. ELECTRONIC SYSTEMS PROGRAM 182

GUIDANCE SYSTEMS 182

System and Trajectory Analysis 182

A. Application of Calculus of Variations Theory to Problems of Performance and Guidance 182

B. Methods of Fitting Multivariant Functional Models in the Area of Large Computer Exploitation 182

C. Development of Methods for Large Computer Exploitation 184

D. Developing Methods for Functional Model Development 185

E. Orbital Transfer and Guidance Studies 186

F. Satellite Rendezvous and Orbit Transfer Studies 188

G. Orbital Transfer and Guidance Studies 190

H. Analytical Tools for Guidance 191

TABLE OF CONTENTS (Cont'd)

Page

I. Direct Methods of Optimized Reentry to Establish Abort Conditions 192

J. Investigation of Orbital Mechancis, Space Flight Theory and Numerical Analysis 193

K. Performance and Guidance Theory Studies 194

L. Docking Study 195

M. Study for Purpose of Defining Navigation and Guidance System Requirements Peculiar to Lunar Surface Operations 196

Inertial Sensors and Systems 198

A. Cryogenic Gyro (Project SPIN) 198

B. Analysis, Design, and Prototype Development of Squeeze Film Bearings for AB-5 Gyro 199

C. Design and Development of an Optical Servo Pickup 201

D. Gas Bearing Research 202

E. Gas Bearing Research 203

F. Study for the Development of Accelerometer Test Methods 204

Active Electronics Devices and Systems 206

A. Jam-Resistant Secure FM Command Receivers 206

B. Studies in the Theory and Application of Statistical Filter Theory to Selected Problems of Guidance, Control, and Navigation of Space Vehicles 207

TABLE OF CONTENTS (Cont'd)

Page

C. Studies in the Theory of Statistical Filters and Their Application to Selected Problems of Guidance, Control, and Navigation of Space Vehicles 208

D. Basic Sensor Requirements for an Advanced Spaceborne Detection, Tracking and Navigation System Capable of Performing an Interplanetary Mission 209

E. Compilation of Analytical Data Relative to Development of Advanced Spaceborne Detection, Tracking, and Navigation System 211

F. Optical Guidance Feasibility Study 213

G. Lunar Landing Sensors 216

H. Study of Basic Requirements of a Navigation, Guidance, and Control System for an Unmanned Lunar Landing Vehicle. 219

I. Survey and Comparison of the Astrionics Systems of Existing or Development Space Vehicles 220

Systems and Trajectory Analysis 226

A. Analytical Study and Mathematical Research for Development and Implementation of the Path Adaptive Guidance Mode 226

B. Trajectory Studies for Varying Missions Including Orbit Transfer and Rendezvous 228

C. Study and Research in New Methods for Systematic Generation of Liapunov Functions for Control Systems 228

TABLE OF CONTENTS (Cont'd)

Page

CONTROL SYSTEMS 229

Advanced Control Theory 229

A. Booster Attitude Stabilization Network Synthesis 229

B. Transmission Concepts in Flexible Launch Vehicle Control 231

C. Research Study of Large Flexible Launch Vehicle 232

Advanced Component Technology. 233

A. Development of a Pressure and Force Transducer Calibration Procedure for the Hypersonic Shock Tunnel 233

B. Pure Fluid Facility Development 234

COMMUNICATIONS 238

Communications Techniques and Components 238

A. Location of Pattern-Disturbing Structures in the Near-Field of an Antenna 238

B. Study of Short Term Phase Stability 239

C. Phase Variation Characteristics of Low Frequency Transmission 240

D. Absorption Measurements at 33 GHz and 93 GHz 242

E. Design, Development and Fabrication of a Two Axis Pedestal for Missile Tracking Using Coherent Light Techniques 243

TABLE OF CONTENTS (Cont'd)

Page

F. Development of an Optical Superheterodyne Receiver 243

G. Determination of Optical Technology Experiments for a Satellite 244

Advanced Electronic Devices 246

A. A Development Program on an Array of Gallium Arsenide Injection Lasers 246

B. Development of a Frequency Stabilized Laser 247

C. Research on Semiconductor Injection Lasers 248

D. Research and Development of Solid State Photomixing Devices 249

E. Development of a 10 Ampere Laser Modulator 250

F. Laser Amplifier Development 251

G. Investigation of Electro-Optical Techniques for Controling the Direction of a Laser Beam 252

H. Development of Fusion Welding for Electronic Connections 253

I. Improvement of Technology for Electronic Welding and Electrical Manufacturing Methods and Processes . . 254

J. Development of Technology for Analysis of Electronic Connections 255

K. Quality Control Requirements for Integrated Circuits 256

TABLE OF CONTENTS (Cont'd)

Page

TRACKING AND DATA ACQUISITION 261

Tracking, Data Acquisition and Components 261

A. Onboard Determination of Orbital Parameters 261

Advanced Electronic Devices 262

A. Development of High-Power Gas Lasers 262

B. Frequency Stability Measurements and Improvements of the Hydrogen Maser 263

C. Frequency Synthesizing System for the Hydrogen Maser 264

INSTRUMENTATION 265

Engineering Instrumentation 265

A. Development of Low Range Absolute Pressure Calibration System 265

B. Strain Gage Accelerometer with Self-Calibrating Feature 266

C. Self-Calibrating Piezoelectric Accelerometer 267

D. Development of Thermocouple Seals to Withstand 1500 psi at 800° C 268

E. Self-Calibrating Cryogenic Pressure Transducer 269

F. Development of an Image Converter of Radical Design 270

G. Design and Development of Solid State Image Converter for Space Vehicles 272

TABLE OF CONTENTS (Cont'd)

Page

H. Pressure Probe Characteristics in Transitional Knudsen Number Range 274

I. Development of Advanced Flight Strain Measuring Techniques 276

Astrophysical Instrumentation 279

A. Electric Field Meter Investigation 279

B. Design and Development of a Breadboard Model of an Ultraviolet Air Density Gage 280

DATA HANDLING 282

Advanced Computing Devices 282

A. Studies of Random Process Theory and Physical Application 282

B. Improved Integration Techniques for Digital Differential Analyzer 283

C. Development of New Methods and Applications of Analog Computation 284

D. Research and Development, Fluid Amplifier and Logic 285

E. Study of Fluid Amplifier Scaling 288

F. Analytical Investigation of Fluid Amplifier Dynamics . . 290

G. Investigation and Analysis of Data Compression Techniques and Associated Problems (SS-FM Telemetry System) 293

TABLE OF CONTENTS (Cont'd)

Page

SECTION IV. RESEARCH PROGRAM 295

MATERIALS RESEARCH 295

Coatings 295

A. Development of Low Temperature Dielectric Coatings for Electrical Conductors 295

Polymers 296

A. Silicon-Nitrogen Polymer Studies 296

B. Study of Polymers Containing Silicon-Nitrogen Bonds . . 298

Bearings and Lubrications 301

A. Research on Bearing Lubricants for Use in High Vacuum 301

B. Lubrication 303

Fabrication and Processing 305

A. General Purpose Laser for Drilling and Welding 305

B. Electric Discharge Forming 312

C. Vacuum Sealing by Magnetic Pressure 319

D. Development of Vacuum Deposition Techniques 321

E. Fundamental Study of Inclusion, Phases, and Precipitates in Aluminum Alloy Weldments 321

F. Experimental Welding 323

TABLE OF CONTENTS (Cont'd)

Page

Solid State Chemistry and Physics of Materials 324

A. Surface Physics of Metallic Surface 324

B. Physics of Materials at Low Temperature 326

C. Interactions of Slow Electrons with Light Gas Atoms 328

D. Interaction of Electronic Current with Hypersonic Waves in Solids 329

E. Study of Impact Characteristics of Selected Non-metallic Materials in Vacuum Environment 330

F. Determination of the Coefficient of Friction of Metals on Non-metals at Ultra-High Vacuum 331

G. Effects of Vacuum Conditioning on the Physical Properties of Selected Materials 333

H. Research into the Suitability of Various Materials for Optical Maser Action 334

I. Optical Properties of Transition Ions in Crystals 335

J. Research on Molecular Surface Interactions at Space Probe Escape Velocities 336

K. A Determination of the Effects of Rocket Engine Exhaust Impingement on Simulated Lunar Surfaces 337

APPLIED MATHEMATICS 339

Gravitation and Orbital Mathematics 339

A. Digital Filters 339

TABLE OF CONTENTS (Concluded)

Page

B. Methods Study for the Numerical Solution of Ordinary Differential Equations 340

C. Research on Numerical Integration of Second Order Differential Equations 342

D. Research and Applications of Topological Dynamics 343

E. Synthesis of Approximate Trajectories for Low-Thrust Vehicles in Earth-Moon Space 344

F. Orbital Lifetime Study 349

Electromagnetic and Radiation Mathematics 350

A. Integral-of-the-Motion Method of Solving the Boltzmann-Vlasov Equations 350

Geophysical and Planetary Mathematics 353

A. Search for Good Algorithms for Practical Solutions to Discrete Optimization Problems 353

FLUID PHYSICS RESEARCH 354

Thermodynamics and Transparent Properties 354

A. Nonequilibrium Gas Kinetics 354

SECTION V. NUCLEAR ELECTRIC SYSTEMS 356

ELECTRIC PROPULSION 356

Component Technology 356

A. Study of Electrically Propelled Cargo Vehicles for Sustained Lunar Supply Operations 356

LIST OF ILLUSTRATIONS

Figure	Title	Page
1.	Power Amplifier	27
2.	Bifilar Winding Suppression	32
3.	Solar Flare Dose (RAD) - Eight Man Module	35
4.	Critical Current Density Versus Applied Transverse Magnetic Field, Measured at Indicated Temperatures	47
5.	Critical Current Density Versus Applied Transverse Magnetic Field, Measured at Indicated Temperatures	48
6.	Magnetization of NbZr Superconducting Cylinder at 6.2°K	51
7.	Practical Magnetization as a Function of Applied Magnetic Field	51
8.	Practical Critical Current as a Function of Temperature	52
9.	Regions of Critical State Operation of Nb_3Sn + NbZr	53
10.	Materials Division Ion Accelerator Facility	63
11.	Far Infrared Reflection Spectrum of Stainless Steel Type 304	67
12.	Far Infrared Reflection Spectrum of Magnesium	67
13.	Far Infrared Reflection Spectrum of Aluminum Alloy Type 20-24 at 8.5 ±1°K	68
14.	Far Infrared Reflection Spectrum of Chromium	68
15.	Far Infrared Reflection Spectrum of Al_2O_3 (90°)	69
16.	Far Infrared Reflection Spectrum of SiO_2 (Z Cut Quartz)	69

LIST OF ILLUSTRATIONS (Cont'd)

Figure	Title	Page
17.	Far Infrared Transmission of Quartz	70
18.	Spectral Reflectance of Gold Sample Before and After Particle Bombardment	71
19.	Effect of Simulated Micrometeoroid Bombardment Upon Integrated Directional Reflectance	72
20.	Effect of Simulated Micrometeoroid Bombardment Upon Specular Reflectance	73
21.	Calculated Crater Coverage for Natural Meteoroids	73
22.	Thermal Similitude	81
23.	Transients Tests on Prototype and Model (Identical Initial Conditions and 1/2 Scaling)	82
24.	Prototype Configuration 'A'	83
25.	Truncated Cone with Closed Ends Prototype Configuration B	84
26.	Experimental Apparatus	85
27.	Schematic of Ultilayer Coating and Resultant Optical Density of Layers	94
28.	Ray Behavior in Idealized Paint Film Containing Totally Transparent Pigments	95
29.	S-IV 4 Engine Model Base Plate Showing Instrumentation	106
30.	SI Booster Short Duration Base Heating Model	107
31.	S-IV 6 Engine Model	109

LIST OF ILLUSTRATIONS (Cont'd)

Figure	Title	Page
32.	S-I/S-IV Stage Separation Model	110
33.	S-IC Model Installation in LRC 10 by 10 Tunnel	111
34.	S-II Prototype with Basic Heat Shield	112
35.	Ratio of Heat Transfer Coefficients for Cold and Hot Calorimeters in a 1000° F Surface	114
36.	Splitter Plate Installation with S-IV Four Engine Model	115
37.	Plug Cluster Model Installation	116
38.	Heat Transfer and Recovery Temperature Variation with Combustor Reynolds Number at Center of Base Plate	117
39.	Radial Heat Transfer Variation on S-IV 4-Engine Model Base as a Function of Nozzle Wall Temperature	118
40.	Engine Model with Cylindrical Gage Rake Mounted	119
41.	Nusselt Number - Reynolds Number Correlation	120
42.	External Flow Reynolds Number Nozzle Installation	122
43.	Operating Envelope - External Flow Reynold's Number Nozzle System	123
44.	External Flow System Operating Characteristics	124
45.	External Flow Reynolds Number Nozzle S-IC Base Pressure Radial Distribution BFS_1N_1 - 5 Engine Off	125
46.	Installation of Solid Propellant Combustor and Impingement Plate in the 13 ft. High Altitude Facility	126

LIST OF ILLUSTRATIONS (Cont'd)

Figure	Title	Page
47.	Pressure Records - Solid Propellant Impingement Program	127
48.	Solid Propellant Impingement Pressures Along Plate c_L	128
49.	Heat Transfer Records - Solid Propellant Impingement Program	129
50.	Schematic of Electron Beam Density Probe Setup	131
51.	Electron Beam Installation with S-IV 4-Engine Splitter Plate Model	132
52.	Beam Density and Pressure Instrumentation	132
53.	Spectral Absorptivity of CO Fundamental at Temperature 300°K and Path Length 10 cm	139
54.	Spectral Absorptivity of CO Fundamental at Temperature 300°K and Path Length 20 cm	139
55.	Spectral Absorptivity of CO Fundamental at Temperature 1800°K and Path Length 10 cm	140
56.	Spectral Absorptivity of CO Fundamental at Temperature 1800°K and Path Length 20 cm	140
57.	Specimen Geometry and Liquid-Fill Conditions	165
58.	January (434 Observations)	178
59.	Optical Guidance System	215
60.	Breadboard System	215
61.	Breadboard System	216

LIST OF ILLUSTRATIONS (Cont'd)

Figure	Title	Page
62.	Birefringent Flow Stand	236
63.	Birefringent Test Cell	237
64.	Transadmittance Measurements of Motorola MM-1154 Transistor at 200 Megocycles and Comparison with Manufacturer's Data Sheet	258
65.	Schematic Diagram for Emmittance Measurements	260
66.	Transducer Load Calibration at Ambient Temperature	278
67.	Transducer Load Calibration at LN_2 Temperature	278
68.	Fluid Amplifier Compensation - Circuit Diagram	287
69.	Actuator System Block Diagram	287
70.	Vortex Diode	289
71.	Scaled Drawing of Designed Bistable Amplifier	289
72.	Boundary Layer Amplifier	290
73.	Computational Flow Field for Time-Dependent Viscous Jet with Control	292
74.	Present 240,000 Joule Laser Head Lasing	306
75.	Progress on New 240,000 Joule Laser Head	306
76.	Front View of Laser Head Showing Quartz Lens Focussing System	307
77.	View of Laser Head Showing Cassegrainian Mirror Focussing System	307

LIST OF ILLUSTRATIONS (Concluded)

Figure	Title	Page
78.	Experimental Set-Up to Measure High Photo Intensity	309
79.	Frosting of Pyrex Jacket for Ruby in Present 240,000 Joule Head	310
80.	Ruby Damage	310
81.	Dewar Jacket for Ruby in New 240,000 Joule Head	311
82.	Schematic of Low-Inductance 20 Kilojoule Device	313
83.	Electromagnetic Transducer Pressure Records	315
84.	Pressure-Time Profile Showing Theoretical Versus Experimental Curves	316
85.	12-Inch Pancake Coil	317
86.	Pancake Coil Assembly	318
87.	New Design of Coil for Joining Stainless Steel Tubing to Titanium for Cryogenic Fluid Transfer	320
88.	Typical Composite Trajectory (Cislunar Match)	348

LIST OF TABLES

Table	Title	Page
I.	Material for Evaluation in Combined Enviroment	57
II.	Properties of Dry Film Lubricants	302
III.	Maximum Coefficient of Friction of Lubricants Evaluated at Extreme Pressures	304

TECHNICAL MEMORANDUM X-53236

SEMI-ANNUAL PROGRESS REPORT

PART I

OART PROGRAM

SUPPORTING RESEARCH PROJECTS

SUMMARY

Presented in this summary is a brief account of progress as reported during this period to include the program areas of Space Power Technology, Space Vehicle Systems, Electronic Systems, and Research, within the Office of Advanced Research and Technology.

SECTION I - SPACE POWER TECHNOLOGY PROGRAM

This section of the report pertains to research relating to the generation of electrical power by fuel cells and batteries. Study of the distribution and control of electrical energy is also included in this section of the report.

Chemical Power Generation

Fuel Cells

Study within this area is being directed toward the accomplishment of adequate research to develop materials, processes, and engineering criteria needed to assure the realization of an operational open-cycle fuel cell system which will meet wide range applications for space vehicles.

The accomplishments have been outstanding to date although most of the effort has been concentrated on the breadboard system, and on detail plans and

specifications required for the systems program. Two of the three breadboard systems have been completed and tested extensively.

Another study, which is obtaining a better understanding of the application limits of the fuel cell and combinational systems, reports that a battery-fuel cell parallel combination offers definite advantages with regard to optimization.

Batteries

This area is currently concerned with the research and development of primary zinc-silver oxide batteries with long stand capabilities. The work includes investigation of separator materials, plate materials, and the special treating of plates to increase stand of primary batteries.

Among other things, separator materials are being studied with the objective of decreasing the thickness of open separator material while increasing the membrane thickness. Studies of density effects in positive plate materials are planned.

Electrical Power Distribution and Control

This area presents the status of several tasks involving the improvement of electrical systems and devices such as the preamplifier, transistor, and electrical connector.

The semiconductor preamplifier study is an attempt to develop and fabricate and integrated circuit preamplifier for use in static inverters. Final devices were developed which met or surpassed all specifications as set out in the scope of work.

The work unit, "Development of a 100 Ampere Silicon Transistor" is developing a device for application in dc distribution systems, high power static inverters, and in ac motor drive systems.

Prototype samples have been developed which meet the requirements of the contract except in breakdown voltage problem.

SECTION II - SPACE VEHICLE SYSTEMS PROGRAM

This section of the report encompasses study areas relating to vehicle environmental factors, aerothermodynamics, structures, and design criteria. More specifically, problems involving radiation effects, meteoroid impact, temperature control, base heating, structures, and environmental criteria are included in this section.

Space Vehicle Environmental Factors

High Energy Radiation Effects and Shielding

This area includes studies pertaining to the shielding of high energy radiation by materials and superconducting magnets. The effects of radiation on materials, and the evaluation of shielding techniques are also found in this group of work units.

In the study to obtain experimental data on the combined effects of nuclear radiation, vacuum, and cryogenic temperatures on engineering materials, mechanical and electrical property measurements have been made on approximately eighty-three aerospace engineering materials while exposed to environmental parameters. Within each group of materials, those which are useful in areas involving high energy irradiation have been selected, and those which show serious degradation have been listed for designers of space vehicles.

The study to perform an extensive set of Monte Carlo calculations for the transport of energetic neutrons released by the non-elastic collisions of protons is now complete. An analysis of neutron transport in polyethelene, iron and aluminum with energies from .5 to 14 MeV has been made.

Several tasks dealing with the pehnomenon of superconductivity are presented during this reporting period. These studies range from an investigation of the feasibility of protecting space vehicles against charged particle radiation, to the study of some of the mechanisms involved in superconductivity. Other tasks involve the advancement of the state-of-the-art of high field superconducting solenoids. One study, involving the experimental investigation of advanced superconducting magnets, the strip magnet was tested with favorable results. Plans call for an improved strip coil to be built and thoroughly tested. In another study, results of scientific importance are being produced relative to the investigation of the changes in the properties of high-field superconductor materials due to irradiation with charged particles.

Meteoroid Environmental and Impact Hazard

This area takes into account studies concerned with obtaining a quantitative description of meteoroid particles in space, and the assessment of hazard posed by meteoroids impacting on space vehicles.

The work unit, "Meteoroid Penetration Distributed Transducer" is looking into possible transducer material and/or a geometry which, when subjected to hypervelocity impact, will yield useful information concerning impacting particles. A transducer material has been selected and the study appears to be progressing satisfactorily.

The study, "Feasibility Study for a Hypervelocity Rail Gun" is based upon a previous study (NAS3-1924), in which a unique method of mechanical interaction between pellet and a magnetic field produced by condenser discharge was demonstrated. The study is now attempting to explain the observed interaction and to evaluate its feasibility in hypervelocity gun application. A decision as to feasibility is expected in the next reporting period.

Thermal Radiation Effects and Temperature Control

This area involves the investigation of the effects of thermal radiations and extends into studies of the thermal control of space vehicles.

The purpose of the study, "... Thermal Models for Environmental Testing" is to confirm by experiment the theoretical validity of dimensional analysis and similitude as applied to the thermal behavior of materials in a hand vacuum. The first phase of the thermal similitude experiments has been completed. Plans are to perform the entire series of experiments again in order to eliminate certain temperature gradients.

Normal spectral emittances from 1 to 15 microns were measured for platinum at 1400°K and for 11 ceramic oxide specimens at 1200°K in the study, "Emittance of Materials at Very High Temperatures". The agreement between emittance and reflectance measurements was good for aluminum oxide, calcium zirconate, and magnesium oxide.

The work unit, "Development of Space-stable Thermal-Control Coatings," is being directed toward obtaining coatings with the lowest possible ratio of solar absorptance to infrared emittance. During this period it is reported that potential of the microporous coatings system has been indicated, and that progress toward the silicone polymer of necessary stability has been achieved.

Several thermal control coatings and their components have undergone simulation of ten years or more of proton bombardment showing various degrees of degradation in the study, "Solar Wind Damage to Spacecraft Thermal Control Surfaces". The major accomplishment, at this time, is reported to be in the simulation of solar wind particles without a resultant charge build-up on the dielectric surfaces, and measurements of current densities.

Vehicle and Base Heating

This area is concerned with experimental investigation of launch vehicle heating and includes heat transfer, base heating, and exhaust gas radiation studies.

The work unit, "Experimental Investigation of Combustion Phenomena in the Base Region of Vehicles Caused by Upstream Injection of Fuels" is attempting to determine the parameters which govern the base heating of a cylindrical body when combustion of entrained gases occurs in the base region. Supersonic tests are being performed on a blunt-based cylinder model. Among other accomplishments, it is reported that the heat transfer to the base of a cylinderical body can be estimated if the concentration of the entrained fluid, as well as the initial conditions without injection is known.

The study, "Base Heating and Separation Studies" reports that an oscilloscope display of the hot wire outputs seems to indicate that self-induced resonance vibrations might exist in the base recirculation zone similar to those that have been suspected in the short duration tests of the S-IC model. Plans call for a correlation analysis of velocity and temperature fluctuations in order to determine the extent of cavity resonance in base recirculation flows.

The study "Research on Base Heating..." is presented in a rather comprehensive report. As previously noted, the basic feasibility of using short duration (short tube) techniques has been demonstrated. This method is being used to study the base heating of launch vehicles and upper stages. Among many other accomplishments, this study has permitted the attainment of design data essential to the S-IC, S-II, and S-IV Saturn stages at a fraction of the cost, on a timely basis, and with a greater confidence level than would have been possible using conventional techniques.

In the study of "... Heating by Radiation from Exhaust Gases", the fabrication and checkout of a high-temperature furnace and the optical system for measuring the infrared spectral absorption characteristics of gases was completed. Also, a series of tests, using carbon monoxide gas has been performed.

Launch Vehicle Structures

Structural Loads

This area is concerned with theoretical and experimental studies that pertain to wind loading on launch vehicle structures. One of the primary objectives is to gather limited samples of detailed and accurate vertical wind profile data for use in vehicle design studies. Low level turbulent wind definitions and wind induced oscillations are also considered during this reporting period.

The "Wind Induced Oscillations" study is dealing with the problem of developing a generalized design criterion to insure structural integrity of the Saturn under wind-induced oscillations in the vertical launch position. Design criteria have been developed for the Saturn Block I and Block II vehicles. Until full scale response measurements have been taken, the design criteria applicability is uncertain.

The task, "Engineering Development of JIMSPHERE Wind Sensor" reports the development of a method of fabricating two-meter diameter balloons out of milar. The purpose of this study is to develop wind sensors for high resolution wind profile measurements to 20-km altitude and to determine aerodynamic and response characteristics. In another study, comparisons have been made between induced motions from one-meter and two-meter diameter balloons. It has been shown that the incuced motions associated with the large balloons have larger amplitudes and longer wave lengths than those associated with the smaller balloons.

Structural Dyanmics

This area is investigating the effects of dynamic loading on launch vehicle structures. Studies concerned with fuel sloshing, vibrations, and bending oscillations are found in this area of study.

The work unit, "Fuel Sloshing Studies" has produced a comprehensive report relating to the problem of liquid impact in space vehicle tanks. This report constitutes a significant achievement in defining the role which experiment can play in determining the effects of liquid impact.

In the study to perform theoretical research on unsteady air loads, a solution for the oscillating cone in supersonic flow has been developed and programmed on the IBM 7094 computer. Future work will involve detailed studies of flared, multi-stage boosters.

The study "... Natural Vibration Modes and Frequencies of Space Vehicles" reports the development of a computer program which will greatly reduce uncertainties in the analysis of Saturn-Type vehicles. Results of comparison studies will be published in the next reporting period.

Two studies are underway which involve the understanding of the vibrational phenomenon with regard to random and sinusoidal vibrations. One task is continuing work in verification of theoretical material damping laws. The other study is concerned with understanding the failure mechanism associated with certain types of equipment. Some relationships have been worked out which relate specific vibration motion within vacuum tubes to the electrical output. The harmonics and subharmonics present in the response of certain tubes indicated pronounced nonlinearities of structures.

Structural Mechanics

This area is concerned with the effects of steady load on launch vehicle structures, sub-structures, and materials. Work units presented during this period are those investigating the elastic behavior of sandwich shells, and the stability of reinforced cylindrical and conical shells.

The "... Sandwich Shells" study reports that non-dimensional design curves for face stresses in the spherical and ellipsoidal sandwich bulkhead configurations have been developed and verified. This study is investigating various bulkhead configurations fabricated from sandwich material and subjected to external pressure and temperature gradients.

Structural Fabrication Techniques

This task area contains tasks that pertain to the investigation and development of the laser for drilling and joining structural components of launch vehicles: and to the development of techniques for fabricating advanced materials.

The study involving the general purpose laser is an in-house effort to explore the potentialities of the laser with regard to its drilling, cutting, and welding capabilities. It was previously noted in the last issue of this Summary that the design of the super power laser (240,000 Joul input range) has been completed. The flash tube has been successfully operated with light output of up to 8.3 billion candle power.

SECTION III - ELECTRONIC SYSTEMS PROGRAM

This section of the report consists of theoretical and experimental studies concerning guidance, navigation, control and stabilization, communications, tracking and data acquisition, and instrumentation.

Guidance and Navigation

System and Trajectory Analysis

This area is composed of studies that deal with orbital transfer and guidance, abort guidance, the re-entry trajectory, and other similar studies.

The purpose of the work unit, "Satellite Rendezvous and Orbit Transfer Studies" is to investigate problems of optimum satellite rendezvous with particular emphasis on error analysis and guidance tradeoffs. During this period two problems were investigated. A method was developed for the precise numerical determination of two-impulse orbital transfers. Also, numerical and analytical results concerning optimum one-impulse orbital transfer maneuvers were investigated.

The study to develop procedures for implementing the path adaptive guidance mode has been concerned with optimal guidance polynomial approximations by an ensemble - averaging approach. The results of this study are available where details have been developed.

The work unit, "Docking Study" is seeking the analytical formulation of the optimum solution for docking with an earth satellite. This study reports that the formulation is based on the use of calculus of variation and includes the equations for target and chaser motion. All equations are developed in three dimensions.

The study, "Developing Methods for Functional Model Development" reports that studies were made of methods for deriving a given error tolerance on least squares functional models. One such method has been developed in detail.

During this period, the major accomplishment of the study, "Application of Calculus of Variations Theory to Problems of Performance and Guidance" involved extention of the Denbow treatment of the problem of calculus of variations to include inequality and control variable constraints. This provides for application to the multistage vehicle problem such as earth-to-moon trajectories and reentry trajectories.

Inertial Sensors and Systems

This area is devoted to the improvement or introduction of new systems for use in the guidance and control of space vehicles.

During the reporting period, progress is reported in the study to design, fabricate and test an engineering model of a cryogenic gyro (Project SPIN). Among other things, a miniature ARC design of the MARK II gyro has proceeded toward improvement in several areas of development. Plans call for additional gyro testing and evaluation.

The work unit, "Analysis, Design, and Prototype Development of Squeeze Film Bearings for AB-5 Gyro" reports that the behavior of the gas in a squeeze film bearing, both thrust and journal, has been characterized. The result of this is the ability to calculate load carrying capacity and stiffness. The study "Gas Bearing Research" reports, among other things, the construction and operation of a squeeze film bearing of the right circular cylinder type. This appears to be among the first of its type to be fabricated in this country.

Active Electromagnetic Devices and Systems

This area consists of an assemblage of studies that pertain to the development of electromagnetic devices for special application such as optical guidance, orbital rendezvous, and lunar landing operations.

One study is being directed toward the development of an experimental prototype antenna system for optical guidance and has progressed from the feasibility study portion into the developmental phase. A complete optimized system would probably utilize radio frequency techniques for acquisition, and optical technicques for tracking, ranging, and docking of two rendezvousing spacecraft. Significantly, it has been shown that once acquisition has been accomplished, optical techniques provide major advantages for tracking and ranging. The breadboard antenna system is complete and is now undergoing technical evaluation.

The study, "Lunar Landing Sensors" is an attempt, among other things, to determine the sensor systems which will be required for a controlled soft landing on the moon. General requirements for the sensor system have been established and specifications defined. During this period, the development of a solid-state source, having an output of one watt at x-band, is considered to be a significant achievement. Moreover, patent disclosures, covering the circuit designs, have been initiated.

The purpose of the work unit, "Survey and Comparison of the Astrionics Systems of Existing or Development Space Vehicles" is to collect all available up-to-date data on the astrionics implementation of selected space vehicles for inclusion into a reference handbook. This study appears to be progressing satisfactorily. Plans call for new, revised or updated data to be added to the existing descriptions. This study should provide quick access, accurate data, and realistic performance figures on state of the art of astrionics systems.

Communications

Communication Techniques and Components

This task area presents studies that are generally concerned with communication techniques and components. For example, studies pertaining to advanced telemetry systems, absorption measurements, phase variation, coherent radiation, and the optical superheterodyne receiver are found in this area.

The objective of the study "Phase Variation Characteristics of Low Frequency Transmissions" is to determine the maximum phase variation occurring in low-frequency transmission over a path of about 400 miles in length. Plans and techniques for the two-way transmission system have been completed. Procurement modification, and installation of equipment will proceed.

The study to develop an optical superheterodyne receiver reports that a receiver has been designed and tested over a range of 6,000 feet through the atmosphere using a laser source operating at 6328 Å. Using this system the effect of atmospheric turbulence on heterodyning of coeherent light has been studied. A frequency translator has also been constructed for use with this receiver. Plans call for an attempt to heterodyne over a range of 14 miles.

The work unit to design and fabricate a precision two axis air bearing tracking mount for an experimental laser tracking system reports that the design is complete and the system is being assembled. This is the first precision air bearing mount in existence. Its use in conjunction with optical tracking techniques will allow tracking of space boosters with an unprecedented degree of accuracy.

Advanced Electronic Devices

The group of tasks found in this task area are concerned with the advancement of such electronic devices as solid state photomixing devices, and injection lasers. The development of devices for phase stable circuitry is also considered during this reporting period.

The objective of the task, "Solid State Photomixing Devices" is to design and develop devices suitable for use in optical communications and space tracking and guidance, using coherent and incoherent light sources. During this period, some photomixer diodes were fabricated and delivered to MSFC. These included InAs diodes for the wavelength region from .9 to 3.5 microns, and si diodes for the wavelength region from .4 to .9 microns. This study is now being extended to develop photomixer diodes using avalanching as current-multiplication.

Design and construction of an optical ellipsometer to measure the ellipticity of light is complete and operable in the task, "Research on Semiconductor Injection Lasers". This study is attempting to improve the injection laser with the end view of developing more efficient devices.

Some very significant breakthroughs in injection laser technology are reported in the study "... Gallium Arsenide Injection Lasers". For example, accomplishments include: Incoherent Radiation at 77° K in excess of 70 percent efficiency (a ten to one improvement over any previous announcement); efficiencies up to 15 percent for laser diodes at room temperature (an improvement by an order of magnitude); and development of lasing diodes up to .25 inches long (indicating about a one hundred to one improvement in optical homogeneity of the diode junction).

The work unit to develop a high current, high speed silicon transistor for use as a modulator for injection lasers reports that the design of this unit is complete and under evaluation. If the prototype units meet the specifications, this will provide the fastest high current switch to date for use with injection lasers.

Tracking and Data Acquisition

Tracking and Data Acquisition and Components

At this time, the only study presented in this task area is entitled "Onboard Determination of Orbital Parameters".

This study has as its objective the definition of advanced systems for the determination of orbital parameters and position relative to space-fixed coordinates, employing onboard electromagnetic sensors. One of the accomplishments reported during this period includes the completion of a study of orbit determination minimum variance techniques. The results of this study is now embodied in a computer program.

Advanced Electronic Devices

This task area includes theoretical and experimental investigations of advanced electronic devices which incorporate new or novel concepts. For example, tasks are being directed toward the development of a frequency synthesizing system, and other developments concerning the use of the hydrogen maser.

The task, "Frequency Stability Measurements and Improvements of the Hydrogen Maser" is being directed toward a number of objectives concerning the relative frequency stability of two NASA hydrogen masers. It should be noted that the use of hydrogen maser as a frequency standard is considered to be important as a laboratory tool as well as a reference for future tracking systems. A cross correlation system has been completed and short term measurements were accomplished. It is now planned to continue study to determine if a hydrogen maser can be optically pumped.

Instrumentation

Engineering Instrumentation

This task area contains an assemblage of studies that are developing instrumentation necessary to measure space vehicle performance and integrity. The study and development of sensors for detecting and measuring phenomena and the development of transducers for translating such measurements into other forms for transmission of recording is the type of effort being considered in this area of the report.

The study, "Solid State Image Converter" is developing a device which will allow for visual evaluation of areas of a launch vehicle or spacecraft not now possible by any other means. One accomplishment consists of the production of 50 by 50 element mosaics with improved sensitivity over a wider temperature range. This study will continue toward developing mosiac design, and toward the completion of peripheral scanning equipment. Another study, aimed at determining the feasibility of a solid state image device reports that photo conductors have been improved.

The task to develop flight models of high accuracy "Self-Calibrating Cryogenic Pressure Transducer" has shown the feasibility of self-checking and self-calibrating pressure transducers. The prototype has been delivered for testing. An important aspect of this development consists of the fact that it provides a transducer that can be installed in a system and completely checked without breaking into the system to apply pressure to the transducer.

Initial results indicate that a highly accurate vacuum calibration system will result from the effort to develop a low range absolute pressure calibration system. The basic system design is complete. Study will continue toward developing an accurate system for 10^{-10} torr.

An accelerometer with very high sensitivity, good stability and excellent frequency response has been demonstrated in the study, "Strain Gage Accelerometer with Self-Calibrating Feature". The unit is built to a 10^{-18} transistor case and is applicable as a pressure transducer and microphone.

SECTION IV - RESEARCH PROGRAM

This section of the report is concerned with research as related to materials investigations, and mathematical concepts. Areas of specific interest pertain to coatings, lightweight alloys, compounds produced by polymerization, lubricants, new fabrication concepts, solid state physics, and applied mathematics.

Materials Research

Coatings

Work units included in this area are concerned with studies such as the behavior of dielectric materials at high field strengths, the development of low temperature dielectric coatings, and the development of seals and sealants.

A polyimide enamel film which is superior to any commercially available wire coating at extreme temperatures and reduced pressures has been developed in the task, "... Low Temperature Dielectric Coatings for Electrical Conductors". Cables have been manufactured using this material to demonstrate its practicality for electronic application.

Polymers

This task area contains studies of polymeric materials for application at various temperature levels, and thus may be important in several aspects of launch vehicle development.

Accomplishments are reported in the in-house and out-of-house tasks, "A study of Polymers Containing Silicon-Nitrogen Bonds". It should be noted that

the compounds suggested in the tasks' titles are characterized generally by their resistance to elevated temperatures. A reproducible procedure has been developed for the curing of a methylphenyl silazane-triethylamine coating agent. This method produced good quality coating which remained intact for 42 hours at 400° C.

Bearings and Lubrication

One task presented in this task area during the reporting period, "Research on Bearing Lubricants for Use in High Vacuum" is developing dry film lubricants that have potential application for use on instrument bearings in high vacuum.

Several lubricant films developed by the contractor have been evaluated in connection with lubrication tests. These films are finding wide use in the aerospace field under both vacuum and earth ambient environments.

Fabrication and Processing

Studies grouped in this task area tend to offer fundamental knowledge to fabrication technology and processing techniques with particular regard to forming, welding, and casting techniques.

As previously reported, the in-house study, "Electric Discharge Forming Development" resulted in the development of a new method. In this method, a large flat pancake coil is used to induce a shock wave into a metal plate, or diaphragm, in proximity. This diaphragm then transmits its energy to the fluid (water). A planer wave is generated, which in turn, forms metal into an evacuated die. This method is considered to be a new development in the area of high energy rate forming techniques. Most of the progress during this period was in the area of theoretical analysis and supporting tests.

Solid State Chemistry and Physics of Materials

This task area is concerned with the physics of the solid state and studies of the physical and chemical properties of materials. Some of the studies presented during this reporting period consist of the investigation of atomic interactions in certain crystals; the investigation of the interactions of slow electrons with light gas atoms; the study of surface ionization on metallic surfaces; and the study of potential laser materials.

The study, "Surface Physics of Metallic Surfaces and Space Technology" is an investigation of ultra high vacuum techniques, and the implication of

surface physics to space vehicle technology. Presently, this study is concentrating on ultrahigh vacuum technology. Also, the field ion microscope technique has been developed for application to various problems pertaining to detailed location of atoms, etc.

The work unit, "Research into the Suitability of Various Materials for Optical Maser Action" is attempting to develop more efficient laser materials and materials that will operate at wavelengths other than those presently available. A new laser material, Yttrium, aluminum garnet doped with Neodymium ($YAG:Nd^{+3}$) has been developed. This material operates at 1.0639 microns continuously at room temperature. This material is the first truly cw solid state laser material which is practical.

Applied Mathematics

Gravitational and Orbital Mathematics

Studies found in this task area pertain to research in topological dynamics and related fields; the development of trajectory data; the study of orbital lifetime; and the investigation of numerical integration of second order differential equations.

The work unit, "Synthesis of Approximate Trajectories for Low-Thrust Vehicles in Earth-Moon Space" is intended to develop a body of approximate trajectory data for low-thrust vehicles operating between satellite orbits of the Earth and Moon. The principal result obtained so far appears to be the development of a new method for approximating low thrust trajectories.

The study to investigate methods of numerical integration reports the discovery of a ninth order formula. Future effort will attempt to complete the formula and to carry out studies related to step-size control and error analysis with particular reference to continuing techniques.

The study, "Orbital Lifetime Study" reports that a comparison of various lifetime prediction models has been completed; this has resulted in several improvements to the model in use at MSFC.

Electromagnetic and Radiation Mathematics

This task area presents a study that is concerned with the exact solution of the Boltzmann-Vlasov equations for a fully-ionized plasma.

The work unit, "Integral-of-the-Motion Method of Solving the Boltzmann-Vlasov Equations" reports progress in several areas of development. For example, considerable progress has been made in obtaining exact numerical solutions for planar, cylindrical and spherical elastrostatic diodes.

SECTION I. SPACE POWER TECHNOLOGY PROGRAM

CHEMICAL POWER GENERATION

Fuel Cells

A. Fuel Cell Systems

Submitted by
(Technical Supervisor)

Mr. Richard J. Boehme
R-ASTR-E, 876-6762

Mr. Charles Graff
R-ASTR-EAP, 876-1518

1. Project Data

Contract Number: NAS 8-2696, Mod. 6, August 14, 1964 - March 14, 1966

Contractor: Allis-Chalmers Manufacturing Co.
Milwaukee, Wisconsin

2. Purpose of Project. The goal of this project is to establish materials and process technology and systems design criteria that will assure a reliable, versatile, high performance fuel cell system capable of meeting the stringent demands of space vehicle applications.

3. Technical Status. The project became a joint effort by MSFC and MSC, Houston when modification 6 of the contract was implemented. The contract was expanded and extended, considerably, because of previous progress and because the subject system potentially fulfills both centers needs.

The effort is divided into three parts as follows:

a. Part I - Research and Technology. Eleven specific tasks have been enumerated to advance the state-of-the-art of fuel cell technology. Briefly, these tasks include investigations and experimental work on electrolyte and water transport matrices, cell fabrication and assembly techniques, reactant purities and contaminant effects, cell plate and electrode materials catalysts

and platings, control components, thermal properties, water recovery techniques, and cell configurations and gas distribution studies. In addition mathematical models of the fuel cell subsystems and components are to be established.

b. Part II - Breadboard Systems. The Part II tasks provide for the materials and construction of experimental items to support the Part I investigations. This part also provides for the construction, test, and evaluation of three complete, breadboard fuel cell systems. In addition to demonstrating systems performance characteristics, the breadboards shall serve as tools to evaluate Part I items within a system and will allow investigation of the interrelationship of various subsystems.

c. Part III - Engineering Evaluation Models. The Part III tasks call for the design, development, test, and evaluation of complete fuel cell systems equipped with flight oriented components and using the latest cell technology. Four systems, one with a water recovery subsystem are to be delivered for performance and environmental testing.

4. Major Accomplishments. The accomplishments have been outstanding to date although most of the effort has been concentrated on the Part II breadboard systems and on the detail plans and specifications required for the Part III systems program. Two of the three breadboard systems have been completed and tested extensively. It is noteworthy that the second system was delivered on schedule in 2-1/2 months from initiation of the present contract period.

Although these units were not equipped with optimum components or auxiliaries, they closely resembled the configuration expected for a flight type assembly. The fuel cell module of these systems were constructed with recently developed cells employing (SINAC) silver cathode electrodes. The weight of these assemblies was about 50 kilograms (110 pounds).

In general, test results were very good. Difficulties experienced are discussed in the subsequent section 5, "Problems." The system thermal efficiency determined after 400 hours operation with an average load of 1100 watts was 58.7 percent. The specific fuel consumption was 0.385 Kg/KWH.

The unit delivered to MSC, Houston was operated by their personnel on a 120 hour duty cycle with a load profile that was a composite of the Gemini, Command Service Module, and Lunar Excursion Module requirements. Under the severe conditions, the unit fulfilled the contractual requirements of 200 hours life for loads between 600 and 1800 watts and a voltage regulation of 32 to 27 volts. Testing was continued to over 500 hours of operation with the unit producing

1400 watts at 27 volts at that time. Further tests are planned for this system up to 720 hours. The tests demonstrate the capability of performing the above missions as well as that of the Saturn vehicle. Details of these tests have been published in MSC Internal Note No. MSC-IN-64-EP12.

Centerline specification and schematics have been established for the engineering model systems and major components. Vendor parts are on order and first system fabrication is expected in about 2 months.

The Part I tasks are progressing well. Simplified mathematical models developed are already being used for thermal design evaluation and for moisture removal and reactant inlet subsystems.

Two new cathode electrodes are showing good performance on single cell tests. One of these called HYSAC is essentially the same silver material as the SINAC, presently used, and is to be used in the next breadboard. The process of forming the powered metal to the electrode nickle screen is different so that the porosity and effective surface area is greatly increased. This gives over a 10 percent increase in cell output and appears to reduce the long term voltage decrease with load time.

The other electrode is a similar, silver electrode that is highly loaded with a noble metal catalyst. This increases performance even more, but the long term effects are yet to be evaluated. This approach is also considerably more explosive.

5. Problems. The major problem is still the obtaining, test, and incorporation of flight oriented, auxiliary components. Specific problems with any of these vendor items are yet to be determined.

Problems that were experienced during initial breadboard operations are not considered major because of the hurried construction of these units and because corrective actions have been taken to eliminate reoccurrence. The validity of the solutions will be demonstrated by the next breadboard performance. The corrections made were:

a. Increase oxygen pressure setting to 27 psig for optimum voltage was attributed to higher density of silver cathode.

b. Provide flexible mounting for heat exchanger to eliminate joint leaks caused by thermal expansion.

c. Control thickness and density of asbestos and pre-select to assure uniformity of cells within an assembly.

d. Closely inspect electrodes for fine burrs or protrusion which may result in minute gas leakage into water system.

e. Return to original reactant manifold and plate configuration. Dual port approach did not increase performance and did increase the purge requirements.

6. Future Plans. Continue work as scheduled.

7. Illustrations. None.

B. Study of Energy Conversion Systems

Submitted by
(Technical Supervisor)

Mr. Richard J. Boehme
R-ASTR-E, 876-6762

Mr. Charles B. Graff
R-ASTR-EAP, 876-1493

1. Project Data

Contract Number: NAS 8-5392 Mod. 4, August 15, 1964 - August 15, 1965

Contractor: Allis-Chalmers Manufacturing Co.
Defense Products Division
Box 512
Milwaukee 1, Wisconsin

2. Purpose of Project. The object of this study is to obtain a better understanding of the application limits of the fuel cell and combinational systems compared to solar cell, radioisotope, and chemical engine systems. Theoretical and empirical parameters will be incorporated into mathematical models for design opimization studies. These will include environmental parameters as well as vehicle requirements and instrumentation requirements. This study will also include such things as the use of batteries for peak loads, solar

regenerative concepts, and the interrelationship of these power systems with interfacing vehicle systems such as reactant storage, distribution systems,and primary coolant or radiator systems.

3. Technical Status. Investigation of cold storage of a 2 kw fuel cell system for proglonged periods of time is in progress. Preliminary studies indicate that optimum storage conditions call for operation of light loads throughout the storage period.

Studies are in progress to determine a mathematical model of distribution of cell voltages of the fuel under different operating conditions. This model will be used in reliability studies when mean cell voltage as a function of current density and time, and standard deviation are known.

Work is proceeding satisfactorily. Some of the simplified subsystem models that have been evolved are already in use for preliminary design purposes.

4. Major Accomplishments. By iterative mathematical procedure, a battery - fuel cell parallel combination was sized from a standpoint of weight optimization. It was established that this method could be used for optimizing a battery - fuel cell system.

A method has been worked out for the design of space radiators. This method was evolved by modifying existing design programs and incorporating considerations for failure probability due to meteoroid puncture.

5. Problems. For certain missions it may be required to allow a fuel cell system to remain dormant for extended periods of time in a cold environment. Studies to date indicate that continuous low power operation must be maintained in order to keep the fuel cell warm. The problem lies in working out a design which will endure a deep freeze so that fuel requirements will not become restrictive.

Storage at elevated temperature to 130°C do not appear detrimental except for the burden this would impose on fuel storage systems.

6. Future Plans.

a. Study of insulation and fuel requirements for systems enduring long terms in the lunar type environment will be continued.

b. Establishment of computer programs for fuel cell systems parameters will be continued.

c. Methods of treating parallel battery - fuel cell combinations will be refined and programmed.

d. A number of radiator designs covering the normal range of heat rejection load and environmental temperatures will be generated in an attempt to optimize radiator design schemes.

e. Development of a fuel cell reliability model will continue.

f. Development of a mathematical model of the static moisture removal system which will handle transients and upsets, will be undertaken.

g. The study of fuel cell combination systems and comparisons with other systems will be continued.

7. Illustrations. None.

Batteries

A. Research and Development of Primary Zinc-Silver Oxide Battery with Long Stand Capabilities

Submitted by
(Technical Supervisor)

Mr. Charles B. Graff
R-ASTR-EAP, 876-1493

Mr. William J. Britz
R-ASTR-EAP, 876-1493

1. Project Data

Contract Number: NAS 8-5493, Mod. 3, June 29, 1963 - June 29, 1965

Contractor: Eagle-Picher Company
P. O. Box 47
Joplin, Missouri

2. Purpose of Project. The objective of this project is to accomplish adequate research and development to establish a zinc-silver oxide battery cell with long activated stand capabilities and with limited cycle capability, but retaining the high rate and density of a primary cell. The work under this program will include investigation of separator materials, plate materials and special treating of plates to increase stand of primary batteries.

3. Technical Status. The results of the previous investigation conducted to achieve an improved primary silver-zinc cell included findings useful to the new task:

a. Life cycle tests indicated relative abilities of separators to withstand service conditions; cellulose products have low resistance, necessary for high rates.

b. The most desirable electrical characteristics were obtained from cells employing multiple wraps of cellulose membranes in combination with a woven nylon fabric.

Factors affecting the performance of a silver-zinc include combinations of separator materials. Some materials are undergoing treatments, such as the isocyanate treatment of cellophane, to help prevent silver transport. These materials have been and are being evaluated as to effectivity. Indications are that benefits of charge retention produced by lower zinc densities may be offset by the required anode active materials this entails.

4. Major Accomplishments. A series of pre-prototype cells were designed, constructed and tested. These cells were designed utilizing knowledge gained in previous phases of the primary cell study. Equal numbers of cells were constructed using nickel and silver positive grid metals to gain further insight into the relative performance characteristics, particularly after stand times of greater than ten days. This resulted in an improved primary silver-zinc cell; it was found that individual cells could be expected to perform satisfactorily after four days activated stand at +130° F or approximately two weeks at +75° F.

Cells were constructed of similar design to those of previous prototype cells which were designed for primary cell research, but these employed silver rather than copper grid material in the negative plate. These cells showed an initial capacity of 10 to 11 ampere hours at a 30-ampere rate. After a 90° F stand for 30 days, with three 1/4 discharge cycles during this period, the cell performances were redetermined and were found to have increased.

5. Problems. Post-mortem of the cells revealed 5 percent loss of silver active material to the separator. There were indications that a larger sample size might have included some cell failures.

6. Future Plans. Studies of density effects in positive plate materials are being planned. Additional separator material while increasing the membrane thickness. Investigating the use of electrolyte additives will commence.

7. Illustrations. None.

Electrical Power Distribution and Control

A. Development of 100 Ampere Silicon Transistor

Submitted by
(Technical Supervisor)

Mr. D. L. Anderson
R-ASTR-RS, 877-2168

1. Project Data

Contract Number: NAS 8-5335, Mod. 1, June 29, 1963 - January 31, 1965

Contractor: Westinghouse Electric Corporation
Semiconductor Division
Youngwood, Pennsylvania

2. Purpose of Project. To develop a 100 ampere silicon transistor for high current application in launch vehicle systems. These devices should find applications in dc distribution systems, high power static inverters and in ac motor drive systems.

3. Technical Status. The design of this device has been completed and five prototype samples submitted for evaluation. The performance of the samples meet the requirements of the contract except in breakdown voltage. The problem of building large area devices without imperfections at some point in the wafer is a serious one. The basic problem is that a whole wafer is required for this transistor and it is statistically difficult to process a wafer

without at least one flaw. To date, expitaxial material grown on a standard wafer has been used. It is believed that a new process in which an inverted expitaxial wafer is used, with the device being fabricated in the starting material, stands a good chance of raising the breakdown voltage to the desired level. An extension of the contract is being considered using this new technology.

4. Major Accomplishments.

a. The use of a computer for making the basic design of the unit.

b. The development of a silicon double diffused transistor that is rated at five times the current of anything to date.

c. Solving the packaging problem of a large area transistor.

5. Problems. The remaining problem in this contract is the low breakdown voltage of the units. This is a material problem rather than a design problem. The inverted epitaxial process mentioned above will allow the device to be fabricated in the starting wafer rather than in the epitaxial material and should solve the problem.

6. Future Plans. A device of this nature should be made available for use by design engineers. The contract will be extended to adapt the inverted epitaxial process to the fabrication of this device.

7. Illustrations. None.

B. Integrated Circuit Semiconductor Preamplifier

Submitted by
(Technical Supervisor)

Mr. Carl E. Winkler
R-ASTR-RS, 877-2168

1. Project Data

Contract Number: NAS 8-5455, Mod. 3, June 25, 1963 - December 14, 1964

Contractor: Westinghouse Electric Corporation
Molecular Electronics Division
Elkridge, Maryland

2. Purpose of Project. The contract calls for the design, development, fabrication, and delivery of integrated circuit preamplifiers to be used in static inverters.

3. Technical Status. The final units have been received and evaluated and found acceptable.

4. Major Accomplishments. The final devices met or surpassed all specifications as set out in the scope of work.

5. Problems. It still remains to be shown that these units will be compatible with the integrated power amplifiers being developed under Contract No. NAS8-11599 by Westinghouse. Also, a low voltage, highly efficient dc power supply is needed to make these preamplifiers attractive.

6. Future Plans. A rough draft of the final report has been approved and when the required number of copies are received in the final form the contract will be complete.

7. Illustrations. The illustration shown in the previous report is still applicable.

C. Integrated Circuit Power Amplifier

Submitted by
(Technical Supervisor)

Mr. Carl E. Winkler
R-ASTR-RS, 877-2168

1. Project Data

Contract Number: NAS 8-11599, Mod. 2, March 24, 1964 - March 19, 1965

Contractor: Westinghouse Electric Corporation
Transistor & Controlled Rectifier
Engineering Department
Youngwood, Pennsylvania

2. Purpose of Project. The purpose of this task is to design, develop, fabricate, and deliver integrated circuit power amplifiers to be used in static power inverters and other switching applications.

3. Technical Status. An extension to the original contract was granted to change certain electrical specifications. These involved a higher voltage rating, the including of back-up diodes for increased reliability, and an improved smaller package.

4. Major Accomplishments. A prototype has been tested which includes the above technical changes.

5. Problems. The prototype tested did not meet the voltage and gain requirements. Another problem is to make these devices compatible with the integrated preamplifiers developed under contract No. NAS8-5455 by Westinghouse.

6. Future Plans. According to Westinghouse engineers higher voltage and higher gain units will soon be forthcoming from runs presently under way. No extension of the contract is contemplated at this time.

7. Illustrations. A schematic of the power amplifier is included. The upper half is on one piece of silicon and the lower half is on a second chip. The two are encapsulated in a stud-mounted flat package.

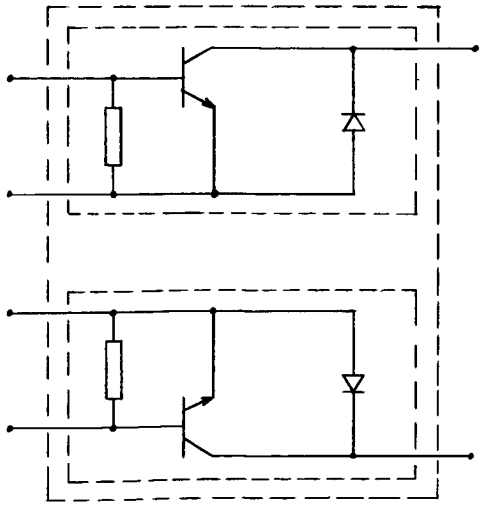


FIGURE 1. POWER AMPLIFIER

D. High Current Switching Devices

Submitted by
(Technical Supervisor)

Mr. W. J. Shockley
R-ASTR-EAC, 876-8641

1. Project Data

Contract Number: NAS 8-2552, Mod. 3, January 1, 1962 - January 31, 1965

Contractor: Oklahoma State University
School of Electrical Engineering
Stillwater, Oklahoma

2. Purpose of Project.

a. To conduct design analysis and performance evaluation under vacuum and under different gaseous environments to establish optimum design specification for high-current, electrical contactors for space launch vehicles, using three experimental contactor units of the magnetic-latching, single-pole, double-throw type, hermetically sealed, in addition to types previously tested.

b. To continue the development of design modifications to produce a contactor that will:

(1) withstand vibration forces of 20 g or more at 10 to 2000 cps.

(2) operate at rated load for a minimum of 10,000 cycles.

(3) operate within a temperature range of -65°C to +125°C.

3. Technical Status. Contactors purchased from six manufacturers were initially tested. None met specifications for launch vehicle usage. A development contract with another manufacturer also yielded an unsatisfactory contactor. Extensive investigation has been made by this contractor into all identifiable parameters, and relationships existing among them, in a selected contactor. Analysis has been performed from the concept that three subsystems comprise the component. They are (1) the electrical-to-magnetic conversion

performed by the coil, (2) the magnetic-to-mechanical phase involving the moving parts, and (3) the mechanical-to-electrical transfer occurring through the contact subsystem.

A design-map technique was developed for simultaneous solution of equations covering the mathematical model of a contactor. This technique permits computation of compatible values for specified and unknown parameters within the magnetic circuit subsystem, such as coil current and power, total coil turns, core size and diameter of wire, magnetic pull of different air gap configurations, and the effective mass of the armature.

Analysis of the effects of vibration forces at 20 g on a rotary-armature type of contactor has led to design modifications being recommended to the manufacturer to alter tension on the over-travel spring and the restoring spring, and to increase the contact pressure force.

Vibration testing was approached first using a mathematical model, assuming a two-mass, two-spring, linear system. Further analysis of the particular type of contactor to be studied showed that the cantilever manner of mounting the unit in its container produced a multi-mass, multi-spring system with several degrees of freedom. Several mounting arrangements have been evaluated, but shifts of resonance frequencies have not yet been sufficient to decrease the g amplification produced on the contacts. Work is continuing in an attempt to move the resonant frequency of the relay and container far enough above 2000 cps so that a satisfactory contactor will result.

Additional analysis is being performed on the contact subsystem of a contactor, covering parameters which are mechanical (contact forces, impact and closing velocities and accelerations, bounce, thermal conductivity and temperature) and those which are environmental (atmosphere temperature, gas mixture for backfilling, pressure, humidity and rate of gas flow). Equipment has been developed to measure the arc energy per operation and to measure contact material transferred. A method for solution of contact equations by computer techniques has also been developed.

4. Major Accomplishments. The feasibility of development of a mathematical model of a contactor has been established by testing and by writing suitable performance equations expressing the various functions of the subsystems in the component.

Application of the design mapping technique developed by the contractor to a project for minimum modification of a 10 g rotary actuator involved a mathematical model containing 27 parameters and 15 relationships. The actual

modification by the manufacturer, in accordance with recommendations of the contractor, has produced a contactor which is expected to exhibit reduced requirement for operating power, increased life, a reduction in mass and size, and increased ability to withstand vibration forces to 20 g.

A method for quantitatively comparing the required and the desirable characteristics of several possible contactors has been developed, using an equation to produce a "figure of merit". Factors included are: the g force that the unit will withstand without chatter, the contact voltage rating, the contact current rating, plunger or armature seating time, coil power at rated voltage, weight of the unit, and the stability factor (rate of pick-up to steady state current). Calculations from this equation bring out advantages or deficiencies of different types of contactors.

5. Problems. Difficulty has arisen in determining the influence of damping devices on vibration effects and on resonant characteristics. An approach to design a contactor having resonant frequencies that were outside of the natural range of the device proved impractical.

One major problem has been the limitation of the work thus far to an effort covering only minimum modification of an existing design in order to produce an acceptable contactor. The accumulation of data that has been made, however, should prove to be a significant contribution toward new design of such components, if such should occur.

Thus far, no suitable method for mounting the relay at the coil end has been found which will withstand 20 g at frequencies between 20-2000 cps. By rotating the "bare relay" 180 degrees about the z-axis (inverting the relay) and mounting the relay at the contact end the relays tested will withstand 20 g at frequencies between 20-2000 cps. The problem now is finding a suitable method to mount the inverted relay in its container.

6. Future Plans. Testing of contactors modified by the manufacturer according to recommendations of the contractor is to continue as provided in the contract. The analyses of these tests are expected to indicate further avenues of research toward development of an optimum power relay. If favorable findings and conclusions are presented in connection with most of the goals of the contract except the capability to withstand the specified vibration force, a modification or new design from the standpoint of packaging and mounting the three subsystems of the contactor as a dense, low-profile unit shall likely be investigated.

The development of the design equations for the magnetic latching contactor will be continued. An enlarged experimental magnetic latch actuator is being constructed and will be used to obtain data to verify the form of the design equations.

Two modified configurations of the 75 ampere rotary type contactor are under construction and will be evaluated to determine if the 20 g at 2000 cps has been attained. The contacts and contact housing will withstand 20 g at 2000 cps but difficulty has been encountered in fastening the contact housing to the base.

Work will continue on the development of techniques to predict the behavior of nonlinear spring mass systems. Linear techniques are being used presently but most spring mass systems are nonlinear.

Work will continue on obtaining data that can be used to correlate the amount of contact material eroded away and transfered, with the energy present in the electrical arc during contact opening. It appears now that most of the problems involved in measuring the instantaneous power in the electrical arc have been solved and that consistent data can be obtained from the instruments developed. As indicated previously, the large number of variables involved requires that considerable time be spent on obtaining the data necessary to postulate an acceptable mathematical model.

7. Illustrations. None.

E. Bifilar-Wound Relays

Submitted by
(Technical Supervisor)

Mr. R. M. Acker
R-ASTR-EAC, 876-8641

Mr. W. J. Shockley
R-ASTR-EAC, 876-5947

1. Project Data

Contract Number: Not Applicable

Contractor: MSFC - In-House

2. Purpose of Project. The technical objective is to develop relays, contactors and solenoid actuated valves with bifilar wound coils to suppress the high voltage transients generated when these devices are de-energized.

3. Technical Status. In-house investigation of high-voltage transients caused in vehicle electrical systems by relays and contactors upon being de-energized has shown levels of over 1000 volts. A study of methods to suppress these transients has led to a decision that bifilar winding of the coil, using a wire size two sizes smaller for the suppress coil than that used for the actuate coil, will more reliably suppress the transients to levels allowed by MIL-E-6051C than any other method. Manufacturers of relays now on MSFC-QPL-339 have been requested to supply bifilarly-wound units of the QPL types for qualification tests.

4. Major Accomplishments. Successful prototypes of bifilar-wound relays were tested in R-ASTR-EAC laboratory. Test samples from two manufacturers are undergoing qualification to MSFC-SPEC-339 with promising results.

5. Problems. Availability of sufficient sample sets of bifilar relays is hampering the program to qualify this type of unit to replace all relays now used in vehicle electrical systems. Facilities for in-house testing are also inadequate to perform this conversion project at the desired speed.

6. Future Plans. Expanded investigation will cover contactors and solenoid-actuated valves. Sizable costs to the manufacturers in the current and expected effort will necessitate an RFQ through the Purchasing Office, and subsequent placement of contracts to develop these items.

7. Illustrations. Figure 2.

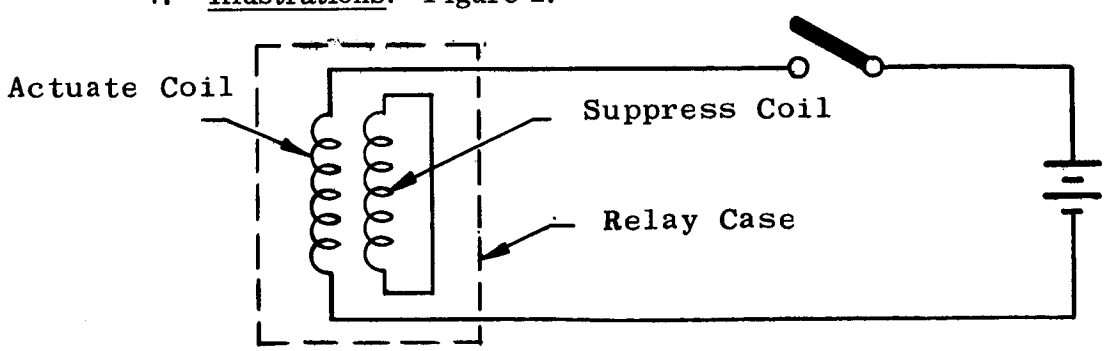


FIGURE 2. BIFILAR WINDING SUPPRESSION

SECTION II. SPACE VEHICLE SYSTEMS PROGRAM

SPACE VEHICLE AND ENVIRONMENTAL FACTORS

High Energy Radiation Effects and Shielding

A. Evaluation of Simulated Radiation Shielding

Submitted by
(Technical Supervisor)

Richard A. Potter
R-RP-N, 876-8036

1. Project Data

Contract Number: Not Applicable

Contractor: Not Applicable MSFC In-house

2. Purpose of Project. To conduct an in-house effort to evaluate the gamma probe technique as a possible tool for space radiation shield evaluation and space radiation shield design. To develop in-house competence for handling MSFC nuclear radiation problems.

3. Technical Status. The equipment used in the gamma ray probe study is set up and operating. The ratio of intensities is being measured varying the source, shield and detector geometries. The data obtained is being reduced and analyzed.

4. Major Accomplishments. The Cobalt-60 source and 2-inch scintillation detector were placed 100 cm apart and the intensity of the gamma ray beam was measured for 8000 seconds. An aluminum shield approximately 1 cm thick was then placed close to the source and the intensity counted for 800 seconds. The shield was moved in steps of 10 cm each until close to the detector. The ratio of intensity was plotted versus shield distance from source and the conclusion reached that using the 1.33 MeV peak, the source, shield and detector distances have very little effect on the ratio of intensities. The data obtained for wider spreads in energy has not been reduced at this time. Data is also being reduced that will indicate the magnitude of scattered radiation that will be accepted using only the energy discrimination over various energy segments. This data will be compared to that of a collimated beam.

5. Future Plans. Gamma ray probe experiments will be conducted to experimentally determine the effect and limitations of varying the shield material (z number), the shield thickness, the shield position relative to source and detector, detector size, and source position relative to detector.

6. Problems. No major problems have been encountered.

7. Illustrations. None.

B. Data Compilation and Evaluation

Submitted by
(Technical Supervisor)

M. O. Burrell
R-RP-N, 876-1891

1. Project Data

Contract Number: NAS8-11164

Contractor: Lockheed Georgia Company
Marietta, Georgia

2. Purpose of Project. The purpose of this project is to update and extend the radiation shielding data and methods developed by the contractor under previous contract; specifically NAS8-5252.

3. Technical Status. The above work has been pursued for approximately eight and one-half months, since the start of contract. The primary undertaking to date has been the development of geometry codes for treating complex arrangement of equipment inside a space ship.

4. Major Accomplishments. The contract has not been pursued sufficiently long to have completed the major goal. However, a summary of the work was presented at the "Second Symposium on Protection Against Radiation in Space." This symposium was held in October in Gatlinburg, Tennessee.

5. Problems. None to date.

6. Future Plans. At present there are plans for the extension of the above work to include near-earth orbits.

7. Illustrations. Figure 3.

$$\frac{d\phi}{dp} = 5.675 \times 10^{8} \text{ Exp } (-p/80) \ \frac{\text{protons}}{\text{cm}^2 \text{ MV}}$$

Detectors	1E	1A	2E	2A	3E	3A	4E	5E	5A	6E
7.6" Polyethelene										
Shield Only	2.87	2.87	1.49	2.07	3.00	2.51	2.36	1.59	2.08	1.62
Shield + Equipment	1.82	1.92	1.36	1.80	2.18	2.10	1.66	1.43	1.80	1.44
Shield + Crew + Equipment	1.17	0.29	0.78	0.20	1.24	0.30	1.28	0.82	0.20	0.84
1.0" Polyethelene										
Shield Only	203.	194.	98.0	122.	198.	165.	176.	107.	124.	105.
Shield + Equipment	83.5	95.5	91.6	96.5	116.	115.	88.6	98.1	97.4	89.5
Shield + Crew + Equipment	30.4	1.87	47.6	1.16	42.1	2.12	54.4	48.9	1.23	49.7

E = detector in eye
A = detector in abdomen
1 = middle crew member at instrument console
2 = crew member in top bunk, head under instrument console
3 = crew member in hatchway
4 = right crew member at instrument console
5 = crew member in top bunk, feet under instrument console
6 = crew member in bottom bunk, head under instrument console

FIGURE 3. SOLAR FLARE DOSE (RAD) - EIGHT MAN MODULE

C. Transport of Neutrons Induced by Space Radiation

Submitted by
(Technical Supervisor)

M. O. Burrell
R-RP-N, 876-1891

1. Project Data

Contract Number: NAS 8-11047

Contractor: Radiation Research Associates, Inc.,
Fort Worth, Texas

2. Purpose of Project. The purpose of this contract is to perform an extensive set of Monte Carlo calculations for the transport of energetic neutrons released by the nonelastic collisions of protons.

3. Technical Status. The work in this contract is completed. The final report is now due but was not available in time for this progress report.

4. Major Accomplishments. A fairly complete analysis of neutron transport in polyethlene, iron, and aluminum with energies from 0.5 to 14 MeV has been made. Some results of the above work was given as a technical paper at the 1964 Annual Meeting of the American Nuclear Society, Philadelphia, Pa., June 14-17, 1964.

5. Problems. No problems of consequence have been encountered.

6. Future Plans. At present a short extension is being considered to investigate the effects of multilayer and multimaterial shields.

7. Illustrations. None.

D. Evaluation of Nuclear Rocket Shield Calculation Methods

Submitted by
(Technical Supervisor)

H. E. Stern
R-RP-N, 876-3542

1. Project Data

Contract Number: NAS 8-9500 (The work is being performed under a modification to this contract)

Contractor: Lockheed Missiles and Space Company (The work covered under the contract modification is being carried out by the Lockheed Georgia Company, Marietta, Georgia).

2. Purpose of Project. To evaluate and compare various existing shielding calculation in regard to their applicability to nuclear rocket shield systems.

3. Technical Status. Work under this contract was initiated in July 1964. Two simplified shield configurations were chosen to represent geometries typical of those to be expected in a nuclear rocket system. A set of "standard cross section data" was specified for use insofar as possible in all calculations. It was agreed that codes to be compared would include representative transport, point-kernel and Monte Carlo programs. Judgement criteria would include flexibility, ease of data input preparation, type of results obtained (for example, neutron flux, gamma dose energy spectra, heat deposition), accuracy, and efficiency.

4. Major Accomplishments. The contractor has performed calculations using the following codes: (1) Los Alamos DDK - angular segmentation method; (2) General Electric 14-0 Albert-Welton (non-hydrogenous) Moments; (3) various versions of the Los Alamos QAD point kernel code.) Computed quantities include neutron and gamma dose rates, flux of neutrons with energy greater than 0.1 MeV, and neutron energy spectra. Gamma spectra were computed at a flux point using 14-0. QAD does not have this capability. Preliminary results indicate that each of the codes examined to date is superior to the others for some particular class of problems. Also, difficulties preventing reasonable answers have shown up in some cases.

Preliminary test calculations have been run with the General Electric 18-0 and the Los Alamos MCS and MCG - all Monte Carlo codes.

5. Problems. No unusual problems have been encountered.

6. Future Plans. Rather detailed comparisons are planned for the results (moderate depth) obtained and currently being generated. A presentation summarizing the work to date is scheduled for early in the next reporting period. Future work will include calculations in as much detail as possible at greater depths.

7. Illustrations. None.

E. Compilation and Summary of Space Radiation and Shielding Data

Submitted by
(Technical Supervisor)

Henry E. Stern
R-RP-N, 876-3542

1. Project Data

Contract Number: NAS 8-11083, with three modifications, June 29, 1963 - March 29, 1965

Contractor: Advanced Research Corporation
Atlanta, Georgia

2. Purpose of Project. To compile, evaluate and summarize pertinent information concerning space radiation and shielding.

3. Technical Status. Work under this contract has comprised essentially one-man effort. Two areas of interest have been investigated: (1) an evaluation of the calculations of intranuclear cascade and evaporation nucleons performed at Oak Ridge National Laboratory and (2) a compilation and evaluation of bremsstrahlung production formulas for electrons in the earth's natural belts.

A brief preliminary analysis of the Oak Ridge data indicated that a considerable amount of work would be required to put them into a form readily usable for shielding calculations. Since this analysis, ORNL recalled all the data it had released, due to an error in their machine program, and has been recomputing a portion of it. Preliminary comparisons of the new data with experimental results obtained by ORNL show some discrepancies, particularly in directions near that of the primary particle. The agreement seems to be good enough, however, to allow fairly good estimates using the calculated data. While the limited manpower under this contract does not permit the extensive effort required to make it available for immediate engineering application, such a project is being considered as a possible future in-house or contracted effort.

4. Major Accomplishments. Work has continued, at a somewhat reduced level, on the survey of existing calculation methods for computing bremsstrahlung production. In particular, rapid approximate calculation methods are being considered, and further computations of corrections for Coulomb and atomic electron shielding effects are being performed. Plans are being made to use the facilities of the Rich Computer Center at Georgia Tech to get an automatic machine program written. Such a program, written in Fortran, would utilize spectral-depth electron data as input and compute doses due to bremsstrahlung for slabs of specified thickness.

5. Problems. No unusual problems have been encountered.

6. Future Plans. It is anticipated that this work will be completed by the end of the contract period. In view of some rather sophisticated work on electron transport and bremsstrahlung production initiated elsewhere since the beginning of this contract (Ref. - Dr. Edmonson's contract), no extension of this particular effort is expected.

7. Illustrations. None.

F. Electron Shielding Studies

Submitted by
(Technical Supervisor)

N. Edmonson, Jr.
R-RP-N, 876-4126

1. Project Data

Contract Number: NAS 8-11304

Contractor: General Atomic Division of General Dynamics Corporation
San Diego, California

2. Purpose of Project. To investigate theoretically and experimentally the transport of electrons through materials covering a range of Z numbers and in the forms of slab targets of various thickness in the electron energy range 1-10 MeV. The theoretical results will be compared with the experimental results to develop reliable analytical procedures for shield design for space vehicles. Accurate shielding computation procedures are necessary for the construction of the lightest possible shields against the electron radiations in space.

3. Technical Status. Experimental - The experimental work will be done on the GA 45 MeV linear accelerator, and calls for the design and construction of special equipment and careful calibration of this equipment. This work is on schedule. The following phases have been finished during the reporting period:

a. Vacuum system and mechanical support equipment has been designed, fabricated and checked out for leaks in the experimental cell.

b. Beam translation magnets and electron spectrometer magnet have been designed. Delivery is expected soon after January 1, 1965.

c. Preliminary detector development has been carried out.

d. Preliminary electron and bremsstrahlung measurements have been made.

e. Procedures to unfold the γ spectrum have been set up.

f. Magnetic field monitoring system has been set up.

g. NaI crystal detector responses to γ radiation from radioactive sources and to monoenergetic $\beta+$ radiations from annihilation have been measured.

Theoretical - (1) Basic coupled transport equations for electrons and γ rays have been constructed; (2) Procedures for computing elastic collision cross sections for electrons have been constructed; (3) Procedures for computing inelastic collision cross sections for electrons have been constructed; (4) Bremsstrahlung cross sections were studied.

4. Major Accomplishments. These are summarized in the status portion of this report.

5. Problems. No serious problems were encountered. Project is on schedule both chronologically and financially.

6. Future Plans. During the remaining six months of this contract work will proceed according to the plan.

7. Illustrations. None.

G. Experimental Simulation of Large, High Field Superconducting Magnet Operation

Submitted by
(Technical Supervisor)

Eugene W. Urban
and
James Ashley
R-RP-N, 876-4126

1. Project Data

Contract Number: Government Order H-71484, April 3, 1964 - February 28, 1965

Contractor: United States Atomic Energy Commission
Oak Ridge, Tennessee

2. Purpose of Project. To investigate the scaling laws which might apply to the design and construction of large, high field superconducting magnets based on the behavior of lower field and/or smaller sized magnets. The high cost of superconducting magnets makes it highly important to be able, to as great a degree as possible, to predict the behavior of the types of magnets to be used for space radiation shields from experiments on laboratory sized magnets.

3. Technical Status. Several standard sample coils have been constructed (5.7 cm I.D., 9.5 cm O.D., 2 cm length, copper plated) of various commercially available materials for testing in the ORNL 16 cm I.D., 80 kilogauss, copper magnet. Four series of experiments are being run on these coils:

a. External field preset - sample coil current raised from zero to quenching value; external and sample coil self-field aiding.

b. Sample current preset - external field varied until critical field H_c is reached; both fields in the same direction.

c. Like a, but fields opposing.

d. Like b, but fields opposing.

Considerable data have been taken so far and the experiments are continuing. Design has been completed for a 33 cm I.D. copper magnet in which much larger sample coils will be tested.

To provide adequate conductor joints in the high and very inhomogeneous magnetic fields, a portion of the effort was devoted to a study of soldering and swaging techniques for joints.

In addition, design of a vibrating coil field sensing meter of high sensitivity has been completed.

4. Major Accomplishments. None of the results are of sufficient importance to warrant comment here, with the possible exception of the soldering technique for making superconductor to normal joints which are stable in inhomogeneous fields.

5. Problems. None.

6. Future Plans. The present contract is being extended for an additional year with essentially the same scope of work. During this time the 33 cm I. D. test magnet should be installed and a comprehensive series of experiments made on large diameter sample coils under various conditions.

7. Illustrations. None.

H. Experimental Investigation of Advanced Superconducting Magnets

Submitted by
(Technical Supervisor)

Eugene W. Urban
and
James C. Ashley
R-RP-N, 876-4126

1. Project Data

Contract Number: NAS 8-5279, May 13, 1963 - June 13, 1965

Contractor: AVCO-Everett Research Laboratory
Everett, Mass.

2. Purpose of Project. To advance the state-of-the-art of advanced high field superconducting solenoids with large field volumes by design, construction, and evaluation of magnets using strip superconducting material rather than conventional superconducting wire. Ultimate application of superconducting magnets to the shielding of space vehicles against charged particle radiation requires early information as the field strength, field volume, and mass characteristics which can ultimately be expected for these devices. A considerable amount of supporting research is also to be accomplished.

3. Technical Status.

Task I - Superconducting Coil - The major portion of the effort during the period was devoted to supporting research as outlined below. The original strip magnets, described in the previous semiannual report, were unwound for redesign. Toward the end of the present period a new coil was designed based on the optimum annealing and copper backing techniques found from the supporting research.

Task II - Supporting Research - The annealing and copper backing techniques for improving the behavior of NbZr strip, which were briefly mentioned in the last report as being promising, were thoroughly studied. The results, outlined below, confirmed the earlier indications.

Intimate bonding of copper or other high conductivity (thermal and electrical) normal metal to the superconductor strip greatly alleviates the problem of truncation (dependence of current density on strip width for small angles between strip plane and magnetic field).

The spot welding technique of bonding is quite adequate for this purpose.

The optimum ratio of copper to superconductor is about 10:1.

Heat treatment, including correct selection of annealing time and temperature, is instrumental in reducing anisotropy (dependence of maximum current on magnetic field orientation). However, heat treatment also reduces maximum current and a balance must be achieved. The optimum is about 650° C for 20 minutes which result in an isotropy index (minimum current divided by maximum current) of 0.55 and a critical current density of 1.6×10^8 A/cm^2 at a magnetic field of 4T.

The presence of copper backing during anneal does not affect the superconductor properties.

No reduction in current density is found in the optimized conductors due to proximity of two or more conductors.

4. Major Accomplishments. These are summarized under Technical Status.

5. Problems. No serious problems remain except for the inability of the contractor to construct a stable Hall probe for measuring current distributions at 4.2° K.

6. Future Plans. The improved strip coil now being designed will be built and thoroughly tested to prove the success of the above mentioned techniques. Attempts to construct a stable Hall probe will continue.

7. Illustrations. None.

I. Investigation of the Current Degradation Phenomenon in Superconducting Solenoids.

Submitted by
(Technical Supervisor)

James C. Ashley
and
Eugene W. Urban
R-RP-N, 876-4126

1. Project Data

Contract Number: NAS 8-5356, May 12, 1963 - January 14, 1965

Contractor: Atomics International Division of
North American Co.
Canoga Park, California

2. Purpose of Project. To investigate theoretically and experimentally the phenomenon whereby the maximum current of a wound superconducting solenoid is less than the maximum current of a short sample of the same conductor in a similar magnetic field. Reduced current carrying capacity of a superconducting solenoid means that larger and heavier solenoids must be built to achieve the same magnetic field strength that would be realized if short sample currents were attainable. Thus with the goal of applications of high-field superconducting solenoids to the shielding of space vehicles against charged particles, it is important to seek ways to remove or reduce the degraded current limitation.

3. Technical Status. The investigation of flux jumping in individual wires and of superconducting to normal transitions in solenoids has been unrevealing. One experiment showed that flux jumps could not be detected in an open, one turn, Nb Zr loop. A second experiment showed that although the superconducting to normal transitions can be followed and mapped, further interpretations

of the results were virtually impossible. Although both of these approaches suggest additional experiments, other work is felt to have a higher priority.

The response of the Nb Ti to warm-aging treatments is very encouraging. The critical current of the wire is quite sensitive to both temperature and time variations. It thus appears more constructive to fully characterize this material and lay a sounder basis for any future multi-probe work.

The metallurgical characterization includes a study of at least 30 wire samples, where 18 had been planned. Other measurements include both longitudinal and transverse field magnetization as well as T_c and H_{c2} measurements. The effect of copper plating on the wire in small magnets will also be checked.

4. Major Accomplishments. The main accomplishments to date are summarized in the technical status portion of this report.

5. Problems. No serious problems have been encountered and the objectives of the task are being fulfilled essentially as planned.

6. Future Plans. Work in the immediate future will concentrate on completing the wire sampling. Photomicrographs, X-ray diffraction and electron beam studies will be completed as will the analysis of matrix and precipitate composition, and precipitate size and density. Measurements of magnetization and T_c will be set up and appropriate tests run. Attempts will be made to correlate the metallurgical structure with critical-current models as determined by the J_c versus H and magnetization measurements.

7. Illustrations. None.

J. Investigation of Mechanisms of Superconductivity by Nuclear Irradiation

Submitted by
(Technical Supervisor)

James C. Ashley
and
Eugene W. Urban
R-RP-N, 876-4126

1. Project Data

Contract Number: NAS 8-11098, September 13, 1963 - March 1, 1965

Contractor: Westinghouse Research Laboratories, Pittsburgh, Pennsylvania

2. Purpose of Project. The main purpose of this project is to investigate the changes in the properties of high-field superconductor materials due to irradiation with charged particles. These studies are particularly important for the operation of superconducting magnets in space. In the use of these magnets for active shielding of space vehicles, where the magnet system is exposed to cosmic ray and solar flare protons, and neutrons and gammas from nuclear reactors, the results of these studies will materially assist in determining the feasibility of various active shielding systems.

3. Technical Status. During this period all the equipment for this project has operated satisfactorily or has been modified to do so. Three irradiation runs have been made at the cyclotron with integrated fluxes of about 10^{17} deuterons/cm^2. The fluxes are measured electrically by integrating the beam current reaching a collector electrode over the duration of the run. The cross section for atomic displacement by deuterons is 40 to 50 times greater than by fast neutrons so the deuteron irradiations will displace about as many atoms as an integrated flux of 5×10^{18} fast neutrons/cm^2. The temperature of the samples during irradiation is estimated by determining the cyclotron beam current at which each sample becomes resistive. Knowing T_c, we then have a figure for temperature rise per microampere and thus we can estimate the sample temperature for any beam current.

4. Major Accomplishments. Many results of scientific importance are being produced in this program. As typical of some of the information we are obtaining, the results of the second irradiation will be outlined in some detail. Some of these results are:

a. Cold-worked Nb-25 percent Zr - Figure 4 shows some of the measurements of J_c versus H at two different temperatures. The dose of 1.1×10^{17} deuterons/cm^2 appears to have produced a systematic reduction of about 25 percent in the critical current of the sample. Subsequent anneals at 77°K and 300°K eliminated about half of this reduction in J_c.

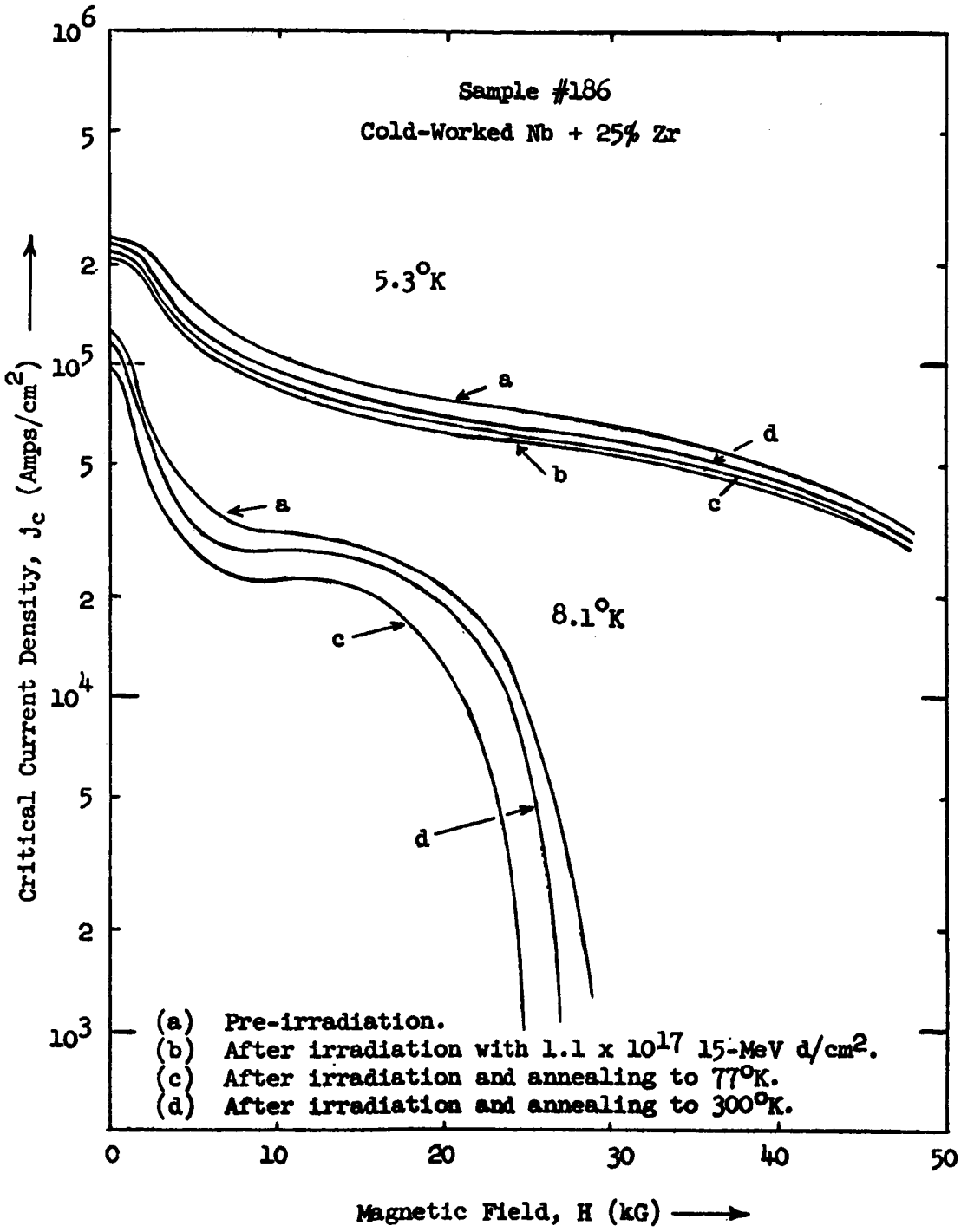


FIGURE 4. CRITICAL CURRENT DENSITY VERSUS APPLIED TRANSVERSE MAGNETIC FIELD, MEASURED AT INDICATED TEMPERATURES

b. Annealed Nb-25 percent Zr - This sample was made from a strip of cold-worked Nb-25 percent Zr annealed in a high vacuum at 1500° C. This treatment should remove most of the dislocations and may also change the composition somewhat. In the preirradiation J_c versus H data in Figure 5, curve (a) shows the greatly reduced critical currents which result from removing the dislocations which serve as current pinning-centers in a material of this type.

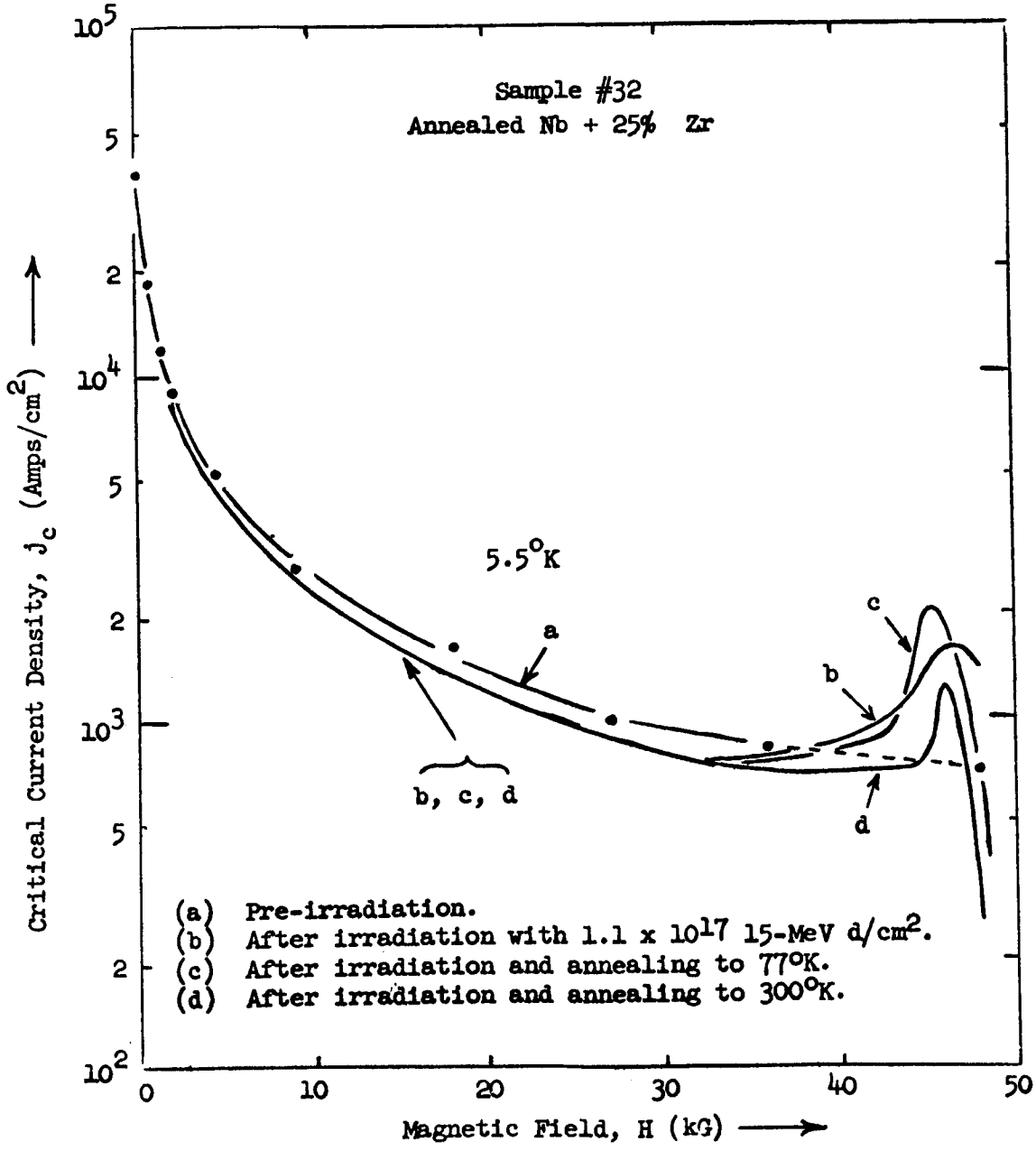


FIGURE 5. CRITICAL CURRENT DENSITY VERSUS APPLIED TRANSVERSE MAGNETIC FIELD, MEASURED AT INDICATED TEMPERATURE

At most magnetic fields the critical currents were only slightly changed after the irradiation, indicating that the clumps of displaced atoms left by the deuterons do not act as centers for pinning currents. This interesting problem will be investigated further. The peak seen at the higher fields has been confirmed in the third series of cyclotron runs as being produced by the irradiation. The peak occurs at the upper critical field H_{c2} and the height of the peak is reduced by post-irradiation annealing. Explanations for this unexpected effect are under investigation.

c. Nb_3Sn- A sample of vapor-deposited Nb_3Sn on a stainless steel ribbon, with copper coating, was irradiated to determine J_c versus H and to compare with previous studies using neutrons. The post-irradiation measurements indicate that at 45 kilogauss the 5.7°K critical current increased by about 150 percent. At a measurement temperature of 10.9°K, however, the critical current after irradiation was less than one third its preirradiation value.

d. Samples of pure lead (Pb) and annealed pure niobium (Nb) are being studied for changes in resistivity and critical temperature T_c. Changes in resistivity may be accounted for by the introduction of additional electron scattering centers due to the irradiation.

5. Problems. All the problems which plague the earlier stages of this work seem to have been solved satisfactorily.

6. Future Plans. Further cyclotron runs will produce more information on radiation induced changes in the properties of superconductor materials. A room temperature irradiation is planned with the samples inside the cyclotron. The higher beam currents available here should permit massive doses (10^{18} - 10^{19} deuterons/cm^2) in the samples.

7. Illustrations. Figures 4 and 5.

K. Study of Properties of High Field Superconductors at Elevated Temperatures

Submitted by
(Technical Supervisor)

E. W. Urban
and
J. C. Ashley
R-RP-N, 876-4126

1. Project Data

Contract Number: NAS 8-11272, July 26, 1965 - April 26, 1966

Contractor: RCA Defense Electronics Products
Camden, New Jersey

2. Purpose of Project. The object of this study is to evaluate indirectly the possibilities of enhancing current density and magnetic field capabilities of superconducting solenoids by operating them at temperatures greater than 4.2° K.

3. Technical Status. Omitting many of the details, the experimental arrangement consists of a sample of superconducting material (presently Nb_3Sn, NbZr, and NbTi are being tested) in the shape of a hollow right circular cylinder in an external magnetic field (H) which may be varied from 0 to 30 kG. The magnetic field penetrating the cylinder (H') is measured by a Hall probe in the center of the cylinder with the sample in an isothermal enclosure which can be maintained at some constant temperature below the critical temperature (T_c). Plots of H versus H are then taken for the various samples at different temperatures between 4.2° K and T_c. These plots show the usual pattern of flux jumping up to some field H for a given T, with "critical-state behavior" for larger values of H(smooth variation of H' versus H) (Fig. 6). It is found that above some temperature T_s for a particular sample the material exhibits "critical-state behavior" (i.e., no flux jumping) for all H. Approximate values of these parameters are:

Material	T_c (°K)	T_s (°K)
Nb_3 Sn	18	14
NbZr	10	7-8
NbTi	9.8	undetermined

The H' versus H plots for different T's allow one to calculate an actual critical current density J_c for the values of H where critical state performance obtains, and a "practical" critical current density for smaller values of H. Figure 7 is a plot of magnetization as a function of applied field. A plot of practical critical current as a function of sample temperature for a Nb_3Sn sample is seen in Figure 8. Since $J_c \sim M$, this data allows evaluation of the constants B_o and α_c in the semi-empirical relation $J_c (H^* + B_o) = \alpha_c$ proposed by Kim et. al. H^* is the mean field in the tube wall. This relation is confirmed at low temperature but

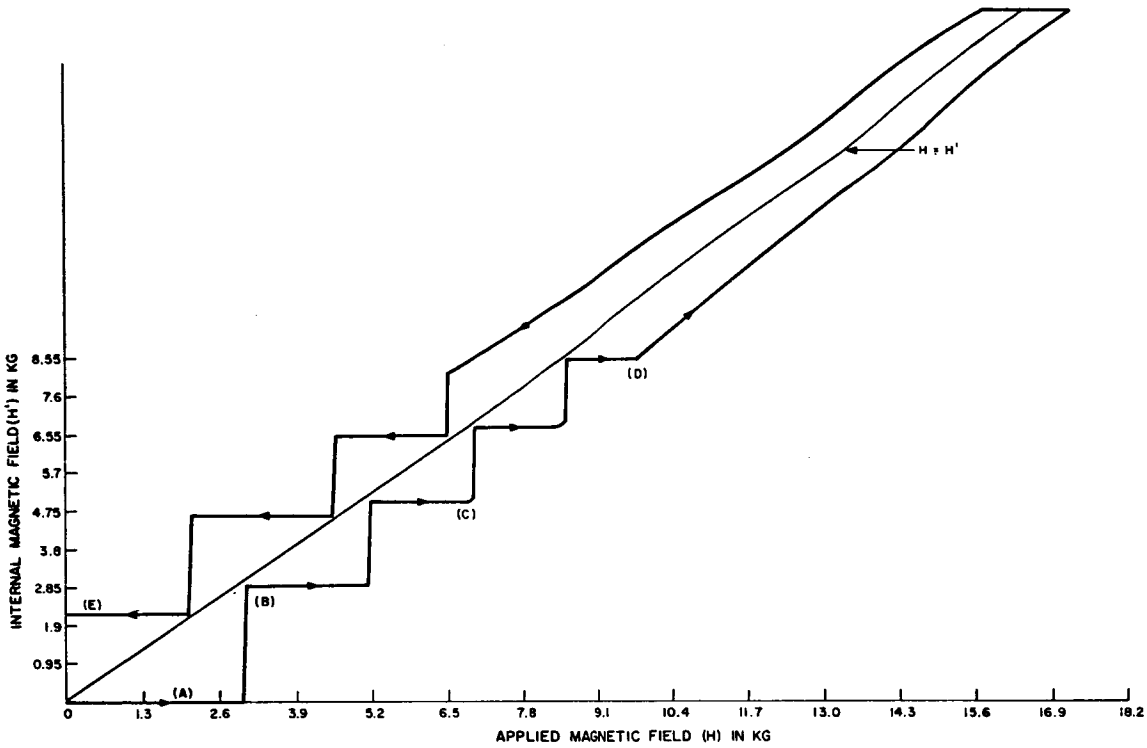


FIGURE 6. MAGNETIZATION OF NbZr SUPERCONDUCTING CYLINDER AT 6.2°K

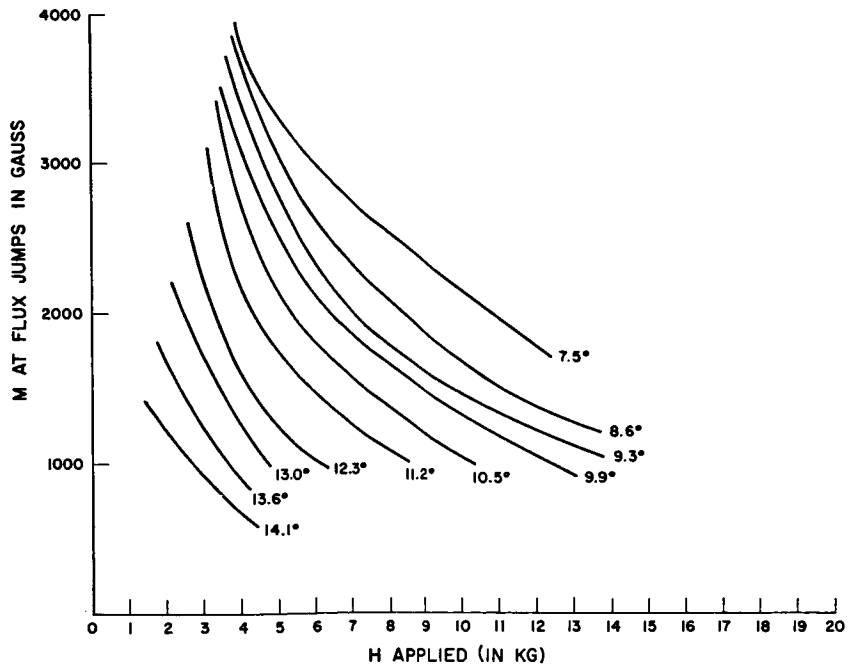


FIGURE 7. PRACTICAL MAGNETIZATION AS A FUNCTION OF APPLIED MAGNETIC FIELD

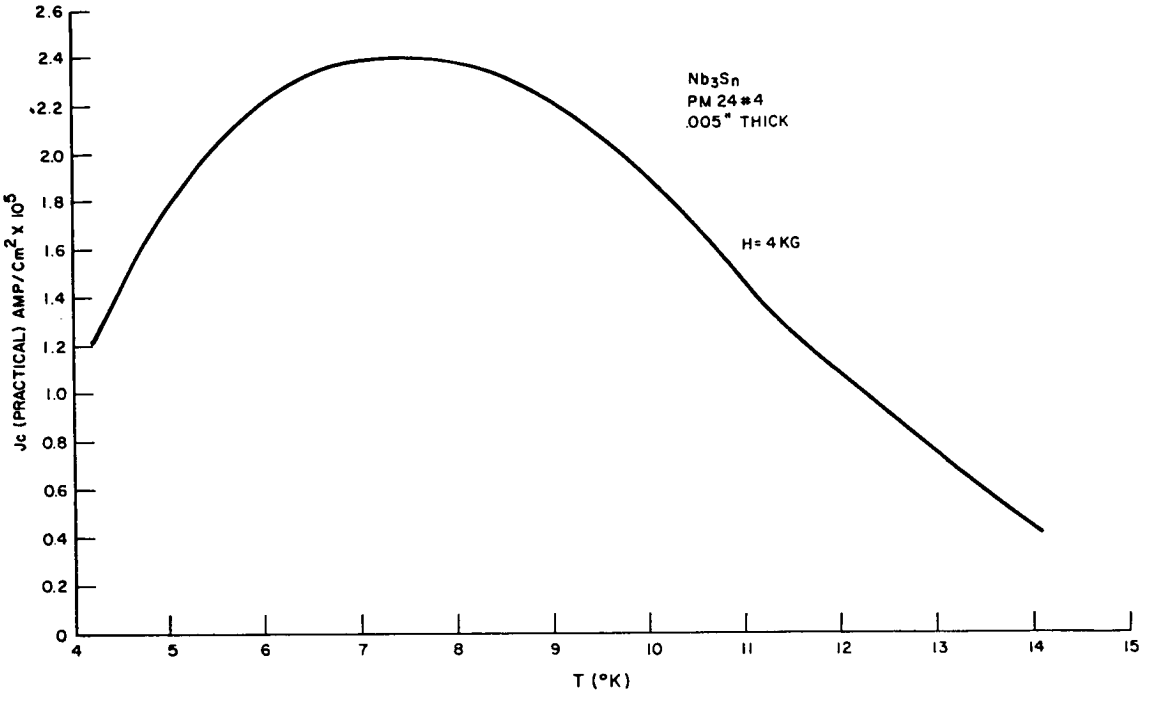


FIGURE 8. PRACTICAL CRITICAL CURRENT AS A FUNCTION OF TEMPERATURE

at temperatures near T_c the data is better described by the relation $J_c \times (H)^{1.5} = \alpha_c$. This last observation is in agreement with the high-temperature J_c measurements of Cody and Cullen (RCA, Princeton) on Nb_3 Sn.

From data of the above type, the point on the magnetization curve at which critical state performance was continuous can be taken from all the curves and the value of applied magnetic field corresponding to these points plotted as a function of temperature (Fig. 9). The indicated areas in the figure show theoretical areas of operation in which the solenoid would be stable from flux jumps while still in the superconducting state. Note that if an Nb_3 Sn solenoid is to be operated at 8°K, the entire solenoid must be in a magnetic field of 25 kG, or higher, for critical state performance.

4. Major Accomplishments. The major types of experimental data obtained to date are reviewed in paragraph 3. Although no major accomplishments may be reported, yet, the data should produce information on regions of critical state operation as well as other information of importance in the study of superconductors operated at elevated temperatures.

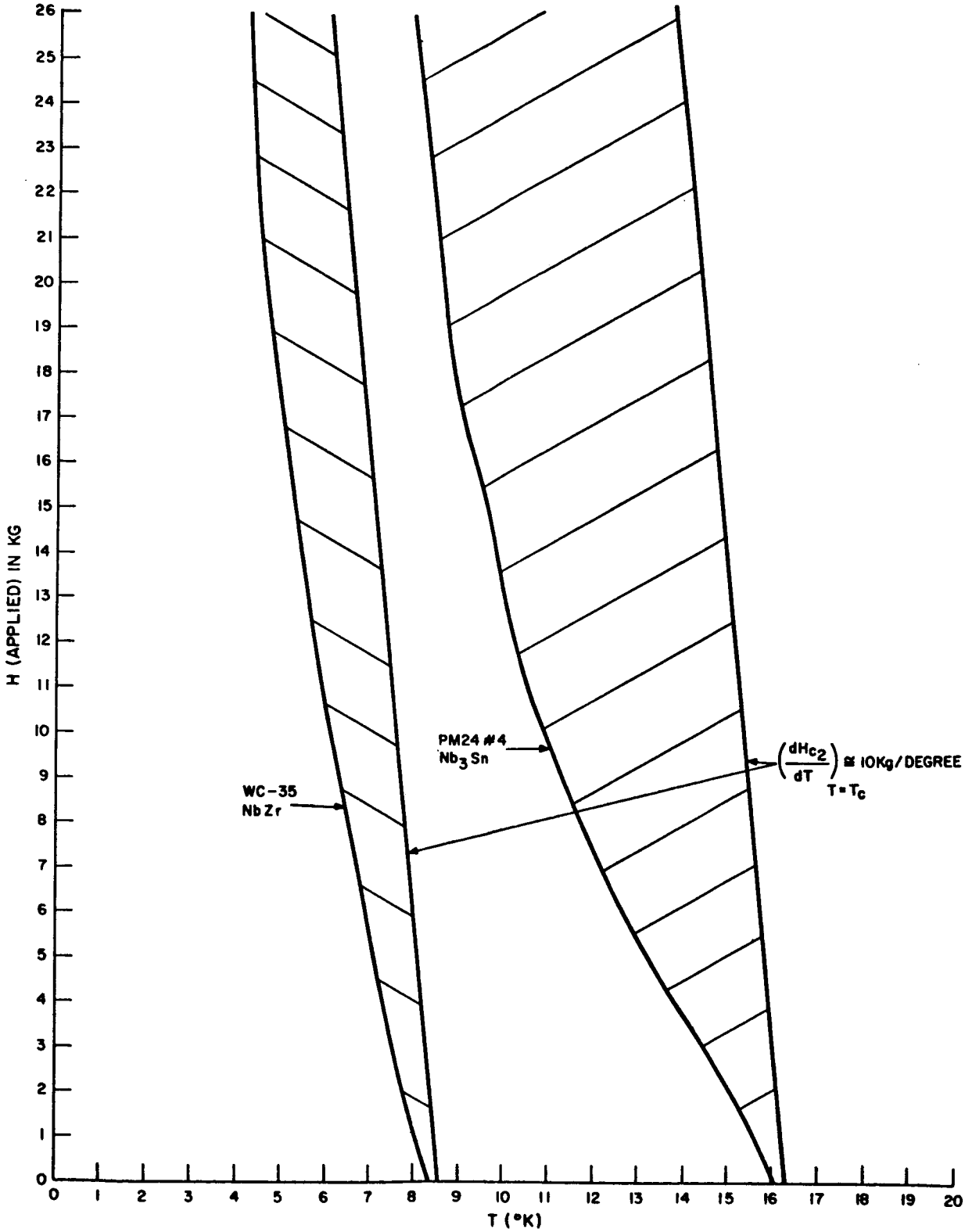


FIGURE 9. REGIONS OF CRITICAL STATE OPERATION OF Nb_3Sn + NbZr

5. Problems. Some problem has been encountered in making the temperature measurements but these have been overcome through engineering.

6. Future Plans. Work to follow will consist of further measurements (as in (2)) on NbTi. Studies are planned on NbTi cylinders after annealing at 600°C to enhance current carrying capacity, and on a sample after full annealing in a high vacuum at 1350°C.

A second line of inquiry for future work is the effect of surface treatments such as etching, polishing, and metallic surface coatings on the superconducting properties of hollow cylinders. Special attention will be given to the critical current of these samples near the critical temperature. Variations in wall thicknesses to give improved sensitivity will also be used.

The third area for future work will be studies of small coils, either shorted or fed by an external current, so as to discover the effect of constraining the current to be everywhere constant in the coil. The two solenoids presently planned for testing are a NbZr wire coil and one wound of copper clad Nb_3Sn ribbon. The use of coils permits one to readily change sample shape by rewinding.

7. Illustrations. Figures 6, 7, 8, and 9.

L. Theoretical Investigation of Mu-Capture Ratio and Properties of Comparable Beta Transitions

Submitted by
(Technical Supervisor)

James C. Ashley
R-RP-N, 876-4126

1. Project Data

Contract Number: NAS 8-11169, March 14, 1964 - April 13, 1965

Contractor: Board of Trustees of the University of Alabama
University, Alabama

2. Purpose of Project. In general terms the purpose of this project is to improve methods of calculating Mu-capture rates in the following ways:

a. attempts will be made to determine more accurately the form of the interaction, seeking in particular the magnitudes of the induced effects.

b. improvements will be made in the accuracy of beta-decay analyses which should allow calculation of more accurate values of nuclear matrix elements.

c. attempts will be made to calculate Mu-mesonic radial functions in a form that will be similar to the treatment of electron radial functions.

3. Technical Status. The following two items represent a suitable summary of the current status of this project:

a. Theoretical Calculation of the Nuclear-Recoil Spectrum following the Beta Decay of H_e^6 - The $\beta - \nu$ angular correlation for Gamow-Teller allowed beta decay has been calculated using Coulomb electron radial functions. The nuclear-recoil spectrum of H_e^6 was obtained for approximate Coulomb radial functions and for several sets of values for "induced" couplings. Results have been compared with experiment in order to obtain information about "induced tensor" couplings. The result of this analysis indicates that the "induced tensor" coupling vanishes or is much smaller than had been previously indicated. The results for the $\beta - \nu$ angular correlation compare favorably with the results of Greuling and Kim.

b. Muon Capture Calculations for C^{12} - The partial muon capture rate from the ground state of C^{12} to the ground state of B^{12} has been calculated. The calculation assumes the validity of the Universal Fermi Interaction and the "conserved vector current." The effects of the "induced pseudoscalar" and "induced tensor" couplings are included. Relativistic muon wave functions corrected for finite nuclear size are used. The magnitudes of the induced coupling constants appear as parameters in the final capture rate. A comparison of these results with recent experimental work will be included in the final report.

4. Major Accomplishments. The major accomplishments to date are recorded in the technical status portion above. An added dividend from this project is an outline of the principal publications relating to mu-capture.

5. Problems. No insurmountable problems have been encountered and work is proceeding at the proper rate.

6. Future Plans. In the remaining portion of the contract several more types of single-level mu-capture rates will be calculated and the electron radial-wave-function approximations will be completed. If further funding were available, total mu-capture rates could be calculated for light nuclei from the single-level formulae and theoretical values of nuclear matrix elements for captures to excited states.

7. Illustrations. None.

M. Investigation of the Combined Effects of Nuclear Radiation, Cryogenic Temperatures, and Vacuum on Engineering Materials

Submitted by
(Technical Supervisor)

E. C. McKannan
R-P&VE-MEE, 876-1233

1. Project Data

Contract Number: NAS 8-2450, November 9, 1961 - September 9, 1965

Contractor: General Dynamics
Fort Worth, Texas

2. Purpose of Project. This program is directed toward the development of expermental data on the combined effects of nuclear radiation, vacuum, and cryogenic temperatures on engineering materials. Materials of major interest to this project are primarily organic, such as lubricants, plastics, elastomers, and surface coatings. Tests are to be made during exposure to (a) radiation from a nuclear reactor, (b) reduced pressures of 10^{-6} millimeters of mercury, and (c) cryogenic temperatures to determine progressive changes in the physical and mechanical properties of selected materials of potential use in nuclear-propelled vehicles. Tests are to determine weight loss, gas evolution, and physical properties as appropriate to the material and its proposed use.

3. Technical Status. The final report covering the second year of materials testing and data evaluation has been published. Mechanical and electrical property measurements have been made on 83 aerospace engineering materials. The current work has been planned to fill in missing data points, to

check anomalies, and to complete the characterization of materials previously evaluated. This work will require three weeks of irradiation time with vacuum chambers, liquid nitrogen and liquid hydrogen dewars, and should complete the planned evaluation of the materials listed in Table I.

4. Major Accomplishments. Within each group of materials those which are useful in areas involving high energy irradiation have been selected and those which show serious degradation have been listed for designers of space vehicles.

5. Problems. None.

6. Future Plans. The test program is scheduled for completion at the end of this year. Reports showing a comprehensive evaluation of the data, comparison of the materials, and interpretation of the significance of the results in terms of design needs will be written.

7. Illustrations. Table I

TABLE I.
MATERIAL FOR EVALUATION IN COMBINED ENVIRONMENT

A. Adhesives	B. Plastics
Aerobond 422J or Epon 422J	AC Polyethylene 1220
Aerobond 430	DC-7-170 (Silastic 7-170)
Epon VIII	Duroid 5600
APCO 1252	Estane 5740X1
FM-47	Geon 2046
FM-1000	Geon 8800
Hexcel 1252	H-Film (2 Mil)
HT-424	Kel-F-81 (Flexure)
Metlbond 302A	Kel-F-81 (Tensile)
Metlbond 406-1	Kynar
Metlbond 408	Marlex 6002
Metlbond 4021	Mylar A (10 Mil)
Narmco A	Mylar A (3 Mil)
Narmco C	Mylar C (1 Mil)
Scotchweld AF-6	Tedlar
Scotchweld AF-40	Teflon FEP (10 mil)

TABLE I (Concluded)

A. Adhesives

Schell 929
Schell 934

B. Plastics

Teflon FEP (40 Mil)
Teflon TFE (10 Mil)
Teflon TFE-7 (125 Mil)
Tedlar
Thermofit RNF
Lamicoid 6038E

C. Laminates

Conolon 506
CTL-91-LD
DC-2106
DC-2104
Epon 828/A (Flexure)
Epon 828/A (Tensile)
HRD Honeycomb
Mobaloy 81-AH7
Paraplex P-43
Selectron 5003

D. Lubricants

Alpha-Molykote X-15
Duroid
Electrofilm 66C
G. E. Versilube F-50
MLF-5
Shell ETR-H

E. Potting Compounds

DC-R-7521
Durock D-133
Epon 828/Z (Compression)
Epon 828/Z (Wire-Pull)
EC-2273 B/A (Compression)
EC-2273 B/A (Wire-Pull)
RTV-60 (Compression)
RTV-60 (Wire Pull)
RTV-501 (Compression)
RTV-501 (Wire Pull)
RTV-501 (Wire Pull)

F. Elastomers

Parker 66-581 (Tensile)
Parker 66-581 (O-Rings)
Viton A
Viton B (PRP 19007)
PRP 2277 (Neoprene)
PRP 737-70 FLX
RA 33860 (Natural Rubber)
RA 24160 (Neoprene)
Polymer SP-1
Buna N (RA 30760)
EC-1663
EC-1949

Meteoroid Environmental and Impact Hazard

A. Meteoroid Impact Simulation by Magnetic Gradient Particle Acceleration Techniques

Submitted by
(Technical Supervisor)

Dr. O. K. Hudson
R-RP-P, 876-2595

1. Project Data

Contract Number: NAS 8-5266, April 18, 1963 - November 17, 1965
NAS 8-11174, June 27, 1964 - August 27, 1965

Contractor: Aerojet-General Nucleonics
P. O. Box 77
San Ramon, California

2. Purpose of Project. To demonstrate the feasibility of accelerating particles whose mass lie between 1.0 mg and 100 mg to velocities in excess of 15 Km/s by means of the magnetic gradient technique. Said magnetic gradient will be derived from the phenomenal magnetic energy present in a magnetic implosion. Meteoritic velocities are thought to range between 10 and 80 Km/s; present laboratory accelerators have not exceeded 11 Km/s using a known particle of the mass range in question.

3. Technical Status. The theoretical work is substantially complete; this work serves to indicate the important considerations in the construction of the accelerator. The experimental work is behind schedule for a number of reasons - some of them unavoidable. It is expected that lost time will be substantially recaptured.

4. Major Accomplishments. In one "sloppy" experiment an eight million gauss magnetic field was measured; this corresponds to a magnetic pressure of about 32 million atmospheres. When the experiment is "cleaned up" the design field of twelve million gauss will probably be accomplished.

5. Problems. A ring detonator assembly is now being used since it is cheaper, however this has introduced simultaneity problems. These can be solved.

6. Future Plans. See Technical Status.

7. Illustrations. None.

B. Meteoroid Distributed Transducer

Submitted by
(Technical Supervisor)

Dr. O. K. Hudson
R-RP-P, 876-2595

1. Project Data

Contract Number: NAS8-5336, May 20, 1963 - November 19, 1963
March 4, 1964 - December 21, 1964

Contractor: Northrop Space Laboratories
Hawthorne, California

2. Purpose of Project. A feasibility study of acoustic detectors to discover a transducer material and/or a geometry which, when subjected to hypervelocity impact, will yield useful information as to the damage caused in the target and also characteristics of the impacting material.

3. Technical Status. The work has been completed; the final report has been written, submitted and accepted. Feasibility is questionable since adequate testing of the final model was not possible with above funds.

4. Major Accomplishments. An up-to-date annotated bibliography of piezo-electrical materials has been produced. This may be published separately by NASA so that it will be available to workers with other applications in mind. It has been determined that for hypervelocity impact, quartz is the best piezo electric material, but must be used in a certain way.

5. Problems. More experimental data using different thicknesses of target, different impacting materials, different impacting masses, and different impacting angles are required to finally answer the question of feasibility of this device.

6. Future Plans. Attempts are underway to fund this work to completion, also since a great deal of acoustical impact data will be available from the proposed continuation, some impacts will be made using lasers to see if the generated shock waves are the same from both particles and radiation. Criteria for this are provided in the technical supervisors paper: Meteoroid Simulation Using Lasers, NASA TM X-53122.

7. Illustrations. None.

C. Feasibility Study for A Hypervelocity Rail Gun

Submitted by
(Technical Supervisor)

Dr. O. K. Hudson
R-RP-P, 876-2595

1. Project Data

Contract Number: NAS 3-1924 (Lewis Contract, Dates Unknown)
NAS8-11204, May 14, 1964 - March 14, 1965

Contractor: MB Associates
San Ramon, California

2. Purpose of Project. The work to be performed is based upon and constitutes a continuation of the work performed under contract NAS 3-1924 during which a unique method of mechanical interaction between a pellet and a magnetic field produced by condenser discharged was demonstrated. It is the objective of this study to explain the observed interaction and to evaluate its feasibility in hypervelocity gun applications.

3. Technical Status. At the time of this report the contractural effort is two-thirds complete. Theoretical work has been done; numerous experiments have been performed and more are planned. Work is on schedule and it is expected that it will be complete on schedule.

4. Major Accomplishments. This subject has been pursued practically from the time of Napoleon's Army by many investigators. None have been so successful as MB Associates (since they have achieved the highest known projectile velocities) in uncovering the fundamental problems of this acceleration technique.

5. Problems. None.

6. Future Plans. A decision as to feasibility can be expected in the next reporting period. If it is feasible, support for a pilot-engineering model will be sought.

7. Illustrations. None.

Thermal Radiation Effects and Temperature

A. Study of the Effects of Ultraviolet Radiation

Submitted by
(Technical Supervisor)

E. C. McKannan
R-P&VE-MEE, 876-1233

1. Project Data

Contract Number: Not Applicable

Contractor: MSFC, In-House

2. Purpose of Project. The objective of this program is to develop thermal control coatings and evaluate their stability in the pre-launch and space environment. The reflectance and emittance of candidate materials, particularly highly reflective coatings, will be measured both at standard laboratory conditions and at space environmental conditions over a broad spectrum of incident radiation in order to analyze the causes of instability and to modify the materials. The materials will be measured "in-situ" after exposure in the specified environment without the necessity of removing them from the environment into laboratory conditions for evaluation. The environmental parameters which will be controlled individually and/or in combination will include:

1. vacuum to 10^{-9} mm Hg,

2. temperature from -195° C to +200° C,

3. charged particles, both protons or electrons from 0.5 to 2.0 Mev,

4. solar radiation from about one to four times the solar constant at the specimen surface.

The development of materials will involve the continuing search for:

1. inherently stable materials,

2. additives such as (1) anti-oxidants, (2) thermal stabilizers (3) anti-rads, (4) ultraviolet absorbers, (5) surface passivators,(6) moisture barriers.

3. Technical Status. Reflectance and emittance measurements are being made at laboratory conditions on S-13, the zinc oxide pigment in a modified silicone resin binder, which is used on Pegasus. The measurements are being made on specimens taken after coating, assembly, shipping, and after standing at Cape Kennedy to determine the degradation in properties due to the atmospheric conditions.

Equipment in the space environmental simulation facility is being assembled for the "in-situ" measurements. All of the sub-systems have been designed. The vacuum chamber, temperature control, particle accelerator, and particle spectrometry systems are in operation. The solar simulator, beam control, integrating sphere, and broad band spectrometers are ordered and currently under construction.

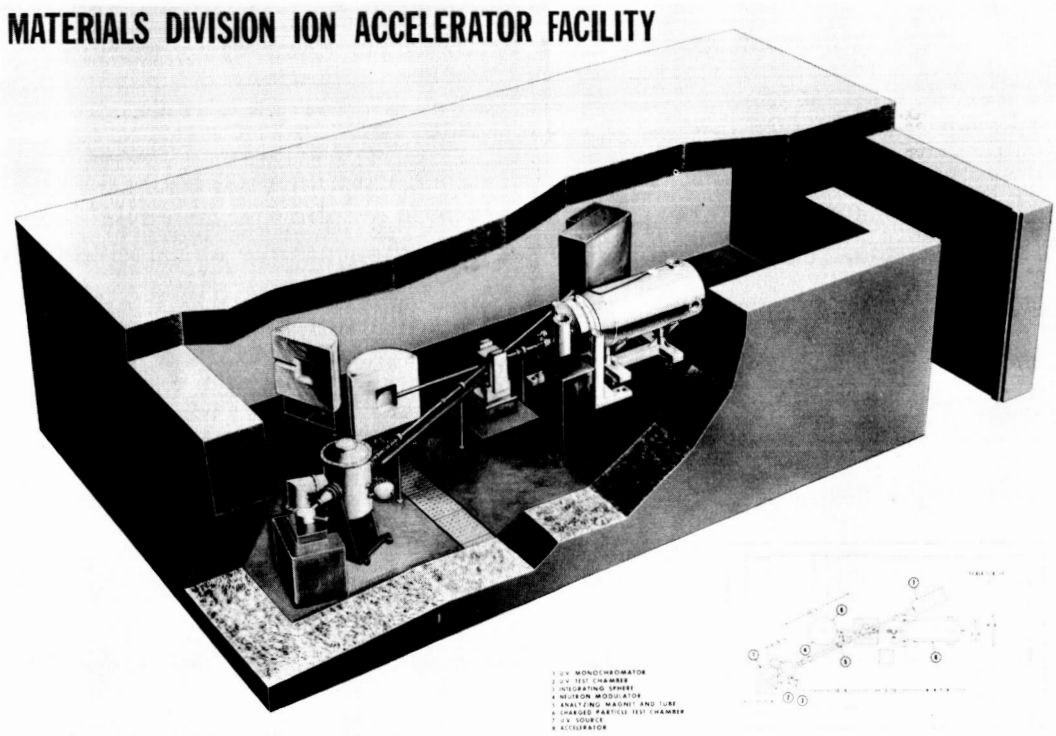


FIGURE 10. MATERIALS DIVISION ION ACCELERATOR FACILITY

4. Major Accomplishments. The program is in an early phase.

5. Problems. The "in-situ" measurements are beyond the present state-of-the-art and require careful assembly and calibration to insure validity.

6. Future Plans. See Purpose of Project.

7. Illustrations. Figure 10.

B. Theoretical Study of the Radiative Emissivity of Materials

Submitted by
(Technical Supervisor)

Klaus Schocken
R-RP-T, 876-3391

1. Project Data

Contract Number: NAS 8-5210M2, April 1, 1963 - May 1, 1965

Contractor: PEC Corporation
Boulder, Colorado

2. Purpose of Project. The actual state of a solid near the surface is generally unknown. In addition, the published literature on emissivity is based on considerations of thermal equilibrium between a solid and its environment, where by Kirchhoff's law the emissivity of a solid equals the absorptivity.

3. Technical Status. Thermal equilibrium between a solid and blackbody radiation is maintained partially by spontaneous emission and partially by stimulated emission of the emitter. If the radiation falling on the emitter is not blackbody radiation of the same temperature as the solid, the stimulated emission may be more, or less than the predicted by Kirchhoff's law.

4. Major Accomplishments. For a very hot metallic body in a cold environment, the power radiated is only a fraction of what it would be at thermal equilibrium. The electrons respond so rapidly to the impinging electromagnetic field that it is prevented from penetrating more than a few thousand angstroms into the metal. In the case of sodium at long wavelengths, the penetration depth

for these basic functions is about 2100 Å and does not change appreciably until the wavelength of the incident radiation approaches the ultraviolet. In this respect, calculations performed with the new basic functions will differ markedly from all other calculations in which plane waves are used.

5. Problems. The most important problem is to prove the theoretical results experimentally.

6. Future Plans. The calculations are to be extended to semiconductors and non-conductors.

7. Illustrations. None.

C. Emittance of Materials at Very High Temperatures

Submitted by
(Technical Supervisor)

Klaus Schocken
R-RP-T, 876-3391

1. Project Data

Contract Number: H-71435, January 1, 1964 - August 31, 1964

Contractor: National Bureau of Standards
Washington, D. C.

2. Purpose of Project. The objective of this project was to develop techniques for the measurement of the thermal radiation properties of both metals and non-metals at temperatures up to 2500°K and to provide emittance data of known accuracy for materials of interest to the space program.

3. Technical Status. A rotating cylinder method was used for normal spectral emittance between 1 and 15 microns in the range of about 1000 to 1800°K, and an induction-heating method for total normal emittance at temperatures as high as 2500°K. A Cary Model 14M recording spectrophotometer equipped with an integrating sphere was used for the reflectance measurements.

4. Major Accomplishments. Normal spectral emittances from 1 to 15 microns were measured for platinum at 1400°K and for 11 ceramic oxide

specimens at 1200°K. The agreement between emittance and reflectance measurements was good for aluminum oxide, calcium zirconate, and magnesium oxide; reasonably good for thorium oxide and zirconium silicate; poor for zirconium oxide.

5. Problems. The two measurements were performed at different temperatures. There exists an uncertainty in converting reflectances from relative to absolute values.

6. Future Plans. The contract has been terminate.

7. Illustrations. None.

D. Emission Properties of Materials at Cryogenic Temperatures

Submitted by
(Technical Supervisor)

Klaus Schocken
R-RP-T, 876-3391

1. Project Data

Contract Number: NAS 8-2537M7, December 31, 1963 - January 31, 1965

Contractor: Arthur D. Little, Inc.
Cambridge, Massachusetts

2. Purpose of Project. The far infrared region of the spectrum has been relatively ill-explored. It was the purpose of this task to conduct an experimental investigation of the spectral reflectance of selected materials at cryogenic temperatures under environmental conditions as would be encountered by space vehicles.

3. Technical Status. All the materials were run at room temperature as well as at liquid helium temperature. Measurements were obtained on stainless steel, magnesium, aluminum, chromium, sapphire, and quartz.

4. Major Accomplishments. All the metals which were measured obey the Hagen-Rubens relation yielding essentially 100 percent reflectance in the far infrared. The room temperature data are in agreement with previously measured values.

5. Problems. The error limitations are about ±5 percent. They are relatively large.

6. Future Plans. None.

7. Illustrations. Figures 11, 12, 13, 14, 15, 16, and 17.

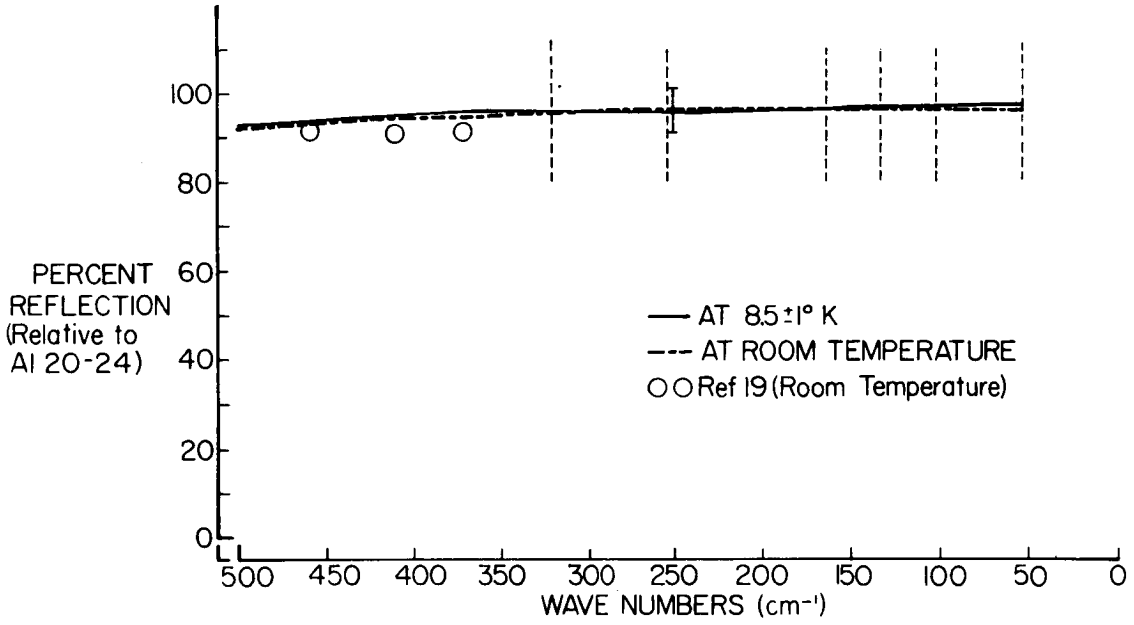


FIGURE 11. FAR INFRARED REFLECTION SPECTRUM OF STAINLESS STEEL TYPE 304

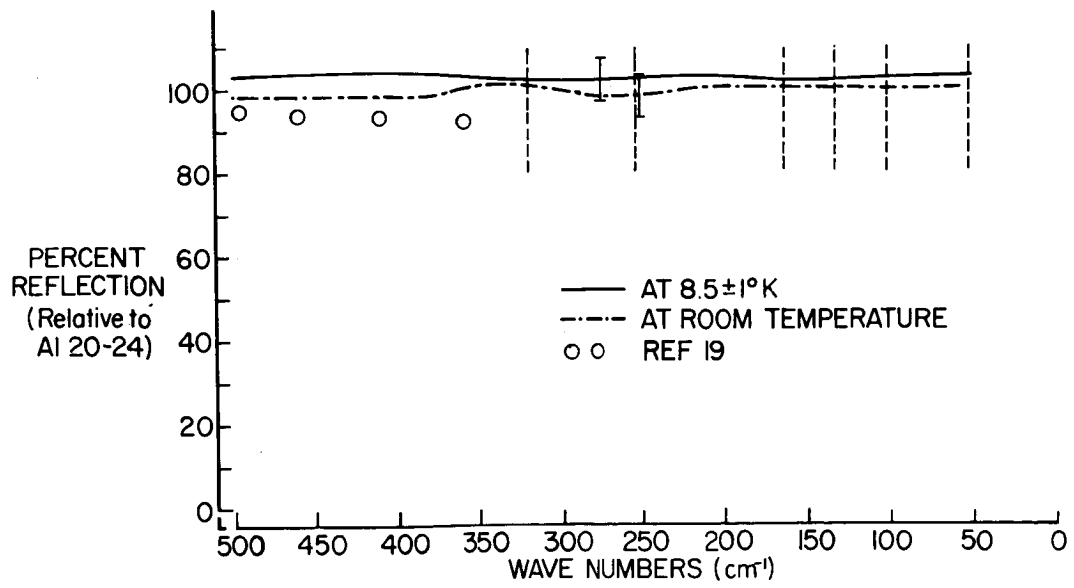


FIGURE 12. FAR INFRARED REFLECTION SPECTRUM OF MAGNESIUM

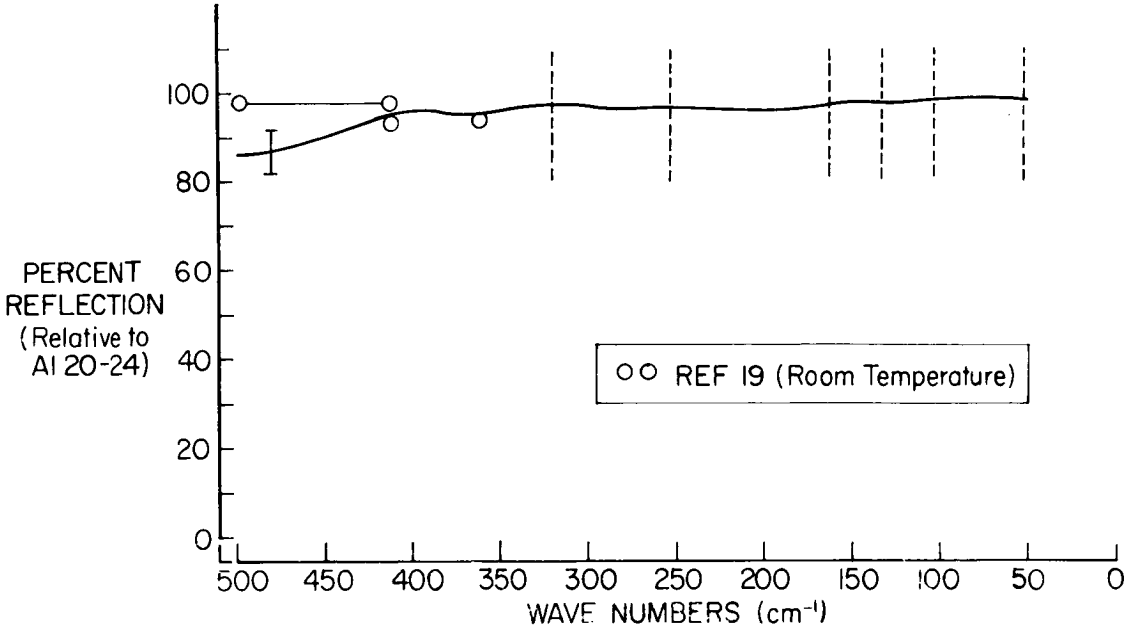


FIGURE 13. FAR INFRARED REFLECTION SPECTRUM OF ALUMINUM ALLOY TYPE 20-24 at 8.5 ±1° K

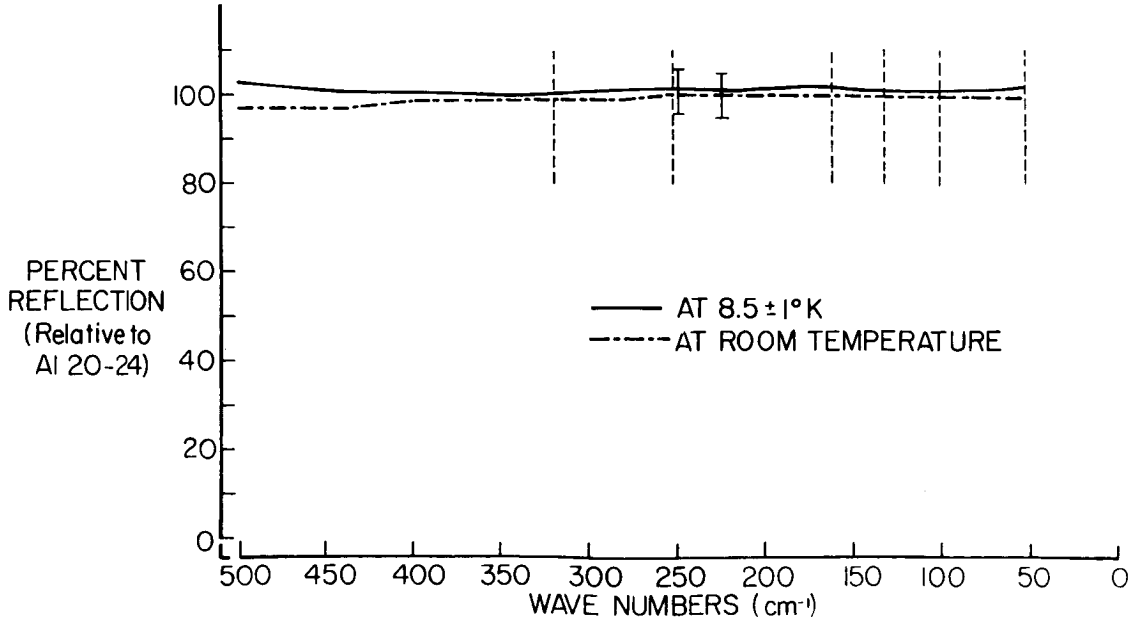


FIGURE 14. FAR INFRARED REFLECTION SPECTRUM OF CHROMIUM

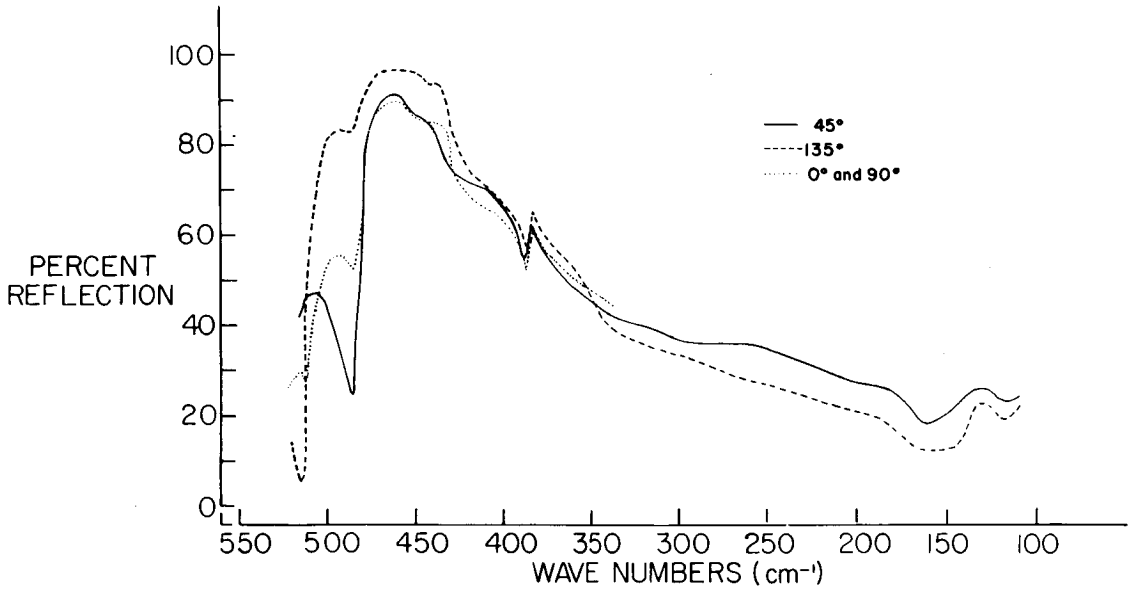


FIGURE 15. FAR INFRARED REFLECTION SPECTRUM OF Al_2O_3 (90°)

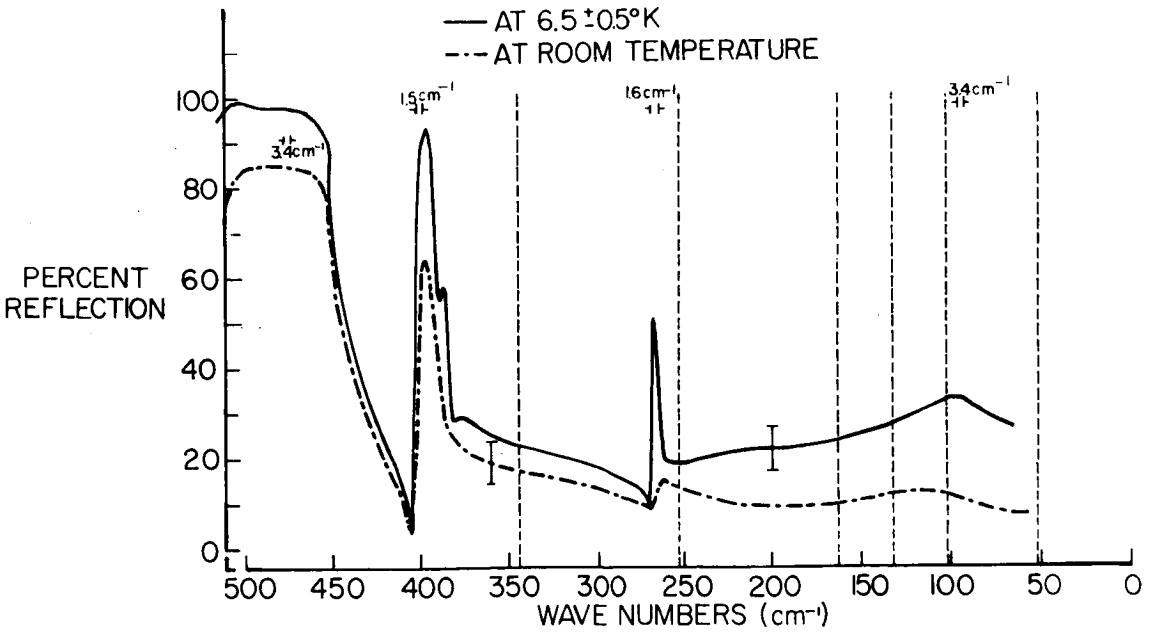


FIGURE 16. FAR INFRARED REFLECTION SPECTRUM OF SiO_2 (Z Cut Quartz)

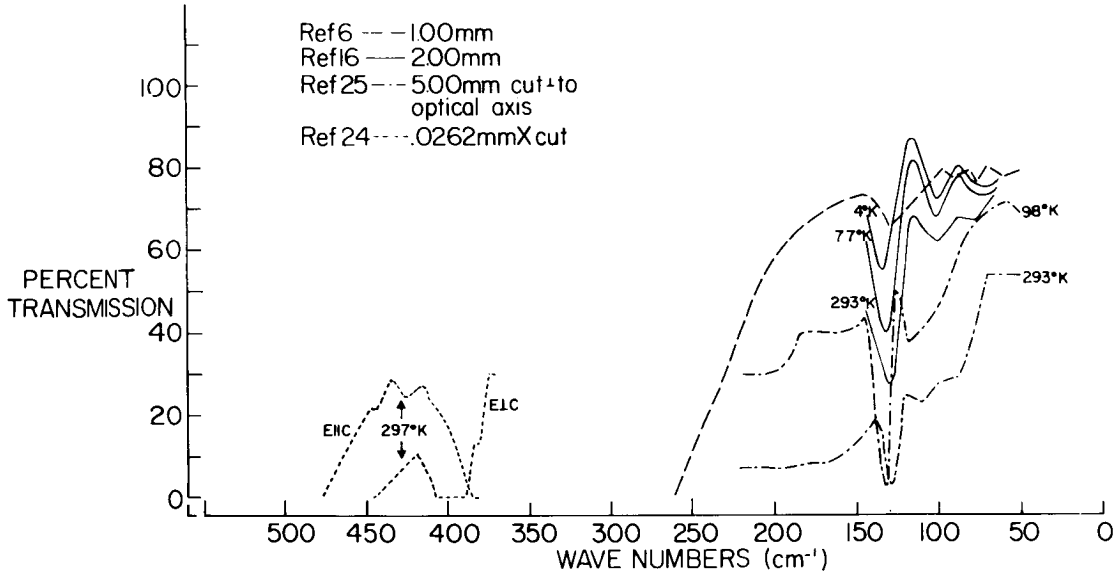


FIGURE 17. FAR INFRARED TRANSMISSION OF QUARTZ

E. Study of Micrometeoroid Damage to Thermal Control Materials

Submitted by
(Technical Supervisor)

James A. Fountain
R-RP-T, 876-5557

Klaus Schocken
R-RP-T, 876-3391

1. Project Data

Contract Number: NAS 8-11149, February 9, 1964 - November 9, 1964

Contractor: Space Technology Laboratories
Physical Electronics Laboratory
Meteoritics Department
Redondo Beach, California

2. Purpose of Project. The purpose of this task is to simulate the micrometeoroid space environment on materials used as thermal control surfaces and to study the resultant effects.

3. Technical Status. Micrometeoroid damage was simulated in the laboratory by accelerating spherical iron particles to velocities of up to ten kilometers per second and impacting them into thermal control surfaces. The particles ranged in size from about 0.6 microns to about 4 microns. The accelerator was a two-million-volt Van de Graaf generator. Since the particles were electrically charged, the number of particles were counted accurately by electrostatic detectors. The velocity of a statistically significant number of particles was also measured electronically.

The test samples were placed in an evacuated chamber, and since there are no exploding gases associated with the accelerator system, the chances of contamination are minified.

The samples were as follows: (1) electroplated gold on a polished substrate, (2) vacuum deposited aluminum on a resin undercoat on an aluminum substrate, and (3) stainless steel, Type 304.

4. Major Accomplishments. Each of the samples was (1) measured for reflectance over a wavelength range from 0.3 to 20 microns, (2) bombarded in the accelerator with the iron particles, and (3) again measured for reflectance. A typical reflectance change due to the craters produced is shown in Figure 18 for the gold sample. The reflectance curves were integrated over the

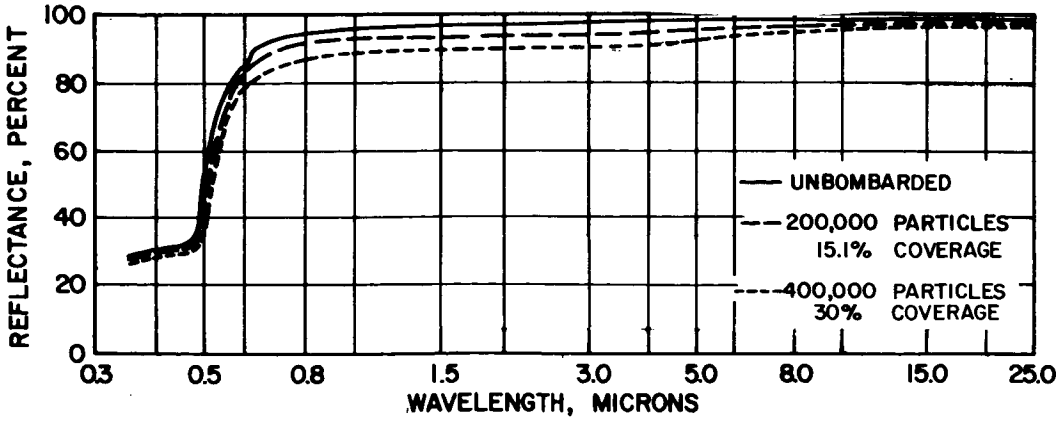


FIGURE 18. SPECTRAL REFLECTANCE OF GOLD SAMPLE BEFORE AND AFTER PARTICLE BOMBARDMENT

appropriate wavelengths to show the changes in solar absorptance and infrared emittance. Figure 19 shows a table summarizing these results for several numbers of impacts and percent coverages.

TOTAL DIRECTIONAL EMITTANCE ($\theta = 15°$) OF THE TEST SAMPLES

DESCRIPTION				EMITTANCE			SOLAR ABSORPTANCE		
	Materials	Impacts	%Coverage	Initial ϵ	After ϵ	Increase $\Delta\epsilon$	Initial α	After α	Increase $\Delta\alpha$
38-64	Gold	100,000	9.1	$.02_0$	$.02_1$	$.00_1$	$.23_7$	$.27_3$	$.03_6$
47-64	Gold	200,000	15.1	$.02_2$	$.02_8$	$.00_6$	$.23_2$	$.27_1$	$.03_9$
47-64	Gold	400,000	~30	$.02_0$	$.04_4$	$.02_4$	$.24_0$	$.29_3$	$.05_3$
51-64	304 Stainless Steel	300,000	~8	$.09_6$	$.11_4$	$.01_8$	$.45_4$	$.46_3$	$.00_9$
97-64	304 Stainless Steel	600,000	~16	$.10_3$	$.12_8$	$.02_5$	$.45_4$	$.48_3$	$.02_9$
40-64	Vacuum Deposited Aluminum	300,000	-	$.02_3$	$.04_0$	$.01_7$	$.11_0$	$.13_0$	$.02_0$
105-64	Vacuum Deposited Aluminum	600,000	-	$.03_0$	$.06_0$	$.03_0$	$.12_0$	$.15_8$	$.03_8$

NOTE: The third significant figure is given as shown because the accuracy of the measurement does not justify giving the absolute value to more than plus or minus .01. The values of the measurements relative to each other should, however, be more accurate and the small changes involved would be distorted if the values were reduced to two significant figures.

FIGURE 19. EFFECT OF SIMULATED MICROMETEOROID BOMBARDMENT UPON INTEGRATED DIRECTIONAL REFLECTANCE

The effects upon the specularity of the reflective surface were determined at an angle of 15 degrees and over the spectral range from 2 to 20 microns. These results are shown in Figure 20. A trend of increasing change in specularity is noted as wavelength decreases.

An attempt was made to extrapolate the laboratory crater coverage to actual space conditions. The mean particle velocity in the tests was about 5 kilometers per second and the density of the particles about 8 grams per cubic centimeter. Using the cratering efficiency for the gold sample and extrapolating upwards in velocity to thirty kilometers per second and downwards in density to two grams per cubic centimeter, a table was produced showing predicted percent

SPECULAR REFLECTANCE OF BOMBARDED AREA DIVIDED BY SPECULAR REFLECTANCE OF UNBOMBARDED AREA (θ = 15°)			
Wavelength Microns	Gold 47-64 400,000 Impacts	Stainless Steel 94-64 600,000 Impacts	Vacuum Deposited Aluminum 105-64 600,000 Impacts
2.0	.71	.70	.87
2.95	.75	.76	.86
4.0	.80	.78	.87
5.0	.85	.87	.90
6.0	.83	.93	.90
7.0	.90	1.00	.93
7.8	.93	.98	.96
9.0	.98	1.00	1.00
9.8	.99	1.00	1.00
11.0	1.00	1.00	1.00
12.0	1.00	1.00	1.00
13.0	1.00	1.00	1.00
14.0	1.00		1.00
15.0		1.00	1.00
16.0	1.00		1.00
17.0		1.00	1.00
18.0	1.00		1.00
19.0		1.00	1.00
20.0	1.00		1.00
21.0		1.00	

FIGURE 20. EFFECT OF SIMULATED MICROMETEOROID BOMBARDMENT UPON SPECULAR REFLECTANCE

crater coverage for a year in space. The flux density is based on the curve of Alexander, et al (1962). This table is shown in Figure 21. It is concluded that the laboratory tests represent roughly one year in space.

Meteoroid Mass Grams	Flux (Particles / m ^{2}/ sec)	Meteoroid Density (gm/cm^3)	Particle Diameter (Microns)	Crater* Diameter (Microns)	Crater Area (Microns^2)	Coverage (%/Year)
10^{-13}	150	2	0.5	3.3	8.5	4.0
10^{-12}	100	2	1.0	6.6	34.2	10.8
10^{-11}	10	2	2.1	13.8	150.0	4.7
10^{-10}	1	2	4.5	29.7	690.0	2.2

* based on cratering efficiency for gold sample.

FIGURE 21. CALCULATED CRATER COVERAGE FOR NATURAL METEOROIDS

6. Future Plans. The initial phase of the contract has expired. However, an extension has been applied for. It will have the following objectives.

a. verification of the previous work,

b. extension of the work to other samples,

c. extension of specular measurements to include the spectral range from .4 to 20 microns, and at three different angles,

d. analytical investigation of the mechanisms involved in the changing of the thermal properties,

e. measurements of crater parameters and crater shapes to aid in the analytical investigation and also to make the data produced under this contract useful in the problem of impact physics.

7. Illustrations. Figure 18, 19, 20, and 21.

F. Directionally Reflective Surface Study

Submitted by
(Technical Supervisor)

Edgar R. Miller,
R-RP-T, 876-4861

1. Project Data

Contract Number: NAS 8-11273

Contractor: Ling-Temco-Vought
Astronautics Division
Dallas, Texas

2. Purpose of Project. To conduct theoretical and laboratory experimental studies on surfaces whose reflectance by scattering is directional with angle of incidence. The Rayleigh-Gans domain was used so that test models could (fiber optics plates) be fabricated to closely conform to the theoretical model.

3. Technical Status: Theoretical predictions of the directional backscattering of the fiber optics plates have been predicted. The fiber optics plates have been fabricated and directional reflectance measurements are being performed on three different thicknesses. Preliminary data indicates good experimental to theoretical correlation of directional reflectance except that the magnitude of reflectance from the models is less than predicted. This is partially due to the fibers being approximately 0.6 microns in diameter instead of 0.25 to 0.5 microns as anticipated.

4. Major Accomplishments. Two IBM 7090 computer programs have been written: (1) "Calculation of Rayleigh-Gans Back-Scattering Cross Sections for Dielectric Cylinders", (2) "Experimental Backscattering Cross Sections for Dielectric Cylinders."

5. Problems. The major problems have been in obtaining test models which conform to the Rayleigh-Gans region of scattering. The present models have larger fibers than desired and are somewhat unevenly spaced.

6. Future Plans. Extend present work to include infinite dielectric cylinders, the relative index range of about 1.1 to 2.0, the solar range of wavelengths, and the range of angles of incidence from normal to the cylinder axis, to parallel to the axis, using rigorous single particle scattering theory.

7. Illustrations. None.

G. Research on Thermal Control Surfaces for the Extraterrestrial Environment

Submitted by
(Technical Supervisor)

Edgar R. Miller
R-RP-T, 876-4861

1. Project Data

Contract Number: Defense P. R. No. H-71465

Contractor: WADD, Project "Super"

2. Purpose of Project. Perform research and development on surfaces for the extraterrestrial environment in the areas where there exists almost no choice of stable surfaces, especially for large area surfaces. These areas being (1) High α_S/ϵ_T Surfaces (ratio of 1:3), (2) Universal Reflector Surfaces ($\alpha_S \simeq \epsilon_T$, < 0.1).

3. Technical Status. High α_S/ϵ_T surfaces are being obtained by using optical dyes in commercially available Fuller aluminum pigmented silicone paints. The dyes that are being used are: (1) Methexybenzeylferrocene (MBF), (2) Hydrobenzeylferrocene (HBF), (3) Dibenzeylferrocene (DBF), (4) 2-4 Didrexybenzeylferrocene (DHBF) (5) Carbon Black.

The optical dyes in solution enhance solar absorptance (α_S) without affecting greatly the thermal emittance (ϵ_T) thereby giving higher ratios of α_S/ϵ_T.

Silver is a prime candidate for the Universal Reflector Surface since pure silver is the best reflector of the whole electromagnetic spectrum known. Silver is considered relatively stable in the extraterrestrial environment, but very unstable in the earth environment. Problems of silver surface preparations and protection are being explored. These include application from the metallo-organic salt solution and self-evaporating protective coatings.

4. Major Accomplishments. The major accomplishments have been obtaining solvents compatible with the silicone aluminized coatings and the ferrocene dyes.

5. Problems. The major problems involve the universal reflector coatings in that short exposures to air tarnishes the silver (Ag_2S). Study shows that Ag_2S is stable in UV-vacuum and cannot be expected to decompose.

6. Future Plans. It is assumed that the present approach using the dyed metal-pigmented organic systems will be fully explored during the present program.

Work will continue with silver as a universal reflector and its problems of preparation and protection.

7. Illustrations. None.

H. Solar Wind Damage to Spacecraft Thermal Control Surfaces

Submitted by
(Technical Supervisor)

Edgar R. Miller
R-RP-T, 876-4861

1. Project Data

Contract Number: NAS 8-11269

Contractor: Litton Systems, Inc.
Applied Science Div.

2. Purpose of Project. To establish experimentally the effect of simulated solar wind bombardment on surfaces for thermal control and to perform theoretical and experimental investigation of the damage mechanisms involved and separation of synergistic effects.

3. Technical Status. Several thermal control coatings and their components have undergone simulation of ten years or more of proton bombardment showing various degrees of degradation. Typical data is shown below for ten years of simulated bombardment.

Surface	ρ/ρ_0
SP-500 - ZnO in LTV 602 Silicone	0.97
Andrew Brown Paint Co. A423	0.97
SP-500 ZnO - Potassium Silicate	0.80
TiO_2 - DC 808 Silicone	0.58

Where ρ/ρ_0 is the ratio of solar reflectance after bombardment to the original solar reflectance.

Also, generally the binder is the component which is most affected by the bombardment.

4. Major Accomplishments. The major accomplishments have been in the simulation of solar wind particles without a resultant charge build-up on the dielectric surfaces and measurements of current densities.

5. Problems. No significant problems have been encountered.

6. Future Plans. Work is continuing on studying coating components. It is anticipated that heavier ions (H_g and H_e) will be used to determine effects of particle size and non-reactive particles.

7. Illustrations. None.

I. Electromagnetic Irradiation Effects on Thermal Control Surfaces

Submitted by
(Technical Supervisor)

Gary M. Arnett
R-RP-T, 876-3314

1. Project Data

Contract Number: Not Applicable

Contractor: Not Applicable (In-House)

2. Purpose of Project. The overall purpose of the project is to do experimental and theoretical studies of the interaction and corresponding damage done to thermal control surfaces by electromagnetic irradiation. More specifically, the purpose of the project is to supplement out-of-house contracts in this area and to define more clearly the experimental parameters which lead to concise and accurate data. Of specific interest is the ultraviolet portion of the electromagnetic spectrum in this project.

3. Technical Status. Several pieces of equipment have been ordered and are being fabricated which will be used in conducting a thorough study. Results obtained to date are preliminary and incomplete. The equipment needed should be received and operational shortly.

4. Major Accomplishments. Preliminary results show that much care must be taken in irradiating samples which are in a chamber evacuated by an oil diffusion system. Although the system may be well cold-trapped and baffled, preliminary results show that backstreaming of the oil and the resulting deposit on the samples can cause severe damage to the thermal control surface.

Characterization of the incident irradiation upon the sample is very important when doing basic damage mechanism studies. After a study of the fluctuations in the intensity of the electromagnetic irradiation source, it has been decided that a device should be designed to adjust the height of the lamp above the sample to deliver a more constant flux density to the samples over a period of time. Design work on such an item is complete and fabrication is now underway.

Several Alodine samples were submitted to electromagnetic irradiation to determine if physical looseness of the coating would cause it to degrade more rapidly. Preliminary results show that although the change in solar absorptance was greater in the "looser" coatings, their initial solar absorptance was much better than in the "tight" coating. The longest study was approximately 1000 equivalent sun-hours (in the wavelength region of 0.2 to 0.4 μ). The solar absorptance values of the "loose" coatings were still better than the "tight" coatings after this period of irradiation.

5. Problems. None.

6. Future Plans. In approximately three months the laboratory will have an "Electron Paramagnetic Resonance Apparatus". This apparatus will be an ideal tool to study induced electromagnetic irradiation damage to powders and single crystals which make up pigments for thermal control coatings. The instrument will be used to investigate such things as structure and stability of damage centers as well as altered electronic structure in the irradiated crystals. By comparing the un-irradiated to the irradiated samples it will be more feasible to correlate theory with experimental result.

7. Illustrations. None.

J. Thermal Similitude

Submitted by
(Technical Supervisor)

Jimmy R. Watkins
R-RP-T, 876-7265

1. Project Data

Contract Number: a. NAS 8-5270, April 12, 1963; Mod. 1, February 5, 1964 (no cost change); Mod. 2, June 29, 1964 (12-month extension - 21.75K); Mod. 3, October 1, 1964 (15K effort increase with same work scope). Appointment of alternate COTR: Jimmy R. Watkins, October 9, 1964.

b. NAS 8-11152, May 19, 1964; Mod. 1, 4-month extension, approximately 15K. Appointment of alternate COTR: Jimmy R. Watkins, October 2, 1964.

c. Contract requested on "Mathematical Aspects of Dimensional Analysis and Similitude.

Contractor: a. Board of Trustees of the University of Alabama
Tuscaloosa, Alabama

b. Lockheed Aircraft Corp
(Lockheed Missiles and Space Company)
Palo Alto, California

c. Dr. A. G. Hansen, principal investigator with University of Michigan

2. Purpose of Project. To study analytically and experimentally the possibilities of the application of the principles of similitude to thermal energy exchange, in particular, radiant energy, the combination of specular and diffuse reflections, and the techniques of thermal modeling.

To determine the feasibility of scale modeling of the thermal properties of spacecraft. The work is primarily experimental, in vacuum with a low temperature sink. Emphasis will be placed initially on transient experiments, based upon modeling laws derived from the differential equations used in practice for thermal analysis. Particular attention will be given to the possibility of using distorted models, especially geometric distortion, to avoid searching for exotic or non-existent materials.

To extend the theory of similarity principles and techniques through further mathematical research.

3. Technical Status. A series of experimental thermal tests have been run using prototypes and 1/2 scale models of two configurations. Experiments have been conducted for the simple case of two parallel disks symmetrically located. The tests were in vacuum of 5×10^{-5} mm Hg with LN_2 cooled walls surrounding the test objects. Both prototype and model disks were made of copper. The results are shown in Figure 22. The scaling ratios used for the model are as indicated on Figure 22. The results indicate that the temperature-time data for the model together with the scaling ratios could be used to predict the prototype temperature-time data fairly well. The maximum difference for the passive elements is about 15° K.

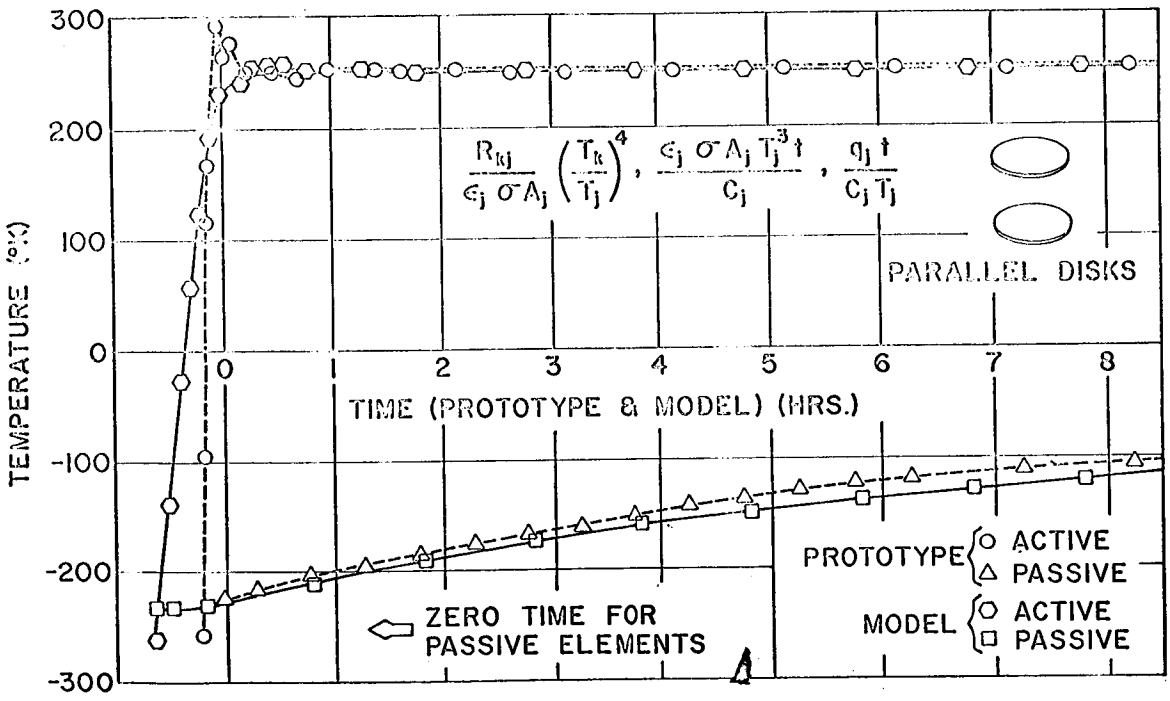


FIGURE 22. THERMAL SIMILITUDE

The preceding case is really preparatory to a more detailed investigation of the problem of surfaces in radiant exchange that are connected by a conducting member -- a case where the modes of energy exchange are not linearly independent. The experimental setup is generally the same as for the preceding case. The results of the tests plus the scaling ratios used are shown in Figure 23. The

dimensionless ratios shown in Figure 23 and used to model the disk conducting member configuration were derived using a computer program of the pi theorem, which was developed in-house. The results shown in Figure 23 indicate more conclusively that the temperature-time data for the model, together with the scaling ratios, could be used to predict the prototype-temperature-time data very closely (NAS8-5270).

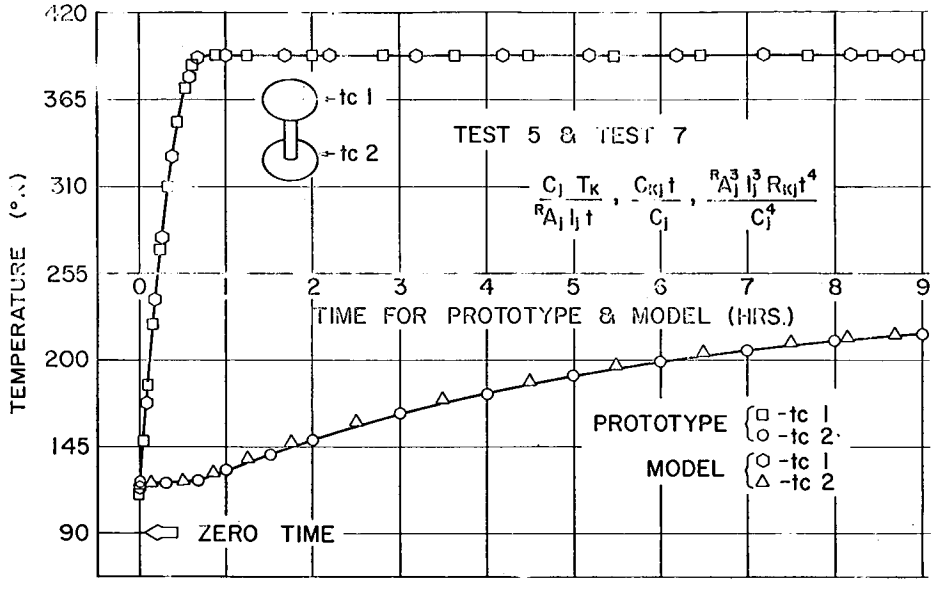


FIGURE 23. TRANSIENTS TESTS ON PROTOTYPE AND MODEL (Identical Initial Conditions and 1/2 Scaling)

Effort has been devoted to detail design considerations of the test prototypes A and B and their 1/2 and 1/4 scale models where prescribed thermal behavior is desired under available chamber conditions (Figs. 24 and 25). The 8 foot by 10 foot test chamber has been installed and performance checked, cold wall sections received, and liquid nitrogen facilities installed. The system is in operation; thus, thermal testing is to begin shortly (NAS 8-11152).

The effort has just been initiated and is still in the procurement and contracting stage.

In-house work has included additional analytical investigations into various aspects of thermal similitude.

4. Major Accomplishments. Analysis and experimental work discussed under technical status.

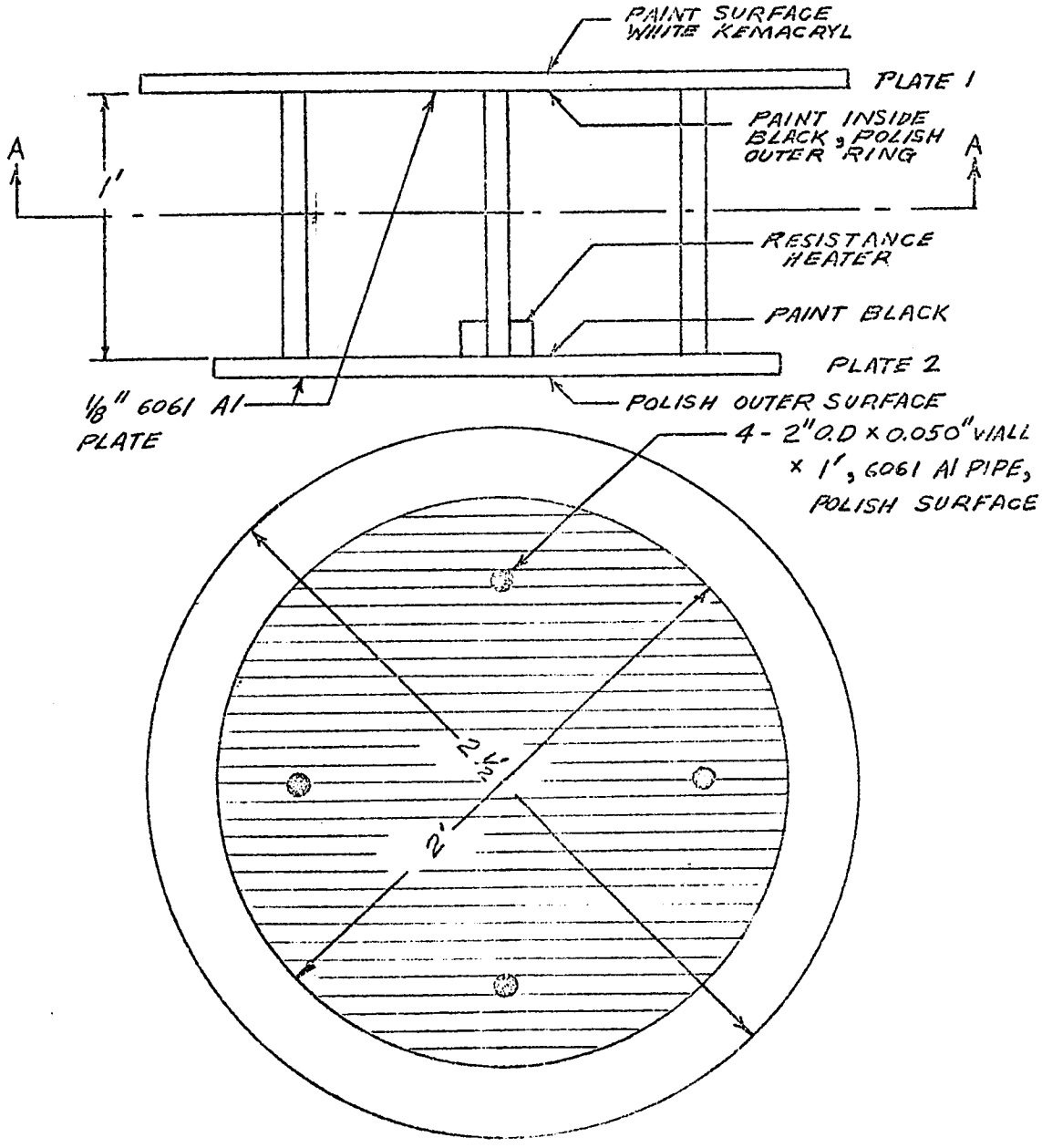


FIGURE 24. PROTOTYPE CONFIGURATION 'A'

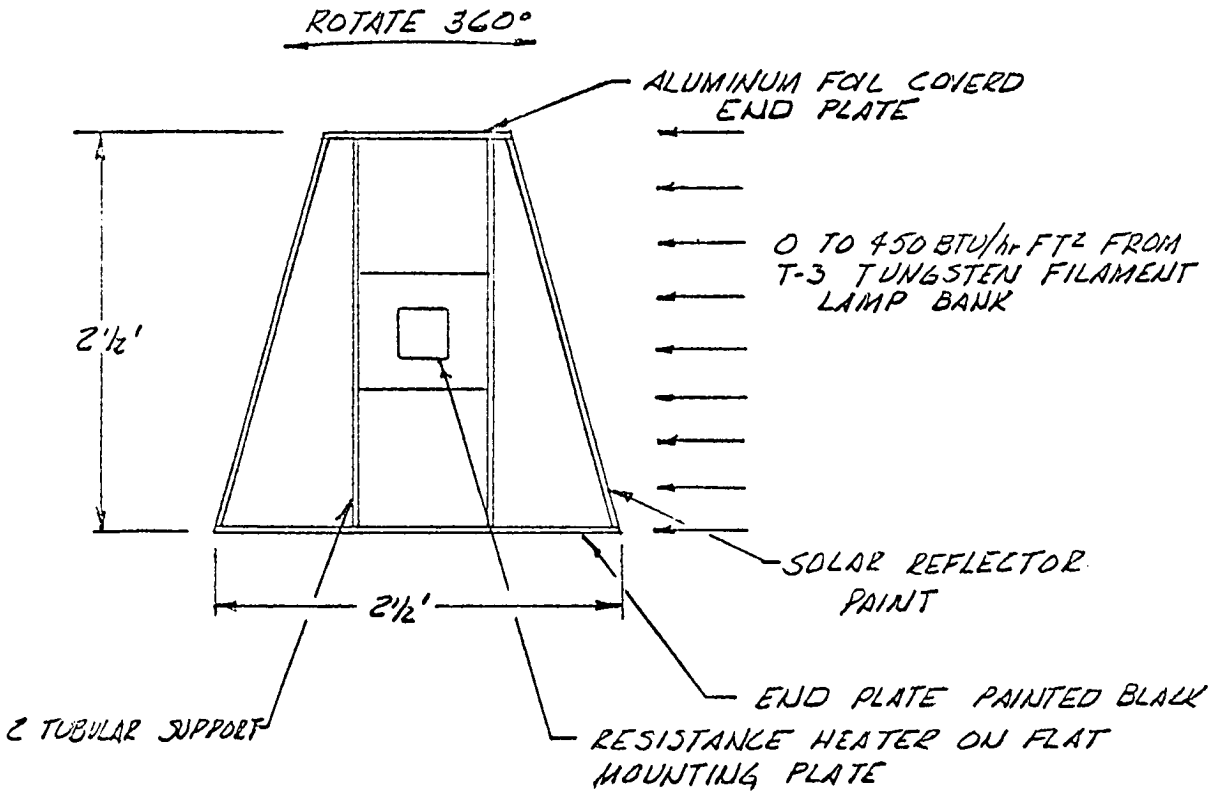


FIGURE 25. TRUNCATED CONE WITH CLOSED ENDS PROTOTYPE CONFIGURATION B

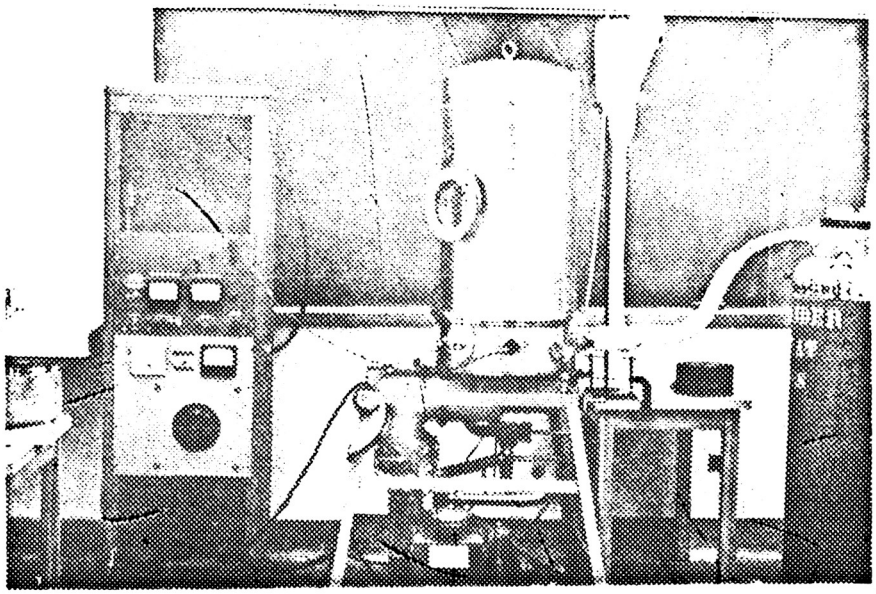
5. Problems. There are no special problems known at this time.

6. Future Plans. Several more experiments will be conducted with the disk conducting member configuration, changing the diameter and length of the member to determine which geometries require radiation to the member to be taken into account.

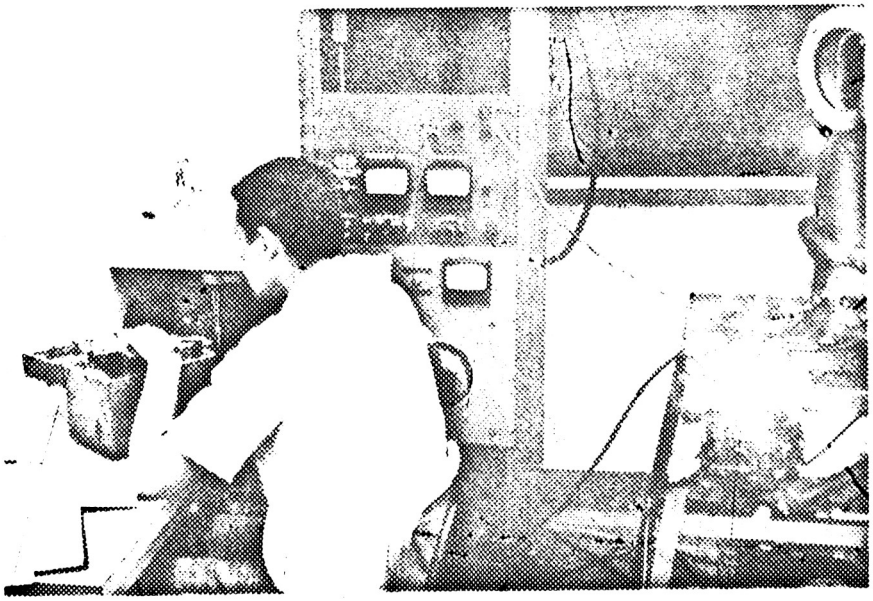
Study effects of emissivity, temperature, and specular radiation on the scaling laws.

Work on finding a method of scaling where the surfaces cannot be divided into essentially isothermal surfaces and essentially conducting members.

7. Illustrations. Figures 22, 23, 24, 25, and 26.



A. Test Apparatus



B. Personnel Reading Thermocouples

FIGURE 26. EXPERIMENTAL APPARATUS

K. Study of Interface Thermal Contact Conductance

Submitted by
(Technical Supervisor)

Harry L. Atkins
R-RP-T, 876-0925

1. Project Data

Contract Number: NAS 8-11247, March 25, 1964 - March 25, 1965

Contractor: General Electric Company
Valley Forge Space Technology Center

2. Purpose of Project. In the field of thermal design the problem of heat transfer across two metals in contact (interface) is of major concern. These metals touch only at tiny irregular points. Because of their small size and irregular distribution, a thorough knowledge of their roll in interface conductance is not known.

There are many parameters affecting interface conductance. Because this problem occurs in spacecraft thermal design, it is desirable to know its change as a function of applied mechanical pressure. In fact, this seems to be the main parameter that determines a change in the heat flow.

This project is aimed at using the past experience of the contractor for measuring and predicting thermal interface conductance of certain metals that are representative of those currently used in spacecraft components and structures.

Phase I - Continuation of Contact Conductance Experiments - The effort planned for this phase represents a continuation of the experimental data acquisition started during the preceding contract period. Since the understanding of the complex interfacial heat transfer mechanism depends on accurate, plentiful, and reproducible data, a number of additional surfaces were tested within the contractual 9-month period. The test apparatus used during the preceding contract was again used. During this phase, the vacuum level will again be in the 10^{-6} mm Hg range. Contact pressures range from a minimum pressure to values of 8×10^6 newton/m^2 (1000 psi) to cover the pressure range required for this study. Approximately six test points were taken at ascending, and at least three to four points at descending contact pressures.

Phase II - Data Analysis and Correlations - Concurrent with the effort on Phase I experiments, data analysis and correlations were carried out in order to provide direction to the experimental effort. The literature survey and interchange of information with other investigators in related fields carried out over the past 3 years was continued to benefit this program. It has proven its value. Theoretical models set up by other researchers were also tried. Increased emphasis was placed on surface property definition, since this was found to be a difficult item to determine and to describe. Particularly, the inconsistencies in variation in thermal contact conductance with surface definition, which was noted in a number of investigations in vacuum (presence of a gas tends to mask this effect) were studied.

Phase III - Accomodation Coefficient and Effects of Trapped Gas - In order to determine the importance of the accomodation coefficient on the overall heat transfer in the interface, analysis and computations were in the interface, analysis and computations were carried out to assess its magnitude. In addition, this phase consisted of an experimental evaluation of the effects of trapped gases on the heat transfer of metallic joints at moderate contact pressure where the solid conduction contribution is not overriding. The following program was carried out. The sample materials and surfaces were similar to some of those used in Phase I tests. Two sets of identical interface test specimen were made up for each test material. A record was kept on each sample surface history. Thermal conductance tests were obtained at moderate contact pressures for each of the two interface types for (1) one interface assembled in air, and (2) one interface outgassed for 24 hours with surfaces separated and then assembled in vacuum.

3. Technical Status. Tests of 2024T3 aluminum, 304 S. S., and beryllium samples have been completed under the following conditions:

a. Coarse finish - one test in air; one test in a vacuum.

b. Fine finish - one test in air; one test in a vacuum.

Data reduction is now being accomplished by an IBM 7094 computer. Plated samples have been tested.

4. Major Accomplishments. The results of last year's work were published at an AIAA meeting and at thermal conductivity conferences in San Francisco and London, England, "The Use of a Computer Program to Analyze Data."

5. Problems. Some of the problems encountered are:

a. obtaining optical flat test samples,
b. alignment of testing apparatus,
c. accurately predicting the test sample surface characteristics,
d. predicting heat losses from the samples,
e. reaching steady state conditions,
f. "debugging" the data reduction computer program,
g. plating the samples.

6. Future Plans. Due to the necessity of better understanding both the bulk and interface thermal transport properties, both electrical and thermal measurements will be taken.

7. Illustrations. None.

L. Thermal Control by Use of Fusible Material

Submitted by
(Technical Supervisor)

Tommy C. Bannister
R-RP-T, 876-3314

1. Project Data

Contract Number: NAS8-11163

Contractor: Northrop Space Labs

2. Purpose of Project. Development of analytical and engineering techniques for utilizing (in a sealed passive system) the heat associated with changes in state, phase, and temperature of specially selected materials for the thermal control of temperature sensitive vehicle and satellite components. Studies would include operation in zero-g environment.

3. Technical Status. Research on the development of packaging techniques and experimental verification has recently been initiated. A test apparatus has been manufactured in which a molded silicone rubber boot was used so that pressure is maintained between the fusible material and the fin of the package.

4. Major Accomplishments. A literature survey was made where promising materials were selected for further study. Many necessary thermophysical properties were not given in the literature. Thermal conductivity in liquid phase was usually not available for materials with high heats of fusion. Four materials -- formic acid, hexadecane, octadecane, and camphene -- were selected for laboratory study. The formic acid and camphene were found to be unsuitable. Tetradecane and eicosane were then selected. These materials have a span of melt temperatures from 40°F to 100°F with heats of fusion of ~ 100 BTU/lb. Measurements of density versus temperature and melt temperature were also made in addition to conductivity measurements. Analytical feasibility studies were made for fusible material radiators and for increasing thermal "inertia" with fusible materials. In these studies the thermal properties mentioned above were utilized. Curves have been generated which present the thermal characteristics of both fusible material radiators and similar non-fusible material radiators. These illustrate the advantage of utilizing fusible materials in passive thermal control. Also heat absorption curves relating cold plate temperature, time, generated heat, and melt thickness (or weight of fusible material) have been generated for the four materials.

5. Problems. As was anticipated, the development of packaging techniques is difficult. Four containers were ruptured during experiments with pressurization and filling of the test apparatus. It was found that the strength properties of silicone rubbers after slight surface damage makes them a poor choice.

6. Future Plans. Continuation of the development of packaging techniques and experimental verification. This includes fabrication of test containers, thermal testing in vacuum, and analysis of the results. Studies will be made toward obtaining higher thermal diffusivity for the package and the fusible materials. Studies will be made predicting the behavior in the space environment of the materials (such as effects of zero-g on supercooling). The contractor will keep updated on those phases of the contract that are completed.

7. Illustrations. None.

M. Development of Space-Stable Thermal-Control Coatings (Paints with Low Solar Absorptance/Emittance Ratios)

Submitted by
(Technical Supervisor)

D. W. Gates
R-RP-T, 876-4040

1. Project Data

Contract Number: NAS 8-5379, May 20, 1963 - November 1963
Mod. 2, 21 November - May 1964
Mod. 3, change in order number
Mod. 4, May 20, 1964 - April 1965
Mod. 5, January 28, 1965 - April 20, 1966

Contractor: Illinois Institute of Technology Research Institute (IITRI)
10 West 35th St.
Chicago, Illinois (60616)
Attn: G. A. Zerlaut
Chemistry Research

2. Purpose of Project. To obtain coatings with the lowest possible ratio of solar absorptance to infrared emittance, and with these very low solar absorptivity/emissivity ratios, easily applied and stable to long time solar exposure in the space environment.

3. Technical Status. In the study of inorganic alkali silicate and semi-organic methyl silicone paints the approaches are as follows:

a. microporous coating investigations

b. inorganic pigments

c. inorganic binders

d. silicone photolysis

e. associated foaming experiments on stable silicones

f. methyl silicone synthesis (to obtain stable polymeric film material)

g. heat and chemical treatment effects on pigments

h. purification of polydimethylsiloxane (methyl silicone vehicle)

i. mixtures of ZnO and secondary ultraviolet-reflecting pigment

j. overlayers of ultraviolet-reflecting coatings

k. search for pigments with lower ultraviolet edge than ZnO, which candidate pigment materials must be stable to ultraviolet exposure

4. Major Accomplishments. Potential of the microporous coatings system has been indicated, and progress toward the silicone polymer of necessary stability has been achieved. This is indicated by reduction in ultraviolet adsorption. Eventual success after obtaining the ultraviolet resistant very-stable polymer depends on the possibility of a foaming material which has a polymerization reaction which simultaneously evolves a gaseous product. Further experimental work with zinc titanate pigment (our only present alternate pigment to ZnO) in both silicates and aluminophosphate and with both heat and chemical treatment of the pigment material has shown consistent improvement. Linear low-molecular-weight polymer has been obtained by molecular distillation. With little or no aeromatic contamination, this material shows transparency with very low ultraviolet adsorption, and is a superior ultraviolet resistant vehicle. Present values of $ZnTiO_2$ pigment in potassium cilicate vehicle are alpha of 0.12 and delta alpha after 2000 ESH of below 0.03. Polydimethylsiloxane and octamethylcyclotetrasiloxane have above 98 percent transparency from 4000 to less than 1900 Å, and minimum degradation in ultraviolet exposure. Pigment size characteristized.

5. Problems.

a. Because of ultraviolet absorption edge of ZnO, the best coating obtainable with this pigment will not be more than 90 to 92 percent reflective in solar.

b. Zinc titanate is the only other pigment presently showing promise of long time stability with ultra violet exposure, and the necessary low alpha value.

c. The ultimate minimum alpha values presently obtainable are in silicate vehicles, with their intrinsic porosity.

d. Because of deeper penetration of incoming ultraviolet in the microbubble opacified coatings, the vehicle must be much more stable than here-to-fore necessary in the pigmented coatings.

e. Color center formation would seem to show aeromatic contamination acting as energy traps, and small contamination seems to bring about large effects through several mechanisms - energy transfer and photo-sensitization.

f. Some improvement in pigments resulting from chemical and heat treatments are not stable to ultraviolet exposure for long times.

g. After the stable polymer has been found, it will be necessary to develop a blowing agent which both generates the bubble structure desired and enters into a polymerization reaction, so that no deleterious products remain after the blowing process.

h. Dielectrics seem to be the best candidate pigments, because of their low absorption edge, but are unstable to 2000 ESH exposure.

i. Mechanisms of heat treatment improvement of pigments, color center formation in vehicles (as well as pigments), and chemical treatments have been difficult to explain.

j. Pigment mixtures have not proved satisfactory.

k. Overlayers of highly reflecting (ultraviolet) pigments are difficult to obtain thin enough to give the desired results without their degredation causing a lower reflectance than the underlying ZnO by itself.

l. While pigment particle size has been characterized, the separation into close cut fractions (for at least one proposed scheme) is still to be solved for large size batches.

6. Future Plans. In the three areas of interest, the following work is in progress:

a. Microporous structure in paint vehicles - Because of deeper penetration of the incoming radiation, it has been found necessary to obtain vehicles that are much more stable than those we had available. The foaming process must be obtained by a material that enters into the polymer structure and evolves gas - no residue can be tolerated. After these problems have been solved, average diameter, concentration, and dispersion will again be our point of effort. Techniques to date have produced white films that degrade in an ultraviolet/vacuum environment rather quickly. Progress in this work is based on the following considerations: (1) the matrix must be completely transparent to solar radiation - at all wavelengths, (2) the matrix must have an index of refraction different from unity, (3) it must have a void structure whose dimensional characteristics are stable and are important in terms of interaction with optical wavelengths.

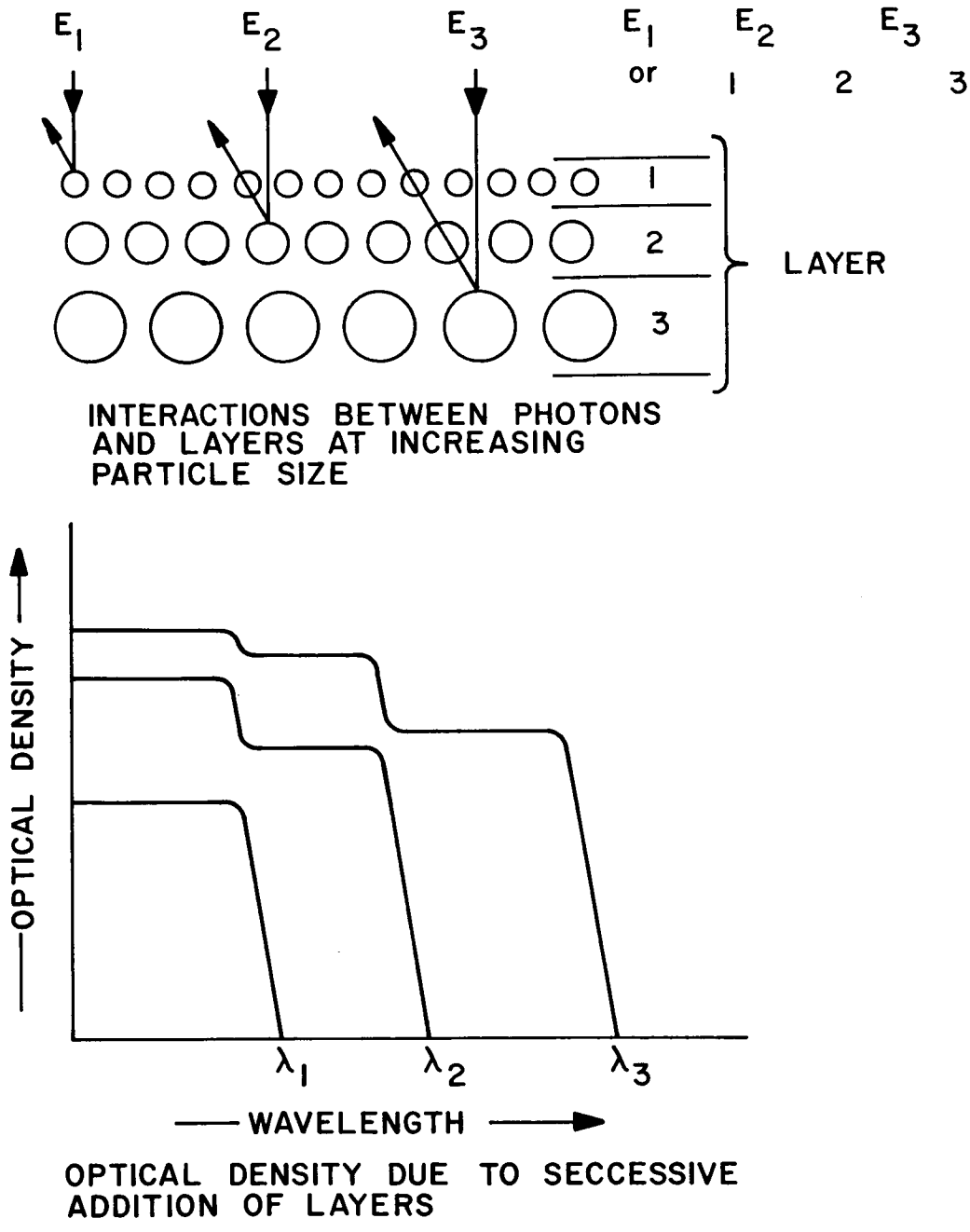
b. Inorganic coatings - In the area of pigment screening it has been found that heat treatment and chemical treatment usually enhance both ultraviolet resistance and initial reflectance. Mechanisms and further improvement

are desired objectives. Pigment screening has shown $ZnTiO_2$ to be a satisfactory pigment prospect and work will continue with this material, but the long range search for a new pigment will concentrate on development of a dielectric material with the inherent lower ultraviolet adsorption edge. Other vehicles than the silicates will be evaluated.

c. Methyl silicone photolysis studies - In the effort to synthesize a silicone polymer that is totally resistant to solar radiation, linear low molecular weight polymers have been prepared. The nature and extent of free radical formation will be determined from the study of well-characterized polymers and the mechanism of ultraviolet degredation established. These mechanisms will be intrepreted as a function of chemical composition and structure of the polymer; nature, type and quantity of contaminants; environmental parameters; and the importance of each of these factors.

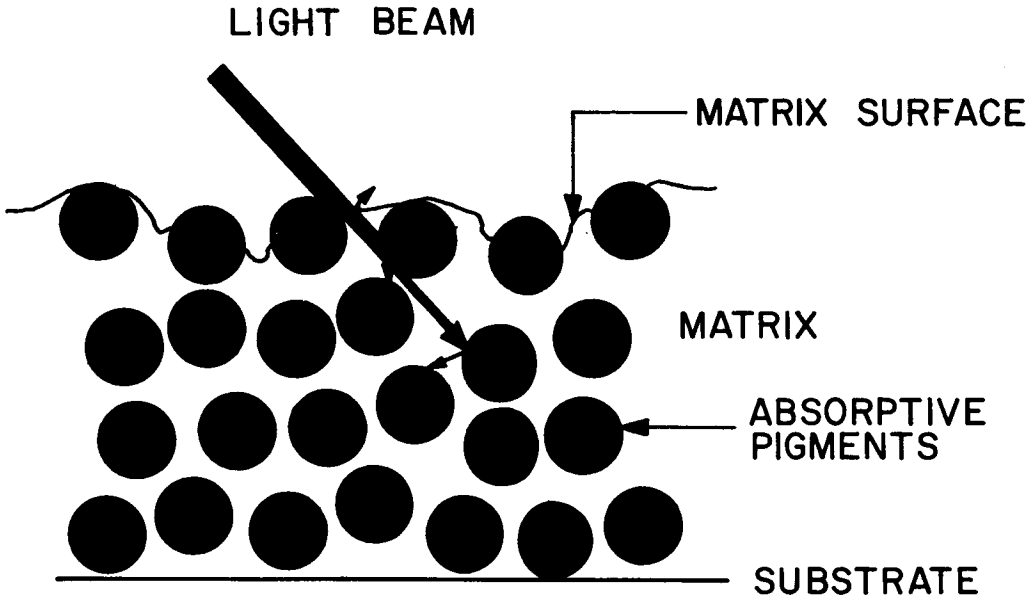
Note: Of special importance on this project is a Triannual report now being released that contains the most extensive data here-to-fore gathered in one volume; reflectance curves, transmission curves of vehicles, particle size analysis via Kaye Disc Centrifuge, and ultraviolet effects.

7. Illustrations. Figures 27 and 28.

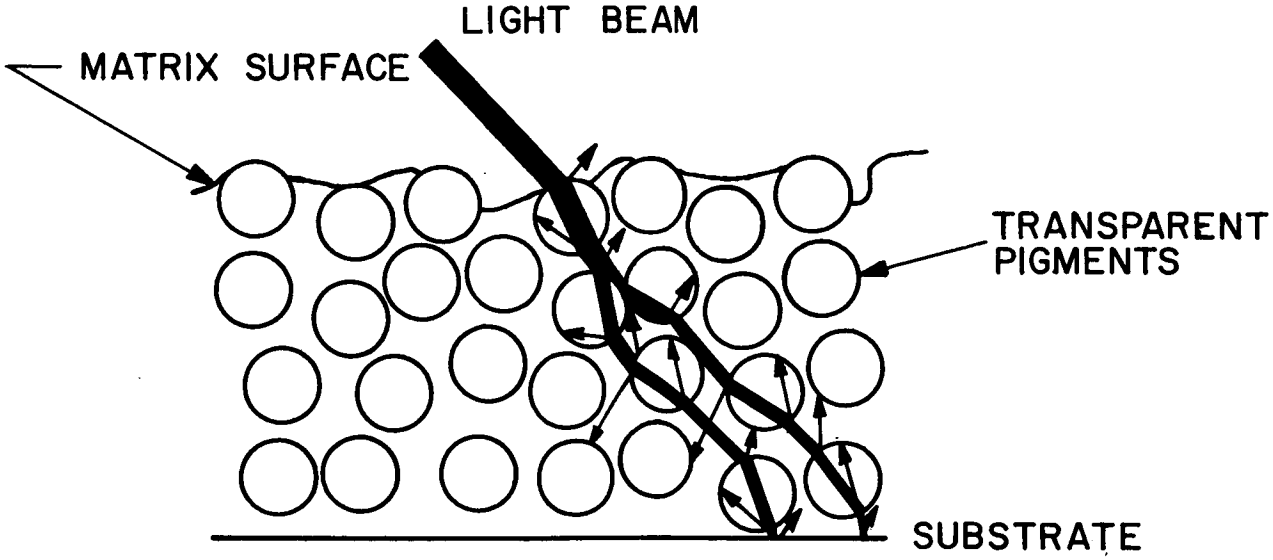


SCHEMATIC OF MULTILAYER COATING AND RESULTANT OPTICAL DENSITY OF LAYERS

FIGURE 27. SCHEMATIC OF ULTILAYER COATING AND RESULTANT OPTICAL DENSITY OF LAYERS



RAY BEHAVIOR IN IDEALIZED PAINT FILM CONTAINING TOTALLY ABSORBING PIGMENTS



RAY BEHAVIOR IN IDEALIZED PAINT FILM CONTAINING TOTALLY TRANSPARENT PIGMENTS

FIGURE 28. RAY BEHAVIOR IN IDEALIZED PAINT FILM CONTAINING TOTALLY TRANSPARENT PIGMENTS

N. Use of Thermal Models for Environmental Testing

Submitted by
(Technical Supervisor)

James K. Harrison
R-RP-T, 876-3391

1. Project Data

Contract Number: H-71483, July 15, 1964 - July 15, 1965

Contractor: Arnold Engineering Development Center

2. Purpose of Project. The purpose is to confirm by experiment the theoretical validity of dimensional analysis and similitude as applied to the thermal behavior of materials in a hard vacuum. Also to investigate the practical problems associated with such an endeavor.

3. Technical Status. The first phase of the thermal similitude experiments has been completed. Three bodies (flat plate, sphere, and cylinder) were involved. Scaling of gross dimensions from prototype to model was 2 to 1. The temperature correlation from prototype to model for corresponding locations and times for the flat plate and cylinder was reasonably good. For the sphere the correlation was poor. Extreme temperature gradients were present in the sphere and are blamed as the major factor for the poor correlation.

4. Major Accomplishments. Completion of first phase of program.

5. Problems. None.

6. Future Plans. The entire series of experiments will be performed again and a concerted effort will be made to eliminate the temperature gradients.

7. Illustrations. None.

O. A Mathematical Expression for the Radiation Intensity and Reflectivity of the Lunar Surface

Submitted by
(Technical Supervisor)

James K. Harrison
R-RP-T, 876-3391

1. Project Data

Contract Number: NAS 8-11351, June 15, 1964 - June 16, 1965

Contractor: PEC Research Associates, Inc.

2. Purpose of Project. The purpose is to determine a mathematical expression for the infrared radiation intensity and for the reflected sunlight of the lunar surface in terms of angular properties.

3. Technical Status. A considerable part of the program to date has been concerned with reflected radiation. Close study of the mathematical expressions developed by other investigators, particularly the expression developed by Hapke, has been made. Some modifications to improve the accuracy of Hapke's expression have been attempted. It appears that a general expression describing the reflectivity and emissivity characteristics of lunar surface can be written in the near future.

4. Major Accomplishments. None to report at this time.

5. Problems. None.

6. Future Plans. The emitted radiation from the lunar surface will be considered in greater detail. General and particular solutions for the emissivity and reflectivity will be obtained. Electronic computers will be used where necessary for the final output.

7. Illustrations. None.

P. Development and Construction of an Infrared Radiometer

Submitted by
(Technical Supervisor)

Charles D. Cochran
R-RP-T, 876-3391

1. Project Data

Contract Number: NAS 8-11762, June 30, 1964 - February 28, 1965

Contractor: Southern Research Institute
Birmingham, Alabama

2. Purpose of Project. The purpose of the contract is to construct the infrared radiometer which was designed under contract NAS 8-5361, "Design of a Radiometer to Measure the Temperature Distribution of the Moon."

3. Technical Status. An infrared radiometer has been designed by Southern Research Institute under NASA contract. (References: Semi-Annual Progress Reports for July 1, 1963 - January 1, 1964, and for January 1, 1964 - July 1, 1964, and Southern Research Final Report entitled, "Design of a Radiometer to Measure the Thermal Radiation from the Moon," Contract Number NAS 8-5361.) The present contract was begun in June 1964 to construct the radiometer with certain changes to convert it for use in an MSFC in-house effort to study the thermal properties of powders at ultra high vacuums.

4. Major Accomplishments. The radiometer design completed under contract NAS 8-5361 was developed around the choice of the mercury doped germanium detector. To obtain a much broader spectral response, the design was changed to accomodate a gallium-doped germanium bolometer. This change in detectors require a new radiometer case design and a slower chopping speed. The design changes were made without compromising the performance of the original design.

A study of the optical system indicated that the sensitivity of the radiometer might be improved by using a field lens before the detector which will limit the field of view of the detectors to an /16 cone and exclude direct radiation from the radiometer case. The lenses were selected so that the radiometer collecting mirror was imaged on the detectors. With the lenses in place, the detectors can only "see" the cooled radiometer mirrors. This will reduce the noise level of the detectors and improve the sensitivity of the radiometer. Another aperture was added between the field lens and the detector to define the field of view more completely.

Thirty-two detailed design drawings were produced for the entire system. Many of the components were machined at Southern Research and many component parts have been received, and assembly of the instrument has begun. The detector and dewar system has not been received from Texas Instruments.

5. Problems. As the radiometer case cools from room temperature to near 80°K, the aluminum case contracts about 0.004 inches per inch. If there are no external gradients in the radiometer case, the distance from the entrance aperture to the spherical mirror (about 250mm at room termperature) will change by about 1mm. The dewar housing will be equipped with a differential screw with which the detector can be refocused after the case has been cooled. However, if temperature gradients are present in the case, the angle of the mirror could change and the image of the 0.5mm diameter aperture could miss the detector completely.

The radiometer case was designed to reduce thermal gradients to a minimum. Also, the dewar housing was redesigned so that it could be adjusted in three degrees of freedom. A Teflon mirror mount was designed to reduce the magnitude of the adjustments to be made. The shrinkage factor for Teflon is greater than that of aluminum by a factor of six to one. This mount will be used in such a manner so as to offset the shrinking of the aluminum case. This combination of measures seems to have reduced the problem to insignificance.

6. Future Plans. Plans are to finish the construction of the radiometer and to use it in the Radiative and Conductive Physics Laboratory in studying the thermal properties of powders at ultra high vacuum.

7. Illustrations. None.

LAUNCH VEHICLE AEROTHERMODYNAMICS

Vehicle and Base Heating

A. Experimental Investigation of Combustion Phenomena in the Base Region of Vehicles Caused by Upstream Injection of Fuels

Submitted by
(Technical Supervisor)

Werner K. Dahm
R-AERO-A, 876-4566

1. Project Data

Contract Number: NAS 8-11032, June 26, 1963- June 26, 1964
Modification 1, June 26, 1964 - June 26, 1965

Contractor: General Applied Science Laboratories, Inc.
Westbury, L. I., New York

2. Purpose of Project. The purpose of this program is to experimentally determine the parameters which govern the base heating of a cylindrical body when combustion of entrained gases occurs in the base region. In particular, the possibility of relating the base heat transfer with combustion, to measurements made without combustion is to be investigated. Since the flow geometry in the base region can be strongly influenced by both bleeding and local combustion, emphasis is to be on fuel flow rates sufficiently low so as to minimize changes in the base pressure from the normal values.

3. Technical Status. Supersonic tests are being performed on a blunt-based cylinder model which is an integral part of a Mach 3.1 contoured nozzle. All instrumentation, including pressure taps, flow meters, heat transfer gages, and flow sampling probes, has been completed and is operational for supersonic testing. Upstream injection of hydrogen by two methods - circumferential slot, circumferential tubes - is possible.

Preliminary calibration runs and fabrication of necessary hardware for the purpose of developing a subsonic capability with the existing facilities have already been carried out.

4. Major Accomplishments. A total of 165 tests has been carried out. Thirty percent was concerned with the determination of fuel concentrations and other nonburning parameters using both the circumferential slot and the tubes method of hydrogen injection. Thirty-five percent was utilized for the measurement of base heat transfer with combustion by natural ignition using tubular injection. The remaining tests involved tunnel calibration runs, as well as numerous unsuccessful attempts of base burning at low temperatures, utilizing artificial ignition schemes. From the data obtained, the following preliminary conclusions can be made:

a. The heat transfer to the base of a cylindrical body can be estimated if the concentration of the entrained fluid, as well as the initial conditions without injection, is known. Heat trasfer increases of 60 percent to 360 percent have been observed.

b. Substantial increases in heating can occur with relatively slight associated base pressure rises. The 60 percent increases in heat transfer were accompanied by 10 percent increases in base pressure.

c. The mechanism of mixing between the external stream and the injected fluid is enhanced when the injection is accomplished by the circumferential slot.

5. Problems. The principal difficulty encountered was the inability to initiate combustion artificially at low stagnation temperatures. In these attempts, spark discharges of various energy levels were used; continuous as well as short (0.9 sec) discharges were employed. Use of pyrophoric fuel pilot ignition was also unsuccessful, as well as being found unsuitable because of the large amount of energy released by the pilot. However, the purposes of the program were met by the natural ignition test series.

6. Future Plans. Tests at a suitable subsonic Mach number shall determine heat transfer factor, recovery temperature, and fuel concentration without combustion, as well as heat transfer factor and recovery temperature with combustion. Main emphasis is to be placed on low fuel flow rates, where the effect of combustion on the base pressure is a minimum.

Results of the experimentation shall be evaluated and suitable correction procedures shall be sought to estimate heat transfer factors with combustion from those without combustion. The relationship between the recovery temperature with combustion and the fuel concentration without combustion will be investigated.

7. Illustrations. None.

B. Base Heating and Separation Studies

Submitted by
(Technical Supervisor)

Werner K. Dahm
R-AERO-A, 876-4566

1. Project Data

Contract Number: DA-II-022-ORD-3148, June 17, 1959 - June 17, 1960
NAS 8-1698, June 23, 1961 - July 28, 1962
NAS 8-5209, January 7, 1963 - Jaunuary 7, 1964
NAS 8-11299, June 27, 1964 - June 27, 1965

Contractor: Applied Science Division of Litton Industries
St. Paul, Minn.

2. Purpose of Project. The present program is designed to compare the existing theories concerning stagnation point heat transfer in laminar and turbulent flow and concerning the expansion of the forebody boundary layer with measured base boundary and free shear layer profiles of stagnation temperature, mean velocities and RMS-velocities. This will permit the establishment of the accuracy of present base heating and base pressure estimates.

Flow phenomena and heat transfer have been studied behind a blunt trailing edge in a two-dimensional supersonic stream (M = 3) with a turbulent boundary layer since June 1959. In spite of some interruptions, the program has demonstrated that a new type of shear layer exists below the base recirculation zone. Further, unexplained phenomena like "lip shocks" exist in the expansion of the forebody boundary layer and "resonance vibrations" might be superimposed. Extensive hot wire and Pitot tube traverses across the base boundary layer and the free shear layer suggest that the current base heating models and scaling procedures might have to be modified for the discovered new type of shear layer.

3. Technical Status. The past phase of the contract concentrated on hot wire measurements. Numerous mean velocities and RMS velocities have been recorded and are being analyzed. In view of the extremely low density levels combined with extremely high turbulence levels, the reliable interpretation of hot wire data required an extensive dynamic calibration program. To this purpose, the following new facilities have been made available:

a. A very small probe (.032" dia.) support with careful isolation against changes of impedance.

b. A constant temperature (DISA) hot wire set minimizing heating currents.

c. Reference baths of various temperatures.

d. A calibration duct producing subsonic flow at extremely low pressures extending through the slip flow regime.

e. A special small wind tunnel producing sinusoidal subsonic velocity fluctuations at atmospheric densities. The original design was aimed at a study of vortex shedding behind heated cylinders (1).

References:

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(1) Hanson, A. R.; Larson, R. E., "Periodically Fluctuating Flow Studies," Applied Science Division of Litton Industries, proposal 2226, dated May 20, 1964.

4. Major Accomplishments. The oscilloscope display of the hot wire outputs seems to indicate that self-induced or resonance vibrations might exist in the base recirculation zone similar to those that have been suspected in the short duration tests of the S-IC model (2). Cavity resonance superimposed on base heating would lead to a more severe thermal environment and might produce additional dangerous acoustical loads.

5. Problems. An instrumentation problem did arise because of the heat release at the wire. A heating current is always necessary to measure the voltage drop across the wire. For accurate fluctuation measurements in a large dynamic range, rather high wire currents will be necessary. However, the heat, which is produced by the current, might not be carried away from the wire if the density is small or if the fluctuations are comparable to the mean values. The hot wire then operates in a hot cloud and its temperature fluctuations are averaged out. In the base boundary layer the wire frequency response was found to be extremely velocity dependent which makes accurate cross correlations impossible. Planned solutions are to increase the density level by transferring the model to a blow-down tunnel and to use hot film coatings on capillary tubes instead of hot wires. Such a probe can withstand the higher pressures. An additional heat release is then supplied by passing a coolant through the capillaries.

6. Future Plans. The only method available for deciding whether a dangerous cavity resonance exists in base recirculation flows is a correlation analysis of velocity and temperature fluctuations which could disentangle convection and sound radiation phenomena. Therefore, the future plans are: to establish a model of wall pressure fluctuations below and the heat transfer mechanism across the type of shear layer which has been discovered below the base recirculation flow. This layer was discovered by performing velocity and temperature cross correlations at increased density levels and by replacing the hot wire system with a new hot film system, which has sufficiently velocity independent frequency response.

7. Illustrations. None.

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(2) Thornton R., Krause F., "Pressure and Heat Transfer Rate Fluctuations in the MSFC Impulse Base Flow Facility S-I Model," MSFC Memorandum R-AERO-AM-64-4.

C. Research on Base Heating of Rocket Motor Vehicles Using Shock Tube Techniques

Submitted by
(Technical Supervisor)

Homer B. Wilson, Jr.
R-AERO-AT, 876-1833

1. Project Data

Contract Number:	NAS 8-823, November 23, 1960 - November 23, 1961
Modification 2	September 11, 1961 - March 23, 1961
Modification 3	October 16, 1961 -
Modification 4	December 14, 1961
Modification 5	January 19, 1962
Modification 7	May 15, 1962 - December 31, 1962
Modification 8	September 7, 1962
Modification 9	October 4, 1962
Modification 10	October 9, 1962
Modification 11	October 19, 1962
Modification 12	October 9, 1962
Modification 13	March 4, 1963
Modification 14	February 5, 1963
Modification 15	February 11, 1963
Modification 16	February 15, 1963
Modification 17	February 13, 1963
Modification 18	June 29, 1963
Modification 19	June 29, 1963
Modification 20	June 29, 1963
Modification 21	January 7, 1964
Modification 22	March 20, 1964
Modification 23	May 28, 1964
Modification 24	May 28, 1964
Modification 25	May 28, 1964
Modification 26	June 24, 1964
Modification 27	June 24, 1964

Contractor: Cornell Aeronautical Laboratory, Inc.
Buffalo, New York 14221

2. Purpose of Project. The original objectives of the Cornell program were to establish the feasibility of applying short-duration (shock tube) techniques to the study of base heating of launch vehicles and upper stages and to conduct general research studies of the base recirculation and heating mechanisms. The approach proposed by CAL may be described briefly as follows: short-duration techniques are used to duplicate the composition and thermodynamic properties of the combustion products of rocket engines. Flow durations through scale model nozzles are sufficient to permit the establishment of base flows but are short enough to alleviate the usual complex engineering problems associated with conventional hot-flow models. Heat transfer and pressure instrumentation developed for shock tunnels is then ideally suited for base heating studies.

By May of 1961, the validity and feasibility of the short-duration techniques for high-altitude research had been demonstrated. Subsequent to that time the program has been reoriented to (1) conduct particular basic research studies (described later), (2) provide certain specific data essential to the design of all stages of the Saturn I and Saturn V boosters, and (3) to evaluate performance characteristics of advanced propulsion systems.

The demonstration of feasibility of these techniques for lower altitude studies with external flows where the fluid mechanical and chemical effects are, in general, quite different from the high-altitude case was initiated in the spring of 1962. At this time, a program was conducted in the CAL 8 Foot transonic tunnel which did prove the suitability of the Cornell technique for such studies. Subsequent to this initial program, additional wind tunnel tests have been completed, further verifying the validity of the short-duration techniques in such an environment.

3. Technical Status.

Summary of Previous Activities: December 1960 - June 1964

The CAL program was initiated in December 1960 with the primary objective of demonstrating the utility of short duration techniques for base heating studies. A two-part experimental program was established: one consisting of an investigation of the S-IV four engine configuration at high simulated altitudes (Fig. 29), and the second, a study of the Saturn S-I booster configuration in an external flow environment in the CAL Transonic Wind Tunnel (Fig. 30). Both of the test programs were designed to provide comparative data with results being obtained at other facilities.

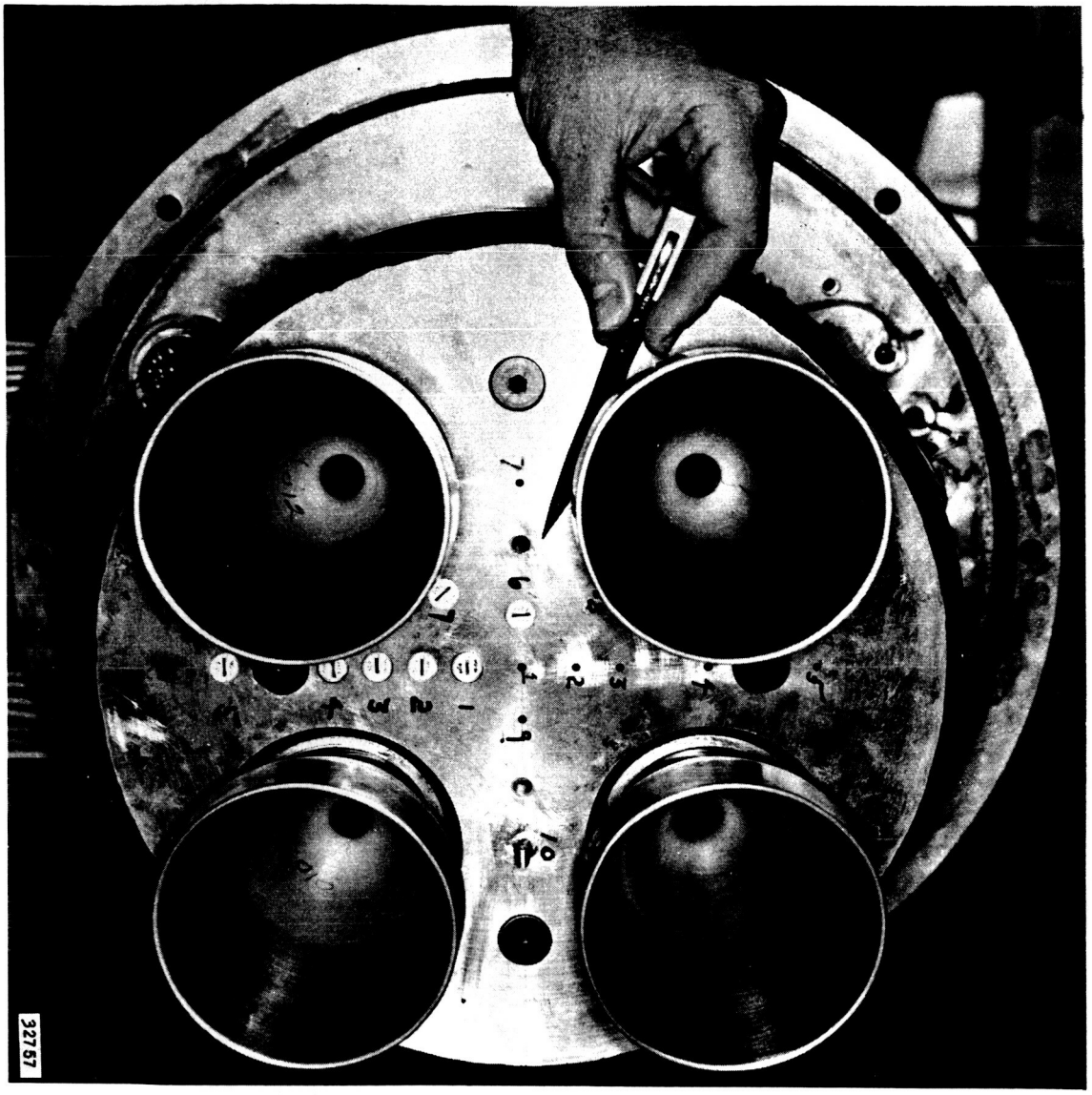


FIGURE 29. S-IV 4 ENGINE MODEL BASE PLATE SHOWING INSTRUMENTATION

The high altitude S-IV program was successfully completed during 1961, and the feasibility of the short-duration experimental approach to base heating studies at high simulated altitudes adequately demonstrated.

Transonic investigations of the S-I booster configuration were also successfully concluded during 1962. Tests were conducted over a range of free-stream Mach numbers from 0.6 to 1.2 at simulated trajectory altitudes. Heat

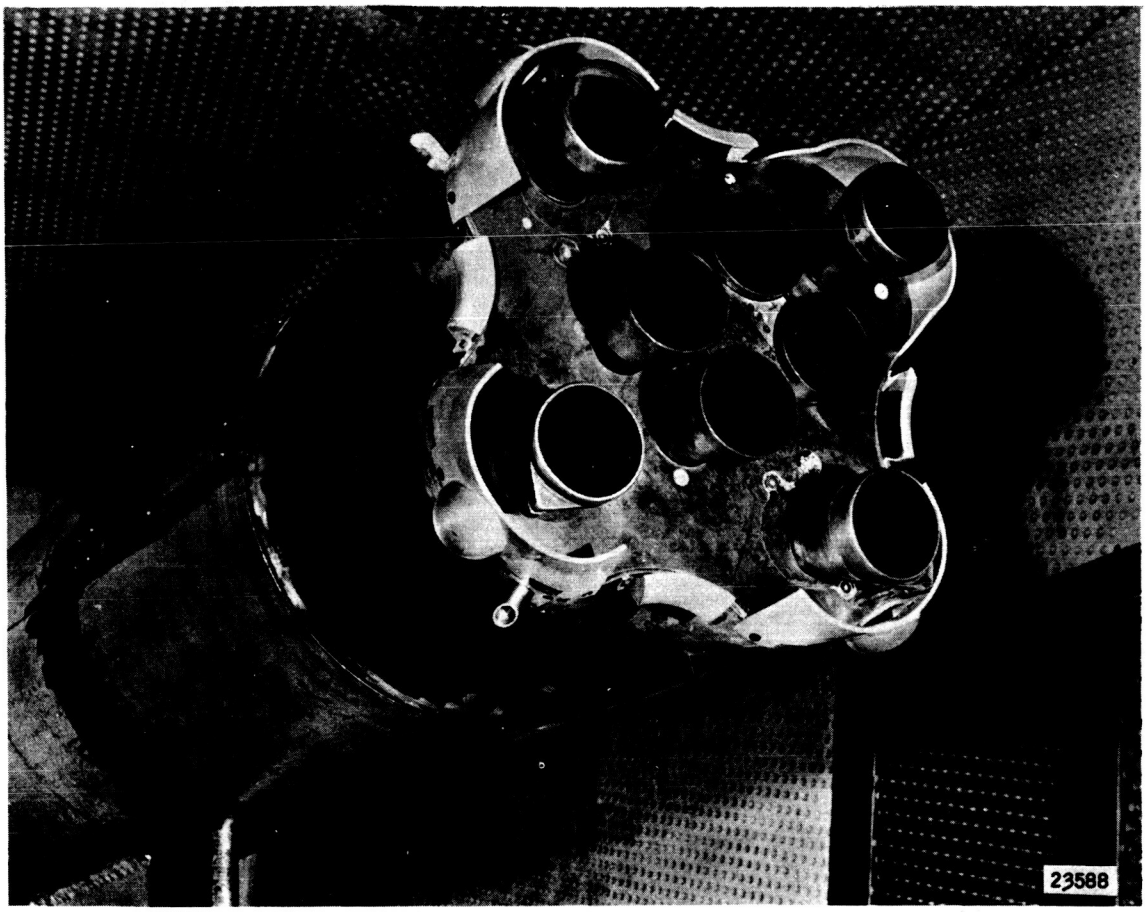


FIGURE 30. SI BOOSTER SHORT DURATION BASE HEATING MODEL

transfer, pressure, and recirculated gas concentration measurements were obtained on the primary base plate and on the flame shield. No basic problems were experienced during the transonic tests, and the basic program objectives of showing feasibility of using short duration techniques with external flow were successfully accomplished. Comparison of the results with those from other facilities as well as flight test data has been generally good with the confidence level in the CAL data being as high as any other model test data.

Subsequent to the completion of these initial phases of the program, CAL was asked to continue the base heating research program, both for the purpose of improving and extending the available testing techniques and to provide a better understanding of the fundamental mechanism of base flow and heating phenomena.

The first of these programs was a direct result of relative ease with which rocket chamber pressure (or nozzle flow Reynolds number) can be varied using the short duration approach. An investigation was carried out in which ambient altitude was systematically varied in conjunction with rocket chamber pressure (which ranged from one-third to five times the normal 4-engine S-IV chamber pressure) such that jet exit pressure ratio, and hence plume geometry, was maintained fixed. Base heat transfer and pressure data obtained from these experiments were the first available over a sufficiently wide Reynolds number range (approximately 15 to 1) to establish the general character of base flows. The results of this program are summarized in CAL Report No. HM-1510-Y-1 (I), "The Application of Short-Duration Techniques to the Experimental Study of Base Heating," April 1962.

Other programs were also conducted during 1962 to provide supporting research closely related to the needs of the over-all Saturn booster program. One of these programs was an extensive study conducted at CAL during 1962 which investigated the effects of altitude, rocket chamber pressure, heated hydrogen secondary flows, and various gimbaling patterns on heat transfer, static pressure, and total pressure distributions in the base region of an S-IV 6-engine configuration (Fig. 31). Excellent heat transfer and pressure data were obtained during this test program, the results of which have been reported in CAL Report No. HM-1510-Y-3, "High Altitude Base Heating and Pressure Distribution Investigations on the Saturn S-IV 6-Engine Stage Using Short-Duration Techniques," June 1963.

An extensive parametric study was completed on the S-II stage configuration during 1962 to provide NASA and NAA with the necessary design information to establish the base geometry and heat shield configuration for the S-II vehicle. Geometric parameters such as engine pitch diameter, heat shield size and location, engine gimbal patterns, and many others were systematically varied during this program to determine their effect on heating rates and pressure distributions. Similarly, the effects of operating and environmental variables such as rocket chamber pressure, ambient altitude, turbine exhaust flow, etc., were also investigated over a wide range to determine their effect on base conditions. A heated base plate technique was also successfully employed to determine recovery temperatures in the base region for a range of rocket chamber pressures.

During late 1962 and early 1963, a comprehensive experimental program was carried out to explore the gas dynamic processes involved in the inflight "fire-in-the-hole" separation of the S-I and S-IV stages of the Saturn I booster. Heat transfer, pressure, and force measurements were obtained for a range of vent areas, shapes, and locations as well as for various stage separation

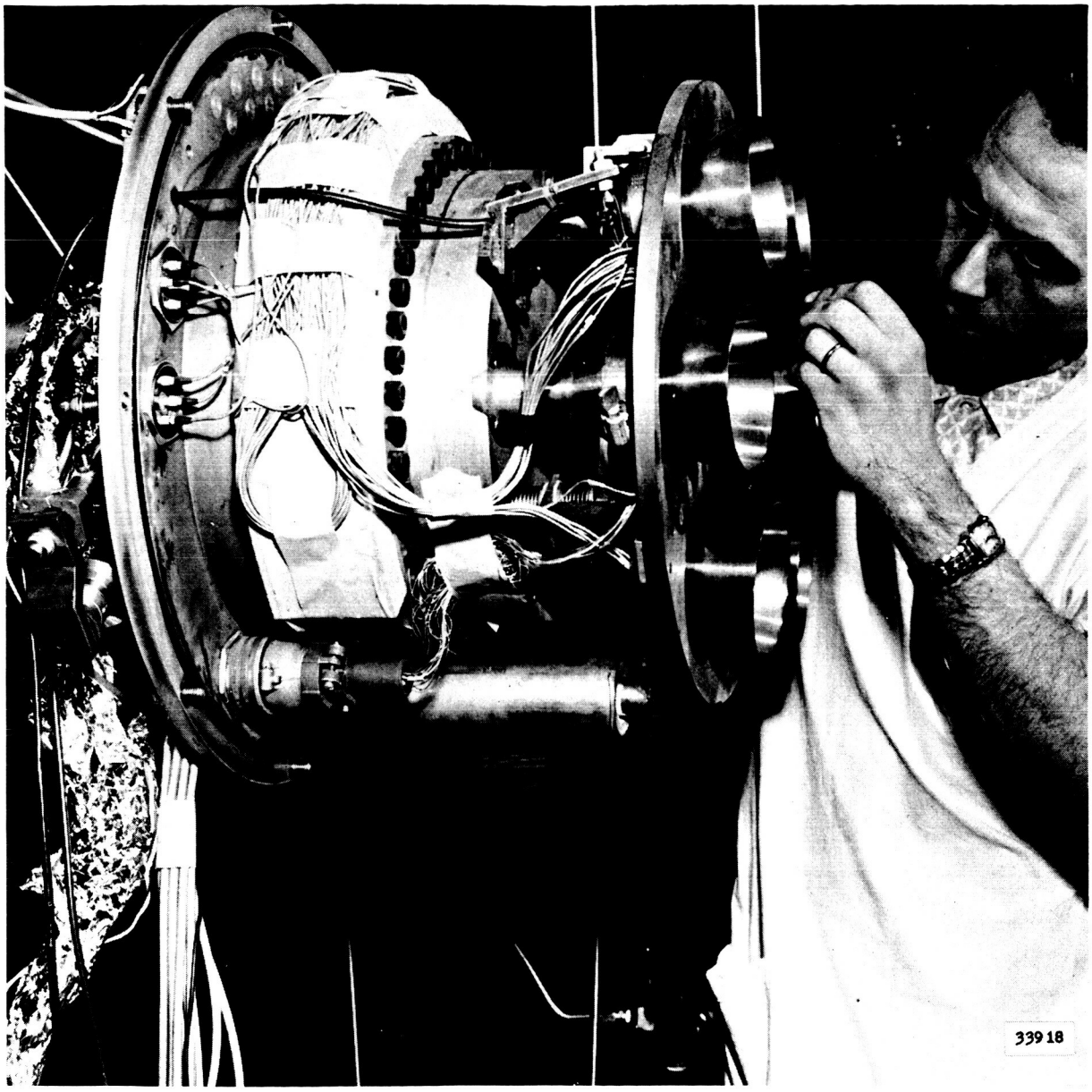


FIGURE 31. S-IV 6 ENGINE MODEL

distances. Figure 32 illustrates one of the several vent areas configurations investigated. The excellent results of this test program conclusively demonstrated the applicability of extending the short-duration test techniques to both stage separation studies and force measurements in the flow field of highly expanded rocket exhaust flows. The results of the heat transfer and pressure

FIGURE 32. S-I/S-IV STAGE SEPARATION MODEL

phase of this two part program have been summarized in CAL Report No. HM-1510-Y-11, "Heat Transfer and Pressure Investigations of an S-I/S-IV Stage Separation Model Using Short-Duration Techniques," which was issued during August 1964. The results of the force program are described in CAL Report No. HM-1510-Y-16, "Force and Pressure Investigation of a S-I/S-IV Stage Separation Model Using Short-Duration Techniques," which will be issued in January 1965.

An experimental base heating program on the S-IC booster configuration was initiated in February of 1963. Initial studies were conducted in the CAL Transonic Tunnel over a range of freestream Mach numbers from 0.6 to 1.2. Convective and radiative heat transfer and pressure measurements were made in the base region and appeared to be of excellent quality. Turbine exhaust flow was simulated with gaseous hydrogen injected directly into the rocket nozzles as is the case with the full-scale F-1 engines. Subsequent to the transonic testing of the S-IC configuration, the high altitude portion of the program was conducted in the CAL vacuum tank facility over an altitude range of 125,000 to 205,000 feet during June 1963. Various base configurations including shrouds and scoops, engine gimbal patterns and single engine-out were investigated. The effects of hydrogen turbine gas simulation and hot base plate on base heating rates were also studied.

Following the high altitude program at CAL, the S-IC external flow base heating program was continued in the NASA Lewis Research Center 10 by 10 wind tunnel during October 1963 (Fig. 33). Over 100 test runs were made

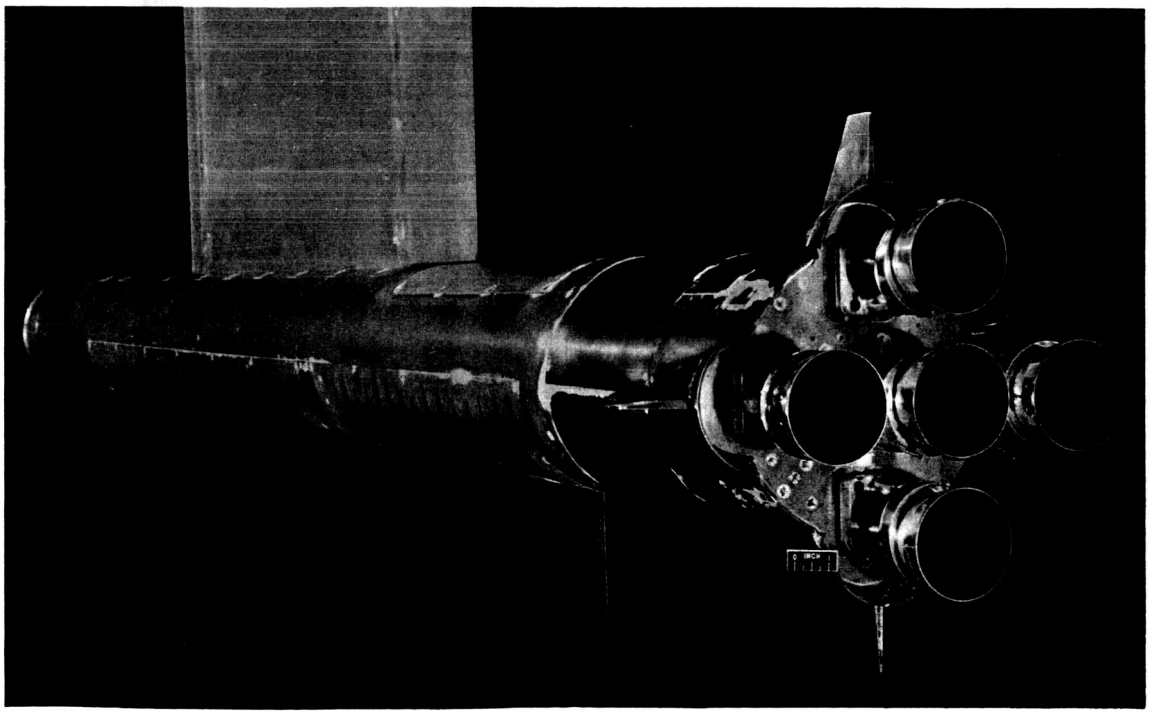


FIGURE 33. S-IC MODEL INSTALLATION IN LRC 10 by 10 TUNNEL

covering the Mach 2.0-3.5 portion of the S-IC trajectory, in which a number of scoop, shroud, and deflector configurations were investigated (both with and without turbine exhaust flow) to determine their effect on the base thermal environment. Single engine out and various engine gimbal conditions were also studied. Model base pressures and booster body boundary layer pressure distributions were obtained. Gas concentration samples were successfully acquired from the base region. The program proceeded smoothly with operation of the tunnel, model, instrumentation, and recording equipment being excellent.

Initiated in August 1963 and concluded in March 1964, a comprehensive experimental program was conducted in the CAL high altitude facilities to document the thermal and pressure environment in the base region of the S-II stage prototype configuration (Fig. 34). Over 300 test runs were made, and design

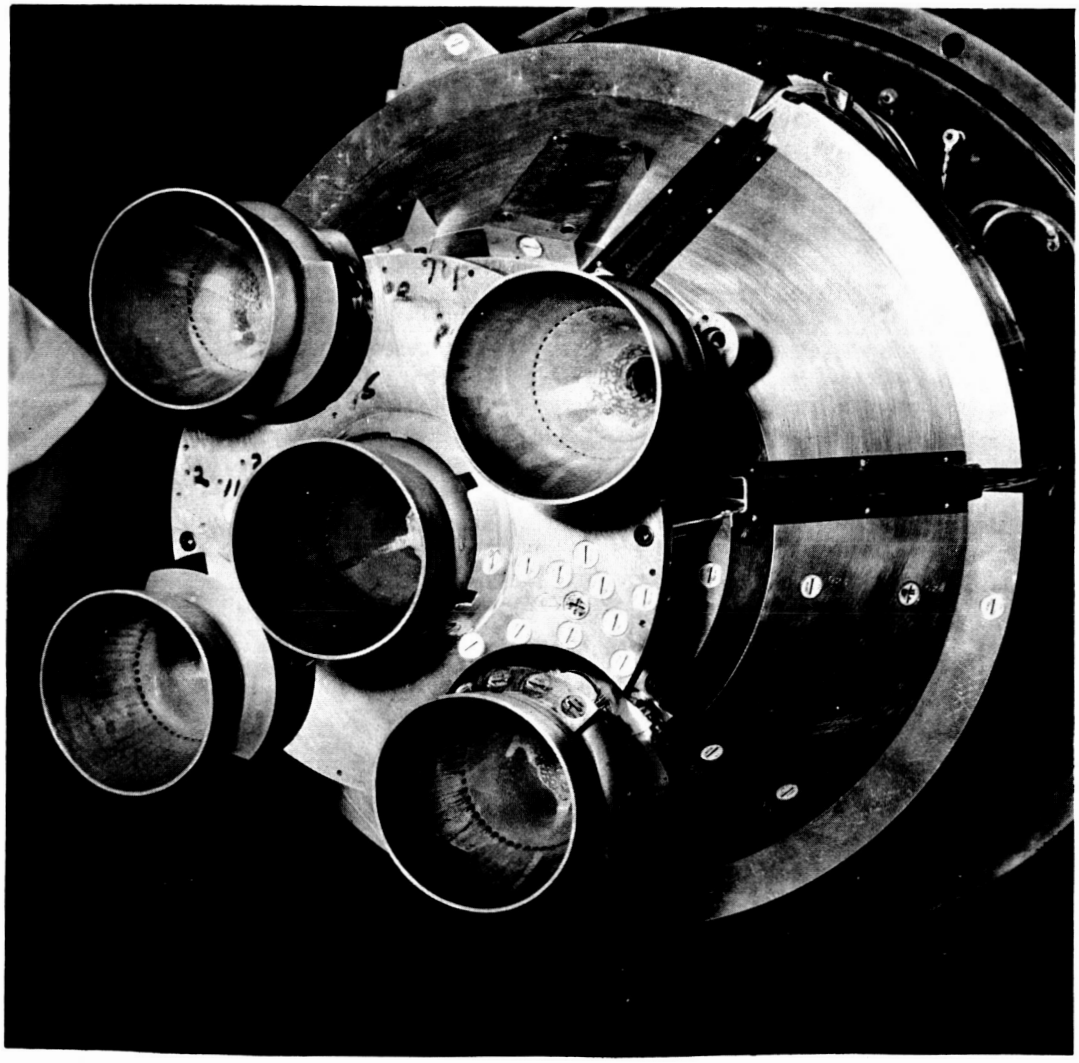


FIGURE 34. S-II PROTOTYPE WITH BASIC HEAT SHIELD

data on thrust cone and heat shield configurations and several engine gimbal patterns. The effects of interstage on and off, turbine exhaust flow, and varying ambient altitude on the base environment were also investigated in considerable detail. The results of this program are reported in CAL Report HM-1510-Y-17 (II), "High Altitude Base Environment Investigations on the Saturn S-II Stage Using Short-Duration Techniques," which will be issued during January 1965.

It is common practice to employ means of keeping calorimeters cool until all of the model engines are operating at steady-state conditions in conventional wind tunnel model base heating tests. The cooling of the calorimeters is then stopped and transient response measurements are made. Similar procedures are followed in full-scale flight test measurements. There is evidence that a series of locally cooled calorimeters on an otherwise hot base will influence the heat transfer to the calorimeters and possibly the flow itself. Two-dimensional tests with boundary layer flows have also shown that different temperature levels on a flat plate can have an appreciable effect on film coefficients. In order to quantitatively evaluate the magnitude of these effects, an extensive experimental program was conducted at CAL during May of 1964. A 1/10 scale S-IV 4-engine model was used in conjunction with a hot base plate containing a number of cooled calorimeters whose individual temperatures could be maintained at any level between ambient and base temperature. Various combinations of base plate/calorimeter temperatures were investigated. From these experiments it has been concluded that significant effects are induced by the local cold spots as illustrated in Figure 35. It may be noted from this figure that the indicated local heat transfer coefficient at the surface of a cold gage located in an otherwise hot surface varies considerably from the coefficient obtained with a uniformly heated surface. The significance of this observation and other results of the program are presented in CAL Report HM-1510-Y-1 (II), "The Application of Short Duration Techniques to the Experimental Study of Base Heating, Part II - The Determination of Recovery Temperature and Reynolds Number Effects for a Four-Engine Hot Rocket Configuration," which will be issued early in 1965.

Consistent with a continuing interest in gaining a better fundamental understanding of the gas dynamic processes involved in recirculating base flows, immediately following the cooled calorimeter program described above, a brief experimental investigation to determine the applicability of reflection plane techniques to the examination of base flow fields was successfully conducted during June of 1964. Surface heat transfer and pressure, as well as pitot pressure measurements, were successfully obtained with a splitter plate mounted

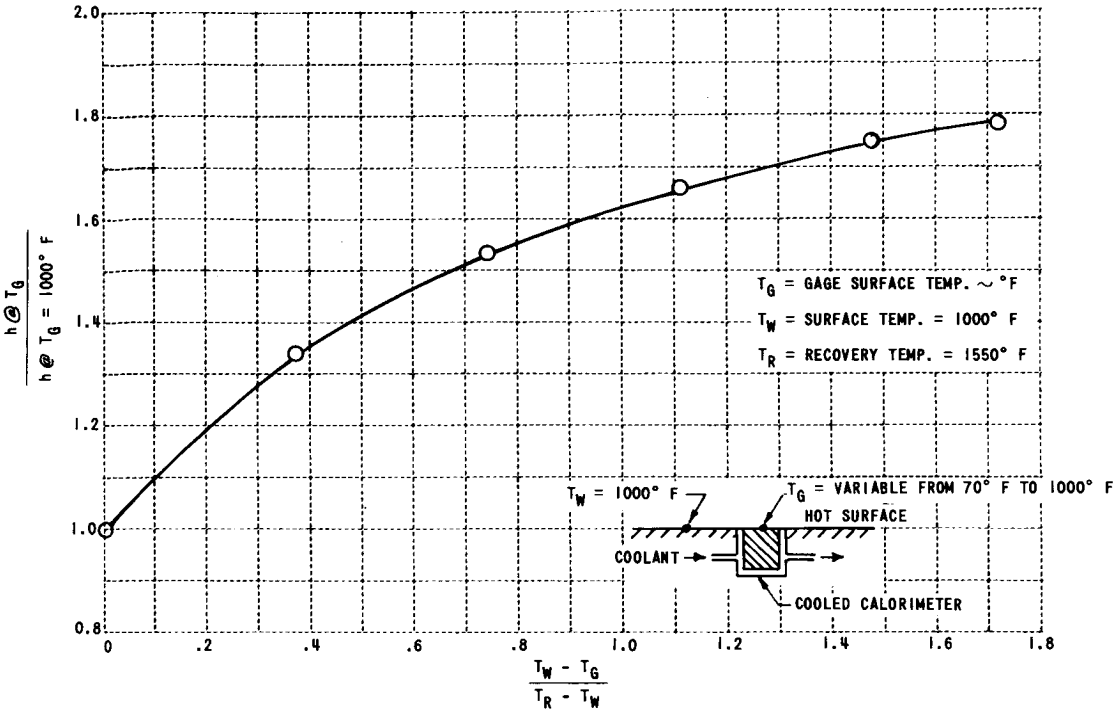


FIGURE 35. RATIO OF HEAT TRANSFER COEFFICIENTS FOR COLD AND HOT CALORIMETERS IN A 1000° F SURFACE

on a plane of symmetry of the S-IV 4-engine model (Fig. 36). The excellent quality of the experimental data, in conjunction with good agreement with similar data obtained by other investigators without the use of a splitter plate[1], indicates that the reflection plane technique offers a potentially powerful diagnostic tool in the experimental analysis of base flow fields. Further use is being made of this technique in the Electron Beam Density program described elsewhere in this report.

Extension of the short duration experimental techniques to the study of performance characteristics of advanced rocket engine propulsion systems was also successfully demonstrated during May of 1964. Thrust and base pressure data were obtained for a scale model of a plug cluster propulsion system

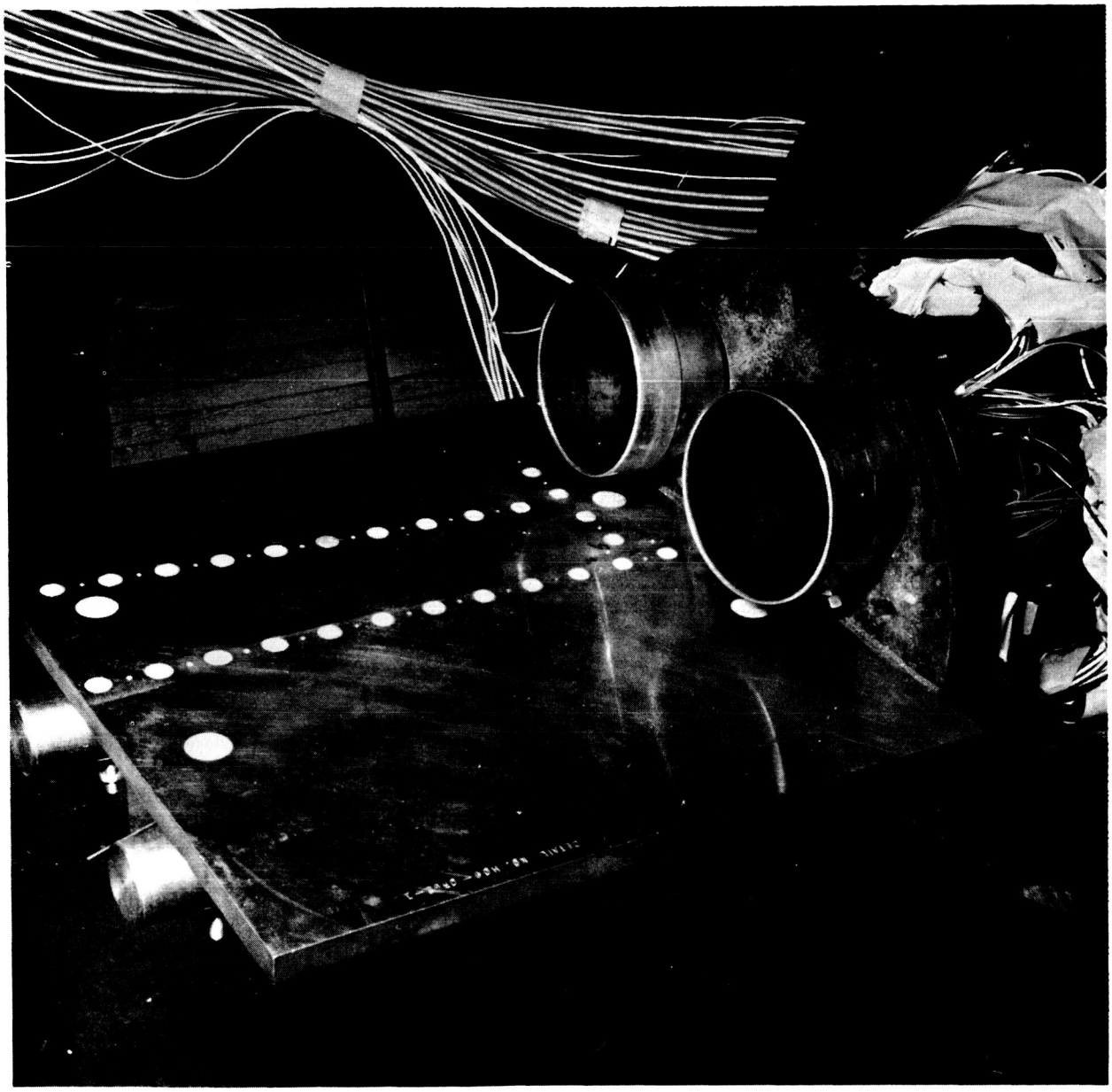


FIGURE 36. SPLITTER PLATE INSTALLATION WITH S-IV FOUR ENGINE MODEL

(Fig. 37) utilizing cold air as the working fluid. Test variables included various plug lengths and a range of combustor-to-ambient pressure ratios. The measured system thrust and base pressures were found to be in substantial agreement with comparable long duration test data obtained by other investigators utilizing an identical model configuration.

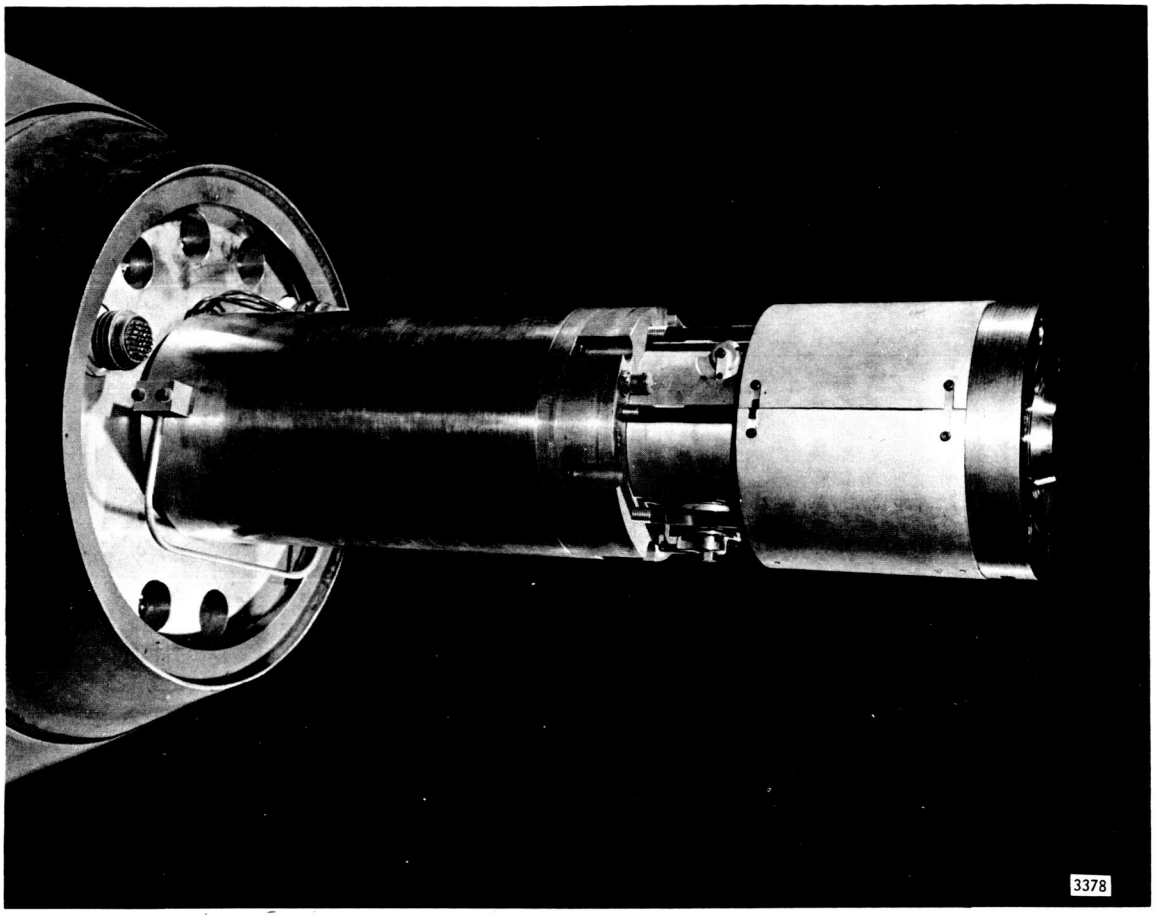


FIGURE 37. PLUG CLUSTER MODEL INSTALLATION

The results of this program are presented in CAL Report HM-1510-Y-13, "Cold Flow Force and Pressure Investigations on a Plug Cluster Propulsion System Using Short Duration Techniques," to be issued early in 1965.

Activity During Reporting Period: July 1964 - December 1964

a. Recovery Temperature/Reynolds Number Program

The experimental investigation directed toward determining the relationship between combustor Reynolds number, nozzle wall temperature, and base plate recovery temperatures was concluded during this period. Correlation of these parameters, in conjunction with previously established heat transfer data, should provide considerable insight into the scaling laws involved in model tests and in the prediction of base heating on future full-scale designs.

Excellent heat transfer data have been obtained for a range of combustor pressures from 85 to 700 psia, from which the variation in recovery temperature and heat transfer as a function of combustor Reynolds number could be established. Representative experimental results are shown in Figure 38, which indicate a laminar flow type variation in heat transfer for the lower Reynolds number range and a turbulent variation for higher Reynolds numbers. The recovery temperature appears to vary approximately as the one-fifth power of the combustor Reynolds number.

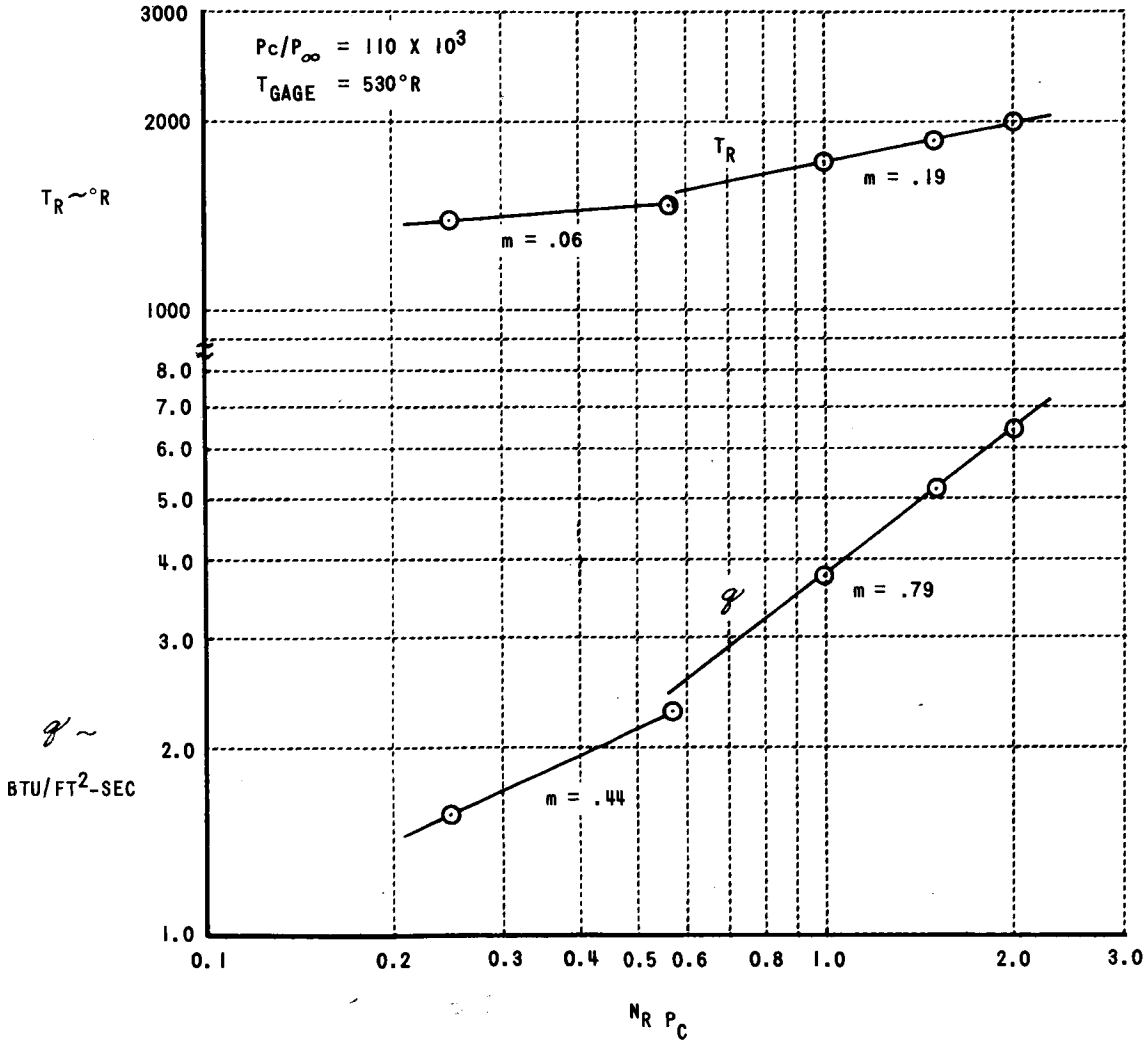


FIGURE 38. HEAT TRANSFER AND RECOVERY TEMPERATURE VARIATION WITH COMBUSTOR REYNOLDS NUMBER AT CENTER OF BASE PLATE

Although the recovery temperature investigations discussed were conducted with the nozzle wall temperature maintained near ambient, it is recognized that in full-scale flight vehicles, nozzle wall temperatures may reach values as high as 1000° F during operation. Since the exhaust gases recirculated into the base region originate predominantly from the rocket nozzle boundary layer, the recovery temperature will be strongly dependent on the character of this boundary layer flow. In view of this consideration, the next phase of this program included a systematic variation in nozzle wall temperatures to determine its effect on base heat transfer and recovery temperature. As suspected, significant increases in heat transfer rates were observed for the heated nozzle wall case. To illustrate, the representative results of Figure 39 indicate that an increase in nozzle wall temperature from 70° F to 1000° F increased the base heat transfer rate by approximately 40 percent.

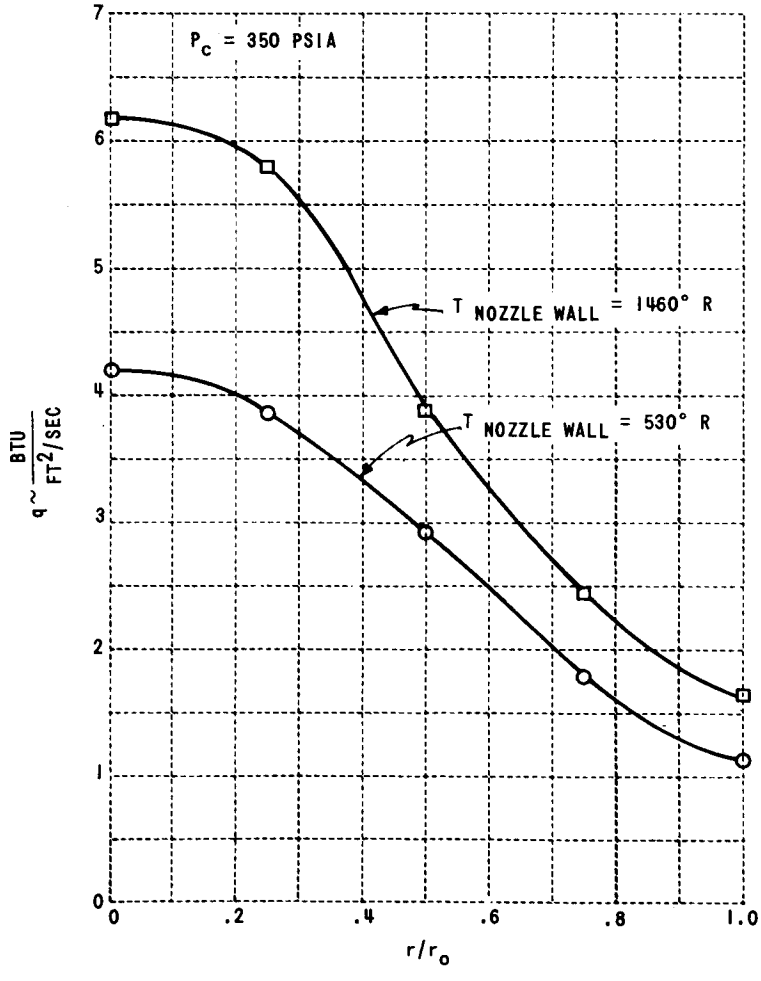


FIGURE 39. RADIAL HEAT TRANSFER VARIATION ON S-IV 4-ENGINE MODEL BASE AS A FUNCTION OF NOZZLE WALL TEMPERATURE

In order to gain further insight into the scaling laws governing the correlation between model data and full scale base environments, the next phase of this program was directed toward evaluating the influence of Reynolds number on heating rates to cylindrical bodies immersed in the reverse flow field above the base plate. Cylindrical rods of 1/8 inch, 1/4 inch, and 1/2 inch were mounted on a support which could be moved axially in the base region as shown in Figure 40. While maintaining a constant $P_c/P_\infty = 106,000$ (so as to hold the reverse flow field characteristics unchanged) Reynolds number was varied both by changing combustion pressure and model diameter.

FIGURE 40. ENGINE MODEL WITH CYLINDRICAL GAGE RAKE MOUNTED

For the conditions investigated, it was found that stagnation point heat transfer varies directly with combustion pressure to approximately the 0.78 power and inversely with the diameter to approximately the 0.25 power. Combining these results into the familiar form of Nusselt number $N_u = \frac{qD}{\Delta Tk} \alpha \left(\frac{PVD}{T\mu}\right)^n$, it is shown in Figure 41 that the Nusselt number varies nearly as the Reynolds number

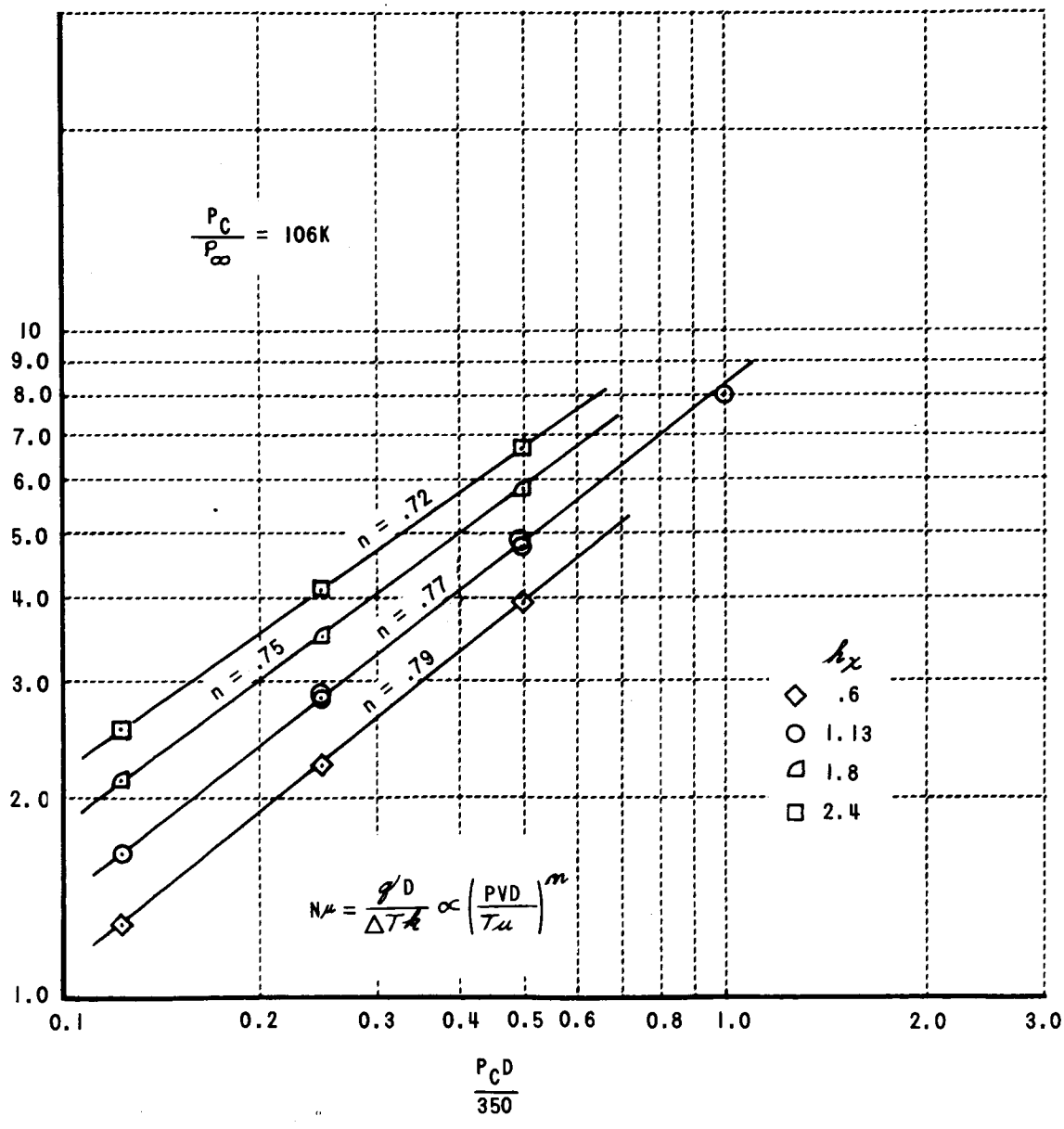


FIGURE 41. NUSSELT NUMBER - REYNOLDS NUMBER CORRELATION

number to the 0.80 power, thus indicating turbulent flow conditions. These values are found to be in good agreement with the theory of Truitt[2] for turbulent flow normal to cylinders.

The results of this multipart program are summarized in CAL Report HM-1510-Y-1 (II), "The Application of Short Duration Techniques to the Experimental Study of Base Heating, Part II - The Determination of Recovery Temperature and Reynolds Number Effects for a Four-Engine Hot Rocket Configuration," to be issued early in 1965.

b. External Flow Reynolds Number Nozzle Program

The relative complexity and frequent scheduling problems associated with the operation of base heating models in wind tunnel facilities have prompted the investigation of alternate means of providing a suitable external flow environment. Furthermore, to provide a better understanding of the scaling laws involved with model tests, a large variation (say an order of magnitude, or more) in the external flow Reynolds number is very desirable, a condition which cannot be satisfied by many available tunnels. As a result of these considerations, a short-duration external flow system has been constructed at CAL which will provide the desired range of free stream conditions about the S-IC model base. The external flow system is basically a blow-down wind tunnel. The test air is stored in an 18-foot long charge tube and exhausts through a conical nozzle into a vacuum tank (Fig. 42). The model is cantilevered from struts in the supply tube and extends through the nozzle throat to the nozzle exit plane. Although the system currently employs a fixed geometry nozzle capable of providing a Mach 2.0 external flow only, the over-all system design capabilities encompass a large ultimate operating spectrum as shown in Figure 43.

With the S-IC model mounted in the nozzle, the flow characteristics of the system were evaluated without model combustion during this period. Typical qualitative pressure histories at various locations throughout the system are presented in Figure 44. It appears that all pressures stabilize and remain steady for time periods compatible with the S-IC model operating time. A quantitative airflow calibration was also performed and found to be entirely satisfactory. Pressure instrumentation for the calibration consisted of a nozzle exit pitot pressure survey rake, static wall pressures on the S-IC centerbody, S-IC base pressure, nozzle total pressure, and tank pressure located as shown in Figure 44. Nozzle total pressure, S-IC centerbody wall pressure and nozzle exit pitot pressure were within 5 percent of theoretically predicted values for the Mach 2 design condition. The S-IC base pressures were in good agreement with

FIGURE 42. EXTERNAL FLOW REYNOLDS NUMBER NOZZLE INSTALLATION

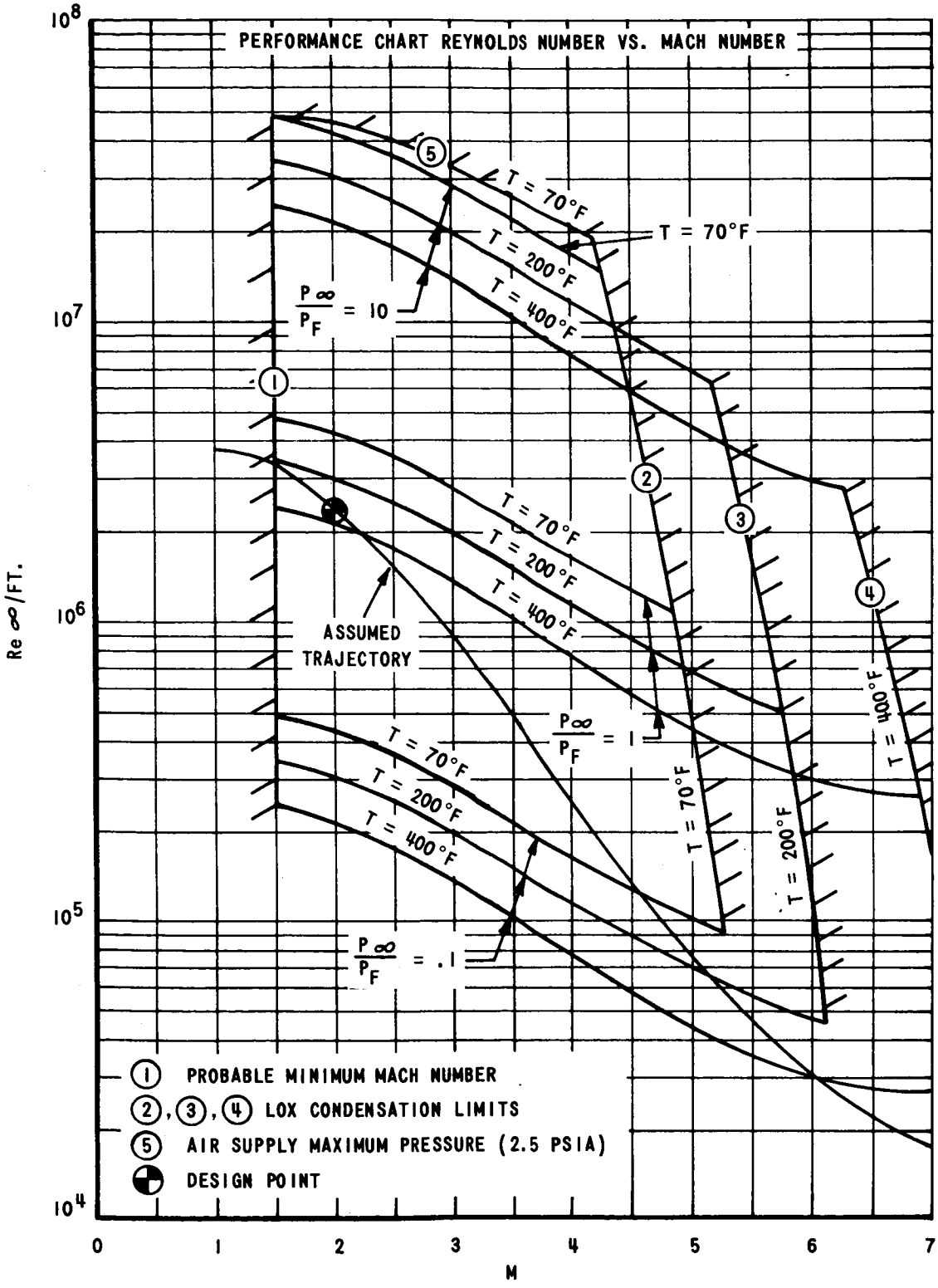


FIGURE 43. OPERATING ENVELOPE - EXTERNAL FLOW REYNOLD'S NUMBER NOZZLE SYSTEM

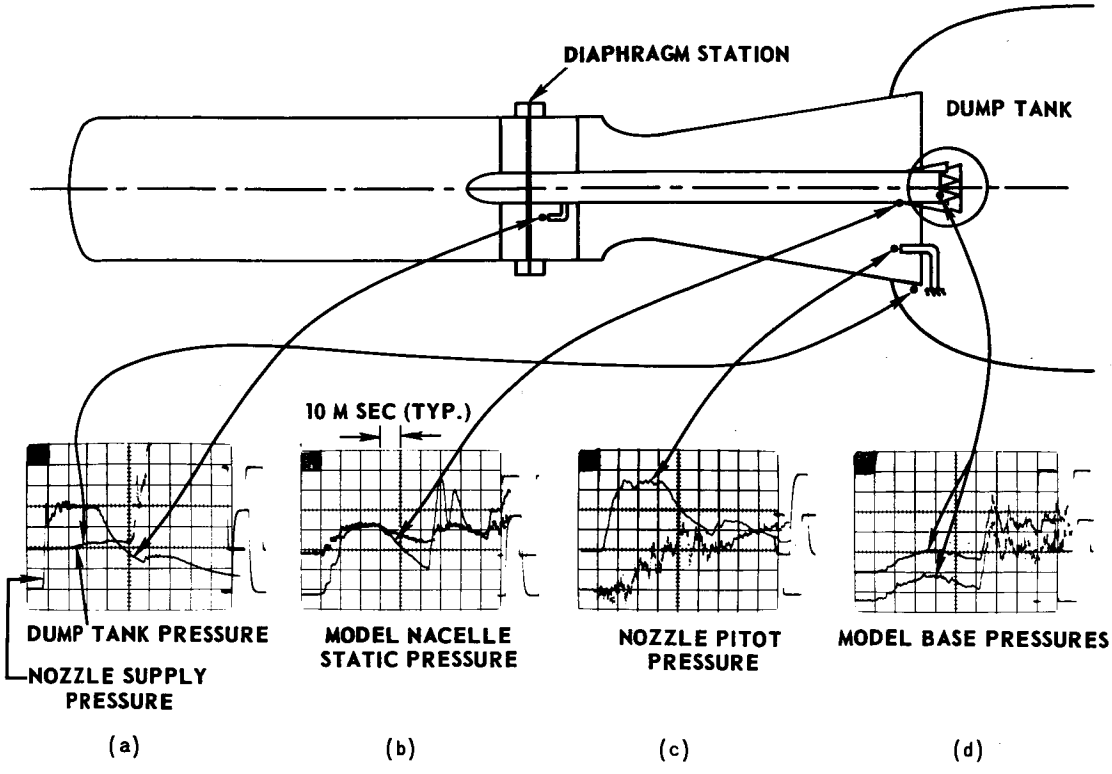


FIGURE 44. EXTERNAL FLOW SYSTEM OPERATING CHARACTERISTICS

the engine-off steady state base pressures measured during the November 1963 S-IC test program in the Lewis Research Center 10 inches by 10 inches Supersonic Tunnel (Fig. 45).

In December 1964, during an attempt to operate the S-IC model in the external flow system with combustion, a model explosion occurred which precluded any further evaluation of the system characteristics during this reporting period. All damage has subsequently been repaired and operations resumed in January 1965.

c. Solid Propellant Impingement Program

Successful development of a practical technique for short-duration simulation of solid propellant exhaust flows was described in Reference 3. Based on this technique, an exploratory experimental program was conducted during this period to investigate the effects of solid propellant rocket exhaust plume

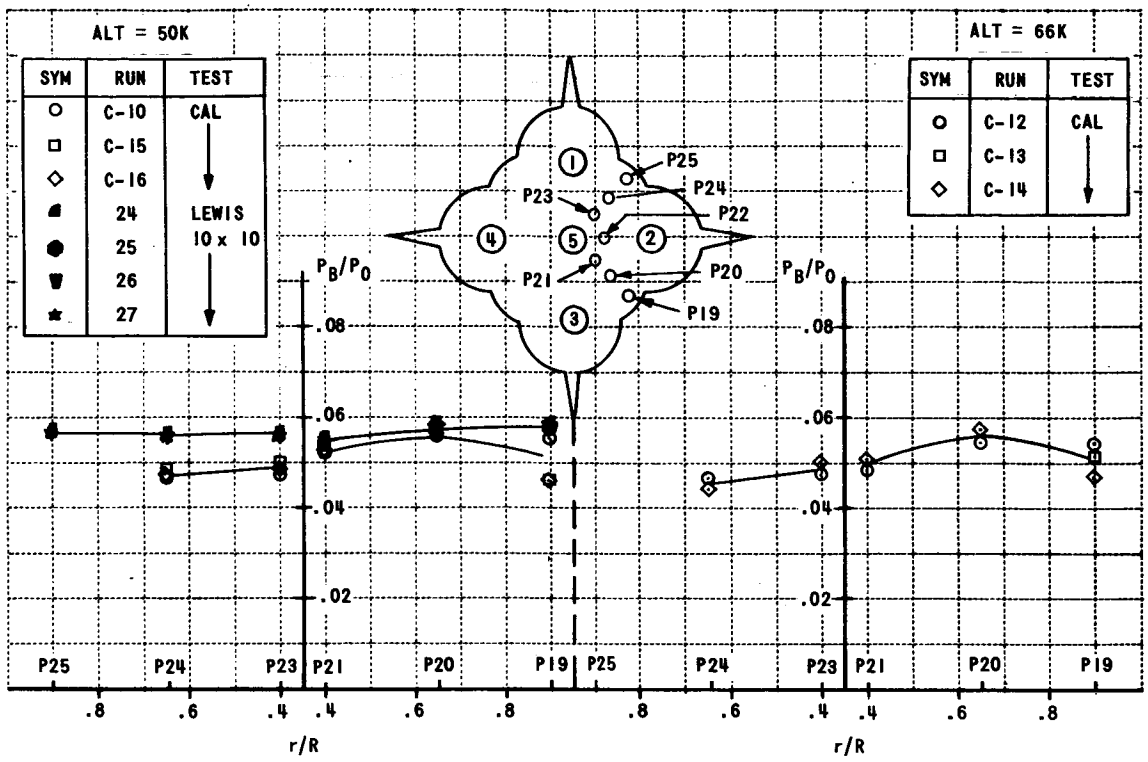


FIGURE 45. EXTERNAL FLOW REYNOLDS NUMBER NOZZLE S-IC BASE PRESSURE RADIAL DISTRIBUTION BFS_1N_1 - 5 ENGINE OFF

impingement on adjacent surfaces. Ultimately, the results of such a program can have direct application to the design of upper stage vehicles subjected to direct impingement by solid propellant ullage or retro-rockets. In addition, they can also provide a better understanding and a useful addition to the limited available information relative to the interaction phenomena associated with impingement of highly expanded exhaust plumes on adjacent surfaces.

For the experiments, the combustor and flow nozzle were installed parallel to, and above an instrumented flat plate as shown in Figure 46. Three different nozzle expansion ratios were investigated, while maintaining a fixed nominal combustor pressure of 1000 psia and ambient altitude of 200,000 feet. Excellent combustor and surface impingement pressures were obtained as seen in Figure 47. The axial pressure distribution along the centerline of the

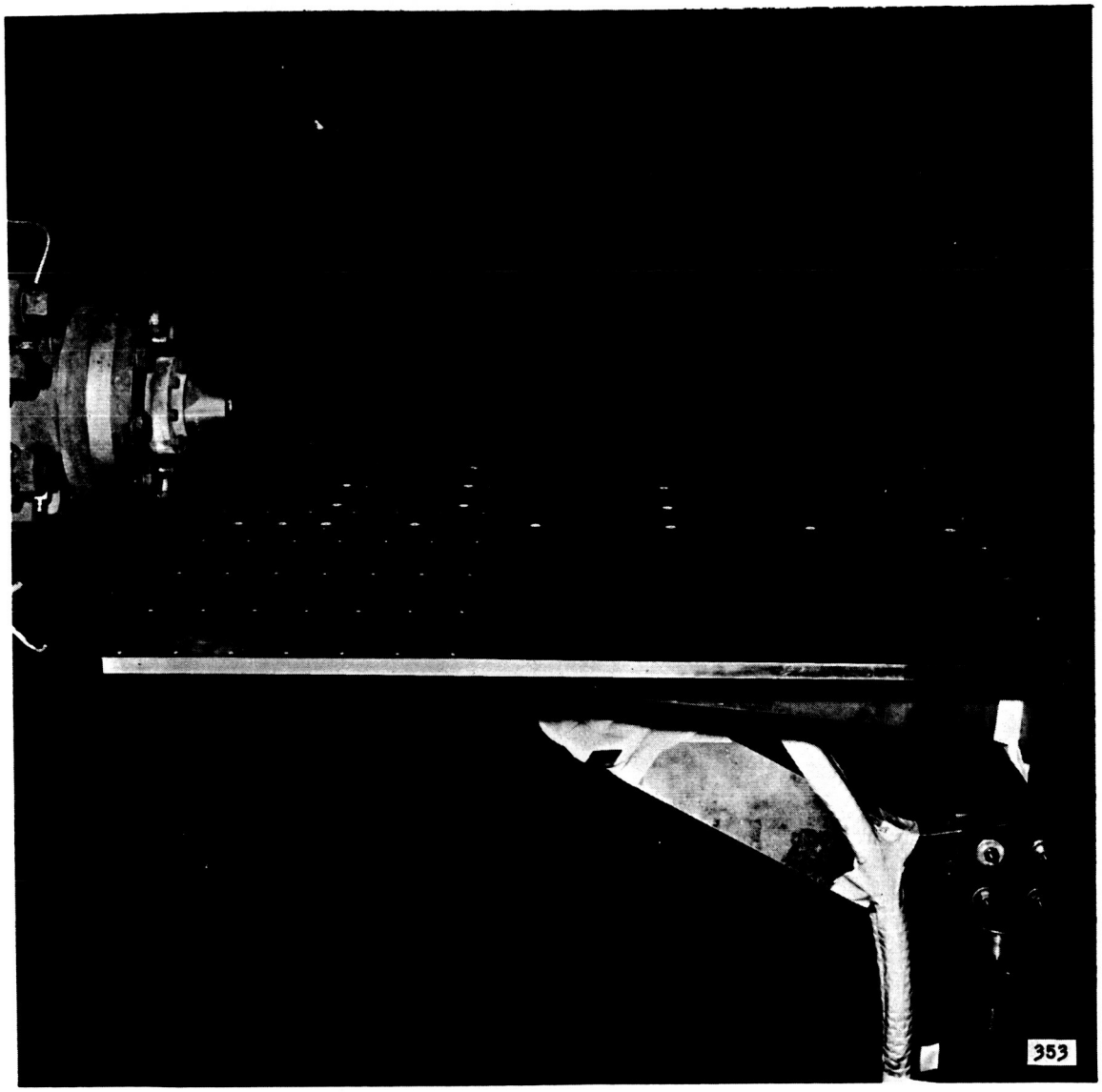
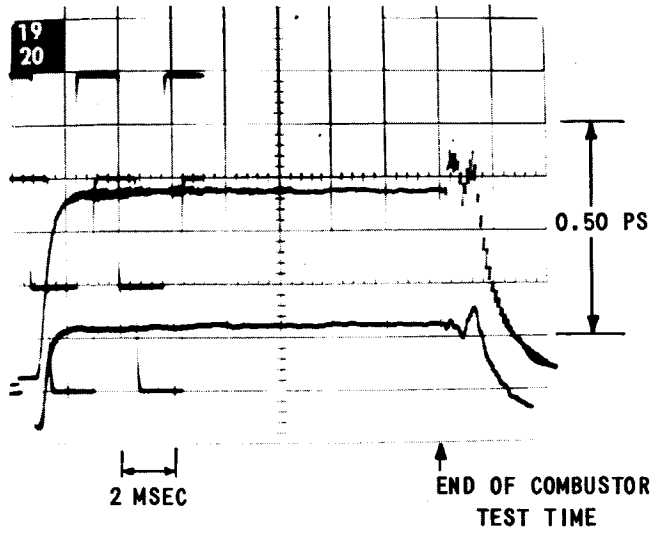


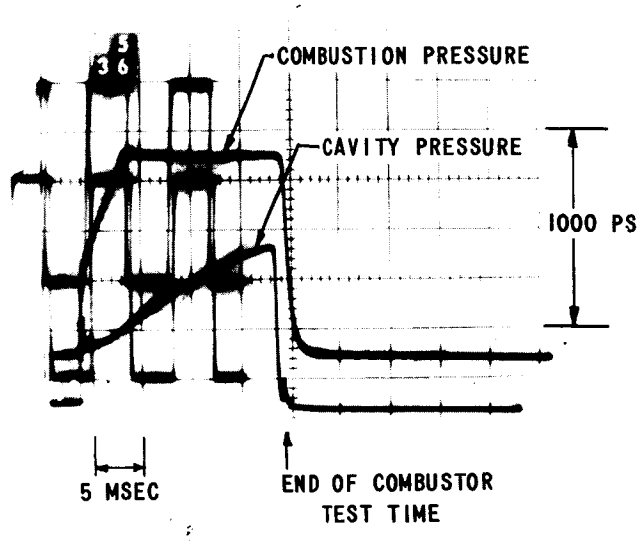
FIGURE 46. INSTALLATION OF SOLID PROPELLANT COMBUSTOR AND IMPINGEMENT PLATE IN THE 13 FT. HIGH ALTITUDE FACILITY

impingement surface for several nozzle expansion ratios is presented in Figure 48. It should be noted that the distributions shown for each nozzle area ratio in Figure 48 have been displaced axially by an amount sufficient to cause all the initial impingement points to occur at the same relative instrumentation location. This allows a direct comparison between the pressure profiles to be made. However, each of the exhaust plumes impinges on the plate at a different axial location relative to the nozzle exit plane.

RUN #2



(a) IMPINGEMENT PRESSURES ON FLAT PLATE



(b) COMBUSTION AND DIAPHRAGM CAVITY PRESSURES

FIGURE 47. PRESSURE RECORDS - SOLID PROPELLANT IMPINGEMENT PROGRAM

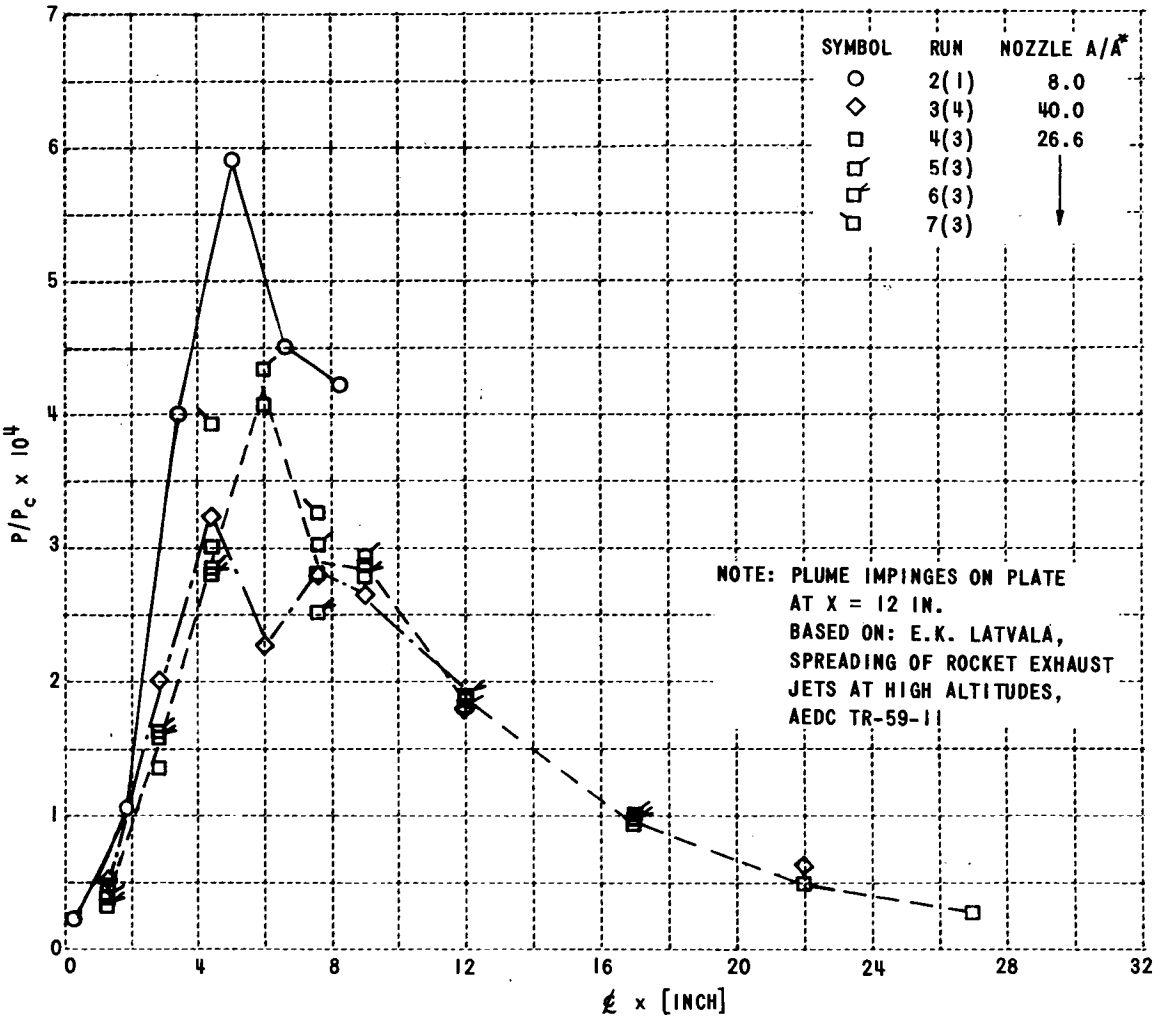
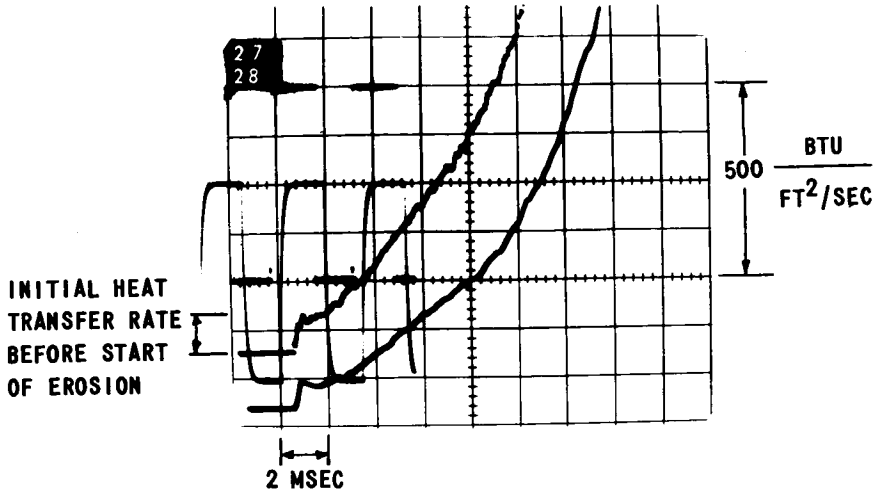
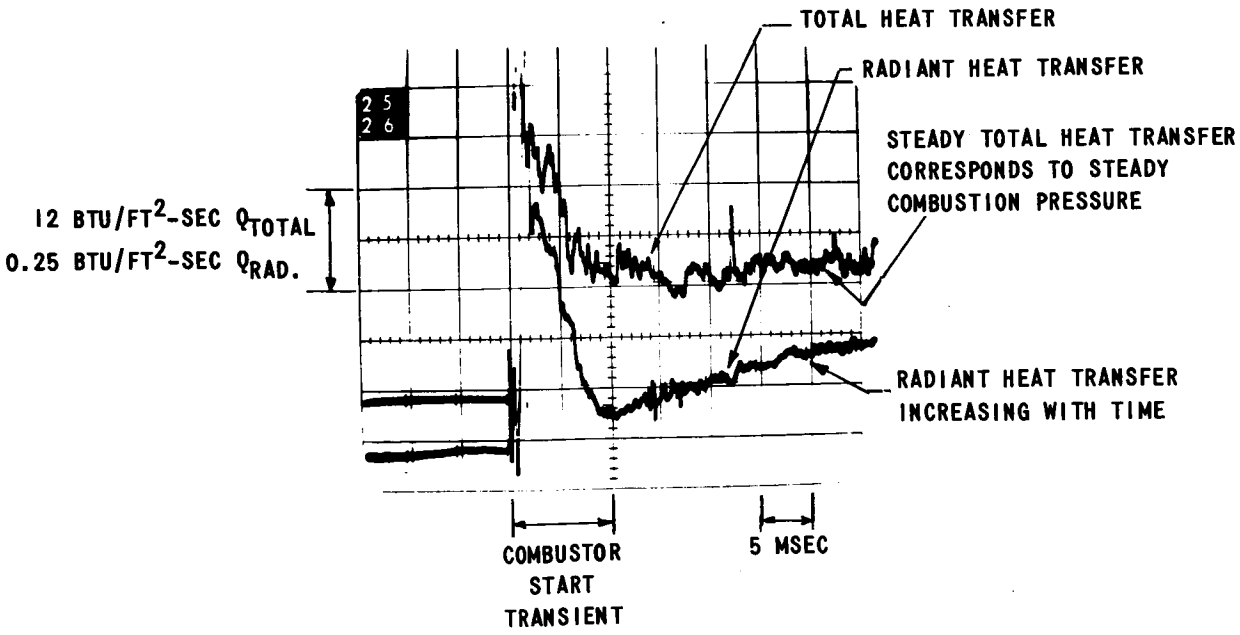


FIGURE 48. SOLID PROPELLANT IMPINGEMENT PRESSURES ALONG PLATE ℄

Alternately, excessive erosion of the heat transfer gages due to solid particle impingement severely compromised both the quality and quantity of heat transfer measurements during the program. Although some gage erosion was anticipated prior to the test program, it was felt that standard post-run compensating corrections could be made. However, the gages in the direct impingement region encountered such severe erosion throughout the test run that suitable corrections could not be applied. Figure 49, a and b, presents typical oscilloscope records from gages located both within and outside the direct particle impingement region. The increasing output with time associated with gage erosion is apparent in Figure 49. Alternately, reasonable gage behavior is observed outside the particle impingement area as evidenced by the data of Figure 49.



(a) TOTAL HEAT TRANSFER WITH GAGE EROSION



(b) TOTAL AND RADIANT HEAT TRANSFER WITHOUT GAGE EROSION

FIGURE 49. HEAT TRANSFER RECORDS - SOLID PROPELLANT IMPINGEMENT PROGRAM

d. Electron Beam Density Measurements

The feasibility of applying an electron beam probe technique to the point measurement of gas density has previously been demonstrated at CAL by means of comparatively simple laboratory bench tests as discussed in Reference 3. The major emphasis on this program at CAL during this reporting period has been directed toward the development of an electron beam probe system suitable for routine measurements in the base region of a clustered engine model. Because of the requirement of locating the beam apparatus close to the model assembly, the entire system must be contained within the test chamber. The apparatus consequently is totally exposed to the high vacuum environment necessary for the tests as well as the high shock loading associated with initiation of flow from the model engines. This situation represents a unique application of the electron beam density measuring techniques because of the stringent operational requirements determined by the environment and has led to inevitable development difficulties which have had to be overcome.

Final installation of the beam apparatus along with the 1/10-scale S-IV four-engine base heating model was initiated in the vacuum chamber during November 1964 and is currently in progress. Installation followed a successful assembly and checkout of the system outside the chamber. The salient features of the beam source, detection system, and model assembly are shown schematically in Figure 50. Photographs of the entire system installation within the vacuum chamber are shown in Figures 51 and 52.

4. Major Accomplishments. The major accomplishments of this program may be summarized as follows:

a. It has been demonstrated that short-duration (shock tube) techniques may be used to duplicate the composition and thermodynamic properties of the combustion products of both liquid and solid propellant rocket engines. Flow durations through scale model nozzle are sufficient to permit the establishment of base flows but are short enough to alleviate the usual complex engineering problems associated with conventional hot-flow models.

b. The ease with which such parameters as flow Reynolds number, pressure ratio, etc., may be varied over wide ranges has permitted extensive study of the general base heating scaling laws. Recent investigations have indicated that base heat transfer rates and film coefficients may be conveniently correlated by the familiar Nusselt and Reynolds number relationships originally developed for pipe and flat plate flow.

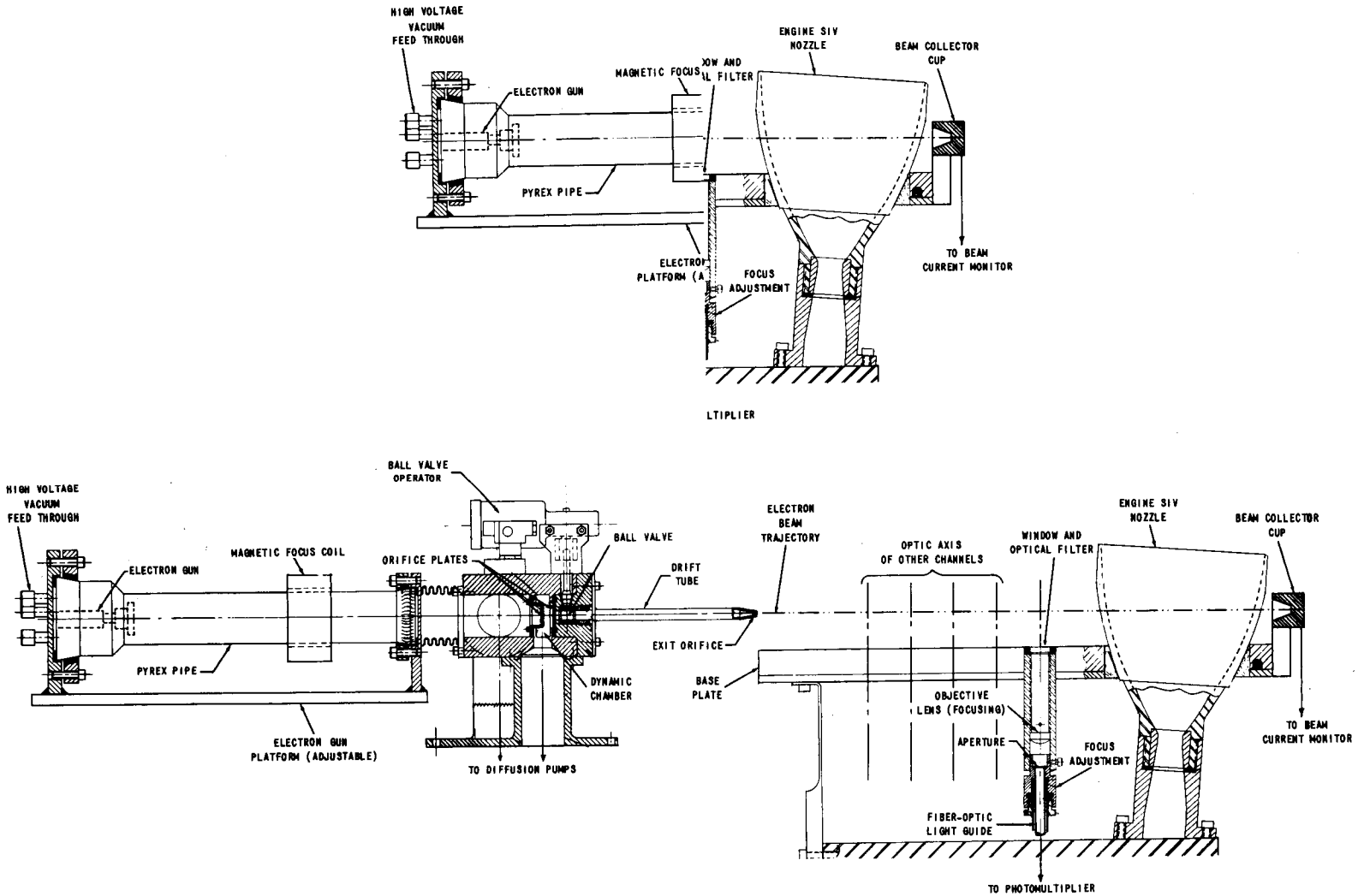


FIGURE 50. SCHEMATIC OF ELECTRON BEAM DENSITY PROBE SETUP

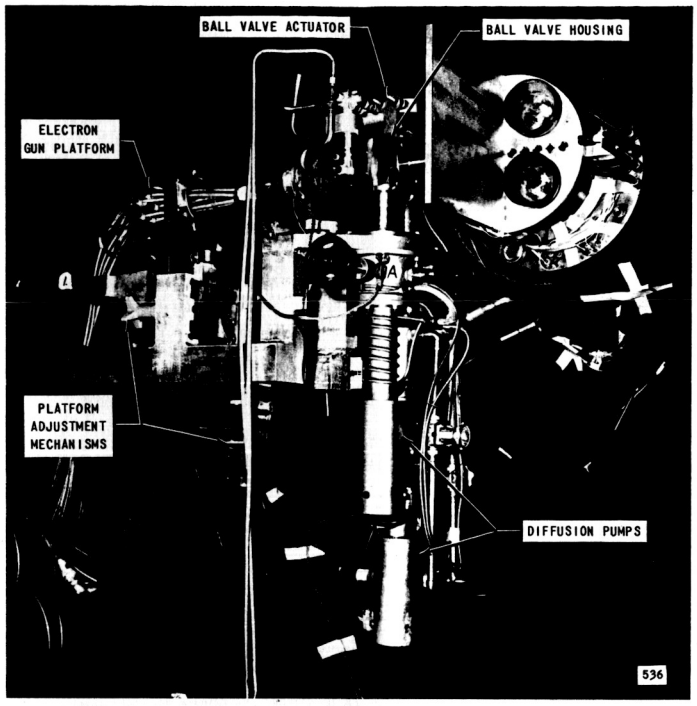
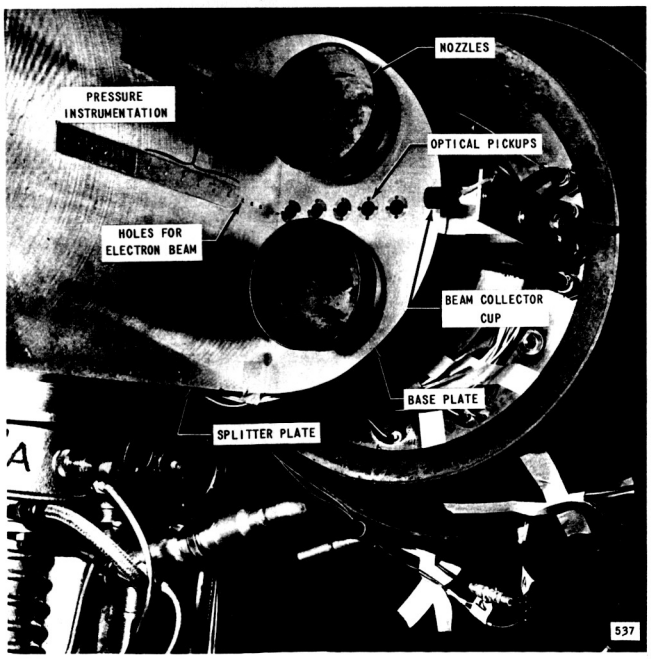


FIGURE 51. ELECTRON BEAM INSTALLATION WITH S-IV 4-ENGINE SPLITTER PLATE MODEL



S-IV 4-ENGINE SPLITTER PLATE MODEL SHOWING ELECTRON

FIGURE 52. BEAM DENSITY AND PRESSURE INSTRUMENTATION

c. It has been shown that a knowledge of the recovery temperature is essential to the understanding and scaling of model test data. Various techniques for determining recovery temperature have been evaluated, and useful measurements have been made for several base configurations of interest. Correlation rules relating base recovery temperature and rocket exhaust Reynolds number have been experimentally established, thus providing a basis for extrapolation to full scale conditions.

d. Short-duration techniques have permitted altitudes in excess of 400,000 feet to be simulated, thus essentially eliminating the altitude restrictions (100,000 to 150,000 feet) normally encountered in model test programs conducted in continuous flow altitude facilities.

e. Secondary flows (turbine exhaust) have been duplicated and found in some cases to have a significant effect on the base heating and pressure distributions.

f. The feasibility of using the short-duration techniques in conventional wind tunnels on a routine operational basis has been demonstrated.

g. Procedures for obtaining meaningful gas concentration measurements in the base region during the limited combustion periods available using short-duration techniques have been developed.

h. The feasibility of combining shock tunnel force measurement procedures with the short-duration combustion techniques in the study of phenomena associated with the inflight separation of booster stages has been successfully demonstrated.

i. Preliminary results have indicated the feasibility of utilizing an electron beam technique to determine local flow density in a recirculated flow region. It also appears that the technique can be readily extended to allow point temperature measurements in complex reverse flow fields.

j. Use of a solid reflection surface in place of a plane of symmetry has been shown to provide a feasible means of obtaining meaningful measurements in a complex recirculated flow region.

k. The application of short-duration techniques to the evaluation of performance characteristics of geometrically complex propulsion systems with accuracies comparable to those obtained from long duration model experiments has been demonstrated.

l. The simulation of solid propellant rocket exhaust flows by means of short duration techniques has been shown to be possible. Exploratory investigations of solid propellant exhaust plume impingement characteristics on adjacent surfaces have been successfully carried out.

m. Transfer of the large, variable density propulsion wind tunnel into a laboratory environment has been shown to be practical by utilization of short-duration flow techniques. Scheduling problems, inadequate free stream Reynolds number simulation, and large operating costs often encountered with continuous flow wind tunnels have been minimized by the successful application of nonsteady flow principles to wind tunnel design.

n. The supporting research program at Cornell has led to an increased understanding of many facets of the base recirculation processes and has made a significant forward step in the state of the art experimentally. These accomplishments have permitted the attainment of design data essential to the S-IC, S-II, and S-IV Saturn stages at a fraction of the cost, on a timely basis, and with a greater confidence level than would have been possible using conventional techniques.

5. Problems.

a. During the course of the base heating program, the general trend has been toward higher operating pressures, increased environmental temperatures, and longer test times. These requirements have imposed increasingly severe operating demands on the model instrumentation which was originally developed for the considerably less severe shock tunnel environment. A continual review of instrumentation usage, improvements in current instrumentation operating characteristics, and development of new transducer designs when required has been found necessary to ensure adequate instrumentation to meet the demands of the base heating program.

b. Loss of mylar diaphragm petals during the test event has compromised the full operating potential of the external flow system because of the flow disturbances they produce. Procedures whereby these particles are captured ahead of the test section by means of screens or wall suction devices are being investigated and should effectively resolve this difficulty.

c. Severe erosion of heat transfer gages exposed to solid propellant exhaust flows has compromised the procurement of data in such an environment. Since knowledge of the thermal environment in such impingement regions (especially when solid particles are present) is necessary to the design of current

and future booster vehicles, a solution to this experimental difficulty must be found. Promising techniques currently being considered for this application are the use of a more rugged calorimeter type gage or protective surface coatings for the thin film gages currently in use.

6. Future Plans. The base heating research program at CAL over the past four years has followed a logical evolutionary pattern. The basic feasibility of using short-duration techniques was first demonstrated. Various refinements and improvements were then instituted to make the technique consistent with the demands of the immediate specific development program requirements of the various Saturn stages. At the same time, technique extensions were pursued which increased the general store of knowledge concerning base recirculation processes. Supporting research plans in the future will continue to emphasize additional technique development as well as maintaining a high degree of emphasis on systematic studies aimed at a better fundamental understanding of the base recirculation problem. Among the programs to be conducted in the future we have:

a. Electron Beam Density Measurements

As discussed elsewhere in this report, assembly and calibration of the electron beam probe/S-IV four-engine model are currently in progress. Early in 1965 an experimental program will be conducted in which the density variations throughout the reverse flow field in the S-IV base region will be investigated. Experiments will be carried out both with and without a reflection plane in the plane of symmetry. The effects of varying combustor pressure and temperature on density distribution will be evaluated using shock heated nitrogen as the nozzle working fluid.

b. Supersonic External Flow Studies

Subsequent to the return of the Saturn S-IC model from the Lewis Research Center 8 by 6 wind tunnel program in the Spring of 1965, an experimental program will be conducted in the external flow nozzle to determine the effects of varying free stream Reynolds number on various parameters in the base region. It is hoped that the results of this investigation will promote a better understanding of the complex free stream/base flow interactions and provide a basis for extending scale model data obtained in an external flow environment to full-scale configurations. Studies will also be made on the free-stream mixing and ignition characteristics of fuel-rich main rocket exhausts and secondary turbine exhaust flows in an attempt to more accurately define the nature of exhaust jet afterburning and to evaluate analytical methods of predicting the radiation characteristics of such afterburning regions.

c. Advanced Propulsion System Base Environment Studies

During the Spring of 1965 an experimental study will be initiated to define the thermal and pressure environment in the base region of an advanced plug cluster rocket engine propulsion system similar to that discussed previously in this report. Heat transfer and pressure distributions will be obtained for various truncated isentropic plug configurations. Hydrogen-oxygen combustion products will be used as the working fluid at combustion pressures up to 3000 psia.

d. Wind Tunnel Test Programs

A continued investigation of the S-IC base environment over the Mach 0.6 - 2.0 portion of the Saturn V trajectory is currently scheduled to be conducted in the Lewis Research Center 8 by 6 wind tunnel during February - March, 1965.

An experimental model program to provide optimum turbine exhaust configuration design data for the S-IB stage, as well as to obtain additional model base heating data for the S-I stage for comparison with full-scale flight test results, is also scheduled to be carried out during March - June 1965, in the AEDC Rocket Test Facility.

7. Illustrations. Figures 29 through 52.

References:

1. Marion, E. D.; Daniels, D. J.; Herstine, G. L.; and Burge, G. W.: "Exhaust Reversal From Cluster Nozzles - A New Flow Model," American Rocket Society Preprint 2706-62, Presented at ARS 17th Annual Meeting and Space Flight Exposition, Los Angeles, California, November 1962.

2. Truitt, R. W.: "Fundamentals of Aerodynamics Heating," pp. 162-179, Ronald Press Co.

3. Semi-annual Progress Report, Supporting Research Projects Contract NAS 8-823, "Research on Base Heating of Rocket Motor Vehicles Using Shock Tube Techniques," January 1, 1964 to June 30, 1964.

D. Radiation from Gases

Submitted by
(Technical Supervisor)

George D. Hopson
R-P&VE-PTD, 876-3474

1. Project Data

Contract Number: NAS 8-11468, June2 9, 1964 - July 29, 1965

Contractor: University of California
Berkeley, California

2. Purpose of Project. The purpose of the project is to generate absorption coefficient data required in prediction of radiation from gases. The analytical work shall consist of a survey of existing theory applicable to the prediction of gas absorption coefficients, and the correlation of theory with experimental data. Where existing theory is lacking or inadequate, new theory and analytical prediction techniques are to be developed. Existing gas absorption coefficient experimental data are to be supplemented with measurements so as to extend the data to the pressures, temperatures, and constituents commonly present in rocket engine exhaust jets.

3. Technical Status. The primary effort during the reporting period was expended on testing and on redesign of the windows of the high temperature furnace used in measurement of gas absorption coefficient data. All testing to date has been done using carbon dioxide gas. Preliminary tests using CO at 1200° K showed a 400° K gradient between the center of the furnance and the zinc selenide windows. A redesign was accomplished to reduce the gradient. The window holding fixture was changed from a metal, water cooled design to alumina, and saphire was substituted for the zinc selenide window material. Tests using CO at 1500° K with the new design showed a gradient of only 50° K. The data are being analyzed to determine the effect of the temperature gradient on the measured data, as basis for evaluating future tests where it may not be practical to avoid a significant gradient (the saphire window material is transparent over the 2 to 6 micron range, which is satisfactory for CO but not for CO_2).

4. Major Accomplishments. The experimental device for measuring gas adsorption coefficients was redesigned so as to significantly reduce the gas temperature gradient.

5. Problems. No significant problems have been encountered.

6. Future Plans. Testing with CO will be resumed with the redesigned experimental apparatus. The effect of gas temperature gradient on measured adsorptivity will be investigated. Further design changes to the apparatus will be considered which will minimize gas temperature gradients and also be compatible with CO_2 and water vapor testing.

7. Illustrations. None.

E. Study of Heating by Radiation From Exhaust Gases

Submitted by
(Technical Supervisor)

George D. Hopson
R-P&VE-PTD, 876-3474

1. Project Data

Contract Number: NAS 8-850, September 24, 1961 - September 30, 1964

Contractor: The University of California
Berkeley, California

2. Purpose of Project. The purpose of the project is the development of techniques for the prediction of heating by radiation from exhaust gases. The technical approach includes survey of existing literature, laboratory testing, and theoretical analysis. This work is fundamental by nature rather than oriented toward a single application.

3. Technical Status. Prior to the reporting period a high temperature (2000° K) furnace system for infrared spectral radiation studies was designed, assembled, and partially checked out. During the reporting period a series of tests, using carbon monoxide gas, were performed.

4. Major Accomplishments. Data were measured for the fundamental band of CO at temperatures of 300 and 1800° K and at pressures from 0.25 to 3.0 atmospheres. Measurements were made over optical path lengths of 10 and 20 cm. Since data were available on CO absorptivities at 300° K, tests were performed at this temperature for comparison. Figures 53 and 54 show

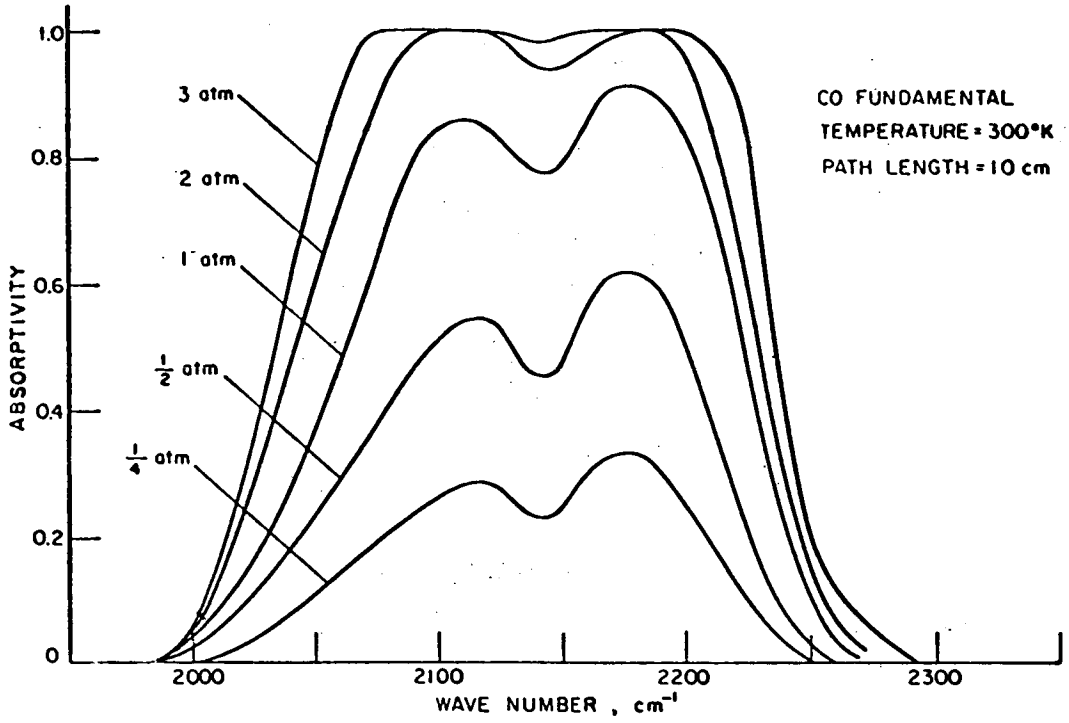


FIGURE 53. SPECTRAL ABSORPTIVITY OF CO FUNDAMENTAL AT TEMPERATURE 300° K AND PATH LENGTH 10 cm

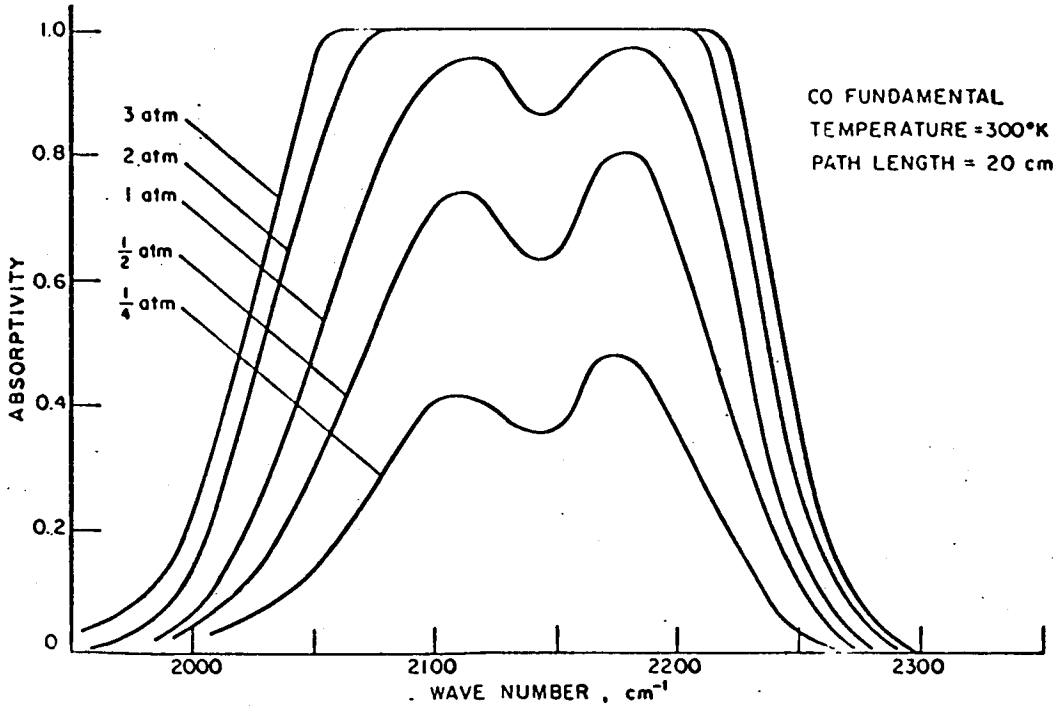


FIGURE 54. SPECTRAL ABSORPTIVITY OF CO FUNDAMENTAL AT TEMPERATURE 300° K AND PATH LENGTH 20 cm

the measured data at this temperature. Comparison of integrated fundamental band absorptivities with those of Burch and Williams (Applied Optics, 1, 587, 1962) showed a deviation of less than 10 percent. Figures 55 and 56 show data measured at 1800° K, where no directly comparable data from other sources are available.

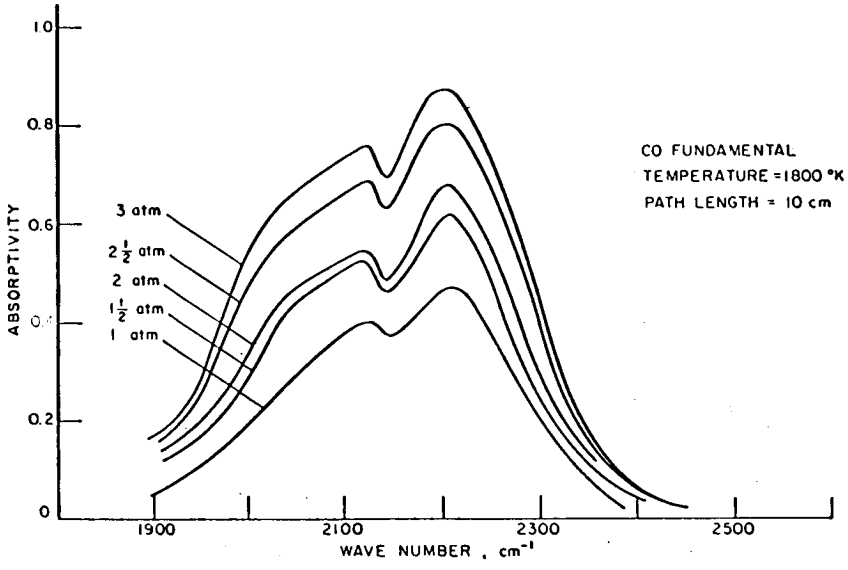


FIGURE 55. SPECTRAL ABSORPTIVITY OF CO FUNDAMENTAL AT TEMPERATURE 1800°K AND PATH LENGTH 10 cm

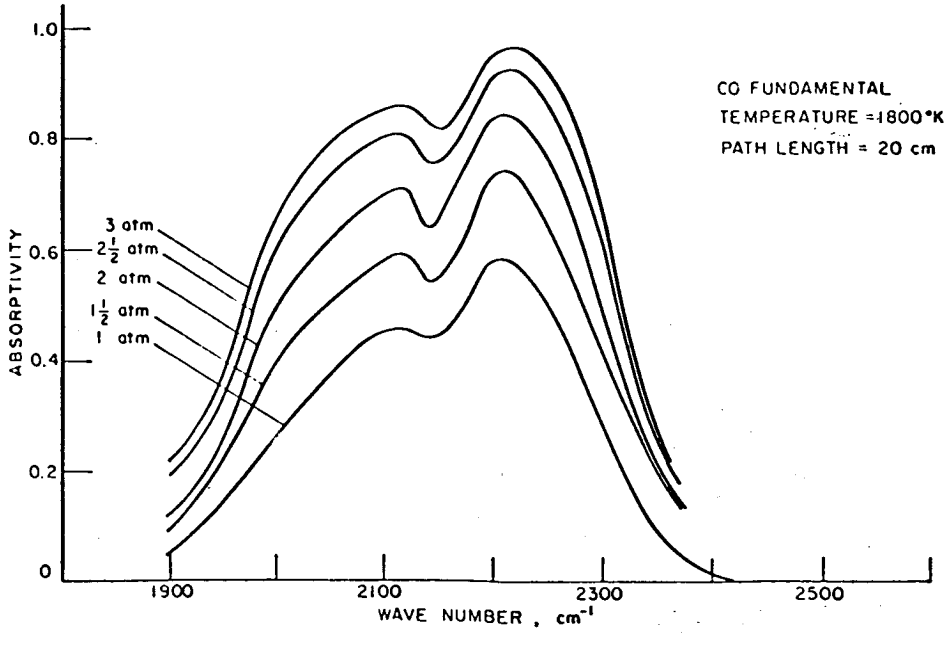


FIGURE 56. SPECTRAL ABSORPTIVITY OF CO FUNDAMENTAL AT TEMPERATURE 1800° K AND PATH LENGTH 20 cm

5. Problems. No significant problems have been encountered.

6. Future Plans. Future experimental plans include CO measurements at intermediate and possibly higher temperatures, and similar measurements of CO_2 and H_2O.

7. Illustrations. Figures 53, 54, 55, and 56.

F. Rocket Mainjet Radiation

Submitted by
(Technical Supervisor)

William B. Anelly
R-P&VE-PTD, 876-3483

1. Project Data

Contract Number: NAS 8-5398, June 1, 1963 - August 31, 1964

Contractor: Rocketdyne Division
North American Aviation, Inc.
Canoga Park, California

2. Purpose of Project. The purpose of this work is the development of a computer program for the calculation of vehicle incident thermal radiation from rocket exhaust jets. Effects of changing altitude on jet radiation is to be included. Analytical work is to be correlated with total and spectral radiation measurements from full scale ATLAS vernier, F-1, and J-2 rocket engines.

3. Technical Status. A general method has been developed to complete the radiant flux to the base of a gas system. The calculation procedure consists of calculating the radiant flux emitted by and transmitted through each differential volume element of gas. This procedure is carried through for each pertinent differential element and then summed to obtain the total. The radiation emitted and absorbed is defined by the gas absorption coefficient. The entire procedure was programmed for solution by a digital computer. The resulting computer program gave a general method for evaluating radiant flux with the following capabilities:

a. gas can have non-uniform distribution of thermodynamics properties but must have an axis of symmetry,

b. interlayer absorption and emission, both temperature and wavelength dependent, can be accounted for,

c. effect of shadow or silhouette of any axisymmetric occlusion can be accounted for.

The program uses the following input:

a. spatial definition of thermodynamic properties of the geometry under consideration,

b. absorption coefficients of a gaseous body as a function of wavelength and temperature,

c. geometry of any occlusion.

At present this program is restricted to the calculation of radiant flux to a differential area which has a normal axis parallel to the axis of symmetry of the gaseous body. In addition to the computer program measurements of radiation, emittance from the plumes of the F-1 and J-2 engines was also measured, as a basis for defining computer program input and checking the accuracy of the calculation.

4. Major Accomplishments. The major accomplishments of this program have been the development of the computer program and the measurement of the plume radiation emittance.

5. Problems. The objectives of this task were only partially obtained due to the higher than predicted costs of measuring the plume emittance. It was originally intended to have a computer program which could compute the radiant flux to any differential area regardless of its orientation and account for multiple and non-axisymmetric bodies. Depletion of available funds prevented the latter.

6. Future Plans. If funds become available, it is intended to improve and extend the existing program (Item 5) and to develop an appropriate description of after burning and particle radiation. In addition more measurements of radiation emission during static firings would be desirable.

7. Illustrations. None.

Aerodynamic Forces, Steady Loads, Stability and Control

A. Experimental and Theoretical Investigation of the Dynamics of Separated Flow over Blunt Bodies

Submitted by
(Technical Supervisor)

James C. Young
R-AERO-AUE, 876-1611

1. Project Data

Contract Number: NAS8-5338, May 10, 1963 - April 15, 1965

Contractor: Lockheed Aircraft Corporation
Lockheed Missile and Space Co.
Sunnyvale, California

2. Purpose of Project. The quasi-steady technique for the prediction of dynamic aeroelastic and rigid-body instability, caused by flow separation, has been developed by Lockheed. The technique is essentially the determination theoretically, and/or experimentally, of the static primary, induced aerodynamic characteristics of each component of the vehicle. From these data, the aerodynamic damping of each component may be estimated. This damping information can then be applied to the dynamic equations of motion of the vehicle.

The purpose of the subject contract is:

a. to demonstrate the applicability of this technique to aerodynamic configurations typical of the Saturn/Apollo launch vehicles; and

b. to develop a procedure for the application of this technique for the prediction of the aeroelastic characteristics of the "general" vehicle configuration.

3. Technical Status. Analysis of the wind tunnel experiments mentioned in the previous progress report is continuing. Additional experiments to better define the wake steering ability of various wake sources have been completed. An analysis of the static and dynamic loads on bluff bodies has been completed.

4. Major Accomplishments. During the reporting period, two additional experimental programs have been completed. In addition, Lockheed

reports LMSC/804382 entitled "Static Pressures and Forces Generated by a Flow Separation Disk" and LMSC/840651 entitled "Unsteady Characteristics of a Spiked Bluff Body" have been released.

5. Problems. None.

6. Future Plans. Future analytical studies include: the investigation of steady loads on blunt-ogive-cylinder-flare bodies; unsteady loads on cone-cylinder-flare bodies; unsteady loads on blunt-ogive-cylinder flare bodies; steady and unsteady loads in cavities. In addition, a final report summarizing the complete project should be issued. Target date for project completion is July 15, 1965.

7. Illustrations. None.

Acoustic Noise Propagation

A. Investigation of Noise Generated by Internal and External Rocket Combustion Phenomena

Submitted by
(Technical Supervisor)

Dr. G. H. R. Reisig
R-TEST-T, 876-2322

1. Project Data

Contract Number: NAS 8-11150, March 4, 1964 - March 4, 1965

Contractor: The Ohio State University
Research Foundation
Department of Aeronautical and Astronautical Engineering
Rocket Research Laboratory
Principal Investigators: Dr. R. Edse
L. Bollinger
Dr. E. Fishburne

2. Purpose of Project. Observations made during static rocket engine tests, with effective suppression of the jet boundary noise process, show that sound sources are also contained in the exhaust jet itself, generated either in the jet, e.g., by explosive afterburning, or in the rocket engine. The objective of the research project is the investigation of any physical processes responsible

for the noise generation due to the combustion phenomena, and surveying technically feasible means of reducing the noise energy levels at the very noise source embedded within the combustion gases.

3. Technical Status. The rocket motor test setup is now fully operational. Firing of the motor in the nozzle-vertically-upward position has been developed into a reliable procedure. The vertically-upward position warrants a sound field of the rocket jet noise virtually undisturbed by any surface effects. Thus, the main step for the gathering of significant acoustical and jet flow data has been accomplished.

4. Major Accomplishments. With this unique vertical firing arrangement, the first set of measuring data has been collected during 15 firing tests. The data are still in the process of being analyzed. The specific test conditions included primarily the variation of the propellant mixture ratio. The conditions were, first for qualitative purposes, modified from the original (F-1 and H-1 motors) fuel rich mixtures through to oxidizer rich mixture ratios.

Accidentally, but fortunately for phenomenological experience, a natural longitudinal oscillation of around 1600 cycles of the combustion chamber of the test motor was observed. Parameter studies will be conducted to widely modify this frequency, or rather suppress the oscillation, by geometric changes of the combustion chamber dimensions.

5. Problems. The research performance on rocket combustion noise phenomena apparently is now in full swing. However, the contract is to expire by March 4, and virtually no funds will remain for even a short extension of the contract without cost. The withdrawal of the planned FY 1965 funds by OART is just about abortive for this essential and most informative research project. Exceptional measures for keeping this valuable research program alive appear mandatory.

6. Future Plans. None reported.

7. Illustrations. None.

B. Development of Data Analysis Methods for High-Intensity Sound Propagation

Submitted by
(Technical Supervisor)

Dr. Gerhard H. R. Reisig
MSFC/R-TEST-T

1. Project Data

Contract Number: NAS8-11135, December 7, 1963 - December 7, 1964

Contractor: Tulane University
School of Engineering
Department of Mechanical Engineering (ME)
Department of Electrical Engineering (EE)

Principal Investigators: Dr. R. Rotty
Dr. J. O'Hara
Prof. J. Cronvich
Mr. P. Duvoisin

Consultants: Prof. C. Sperry
Dr. H. Hrubecky

2. Purpose of Project. Mechanical Engineering: "Investigation of acoustic and fluid-mechanical relations of jet flows and exterior fields." (a) Analysis of frequency spectra of sound emanating from superonic and subsonic jets. (b) Measurements and analysis of effects of cross flow on air jet noise frequency spectrum. (c) Theoretical investigation on sound production of jet turbulence in a jet curved due to cross flow.

Electrical Engineering: "Development of analytical and experimental methods for quantitative determination of sound intensities in a complex sound field in the free atmosphere." (a) Analysis and development of a pilot pattern for an areal sound intensity monitoring system. Investigations on optimal instrumentation and data analysis methods for determination of the effects of rapidly changing atmospheric conditions on the fluctuations of local sound levels. (b) Investigation of feasibility of VHF radio propagation analogies for atmospheric sound propagation.

3. Technical Status. Mechanical Engineering: The planned measuring systems for jet noise versus jet flow analysis are ready for use (cross flow anechoic chamber) or already in operation (schlieren optical system). Schlieren pictures of supersonic (or choked) jets were taken, obtaining shock wave (diamond) patterns, with measurement of the acoustical spectrum of the jet noise simultaneously. The two sets of corresponding data are in process for correlation analysis.

The cross flow setup has not been operated yet because of expiration of contract funds which prevents a necessary increase of scientific manpower (cf. "Problems").

Another series of measurements has been taken for correlating the turbulence fluctuations inside the jet with the noise spectrum closely outside the jet. The obtained correlations for the longitudinal velocity fluctuations were very low. A few correlations derived for lateral and radial velocity fluctuations indicated somewhat higher correlation coefficients. The measuring operation with the hotwire turbulence meter remains problematic. Under the present contract situation it appears preferable to emphasize the "gross effect" problems, like noise source localization by "masking", multijet cluster noise spectra, and cross flow noise spectra, rather than pursueing with more refined means the intricate correlations between flow fluctuations and noise spectra (cf. "Problems").

Electrical Engineering: For the project of sound propagation fluctuation studies ("SPFS"), a site for the layout of the microphone network has been selected at Mississippi Test Facility, about 12-km distant from the sounding horn, in the azimuth direction of 103 degrees (i.e., towards Bay St. Louis). Assemblies for the first five measuring stations of the measuring network, consisting of microphone and sensor unit, are ready for operation. Also, a filter unit has been developed and environmentally tested for background noise suppression. The acoustical spectra of background noise at the Mississippi Test Facility network site have been measured and analyzed. The start of the SPFS is still delayed by the lack of delivery of the recording equipment. Also, the physical clearance of the network site, and the installation of the network proper, are behind schedule.

4. Major Accomplishments. None reported.

5. Problems. The task of the contract to be performed by the Mechanical Engineering Department of Tulane University is without funding as per February 1, 1965, because of the withdrawal of the remaining FY-65 funds by OART. This adverse funding situation has the most disastrous effects on the acquisition of knowledge on rocket engine noise which is vitally needed for the static testing program of the Saturn V project. The research project at Tulane University has just reached the status of optimum performance, with basic scientific issues of jet noise analysis having been cleared, and the experimental facilities being completed and ready for really productive work. With the present interruption of the research work, caused by lack of funds, the previous efforts and expenditures of the contract appear to be useless, and wasted. Immediate remedy of the funding situation is mandatory.

6. Future Plans. None reported.

7. Illustrations. None.

C. Establishment of Contingency Tables for Sound Propagation Forecasting

Submitted by
(Technical Supervisor)

Dr. G. H. R. Reisig
R-TEST-T, 876-2322

1. Project Data

Contract Number: Government Order H-61485

Contractor: Command General
U. S. Army Missile Command
Redstone Arsenal, Alabama
Principal Investigator: Dr. O. M. Essenwanger, Chief, Aerophysics Branch, Physical Sience Laboratory, Research & Development Directorate, U. S. Army Missile Command

2. Purpose of Project. Establishment of physical and statistical correlations between the instantaneous and characteristic atmospheric parameters and the instantaneous and characteristic sound propagation parameters, in the format of contingency tables.

For the forecasting of sound propagation conditions at space booster static firing test sites, a confidence level of 95 percent for a 24-hour period is required. The problem has to be attacked by specific statistical methods because of lack of adquate analytical forecasting methods.

The statistical method to be applied is based on the concept of characteristic atmospheric profiles (temperature, wind, sound velocity, etc.), which are established from local semi-daily atmospheric observations (radiosonde ascents). These profiles are to be expressed in sets of mathematical coefficients (polynomials; Fourier series) which are to be analyzed in terms of frequency distributions

of occurrence. These frequency distributions have to be correlated with coincident empirical sound propagation parameters in patterns of contingency tables, which are the instrument for objective sound propagation forecasting.

3. Technical Status. The frequency distributions of the characteristic profile coefficients of wind direction, wind speed, and temperature for the radiosonde data at Marshall Space Flight Center and Mississippi Test Facility have been established. The pertinent computer programs have been comprehensively completed and are now available for any other station being desired. For the temperature profiles, a particularly intricate system of coefficients has been developed, preserving such characteristic discontinuities as temperature inversions. This system is based on the temperature gradient rather than on the straight temperature parameter itself.

4. Major Accomplishments. Contingency tables have been established for the correlations between wind and temperature profile characteristic coefficients for the Huntsville observations. The pertinent computer programs have been established and are now readily applicable to any station and time period of observation.

One complete year of empirical sound intensity measurements at the Mississippi Test Facility has been statistically evaluated in terms of mean sound pressure level and its dispersion (standard deviation), and with regard to azimuth, distance, and season of the year. The observational material (sound measurements) was extremely heterogeneous and extensive efforts had to be made to obtain a statistically homogeneous collection of data. The particular significance of background noise data was recognized, and criteria for more adequate monitoring of the background noise were established. The computer programs for analyzing to intricate details the empirical sound intensity data are now completely established and ready for efficient and productive utilization with any future acoustic measurements.

Characteristic coefficients have been derived for the sound velocity profiles in 10-degree azimuth increments around the whole windrose for the Huntsville radiosonde data. An objective classification scheme was developed to assign each sound velocity profile to the proper profile class by means of mathematical criteria. The concept of classification is based on optimum combinations of correlation coefficients between characteristic profile coefficients and profile prototypes. The computer programs for the objective classification of the sound velocity profiles are close to completion and then can be applied to any selected station and time period of observation. Frequency distributions of sound velocity profiles, based on the outlined classification scheme, are the prerequisite for

contingency tables correlating atmospheric conditions (represented by sound velocity profile classes) and empirical sound intensity profiles (versus distance from sound source). The latter are the next topic in the sound propagation analysis.

5. Problems. None reported.

6. Future Plans. None reported.

7. Illustrations. None.

D. Absorption of Low Frequency Acoustic Energy in the Atmospheric Media

Submitted by
(Technical Supervisor)

J. H. Farrow
R-P&VE-SV, 876-3540

1. Project Data

Contract Number: NAS 8-11002

Contractor: Columbia University
New York, New York

2. Purpose of Project. When sound is propagated under various field conditions the sound pressure levels decrease due to (1) divergence, normally termed inverse square law losses or attenuation, and (2) other effects including molecular absorption, heat conduction losses, etc. These additional losses, often referred to as "excess attenuation," are highly dependent on frequency of the sound and humidity, and to some lesser degree upon temperature and atmospheric pressure. The determination of the magnitude of these excess attenuation values as a function of atmospheric variables is the purpose of this study.

3. Technical Status. All needed information has been obtained for frequencies between 1000 and 125 cps. The new techniques for obtaining such data for frequencies down to possibly 25 cps is being prepared and checked out.

The project is approximately 80 percent complete with 75 percent of funds depleted.

4. Major Accomplishments. The most important result of the study so far is the completion of the first phase report, "Absorption of Sound in Air Below 1000 cps." This report gives excess attenuation values for various humidities, temperatures, and pressures for frequencies down to 125 cps.

5. Problems. In November the full time engineer on this project left. Supposedly another full time man, who will need some preparation time, will start work in December or January and continue the project. No real problems have been expressed by the contractor.

6. Future Plans. None at present.

7. Illustrations. None.

E. Aeordynamic Noise Research

Submitted by
(Technical Supervisor)

Gilbert A. Wilhold
R-AERO-AU, 876-0962

1. Project Data

Contract Number: NAS 8-11308, June 30, 1964 - June 30, 1965

Contractor: Wyle Laboratories,
Huntsville, Division
Huntsville, Alabama

2. Purpose of Project. The purpose of this task is to arrive at an understanding of the physical mechanisms of oscillating shocks and boundary layer separation phenomena. These adverse phenomena are associated with protuberances and vehicle interstage geometry changes.

3. Technical Status. The analysis of existing fluctuating pressure data obtained from wind tunnel tests on idealized vehicle protuberances and on scaled models of flight vehicle configurations is being continued as additional data become available. Empirical and analytical work is being directed toward correlation of these data with the vehicle flight environment and the development of techniques for predicting this adverse environment for advanced vehicle designs. Theoretical studies of the mechanisms of induced flow separation and the turbulent-shock wave interaction are being conducted concurrently.

4. Major Accomplishments. An analytical empirical treatment of the separated flow data has yielded a model to describe the extent of the separation area in the vicinity of typical interstage geometries. Also, the effect of eddy deceleration in the flow has been investigated and presents a possible mechanism for flow separation.

5. Problems. None.

6. Future Plans. The reduced pressure fluctuation data from the Ames general protuberance test are now becoming available. These data will be analyzed in regard to the physical mechanisms of shock oscillations and boundary layer separation phenomena.

7. Illustrations. None.

LAUNCH VEHICLE STRUCTURES

Structural Loads

A. Wind Induced Oscillations

Submitted by
(Technical Supervisor)

James C. Young
R-AERO-AUE, 876-1611

1. Project Data

Contract Number: NAS 8-5322, April 29, 1963 - December 29, 1963
Modification 1-4 December 29, 1963 - December 31, 1964

Contractor: Martin Company
Denver Division
Denver, Colorado

2. Purpose of Project. To develop a generalized design criterion to insure structural integrity of the Saturn boosters and various multi-stage launch vehicle configurations under wind-induced oscillations in the vertical launch position.

3. Technical Status. Since the last reporting period and the publication of the interim report under this contract, Martin Denver has updated their present methods to improve the accuracy, reliability, and range of application at generalized design criteria. As part of this process, they have extended the scope of work (in accordance with modification 2) to include the effects of changes in the spatial distribution, Mach number, and surface roughness to scale the wind tunnel results to full-scale parameters. It was anticipated that another series of Saturn V and Saturn IB wind tunnel test results would be available to Martin during this reporting period; however, unavoidable schedule slippage of the experimental program has prevented this. Negotiations are in progress for another modification to this contract. The scope of work will be expanded to include the analysis of the Saturn V and Saturn IB test results. Of course, the applicability of the design criteria generated under this contract cannot be assessed until full-scale tests have been performed.

4. Major Accomplishments. The design criteria for the Saturn, Block I and Block II vehicles, have been generated under this contract. An interim report was published covering all work done under this contract as of July 1964.

5. Problems. The ultimate proof of the applicability of the design criteria is a comparison of predicted and measured full-scale response. Until full-scale response measurements are obtained, the design criteria applicability is uncertain.

6. Future Plans. An extension of this contract is presently under negotiation. This modification will extend the completion date to December 31, 1965, and will expand the scope of work to cover the following:

a. analysis of the Saturn IB and Saturn V wind tunnel tests performed during the fall of 1964 and the spring of 1965,

b. effect of spoilers and adjacent structures,

c. effect of slosh modes,

d. response of full-scale Saturn vehicles to verify the adequacy of structural strength.

It is anticipated that upon completion of this modification this contract will be terminated.

7. Illustrations. None.

B. Evaluation of Spherical Balloon Aerodynamically Induced Motions

Submitted by
(Technical Supervisor)

James R. Scoggins
R-AERO-YE, 876-5645

1. Project Data

Contract Number: NAS 8-11140, March 6, 1964 - March 6, 1965

Contractor: Cornell Aeronautical Laboratory, Inc.
Buffalo, New York

2. Purpose of Project. The purpose of this contract is to evaluate aerodynamically induced motions of a spherical balloon wind sensor. This is to be done by tracking balloons of different sizes at supercritical and subcritical Reynolds numbers with a Doppler radar and comparing results obtained from each flight. Comparisons will also be made with the Jimsphere which is a rough balloon developed at MSFC for making detailed wind profile measurements. An assessment will be made of the aerodynamic properties of the Jimsphere.

3. Technical Status. Approximately 75 balloons have been flown and the resulting data have been reduced. Three configurations have been used; 1-meter and 2-meter diameter plain spheres and the 2-meter diameter Jimsphere. Data have been gathered for supercritical and subcritical Reynolds numbers.

4. Major Accomplishments. Comparisons have been made between induced motions from 1-meter and 2-meter diameter balloons at both subcritical and supercirtical Reynolds numbers, and these induced motions have been compared with the Jimsphere. Variance spectra have been computed, and it has been shown that the induced motions associated with the large balloons have larger amplitudes and longer wave lengths than those associated with the smaller balloons. It has also been shown that the Jimsphere experiences high frequency oscillations which are negligible when used as a wind sensor and tracked by the FPS-16 radar. The data reduction program being used at MSFC is adequate for reducing the FPS-16 radar data.

5. Problems. None.

6. Future Plans. Complete the final analyses and prepare the final report.

7. Illustrations. None.

C. Engineering Development of JIMSPHERE Wind Sensor

Submitted by
(Technical Supervisor)

James R. Scoggins
R-AERO-YE, 876-5645

1. Project Data

Contract Number: NAS 8-11158, February 27, 1964 - February 27, 1965

Contractor: G. T. Schjeldahl Company
Northfield, Minnesota

2. Purpose of Project. To develop a spherical balloon wind sensor for high resolution wind profile measurements to 20-km altitude and to determine its aerodynamic and response characteristics.

3. Technical Status. Eight different balloon configurations have been built and flown at Cape Kennedy. Tracking was accomplished by an FPS-16 radar. A balloon configuration has been chosen which provides highly accurate wind profile measurements. Apparent mass for the spherical balloon chosen has been determined by drop tests at the University of Minnesota under subcontract to G. T. Schjeldahl Company. Wind tunnel drag coefficients have been determined, and dynamic response analyses for the selected balloon have been conducted. Most of the analytical work has been completed and the final report is in preparation.

4. Major Accomplishments. A method of fabricating 2-meter diameter balloons using 1/2 mil mylar with roughness elements of various sizes and shapes was developed. This was done by a drape forming process. An accurate spherical balloon wind sensor has been developed and proven at Cape Kennedy, Florida.

5. Problems. None.

6. Future Plans. Unless some unexpected problems arise, there are no plans to pursue this work beyond the present effort. The purpose of the contract, that of developing an accurate wind sensor, has been accomplished.

7. Illustrations. None.

D. Critical Evaluation of Methods for Making High Resolution Wind Measurements

Submitted by
(Technical Supervisor)

1. Project Data

Contract Number: NAS 8-11286, June 30, 1964 - June 30, 1965

Contractor: Lockheed Aircraft Corporation
2555 North Hollywood Way
P. O. Box 551
Burbank, California

2. Purpose of Project. To perform a critical scientific and engineering evaluation of all known methods for measuring winds with high accuracy in the free atmosphere. This is a study contract rather than a development contract and will be done in three phases during a 12 month period.

3. Technical Status. A literature survey has been completed. Several companies which have proposed methods for measuring winds with high accuracy have been visited to gather pertinent information concerning these methods. A technical report covering phase 1 has been submitted. As a result of phase 1 work, several of the more promising systems were chosen for detailed analysis in phase 2. The systems chosen for further analysis include the use of sound, smoke trails, Doppler radar, shearsonde, balloon, and chaff methods.

4. Major Accomplishments. Thus far the study has eliminated several proposed techniques because of engineering and/or scientific limitations. These will not be considered further.

5. Problems. None.

6. Future Plans. Each of the methods which have been chosen for further study will be analyzed in detail from both a scientific and an engineering point of view. Each system will be rigorously evaluated to determine their limitations and capabilities.

7. Illustrations. None.

E. Analysis of Variance with Correlated Variables and its Significance for Meteorological Statistics

Submitted by
(Technical Supervisor)

Orvel E. Smith
R-AERO-YT, 876-7580

1. Project Data

Contract Number: NAS 8-11175, March 23, 1964 - March 23, 1965

Contractor: The University of Georgia
Institute of Statistics
Athens, Georgia

2. Purpose of Project. The objective of this contract effor is to advance basic statistical principles applicable to problems encountered in the statistical treatment of geophysical data. Statistical data samples will be examined to determine the distribution form and to postulate the causative effects which produce the distribution. It is recognized that atmospheric variables are related in a rather complex manner by physical processes, thus, producing correlations between sampling intervals; i.e., the variables are time dependent. Therefore, basic research will be performed to extend the techniques of the analysis of variance to include the conditions for correlated variables.

3. Technical Status. Two contract reports (a) "Estimation in Mixtures of Two Poisson Distributions," and (b) "Estimation in Mixtures of Two Expoential Distributions" are being combined into one report for publication as a NASA Technical Report. Specific examples have been computed to illustrate

the methodology and principles in the separation of mixed distributions of these types into their respective homogeneous distribution. The techniques for the computation of the parameters from a mixture of two normal distributions have also been derived.

In-house efforts have been devoted to devising techniques to compute the parameters for doubly truncated distributions.

4. Major Accomplishments. A statistical method using analysis of runs and conditional probabilities has been applied to sample data, i.e., the maximum winds in the 10-15-km layer. The conditional probabilities can be used to make deterministic predictions.

5. Problems. None.

6. Future Plans. Publication of technical reports mentioned in the paragraph above on technical status. Pursue analysis of runs and conditional probabilities to include computation procedures to derive confidence limits on the conditional probabilities.

7. Illustrations. None.

Structural Dynamics

A. Sound Transmission Loss of Structures and Materials at Low Frequency

Submitted by
(Technical Supervisor)

J. H. Farrow
R-P&VE-SV, 842-3540

1. Project Data

Contract Number: NAS 8-11217, June 30, 1964 - June 30, 1965

Contractor: Wyle Laboratories
Huntsville, Alabama

2. Purpose of Project. Supplement the present state of art in mid-frequency transmission loss by both analytical and experimental work in determining the sound transmission loss of structures and material at low frequencies. Provide design and damage criteria for ground support equipment and structure.

3. Technical Status. Literature survey is almost complete and evaluation of the published data on rocket noise effects on window glass breakage and damage to structural walls is in progress.

4. Major Accomplishments. Planning and start of construction of a large reverberant room for sonic fatigue testing of industrial and residential walls which will include a complete 4-room 20 by 20 foot structure.

5. Problems. Major problem is the delay in starting construction of test facilities.

6. Future Plans. Conduct subjective loudness tests at low frequencies to determine annoyance criteria for personnel who are exposed to large vehicle rocket noise.

7. Illustrations. None.

B. Axial Transmissibility Characteristics of Typical Rocket Vehicle Structures

Submitted by
(Technical Supervisor)

J. H. Farrow
R-P&VE-SV, 876-3540

1. Project Data

Contract Number: NAS8-11162, June 30, 1964 - June 30, 1965

Contractor: Space and Information Division, NAA
Downey, California

2. Purpose of Project. To obtain basic information concerning the propagation of transient mechanical energy through typical space vehicle structure. This information is needed to support the definition of transient environments at critical locations on Saturn structure.

3. Technical Status. Model testing will commence in February 1965.

4. Major Accomplishments. Model design has been completed and approved, and model fabrication is near completion. Mode shapes and natural frequencies have been computed for first seven modes of simplest model.

5. Problems. Difficulties were encountered in specimen fabrication due to space limitations. This problem has been satisfactorily resolved.

6. Future Plans. The test phase is about to begin. Major effort will be directed towards correlating analytical predictions with measured response.

7. Illustrations. None.

C. Correlation of Random and Sinusoidal Vibrations

Submitted by
(Technical Supervisor)

J. H. Farrow
R-P&VE-SV, 842-3540

1. Project Data

Contract Number: NAS 8-2504, July 1, 1964 - January 1, 1965
June 30, 1961 - December 30, 1965

Contractor: Massachusetts Institute of Technology
Cambridge, Massachusetts

2. Purpose of Project. To study the basic vibration problem with the objective being to determine what is the relationship between sinusoidal and random vibration for certain conditions.

3. Technical Status. This is a four year program. Efforts for the past two years have been directed toward the understanding of material damping and its scaling. Experiments with cantilever beams of various materials both in and outside of a vacuum have shown that for stress levels below the stress sensitivity, the principal non-linear element is the effect of air damping. For higher stress levels the material damping indicates a degree of nonlinearity but generally less than have been expected. Verification of Crandall scaling theory is being abandoned by this contract at present to concentrate on the measure of material damping for systems in other modes of vibration. The facilities for performing these tests are in final stages of design.

4. Major Accomplishments. An experimental program has been established and work is continuing in the experimental verification of the theoretical material damping laws.

5. Problems. There were no significant problems during the reporting period.

6. Future Plans. To continue the program in conjunction with the California Institute of Technology contract, NAS8-2451.

7. Illustrations. None.

D. Study on the Failure of Equipment Due to Vibration

Submitted by
(Technical Supervisor)

J. H. Farrow
R-P&VE-SV, 842-3540

1. Project Data

Contract Number: NAS 8-2451, July 1, 1964 - January 1, 1965
July 10, 1964 - November 9, 1965

Contractor: California Institute of Technology
Pasadena, California

2. Purpose of Project. To determine failure mechanisms associated with certain types of equipment and then to study how these react to various types of forcing functions, i.e., random and sinusoidal vibrations.

3. Technical Status. The investigation is into the feasibility of cataloging equipment failures under a variety of types of vibration environments, and to determine whether a similar failure is or can be induced by both sine and random vibrations. To date the investigation has been carried out on a 12AU7 vacuum tube. The results indicated that for this particular equipment it was not possible to predict the mode of malfunction or failure, nor was there any correlation which could be determined between different environments. Work is continuing on at least two other equipment items; a relay, and one other, possibly a thyratron.

4. Major Accomplishments. Some relationships have been worked out which relate specific vibration motion within vacuum tubes to the electrical output. The harmonics and subharmonics presented in the response of certain tubes indicated pronounced nonlinearities of structures.

5. Problems. Tests on many tubes have shown a wide variation from tube to tube, and a nonreproducibility of results with any tube. Because of the nonreproducibility of the results, it is believed that further work on this particular component may be unproductive.

6. Future Plans. Plans are to continue the program in conjunction with the MIT NAS 8-2504 program for the purpose of improving on vibration specification and testing criteria.

7. Illustrations. None.

E. Exploratory Studies and Analysis of the Problem of Buckling of Cylindrical Shells with Inclined Stiffeners

Submitted by
(Technical Supervisor)

Larry D. Salter
R-P&VE-SSV, 842-3564

1. Project Data

Contract Number: NAS 8-5324, June 14, 1963 - August 14, 1964
Extended to December 31, 1964

Contractor: University of Florida,
Gainesville, Florida

2. Purpose of Project. Conduct an investigation to provide a clear analytical approach for the determination of stress distributions and deflections for cylindrical shells, pressurized and unpressurized with integral waffle-like oblique stiffeners, including the 0-90 case, and with or without similar circumferential and longitudinal stiffeners, considered together and separately.

3. Technical Status.

a. Existing literature has been surveyed.

b. Fundamental equations for a thin elastic shell were derived.

c. Potential energy relations for discretely inclined stiffened cylinders were derived.

d. Expressions for the energies of a cylindrical shell under axial compression have been obtained.

e. Numerical calculations were performed to determined the minimum axial compression versus internal pressure in a cylindrical shell. (45° stiffeners).

f. Equations have been derived for instability of stiffened cylinders under bending.

g. Axial compression and bending tests were performed with cylinders made of Du Pont mylar material. The cylinders were 8 inches in diameter, 9 to 18 inches long and .0075 inches thick. Mylar tape, 3/16 inches wide, was used for stiffeners on the various cylinders inclined at angles of 30 degrees, 45 degrees, 60 degrees, or 0 degrees to 90 degrees with the generator of the cylinders.

h. Equations were derived for buckling of a cylindrical shell under transverse shear load.

4. Major Accomplishments. See technical status.

5. Problems. No major problems indicated.

6. Future Plans. Correlate test data with theory and submit final reports, which will consist of nondimensional design curves and automatic computer programs.

7. Illustrations. None.

F. Monocoque Bulkhead Hoop Compression

Submitted by
(Technical Supervisor)

Lester Katz
R-P&VE-SSM, 842-3563

1. Project Data

Contract Number: Not Applicable

Contractor: MSFC In-house

2. Purpose of Project. Stability data will be obtained to be used in the theoretical analysis of Saturn V flight bulkheads. The buckling phenomenon being investigated occurs in the circumferential or hoop direction, and is caused by the loads applied to the bulkhead by propellant weight, acceleration, and pressure.

3. Technical Status. A group of twelve aluminum bulkheads have been fabricated. The bulkheads are ellipsoids of revolution and are separated geometrically into four groups of three each, (Fig. 57),with ratios of a/b = 1, 1.2, 2, 1.5, respectively, (where a and b are the major and semi-minor axes of the ellipsoid). The bulkheads will be exposed to inertial forces by the use of a heavy duty centrifuge which will spin the bulkheads filled with varying levels of fluid. Remote controls for photographic coverage as well as stress measurements have been completed.

4. Major Accomplishments. All the specimens have been instrumented with strain gages; coordinate axes have been marked on each specimen for photographic coverage, and preliminary runs on the centrifuge have been completed.

5. Problems. The speed control of the centrifuge has too much tolerance (governor hunting) and will be repaired prior to the start of testing. The portable data acquisition system which was assigned to this test has been removed and loaned to The Boeing Co.

6. Future Plans. To continue test to completion and to write reports covering results of the tests.

7. Illustrations. Figure 57.

SPECIMEN NUMBER	b (in.)	a/b	FLUID HEIGHT (in.)	FLUID SPECIFIC GRAVITY	PERCENT FILLED (By Height)
1A	17.500	1.0	17.500	1.0	100
1B	17.500	1.0	14.000	1.0	80
1C	17.500	1.0	12.250	1.2	70
2A	14.583	1.2	14.583	1.0	100
2B	14.583	1.2	11.667	1.2	80
2C	14.583	1.2	10.208	1.6	70
3A	12.376	$\sqrt{2}$	12.376	1.0	100
3B	12.376	$\sqrt{2}$	9.901	1.6	80
3C	12.376	$\sqrt{2}$	8.663	1.8	70
4A	11.667	1.5	11.667	1.2	100
4B	11.667	1.5	9.334	1.6	80
4C	11.667	1.5	8.167	1.8	70

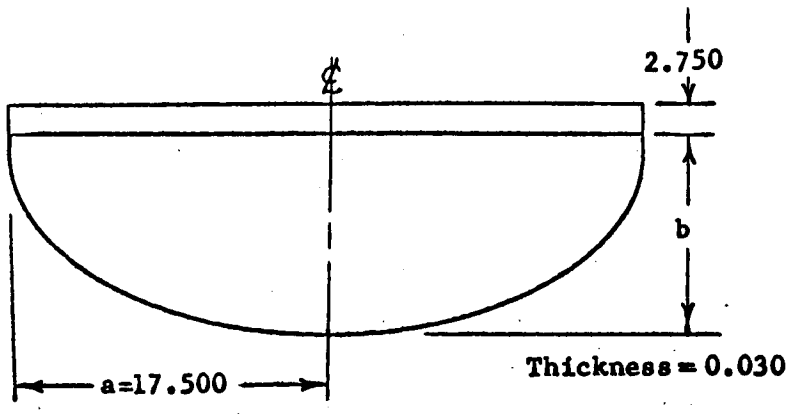


FIGURE 57. SPECIMEN GEOMETRY AND LIQUID-FILL CONDITIONS

G. Theoretical Research on the Pressure Distribution on Non-Spinning Multi-Stage Spacecraft Performing Bending Oscillations

Submitted by
(Technical Supervisor)

Dr. M. F. Platzer
R-AERO-AUU, 876-8063

1. Project Data

Contract Number:	NAS8-873, March 20, 1961 - March 20, 1962
Modification 1	March 20, 1962 - March 20, 1963
Modification 2	March 20, 1963 - March 20, 1964
Modification 3	March 20, 1964 - March 20, 1965

Contractor: Massachusetts Institute of Technology
Fluid Dynamics Research Laboratory

2. Purpose of Project. Perform theoretical research on unsteady airloads of flared, multi-stage boosters and present numerical examples for these configurations.

3. Technical Status. A small perturbation method has been formulated and programmed for predicting the unsteady load distribution due to lateral oscillations of an axisymmetrical body in supersonic flow setting out from a steady flow field which is determined by the method of characteristics.

4. Major Accomplishments. The work on the oscillating cone, as reported in the last progress report, has been completed and a final report has been prepared. Starting out with the nonlinear solution of the basic flow field around a cone, the perturbations which are expressed in terms of a double series are superimposed. By means of linearization, a system of recurring simultaneous linear differential equations for the perturbations has been outlined. Numerical solution of these equations gives the result for the unsteady flow field. This procedure is completely formulated and programmed.

The derivation of the formulation for the method of characteristics for general bodies as applied to the case of unsteady flow has continued. In order to make the formulations more tractable in connection with the formulations given

by Ferri (NACA Report 1044), the same variables were used in the development. The formulations were carefully rederived in the same order as those given by Ferri. Additional auxiliary relations were also developed.

5. Problems. None.

6. Future Plans. Theoretical research of unsteady airloads on elongated sharp-nosed and blunt-nosed bodies in supersonic flow will continue. Current research is focused on the small perturbation technique setting out from a steady flow field which is determined by the method of characteristics. Emphasis will be placed on flared, multi-stage boosters and programming of the procedure will be completed. Special consideration shall be given to the study of shock formations due to the discontinuous changes in meridian profile. These investigations will be illustrated by numerical examples. Furthermore, the feasibility of using the method of characteristics for three-dimensional bodies is to be investigated.

7. Illustrations. None.

H. Environmental Research

Submitted by
(Technical Supervisor)

Gilbert A. Wilhold
R-AERO-AU, 876-0962

1. Project Data

Contract Number: NAS 8-11312, June 30, 1964 - June 30, 1965

Contractor: Wyle Laboratories,
Huntsville Division
Huntsville, Alabama

2. Purpose of Project. The purpose of this task is to achieve a better understanding of the basic noise generation mechanisms associated with rocket exhaust flows and, with this understanding, develop adequate prediction techniques for the definition of the noise environment.

3. Technical Status. An experiment has been designed to measure the simulated mean flow profiles of a hot, high velocity jet. This experiment

will utilize a high temperature helium undeflected jet. Mean flow profiles of temperature, velocity, and density will be made at various axial locations down-stream of the jet nozzle.

Experimental parameters have been defined and instrumentation requirements have been generated. These requirements are all thought to be within the realm of present day instrumentation systems. The helium jet nozzle design has been completed and the nozzle is being fabricated. The experiment will be conducted at the experimental facility of the Aero-Astrodynamic Laboratory.

4. Major Accomplishments. None.

5. Problems. The above experiment requires a large capacity gas heater which had to be ordered. It has been extremely difficult to obtain a suitable heater.

6. Future Plans. The first phase of this program is to arrive at mean or average flow profiles of high velocity, high temperature jet flows. However, the ultimate goal is to study the fluctuation of the flow profiles about these mean values. It is these fluctuations which create the major noise generating sources of the jet.

The instrumentation techniques for measuring these fluctuations are currently being studied. This has resulted in a document on hot wire anemometry. Another method under consideration is an optical cross correlation technique which is presently being developed.

7. Illustrations. None.

I. Fuel Sloshing Studies

Submitted by
(Technical Supervisor)

G. F. McDonough
R-AERO-DDS, 876-6895

1. Project Data

Contract Number: NAS 8-1555, March 25, 1961 - June 30, 1965

Contractor: Southwest Research Institute
8500 Culebra Road
San Antonio, Texas

2. Purpose of Project. Perform experiments in forced oscillation on cylindrical tanks with various baffle configurations to investigate the effects of baffle location, width, spacing and perforation; determine baffle efficiency in terms of damping versus weight. Investigate quarter tanks, eighth tanks and spherical tanks. Extensions were made to this study to include liquid impact in space vehicle tanks, pressure distribution on various baffle configurations for optimum design, and experimental investigations of damping coefficients for mechanical models of fuel sloshing.

3. Technical Status. The work on liquid impact was completed early in the period and reported. Equipment development for experimental determination of pressures on ring baffles was completed and testing begun with first results being obtained late in the six-month period. Test equipment for experiments to determine damping coefficients for mechanical modes is in the final stages of development. First results will be obtained early in the next period.

4. Major Accomplishments. A technical report entitled, "An Exploratory Study of Simulation of Liquid Impact in Space Vehicle and Booster Tanks," by John F. Dalzall achievement in defining the role which experiment can play in determining the effects of liquid impact.

5. Problems. None.

6. Future Plans. Experimental determination of liquid pressure baffles will be the chief effort of the next report period. Optimum presentation of the data in dimensionless form will be pursued as well as correlation with theoretical analysis. Tests to determine damping coefficients for mechanical models will be completed and reported.

7. Illustrations. None.

J. Study of the Natural Vibration Modes and Frequencies of Space Vehicles

Submitted by
(Technical Supervisor)

G. H. McDonough
R-AERO-DDS, 876-6895

1. Project Data

Contract Number: NAS 8-2646, February 19, 1963 - May 29, 1965

Contractor: Republic Aviation Corporation
Farmingdale, N. Y.

2. Purpose of Project. Vibrational analyses of highly redundant structures, such as clustered space vehicles of the Saturn type, generally utilize greatly idealized models. It is important that the degree of idealization be reduced to decrease the uncertainty of results. The purpose of this project is to perform a more realistic analysis by treating sub-structures separately, in great detail, then combining these parts into a total vehicle response by applying equilibrium and compatibility conditions. The key to successful accomplishment of this is the proper choice of the separate elements to be studied. Then a digital computer program must be developed which is capable of calculating the modes and frequencies from these relationships.

3. Technical Status. Optimization of the computer program to handle 144 mass points and 352 degrees of freedom on the IBM 7094 computer has been completed and checked out. First results have been obtained for the Saturn I SA-5 vehicle; these results include all slosh modes and structural modes below 10 cycles per second. These results indicated that a better description of part of the vehicle structure was required; therefore, some improvements in the description are being made. Final results will be available in the next report period. For comparison with SA-5 results, another Saturn I configuration is being analyzed, the SA-8 vehicle. These results, together with the comparison between these and the SA-5 results, will be published in the next report period.

4. Major Accomplishments. Study of the structural details of the Saturn I vehicles has produced greatly improved understanding of the vibration characteristics of these vehicles. Study of the optimization of large computer capabilities to solve more complex problems in shorter time.

5. Problems. Optimization of the computer program has had only limited success in making practical the use of a program which has such a large amount of structural detail.

6. Future Plans. It is expected that the project will have accomplished its purpose by the end of the next report period. No plans for continuation beyond this period are being made.

7. Illustrations. None.

K. The Investigation of the Effects of Longitudinal Vibrations on the Structural Performance of Large Rocket Boosters

Submitted by
(Technical Supervisor)

George F. McDonough
R-AERO-DDS, 876-6895

1. Project Data

Contract Number: NAS 8-11255, May 25, 1964 - February 25, 1965

Contractor: Northrop Corporation
Northrop Space Laboratories
Huntsville, Alabama

2. Puprose of Project. To conduct a parameter study of free-free beams and shells under combined longitudinal and lateral excitation. The longitudinal excitation will consist of a steady-state and a periodic time-varying thrust applied axially; the lateral excitation will be that produced by a simple feedback control system which provides the structure with directional stability as a rigid beam.

3. Technical Status. Two beam configurations have been analyzed: a uniform beam with damping and a composite stepped beam with damping. A limited parameter study has been conducted to determine stability boundaries. The formulation of the cylinder problem has been completed and programmed for computer solution.

4. Major Accomplishments. Two major reports have been prepared for publication: "Influence of Damping and Initial Conditions Upon the Dynamics Stability of a Uniform Free-Free Beam Under a Gimbaled Thrust of Periodically Varying Magnitude," by J. Kincaid, D. Ulbrich, and C. Pearson, and "Response of a Circular Cylindrical Shell to a Gimbaled Periodically Varying End Thrust," by J. Hill, C. Pearson, and D. Ulbrich. These reports describe the analyses and the formulation of the two problems. Numerical results which have been obtained will be present in later reports.

5. Problems. None.

6. Future Plans. Major efforts will be made on stepped beams and cylinders. In addition, more complex structural characteristics and control systems will be studied.

7. Illustrations. None.

Structural Mechanics

A. Study of the Stability of Reinforced Cylindrical and Conical Shells Subjected to Various Types and Combinations of Loads

Submitted by
(Technical Supervisor)

Lester Katz
R-P&VE-SSM, 842-3563

1. Project Data

Contract Number: NAS 8-5168, October 15, 1962 - October 14, 1963
(No-Cost Extension to December 14, 1963
Second No-Cost Extension to January 14, 1964)
NAS 8-11155, March 21, 1964 - May 20, 1965
(This contract serves to continue the effort started under contract NAS 8-5168)

Contractor: Board of Trustees of the University of Alabama
University, Alabama

2. Purpose of Project. The work to be performed shall consist of conducting theoretical and experimental research into the problems of strength and stability analysis of stiffened cylindrical and conical shells. The objective of the program is to provide analytical procedures, design data, and computer programs which may be included in a vehicle structures handbook.

3. Technical Status. Work is progressing in the following areas:

a. Cones

(1) Asymptotic solution of a conical shell of constant thickness subjected to lateral normal loads.

(2) Computer program for membrane stresses in a conical segment subjected to thermal loads, and a complete cone subjected to unit moment.

b. Experimental Buckling Data: monocoque cylinders constructed of cellulose acetate have been internally pressurized and then buckled by uniform load in the axial direction.

c. Shear-Lag Studies: three flat panels (B, C, and D) with seven longitudinal stringers each have been instrumented with strain gages. Each panel is constructed with different values of the ratio of stiffener area to panel area. Testing of panel C has been completed; testing of panel B is 90 percent complete; while panel D has not yet been tested. The computer program which will incorporate the test results is complete. In addition, a survey of current literature in the subject field was continued.

4. Major Accomplishments. Of the three phases of work reported in paragraph 3 under (a) Cones, (b) Experimental Buckling Data and (c) Shear-Lag studies, phases (a) and (c) appear to show the most promising results. If the current rate of progress is maintained, all three phases should be completed by the contract termination date.

5. Problems. The problems encountered during the current report period were primarily in the experimental aspects of the investigation, such as difficulties with instrumentation, and uniformity of loading. These problems are being resolved.

6. Future Plans. The existing effort will be carried to completion. A follow-on effort will be attempted, contingent on the availability of funds, to obtain an analytic solution for orthotropically stiffened cones under load, and for further investigations of the shear-lag problem as applied to panels with tapered stiffeners, cutouts, and stiffened panels transmitting load to an elastic foundation.

7. Illustrations. None.

B. Elastic Behavior of Sandwich Shells

Submitted by
(Technical Supervisor)

C. J. Bianca, Jr.
R-P&VE-SSV, 842-3564

1. Project Data

Contract Number: NAS 8-5255, March 20, 1963 - March 19, 1964
No-cost Extension to September 30, 1964
No-cost Extension to March 15, 1965

Contractor: The Board of Control
University of Florida
Gainsville, Florida

2. Purpose of Project. To conduct an investigation of various bulkhead configurations fabricated from sandwich material and subjected to external pressure and temperature gradients to provide an analytical approach to an effective and technically significant solution of the stresses, deflections, and load deflection characteristics with a view towards determination of load-carrying capacities.

Develope non-dimensional curves, formulate explicit equations and establish digital computer programs to aid in determination of face stresses and critical buckling pressures for spherical, hemispherical, torispherical, and ellipsoidal bulkheads with simply supported, fully fixed, and half fixed edge conditions.

3. Technical Status. FORTRAN digital computer programs and equations for the determination of face stresses for the spherical, hemispherical, torispherical, and ellipsoidal sandwich bulkheads subjected to temperature gradients and external pressures and having the required end fixities have been completed.

4. Major Accomplishments. Non-dimensional design curves for face stresses in the spherical and ellipsoidal sandwich bulkhead configurations have been developed and verified.

5. Problems. None.

6. Future Plans. None.

7. Illustrations. None.

Structural Fabrication Techniques

A. Development of Technology Using Composite Sandwich Structures

Submitted by
(Technical Supervisor)

E. L. Brown
R-ME-MM, 876-1917

1. Project Data

Contract Number: Not Applicable

Contractor: Not Applicable, MSFC In-House

2. Purpose of Project. To establish a working knowledge of equipment capability, manufacturing process requirements and limitations, and to gain experience in the field of honeycomb bonding.

3. Technical Status. An Engineering Project for an "Adhesive Degradation Study" was issued and is 75 percent complete. This study will determine the feasibility of using bonded "break-away" brackets as welding holding fixtures. An Engineering Project to develop bonding techniques for beryllium and titanium was issued and is in progress. A project to develop a honeycomb sandwich joint, liquid cooled during welding, was issued and preliminary welding studies were completed.

4. Major Accomplishments. None.

5. Problems. None.

6. Future Plans. To continue development of techniques for utilizing composite sandwich structures in space vehicle stages with emphasis on lighter and stronger materials.

7. Illustrations. None.

SPACE VEHICLE DESIGN CRITERIA

Environmental Criteria

A. Design Criteria for Theoretical and Experimental Dynamic Analysis

Submitted by
(Technical Supervisor)

Robert Ryan
R-AERO-DD, 876-6895

1. Project Data

Contract Number: NAS 8-11486, October 15, 1964 - October 15, 1966

Contractor: General Dynamics/Astronautics
San Diego, California

2. Purpose of Project. To prepare a series of monographs on various topics in the field of control dynamics. These will be of a tutorial nature and will describe most of the available techniques of analysis in each area of dynamics as well as giving detailed examples using one or two preferred methods. In addition, the type and quality of input data for each area will be evaluated. Complete documentation of all methods and data will be made by means of an annotated bibliography. Major areas of effort include stability, liquid slosh, control, dynamic testing (component, full-scale and model), and wind response.

3. Technical Status. Since this began late in October, mostly exploratory effort has been expended to date. This includes setting the format of the monographs as well as determining order of precedence in writing a rough draft of the first monograph, which describes the analysis of vehicle bending characteristics for stability and control.

4. Major Accomplishments. None.

5. Problems. None.

6. Future Plans. Each monograph will be revised periodically as new and better data and analytical or experimental techniques become available.

7. Illustrations. None.

B. Environmental Design Criteria

Submitted by
(Technical Supervisor)

Orvel E. Smith
R-AERO-YT, 876-7580

J. David Lifsey
R-AERO-YT, 876-8657

1. Project Data

Contract Number: H-66040, December 1, 1963 - December 1, 1964

Contractor: National Weather Records Center
Asheville, North Carolina

2. Purpose of Project. The purpose of this task is the study, analysis, and presentation of natural environmental data for use in space vehicle design studies. Efforts are directed toward the definition and presentation of definitive values of atmospheric variables applicable to the design and operational problems of large launch vehicles. This task also provides for the direct support of the NASA Environmental Criteria Subcommittee efforts under the supervision of OART.

3. Technical Status. The Government Order with the National Weather Records Center has provided data records for simultaneous extreme profiles of temperature, pressure, and density, "exposure period" statistics for surface winds, statistics of solar radiation, analysis of vertical wind shear, and updating of serially completion of winds aloft data, and interparameter relationships between wind and temperature near the ground.

4. Major Accomplishments. As a result of this effort and in-house efforts, the statistics for daily peak surface winds have been derived. These statistics are summarized in Technical Memorandum, NASA TM X-63116, "An Empirical Analysis of Daily Peak Surface Wind at Cape Kennedy, Florida, for Project Apollo." It is in this publication that the concept of "exposure" period statistics is advanced. Such statistics have important applications for vehicle design studies and operations.

5. Problems. None.

6. Future Plans. The computation and analysis of several atmospheric variables taken simultaneous in the form of two and three-way frequency distributions will continue. An analysis of exposure period statistics for maximum winds in the 10-15-km layer will continue to completion.

7. Illustrations. An example of exposure period probabilities for February daily peak wind for Cape Kennedy is shown in the following graph (Fig. 58).

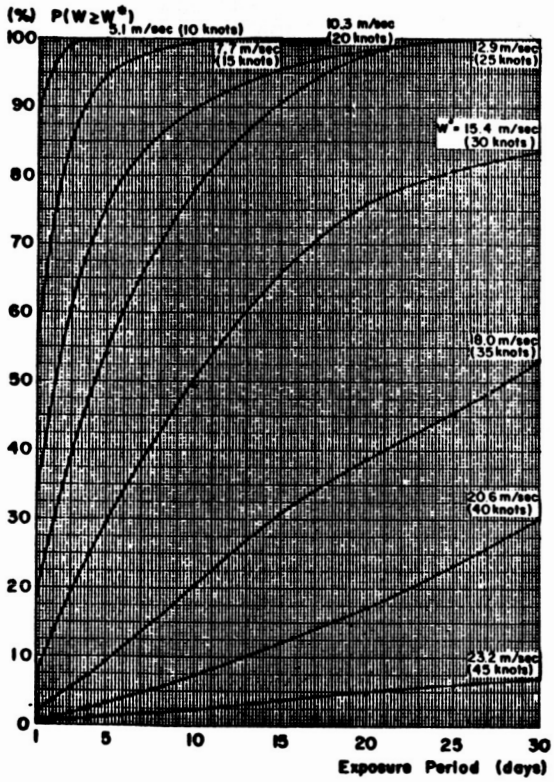


FIGURE 58. JANUARY (434 OBSERVATIONS)

The abscissa values are consecutive days of exposure (e.g., the number of days the Apollo is exposed to the natural forces of wind during launch countdown) and refer to exposure periods beginning on any day of the indicated calendar period. Ordinate values $P(W \geq W^*)$ give the percentage probability (percentage relative frequency that during exposure period a daily peak wind speed (W) will equal or exceed the value (W^*) specified by one of the curves.)

These statistics have been diversified for monthly, seasonal and annual reference periods.

C. Formulation of Space Environment Criteria

Submitted by
(Technical Supervisor)

R. E. Smith
R-AERO-YS, 876-6847

1. Project Data

Contract Number: NAS 8-11285, June 30, 1964 - July 31, 1965

Contractor: Aerojet General Corporation
Azuza, California

2. Purpose of Project. To determine desirable reliability limits for those natural space environment parameters either currently required or for which a requirement is anticipated for future application to problems associated primarily with the flight mechanics and aerodynamics aspects of space vehicle design. Natural space environment is defined as the environment not created by the vehicle in the region from 100 kolometers above the surface of the planets and the Moon. The results of this study will be used to aid in establishment of environmental design criteria. In addition, this project also provides for the direct support of the NASA Environmental Criteria Subcommittee efforts under the supervision of OART.

3. Technical Status. Work began in July and is progressing satisfactorily. A fairly extensive volume of documents has been collected.

4. Major Accomplishments. Data collected during Phase I have been separated into regions of interest, i.e., Mars, Venus, Moon, interplanetary space, etc., and then further subdivided into fields of interest; i.e., radiation, environment, meteoroid environment, atmosphere, surface conditions, etc.

5. Problems. None.

6. Future Plans. All references collected during Phase I will be listed in alphabetical order within these specific fields of interest in the bibliography which will terminate Phase I at the end of January 1965.

7. Illustrations. None.

D. Collection of Material Property Data and Presentation of Said Data in the Form of Material Data Handbooks

Submitted by
(Technical Supervisor)

M. G. Olsen
R-P&VE-MMJ, 876-8405

1. Project Data

Contract Number: NAS 8-1134, June 26, 1964 - June 26, 1965

Contractor: Syracuse University

2. Purpose of Project. The purpose of this project is to collect, analyze, and present technical data in a single source for 14 metal alloys in the form of data handbooks. In addition to mechanical and physical property values, information on the following will be collected and analyzed: stress-strain curves, heat treatment procedures, effect of radiation, vacuum and combined vacuum-solar environments on properties, resistance to corrosion in various media, surface treatments for various environments, alloy stability, forming and machining techniques, joining techniques, metallography and applicable specifications.

3. Technical Status. The collecting and screening of information on the alloys to be covered in the program is continuing. Responsibility for individual chapters of the material handbooks has been assigned to staff members and outside consultants. The preparation of the initial drafts for each alloy has been initiated. The development of programs for the storage and analysis of data by computer techniques will be continued.

4. Major Accomplishments. None to date.

5. Problems. None.

6. Future Plans. Data collection and analysis and preparation of material data handbooks will continue.

7. Illustrations. None.

E. Formulation of Structural Analysis Criteria

Submitted by
(Technical Supervisor)

James B. Sterett
R-P&VE-S, 842-2456

1. Project Data

Contract Number: NAS 8-11197, March 28, 1965

Contractor: Northrop Corporation,
Northrop Space Laboratories,
Huntsville, Alabama

2. Purpose of Project. Provide for development, preparation, editing and writing of Structural Analysis Criteria Monograph. Review existing literature for selection of most useful and important analytical procedures for strength analysis methods and review of completed documents to assure technical correctness and completeness.

3. Technical Status. A monograph of Launch Vehicle Structural Analysis Criteria is nearing completion. Sections covering the introduction to Launch Vehicle Structure and associated components, state of the art in structural analysis, development of design criteria, and recommended strength analysis procedures have been developed and are being evaluated.

4. Major Accomplishments. With the completion of the monograph a very comprehensive document will exist to aid the designer and strength analyst in the development of reliable and optimum Launch Vehicle Structures.

5. Problems. No problems indicated.

6. Future Plans. None concerning this contract activity.

7. Illustrations. None.

SECTION III. ELECTRONIC SYSTEMS PROGRAM

GUIDANCE SYSTEMS

System and Trajectory Analysis

A. Application of Calculus of Variations Theory to Problems of Performance and Guidance

Submitted by
(Technical Supervisor)

W. E. Miner
R-AERO-G, 876-3997

1. Project Data

Contract Number: NAS8-2619, March 14, 1962 - March 14, 1963

Modifications: (1) March 14, 1963 - June 30, 1963
(2) June 30, 1963 - December 31, 1963
(3) December 31, 1963 - December 31, 1964
(4) December 31, 1964 - December 31, 1965

Contractor: Vanderbilt University
Department of Mathematics
Nashville, Tennessee

2. Purpose of Project. To apply the classical theory of calculus of variations to problems of space vehicle performance and guidance and to advise other contractors on its usage.

3. Technical Status. During this reporting period Vanderbilt University worked on extending the work of Dr. Denbow to include constraints on control variables and inequality constraints. The theory for this extension is complete.

4. Major Accomplishments. The major accomplishment of this reporting period was that of extending the Denbow treatment of the problem of calculus of variations to include inequality and control variable constraints so that

it may be applied to the multistage vehicle problems such as Earth-to-Moon trajectories and reentry trajectories. This theory was presented to the contractor's conference and will be reported on in future progress reports.

5. Problems. None

6. Future Plans. Continuation of the study of trajectory optimization by means of calculus of variations. Specific area for investigation are as follows:

(a) Application of the Denbow multistage theory, extended to include control variables and inequality constraints, to the following:

(1) Optimization of Earth-Moon trajectories having a specified number of stages.

(2) Determination of switching functions for finding duration of coasting sub-arcs.

(3) Solution of reentry problems with inequality constraints such as on drag heat and altitude.

(b) Use of the Hamilton-Jacobi theory in determining one-stage optimum trajectories. Extension to multiple stages.

(c) Derivation of conjugate point conditions and their combination with other necessary conditions of calculus of variations to give sufficient conditions for optimum trajectories.

(d) Continued acceptance of special assignments in calculus of variations studies that may arise, including reviews of papers as requested by the project supervisor. Such reviews may be formal or informal as the situation requires.

7. Illustrations. None.

B. Methods of Fitting Multivariant Functional Models in the Area of Large Computer Exploitation

Submitted by
(Technical Supervisor)

W. E. Miner
R-AERO-G, 876-3997

1. Project Data

Contract Number: NAS8-5365, May 23, 1963 - November 22,1963

Modifications: (1) November 22, 1963 - July 22, 1964
(2) July 22, 1964 - January 23, 1965
(3) January 23, 1965 - July 23, 1965

Contractor: Georgia Institute of Technology
Georgia Tech Research Institute
Atlanta 13, Georgia

2. Purpose of Project. To develop methods for fitting multivariant functional models for guidance and mission criteria formulation and to investigate other uses of large computers for space flight and guidance theory.

3. Technical Status. Work is being done to establish procedures for a step-up process in the selection of a fixed number of estimation variables. The selection will be made from a larger number in obtaining functional approximation by the method of least squares and for the development of reasonable rules which will control the process of stopping the estimation variables selection procedure.

4. Major Accomplishments. Procedures for a step-up process have been developed and checked by empirical studies. The step-up process was used with checks on the previously selected vectors. Such checks on known functions indicate that while previously selected vectors may be discarded, they very soon return. Stopping rules have been considered using various statistical measures. Work will continue in this field.

5. Problems. None.

6. Future Plans. Work will continue in the same areas.

7. Illustrations. None.

C. Development of Methods for Large Computer Exploitation

Submitted by
(Technical Supervisor)

W. E. Miner
R-AERO-G, 876-3997

1. Project Data

Contract Number: NAS8-1528, March 1, 1961 - March 1, 1962

Modifications: (1) March 1, 1962 - June 30, 1962
(2) June 30, 1962 - January 31, 1963
(3) January 31, 1963 - September 30, 1963
(4) September 30, 1963 - September 30, 1964
(5) September 30, 1964 - August 15, 1965

Contractor: University of North Carolina
Chapel Hill, North Carolina

2. Purpose of Project. To develop methods of obtaining greater usage from large computers.

3. Technical Status. Work done during the period of this report at the University of North Carolina was confined primarily to work on computer algorithms for cancelling and collecting terms and factoring of algebraic functions. This contract has been terminated. The results of the investigations are given under Major Accomplishments.

4. Major Accomplishments. The work was extended to include the multiplying out of compound factors prior to simplification, complex variable transformation, and identification of a limited class of trigonometric transformations. Some of this work was applied to practical problems of classical celestial mechanics.

5. Problems. None.

6. Future Plans. Work will continue in the same areas.

7. Illustrations. None.

D. Developing Methods for Functional Model Development

Submitted by
(Technical Supervisor)

W. E. Miner
R-AERO-G, 876-3997

1. Project Data

Contract Number: NAS8-2642, May 1, 1962 - May 1, 1963

Modifications: (1) May 1, 1963 - May 1, 1964
(2) May 1, 1964 - February 1, 1965

Contractor: Northeast Louisiana State College
Monroe, Louisiana

2. Purpose of Project. To develop methods for developing functional models where least squares is the basis.

3. Technical Status. Studies were made of methods for deriving a given error tolerance on least squares functional models. One such method has been developed in detail.

4. Major Accomplishments. A method of developing a function $\varphi_{N+1}(\beta')$ has been developed. The error is defined by

$$E = \left\| \bar{\chi} - \sum_{i=0}^{n} A_i \bar{\varphi}_i \right\|^2$$

where the vectors $\bar{\chi}$ and $\bar{\varphi}_i$ have n components corresponding to the number of points used. This error is given a bound and a function φ_{n+1} is sought which brings the error under this bound.

5. Problems. None.

6. Future Plans. It is expected that the program will be completed within the contract period.

7. Illustrations. None.

E. Orbital Transfer and Guidance Studies

Submitted by
(Technical Supervisor)

W. E. Miner
R-AERO-G, 876-3997

1. Project Data

Contract Number: NAS8-1548, March 1, 1961 - March 1, 1962

Modifications:
(1) March 1, 1962 - June 1, 1962
(2) June 1, 1962 - October 31, 1962
(3) October 31, 1962 - June 31, 1963
(4) June 31, 1963 - November 31, 1963
(5) November 31, 1963 - January 31, 1964
(6) January 31, 1964 - January 31, 1965

Contractor: Auburn University
Mechanical Engineering Department
Auburn, Alabama

2. Purpose of Project. To use calculus of variation theory in developing special decks (computing equations outline) for such decks as propelled flight and reentry.

3. Technical Status. A procedure is being developed for optimizing a reentry trajectory for a vehicle with respect to the integral of the total deceleration squared, and under certain constraints imposed by a specific attitude control mode associated with a possible Apollo configuration where the trajectory is so constrained as not to exceed specified values of decelerations and altitude.

4. Major Accomplishments. Preliminary work has been done and the problem is now being reformulated using theory as presented in the paper "Extension of the Denbow Multistage Calculus of Variations Problem to Include Control Variables and Inequality Constraints," by D. M. Boyce and J. Linnsteader of Vanderbilt University.

5. Problems. Some problems have been encountered in establishing methods of satisfying transversality conditions at points of meeting constraints.

6. Future Plans.

a. Apply the principles of "classical mechanics" to develop methods for solving problems associated with space vehicles in the following areas:

(1) Optimized missile trajectories. Study methods for solving optimum three-dimensional reentry trajectories, utilizing a dual control variable, allowing only one degree of freedom at a time in the rotational state variables. Superpose final solutions to satisfy the cut-off equations in an optimum manner.

(2) Optimized steering equations. Study methods for developing the steering program needed by the vehicle at each instant of time in order to satisfy the cut-off equations in an optimum manner.

b. Devote time to conclusion of problems initiated under previous contract extensions.

The period of performance for this extension shall be for twelve months. Reports will continue to be submitted as in the past.

7. Illustrations. None.

F. Satellite Rendezvous and Orbit Transfer Studies

Submitted by
(Technical Supervisor)

W. E. Miner
R-AERO-G, 876-3997

1. Project Data

Contract Number: NAS8-5211, February 11, 1963 - March 11, 1964

Modifications: (1) March 11, 1964 - December 11, 1964
(2) December 11, 1964 - February 11, 1965

Contractor: North American Aviation, Inc.
Space and Information Systems Division
Downey, California

2. Purpose of Project. To investigate problems of optimum satellite rendezvous with particular emphasis on error analysis and guidance tradeoffs. New computer developments and techniques such as numerical optimization of multivariate functions, contour mapping, and symbolic manipulation will

be adapted to a variety of space flight problems. Specific trajectory analysis problems, especially those associated with path adaptive guidance, will be investigated.

3. Technical Status. During this reporting period two problems were investigated. A method was developed for the precise numerical determination of two-impulse orbital transfers and numerical, and analytical results concerning optimum one-impulse orbital transfer maneuvers were investigated.

4. Major Accomplishments. A numerical optimization technique termed "adaptive steepest descent" was developed to overcome convergence difficulties encountered with other less powerful methods. This optimization technique was used to make detailed studies of complicated impulse function spaces associated with various orbit pairs. The results of the one-impulse study indicated that there exists a limited range of shapes over which one-impulse transfer is optimal.

5. Problems. None.

6. Future Plans

a. Attempt solution of the minimum fuel finite thrust (fixed level) orbital transfer problem about a single attracting center. It is planned to make use of the technique of quasilinearization to solve the two-point boundary value problem that arises in the formulation of this problem (Ref. Jurovics in Progress Report No. 6). Ordinary search techniques already attempted on this sensitive problem have been found inadequate, while preliminary attempts with quasilinearization have shown promise. In any case, it is believed that the solution of the optimum impulsive transfer that is available will be essential for determining initial values of the multipliers. Quasilinearization differs from the more conventional techniques which generate solutions to the differential equations that have to be adjusted to meet the boundary conditions by utilizing functions that meet the boundary conditions, which functions are adjusted by linear procedures to satisfy the differential equations. Comparisons between finite thrust and the impulsive optimum transfers will be obtained.

b. Efforts will be made to improve significantly the accuracy of patched conic lunar trajectories by perturbing the Earth conic due to the effect of the Moon using power series development for the elliptical orbit elements. In those cases in which the trajectory passes near a Lagrangian point, additional accuracy is expected from the technique of joining the Earth and Moon centered conics with a section satisfying approximate equations of motion in the vicinity of this point. By this method, it is expected that one will be able to obtain rapidly on small computers moderately accurate lunar trajectories.

c. Assuming that the techniques proposed under (a) are successful, a similar approach will be undertaken to obtain minimum fuel finite thrust transfers between orbits in the three-body problem (two attracting centers). The individual impulsive transfers will be obtained in both the restricted and the unrestricted three-body problems by the quasilinearization technique. If the results of (a) indicate that the impulsive transfer results are not helpful in the finite case, other techniques will be sought for solving this problem.

7. Illustrations. None.

G. Orbital Transfer and Guidance Studies

Submitted by
(Technical Supervisor)

W. E. Miner
R-AERO-G, 876-3997

1. Project Data

Contract Number: NAS8-1549, March 28, 1961 - March 28, 1962

Modifications: (1) March 28, 1962 - March 28, 1963
(2) March 28, 1963 - April 28, 1963
(3) April 28, 1963 - September 28, 1963
(4) September 28, 1963 - December 31, 1964
(Contract amendment is in process.)

Contractor: Grumman Aircraft Engineering Corp.
Bethpage, L. I., New York

2. Purpose of Project. To develop theory for use in solving problems in orbital transfer and for implementing the adaptive guidance mode. Grumman Aircraft Engineering Corporation has been specializing in the area of direct methods of calculus of variations applied to low thrust trajectory calculations.

3. Technical Status. During reporting period, work has been done on interplanetary trajectories, geocentric low thrust trajectories, and geocentric high thrust orbital transfer. The work on the interplanetary trajectories was that of improving existing computer programs. The geocentric low thrust trajectories were computed for extended resolutions. The geocentric high thrust orbital transfers were computed by new numerical means.

4. Major Accomplishments. Ephermeris data for Jupiter and the Earth were added to the decks up to 2000 so that positions could be computed to an accuracy of seven significant figures. This is used in the interplanetary deck. A generalized Newton-Raphson method has been used for computing geocentric low and high thrust trajectories. Low thrust trajectories were computed for durations involving 21 to 26 revolutions depending upon the thrust-to-weight ratio. For longer duration, the accuracy was poor. A high thrust deck has been programmed with bounded control. Before it is used, certain modifications need to be made.

5. Problems. None.

6. Future Plans.

a. Develop capability to determine optimum interplanetary flyby trajectories which take into account the gravitation attraction of the terminal planet. Studies thus far have only considered the sun field.

b. Extend Earth-Mars studies so as to include tangential thrust spiral trajectories out to the sphere of influence followed by an optimum interplanetary portion and a spiral in maneuver inside the Mars sphere of influence.

c. Extend studies of geocentric very low thrust trajectories by converting state variables to slowly varying parameters using higher order numerical integration methods and to other missions; escape trajectories, elliptic-initial on terminal orbits, and plane changing.

7. Illustrations. None.

H. Analytical Tools for Guidance

Submitted by
(Technical Supervisor)

W. E. Miner
R-AERO-G, 876-3997

1. Project Data

Contract Number: NAS8-2600, February 27, 1962 - February 27, 1963

Contractor: General Electric Company
Space Sciences Laboratory
Valley Forge, Pennsylvania

2. Purpose of Project. Apply classical theory of calculus of variations to problems of trajectory calculation and to apply methods of classical astronomy to problems of free flight trajectory calculations.

3. Technical Status. Work done during the period of this report was in applying methods of classical astronomy to problems of free flight trajectory calculations for an Earth-Moon trajectory. This contract has been terminated. The results of the investigations are given under major accomplishments.

4. Major Accomplishments. The two variable method of Lagerstrom and Kevrokian was investigated for the computation of lunar trajectories. The solutions depend on quadratures which must be evaluated. The evaluation of these quadratures amy cause difficulties in the practical matter of computation.

5. Problems. None.

6. Future Plans. None.

7. Illustrations. None.

I. Direct Methods of Optimized Reentry to Establish Abort Conditions

Submitted by
(Technical Supervisor)

W. E. Miner
R-AERO-G, 876-3997

1. Project Data

Contract Number: NAS8-5225, February 11, 1963 - February 10, 1964

Modification: (1) February 10, 1964 - February 28, 1965

Contractor: Raytheon Company
Missile & Space Division
Bedford, Massachusetts

2. Purpose of Project. To establish limits on reentry at 120-km altitude, to establish aiming points for powered abort guidance.

3. Technical Status. During this reporting period the work emphasized the analytical study of considerations relating to the definition of reentry corridors for vehicles capable of both planar and three-dimensional maneuvers.

4. Major Accomplishments. The basic analytical formulation of the new technique for controlling the maximum skip altitude on optimum trajectories involving flight outside of the atmosphere following initial reentry has been completed. Analytical solutions of both the state and adjoint equations have been obtained for such flight, thus eliminating the need for point-by-point integration on long skip-out arcs.

5. Problems. None.

6. Future Plans. None.

7. Illustrations. None.

J. Investigation of Orbital Mechanics, Space Flight Theory and Numerical Analysis

Submitted by
(Technical Supervisor)

W. E. Miner
R-AERO-G, 876-3997

1. Project Data

Contract Number: NAS8-11241, May 25, 1964 - November 25, 1964

Contractor: Analytical Mechanics Associates, Inc.
Uniondale, New York

2. Purpose of Project. To develop procedures for implementing the path adaptive guidance mode. The implementation will include missions of orbital transfer, rendezvous, lunar, and planetary types. In particular, research will be made in the application of celestial mechanics to guidance and navigation logic and space flight theory, in the application of the calculus of

variations to the solution of minimum fuel problems in vehicle ascent, orbital transfer, and rendezvous problems, and in numerical methods in the solution of nonlinear differential equations.

3. Technical Status. This contract has been terminated. During the reporting period work was done on optimal guidance polynomial approximations by an ensemble-averaging approach.

4. Major Accomplishments. The results of this study are presented in a paper where the details are developed. Conclusions on the merits of this approach must be deferred until numerical examples of synthesis procedures have been worked and system simulations performed.

5. Problems. None.

6. Future Plans. None.

7. Illustrations. None.

K. Performance and Guidance Theory Studies

Submitted by
(Technical Supervisor)

W. E. Miner
R-AERO-G, 876-3997

1. Project Data

Contract Number: NAS8-2605, February 21, 1962 - December 21, 1962

Modifications (1 through 6): December 21, 1962 - October 22, 1964

Contractor: Republic Aviation Corporation
Applied Mathematics Section
Farmingdale, Long Island, New York

2. Purpose of Project. To apply methods of celestial mechanics and astronomy to solve problems of free flight space vehicle trajectories, to define mission criteria and to apply methods of classical calculus of variations to compute propelled flight trajectories.

3. Technical Status. Work was done on the Dirac formulation of a particular optimization problem that leads to a Hamiltonian and on deriving solutions for the motion of a satellite about a nonspherical Earth. This contract has been terminated. The results of the investigation are given under Major Accomplishments.

4. Major Accomplishments. The Hamiltonian developed from the Dirac formulation is one to which the Pontryagin Maximum Principle can be applied. This Hamiltonian has the property of being canonical in all its variables. The problem may, therefore, be treated by methods of celestial mechanics. Also, a first order solution to the Polar Oblateness problem was developed with six elements which are not degenerate for nearly circular orbits. It is interesting to observe that no critical angles occur in the second order solution, but that critical angles will appear in a third order solution.

5. Problems. None.

6. Future Plans. None.

7. Illustrations. None.

L. Docking Study

Submitted by
(Technical Supervisor)

W. E. Miner
R-AERO-G, 876-3997

1. Project Data

Contract Number: NAS8-5425, June 17, 1963 - June 17, 1964 (No report was made for the Jan 64 - June 64 period)

Contractor: The Bendix Corporation
Bendix Systems Division
Ann Arbor, Michigan

2. Purpose of Project. The analytical formulation of the optimum solution for docking with an Earth satellite is sought.

3. Technical Status. The formulation is based on the use of calculus of variations and includes the equations for traget and chaser motion. All equations are developed in three dimensions.

4. Major Accomplishments. The mathematical formulation of the docking problem was accomplished in two parts: (1) the derivation of the equations of motion for the target and chaser, and (2) the development of the Eular-Lagrange equations and the transversality conditions for the variational problem. This formulation is presented in the final report.

5. Problems. None.

6. Future Plans. None.

7. Illustrations. None.

M. Study for Purpose of Defining Navigation and Guidance System Requirements Peculiar to Lunar Surface Operations

Submitted by
(Technical Supervisor)

Mr. John W. Harden, Jr.
R-ASTR-AN, 842-2221

1. Project Data

Contract Number: NAS8-11292, June 6, 1964 - June 5, 1965

Contractor: Bendix Corporation
Bendix Systems Division
Ann Ardor, Michigan

2. Purpose of Project. To investigate the problems associated with navigation on the lunar surface in order to determine the technology advances required for accomplishment of lunar surface missions.

3. Technical Status. The contract is two-thirds complete. Two quarterly reports have been prepared and approved, and the third quarterly report is to be prepared shortly.

4. Major Accomplishments. A preliminary analysis of navigation system functional and accuracy requirements as applied to type II missions has been completed. The results indicate that some of these type missions are not feasible with state of the art equipment.

Error models for the position fix and dead reckoning subsystems required to implement the three system concepts have been completed.

Scientific mission tasks have been reviewed to derive tentative requirements for missions of type I, III, and IV.

5. Problems. Procurement of nevigation component data covering present and estimated state of the art up to 1980 has been complicated by security and proprietary interest problems. This affects only the point design in a specific system, however, because error models will be exercised using parametric error values.

6. Future Plans. To use the error models and dynamic program for determining the following:

a. Maximum allowable equipment errors consistent with minimal homing range requirements.

b. Maximum allowable physical uncertainties consistent with minimal homing range requirements.

c. Criticality of equipment and physical uncertainty errors.

d. Optimal (with constraints) error budget.

e. Selenographic constraints.

f. Concept tradeoffs.

g. Point designs.

A final report covering the complete study will be prepared.

7. Illustrations. None.

Inertial Sensors and Systems

A. Cryogenic Gyro (Project SPIN)

Submitted by
(Technical Supervisors)

Dr. W. Haeussermann
R-ASTR-DIR, 876-1642

Mr. Carl E. Winkler
R-ASTR-RS, 877-2168

1. Project Data

Contract Number: NAS8-2418, Mod. 13, June 29, 1961 - August 31, 1965

Contractor: General Electric Company
General Engineering Laboratory &
Advanced Technology Laboratory
Schenectady, New York

2. Purpose of Project. To design, fabricate and test an engineering model of a cryogenic gyro.

3. Technical Status. Since the constancy of gyro drift performance was repeatedly measured at approximately 0.005 degree per hour, despite lack of sufficient mounting stability of the gyro test stand, drift in the optical readout electronics,and mechanical distrubances in the cryostat resulting from batch transfer of liquid helium, it was decided to terminate testing until these conditions could be improved.

The redesign (Mark II) of the cryogenic gyro has been progressing during this six-month period. This has been directed toward the following improvements:

a. Use of a three-axis rotor bearing suspension system in which bearing forces can be varied during changing accelerations to maintain improved rotor centering within the bearing assembly.

b. Use of an optical readout system employing light emitting diodes and sensors which is attached directly to the gyro housing and operated at cryogenic temperatures.

c. Use of continuous liquid helium transfer to the cryostat to avoid mechanical and thermal disturbances to the gyro mounting.

d. Use of a smaller cryostat having greater gyro mounting stability and capable of operation in inclined and inverted positions.

e. Use of improved ambient magnetic field measuring probes capable of operation at cryogenic temperatures and of a size which is readily incorporated into the gyro assembly.

4. Major Accomplishments. This has been a period of design, fabrication and component evaluation effort. The completion of the Mark II gyro incorporating the above improvements will represent the next major accomplishment. Gyro drift performance will then be determined toward the latter part of 1965.

5. Problems. The non-sphericity of the rotors and the small unbalance still tends to cause occasional resonances during spin-up. This problem is under study and it is hoped that recently contrived techniques will improve the situation. Here, as in so many parts of this program, the state of the art is being pushed.

The major problem in project SPIN is the lack of adequate gyro testing facilities at Schenectady. This will be resolved, however, this year either by evaluating the Mark II gyro at some other G. E. installation or by the construction of stable facilities at Schenectady.

6. Future Plans. Tasks during the near future include the completion of the Mark II design studies and the manufacture of the gyro with its cryogenic optical readout system and improved cryostat.

By September 1, 1965, it is expected that the Mark II gyro will be ready for first systems check-out testing in preparation for drift performance tests.

Further into the future it now seems feasible to replace the present rotors manufactured from niobium bulk material with niobium coated ceramic rotors to obtain higher "g" capability.

7. Illustrations. None.

B. Analysis, Design, and Prototype Development of Squeeze Film Bearings for AB-5 Gyro

Submitted by
(Technical Supervisor)

Mr. Carl H. Mandel
R-ASTR-G, 876-5330

Mr. P. H. Broussard
R-ASTR-GCB, 876-2215

1. Project Data

Contract Number: NAS8-11678, June 18, 1964 - June 18, 1965

Contractor: Mechanical Technology Incorporated
968 Albany-Shaker Road
Latham, New York

2. Purpose of Project. Analysis of the squeeze film bearing application to the AB-5 Gas Bearing Gyro, and design, development and prototype fabrication of two AB-5 size squeeze film bearings complete with two power supplies.

3. Technical Status. Since July 1964, MTI has been working directly on the theory of squeeze film bearings. Bendix, under a subcontract with MTI, has been doing the preliminary fabrication of an AB-5 type squeeze film bearing.

Under this contract, MTI has developed a mathematical model of a squeeze film bearing of the AB-5 type. This model, developed from Reynolds lubrication equation, gives the stiffness and load carrying capacity of a squeeze film bearing. A temperature map, and the applicability of isothermal lubrication theory has also been presented by MTI. Bendix has studied strain-producing techniques, configuration design and analysis, and has performed preliminary experimentation.

4. Major Accomplishment. MTI has succeeded in characterizing the behavior of the gas in a squeeze film bearing, both thrust and journal. The result of this is the ability to calculate load carrying capacity and stiffness.

MTI and Bendix fabricated a squeeze film bearing in which the ceramic journal not only provides a squeeze film for the float but also generates a squeeze film to support itself.

5. Problems. No unusual problems have been encountered thus far.

6. Future Plans. The investigation should be extended to include prototype gyros with hydrodynamic spin axis bearing and squeeze film suspended gimbal axis.

7. Illustrations. None.

C. Design and Development of an Optical Servo Pickup

Submitted by
(Technical Supervisor)

Mr. Carl H. Mandel
R-ASTR-G, 876-5330

Mr. Irvin T. Morgan, Jr.
R-ASTR-GS, 876-4437

1. Project Data

Contract Number: NAS8-11517, Mod. 1, June 29, 1963 - April 30, 1964

Contractor: Razdow Laboratories, Inc.
Newark, New Jersey

2. Purpose of Project. The design and development of an optical pickup for measuring the position of a gyro output axis.

3. Technical Status. Contract NAS8-11517 expired April 30, 1964 without completion of a prototype optical pickup. Due to the indefinite status of the contract as to cost and time for completion, a contract supplement was not considered to be in the best interest of the Government. Evaluation of contract results to cutoff date has been delayed awaiting delivery of the residual hardware.

4. Major Accomplishment. None.

5. Problems. Contractor based requests for additional time and funds upon increases in evaluation and design time caused by vendor fabrication and delivery problems.

6. Future Plans. There are no future plans beyond evaluation of the residual hardware.

7. Illustration. None.

D. Gas Bearing Research

Submitted by
(Technical Supervisor)

Mr. Walter B. Panzer
R-ASTR-GC, 876-4437

Mr. P. H. Broussard, Jr.
R-ASTR-GCB, 876-2215

1. Project Data

Contract Number: H-22719, Amendment 3, December 6, 1961 - October 31, 1965

Contractor: Dept. of the Navy
Office of Naval Research
Washington 25, D. C.

2. Purpose of Project. To conduct studies and research investigations in the field of gas lubricated bearings for guidance system components.

3. Technical Status. Since April 1957, the Office of Naval Research has administered a program of research in the field of gas lubricated bearings. The research has covered externally pressurized bearings, hydrodynamic bearings, squeeze film bearings, and hybrid bearings.

4. Major Accomplishment. A major accomplishment of this report period is the receipt from Franklin Institute of a complete summary of all gas bearing work being done by seventy-four agencies. Twenty-four of these agencies are outside the continental United States.

5. Problems. None.

6. Future Plans. Continued emphasis on squeeze bearings is anticipated.

7. Illustrations. None.

E. Gas Bearing Research

Submitted by
(Technical Supervisor)

Mr. Walter B. Panzer
R-ASTR-GC, 876-4437

Mr. P. H. Broussard
R-ASTR-GCB, 876-2215

1. Project Data

Contract Number: Not Applicable

Contractor: In-House

2. Purpose of Project. To conduct studies and research investigations in the field of gas lubricated bearings for guidance system components.

3. Technical Status.

a. Squeeze Film Bearings - The principle of squeeze film bearings has been successfully demonstrated here. Several prototype bearings have been constructed and successfully operated. Work is currently centered around construction of a squeeze film bearing that will be suitable for gyro applications.

b. Squeeze Film-Hydrodynamic Bearings - Preliminary planning is being done on constructing a hybrid bearing that has its pressure generated by both a squeeze film and hydrodynamic film.

c. Hydrostatic Bearings - Mathematical models exist here which adequately describe the static behavior of our operational gas bearings. Research on mathematical models for hydrostatic bearings is proceeding at a slower pace.

d. General Projects - Support of the above projects necessarily entails several fields. Some of these are: vibration analysis (shock, sinusoidal, and random), analysis of vibrating systems (plates, beams, tubes, piezoelectric ceramics, etc.), deformation of materials, fluid mechanics, heat transfer, analysis of random data, etc.

e. Reduction of Torque in Operational Gas Bearings - A preliminary feasibility study has been started concerning the possibility of obtaining specular and diffuse reflections of gas molecules from bearing surfaces in order to reduce turbine torque.

f. A pendulum design to reduce the physical size of a gas bearing pendulum is being studied. One prototype which uses minature pressure transducers for sensing elements has been experimented with. Aim of this design is to produce a pendulum small enough to be mounted directly to the accelometer housing.

4. Major Accomplishment. We have perfected a technique for nickel plating piezoelectric ceramics of the lead zirconate titanate type. (Normal plating techniques leave a salt deposit.) We have successful techniques for grinding and drilling these ceramics.

We constructed, and have operating, a squeeze film bearing of the right circular cylinder type. i.e., the conventional journal-thrust plate type. This appears to be among the first of its type, if not the first, to be fabricated in this country.

In addition to a squeeze film spherical demonstrator, floating a steel ball weighing four pounds, we have fabricated a sherical demonstrator so constructed that the excursion of the ceramic is amplified by mechanical amplification. Excursion has a direct bearing on load carrying capacity.

5. Problems. The problems being encountered are considered normal to the stage of development.

6. Future Plans. Plans are to continue in-house research along the lines described in paragraph 3.

7. Illustrations. None.

F. Study for the Development of Accelerometer Test Methods

Submitted by
(Technical Supervisor)

Mr. Herman E. Thomason
R-ASTR-G, 876-1470

Mr. Billy J. Doran
R-ASTR-GC, 876-1670

1. Project Data

Contract Number: NAS8-11424, June 29, 1964 - June 29, 1965

Contractor: Dynamics Research Corporation
Stoneham, Massachusetts

2. Purpose of Project. To extend accelerometer test capabilities so that accelerometers now under development may be evaluated.

3. Technical Status. Work performed during this period consisted of the Pendulous Integrating Gyro Accelerometer equations of motion.

Effects studied were as follows:

a. Pendulous Integrating Gyro equations of motion.

b. Pendulous Integrating Gyro - Pendulous Integrating Gyro Accelerometer misalignment.

c. Pendulous Integrating Gyro Accelerometer Servo compliance errors.

Work has been started on a statistical design of experiments to measure Gyro Accelerometer misalignment, bias, and scale factors.

4. Major Accomplishment. The accomplishments for this period were as follows.

a. Application of linear regression techniques to the design of an experiment to measure accelerometer bias and scale factor.

b. Equations were developed for expressions for the estimate of bias and scale factor, for the standard error in the estimate of the accelerometer, output, and for the confidence interval for bias and scale factor.

5. Problems. The problems encountered to date are considered normal for the present stage of development.

6. Future Plans.

a. Continued work on procedure for determining gyro-accelerometer misalignment angle.

b. Work on the statistical design of experiments to measure accelerometer parameters.

c. Parameter sensitivity tests will be performed at MSFC.

7. Illustrations. None.

Active Electronics Devices and Systems

A. Jam-Resistant Secure FM Command Receivers

Submitted by
(Technical Supervisor)

Mr. H. R. Lowery
R-ASTR-IRC, 876-4388

1. Project Data

Contract Number: NAS8-2668, Mod. 7, April 19, 1962 - December 31, 1964

Contractor: Adcom, Inc.
808 Memorial Drive
Cambridge, Massachusetts

2. Purpose of Project. Classified Secret.

3. Technical Status. Operation of the basic concept has been demonstrated by an operating breadboard. Design criteria have been established. This study will be phased out within the next six to eight months.

4. Major Accomplishments. New design of receiver front end and various subassemblies within the receiver. (Details involve system classification.)

5. Problem Areas. Involve classified information.

6. Future Plans. Implementation of basic concept with hardware contract.

7. Illustrations. Classified.

B. Studies in the Theory and Application of Statistical Filter Theory to Selected Problems of Guidance, Control, and Navigation of Space Vehicles.

Submitted by
(Technical Supervisor)

Mr. C. R. MacCrone
R-ASTR-AC, 842-2227

1. Project Data

Contract Number: NAS8-11183, May 27, 1964 - July 27, 1965

Contractor: University of Tennessee
Knoxville, Tennessee

2. Purpose of Project. The purpose of the project is to conduct analytical studies in the field of advanced spaceborne navigation systems. The general objective of all the studies is to conduct analyses necessary to determine the basic requirements of systems capable of performing several NASA missions including manned lunar landing, manned Earth space stations, unmanned lunar landing, and interplanetary. The expected results would be in the form of general specifications and identification of areas where research and development is needed.

3. Technical Status. The progress of the contract to this date has consisted primarily of presentation by University of Tennessee personnel concerning the various techniques that have been developed for the analysis and synthesis of systems using the statistical approach.

Analysis in both the time domain and frequency domain have been the subject of presentations to R-ASTR-A personnel. Also, systems have been considered for both stationary and non-stationary inputs, and for sampled data inputs.

In addition, the method of adjoint systems for the solution of vector differential equations with time-varying coefficients was presented.

4. Major Accomplishments. The civil service personnel concerned with the problems of statistical filter theory have received the background necessary for an understanding of the various approaches.

5. Problems. None as yet.

6. Future Plans. Present plans are to continue the review of pertinent current literature. This will include more complex systems such as nonlinear systems. Also, it is planned to apply these techniques to representative problems.

7. Illustrations. None.

C. Studies in the Theory of Statistical Filters and Their Application to Selected Problems of Guidance, Control, and Navigation of Space Vehicles.

Submitted by
(Technical Supervisor)

Mr. John W. Harden, Jr.
R-ASTR-AN, 842-2221

1. Project Data

Contract Number: NAS8-11259, May 27, 1964 - July 27, 1965

Contractor: Clemson College
Clemson, South Carolina

2. Purpose of Project. The purpose of this study is to develop a capability for working with the mathematical tools peculiar to systems with inputs and parameters of a stochastic nature, in order that the various vehicle systems, including guidance, navigation, and control may be properly analyzed and designed.

3. Technical Status. The contract is approximately two-thirds complete and is proceeding according to schedule.

4. Major Accomplishments. A survey of Pazen's textbook has been completed and a summary report prepared for MSFC.

A simulation of the implementation of a Kalman filter has been performed for a simple parabolic trajectory, and final checks are being performed on the program.

Six papers covering the scope of treatment of statistical filters in the current literature have been reviewed and abstracts suitable for use by NASA personnel with a general engineering background are being prepared.

An exemplary problem concerned with filters as pointed out in one of the six papers is about two-thirds complete. A summary of this problem will accompany the abstract of the paper that generated it.

5. Problems. None.

6. Future Plans. After the completion of the present work the following problems will be considered:

a. An investigation of the Hilbert Space approach to statical filter problems using the reproducing Kernel as a tool for solving applied problems.

b. An investigation of linear time systems using the state space approach with Lyapunov stability conditions, and the extension of state space methods from the deterministic to the probabalistic model.

c. Perform a survey of the Fourier analysis approach to stationary random functions with considerations of spectral decomposition, auto correlation functions, spectral density functions, and the use of this approach in obtaining optimal smoothing and predicting filters.

d. To continue work in the simulation of filters on problems involving other types of conics with more realistic hardware influence.

7. Illustrations. None.

D. Basic Sensor Requirements for an Advanced Spaceborne Detection, Tracking and Navigation System Capable of Performing an Interplanetary Mission

Submitted by
(Technical Supervisor)

Mr. W. G. Thornton
R-ASTR-A, 842-3121

1. Project Data

Contract Number: NAS8-11198, June 27, 1964 - June 27, 1965

Contractor: Philco Corporation
Western Development Labs.
Palo Alto, California

2. Purpose of Project. The purpose of the project is to conduct analytical studies in the field of Advanced Spaceborne Navigation Systems. The general objective of all the studies is to conduct analyses necessary to determine the basic requirements of systems capable of performing several NASA missions including manned lunar landing, manned earth space stations, unmanned lunar landing, and interplanetary. The expected results would be in the form of general specifications and identification of areas where research and development is needed.

3. Technical Status.

a. Four system configurations have been selected as representative and which fulfill the requirements of the study.

b. For each configuration and its error sources a mathematical model has been defined and the consequent analysis program developed.

c. Data has been calculated on each system configuration with parametric variations or error sources.

Volume I: Summary
Volume II: Problem Definition
Volume III: Analytical Solution for the Lunar Mission
Volume IV: Earth Orbital Rendezvous
Volume V: Analytical Supplement

4. Major Accomplishments. Volume I (Summary) is one of five volumes which, together, constitute the "Advanced Spaceborne Detection, Tracking, Navigation, and Guidance Systems Compilation Report" compiled for the Marshall Space Flight Center by the Aerospace Division of the Westinghouse Defense and Space Center, Baltimore, under Contract NAS8-11205. This report is compiled from the results of three parallel studies conducted independently by the Cornell Aeronautical Laboratory, Inc., Buffalo, New York, the Missile and Space Division of Raytheon Company, Bedford, Massachusetts, and

the Aerospace Division of Westinghouse Defense and Space Center, Baltimore, Maryland. These studies were performed primarily to determine sensor requirements for advanced space missions for the immediate post-Apollo time period and were conducted along guidelines furnished by Mil-D-8684A (Aer), paragraphs 3. 4. 3. 1 and 3. 4. 3. 2.

Volume I contains the principal assumptions, results, and recommendations of the overall study and is a summary of the study compilation as contained in the remaining four volumes.

Volume II contains the problem definition for the study and, in particular for the lunar mission and shows the development of specific analytical models from the original contract requirements.

Volume II contains the analytical solution for the lunar mission. Specific guidance system models are analyzed and navigation sensor requirements are developed for five major phases of the manned lunar mission. Many of the results are also applicable to the unmanned lunar mission.

Volume IV contains those areas of the study applicable to earth orbital rendezvous and contains its own problem definition, in the main, and its own analytical solution and appendices.

Volume V contains the appendices to Volume III. These appendices constitute an analytic supplement and contain, in Appendix A, a general discussion of mathematical techniques used, and in the succeeding appendices, detailed mathematical techniques as applied in turn to each of the phases of the lunar mission.

5. Problems. None as yet.

6. Future Plans. To distribute the information from the studies as widely as possible.

7. Illustrations. None.

E. Compilation of Analytical Data Relative to Development of Advanced Spaceborne Detection, Tracking, and Navigation System

Submitted by
(Technical Supervisor)

Mr. W. G. Thornton
R-ASTR-A, 842-3121

1. Project Data

Contract Number: NAS8-11205, April 10, 1964 - September 28, 1964

Contractor: Westinghouse Electric Corp.
Aerospace Division
Baltimore, Maryland

2. Purpose of Project. The purpose of the project is to conduct analytical studies in the field of advanced spaceborne navigation systems. The general objective of all the studies is to conduct analyses necessary to determine the basic requirements of systems capable of performing several NASA missions including manned lunar landing, manned Earth space stations, unmanned lunar landing, and interplanetary. The expected results would be in the form of general specifications and identification of areas where research and development is needed.

3. Technical Status. The study was completed and a final report issued by Westinghouse. Subsequently, the report was issued as a NASA contractor report as follows:

NASA CR-61023: Compilation report for Advanced Spaceborne Detection, Tracking, and Navigation Systems Study and Analysis. A mathematical derivation of the method of treating resolution errors has been made. The treatment is exact and is the most complete used in similar programs. A mechanization of the approach guidance hardware and its error model is being pursued both in house and by Philco.

4. Major Accomplishments.

a. A manner of organizing data calculations for good efficiency.

b. Techniques for generating sensible on-board schedules for the observations.

5. Problems.

a. Extremely long run times for evaluation of earth based tracking accuracy.

b. Numerical accuracy problems in the evaluation of guidance accuracy data.

6. Future Plans.

a. To solve the problems of Section 5 above.

b. To determine the effects of guidance execution errors on the terminal accuracy.

c. To determine the effects of uncertainties in knowledge of physical constants and measurement errors of a bias type on the navigation and guidance accuracies.

d. To relate the various phases of the mission.

e. To determine the effects of correlated measurement errors.

7. Illustrations. None.

F. Optical Guidance Feasibility Study

Submitted by
(Technical Supervisor)

Mr. Charles L. Wyman
R-ASTR-RP, 876-5290

1. Project Data

Contract Number: NAS8-2661, Mod. 2, April 25, 1962 - September 30, 1964

NAS8-11673, June 26, 1964 - June 26, 1965

Contractor: Data Corporation
Dayton, Ohio

ITT Federal Laboratories
San Fernando, California

2. Purpose of Project. The purpose of this project is to design, develop, and manufacture an experimental breadboard antenna system of an optical guidance system for rendezvous, and then a miniaturized and optimized engineering prototype for performance testing.

3. Technical Status. The breadboard is complete and is now undergoing technical evaluation. The design and manufacture of the miniaturized prototype is well under way.

4. Major Accomplishments. Optical design of the prototype has resulted in coaxial acquisition and tracking telescopes with folded optics. The design has resulted in an extremely compact system just fourteen inches long and eight inches in diameter.

The tracking and acquisition circuitry has been designed, breadboarded, tested and is presently undergoing final packaging. The circuitry uses microelectronics and has resulted in a package less than one-half the size of any previous package serving the same function.

Recent development of optical sources, specifically, arrays of injection lasers have made it practical and feasible to use optical techniques for the acquisition portion of the optical guidance system to a greater advantage than radio frequency. A description of the progress made in injection laser arrays is described in another report.

5. Problems. None.

6. Future Plans. Complete evaluation of breadboard. Extend contract to complete prototype. Begin investigating the feasibility of flying a system as an experiment on Gemini or Apollo.

Studies are now under way to specify the characteristics of an ultimate rendezvous guidance system. Investigations so far indicate that by use of laser beam steering devices, (described in another progress report) the optical guidance system can be used over wide angles without gimballing and without fuel consuming attitude control of the spacecraft.

7. Illustration.

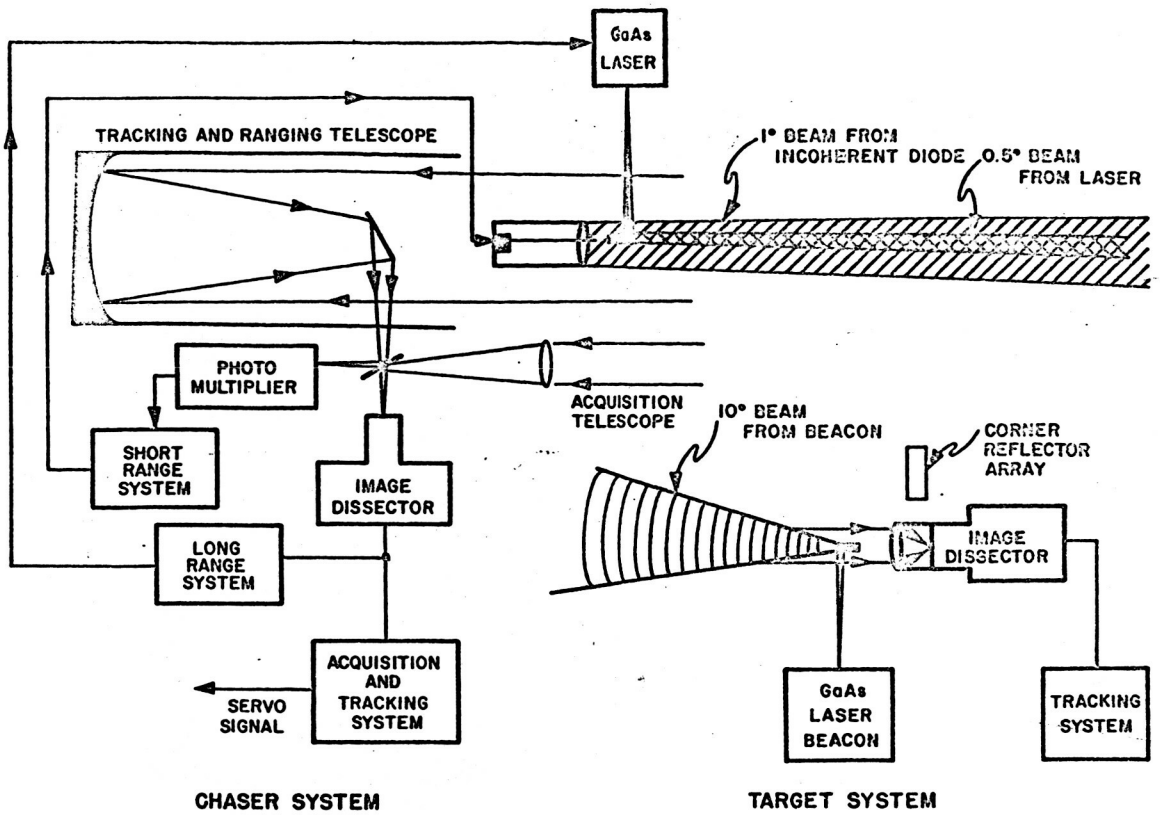


FIGURE 59. OPTICAL GUIDANCE SYSTEM

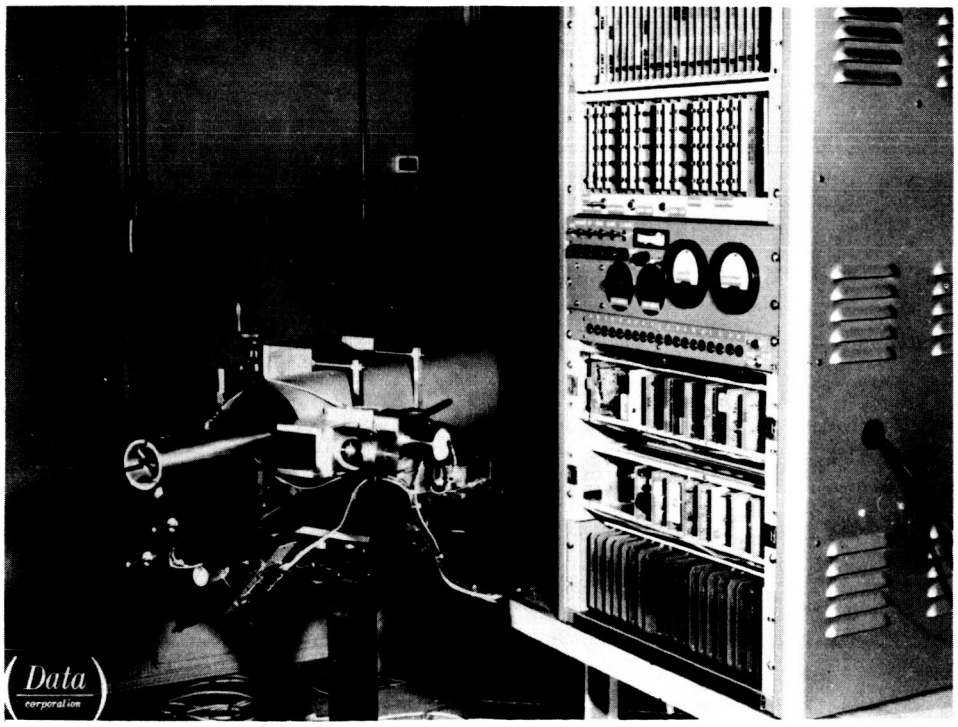


FIGURE 60. BREADBOARD SYSTEM

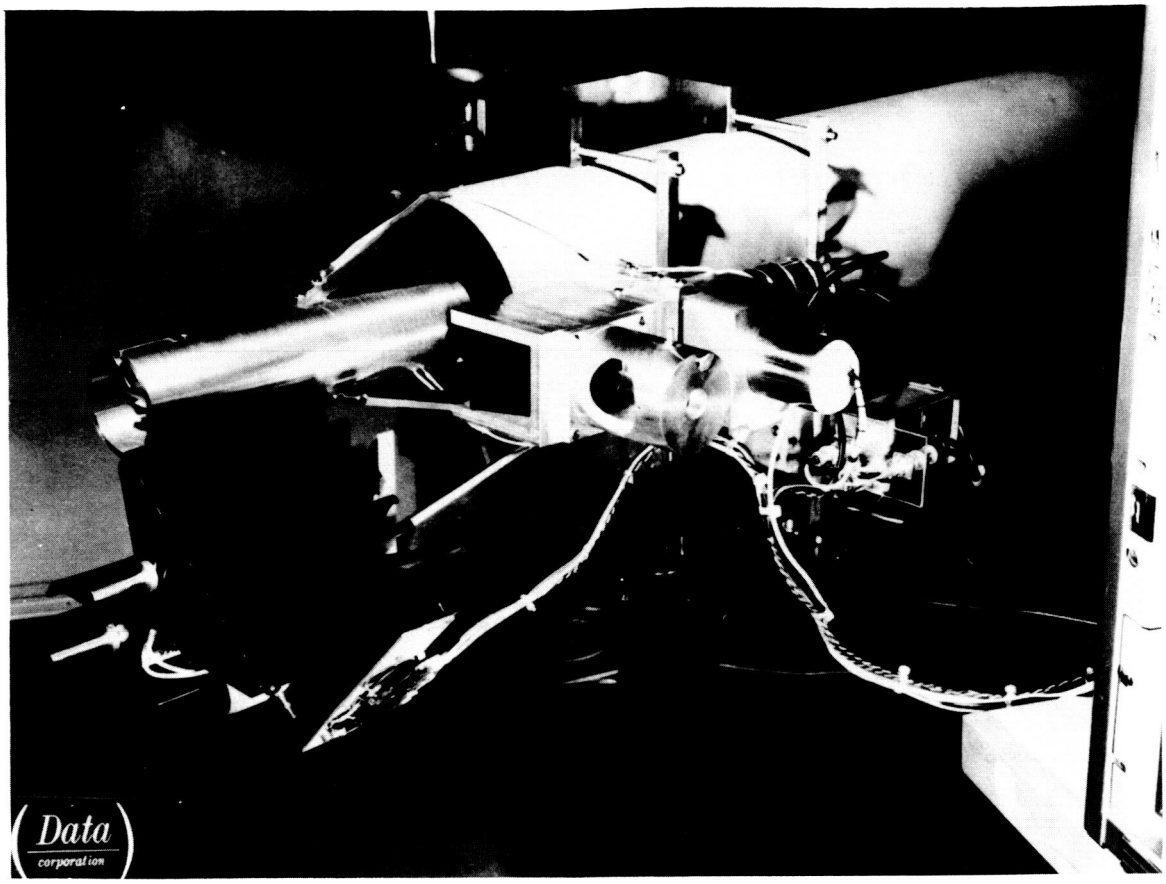


FIGURE 61. BREADBOARD SYSTEM

G. Lunar Landing Sensors

Submitted by
(Technical Supervisor)

Grady H. Saunders
R-ASTR-I, 876-1296

1. Project Data

Contract Number: NAS8-5205, Mod. 8, January 22, 1963 - July 31, 1965

Contractor: TRW Space Technology Laboratories,
Thompson Ramo Wooldridge, Inc.
One Space Park
Redondo Beach, California

2. Purpose of Project. This study is intended to accomplish the following:

a. Determine the sensor systems which will be required for a controlled soft landing on the Moon, both from a direct cislunar transit trajectory, and from lunar orbit, both with and without a previously emplaced beacon.

b. Determine the parameters and develop the preliminary design requirements for the sensor systems which will be required.

c. Determine the requirements for new or improved devices for incorporation into the sensor systems; obtain through analysis and experimentation the necessary information to permit development of such devices; and develop the devices.

3. Technical Status. A laboratory model solid-state, X-band signal source, having an output power of one watt, and operating at an overall efficiency of 1.05 percent, has been developed and tested. The device employs a series of balanced varactor doublers, and a power amplifier operating at 324 MHz. The design is considered to represent the current limits of technology; the circuitry represents an advancement in the state of the art, having been developed for this application.

Operational characteristics of the signal source are as follows:

Input signal frequency	108 MHz
Output signal frequency	10.368 GHz
Input signal power level	0 dbm
Output signal power level	30 dbm
Multiplication factor	96
Overall dc to rf efficiency	1.05 percent
rf bandwidth	0.42 per cent
Spurious level	>25 db below carrier

The device offers promise for further development. The efficiency could be increased by (a) Use of new transistors, now becoming available, in the

power amplifier, (b) Redesign of the circuitry for the doubler having the lowest efficiency (.648 to 1.3 GHz), (c) Redesign of the laboratory as a single, integrated unit, as a prototype for flight hardware. It is anticipated that output of the unit could be increased to a value approaching two watts, through these refinements to the existing model. The status of work in other areas under the contract -- system simulation studies, and varactor bias gating -- has been described in previous reports. No further work was performed in these areas during the period covered by this report.

4. Major Accomplishments. The development of a solid-state source, having an output of one watt at X-band, is considered to be a significant achievement. Neither the use of the varactor chain to achieve X-band frequencies, nor the operation of a power amplifier at 324 MHz is a new development; but the design of the circuitry, and the integration of such circuitry to achieve the realized output is an advancement. Appropriate patent disclosures, covering the circuit designs, have been initiated.

5. Problems. No major problems which would affect the course of the work have been encountered thus far.

6. Future Plans. The contract has been modified to cover the continuation of work on this task in the following areas:

a. Investigation of the feasibility of a unified sensor capable of operating as an altimeter-velocity meter or as a beacon tracker, and the concept definition and preliminary design of such a sensor.

b. Investigation of a square-wave modulated varactor power sources as a means of gating CW type power sources over a range of 100 to 1 variation in prf values.

c. Simulation studies to evaluate the performance of an extended range altimeter under noise conditions such as would be expected to result from lunar terrain scattering.

Continuation of work in the following areas is also being considered. The decision as to whether or not to undertake these items will be made after consultation with interested individuals at MSC and OART.

a. Refinement of the design of the X-band signal source to achieve higher power output.

b. Investigation of solid-state power amplifiers operating at 648 MHz and higher frequencies.

7. Illustrations. None.

H. Study of Basic Requirements of a Navigation, Guidance, and Control System for an Unmanned Lunar Landing Vehicle.

Submitted by
(Technical Supervisor)

Mr. John F. Pavlick
R-ASTR-A, 842-3299

1. Project Data

Contract Number: NAS8-11254, June 11, 1964 - July 11, 1965

Contractor: Westinghouse Electric Corp.
Aerospace Division,
Baltimore, Maryland

2. Purpose of Project. The purpose of the project is to conduct analytical studies in the field of Advanced Spaceborne Navigation Systems. The general objective of all the studies is to conduct analyses necessary to determine the basic requirements of systems capable of performing several NASA missions including manned lunar landing, manned Earth space stations, unmanned lunar landing and interplanetary. The expected results would be in the form of general specifications and identification of areas where research and development is needed. This task is addressed to the Unmanned Lunar Landing Mission.

3. Technical Status. Actual analysis work was started in the early part of August. The study has been divided into five major segments:

Problem Definition
Determination of Nominal Functions
Analysis of Tradeoff Studies
Determination of Possible Subsystems
Selection of Systems and Final Report

The Problem Definition segment was essentially completed at the end of November. In the course of this work a majority of the items concerning the

second segments were defined. Work is well into the third, or tradeoff segment of the studies and a review of this work as well as some involving the determination of possible subsystems is planned for early February 1965.

4. Major Accomplishments. In addition to the briefing data, two reports have been issued:

a. "Problem Definition for Study of Basic Requirements of a Navigation, Guidance and Control System for an Unmanned Lunar Landing Vehicle," December 10, 1964.

b. "Preliminary Analysis of Lunar Beacon Radar Tradeoff," R. H. Laprade, November 4, 1964.

5. Problems. None.

6. Future Plans. At completion of the study the results will be incorporated into existing summary reports for the other missions noted above.

7. Illustrations. None.

I. Survey and Comparison of the Astrionics Systems of Existing or Development Space Vehicles

Submitted by
(Technical Supervisor)

Mr. John Pavlick
R-ASTR-A, 842-3299

1. Project Data

Contract Number: NAS8-11470, June 29, 1964 - January 29, 1965

Contractor: Lockheed Missiles and Space Co.
Huntsville Research and Engineering Center
Huntsville, Alabama

2. Purpose of Project. The purpose of this project is to collect all available up-to-date data on the astrionics implementation of selected vehicles for inclusion into a reference handbook which ultimately will provide quick access, accurate data and realistic performance figures on state of the art astrionics systems.

3. Technical Status. The vehicles selected for data survey and inclusion in the final report are: X-20 (Dynasoar), Centaur, Agena, Titan, Standardized Space Guidance System, Gemini, and Apollo (spacecraft). The initial portion of the work period was spent in concentrating data immediately available to the contractor. A considerable effort was spent on correspondence requesting approval for contractor access to classified data and approval to incorporate this data into the proposed handbook. At the end of this report period, (January 1) the data gathering and collating process was terminated to allow preparation of the final report. The format, outline and contents of the report have been chosen and publication is expected approximately January 29, 1965. This volume will not be released for distribution to qualified groups and individuals until the necessary approvals have been received from Laboratory and Center management and the agencies having responsibility for the above listed vehicles.

4. Major Accomplishments. The fact that a start has been made toward a concise overall picture of the astrionics systems of these vehicles is in itself considered a major accomplishment. The design data to be presented has required the acquisition, reading and assessment of a tremendous quantity of documents.

5. Problems. Gaining information as to the existence and availability of promising documents to use as source data has been a laborious and time consuming task. In addition the perhaps understandable reluctance of some of the responsible agencies to grant contractor access to vehicle data has resulted in a great deal of time being spent in unproductive correspondence and deferment of data gathering for some of the vehicles initially proposed for this survey. This problem is gradually being resolved and should be completely cleared up early in the next study period.

6. Future Plans. It is presently planned to continue these efforts for an additional eight months. During this period new, revised or updated detailed data will be added to the existing vehicle descriptions. Efforts will be concentrated on filling in the gaps where information has previously been unavailable or time did not allow inclusion in the report. Also, additional vehicles will be included in the survey within time and manpower limitations.

7. Illustrations. None. For information, an outline of the vehicle systems description sections of the handbook is given.

OUTLINE FOR VEHICLE SYSTEM SECTIONS OF ASTRIONICS IMPLEMENTATION HANDBOOK

A. INTRODUCTION TO (NAME) VEHICLE - GENERAL

1. Primary Mission (description of mission parameters) (orbit life, etc.)
2. Trajectory Chart (picture)
3. Other Missions (list only)

B. VEHICLE DATA

1. Basic Configuration
   Description Physical Characteristics - Dimensions, Body Coordinates, In board Profile (reference point is common on all vehicles)
2. General Performance Data - Payload Capability
3. Weight Statement
4. Mass Properties - C.G. vs. Time, Moments of Inertia
5. System Limits (maximum gyro torque rate, maximum body rates, orbit life, etc.)
6. Error Analysis Input Data (all vehicle sources)
7. Propulsion System Parameters (includes thrust profile)
8. Vehicle Design Data

   a. Alignment
   b. Wind Profile
   c. Thermo Trajectory
   d. Vibration and Acoustics

9. Vehicle Interface Data

   a. Mechanical
   b. Electrical
   c. AGE

10. Reliability

C. GUIDANCE SYSTEM

1. Components Description (list) (text and illustrations)
2. Block Diagrams and Transfer Functions
3. Sequence of Events - (trajectory picture)

4. Reference or Nominal Trajectory
5. Guidance Scheme - Guidance equations, coordinate systems
6. Functional Data (chart form and text)
   a. Input Power, (tolerance, etc.)
   b. Output Signals - Also Manual Inputs and Outputs (if applicable)

      (1) Functional Block of Component Showing Interface

   c. Weight, Dimensions, Mounting Provisions, Thermal Control
   d. Location in Vehicle (illustration, if available)
   e. Environmental Limits (vibration, shock, temperature, etc.)
   f. Reliability Data (MTBF, parts count.)
   g. Special Tests Required, Special Test Equipment
   h. Design and Construction Features
   i. Cost Data, Quantity Manufactured
   j. Reference Documents (P/N, drawings, specifications, etc.)
   k. Error Contribution Chart

D. NAVIGATION SUBSYSTEM

1. Components Description (list) (text and illustrations)
2. Block Diagrams
3. Modes of Operation
4. Navigation Scheme - Navigation Equations - Coordinate Systems
5. Functional Data (chart form and text)

   a. Input Power
   b. Output Signals (also manual inputs and outputs, if applicable)
   c. Weight, Dimensions, Mounting Provisions, Thermal Control
   d. Location in Vehicle
   e. Environmental Limits
   f. Reliability Data
   g. Special Tests and Equipment Required
   h. Design and Construction Features
   i. Cost Data, quantity manufactured
   j. Reference Documents (drawings, specifications, etc.)
   k. Contribution to System Error

E. CONTROL SYSTEM

1. Components Description
2. Block Diagrams and Transfer Functions (body dynamics equations-moment arms)
3. Modes of Operation
4. Control System Laws (equations, response time, etc.)
5. Functional Data

    a. Input Power
    b. Output Signals
    c. Weight, Dimensions, Mounting Provisions, Thermal Control
    d. Location in Vehicle
    e. Environmental Limits
    f. Reliability Data
    g. Special Tests and Equipment
    h. Design and Construction Details
    i. Cost Data
    j. Reference Documents
    k. Contribution to System Error

F. POWER SUBSYSTEM

1. Component Description (list) (text and illustrations)
2. Block Diagrams
3. Power Profile
4. Grounding and Shielding Provisions
5. Functional Data (chart form and text)

    a. Input Power
    b. Output Signals - Manual Inputs and Outputs (if applicable)
    c. Weight, Dimensions, Mounting Provisions
    d. Location in Vehicle (illustration, if applicable)
    e. Environmental Limits (vibration, shock, temperature, etc.)
    f. Reliability Data (MTBF, parts count)
    g. Special Tests and Equipment Required
    h. Design and Construction Features
    i. Cost Data, quantity manufactured
    j. Reference Documents (drawings, specifications, etc.)
    k. Contribution to System Error

G. TELEMETRY AND INSTRUMENTATION SUBSYSTEM

1. Components Description (list) (text and illustrations)
2. Block Diagrams
3. Instrumentation Schedule - Antenna Coverage Patterns
4. Functional Data

   a. Input Power
   b. Output Signals - Manual Inputs and Outputs (if applicable)

      (1) Functional Block of Component Showing Interface

   c. Weight, Dimensions, Mounting Provisions
   d. Location in Vehicle (illustration, if applicable)
   e. Environmental Limits (vibration, shock, temperature, etc.)
   f. Reliability Data (parts count, MTBF)
   g. Special Tests and Equipment Required
   h. Design and Construction Features
   i. Cost Data, quantity manufactured
   j. Reference Documents (drawings, specifications, etc.)
   k. Contribution to System Error

H. MANNED DISPLAY GROUP

1. Components Description (list) (text and illustrations) (panel layouts)
2. Block Diagrams

   a. Operation Modes
   b. Abort and Malfunction Detection Provisions

3. Functional Data

   a. Input Power
   b. Output Signals
   c. Weight, Dimensions, Mounting Provisions
   d. Location in Vehicle (illustration)
   e. Environmental Limits (vibration, shock, temperature, etc.)
   f. Reliability Data
   g. Special Tests and Equipment
   h. Design and Construction Features
   i. Cost Data, quantity manufactured
   j. Reference documents (drawings, specifications, etc.)

J. GROUND SUPPORT SUBSYSTEM

1. System Test Philosophy (discussion)
2. Tests and Procedures (block diagrams)

   a. Hangar Checkout (by subsystems)
   b. Pad Prelaunch Checkout (by subsystems)
   c. Countdown

3. Alignment Procedure
   Block Diagram and Text
4. Launch and Hold Limitations
5. Targeting or Turn-Around Time
6. Description of Components
   Block Diagrams
7. Equipment Functional Data

   a. Input Power
   b. Output Signals
   c. Dimensions, Weight
   d. Location
   e. Environmental Limits
   f. Reliability Data (MTBF, etc.)
   g. Special Test Equipment and Requriements
   h. Design and Construction Features
   i. Cost Data, quantity manufactured, etc.
   j. Reference Documents (drawings, specifications, etc.)
   k. Contribution to System Error (especially alignment)

K. BIBLIOGRAPHY

Systems and Trajectory Analysis

A. Analytical Study and Mathematical Research for Development and Implementation of the Path Adaptive Guidance Mode

Submitted by
(Technical Supervisor)

John B. Winch
R-AERO-D, 877-2297

1. Project Data

Contract Number : NAS8-11221, May 20, 1964 - July 20, 1965

Contractor: Northrop Space Laboratories, Inc.
Huntsville, Alabama

2. Purpose of Project.

a. To investigate the effects of guidance system hardware errors, random noise, various lunar cutoff hypersurfaces, and other error sources on the existing iterative guidance scheme to find, if any, the situations where it is not valid.

b. To find possible improvements to the scheme for other applications, such as low thrust interplanetary trajectories and rendezvous.

c. Development of other forms of explicit guidance schemes is encouraged and the non-explicit schemes such as polynomial guidance are de-emphasized.

3. Technical Status. Analysis of the existing iterative guidance scheme for the Saturn V Apollo out of orbit case is virtually complete with respect to hardware errors and is complete with respect to time lags and fluctuating thrust. Studies of Saturn V into orbit are in progress. A complete Monte Carlo statistical analysis will be applied to the Saturn V Apollo mission from ignition of the S-II and S-IVB through parking orbit to lunar transit injection.

4. Major Accomplishments. A deck which incorporates the iterative guidance scheme, with the capability of making a closed loop hardware error analysis and with the capability of generating random noise, has been developed. This will be a powerful tool for all guidance studies of existing and future vehicles. It will be used in conjunction with a Monte Carlo statistical deck developed in-house in order to state guidance system errors more realistically.

5. Problems. None.

6. Future Plans. To proceed with the tasks as outlined in paragraph 2, Purpose of Project.

7. Illustrations. None.

B. Trajectory Studies for Varying Missions Including Orbit Transfer and Rendezvous

Submitted by
(Technical Supervisor)

W. E. Miner
R-AERO-G, 876-3997

1. Project Data

Contract Number: NAS8-11244, June 27, 1964 - June 27, 1965

Contractor: The Boeing Company
Aero-Space Division
New Orleans, Louisiana
(Huntsville, Alabama)

2. Purpose of Project. To analyze expedient methods of maximizing booster payloads for advanced space missions.

3. Technical Status. Work during this reporting period has begun on defining a set of booster cut-off equations for a six-hour lunar transfer window and for generating Earth orbit rendezvous launch window data.

4. Major Accomplishments. Reverse Earth to Moon trajectories were "flown" and the resulting data were curve fitted. The result was that, for injection during the six-hour window, errors encountered may be eliminated by mid-course correction. The generation of Earth orbit rendezvous launch window for a 100-nautical-mile orbit is almost complete.

5. Problems. None.

6. Future Plans. No change from original scope.

7. Illustrations. None.

C. Study and Research in New Methods for Systematic Generation of Liapunov Functions for Control Systems

Submitted by
(Technical Supervisor)

C. C. Dearman, Jr.
R-AERO-G, 876-3997

1. Project Data

Contract Number: NAS8-11196, June 30, 1964 - June 30, 1965

Contractor: Drexel Institute of Technology
Philadelphia, Pennsylvania

2. Purpose of Project. To perform studies and research in new methods of generating Liapunov functions and to assist in studying the stability problems of nonlinear automatic control systems.

3. Technical Status. A survey of known methods of generating Liapunov functions for nonlinear dynamical systems is in process. The following methods and the possibility of their application to practical dynamical systems are being studied: (1) integral methods, (2) approximation to exact differential equations, (3) Malkin's methods, (4) Routh canonical form, (7) method of separation of variables, (8) Lure's canonical form, (9) Zubov's method and (10) the method of Szego.

4. Major Accomplishments. None.

5. Problems. None.

6. Future Plans. Continue efforts to find means of generating Liapunov functions applicable to larger classes of nonlinear systems.

7. Illustrations. None.

CONTROL SYSTEMS

Advanced Control Theory

A. Booster Attitude Stabilization Network Synthesis

Submitted by
(Technical Supervisor)

Mario H. Rheinfurth
R-AERO-DC, 876-6979

1. Project Data

Contract Number: NAS8-5016, March 15, 1964 - November 15, 1964

Contractor: Republic Aviation Corporation
Farmingdale L.I., New York

2. Purpose of Project. The purpose of the project is to develop a systematic analytical procedure to synthesize a passive electrical network which statisfies prescribed gain and phase characteristics.

3. Technical Status. A synthesis method using topological considerations was developed to reduce extraneous reactive elements which have to be introduced if classical synthesis procedures are employed. The paramount feature of this new approach is the minimization of a suitable error function between a specified rational function and the transfer function of a judiciously selected network. The method was formulated mathematically and a computer program, which determines the component values of the selected network using a least square error criterion, was written. The program operates in iterative steps starting with initial approximations of the component values and uses the method of steepest descent to arrive at a minimum of the criterion function.

4. Major Accomplishments. A decisive advantage of the topological approach singled out for synthesizing passive networks is seen in the flexibility of network configurations to be selected such that particular attention can be concentrated on reliability, simplicity, size, and ease of implementation of the network.

5. Problems. Difficulties have been encountered in the speed of convergence of the iterative procedure and the fact that there exists a multitude of minima of the criterion function which stem from the nonunique aspects of network synthesis. The difficulties are, however, not considered insurmountable. Corrective steps are presently guided by in-house research efforts in optimum filter techniques, which lead to preferred poly-zero configurations of the network and assist in choosing more favorable initial approximations which hopefully result in faster convergence of the iterative procedure.

6. Future Plans. Due to lack of funds, the contractor has discontinued all research efforts of the program. As soon as additional funds become available, technical discussions will be resumed with the contractor to outline in-house studies on optimum filters and how they can assist in further improvement and refinement of the present computer program.

7. Illustration. None.

B. Transmission Concepts in Flexible Launch Vehicle Control

Submitted by
(Technical Supervisor)

G. F. McDonough
R-AERO-DDS, 876-6895

1. Project Data

Contract Number : NAS8-11420, June 30, 1964 - June 30, 1965

Contractor: Missile & Space Division
Douglas Aircraft Co.
Santa Monica, California

2. Purpose of Project. Work under this contract is directed to applying concepts and techniques which have been developed in the study of electrical transmission lines to the problem of controlling launch vehicles. The differential equation of motion for longitudinal waves in solids is identical to that for a nonuniform electrical transmission line; this analogy has been used to good advantage in the study of elastic ground waves. Flexural equations do not have the same form but can be treated using similar techniques.

3. Technical Status. Transfer functions have been derived to describe lateral bending transmission in a semi-infinite beam. Lateral and longitudinal models have been combined and the effects of a control system included in the analysis. Analog and digital computer models have been developed and preliminary numerical results obtained. These results indicate that the method will be useful in the analysis of elastic vehicles.

4. Major Accomplishments. Development of simple transfer functions for bending which are compatible with longitudinal functions. That the form of the functions is such as to be amenable to analysis greatly improves the chances of obtaining useful results.

5. Problems. The complexity of the lateral analysis might limit the analysis to a fairly simple configuration, such as a composit single-step or two-step beam.

6. Future Plans. Further investigation will be made of the relationships between stabilization based on the usual modal analysis and that by characteristic impedance as in the analysis using transmission operators.

7. Illustrations. None.

C. Research Study of Large Flexible Launch Vehicle

Submitted by
(Technical Supervisor)

D. A. Ford
R-AERO-GG, 876-6477

1. Project Data

Contract Number: NAS8-11206, May 9, 1964 - May 9, 1965

Contractor: Honeywell, Inc.
Military Products Group Research Laboratory
Minneapolis, Minnesota

2. Purpose of Project. To determine, by analytical techniques, a means of controlling launch vehicles in the presence of large wind disturbances. In particular, the limits of capability of linear control systems to minimize aerodynamic loads and vehicle parameter variations during flight will be established.

3. Technical Status. Although linear control is well developed in practice, analytical results have lagged far behind, especially in controlling in the presence of disturbances. This study should provide sound analytical design criteria for the problem in the case of launch vehicle control systems.

4. Major Accomplishments. The study of linear control laws for a linear constant coefficient plant with bounded amplitude winds and with nonzero initial conditions is virtually complete. Questions concerning updating of the controller based on floating initial conditions (principle of optimality) and constraints on the control gains to achieve a given margin in damping and natural oscillation frequency have been settled. Partial results have been obtained for a time varying plant.

5. Problems. None.

6. Future Plans. A class of winds with bounded rate as well as bounded amplitude will be considered in the constant coefficient problem. Work will continue on the time varying plant problem.

7. Illustrations. None.

Advanced Component Technology

A. Development of a Pressure and Force Transducer Calibration Procedure for the Hypersonic Shock Tunnel

Submitted by
(Technical Supervisor)

James W. Clark
R-AERO-AE, 876-8122

1. Project Data

Contract Number: NAS8-5350, May 14, 1963 - November 12, 1965

Contractor: Astro Space Laboratories
Huntsville, Alabama

2. Purpose of Project. The development of prototypes and application techniques for various calibrators for impulse type of high frequency response pressure and force transducers.

3. Technical Status. The analysis and synthesis work has been completed for a typical force and moment transducer during this reporting period. A prototype was built which verified the theoretical analysis.

4. Major Accomplishments. A high frequency sound pressure generator has been developed for acoustic pressure calibrations. Analysis and synthesis have been accomplished for calibrating and optimizing high frequency force transducers. This analytical work has been verified by a prototype model.

The research for the pressure generator was performed with a modified commercial electrodynamic horn drive. Reasonably good results were obtained up to 13k cps and 160 db sound pressure level. Some useful calibration areas were obtainable to 70k cps.

The research on the force sensor was based on aerodynamic model balance with three measuring components. The 200 pound load range device used quartz piezoelectric load elements and a 1000 cps frequency response was obtained. Inertial compensation was analyzed and designed to eliminate effects of support motion.

5. Problems. None.

6. Future Plans. Further study and research will be needed for this impulse or high response instrumentation. This should be done as a follow-on to the work already accomplished. Wide latitudes exist in range and other variables for this type experimental aerodynamic facility.

7. Illustrations. None.

B. Pure Fluid Facility Development

Submitted by
(Technical Supervisor)

Mr. Jerry A. Peoples
R-ASTR-NFM, 876-3525

1. Project Data

Contract Number: Not Applicable

Contractor: In-House

2. Purpose of Project. To develop in-house pure fluid capability.

3. Technical Status. Fabrication and installation is essentially complete. Six sources of regulated air provided in pressure ranges from zero to 150 psig. Equipment is available to measure steady state flows between 0.05 and 10 SCFM. These ranges of pressures and flows are adequate to facilitate any fluid element or elements of conventional size. Pressure transients can be monitored although no capability exists for measuring flow transients. Since our laboratory is not in full operation, transient flow equipment will not be procured until a strong need arises. A pantograph is also available for machining small pure fluid elements for test and evaluation.

The laboratory is equipped with a Birefringent (photoelasticity) flow stand. The purpose of this stand is to make means available for studying flow patterns through channels. Photoelasticity is the art of utilizing a double refracting medium to produce stress patterns in a moving fluid. Such stress patterns can be interpreted in terms of fluid velocities. Our test cell is 9-3/4 inches square. Pressure capability is 100 psig. This flow stand will be very valuable in evaluating fluid flow in pure fluid devices. Figure 62 shows the external features of the stand. Figure 63 is a close up of the test cell.

4. Major Accomplishments. Development of pure fluid test and evaluation capability. Just as important is the successful development of a Birefringent liquid flow stand.

5. Problem. Primary problems have been concerned with limited manpower and time allocation to the fluid effect. At the present time only one engineer is assigned to research and development of pure fluid systems. His efforts are handicapped since other programs under his responsibility allow only 10 percent of his time to be devoted to study and laboratory evaluation of pure fluid phenomena. It is estimated that a minimum of two engineers and one technician are required to adequately support Astrionics' fluid efforts.

6. Future Plans. It is anticipated that our pure fluid capability will increase with time as a result of equipment and facilities which have been made available. Plans are being made to develop an evaluation procedure for use of our Birefringent flow stand. This will be accomplished through in-house and contract efforts.

7. Illustrations. Figures 62 and 63.

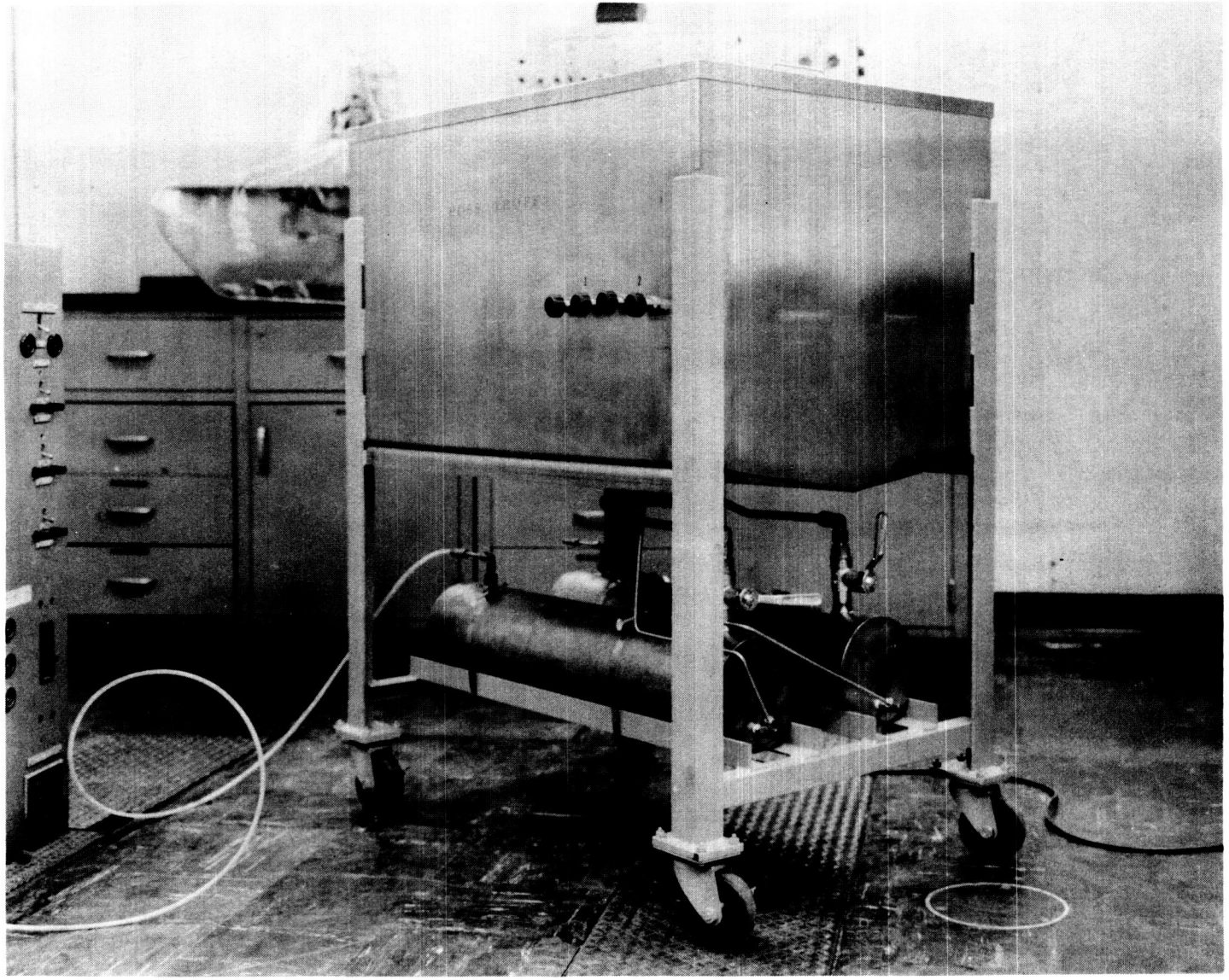


FIGURE 62. BIREFRINGENT FLOW STAND

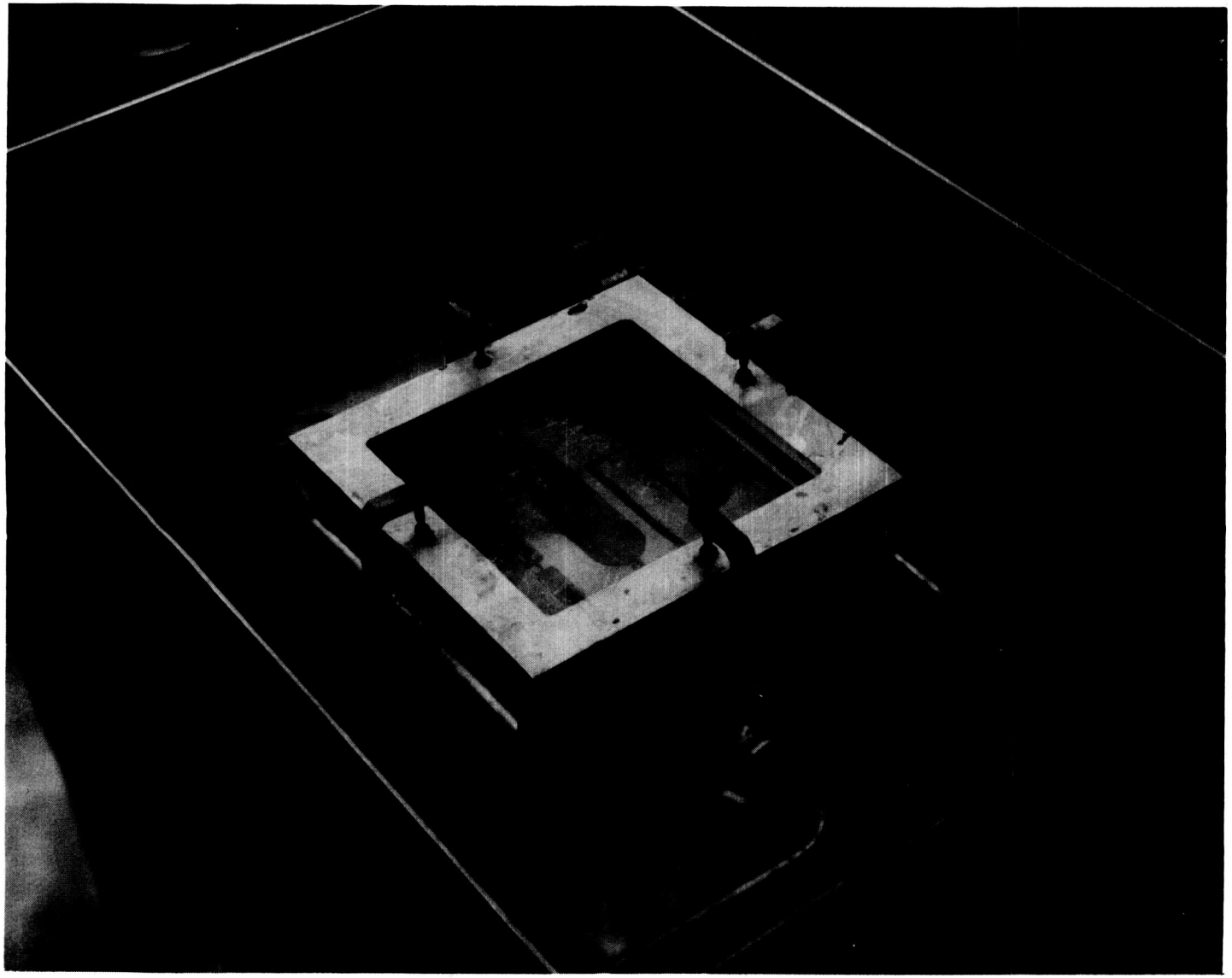


FIGURE 63. BIREFRINGENT TEST CELL

COMMUNICATIONS

Communications Techniques and Components

A. Location of Pattern-Disturbing Structures in the Near-Field of an Antenna

Submitted by
(Technical Supervisor)

Mr. J. W. Harper
R-ASTR-IRA, 876-1071

1. Project Data

Contract Number: NAS8-5412, June 5, 1963 - January 3, 1965

Contractor: University of Alabama

2. Purpose of Project. The radiation patterns of many space vehicle antennas depend to a large extent on various structural features of the vehicle, where induced currents contribute to the radiated energy and thus alter the pattern. The nature and extent of such effects produced by fins, retro-rockets, discontinuities in the vehicle skin, and other secondary radiators are difficult, and sometimes impossible, to predict, and can be determined only by scale-model requirements.

Such measurements reveal the shape of the composite pattern, containing the combined contributions of primary radiator and all secondary sources. Any attempt to improve such a pattern often requires an understanding of the influence of the vehicle itself on the pattern, and this knowledge usually cannot be obtained by simply observing the composite pattern. It is therefore desirable to devise some method whereby a measured radiation pattern may be analyzed by breaking it down into basic components corresponding to primary and secondary sources located at various positions on the vehicle body.

The method being investigated is that of synthesizing the measured pattern by use of a linear array of discrete radiating elements, the axis of the array being identical to the vehicle roll axis. The locations of various elements of the array then represent locations along the length of the vehicle, and the required current amplitude for each element indicates the current amplitude which exists at the equivalent point on the vehicle structure. The synthesis method use is attributed to Schelkunoff, and is described in the referenced report.

3. Technical Status. The validity of the proposed method has been satisfactorily proved, although its degree of usefulness has not yet been demonstrated.

4. Major Accomplishments. Several experimental patterns of antennas on surfaces with simple discontinuities have been synthesized, with encouraging results. Edges, protrusions, and bends in the conducting surface are identifiable.

5. Problems. A telemetry antenna pattern from a Saturn vehicle is now being synthesized, and some difficulty has arisen in attempting to reproduce its extremely complex shape. The problem appears to be related to the very narrow width of the lobes and nulls in some region and to the number of array elements used. This does not appear to be a serious problem.

6. Future Plans. Present intentions are to evaluate the usefulness of the described method, during the remaining portion of the contract, and if it appears highly promising, to put additional effort into its refinement and extension.

7. Illustrations. See Technical Report No. 1, Contract NAS8-5412, September 1964, Bureau of Engineering Research, University of Alabama, University, Alabama.

B. Study of Short Term Phase Stability

Submitted by
(Technical Supervisor)

Mr. B. R. Reed
R-ASTR-IR, 876-7519

1. Project Data

Contract Number: NAS8-11592, March 16, 1964 - March 15, 1965

Contractor: Smith Electronics, Inc.
Cleveland 41, Ohio

2. Purpose of Project. Contract NAS8-11592 has a goal of studying and measuring various causes of the effects of phase instabilities and to analyze and develop phase stable circuitry.

3. Technical Status. Contract NAS8-11592 is 80 percent complete and on schedule.

4. Major Accomplishments. Two summary reports have been submitted that define frequency division, categorizes basic divider concepts and classifies frequency dividers into true or pseudo divider types. The effect upon the signal-to-noise ratio by the dividers was analyzed and discussed.

A charge storage diode ("step recovery" or "snap off") was designed and breadboarded into a parametric divide-by-thirteen circuit. The circuit has a conversion efficiency of 6 percent. The input frequency is 35 mw at 2280 KHz.

5. Problems. The divider study pointed out that a true frequency divider must have signal storage capacity equal in all respects to the input singal. This then eliminated the possibility of real time true frequency division. Pseudo division on the other hand can, with a prior knowledge, perform real time frequency division, however, it is bounded by the limitation of the a priori knowledge.

6. Future Plans. It is planned to continue the effort to lead to a better understanding of the significance of short-term stability, its relationship to noise and its measurement. The program is to include analysis of devices for stability and the development of phase stable circuitry.

7. Illustrations. None.

C. Phase Variation Characteristics of Low Frequency Transmission

Submitted by
(Technical Supervisor)

Grady H. Saunders
R-ASTR-I, 876-1296

1. Project Data

Contract Number: NAS8-5231, February 1, 1963 - June 20, 1965
Note: This contract also includes tasks funded under other programs.

Contractor: Auburn Research Foundation, Inc., Auburn University, Auburn, Alabama

2. Purpose of Project. The objective of this study is the determination of the maximum phase variation occurring in a low frequency transmission over a path approximately 400 miles in length. This is to be accomplished by transmitting a low frequency signal from one station to a second, and then retransmitting it to the first station. The returned signal will be compared with the original signal both on a continuing basis, and on the basis of accumulated phase drift over a period of several months.

3. Technical Status. The past period has been occupied with the continued development, improvement and testing of measuring teachniques. The transmitting antenna, as a possible source of major pahse variation, has been confirmed by investigation and by report from others. This confirmation has resulted in the decision to proceed with caution in the modification and installation of equipment for the two-way VLF link until further investigation proves that the steps taken to minimuze the effect and to compensate for it are effective. The effect from the antenna is not unexpected, but the magnitude of the phase variations in respect to the total phase variation expected was not anticipated. Careful compensation for the effect of the antenna must be made in order to obtain accurate and valid data.

4. Major Accomplishments. The plans and techniques for the two-way transmission system has been completed. The only uncertainties in the procedure now lie in the possible changes required for more refined compensation for the effect of the transmitting antenna, and in circuit non-linearities in the receivers.

5. Problems. No significant technical problems have been encountered to date.

6. Future Plans. Simulation of the two-way system as planned will be made to assure that the phase variations due to the antenna can be removed by the present method employed, and that non-linearities in the system reduce the dynamic range of the system below that required.

With these precautions, the procurement, modification, and installation of equipment will proceed.

7. Illustrations. None.

D. Absorption Measurements at 33 GHz and 93 GHz

Submitted by
(Technical Supervisor)

Mr. J. G. Gregory
R-ASTR-IRT, 876-8654

Mr. Thomas G. Barnes
R-ASTR-IRT, 876-8654

1. Project Data

Contract Number: Not Applicable

Contractor: MSFC In-house

2. Purpose of Project. It is the basic purpose of the experiment to measure differences in the individual received signal strength of these two frequencies over a 10-mile range and correlate the results with atmospheric temperature, humidity, pressure, and other local weather data. Since these frequencies have good possibilities as future telemetry channels, it will also be desirable to make investigations into phase comparison, AM-FM modulation and other techniques.

3. Technical Status. OART funds were not available during this reporting period.

Although this is considered a negative report, it will be of interest to note that the 33 GHz experiment has been temporarily terminated since sufficient data has been gathered at this frequency. The data are now being evaluated and the results will be published as soon as the evaluations are complete and a final analysis has proved the data valid.

4. Major Accomplishments. None.

5. Problems. None.

6. Future Plans. None.

7. Illustrations. None.

E. Design, Development and Fabrication of a Two Axis Pedestal for Missile Tracking Using Coherent Light Techniques

Submitted by
(Technical Supervisor)

Mr. Charles L. Wyman
R-ASTR-RP, 876-5290

1. Project Data

Contract Number: NAS8-11668, June 18, 1964 - March 18, 1965

Contractor: Powertronics System Incorporated
New Rochelle, New York

2. Purpose of Project. To design and fabricate a precision two axis, air bearing tracking mount for an experimental laser tracking system.

3. Technical Status. Design is complete and system is being assembled.

4. Major Accomplishments. This is the first precision air bearing mount in existence and used in conjunction with optical tracking techniques will allow tracking of space boosters with an unprecedented degree of accuracy.

5. Problems. None.

6. Future Plans. Upon delivery of the pedestal we plan installation in the optical tunnel for checkout of angular accuracy, servo stability and tracking capabilities.

7. Illustrations. None.

F. Development of an Optical Superheterodyne Receiver

Submitted by
(Technical Supervisor)

Mr. Cullen Q. Lee
R-ASTR-RP, 876-5290

1. Project Data

Contract Number: NAS8-11588, Mod 1, March 10, 1964 - March 10, 1965

Contractor: Applied Research Branch
Sylvania Electronic Systems
Waltham, Massachusetts

2. Purpose of Project. To design and fabricate an optical superheterodyne receiving (1) modulated laser signals in space communications, and (2) optical Doppler radar signals where the carrier signal may shift due to extremely large Doppler shifts at optical frequencies.

3. Technical Status. The various electrical and optical components that will go into the final receiver are being designed.

4. Major Accomplishments. An optical superheterodyne receiver without spatial tracking capabilities has been designed and tested through the atmosphere using a laser source operating at 6328 Angstroms.

5. Problems. Heterodyning through the atmosphere a distance of 6000 feet has been successful. However, attempts to heterodyne a distance of 14 miles through the atmosphere have not been successful.

6. Future Plans. Further attempts will be made to heterodyne over the 14 mile range, and when the spatial tracking servo is added to the system, ground checks will be made on moving targets.

7. Illustrations. None.

G. Determination of Optical Technology Experiments for a Satellite

Submitted by
(Technical Supervisor)

Mr. E. J. Reinbolt
R-ASTR-RP, 877-2168

1. Project Data

Contract Number: NAS8-11408, June 27, 1964 - February 28, 1964

Contractor: Perkin Elmer Corporation
Electro-Optical Division
Norwalk, Connecticut

2. Purpose of Project. In order to bring about the realization of the potential of optical communication and tracking in space, an optical engineering technology satellite is needed to provide operational as well as engineering and scientific data that will permit the laser and associated equipment to take its place as a serious contender in aerospace communication and tracking systems.

3. Technical Status. This study is being conducted in two phases. The first phase is concerned with a conceptual design of an optical communication system between a satellite and a ground station. Both the satellite and ground station would have a transmitter laser and a tracking system in order to establish a two way communication link. Areas to be considered in this design are the following:

The problem of acquisiton, tracking, and control of the very narrow laser beams (1 arc second or less), velocity aberration lead angles, transmit 10 megahertz information bandwidth, effects of atmosphere on communication and tracking, etc. The results of this phase of the study will determine a list of experiments to be performed to gain a maximum amount of information.

The second phase of the study is concerned with conceptual design of the spacecraft and experiment with considerations of weight, power and size requirements.

4. Major Accomplishments. Phase I of the study has been completed with a conceptual design of the optical communication system and a list of meaningful experiments.

5. Problems. Tracking a laser beam to . 1 arc second and pointing a laser beam back in the same direction is a problem that needs further research.

6. Future Plans. Phase II of the study should be completed by February 28, 1964. Plans also call for an experimental development of a breadboard model to solve the problem of tracking to . 1 arc second and repointing a laser back in the same direction toward the beacon being tracked.

7. Illustrations. None.

Advanced Electronic Devices

A. A Development Program on an Array of Gallium Arsenide Injection Lasers

Submitted by
(Technical Supervisor)

Mr. Charles L. Wyman
R-ASTR-RP, 876-5290

1. Project Data

Contract Number: NAS8-11612, June 2, 1964 - June 2, 1965

Contractor: Radio Corporation of America
Somerville, New Jersey

2. Purpose of Project. To develop techniques to fabricate injection lasers into arrays for the purpose of obtaining more power than can be obtained from single diodes.

3. Technical Status. The first six months of the program was devoted to development of better materials and fabrication techniques in an attempt to improve the size, efficiency and quality of the lasers.

4. Major Accomplishments. Some very significant breakthroughs in injection laser technology have been made. These accomplishments include:

a. Incoherent radiation at 77°K in excess of 70 percent efficiency, a ten to one improvement over any previous announcement.

b. Efficiencies up to 15 percent for laser diodes at room temperature, again an order of magnitude improvement.

c. Development of lasing diodes up to 0.25 inches long indicating nearly one hundred to one improvement in optical homogeneity of the diode junction.

5. Problems. None.

6. Future Plans. The next six months of the contract will be devoted to fabricating and testing arrays of lasers.

In-house studies are directed toward utilization of the arrays in two systems, that is, in the acquisition subsystem of the optical guidance system for rendezvous, and for optical pumping the yttrium aluminum garnet laser.

7. Illustrations. None.

B. Development of a Frequency Stabilized Laser

Submitted by
(Technical Supervisor)

Dr. J. L. Randall
R-ASTR-RP, 877-2168

1. Project Data

Contract Number: NAS8-11773, June 30, 1964 - September 30, 1965

Contractor: TRG, Incorporated
Route 110
Melville, New York

2. Purpose of Project. The purpose of this project is to develop a He-Ne gas laser at 6328 Angstroms which is stable in frequency to one part in 10^{11}. Such a laser sould be stable to about 1 kHz and could be used as a frequency standard and in optical superheterodyne communication.

3. Technical Status. The basic technique to be used in this scheme is discussed briefly. The frequency of a laser is determined by the cavity length and power level in the laser. Thus it is possible to frequency modulate a laser, by modulating the power level. If the output of one laser is sinusoidally power modulated and the output is heterodyned with another laser, a FM beat signal is obtained which is passed through a frequency discriminator. The phase of this FM beat signal with reference to the pump modulation signal is dependent on whether the laser is operating on one side or the other of the center of the fluorescence line at 6328 Angstroms. Therefore, this FM beat signal can be used as an error signal in a servo loop to drive the frequency of the laser, by means of a piezoelectric pusher to change the cavity length, to the center of the fluorescence line and maintain it operating at the center of the fluorescence line. For a complete description, contact Dr. J. L. Randall.

4. Major Accomplishments. See Problems.

5. Problems. Dc pumping of the discharge in the tube has resulted in plasma oscillations in the gas which cause large FM noise on the laser. This plasma FM of the laser causes a heterodyne signal which swamps the error signal that is desired.

6. Future Plans. In order to get around the above mentioned problem, rf discharge and optical pumping are now being pursued in order to derive an error signal minus the plasma oscillation noise which is always attendant with dc pumped discharge.

7. Illustrations. None.

C. Research on Semiconductor Injection Lasers

Submitted by
(Technical Supervisor)

Dr. J. L. Randall
R-ASTR-RP, 877-2168

1. Project Data

Contract Number: NAS8-5269, Mod 1, April 24, 1963 - January 31, 1965

Contractor: Carnegie Institute of Technology
Pittsburgh, Pennsylvania

2. Purpose of Project. The objective of this research is to obtain a full understanding of the operation of existing semiconductor lasers. With this knowledge, improvements may be made in injection lasers. It is hoped that more practical devices may be built that have better efficiency. Reduction of current densities necessary for laser operation is desired. This would hopefully allow laser operation at temperatures approaching room temperature.

3. Technical Status. This program is conducted in two phases. First, epitaxial growth techniques of growing p-n gallium arsenide junctions are being studied. Second, the effect of pressure on optical absorption and emission properties of gallium arsenide is being studied.

4. Major Accomplishments. Design and construction of an optical ellipsometer to measure the ellipticity of light has been constructed and made operable. Two papers on the theory of retardation plates have been published in the Journal of the Optical Society. The theory of the retardation plates study was made in connection with the data obtained in the ellopsometer.

5. Problems. No major problems at this time.

6. Future Plans. Future plans call for the checkout of the ellipsometer and to determine the effect of pressure on the absorption and reflection of GaAs surface.

7. Illustrations. None.

D. Research and Development of Solid State Photomixing Devices

Submitted by
(Technical Supervisor)

Mr. Cullen Q. Lee
R-ASTR-RP, 876-5290

1. Project Data

Contract Number: NAS8-5030, Mod. 2, May 28, 1962 - November 18, 1964

Contractor: Philco Corporation Research Labs.
Blue Bell, Pennsylvania

2. Purpose of Project. The purpose of this project is to perform research necessary to develop solid-state photomixing devices suitable for use in optical communications and space tracking and guidance, using coherent and incoherent light sources.

3. Technical Status. Some photomixer diodes have been fabricated and delivered to MSFC. These include some InAs diodes for the wavelength region from 0.9 to 3.5 microns, and some Si diodes for the wavelength region from 0.4 to 0.9 micron. The contract is in the process of being extended to cover research for developing photomixer diodes using avalanching as current-multiplication.

4. Major Accomplishments. During the period of this contract the limitations on the frequency response and available power from a photodiode due to its lumped-constant electrical parameters were reviewed. As a result of this review, an available power-bandwidth product limitation on photodiodes has been developed, and the effect of contact-geometry and sheet-resistance on the high-frequency performance of the photodiodes has been analyzed and verified. Some preliminary work was done on avalanching as a possible current-multiplication technique.

5. Problems. The output signal from a photomizer diode as developed on this contract is very low when compared to that of a photomultiplier. This makes it necessary to have a very low noise amplifier to amplify the diode output.

6. Future Plans. The contract is in the process of being renewed to include research for the development of photomixer diodes using avalanching as current-multiplication.

7. Illustrations. None.

E. Development of a 10 Ampere Laser Modulator

Submitted by
(Technical Supervisor)

Mr. D. L. Anderson
R-ASTR-RS, 877-2168

1. Project Data

Contract Number: NAS8-11611, Mod. 1, April 22, 1964 - January 22, 1965

Contractor: Bendix Corporation, Holmdel, New Jersey

2. Purpose of Project. To develop a high current, high speed silicon transistor for use as a modulator for injection lasers. The advantage of this type switch is that it can be used up to a 50 percent duty cycle.

3. Technical Status. The design of this unit has been completed and five prototype samples have been received for evaluation. The samples are now being evaluated but the results are not yet available.

4. Major Accomplishments. If the prototype units meet the specifications, this will provide the fastest high current switch to date for use with injection lasers. Although the actual pulse width is not as narrow as other methods used, the repetition rate will be much greater.

5. Problems. The major problem of this development program is that of encapsulation. There has been a problem in obtaining stud packages that can be temperature cycled over the required temperature range without peeling off the gold plating. The package vendor is busy working on this problem and indicates it should be solved shortly.

6. Future Plans. It is intended to extend the contract to April 22, 1965 in accordance with the contractor's request.

7. Illustrations. None.

F. Laser Amplifier Development

Submitted by
(Technical Supervisor)

Mr. Charles L. Wyman
R-ASTR-RP, 876-5290

1. Project Data

Contract Number: NAS8-11663, June 17, 1964 - July 17, 1965

Contractor: International Business Machine Corp.,
Bethesda, Maryland

2. Purpose of Project. To develop GaAs laser amplifiers for possible use as preamplifiers for solid state optical detectors, and for possible use in coherent phased arrays of injection lasers.

3. Technical Status. Several amplifying diodes have been developed, and gains up to 1500 have been observed.

4. Major Accomplishments. Coating techniques to lower the Q of the diodes have been developed. Typically lasing threshold can be lowered by 25 percent or more resulting in diodes with excellent amplifying properties.

5. Problems. Development of diode fabrication techniques to give large diodes with good optical homogeneity throughout is the major problem.

6. Future Plans. Fabrication, calibration and systematic data analysis to improve amplifier characteristics.

7. Illustrations. None.

G. Investigation of Electro-Optical Techniques for Controlling the Direction of a Laser Beam

Submitted by
(Technical Supervisor)

Mr. Charles L. Wyman
R-ASTR-RP, 876-5290

1. Project Data

Contract Number: NASw-731, NAS8-11459, June 1963 - September 1965

Contractor: General Telephone & Electronics
Bayside, New York

2. Purpose of Project. The purpose of this project is to investigate techniques for precision high speed deflection of laser beams for communication and tracking purposes.

3. Technical Status. One dimensional beam steerers of three types has been developed. These include two utilizing variation of the index of refraction in materials exhibiting the correct electro-optic phenomena, and one using piezoelectric shear plate mirror deflectors.

4. Major Accomplishments. Fabrication of several models of the three types of deflectors, and delivery of two shear-plate deflectors for in-house experiments.

5. Problems. A hysteresis effect has been encountered in all three types of deflectors which will have to be more thoroughly understood in order to develop deflectors of the precision desired.

6. Future Plans. Future plans include development of two-axis deflectors, appropriate driving sources, block diagram development of acquisition and tracking systems using beam steerers, and design of a system for use on an optical tracker being developed in house.

7. Illustrations. None.

H. Development of Fusion Welding for Electronic Connections

Submitted by
(Technical Supervisor)

T. N. Vann
R-ME-ME, 876-2276

1. Project Data

Contract Number: Not Applicable

Contractor: Not Applicable, MSFC In-House

2. Purpose of Project. Develop fusion welding techniques and apply techniques to spacecraft manufacture when they result in a product of superior reliability or performance, or reduce manufacturing cost.

3. Technical Status. This task currently encompasses percussion and electron beam welding investigations.

a. Percussive welding. In this process the members to be joined are heated to the molten state by an electric arc spanning a small air gap separating the members; the members are forged together and allowed to cool. During this report period, devices to securely grip and accurately position the weld members during welding have been manufactured and tested. These devices produced more consistent welds than grips furnished with the equipment and confirmed our theories as to the cause of wide variations in weld strength experienced with the original grips. Another welder from a second manufacturer has been ordered. This welder has demonstrated superior welding capability and the manufacturer of this apparatus apparently has solved the weld member gripping and position problems. The range of sizes the latter equipment will accommodate, however, is rather limited.

b. Electron beam welding. This technique utilizes a high energy beam of electrons in a vacuum to produce the heat required for fusion welds. A similar

technique, but with a different machine, is used for small high precision cutting and milling operations. Sophisticated controls and vacuum weld environments made both machines "adept" in the microelectronic area and with exotic materials. An electron beam welder has been received and is in operation. An electron beam milling machine has been received and is in the process of being put into operation.

4. Major Accomplishments. None.

5. Problems. None.

6. Future Plans. In the area of percussive welding, a west coast company has done some basic research on this phenomena. It is our current plan to investigate what they, and possibly other companies, have done and continue the research if results warrant.

7. Illustrations. None.

I. Improvement of Technology for Electronic Welding and Electrical Manufacturing Methods and Processes

Submitted by
(Technical Supervisor)

T. N. Vann
R-ME-ME, 876-2276

1. Project Data

Contract Number: Not Applicable

Contractor: Not Applicable, MSFC In-House

2. Purpose of Project. To continue the development of electronic welding technology and electronic manufacturing methods and techniques to increase reliability and reduce manufacturing manhours and production cost of space vehicles for MSFC and contractor use.

3. Technical Status. This task currently includes the following activities: flat cable connectors, coaxial cable connections by magnetic swaging, ultrasonic welding of electronic connections, and further automation of manufacturing testing.

a. Flat conductor cable connections. Flat conductor cable stripping and bend equipment has been requisitioned. Also, molding dies for flat conductor cable termination have been ordered. Current efforts are directed toward obtaining equipment and acquiring know-how to utilize flat cable.

b. Coaxial cable connection. No work has been done in this area during this report period. Available effort has been diverted to more urgent and/or more promising areas.

c. Ultrasonic welding. The 600-watt unit was modified to make equipment more easily used. No other work was performed during report period in this area.

d. Automation of manufacturing testing. Work on this project has been suspended in favor of more promising utilization of effort.

4. Major Accomplishments. Accomplishments are more or less intangible. Knowledge of equipment, processes, and current state-of-the-art has been acquired, and equipment is being procured.

5. Problems. None.

6. Future Plans. Plans for utilizing the prototype conductor cabling is near completion. Our approach will be the application of the technique under shop conditions and to further refine and adapt equipment and processes to accommodate a production type environment.

7. Illustrations. None.

J. Development of Technology for Analysis of Electronic Connections

Submitted by
(Technical Supervisor)

T. N. Vann
R-ME-ME, 876-2276

1. Project Data

Contract Number: Not Applicable

Contractor: Not Applicable, MSFC In-House

2. Purpose of Project. Develop means for ascertaining the quality of experimental and flight electronic connections through the use of infrared and similar techniques.

3. Technical Status. The infrared analysis is currently in progress. This analysis technique utilizes infrared sensing devices to detect heat rise or irregular heat distribution in defective or inferior connections. An infrared camera has been received; tests thus far indicate the technique is feasible. An infrared microscope, which will give much finer resolution for miniature connections has been requisitioned.

4. Major Accomplishments. None.

5. Problems. None.

6. Future Plans. The prime objectives stated above will be pursued. The infrared equipment on hand has uses in the area of insulation integrity test. Development of technology in this area will be pursued to the extent of the capability of the equipment and as results warrant.

7. Illustrations. None.

K. Quality Control Requirements for Integrated Circuits

Submitted by
(Technical Supervisor)

Mr. M. J. Berkebile
R-QUAL-AAR, 876-6620

1. Project Data

Contract Number: Not Applicable, March 15, 1964 - June 30, 1966

Contractor: In-House

Budget Number: 125-21-03-0011

2. Purpose of Project. MSFC is investigating the possible use of microelectronics (integrated circuits) for the Saturn V Program. Three items were selected for microminiaturization. These items were the Switch Selector,

on contract to Fairchild; the Control Signal Processor, Martin Company; and the Radar Altimeter, Westinghouse. With the advent of this type electronic circuitry many test parameters and procedures now used for discrete components will become obsolete.

The purpose of this project is through in-house advanced test studies in microelectronics, (1) establish Quality Control Requirements for in-process fabrication and (2) evolve MSFC documentation of in-process and final acceptance testing of items to be used in future Saturn Programs.

3. Technical Status. Direct current measurements by means of "XY" transfer functions for Direct Coupled Transistor Logic (DCTL) and Diode Transistor Logic (DTL) circuit components are in progress. The DCTL devices are similiar to the ones used by Fairchild in the microminiaturized version of the Switch Selector. Westinghouse devices, DTL, will be used in the Radar Altimeter.

Dynamic or switching time function tests were begun in September on DCTL units. Emphasis was placed on simplification of automatic checkout of these units. The information from the switching time tests and "XY" transfer tests will be used to prepare final acceptance test procedures of the digital units used in the MSFC microminiaturization study program.

The Radio Frequency integrated circuit study to determine if a trans-admittance bridge can be used as an acceptance test device was completed in October. The tests were performed using Motorola MD1154 high frequency transistors. An attempt was made to correlate the results with a Resistance-Reactance meter.

4. Major Accomplishments. Fairchild, Martin and Westinghouse have presented two oral progress reports each on their contract efforts toward microminiaturization. Westinghouse and Fairchild have progressed to the listing of the microminiature components which they will use in the prototype items. A procurement request has been submitted for the integrated circuits which Westinghouse and Fairchild will use and tests will be performed to provide a final acceptance inspection technique for these circuit components.

An admittance parameter study of high frequency transistors similiar to the ones used in the Motorola Radio Frequency amplifier, Type MC1110, has been completed. The transistor study was chosen rather than the integrated circuit because of (1) the cost of the MC1110, (2) the test fixture for admittance parameters of the MC1110 was prototype by Motorola and accurate only to plus

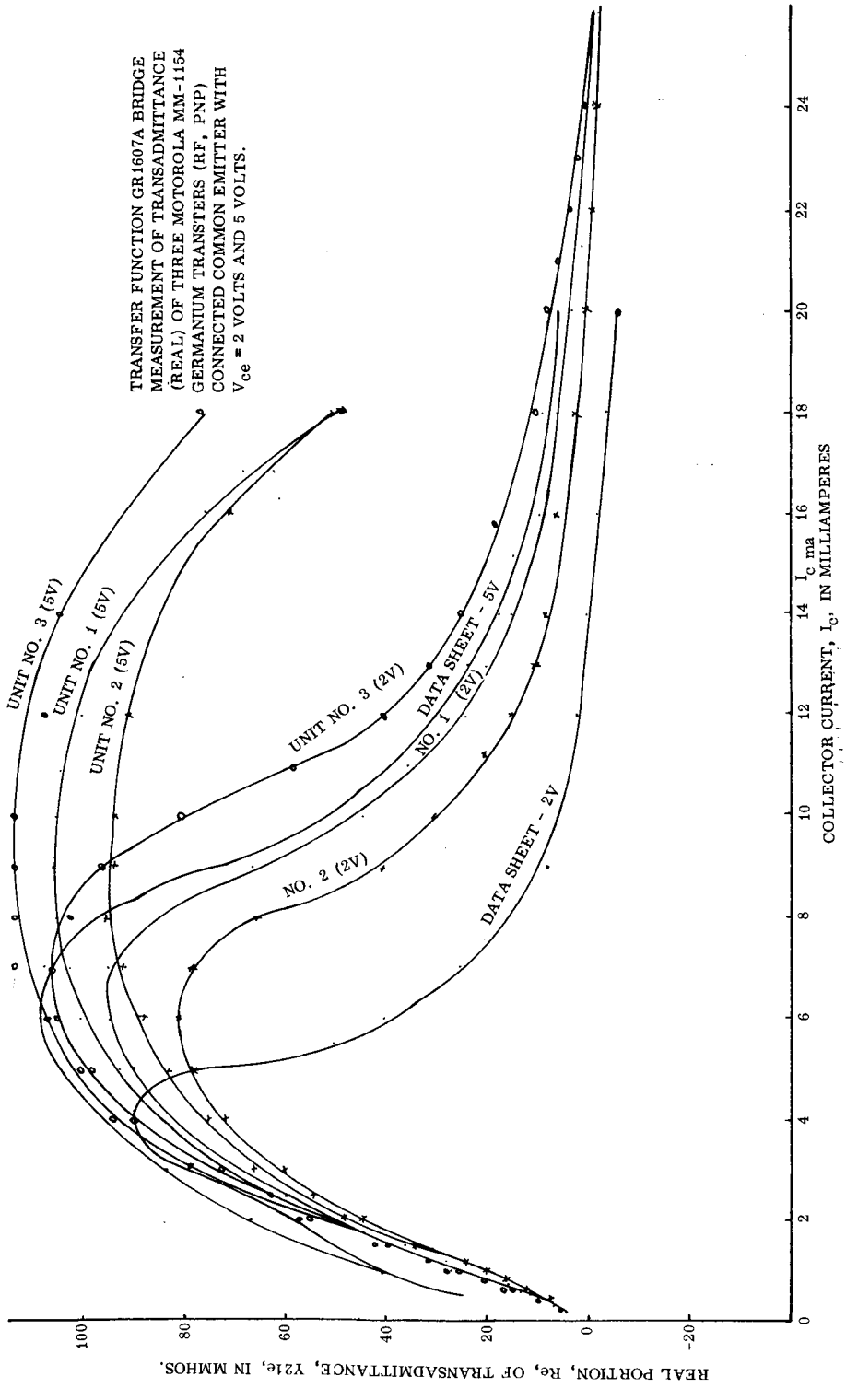


FIGURE 64. TRANSADMITTANCE MEASUREMENTS OF MOTOROLA MM-1154 TRANSISTOR AT 200 MEGOCYCLES AND COMPARISON WITH MANUFACTURER'S DATA SHEET

or minus fifteen percent through careful consideration of all variables, and (3) a commercial test fixture was available for the transistor. It was determined that consistent admittance parameter measurements could not be made (Fig. 64) and it was doubtful as to the usefulness of this method as a test tool.

A study now being conducted on digital logic units revealed certain critical parameters which should be included in the procurement specification microelectronic logic gates. It is expected that continuance of this study will reveal additional parameters.

A study has been initiated to determine optimum measuring techniques for accurate determination of these parameters.

A scope of work was prepared to provide a design study of an automatic checkout test system for microelectronic circuits. Information derived from the "Quality Control Requirements for Integrated Circuits" research was used to prepare this scope of work. Additional information acquired will be used to ensure an optimum checkout test system will be obtained.

5. Problems. The integrated circuits procured to date have been functionally and stress tested without a failure. Since this task is concerned with failure analysis of integrated circuits, other means will have to be utilized to obtain failed circuits in quantities.

6. Future Plans. There will be visits made in the next six months to view leading manufacturers facilities and examine the methods of production and the procedures of in-process testing.

Monolithic circuits, which have failed or which were rejected by the manufacturer for various reasons will be obtained and studied to determine modes of failure.

Printed circuit boards of copper, nickel, kovar, and nickel-kovar-aluminum laminate with line widths ranging from 0.012 inch to 0.25 inch have been procurred. These boards will be used to study integrated circuit parallel gap welding.

7. Illustrations. Figure 64 and 65.

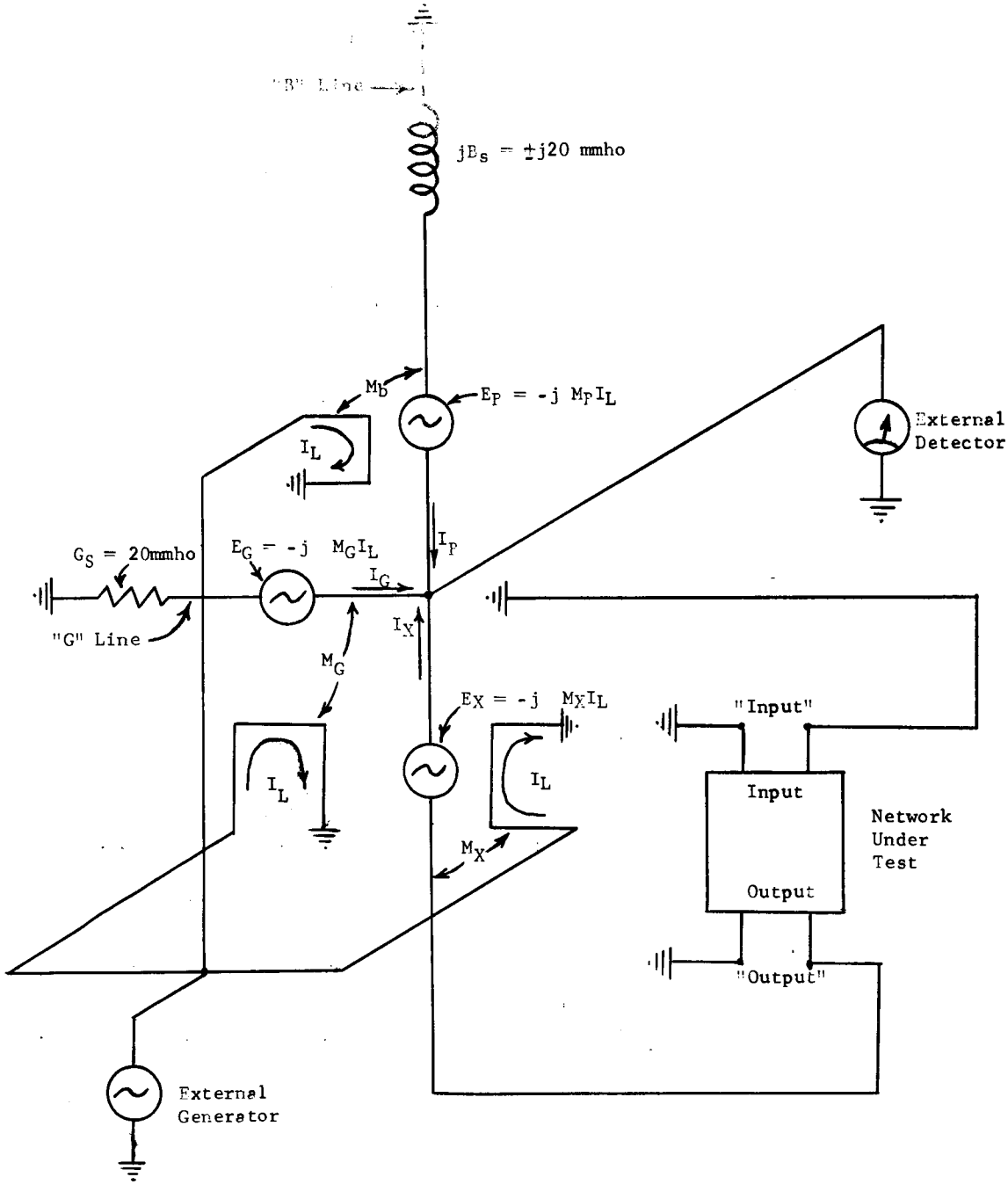


FIGURE 65. SCHEMATIC DIAGRAM FOR EMMITTANCE MEASUREMENTS

TRACKING AND DATA ACQUISITION

Tracking, Data Acquisition and Components

A. Onboard Determination of Orbital Parameters

Submitted by
(Technical Supervisor)

Grady H. Saunders
R-ASTR-I, 876-1296

1. Project Data

Contract Number: NAS8-5411, Mod. 2, June 8, 1963 - July 8, 1965

Contractor: University of Alabama
University, Alabama

2. Purpose of Project. This study has as its objective the definition of advanced systems for the determination of orbital parameters and position relative to space-fixed coordinates, employing onboard electromagnetic sensors. In carrying out this objective, it will be necessary to do the following:

a. Develop mathematic models which will facilitate the evaluation of sensor systems.

b. Define and evaluate sensor system which will provide the desired information on orbital parameters.

c. Define the performance requirements for sensors to be used in these systems.

d. Determine what existing sensors will give optimum system performance and what sensors require development.

3. Technical Status. Work has been continued in analyzing and evaluating the requirements for the optimization of the determination of orbit parameters employing data from existing tracking systems as planned. Work has not reached the simulation stage.

4. Major Accomplishments. A study of optimum orbit determination by minimum variance techniques has been completed and the results embodied in a computer program.

5. Problems. No significant technical problems have been encountered to date.

6. Future Plans. The principal investigator, who has been on this task since its inception, is no longer with the contractor. Also, some of the people that have made major contributions to the work are no longer connected with the task. An overall review and reevaluation of the work that has been performed to date is planned.

Direction of future work on the task will be based on the results of this reevaluation of the present situation.

7. Illustrations. None.

Advanced Electronic Devices

A. Development of High-Power Gas Lasers

Submitted by
(Technical Supervisor)

Dr. J. L. Randall
R-ASTR-R, 877-2168

1. Project Data

Contract Number: NAS8-11613, May 18, 1965 - February 18, 1965

Contractor: Energy Systems, Inc.
Palo Alto, California

2. Purpose of Project. The purpose of this project is to develop two cw He-Ne gas lasers which will operate at 6328 Angstroms, have a power output of 50 milliwatts, be contained in a housing which is no larger than 20 cm by 20 cm by 50 cm, and have a beam divergence of at least 25 arc seconds.

3. Technical Status. The attainment of 50 milliwatts in a 50 cm cavity is difficult. The fact that no cavities of this size have ever yielded 50 milliwatts at 6328 Angstrom is because lossy glass is used for windows in the

discharge tube and that dielectric reflectors are lossy. The basic concept in the construction of these lasers is to obtain the finest quality glass and reflectors available to obtain a very high Q optical cavity.

4. Major Accomplishments. The mechanical design and fabrication of the laser has been completed.

5. Problems. The main problem in the final construction of these lasers has been in not being able to obtain the high quality low light loss glass window material and in obtaining very high quality low loss dielectric reflectors for the cavity. Both can be obtained, but delivery is very slow.

6. Future Plans. Future plans call for further development effort on the dielectric reflectors.

7. Illustrations. None.

B. Frequency Stability Measurements and Improvements of the Hydrogen Maser

Submitted by
(Technical Supervisor)

Mr. Edmund H. Gleason
R-ASTR-IRT, 876-2308

1. Project Data

Contract Number: NAS8-2604, February 1, 1962 - June 30, 1965

Contractor: Bomac Laboratories
Division of Varian Associates
Beverly, Massachusetts

2. Project of Project. To determine the relative short and long term frequency stability between two (or three) atomic hydrogen masers.

To determine the precision to which a given pair of atomic hydrogen masers can be reset in frequency.

To determine very short (0.01 second or less) relative frequency stability between two atomic hydrogen masers.

To determine the ratio of the cesium to hydrogen frequencies of hyperfine separation. This measurement is to be done to eleven significant digits.

To compare in frequency the two NASA atomic hydrogen masers to those at Harvard University.

3. Technical Status. Purposes 1, 2, and 4 have been completed and the results were published in previous semi-annual reports. Purpose 3 has been completed but evaluation of the results have not yet been completely analyzed.

4. Major Accomplishments. Further data for short term measurements were taken. Agreement to within 10 percent was obtained between the calibration technique using a noise generator and that using a known applied frequency perturbation to the maser. A paper was submitted by R. Vessot, L. Mueller, and J. Vanier of Varian Associates at the symposium on the Definition and Measurement of Short Term Frequency Stability. The paper presented the measuring technique and the results of the short term frequency stability task under NAS8-2604.*

5. Problems. There does not appear to be any technical problems at the present time.

6. Future Plans. Further work will be continued to determine the feasibility of optically pumping a hydrogen maser.

The two NASA hydrogen masers will be refitted with new pump elements and new cavity components utilizing quartz before shipment to MSFC.

7. Illustrations. None.

C. Frequency Synthesizing System for the Hydrogen Maser

Submitted by
(Technical Supervisor)

Mr. Edmund H. Gleason
R-ASTR-IRT, 876-2308

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*A Cross Correlation Technique for Measuring the Short Term Properties of Stable Oscillators, by R. Vessott, L. Mueller, J. Vanier from Interim Proceedings of the Symposium on the Definition and Measurement of Short Term Frequency Stability, X-521-64-380, Goddard Space Flight Center.

1. Project Data

Contract Number: Not Applicable

Contractor: MSFC In-House

2. Purpose of Project. To design and Construct a synthesizing system for deriving standard frequencies of 100 kHz, 1.0 MHz, and 5.0 MHz from the hydrogen maser frequency of 1420, 405, 751.7 Hz. The output frequencies are to maintain as closely as possible the accuracy of the maser. The design goal is to be a few parts in 10^{11} for a one millisecond averaging time.

3. Technical Status. OART funds were not available during the reporting period.

4. Major Accomplishments. None.

5. Problems. None.

6. Future Plans. None.

7. Illustrations. None.

INSTRUMENTATION

Engineering Instrumentation

A. Development of Low Range Absolute Pressure Calibration System

Submitted by
(Technical Supervisor)

A. E. Schuler
R-TEST-ID, 876-4938

H. G. Lackner
R-TEST-ID, 876-4938

1. Project Data

Contract Number: NAS8-11629

Contractor: National Research Corporation
Cambridge, Massachusetts

2. Purpose of Project. To perform research in providing a high vacuum calibration system capable of accurately producing pressures down to 10^{-10} Torr.

3. Technical Status. The basic system design has been completed. The pumping systems and the vacuum chambers have been assembled. Research is now underway on refinements necessary to ensure proper operation in the high vacuum range of 10^{-10} Torr.

4. Major Accomplishments. Initial results indicate that a highly accurate vacuum calibration system will result from this research effort. An increase in accuracy over what was expected at the begining of this project due to advances in tolerance control over components.

5. Problems. No major problems have been encountered during this reporting period.

6. Future Plans. Continue research toward the goal of establishing an accurate absolute pressure calibration system for 10^{-10} Torr.

7. Illustrations. None.

B. Strain Gage Accelerometer with Self-Calibrating Feature

Submitted by
(Technical Supervisor)

Mr. A. J. Davis
R-ASTR-IMS, 876-3283

1. Project Data

Contract Number: NAS8-11633, June 23, 1964 - April 23, 1965

Contractor: Raytheon
Research Division
28 Seyon Street
Waltham 54, Massachusetts

2. Purpose of Project. To develop a piezo-resistive strain gage accelerometer-amlifier on a single microelectronics substrate.

3. Technical Status. The working model has been demonstrated. Problems, discussed below, are being investigated.

4. Major Accomplishments. An accelerometer with very high sensitivity, good stability and excellent frequency response has been demonstrated. The unit is built in a TO-18 transistor case and is applicable as a pressure transducer and microphone.

5. Problems. Assembly of the working units into finished cases results, in some cases, in a degradation of performance.

6. Future Plans. Solution of problems and evaluation of the finished units is expected within a few months.

7. Illustrations. None.

C. Self-Calibrating Piezoelectric Accelerometer

Submitted by
(Technical Supervisor)

Mr. A. J. Davis
R-ASTR-IMS, 876-3283

1. Project Data

Contract Number: NAS8-11700, June 30, 1964 - November 30, 1964

Contractor: Gulton Industries
Metuchen, New Jersey

2. Purpose of Project. Develop a self-calibrating accelerometer using a force derived from a source different from that used as the sensor.

3. Technical Status. Contract completed.

4. Major Accomplishments. End-item prototype delivered.

5. Problems. None.

6. Future Plans. Evaluation of prototype to be completed during February 1965.

7. Illustrations. None.

D. Development of Thermocouple Seals to Withstand 1500 psi at 800°C

Submitted by
(Technical Supervisor)

Mr. Harlan D. Burke
R-ASTR-IMT, 876-8434

Mr. Joe E. Zimmerman
R-ASTR-IMT, 876-2780

1. Project Data

Contract Number: NAS8-11626, June 9, 1964 - February 10, 1965

Contractor: Aerojet General Corporation
Sacramento, California

2. Purpose of Project. This effort is directed toward the development of a feed-thru type thermocouple seal designed for zero leakage at high pressures and minimum spurious emf output at high thermal gradients. The seal assembly is to be designed for incorporation into existing thermocouple devices used on space vehicles.

3. Technical Status. Breadboard seals have been developed and evaluated at the contractor's facility. An environmental test plan was submitted to MSFC for approval prior to the evaluation. The NBS recommended practices for thermocouple testing were adhered to as were applicable. The seals were tested for spurious emf's with a 500°C gradient across the seal. Gradients were established by maintaining one side of the seal at -150°C and the other side at 350°C. A second gradient was established by maintaining one side at 300°C and the other at 800°C. Other tests performed were insulating resistance, pressure, vibration, and life expectancy.

4. Major Accomplishments. Thermal gradient testing of the initial seal assemblies generated spurious voltages as high as three millivolts. Subsequent testing, evaluation, and design improvement of each material used and each assembly technique employed has reduced the spurious emf output to 22 microvolts. This is considered to be a significant improvement in thermocouple seal and feed-thru technology.

5. Problems. The technical problems that remain to be solved are (1) optimizing the bonding, brazing, and welding techniques employed in the seal assembly and application, (2) designing the seal for production quantities, and (3) preparing documentation and test reports.

A no cost extension in time will be required, contractually, because the late delivery of the breadboard seals did not allow sufficient time for MSFC evaluation.

6. Future Plans. After MSFC evaluation and confirmation of the breadboard seals, the vendor will construct and deliver prototype seals. A follow on purchase order will be placed for typical Saturn thermocouple transducers with these seals incorporated. These transducers will then be evaluated in an actual vehicle environment to determine the performance of the seals.

7. Illustrations. None.

E. Self-Calibrating Cryogenic Pressure Transducer

Submitting by
(Technical Supervisor)

Mr. Ray C. Holder
R-ASTR-IMP, 876-4581

1. Project Data

Contract Number: NAS8-5460, Phase I, June 28, 1963 - May, 1965

Contractor: Gulton Industries, Inc.
Metuchen, New Jersey

2. Purpose of Project. Provide a self-checking force balance pressure transducer that can self-check its initial calibration to an accuracy of 0.1

percent of full scale. The force summing member actually deflects when a command voltage introduces an error signal. This completely checks the calibration of the instrument except for a leak in the force summing member.

3. Technical Status. The prototype has been delivered and testing should be completed by February 1965.

4. Major Accomplishments. The major accomplishments have been to provide a transducer that can be installed in a system and completely checked without breaking into the system to apply pressure to the transducer. The force balance pressure transducer provides one of the most accurate pressure transducers that has been tested.

5. Problems. There have been three major problems: size, weight, and power requirements. Considerable effort has been made to solve these problems and considerably more will be required before the transducer can be used for flight.

6. Future Plans. This task has been completed. A follow-up task will be required to repackage and reduce the power requirements.

7. Illustrations. None.

F. Development of an Image Converter of Radical Design

Submitted by
(Technical Supervisor)

Mr. Carl T. Huggins
R-ASTR-IR, 876-2944

1. Project Data

Contract Number: NAS8-5112, Phase II, July 1, 1962 - February 28, 1965

Contractor: Westinghouse Electric Corp.
Air Arm Division,
Baltimore, Maryland

2. Purpose of Project. The objective of this program is the development of useful 50 by 50 phototransistor element sensor moasics with suitable peripheral equipment for readout at TV rates.

3. Technical Status. Projection of an image converter system consisting of a 50 by 50 photo transistor mosaic with a 6 by 6 peripheral readout equipment has been made in a single package complete with optics. Interconnection techniques allow scanning of any 6 by 6 section of the 50 by 50 mosaic. This unit is at MSFC undergoing further tests now.

Mosaic characteristics have been presented with regard to junction breakdowns, optical-electrical response, element dynamic range, conversion linearity, and element response uniformity. A modified topology for NPN strip collector phototransistor mosaics has been developed to improve fabrication yield, reproducibility and response levels. Extensive cross-talk investigations have been conducted; effects of a limited magnitude were noted; physical mechanisms and equivalent circuit representations for the observed phenomena were determined. Several steps were taken to minimize the effect of cross-talk by suitable alterations in both the mosaic and the peripheral readout equipment design. The photocurrent produced in a transistor element has been observed to vary approximately linearly as a function of illuminated base area of a constant energy density spot. The temperature dependence of phototransistor dark current has been determined in the range from 0°C to 100°C: with a 6-volt bias a dark current of the order of 3 by 10^{-10} amperes was observed at 0°C; and, 1 by 10^{-7} amperes was observed at 100°C.

The 10 by 10 element peripheral readout system has been completed and tested in the laboratory. Preliminary tests indicate that because of the improved sensitivity of the 50 by 50 mosaics and the more efficient readout system, the sensitivity of this system is significantly better than that of the modified 5 by 5 camera delivered to NASA in June.

Replacement modules are being fabricated for insertion into the peripheral equipment to increase the readout capability to a minimum of 20 by 20 as specified in the latest contract revision.

4. Major Accomplishments. Production of 50 by 50 mosaics with improved sensitivity over a wider temperature range.

Increasing the readout capability of the peripheral equipment to 10 by 10 mosaics.

5. Problems. Design of appropriate interconnections between the peripheral equipment wagers to allow continued extension of the readout capability.

To continue to increase the rate of switching as the number of elements increases to keep the frame scan time the same.

6. Future Plans. Refinement of mosaic design and processing; fabrication, testing and analysis of four groups of NPN 50 by 50 phototransistor mosaics including varying surface treatments; fabrication and testing of three additional groups of 50 by 50 mosaics of a type to be determined by the contract officer; the extension of peripheral equipment to read out a 20 by 20 segment of a 50 by 50 mosaic; and packaging development for the image converter mosaic-peripheral equipment system.

7. Illustrations. None.

G. Design and Development of Solid State Image Converter for Space Vehicles

Submitted by
(Technical Supervisor)

Mr. Carl T. Huggins
R-ASTR-IR, 876-2944

1. Project Data

Contract Number: NAS8-5116, July 1, 1962 - December 31, 1964

Contractor: General Electric Co.
Electronics Laboratory
Syracuse, New York

2. Purpose of Project. To determine the feasibility of constructing a solid state image device approximating vidicon characteristics. Scanning will utilize conic propagation of stress waves. Appropriate nonlinear elements and photosensitive materials will be determined.

3. Technical Status. The work on photoconductors as used in this project is esentially complete. The degree of reproducibility is good. Platinum sputtering is currently being used to assure good adherence to the SiO_2 substrate and the gold coated diode contact on the one side of final structure. It also provides a stable contact to the superimposed photoconductor.

Damping experiments were performed on both the nickel and copper electrode delay lines. Glass cloth tape with a thermo-setting adhesive backing was applied to the copper line edges and extends to cover 4 mm of the line surface on all sides. A rubber based strip-off compound was applied to the nickel electrode line edges and 4 mm of the line surface. These delay lines were incorporated into the equivalent circuit of the 30 by 30 element system. The delay line output impedance was increased to 990 ohms to conserve delay line energy. A smaller charge storage capacitor of 100 pf was also incorporated into the equivalent circuit to decrease the size of the matrix element. Operation of the system with these parameters is satisfactory, with typical output voltage signals of 1 mv corresponding to no illumination to 27 mv corresponding to full illumination (saturation) across a 50 ohm load. A new output circuit, which allows both delay lines to be grounded, has been built and tested using the 30 by 30 equivalent circuit. The scheme uses a silicon diode at each tap of one of the delay lines to extract a signal current to a common load resistance. Delay line noise present in the high Q ceramic lines is no longer present. The system appears to be a promising readout method and will be compared directly with the present system using the 9 by 9 matrix breadboard.

Performance specification and circuit design of the pulse generator, trigger circuits, and video amplifiers has been initiated. In general, conventional components and subassemblies can be used to implement the circuits. As a parallel effort to the delay line scanning, a complete microelectronic scanning scheme has been designed. From this design, cost, size, and performance comparisons can be made.

4. Major Accomplishments. Considering the state of the art in ceramics, the best present type of delay line has been achieved.

Photoconductors have been improved to a fairly well advanced point.

5. Problems. Sputtered photoconductors - Suitable devices have been deposited having the required gain and resistivity. The present hand sprayed targets are imposing a limitation in the minimum usable size of the photoconductor due to imperfect adherence to the target, and subsequent transfer of small CdSe particles to the sputtered plates. The present vertical DC sputtering equipment may have to be modified to eliminate this problem.

Delay lines made from high Q ceramic had low coupling efficiency at first and therefore not usable. Lines were than made from GD 427AA ceramic but only in thick form. However, the required testing and measurements of these lines, along with the development of suitable damping techniques, have not yet been achieved.

To date, the technique for photoconductive elements has been to produce 30 by 30 elements on a wafer; scribe, crack and then reconnect these elements together. The isolated region technique should definitely be used but masking and fabrication techniques for this are just now being studied.

6. Future Plans. Allow completion of present sputtering techniques and damping techniques to the completion of the current phase. But, since the difficulties connected with the lines and especially with the photoconductive mosiac are as stated, it is felt that further pursuit into this approach beyond the current contract of April 30, 1965 is not advisable because of advance work done under NAS8-5112.

7. Illustrations. None.

H. Pressure Probe Characteristics in Transitional Knudsen Number Range.

Submitted by
(Technical Supervisor)

James O. Ballance
R-AERO-AM, 876-3689

1. Project Data

Contract Number: NAS8-11046, June 20, 1963 - August 31, 1964

Contractor: University of Southern California
Engineering Center
Los Angeles 7, California

2. Purpose of Project. The purpose of this project is to determine the characteristics of pressure probes to be used in the checkout and calibration of low density wind tunnel nozzles and on pressure probes to be used on launch vehicle measuring programs.

3. Technical Status. The experimental portion of the study was completed, and analysis of the data was started in August, 1964. Most of the data and the preliminary analysis were presented at the Fourth International Symposium on Rarefied Gas Dynamics, University of Toronto, Canada, July 14-17, 1964. Tests were made at nominal Mach numbers of 1, 3, 9, and 10.

While most analytical methods for free molecular flow impact tubes consider only collisions of free stream molecules and the wall or probe molecules and the wall, a first collision model was generated for the program to include transitional effects on tube response. Both the internal and external effects of tube geometry on the tube response were investigated.

4. Major Accomplishments. The investigations achieved three essential results. First, the experimental response characteristics of several impact probe configurations were determined over nearly the full interval of transition between the free-molecule and continuum flow regimes and over a wide range of Mach numbers. The configurations were designed to distinguish internal and external transition effects and the results show a profound influence of both Mach number and probe aperture length on the extent of the transition interval. The results also indicate that the transition interval can be minimized to about two orders of magnitude in Knudsen number by employing probes with very short aperture lengths and large cavity dimensions relative to the aperture diameter.

Secondly, a theory based on a "first colision" modification to the free-molecule model was developed which accounted for much of the experimentally observed internal and external probe characteristics. The free-molecule theory was also extended to probe geometries which lack the idealized simple aperture and large cavity configuration previously treated by other investigators.

Finally, the techniques for applying the impact probe to the calibration of low density wind tunnel nozzles and to flight measurements in the transitional Knudsen number regime were developed and discussed. The former involves a straightforward separation of nozzle viscous effects from probe effects in the transition regime and can be easily accomplished by employing a set of geometrically similar probes which are relatively insensitive to Mach number changes.

5. Problems. There are several aspects of the investigation in which the results were indecisive and incomplete. The most notable of these are the extent to which the theory was applied to the experimental data, the experimental effects and theoretical effects of probe cooling, and a decisive experimental demonstration of free-molecule conditions for the probe. It was an unfortunate circumstance of the program that the development of the theory in its final and most promising form came too late to influence the course of the experiments or to permit even the large number of calculations necessary to compare it with all of the measured data. The most intense interest naturally centers around the probe cooling data because of the unexplained undershooting effect and its direct application to flight measurement.

An equally inconclusive state of affairs exists regarding the experimental achievement of free-molecular conditions. In spite of the fact that Knudsen numbers approaching and exceeding ten were achieved with the Series A probes at Mach number 1, 3, and 6, and that the corresponding response levels were within a few percent of theoretical free-molecule values, the experimental data showed little indication of asymptotically approaching the free-molecule level. It would appear that new experiments designed to produce Knudsen numbers of at least 30 will be necessary to complete the transition interval for short aperture probes.

6. Future Plans. As experimental facilities to produce the required testing parameters are not available, an inflight system will be investigated to carry this study to higher Knudsen numbers.

7. Illustrations. None.

I. Development of Advanced Flight Strain Measuring Techniques

Submitted by
(Technical Supervisor)

W. B. Cruise
R-ME-MEI, 876-7459

1. Project Data

Contract Number: Not Applicable

Contractor: Not Applicable, MSFC In-House

2. Purpose of Project. The purpose of this project is to continue and expand current testing, evaluation and development of new measuring techniques for flight measurements on Saturn vehicles, particularly in the area of strain instrumentation. This will entail tests involving gages of the most advanced types, cements, vibrational tests, temperature, humidity, vacuum testing, and flight instrumentation calibration for flight Saturns.

3. Technical Status. Currently, we are continuing work on extending the available knowledge of characteristics into the cryogenic region where very little data is available. Characteristics of gages and cements are very necessary in may flight measurements on the Saturn vehicles. Current demands on the Saturn V system in some applications are pushing the state of the art in strain measurements. Many of these are made in either the cryogenic or high temperature regions where little published data is available.

Tests on newly developed gages and cements are continuing. A special test apparatus has been developed, and attempts are being made to standardize the testing procedures to better compare different gages and cements. A special environmental testing apparatus is now being manufactured.

A recent development in the strain gage field is the flame spray process of encapsulating an unbacked gage in ceramic directly sprayed on specimen. Personnel have been factory trained in this application in both cryogenic and high temperature regions. Direct immersion in LOX may be possible. No actual data is available on this process. Extended tests will have to be made.

4. Major Accomplishments.

a. Strain gage characteristics at cryogenic temperatures. Investigations of gage characteristics at cryogenic temperatures are continuing. Considerable data has been gathered in this field. The more common types of gages are being investigated first. Investigation of other types will continue.

b. Transducer characteristics at cryogenic temperatures. Strain gaged bolts were used as load cell transducers in gasket tests on the LOX tank sump manifold. Load calibration of transducers at ambient temperature is shown in Figure 66. Calibration at LN_2 temperatures is shown in Figure 67.

c. Flame spray technique for applying strain gages. Personnel have been factory trained for this technique which shows promise for both cryogenic application and high temperatures to 1500° F. Equipment has been ordered and tests will begin when the equipment is received.

5. Problems. A considerable reduction in FY '65 funds has sharply curtailed the purchase and manufacture of needed equipment.

6. Future Plans.

a. Investigation of characteristics of gages and cements will contine.

b. Flame spray technique will be thoroughly investigated.

c. Stress analysis by newest photoelastic and Moire' fringe method will also be completely investigated.

7. Illustrations. Figures 66 and 67.

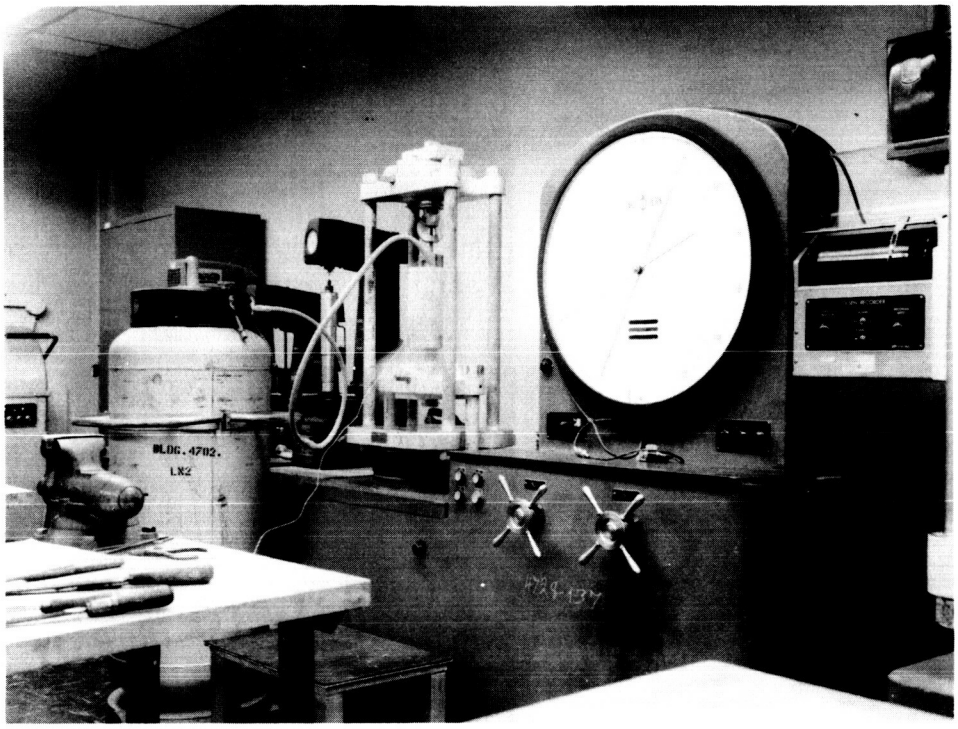


FIGURE 66. TRANSDUCER LOAD CALIBRATION AT AMBIENT TEMPERATURE

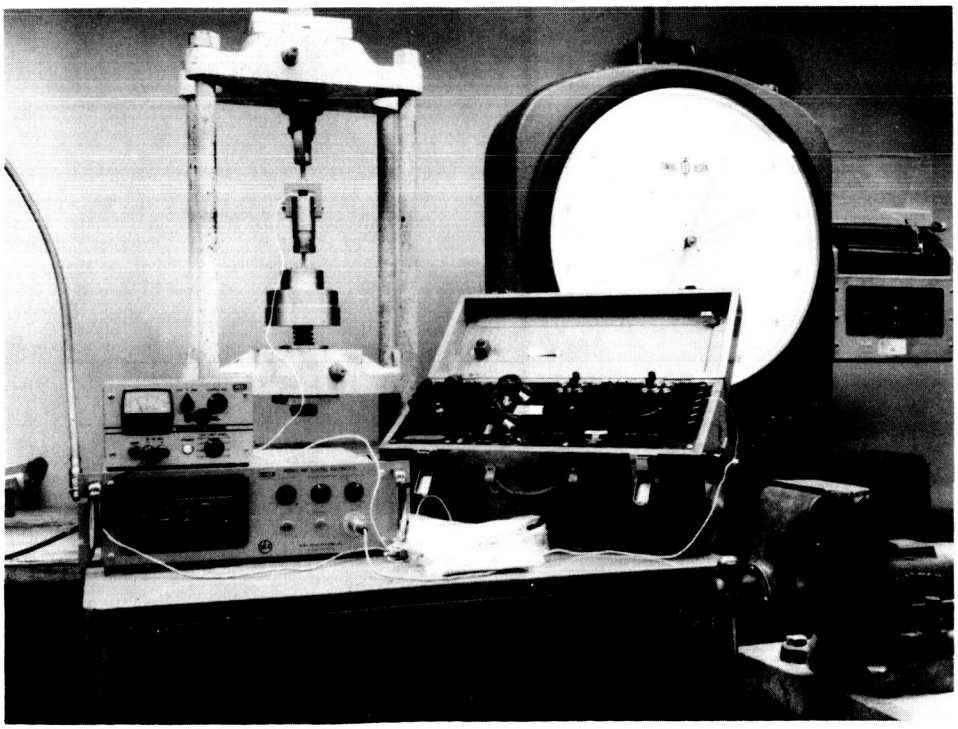


FIGURE 67. TRANSDUCER LOAD CALIBRATION AT LN_2 TEMPERATURE

Astrophysical Instrumentation

A. Electric Field Meter Investigation

Submitted by
(Technical Supervisor)

E. L. Shriver
R-RP-S, 876-7571

1. Project Data

Contract Number: Not Applicable

Contractor: Not Applicable, MSFC In-House

2. Purpose of Project. To investigate the feasibility of using the deflection or displacement of a low energy, less than 100 electron-volt, electron beam by an electrical field to indicate the electrical field strength. It is desired to measure electrical fields as low as 1.0 volt/meter to 10.0 volt/meter.

3. Technical Status. Preliminary tests are underway to determine the compatibility of components and materials in the vacuum chamber. Fabrication of the experimental test setup is in progress.

4. Major Accomplishments. The acquisition, activation, and checkout of test equipment and experimental devices has been the major accomplishment. Some equipment has not yet been received, but enough is on hand to carry out some experimental work.

5. Problems. No demonstrated problems have yet been encountered, but considerable attention has been given to the anticipated effects from magnetic fields. The equations of motion for the electron in a randomly oriented electric and magnetic field uniform in space and time were solved to determine if both the electrical and magnetic field can be measured using this principle. While no procedure for accomplishing this task has been devised yet, the quantitative effects of magnetic fields can be calculated. It may be that some method of nullifying the Earth's magnetic field will be necessary, but if possible this task will be avoided.

6. Future Plans. It is planned that a beam direction be established for the case of no electrical field. This beam direction will be used as a baseline, and the voltage on deflecting plates necessary to return the beam to this baseline when a known electrical field is present will be used to indicate the field strength. If successful, a calibrated field meter principle will be demonstrated.

7. Illustrations. None.

B. Design and Development of a Breadboard Model of an Ultraviolet Air Density Gage

Submitted by
(Technical Supervisor)

John T. Belcher
R-AERO-AEQ, 876-1974

1. Project Data

Contract Number: NAS8-11220, June 11, 1964 - January 11, 1965
NAS8-5226, February 16, 1963 - November 16, 1963
(No cost extension from November 16, 1963, to January 16, 1964.)

Contractor: Electro-Optical Systems, Inc.
Pasadena, California

2. Purpose of Project. Perform an engineering design of a breadboard model of an ultraviolet air density gage.

Design and construct a breadboard model of the density gage, including the sensor, detector, and associated electronics.

Bench and vacuum chamber test the breadboard under conditions of the anticipated density, temperature, acceleration and vibration environment.

Prepare a design and test summary report.

3. Technical Status. The scope of work is complete except for submitting the final report. The tests concluded that the dynamic linear pinch ultraviolet source is of sufficient strength to obtain qualitative air density measurements between 70 and 150-km altitude.

Wavelength (Å)	Photons Per Pulse of 9 sec Duration
200	5×10^{12}
400	9.3×10^{12}
600	9.8×10^{12}
700	9.3×10^{12}
800	9.0×10^{12}
1000	8.0×10^{12}
1500	5.7×10^{12}
1800	5.4×10^{12}

However, to obtain quantitative density measurements, a proposal for further ultraviolet source development and system calibration has been submitted.

The ultraviolet source, a dynamic linear pinch of argon gas, at this stage of development is strictly a laboratory breadboard research model and therefore not suitable as a laboratory intrument without frequent repair. This deduction is based on MSFC requirements for a source that can be pulsed from 1 to 10 times per second; however, the present source has a life span of approximately a year or greater if allowed to cool between cycles.

4. Major Accomplishments. Produced an ultraviolet source which is 50 percent stronger at wavelength of 500A to 700A in photons per sec than a commercially available source.

5. Problems. None.

6. Future Plans. The source appears to be adaptable to low density flow visualization where $P_s = 10^{-4}$ mmHg. It is anticipated that further source reliability development can be accomplished and the source used as a laboratory research instrument.

Another division at MSFC is attempting to obtain a follow-up contract to develop the electronics of the source as a flight package.

7. Illustrations. None.

DATA HANDLING

Advanced Computing Devices

A. Studies of Random Process Theory and Physical Application

Submitted by
(Technical Supervisor)

Jack A. Jones
R-COMP-RRV, 877-8341

1. Project Data

Contract Number: NAS8-11346

Contractor: Cornell Aeronautical Laboratories

2. Purpose of Project. To study and research present state-of-the art concepts concerning stationary and nonstationary random processes. Major area of endeavor should concern those processes when the process is composed at both random and periodic functions. Also, this study should be concerned with making sound recommendations as to the application of existing hardware to analyze functions of the above nature.

3. Technical Status. The majority of technical endeavor has been in the following areas: (1) The analysis of nonstationary processes, (2) Devising of new correlation functions and/or techniques, (3) The synthesis of digital filters.

The work concerning item 3 has been completed and considerable work has been done on item 2. Work on item 1 was started during the past reporting period. The study of nonstationary correlation function was initiated during the last reporting period and will continue for the remainder of the project.

4. Major Accomplishments. Several proposed techniques for computing autocorrelation functions have been investigated and a new high speed technique for obtaining an estimate of the autocorrelation or cross correlation. These techniques were simulated on the IBM 7044 and the results will be published in the final report. The study of optimum discrete double-ended has been completed and the results will be published in the final report.

5. Problems. No serious problems.

6. Future Plans. It is desirable to extend the present scope of work, with minor modifications, for another 12 month period.

7. Illustrations. Illustrations will be contained in the final report.

B. Improved Integration Techniques for Digital Differential Analyzer

Submitted by
(Technical Supervisor)

Mr. Hugh W. Zeanah
R-COMP-RS, 876-1956

1. Project Data

Contract Number: NAS8-11608, June 30, 1964 - July 1, 1965

Contractor: Bunker-Ramo Corp.
8433 Fallbrook Ave.
Canoga Park, California

2. Purpose of Project. To research 300 MC elements and develop prototype DDA with Clock and Control Circuitry and two integrators using the 300 MC logical elements.

3. Technical Status. All circuitry has been designed and tested using chipped diodes and transistors and thin film techniques. Engineering specifications have been released to shops and major part of fabrication has been completed.

4. Major Accomplishments. From results obtained in tests, it appears that a general purpose DDA can be built for 300 MC operation using techniques developed on this project. Multilayered circuit boards, clock bar for distribution of clock signals and other shielding techniques have been used to obtain operation at 300 MC.

5. Problems. Some problems with shielding and construction have been encountered but overcome now. There will be a sizeable overrun in costs if completed.

6. Future Plans. A prototype will be delivered at the end of the contract allowing an evaluation of results at the Computation Laboratory. If results are favorable a new contract might be considered to developed a DDA package of about 60 to 100 integrators.

7. Illustrations. None.

C. Development of New Methods and Applications of Analog Computation

Submitted by
(Technical Supervisor)

Dr. Walter K. Polstorff
R-COMP-RS, 876-5407

1. Project Data

Contract Number: NAS8-2437, September 12, 1961 - December 12, 1965

Contractor: Georgia Tech Inst. of Technology
Engineering Experiment Section
Research Bldg., Atlanta 13, Georgia

2. Purpose of Project. To investigate and develop new methods and applications of analog computation. During this reporting period three (3) areas of interest were investigated:

a. The development of an electronic switch for potential use as an analog computing component.

b. Application of the developed method to generate nonstationary noise to specific technical problems.

c. An error analysis for Hybrid Computation in relation to the power spectrum of the solutions.

3. Technical Status.

a. An experimental evaluation of a variety of circuits has narrowed down the number of approaches which appear to be promising. The results were largely influenced by the rapid development of semi-conductor components.

b. Discussion of the use of nonstationary noise in the simulation of a missile trajectory subject to random wind disturbance.

c. A survey of papers on errors introduced by sampling, truncation, and time delay.

4. Major Accomplishments.

a. A standard evaluation scheme for electronic switches has been set up.

b. A report has been issued which broadens the theoretical background for the application of moise generators to the simulation of nonstationary processes.

c. A conclusion on the best approaches for an error analysis of Hybrid Computation has been reached.

5. Problems. No significant problems.

6. Future Plans.

a. A detailed plan of future efforts in specified areas will be formulated and the usefulness of the switches will be demonstrated in an analog element.

b. Continuation of experimental efforts to demonstrate the use of noise generators in the simulation of random processes of prescribed variable first and second moments.

c. Error analysis of selected groups of Hybrid Computation problems.

D. Research and Development, Fluid Amplifier and Logic

Submitted by
(Technical Supervisor)

Mr. R. J. Alcott
R-ASTR-NFM, 876-8487

1. Project Data

Contract Number: NAS8-5408

Contractor: General Electric
Schenectady, New York

2. Purpose of Project. To define the state of the art and capability of pure fluid elements and systems employing fluid devices.

3. Technical Status. Originally this program began as a three phase effort:

Phase I. State-of-the-art survey
Phase II. Determination of feasible applications
Phase III. Development of critical fluid amplifier components.

1. Fluid amplifier manual
2. Development of digital integrator
3. Actuator demonstrator (consignment for evaluation)

Phase I and II are complete. Phase III is complete except for delivery of demonstration hardware. During Phase III, a need was realized for gathering statistical data from a typical fluid element under pressure, temperature, and controlled contamination. A shift register was selected for this purpose. Failures were determined whenever the register failed to maintain the proper count sequence.

Data for the fluid amplifier manual was obtained through questionnaires distributed to 25 laboratories. Contents of this questionnaire included the request for terminology, nomenclature, schematics, and characteristics data. These data have since been compiled and distributed in a separate report manual titled, "Fluid Amplifier Manual," dated September 1964.

The actuator demonstrator is sized for the RL-10 engine. Fluid amplifiers are used to replace electronics for amplification and shaping network. The fluid cuicuitry is shown in Figure 68. Tow paths are provided: a proportional path with limiter and a rate path (output proportional to error rate). Two interfaces are employed: one between the electrical command and fluid amplifiers and one between the output of the fluid amplifier to a mechanical power spool. Figure 69 illustrates the system block diagram. The entire system is pneumatic.

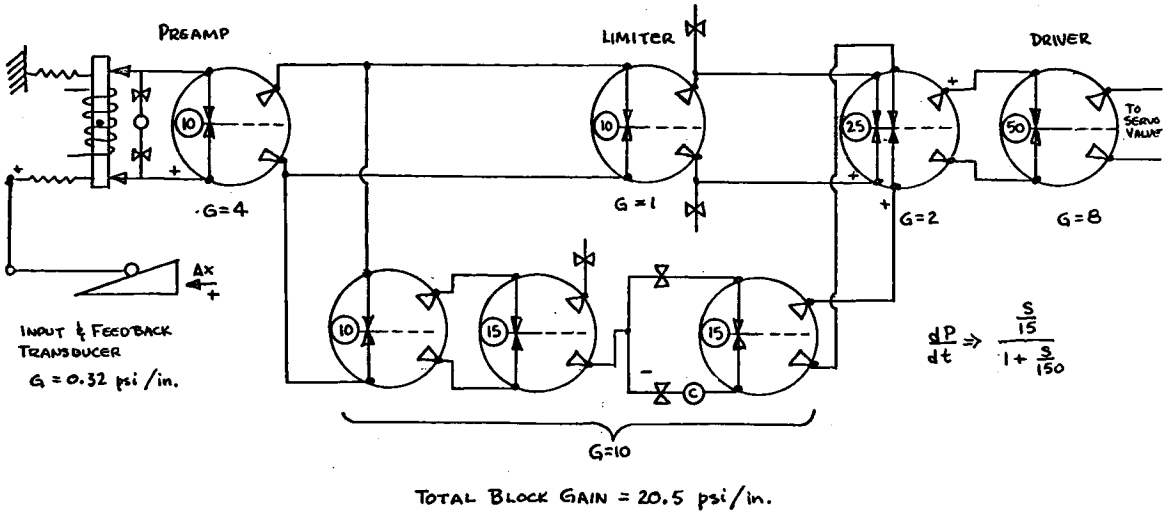
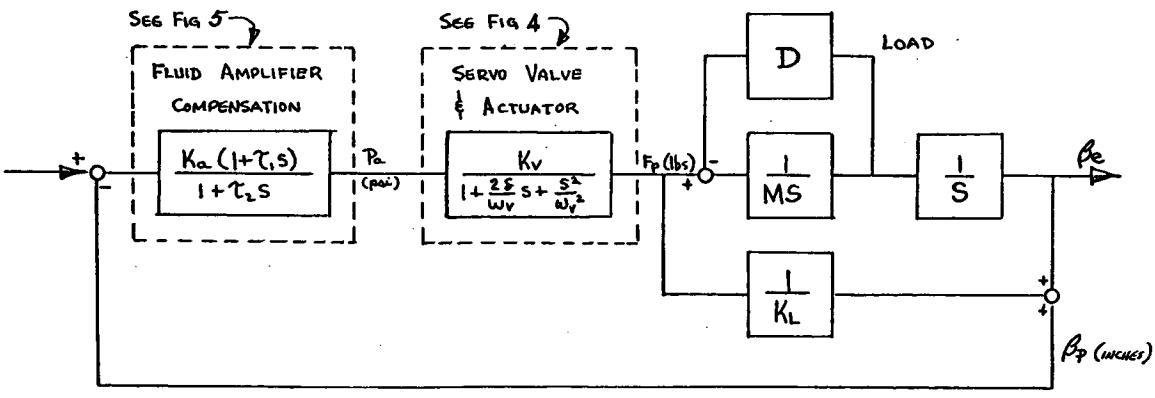


FIGURE 68. FLUID AMPLIFIER COMPENSATION - CIRCUIT DIAGRAM



$K_L = 13700$ lbs/in

$M = 2.12$ lb-sec²/in

$K_a K_v = 1920$ lbs/in

$\omega_v = 180$ rad/sec.

$\tau_1 = 1/15$ sec.

$\tau_2 = 1/150$ sec

FIGURE 69. ACTUATOR SYSTEM BLOCK DIAGRAM

Phase I and II have been published. Reports covering phases III and IV are not available except for the Fluid Amplifier Manual. These reports should be available for distribution by March 1965. The following person should be contacted for report copies.

Mr. Robert L. Murphy
ATSS-AC/Head, Contractor Reports Unit
Scientific & Technical Information Division
National Aeronautics and Space Adm. Hqs.
Washington, D.C. 20546

4. Major Accomplishments. General Electric has established a reference for capability, available, reliability, and applications for pure fluid amplification devices. Final documentation of these studies provides a single reference for fluid technology in most any facet. The wide distribution of phase I and II reports is an indication of the value of this study to industry and government needs.

5. Problems. There have been no problems; however, the completion date is being extended one month making the formal completion in February 1965.

6. Future Plans. It is anticipated that the contract will be amended to incorporate phase V. This phase would include a study of applications of fluid interaction devices as applied to a control system for advanced launch vehicles with primary emphasis on control systems required for recovery of first and second stages.

7. Illustrations. Figures 68 and 69.

E. Study of Fluid Amplifier Scaling

Submitted by
(Technical Supervisor)

Mr. R. J. Alcott
R-ASTR-NF, 876-8487

1. Project Data

Contract Number: NAS8-11267

Contractor: Case Institute of Technology
Cleveland 6, Ohio

2. Purpose of Project. To establish the relationship between size, flow medium, and performance of typical pure fluid amplification-devices. Results and conclusions are to be based on analytical and experimental data.

3. Technical Status. This work is being performed by graduate students of Case under the direction of Charles Taft and Isaac Greber. Analytical studies have been in progress since award of contract. These studies have not progressed to the point where results are easily summarized. Three typical fluid elements are being tested. These elements are illustrated in Figures 70, 71, and 72. These three devices represent the basic principles of fluid operation. Test data is not available.

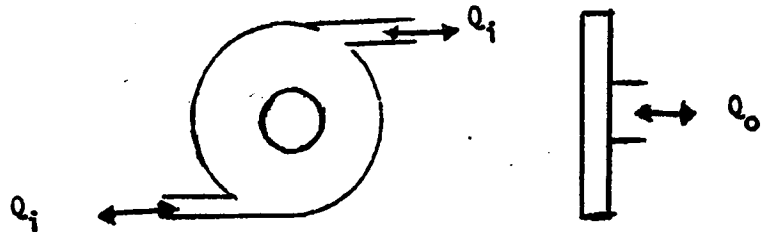


FIGURE 70. VORTEX DIODE

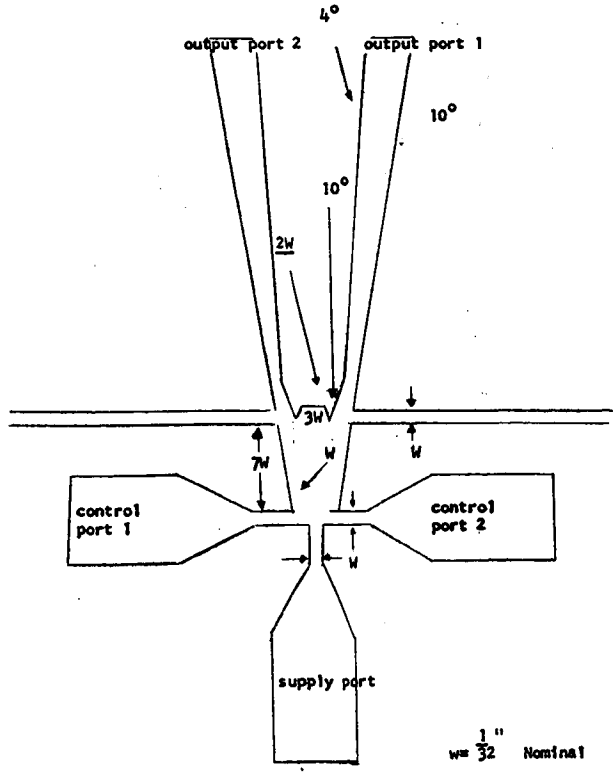


FIGURE 71. SCALED DRAWING OF DESIGNED BISTABLE AMPLIFIER

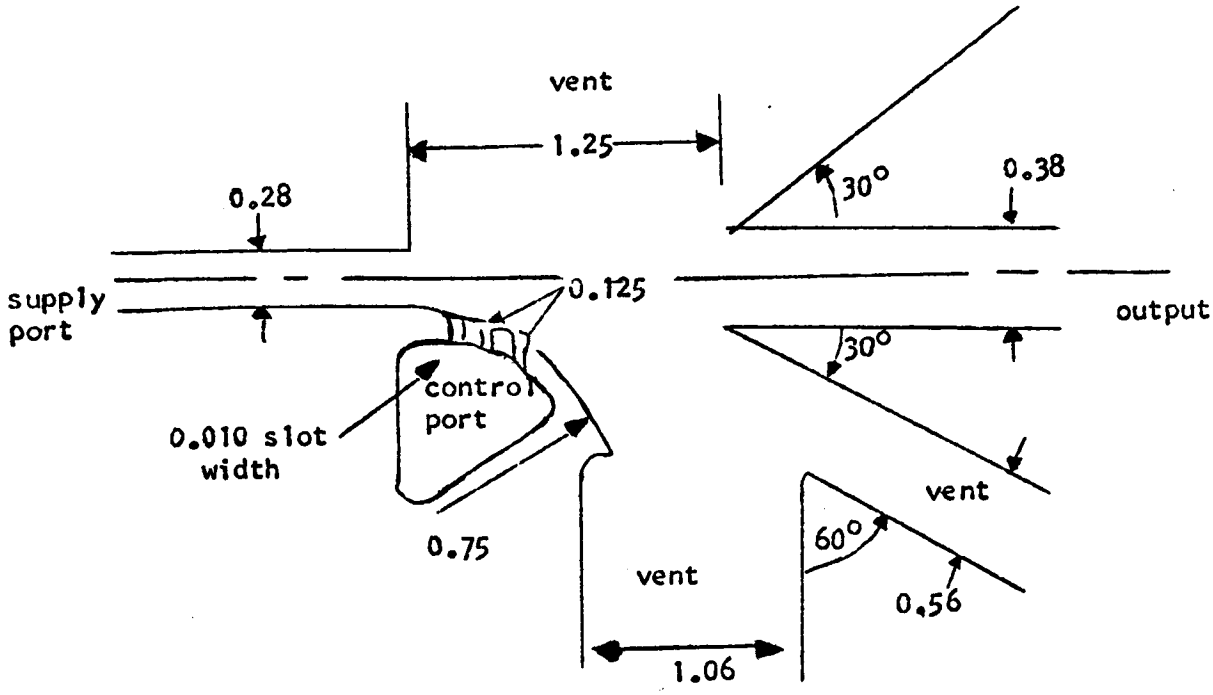


FIGURE 72. BOUNDARY LAYER AMPLIFIER

4. Major Accomplishments. None to report to date.

5. Problems. Lack of manpower has been a problem. The student originally assigned to this program quit school. For several weeks no one was assigned to the program. At the present time there is one student assigned full time to the program.

6. Future Plans. Plans are to correlate the analytical results with the experimental results obtained from the three fluid elements. These results should provide a basis for scaling pure fluid devices. At the present time there are no plans to extend this work.

7. Illustrations. Figures 70, 71, and 72.

F. Analytical Investigation of Fluid Amplifier Dynamics

Submitted by
(Technical Supervisor)

Mr. M. A. Kalange
R-ASTR-NF, 876-5322

1. Project Data

Contract Number: NAS8-11236, June 18, 1964 - December 30, 1964

Contractor: Sperry Utah Company
Salt Lake City, Utah

2. Purpose of Project. To provide analytical data which would reveal performance characteristics of pure fluid amplifier elements and their characteristics in a system operation.

3. Technical Status. This contract is complete. All objectives of the contract were met and the results are reported in "Analytical Investigations of Fluid Amplifier Dynamics Characteristics." A summary of the contract effect is given below:

a. Volume I

(1) Theoretical Study of Digital Fluid Amplifier

(a) Theoretical study of time dependent Navier-Stokes equations describing a viscous jet.
(b) Bynamic test standards.

(2) Analysis of Passive Circuits

(3) Feasibility Study of a Thrust-Vestor Control System

b. Volume II

(1) Fluid Dynamics Fundamentals

(a) Dimensionsl analysis
(b) Law of Stokes-Reynolds similarity

(2) Passive Circuit Elements

(a) Steady state flow
(b) Circuit parameters of passive elements
(c) Fluid instrumentation
(d) Proportional active devices
(e) Applications to typical fluid control system

It is believed that Sperry has made a significant contribution to the fluid field, particularly their work in the area of passive circuits dynamics and the Navior-Stokes equations.

4. Major Accomplishments. Sperry successfully established the criteria for comparing passive fluid circuits of different size and different medium. This criteria allows duplication of performance of fluid elements of different sizes and which use different mediums.

The Navier-Stokes equations were solved for the two-dimensional incompressible case for the flow channel shown in Figure 73. This solution provides detailed data for the dynamic of flow for jet and jet interaction.

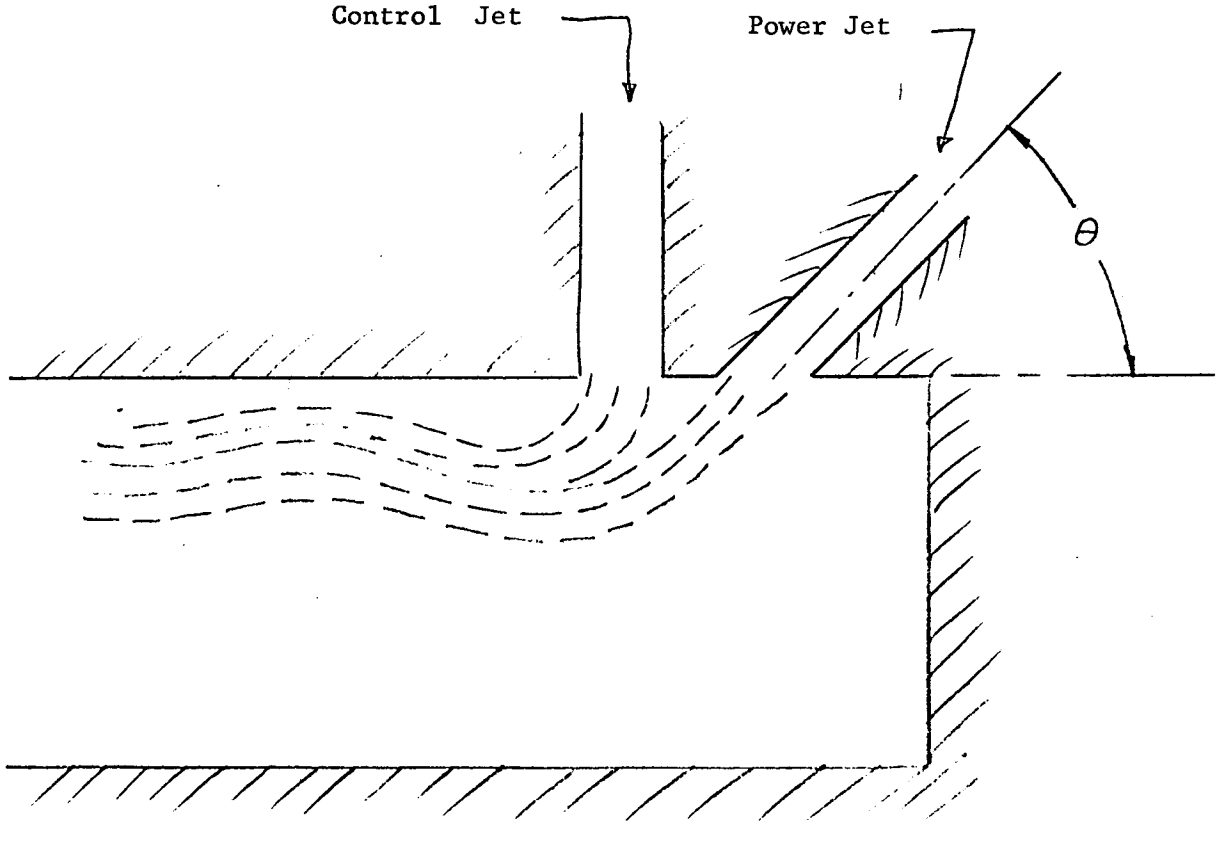


FIGURE 73. COMPUTATIONAL FLOW FIELD FOR TIME-DEPENDENT VISCOUS JET WITH CONTROL

5. Problems. There were no problems experienced during this program.

6. Future Plans. Sperry-Utah is the sole source on a request for proposal on establishing the degree of accuracy that a performance prediction can be made using their established criteria for comparing passive fluid circuits.

7. Illustrations. Figure 73.

G. Investigation and Analysis of Data Compression Techniques and Associated Problems (SS-FM Telemetry System)

Submitted by
(Technical Supervisor)

Mr. James E. Rorex
R-ASTR-IT, 876-1355

1. Project Data

Contract Number: NAS8-5003, May 21, 1963 - March 28, 1965

Contractor: University of Alabama
Systems Engineering Group,
Bureau of Engineering Research,
University, Alabama

2. Purpose of Project. To investigate, evaluate, and document data compression techniques and associated problems.

3. Technical Status. Technical report number 4, "A Queuing Problem Encountered in an Adaptive Telemetry Data Compression System," was delevered August 1964. Technical report number 5, "A Study of Redundancy Removal for Saturn Telemetry Data" was delivered November 1964.

4. Major Accomplishments. Report number 4 includes mathematical models which describe the state of the queue within the buffer of certain data compression systems. Two elementary models are developed. The first model applies to the uncontrolled, open-loop type of compression system. The second model describes a closed-loop, adaptive compression system. The second model was simulated on a digital computer to validate the logic of the mathematical model. Also described in the report is a procedure for evaluating the "error" of an adaptive system.

Report number 5 includes the results of the investigation of redundancy removal for Saturn S-1 PCM telemetry data and for generalized artificial data. Emphasis was placed on the active periods of the flight during which the data is both highly active and nonstationary. Eight methods of redundancy were studied and evaluated to determine compression ratio while maintaining a specified error.

Also, in report number 5, two methods of buffer control were explored. The two methods were queue control and data activity control. The advantages and disadvantages of each method presented.

5. Problems. No significant technical problems were encountered during the semi-annual period covered.

6. Future Plans. Continued investigation and research as outlined by the current scope of work.

7. Illustrations. Bureau of Engineering Research technical reports listed below:

a. Technical report number 4, "A Queueing Problem Encountered in an Adaptive Telemetry Data Compression System."

b. Technical report number 5, "A Study of Redundancy Removal for Saturn Telemetry Data."

SECTION IV. RESEARCH PROGRAM

MATERIALS RESEARCH

Coatings

A. Development of Low Temperature Dielectric Coatings for Electrical Conductors

Submitted by
(Technical Supervisor)

E. C. McKannan
R-P&VE-MEE, 876-1233

1. Project Data

Contract Number: NAS8-2442, June 30, 1961 - July 30, 1965

Contractor: General Electric Company
Schenectady, New York

2. Purpose of Project. This contract is directed toward development of dielectric coatings applicable to electrical conductors and other components which will be exposed to extreme temperatures from 4°K (-269°C) to 523°K (250°C), reduced pressures of 1×10^{-6} torr or less, and other environmental conditions related to launch vehicle and space flight operations.

3. Technical Status. Previously, it was reported that several cable constructions, both round and flat film, employing polyimide insulation had been evaluated seccessfully. Recent work has been aimed at connections and feedthroughs where most of the dielectric losses and mechanical problems remain. The performance of connectors and feedthroughs is adversely affected when frost is formed. The dielectric loss of "wet" polyimide is twice that of the dry polymer at very low temperatures. Yet, the dielectric loss of ice is too low to be measured, and the dielectric loss of cryogenic liquids, helium, and hydrogen, is extremely low. Studies along this line are continuing, and they lead to the suggestion of cryogenic components where extremely low loss and high "Q" are required, as in the instance of energy storage capacitors. Practical work on connector design has involved modified "MS" connectors with longer leakage paths, pressurized locking to take up thermal contraction and expansion, and elimination of frost at the interface. These studies are continuing.

4. Major Accomplishments. As stated previously, much basic information has been revealed by the studies at cryogenic temperatures. A better understanding of the dielectric properties of ice (frost) and of cryogenic fuels has resulted, along with the practical development of wire coatings and connectors for use at low temperatures.

5. Problems. None.

6. Future Plans. This work will be terminated at the end of the current year.

7. Illustrations. None.

Polymers

A. Silicon-Nitrogen Polymer Studies

Submitted by
(Technical Supervisor)

J. D. Byrd
R-P&VE-MNP, 876-3834

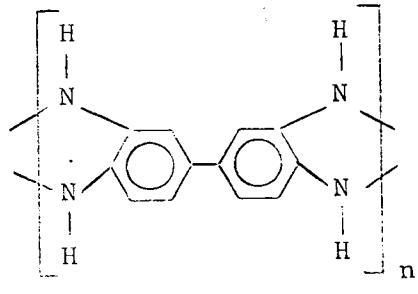
1. Project Data

Contract Number: Not Applicable

Contractor: MSFC In-House

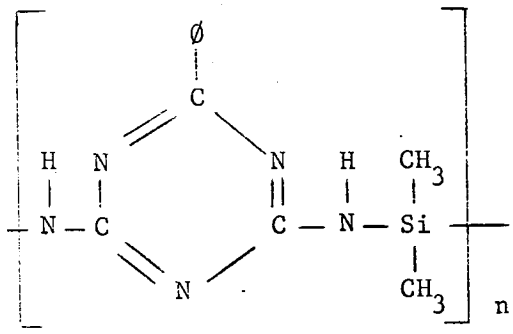
2. Purpose of Project. This work was carried out principally in support of Contract NAS8-1510 with Southern Research Institute for a study of silver-nitrogen polymers.

3. Technical Status. Attempts were made to prepare a polymer by reaction of silicontetrachloride and 3,3',4,4' - tetraaminobiphenyl. The proposed structure for such a polymer is as follows:



In each case a sticky, yellow semi-solid was obtained.

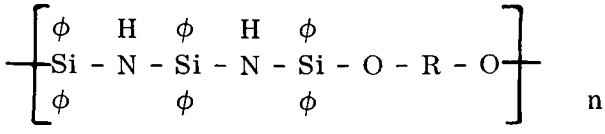
A study was made to determine the effectiveness of ammonium bromide as a catalyst in the polymerization of dimethyldichlorosilane with diamines. It was found that the use of ammonium bromide with ethylenediamine and dimethyldichlorosilane produced a solid foam product which looked the same as the product obtained when this reaction is conducted in the presence of triethylamine. This material could be cured in air to weak elastomeric films. The film was crinkled and rough but remained fairly flexible at -100°C. Also, in an effort to produce a silazane polymer containing an s-triazine ring ammonium bromide was employed as a catalyst in the reaction of dimethyldichlorosilane and 2, 4-diamino-6-phenyl-s-trizaine. The expected polymer would have the following structure:



However, the analysis of the product obtained did not support this structure.

A silazane polymer prepared by the reaction of methylphenyldichlorosilane and ammonia in the presence of triethylamine has shown good adhesion to metal as a coating. Therefore it was decided to test this material as an adhesive for metals. Lap shear samples were made using three different curing agents and lap shear tensile was checked on these samples. The best value obtained was 536 psi using pyromellitic dianhydride as the curing agent.

A series of polymers which were prepared by reacting equal molar quantities of hexaphenylcyclotrisilazane and an organic diol have been evaluated by thermogravimetric analysis (TGA). These polymers have the general formula:



When the diol is p,p'-biphenol, 4,4'-dihydroxydiphenyl ether, 2,7-naphthalenediol or Bisphenol A, the polymers remain stable in the range of 500°C. They have a weight loss of 5 to 10 percent at 500°C by TGA in a nitrogen atmosphere.

4. Major Accomplishments. It was found that the use of ammonium bromide as a catalyst in the reaction of ethylenediamine and dimethyldichlorosilane produced a product similar to that produced when triethylamine is used. The ethylenediamine-silazane was found to have some definite adhesive properties although their strength is not outstanding. The polymers prepared from hexaphenylcyclotrisilazane and organic diols were found to have good thermal stability being stable to about 500°C (932°F).

5. Problems. Our major problem has been failure to obtain a polymer which has high enough molecular weight to determine what properties it would have. In some cases no polymer at all was obtained.

6. Future Plans. Work will continue on the study of elastomeric properties obtained with some of the ethylenediamine silazane materials. Attempts will be made to prepare new types of silicon-nitrogen polymers and to produce higher molecular weights of some of the known systems.

7. Illustrations. None.

B. Study of Polymers Containing Silicon-Nitrogen Bonds

Submitted by
(Technical Supervisor)

J. D. Byrd
R-P&VE-MNP, 876-3834

1. Project Data

Contract Number: NAS8-1510, February 4, 1961 - May 3, 1965

Contractor: Southern Research Institute,
Polymer Division
Birmingham, Alabama

2. Purpose of Project. This contract is directed toward the synthesis and characterization of a class of polymers identified as silazanes. The polymeric structures contain recurring silicon-nitrogen skeletal linkages which may be either linear or cyclic. These compounds are characterized generally by their resistance to elevated temperatures and, thus, may be important in several aspects of launch vehicle development.

3. Technical Status. Curing conditions, prepolymerization, and additives were investigated for improving the method of production and quality of the methylphenyl silazane-triethylamine coating agent. New curing conditions were developed that consistently resulted in coatings with excellent thermal stability and good adhesion. With the new curing conditions (2-10 minutes at 350°C), a coating 0.2-mil thick remained intact for 42 hours at 400°C, and coatings 5-mils thick remained intact for 4 hours at 400°C. Prepolymerization of methylphenyl silazane-triethylamine reduced the amount of weight loss during curing but did not otherwise affect the quality of coatings. The additives investigated had no over-all beneficial effect on the methylphenyl silazane-triethylamine coatings. Ethylenediamine silazane lowered the temperature required for curing, and cobalt naphthenate increased the time of endurance at 400°C, but both additives reduced the hardness of the coatings.

The oligomer obtained from the reaction of 1,4-bis(dimethylchlorosilyl) benzene with methylamine was copolymerized with hydroquinone and with 1,4-bis(dimethylhydroxysilyl) benzene to produce two phenylene-bridged elastomers. The elastomer produced with hydroquinone was soft and had an elongation of about 600 percent. It had some resiliency after heating for an hour at 400°C. The elastomer produced with 1,4-bis(dimethylhydroxysilyl)benzene was tougher but less resilient than the elastomer produced with hydroquinone. It crystallized in a few minutes at room temperature and had some resiliency after heating for 45 minutes at 400°C.

The diol-diaminosilane reaction of 1,4-bis(dimethylhydroxysilyl)benzene with bis(methylamino)diphenylsilane and methylphenyl methylamino silazane resulted in tough elastomers that remained resilient for 2 hours or more at 400°C in air. A molecular weight of 290,000 was obtained in one sample. This system of polymers appears to be appreciably superior to others studied in this program-the products are considerably stronger and they are equivalent in thermal stability to the best that have been produced. Furthermore, they can probably be filled, molded, and cured in useful shapes.

Attempts were made to increase the strength of the resilient polymers made from methylphenyl silazane-TEA by blending them with tougher polymers, but the efforts were largely unsuccessful. Somewhat better results were obtained with fibrous fillers. Potentially useful gasket materials were made by impregnating glass fibers and asbestos with methylphenyl silazane-TEA. Mats 1/8-inch thick retained some resilience for several hours in air at 400°C.

A silphenylene amine polymer with a molecular weight of 52,000 was prepared by thermal condensation polymerization of an oligomer of bis-(methylamino)tetramethyl-p-silphenylene. The polymer was soft enough at 200°C to flow, and attempts to cross-link it to form elastomers of higher melting solids were not successful.

In a study of routes to polymers and derivatives of cyclic silazanes, methylmagnesium iodide was found to react with hexamethylcyclotrisilazane and hexaphenylcyclotrisilazane, but not completely. With hexamethylcyclotrisilazane, about 75 percent of the NH groups reacted; with hexaphenylcyclotrisilazane, about 50 percent of the NH groups reacted. At least two of the three NH groups on each molecule must react if polymers are to be formed. The data do not exclude the Grignard route as a means of making derivatives of cyclic silazanes; but, to be successful, the magnesium halide derivative of the silazane must react with a silicon halide, and that reaction was accomplished to only a slight extent.

In the study of coating agents, a silicon-nitrogen coating on aluminum lost one-third of its nitrogen on heating in air at 400°C for 2 hours. Silicon-nitrogen and silicon-oxygen compounds can be used to enhance the adhesion of silicon-oxygen compounds, which cure with less loss in weight.

4. Major Accomplishments. A reproducible procedure has been developed for the curing of the methylphenyl silazane-triethylamine coating agent. This method produced good quality coating which remained intact for 42 hours at 400°C.

A phenylene-bridged elastomer using hydroquinone as a comonomer had an elongation of about 600 percent and it remained resilient after being heated one hour at 400°C (750°F). A similar material produced by a diol-diaminosilane had a molecular weight of 290,000 and remained resilient for 2 hours or more at 400°C (750°F) in air.

5. Problems. Although a number of useful materials having good thermal stability have been produced, none of these can be classed as true silazane polymers. Thus, a major problem is the failure to obtain high molecular weight of true silazanes. Attempts to use Grignard reagents in an effort to form polymers having cyclic silazane in the chain have been unsuccessful.

6. Future Plans. Additional work will be done on curing methods and filler addition to phenylene-bridged polymers. Also tests will be made to study the effectiveness of these materials as high-temperature adhesives. A study of silazanes as curing agents for epoxy polymers will be made. A study of silicon-nitrogen compounds containing boron, titanium, and aluminum will be made.

7. Illustrations. None.

Bearings and Lubrications

A. Research on Bearing Lubricants for Use in High Vacuum

Submitted by
(Technical Supervisor)

K. E. Demorest
R-P&VE-MEE, 876-4241

1. Project Data

Contract Number: NAS8-1540, June 12, 1963 - June 12, 1965

Contractor: Midwest Research Institute
Kansas City, Missouri

2. Purpose of Project. The purpose of this contract is to develop dry film lubricants having potential applicability on bearings and sliding surfaces in high vacuum. Lubricating films of primary interest are those of ceramics, metals, and cermets. A number of potential lubricants have been selected and are undergoing preliminary evaluations by the contractor. These evaluations are based on film formulation, screening and wear-life investigations, and frictional behavior investigations in ultrahigh vacuum. Those materials offering the most promise are applied to bearing surfaces and forwarded to this Center for final testing and evaluations.

3. Technical Status. The contractor has completed characterization of wear life and friction on MLF-5 (MoS_2, graphite, and gold powder in a sodium silicate binder) and MLF-8 (MoS_2, graphite, and gold powder in an aluminum phosphate binder). A statistically significant number of tests show that the MLF-8 film has an equivalent coefficient of friction and slightly better average wear life than the MLF-5.

A new film designated MLF-9 has been formulated and tested. This film consists of molybdenum disulfide, graphite, and bismuth powder in a binder of aluminum phosphate. From preliminary testing, it appears that this film provides a wear life approximately three times that of the MLF-5 film.

A comparison of these three films are shown in Table II. Friction tests are made at 2.2 psi and speeds of 765 fpm, while life tests are made at 13.5 psi and 765 fpm.

TABLE II

PROPERTIES OF DRY FILM LUBRICANTS

Film	Wear Life Hours	Friction Coefficient
MLF-5	24.2	.155
MLF-8	25.4	.165
MLF-9	86.5	-*

* Friction testing not complete.

4. Major Accomplishments. Lubricant films developed by the contractor are finding wide use in the aerospace field under both vacuum and earth ambient environments.

5. Problems. No signigicant problems have been encountered on this project.

6. Future Plans. The contractor will continue development of special lubricant films. Statistical data is now being obtained providing high confidence level comparisons of friction and wear life characteristics of the various films. Preliminary testing of bearing lubricants in ultrahigh vacuum have been started and a number of gear testers have been obtained and are being modified for lubrication tests.

7. Illustrations. None.

B. Lubrication

Submitted by
(Technical Supervisor)

K. E. Demorest
R-P&VE-MEE, 876-4241

1. Project Data

Contract Number: Not Applicable

Contractor: MSFC, In-House

2. Purpose of Project. This work concerns in-house lubrication studies being conducted in the Materials Division, P&VE Laboratory.

3. Technical Status.

a. Vacuum Lubrication. The problems involved in providing lubrication in the space environment are well established, and considerable progress has been made toward their solution at pressures as low as 10^{-7} torr. Equipment is being modified to permit the study of lubrication at pressures down to 10^{-10} torr. However, pressing Saturn hardware problems have resulted in less emphasis on the necessary modifications than planned. Thus, these modifications are proceeding at a slow pace.

b. High Load Oscillitory Lubrication. An evaluation of a glass-Teflon fabric lubricant (Fabroid) under oscillatory movements was made. The evaluation was planned to cover a load range up to 35,000 psi at temperatures from +200°C to -150°C (+392°F to -248°F), and at environmental pressures from 1 atmosphere to 10^{-6} torr. At this time, the evaluation has been completed over a load range of 12,000 to 30,000 psi, a temperature range of +100°C to -180°C, and environmental pressures between 1 atmosphere and 10^{-6} torr. The evaluation indicates that Fabroid lubricates equally well in air and vacuum (down to 10^{-6} torr) and is relatively insensitive to normal loads in the range tested. At moderate temperatures, above 40°C, Fabroid provides a friction coefficient of 0.05; however, as temperature is decreased, the coefficient of friction rises almost exponentially to 0.34 at -180°C (-350°F). This may be caused, at least in part, by the increased shear strength of Teflon below its glassy transition temperature. A further problem with Fabroid is its tendency to delaminate, which results in shedding of glass particles.

c. Extreme Pressure Lubrication. An extensive evaluation of selected lubricants for extreme pressure lubrication has been underway for some time, and representative data obtained have been reported previously. Updating of that data and new data are included in Table III. As shown by these data, MLF-9, a modified MLF-5, is consistently superior to all lubricants evaluated. MLF-9 is a dry film lubricant consisting of molybdenum disulfide, graphite and bismuth in a matrix of aluminum phosphate.

d. Dynamic Seals. Tests are underway to evalute dynamic seal materials for environments of both LOX and liquid nitrogen. Several of the materials evaluated to date provide good wear life and sealing action when operating in LOX; however, no material tested to date is suitable for service in liquid nitrogen.

4. Major Accomplishments. See Technical Status.

5. Problems. See Technical Status.

6. Future Plans. Not reported at this time.

7. Illustrations. Table III

TABLE III. MAXIMUM COEFFICIENT OF FRICTION OF LUBRICANTS EVALUATED AT EXTREME PRESSURES

	LOAD, PSI X 1,000													
Lubricant, Base Material, Hardness	5	10	20	30	40	50	60	70	80	90	100	110	120	130
MLF-5, 17-7PH Steel R-40	.170	.141	.120	.105	.097	.091	.087	.083	.077	.066	.062			
Halocarbon Grease +4% MoS_2 Electrolyzed 4340 R-43-45 Steel	.075	.074	.074	.083	.099	.106	.118	.118	.128					
Molykote X-51, 440C Steel R-52-55	.140	.102	.070	.061	.059	.059	.058	.055	.051	.049	.049	.048	.047	.047
Molykote X-15, 4340 Steel 43-45	.142	.105	.076	.072	.068	.067	.066	.064	.060					
Halocarbon Grease +4% MoS_2 4340 Steel R-43-45	.090	.104	.135	.133	.110	.114	.114	.117						
Halocarbon Grease +4% MoS_2 17-17PH Steel R-40	.050	.092	.110	.116	.081	.064								
MLF-9, 8480 Steel R-18-20	.125	.075	.063	.056	.060	.059	.055	.052	.049	.047				

Fabrication and Processing

A. General Purpose Laser for Drilling and Welding

Submitted by
(Technical Supervisor)

J. R. Rasquin
R-ME-MM, 876-6573

1. Project Data

Contract Number: Not Applicable

Contractor: Not Applicable, MSFC In-House

2. Purpose of Project. The basic purpose of this project is to explore the potentialities of the laser primarily with regard to the drilling, cutting and welding capabilities. The major portion of the effort is currently being expended in the area of a super power laser in the 240,000 joule input range to provide enough energy to cut and weld metal of useful thickness.

Of secondary interest is the development of high precision alignment location measurement and positioning devices utilizing continuous wave HeNe laser and a ranging device utilizing the 240,000 joule super power laser.

3. Technical Status. Our schedule slippage has still not been made up because of the difficulty in getting optical parts needed in a reasonable amount of time. The output of the 240,000 joule laser head is so powerful that it is difficult to design optics to stand up.

The 240,000 joule laser head is now operative and can be used for trial welding and cutting (Figs. 74 and 75).

The Cassegrainian mirror focussing system and the quartz lens focussing system have been received and tested (Figs. 76 and 77).

A new 240,000 joule laser head has been designed and is now 85 percent complete. This new head is being built to increase the lifetime of the rubies and glassware involved and to increase the efficiency of the head. It is also designed to allow the beam to emerge from the rear of the ruby so as to allow us to "Q" spoil if it is desired to do so in the future.

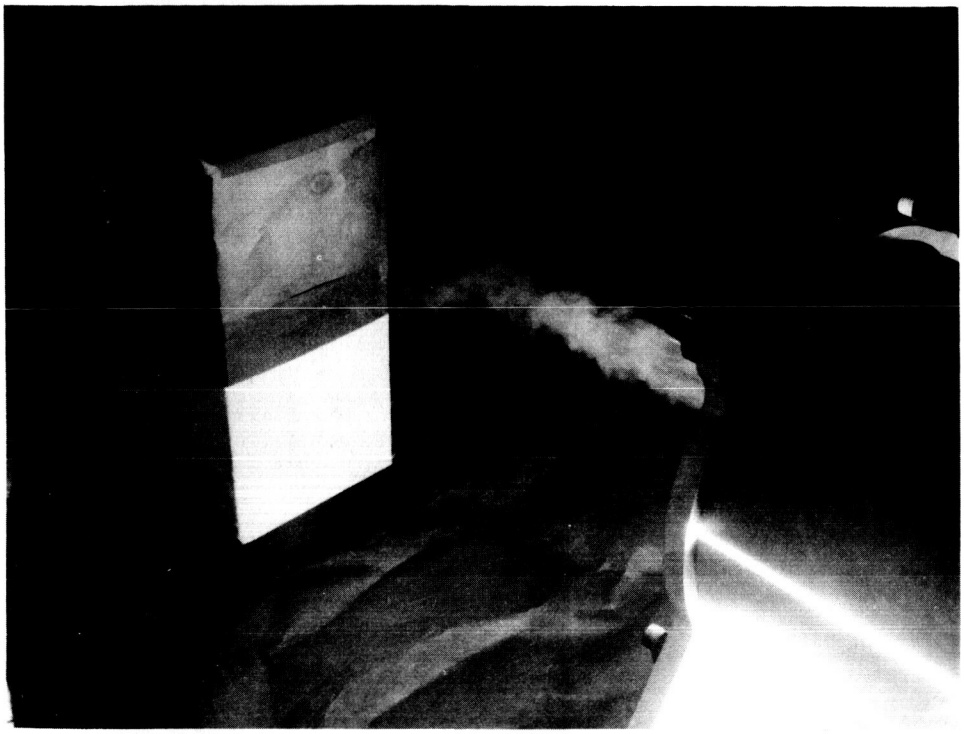


FIGURE 74. PRESENT 240,000 JOULE LASER HEAD LASING

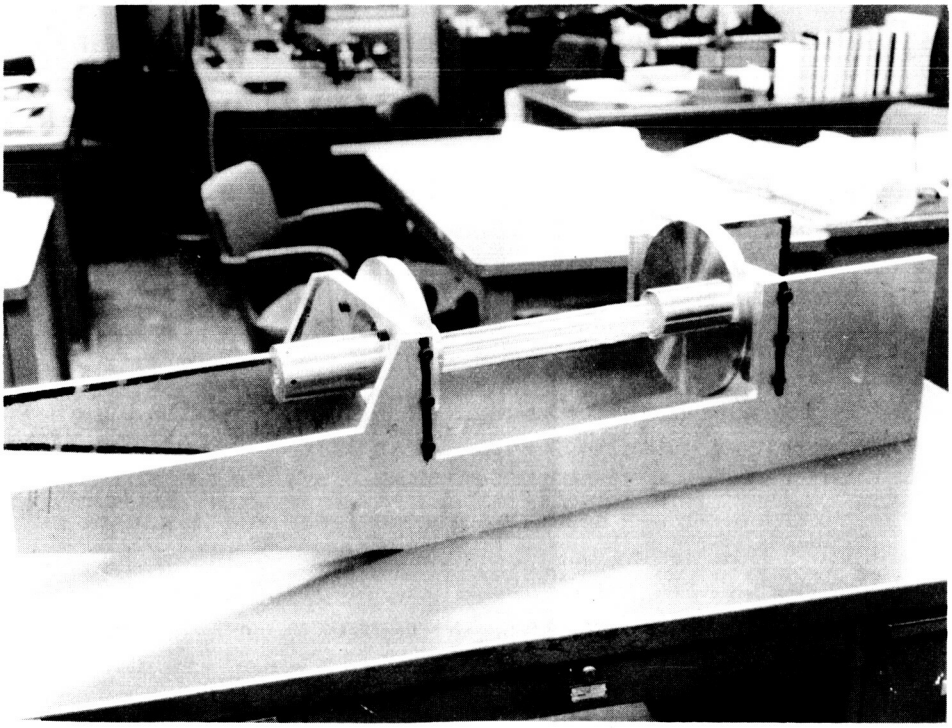


FIGURE 75. PROGRESS ON NEW 240,000 JOULE LASER HEAD

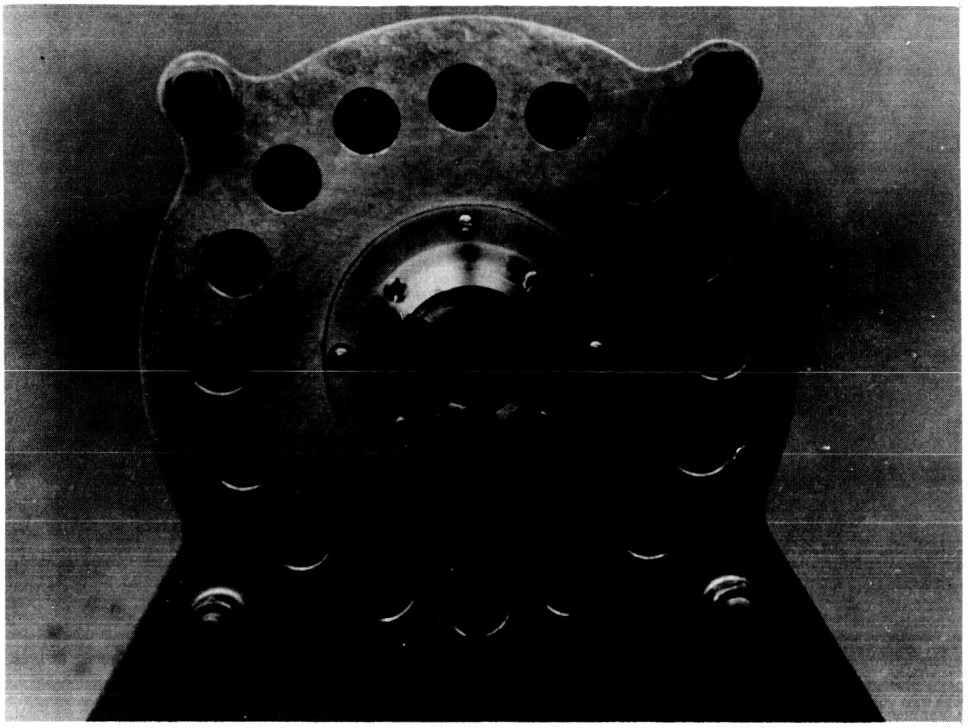


FIGURE 76. FRONT VIEW OF LASER HEAD SHOWING QUARTZ LENS FOCUSSING SYSTEM

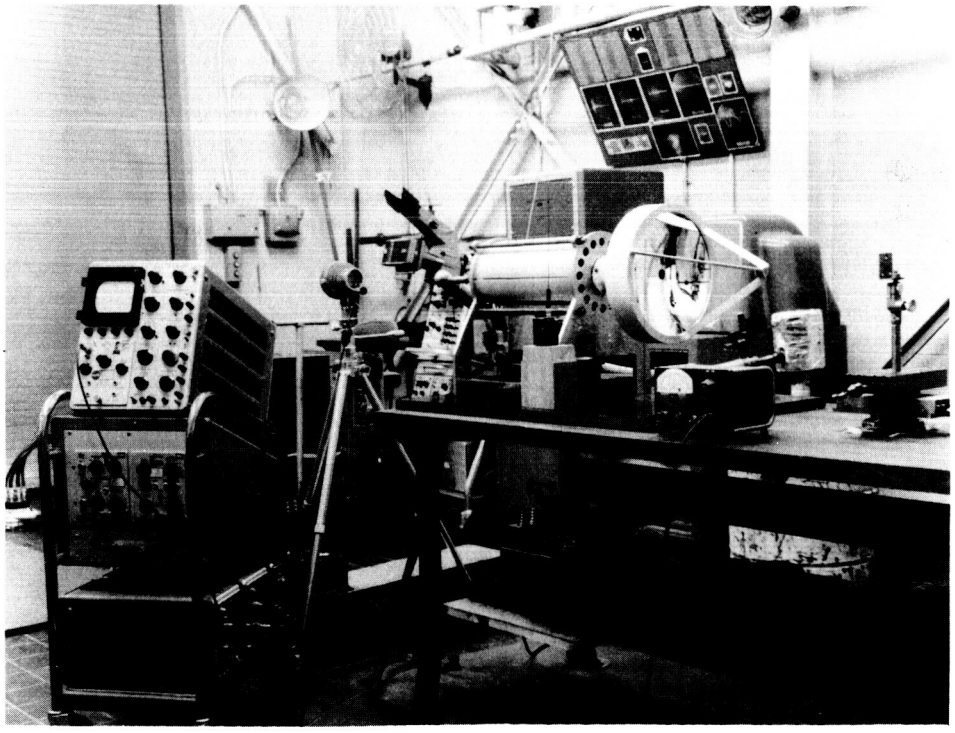


FIGURE 77. VIEW OF LASER HEAD SHOWING CASSEGRAINIAN MIRROR FOCUSSING SYSTEM

4. Major Accomplishments.

a. The 240,000 joule laser head output energy has been measured as high as 2600 joules.

b. The light output from the flash tube has been measured as high as 8.3 billion candlepower. (See Fig. 78)

c. Temperature measurements have been taken of the ruby rod in service. The temperature rise is not a serious problem at present because of the comparatively long charge time on the 240,000 joule capacitor bank.

5. Problems.

a. The output power of the 240,000 joule laser head is so high that ordinary coated mirrors will not stand up. Since that light which is not reflected is absorbed, ordinary relective coatings are vaporized by the beam energy. This is also true of lenses, and if the energy levels are high enough, the lenses melt.

b. The present 240,000 joule laser head has frosting problems. Since the ruby temperature should be as low as possible for best efficiency, there must be a flow of cooling gas or liquid around it. Also, since the output of the flash tube is rich in ultra-violet, there must be an ultra-violet filter between the flash tube and the ruby to prevent bleaching. This is accomplished by surrounding the ruby with a pyrex glass tube which also confines the cold gas (LN_2) used for cooling the ruby. Frost accumulates on this tube and prevents an appreicable amount of light from reaching the ruby. This, in turn, causes a big loss in efficiency (Fig. 79).

c. Tests have shown that there is a great deal of difference in ruby rod output. We have found differences as high as 200 percent for the same power input.

d. The lifetime of the rubies used is too short (Fig. 80).

e. The lifetime of the glassware used is too short.

6. Future Plans.

a. Since the Cassegrainian mirror type optics appear to be the most promising, it is planned to make the primary mirror out of solid metal

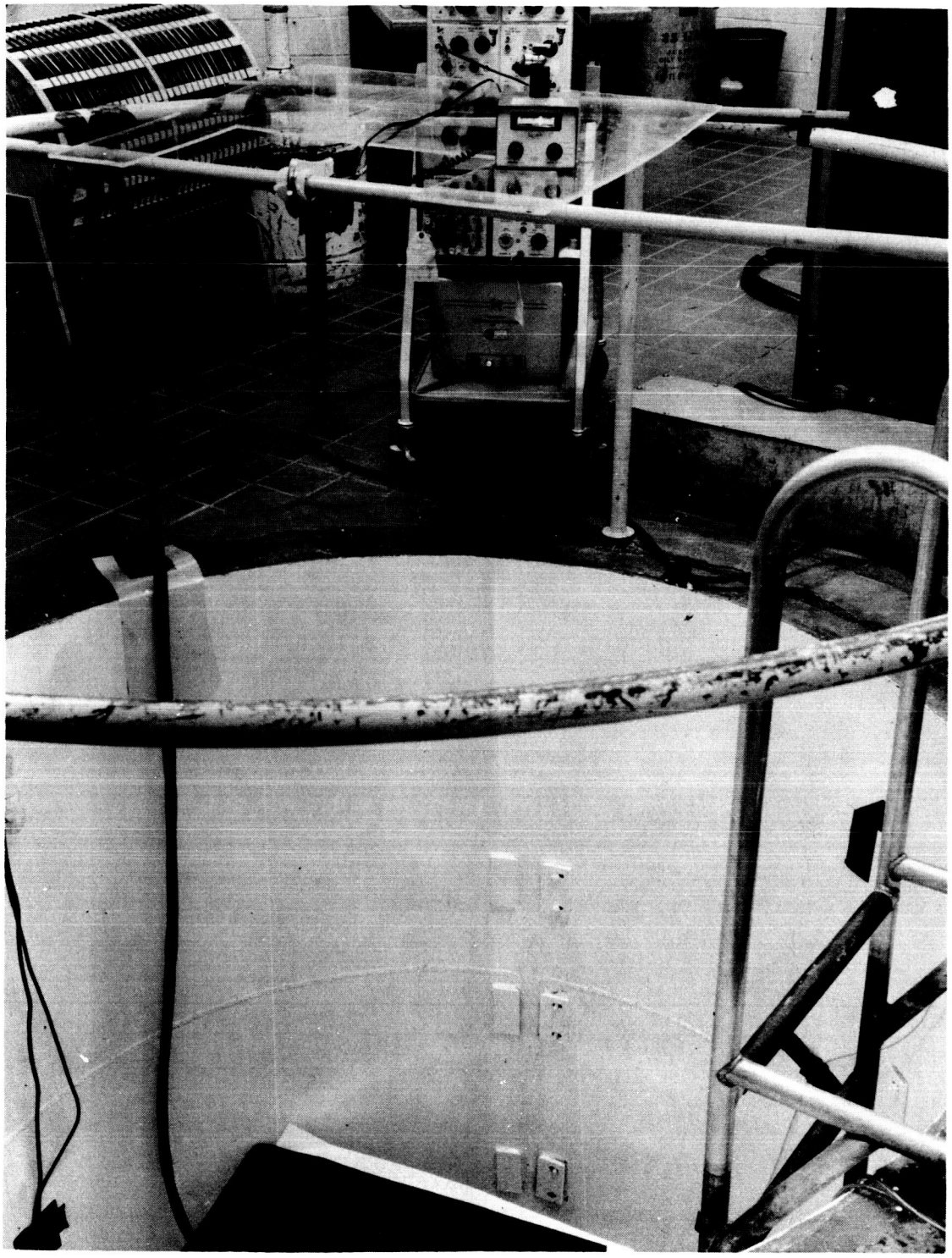


FIGURE 78. EXPERIMENTAL SET-UP TO MEASURE HIGH PHOTO INTENSITY

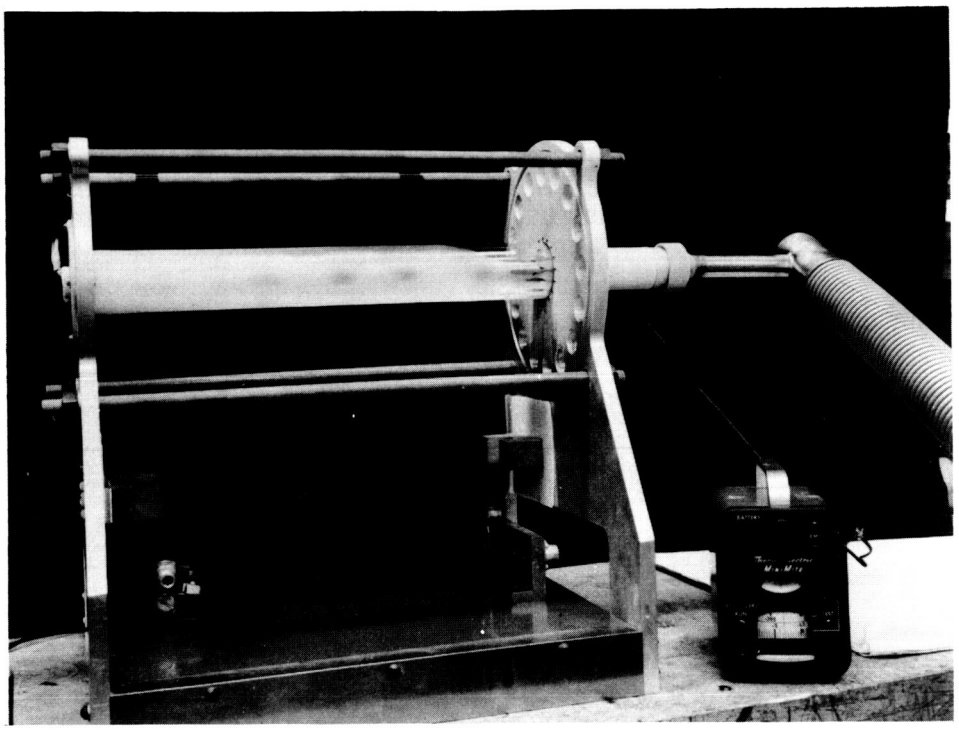


FIGURE 79. FROSTING OF PYREX JACKET FOR RUBY IN PRESENT 240,000 JOULE HEAD

FIGURE 80. RUBY DAMAGE

(silver or aluminum) to solve the problem of the vaporization of mirror coatings. If this does not work, so called "resonant mirrors" will be used.

b. The new 240,000 joule head design mentioned before should alleviate frosting problems. A quartz and pyrex dewar type tube will be used in the new head. This should also extend the lifetimes of the rubies and glassware because the vacuum jacket is a good thermal barrier (Fig. 81).

c. Efforts will be continued to obtain artificial ruby rods which produce uniform output. The only known sources of aritifical ruby in the world are the Linde Crystal Division of Union Carbide and a Swiss company represented in the United States by the Adolp Meller Company.

d. The output of the present system is so high that if the system were "Q" spoiled, the pulse width would be shortened to 50 nano-seconds, or less, and the output peak power would become fantastic. This indicates an excellent source for optical ranging over tremendous distances.

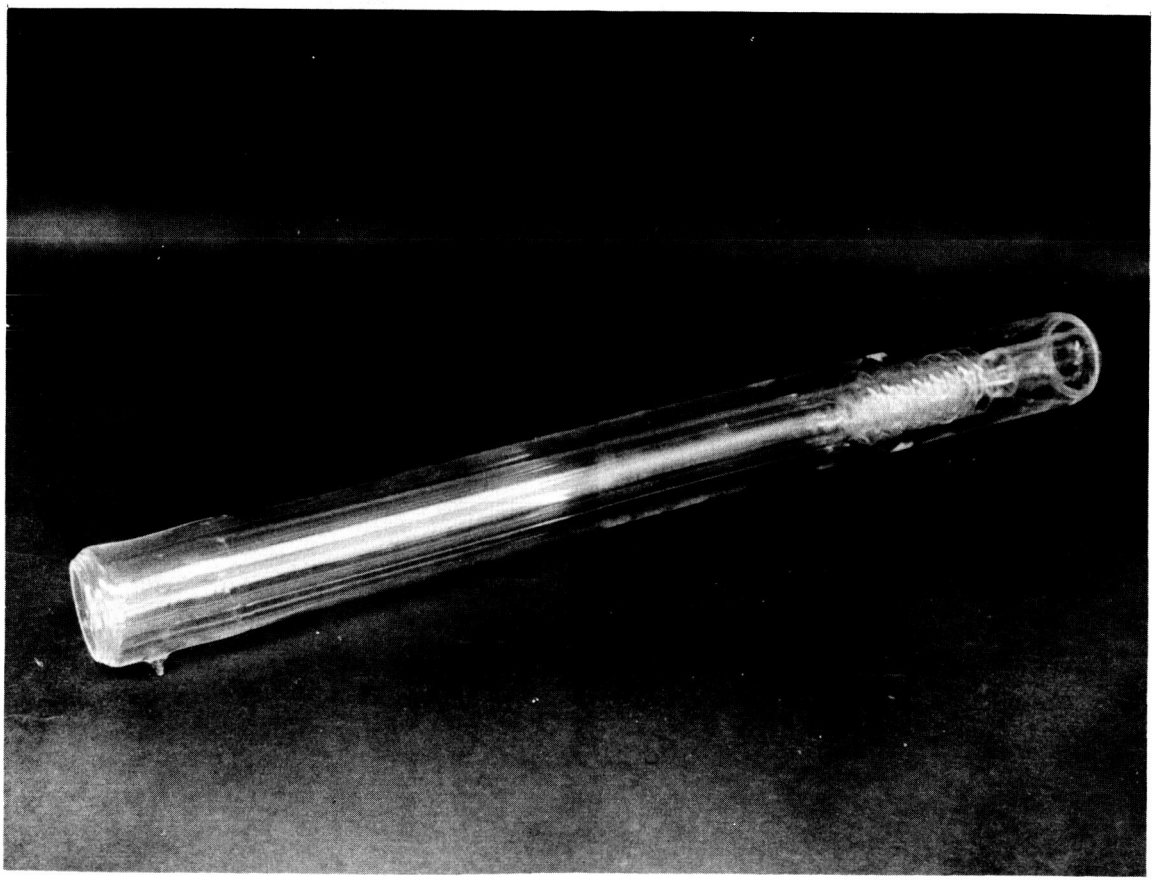


FIGURE 81. DEWAR JACKET FOR RUBY IN NEW 240,000 JOULE HEAD

7. Illustrations. Figures 74, 75, 76, 77, 78, 79, 80, and 81.

B. Electric Discharge Forming

Submitted by
(Technical Supervisor)

L. E. Foster
R-ME-MES, 876-876-4481

1. Project Data

Contract Number: Not Applicable

Contractor: Not Applicable, MSFC In-House

2. Purpose of Project. The purpose of this project is to investigate in detail the more pertinent parameters in electric discharge forming methods from a basic point of view. By definition, electric discharge forming implies any method which entails a rapid pulse discharge of high current. It is intended to eliminate as much guesswork from the process as possible, and to glean enough basic data so that the processes approach the status of a science, rather than an art. It is to be anticipated that diagnostics techniques and equipment must, therefore, play a most important role in these investigations.

3. Technical Status. Most of the progress made during the past six months was in the area of theoretical analyses and supporting tests. Data received from contractors performing work in other areas has produced general equations describing the pressures and forces as functions of time, energy input, and other variables. Comparison of the theoretical work between the contractors with that being performed at MSFC has revealed some interesting aspects. From this study, it appears that enough "common ground" will be found to justify some solid factual-findings upon which to build a usable theory.

The engineering and design of a magnetically driven hydraulic hammer featuring an extremely low inductance at an input of 20 kilojoules has been completed. This device, which is currently being constructed, consists of a 6-inch diameter coil having a total of 18 turns. The current feed-through is a high-amperage, low-inductance rigid coaxial arrangement 5 feet in length. Energy to the parallel plates is supplied by 14 flexible coaxial cables from the storage bank. Handles are also provided to facilitate movement of the device (Fig. 82).

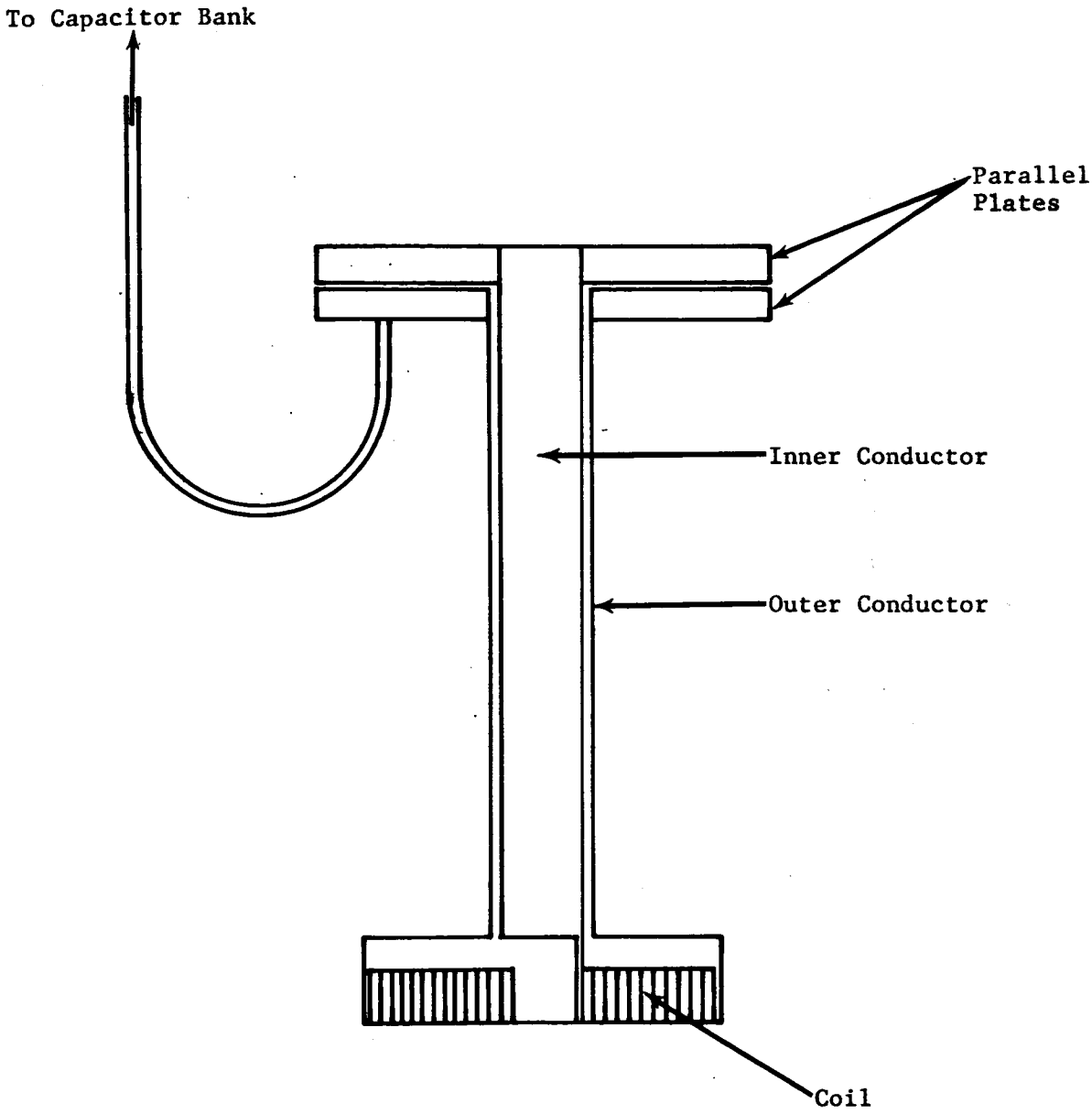


FIGURE 82. SCHEMATIC OF LOW-INDUCTANCE 20 KILOJOULE DEVICE

4. Major Accomplishments.

a. Experiments were performed on probing the sonic field generated with a device using a Hammer I-B configuration. In this investigation, two distinct phenomena were identified which generate two types of waves in the fluid. The first wave travels at the speed of sound in water; the second wave travels at 1/3 the speed of sound in water.

b. Experimental versus theoretical pressure-time profile was obtained (Figs. 83 and 84).

c. The equation of motion for the driver plate was derived. However, more tests must be performed to verify accuracy.

d. A 12-inch coil was built and tested to 58,000 joules. The coupling between the pancake coil and the driver plate was good. Pressures of 7900 psi were recorded (Figs. 85 and 86).

5. Problems. Tests to evaluate work of contractors must be done in the forming pit at MSFC. Due to the laser and intense magnetic field metal-working projects and limited space, these tests cannot be performed as often as they should be.

6. Future Plans.

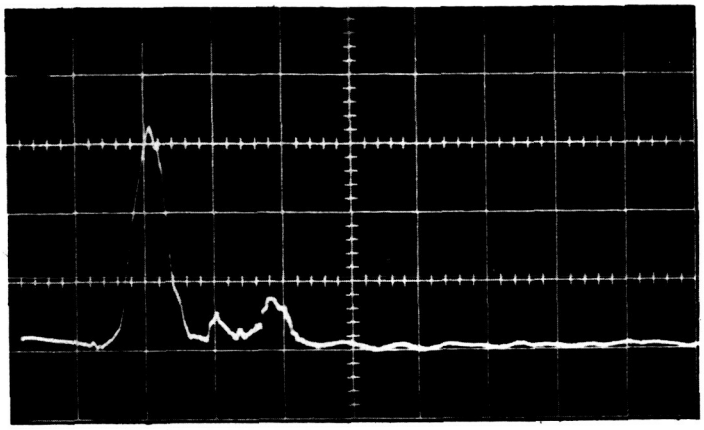
a. Probe sonic field at higher energy input levels.

b. Complete construction of the low-inductance 20 kilojoule magnetically driven hydraulic hammer.

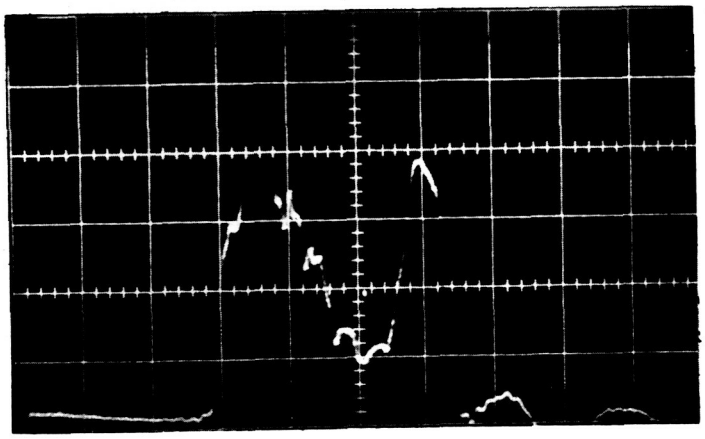
c. Work more examples theoretically and compare with test results. In these runs, other parameters (i.e., plate weight, separation distance and coil turns) will be varied.

d. Attempt to form a 28-inch dome.

7. Illustrations. Figures 82, 83, 84, 85, and 86.



Capacitor Bank 14 KV, 240 uf, 23,520 Joules
0.1 m sec/cm' 1540 psi/cm



Capacitor Bank 14 KV, 240 uf, 23,520 Joules
50 u sec/cm 770 psi/cm

FIGURE 83. ELECTROMAGNETIC TRANSDUCER PRESSURE RECORDS

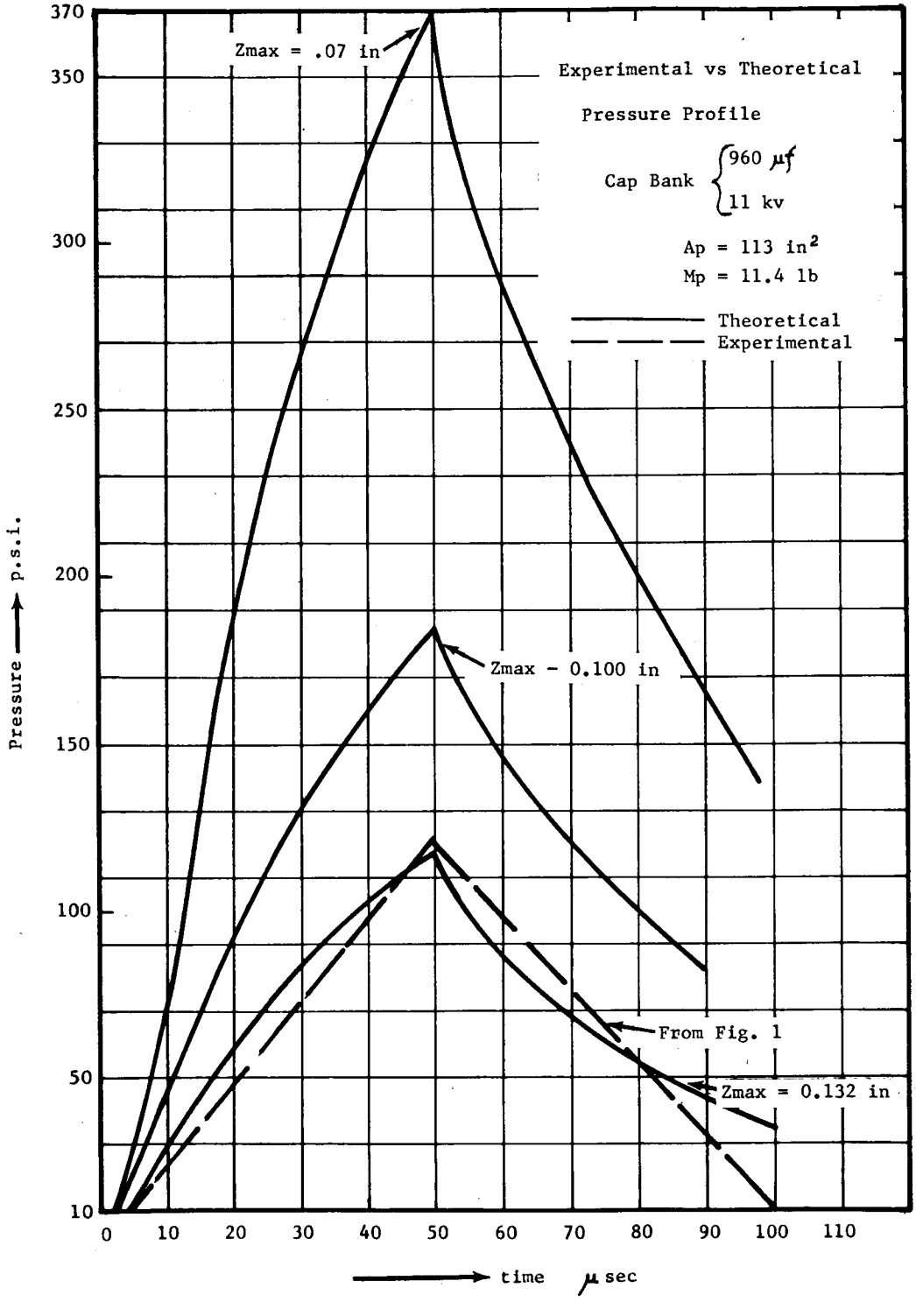


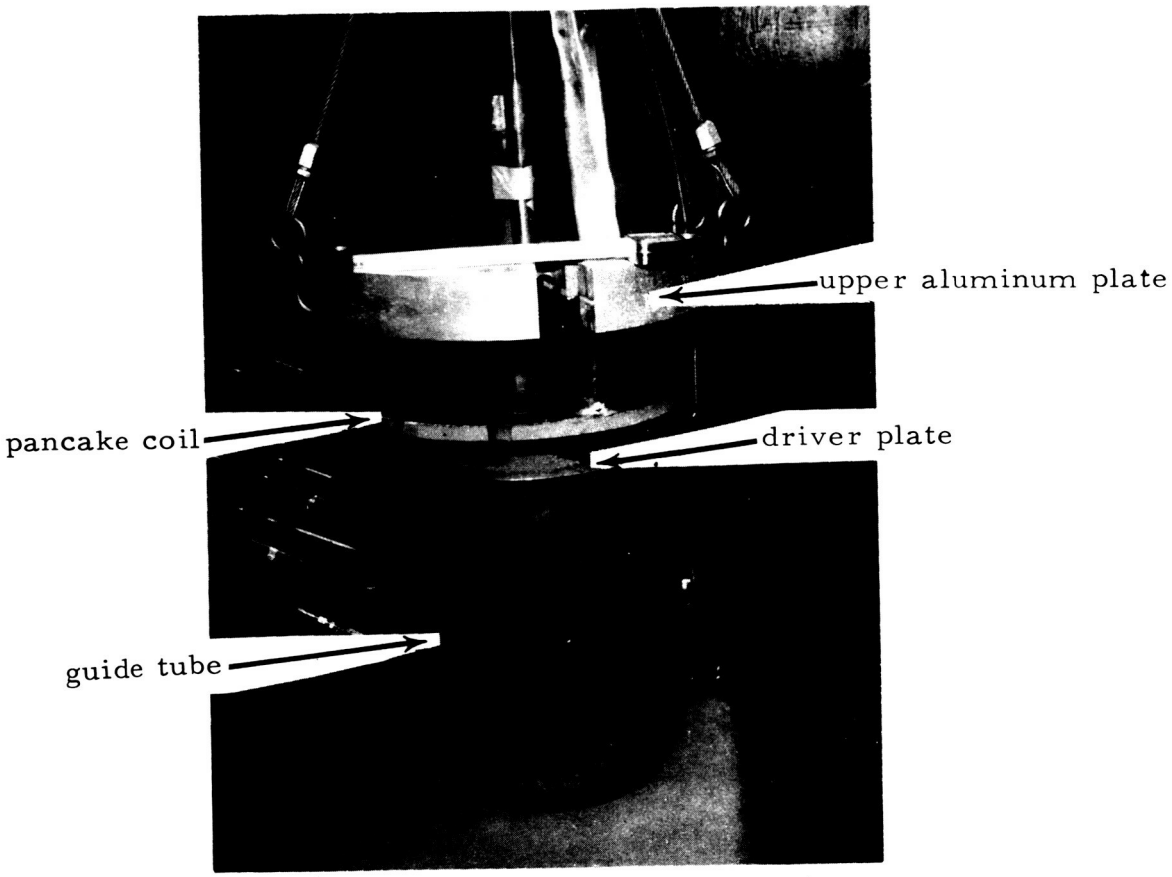
FIGURE 84. PRESSURE-TIME PROFILE SHOWING THEORETICAL VERSUS EXPERIMENTAL CURVES

The coil is held on its periphery

12" PANCAKE COIL. 21 TURNS

Insulation thickness: Front = 0.05 in.
Rear = 0.100 in.

FIGURE 85. 12-INCH PANCAKE COIL



The coil is held on its periphery

FIGURE 86. PANCAKE COIL ASSEMBLY

C. Vacuum Sealing by Magnetic Pressure

Submitted by
(Technical Supervisor)

L. E. Foster
R-ME-MES, 876-4481

1. Project Data

Contract Number: Not Applicable

Contractor: Not Applicable, MSFC In-House

2. Purpose of Project. The purpose of this project is to fully investigate the theory and techniques of metal-to-metal vacuum tight seals, and/or fluid tight seals made by pulsed transient magnetic fields. Metal-to-metal vacuum and fluid-tight seals made with magnetic pressure hold considerable promise, since other synthetic seals leave much to be desired in hard vacuum and for long term use. Metal-to-metal sealing limitations under ambient pressure (760 mm/Hg) will also be evaluated.

3. Technical Status. A complete redesign of the coil for sealing stainless steel into titanium was completed. The coil is now being manufactured. The coil incorporates a machined beryllium winding, utilizing more advanced welding techniques at the coil-connector interface to eliminate problems previously encountered with this connection. The connection must withstand both high current and extremely high pressure simultaneously. Because of the intense pressure the coil must withstand, a second radically new feature is a winding that is completely encapsulated in nylon.

4. Major Accomplishments.

a. New coil design completed - coil is being manufactured.

b. Survey was made on ultra-high vacuum equipment and requirements for vacuum sealing experiments.

5. Problems. Lack of funding has prevented any extensive effort in this area. However, progress has been maintained to the maximum extent possible by collection of data and planning in ultra-high vacuum technology. More funding for FY-66 will permit more effort in this area.

6. Future Plans.

a. Ultra-high vacuum capabilities will be established by extension of present capabilities in vacuum technology. This will require extensive changes in instrumentation and pumping techniques.

b. Attempts will be made to join stainless steel and titanium tubing with newly designed coil. If successful, the joint will be tested for use in transferring cryogenic fluids.

7. Illustrations. Figure 87.

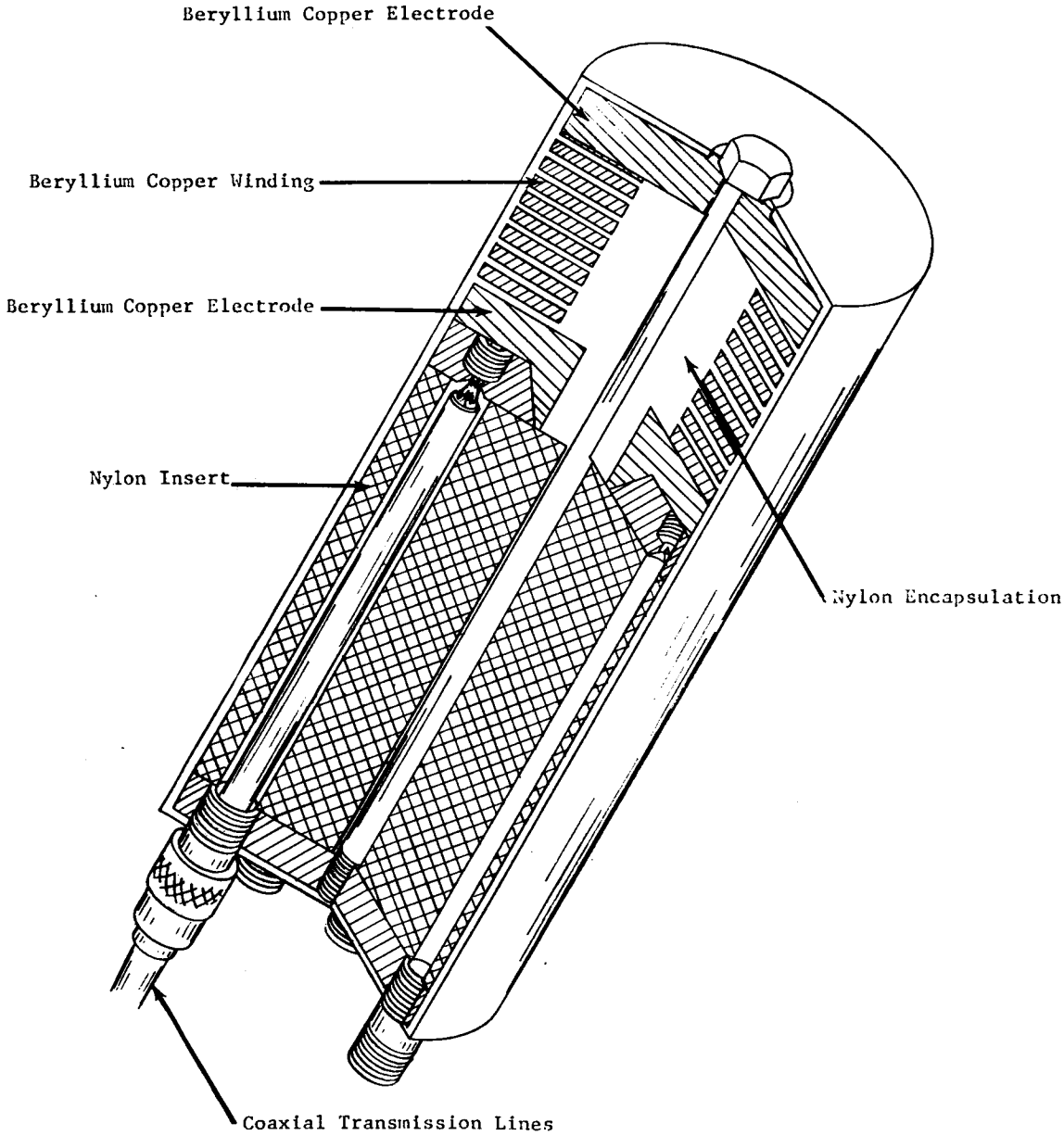


FIGURE 87. NEW DESIGN OF COIL FOR JOINING STAINLESS STEEL TUBING TO TITANIUM FOR CRYOGENIC FLUID TRANSFER

D. Development of Vacuum Deposition Techniques

Submitted by
(Technical Supervisor)

Dr. K. J. Pschera
R-P&VE-MCS, 876-4582

1. Project Data

Contract Number: Not Applicable

Contractor: MSFC In-House

2. Purpose of Project. This project is being undertaken to develop methods of vacuum deposition of thin metal and alloy films. Films to be prepared will subsequently be applied to development of superconducting thin films, dielectrics, and dry lubricants to advance the state of the art in these areas.

3. Technical Status. Denton Vacuum, Incorporated, was awarded a contract on November 24, 1964, to design, fabricate, and check out an advanced vacuum deposition system capable of the wide variety of evaporation processes anticipated.

The equipment currently is due to be received at MSFC on or about March 7, 1965.

4. Major Accomplishments. A contract has been initiated for construction of the specialized vacuum deposition equipment.

5. Problems. None.

6. Future Plans. Upon receipt of the equipment, preliminary checkout runs will be made with several reference or standard type evaporation processes. Initial work will be devoted to preparation of thin films showing promise for use as dielectrics and superconductors.

7. Illustrations. None.

E. Fundamental Study of Inclusions, Phases, and Precipitates in Aluminum Alloy Weldments

Submitted by
(Technical Supervisor)

Dr. K. J. Pschera
R-P&VE-MCS, 876-4582

1. Project Data

Contract Number: Not Applicable

Contractor: MSFC, In-House

2. Purpose of Project. The potential of aluminum alloys in the construction of space vehicles has resulted in the development of superior quality alloys involving aluminum. And although these alloys possess the desirable weight strength properties, they still possess many undesirable characteristics which merit additional research in the material development field.

Among these undesirable characteristics is the weldingpotential of the aluminum alloys. Fabrication of aluminum alloys by welding techniques has not produced metal-to-metal bonding consistent with the high strength and durability of the parent alloy. The loss of alloy strength in or near the weld zone has been qualitatively interpreted in terms of the structural changes in the zone. Since these structural changes must be ascertained and quantitatively described before accurate preventive measures can be predicted, a fundamental study of these welds is an important mission of the materials development program.

3. Technical Status. The task entails the detailed study of the phase distribution in aluminum alloys before and after joining by welding techniques. In addition, the weldments are to be studied as a function of various heat treatments.

Electron microprobe analysis is to be utilized to determine the variation in composition in or near the weld zone. The instrument has been installed at MSFC and, as is customary with highly complex scientific devices, considerable time was expended in checkout and adjustments. It is now considered operational and preliminary studies are underway on 2014-T6 and 2219-T87 aluminum alloys. These are being done in order to establish a sound base line from which to compare the results of the welding precesses.

4. Major Accomplishments. The electron probe microanalyzer has been installed, checked out, and is now operational at MSFC.

5. Problems. None.

6. Future Plans. Determination of the phase changes resulting from various welding processes on aluminum alloys will begin after limited additional studies on the parent metal and the 2319 and 4043 aluminum welding rods to be used.

7. Illustrations. None.

F. Experimental Welding

Submitted by
(Technical Supervisor)

R. A. Davis
R-P&VE-MMJ, 876-3804

1. Project Data

Contract Number: Not Applicable

Contractor: In-House

2. Purpose of Project. The purpose of this project is to perform a feasibility study for welding of widely dissimilar materials by the electron beam welding process.

3. Technical Status. Electron beam welding techniques are being refined in a continued attempt to join type 321 stainless steel to copper. Efforts to join (1) titanium to aluminum, (2) aluminum to stainless steel and (3) stainless steel to titanium have not been successful by the electron beam welding process.

4. Major Accomplishments. It has been concluded that the latter three combinations listed above cannot be joined directly to each other by the electron beam welding process.

5. Problems. None.

6. Future Plans. The joining of copper to stainless steel appears feasible, thus studies will continue on refinement of electron beam welding techniques.

7. Illustrations. None.

Solid State Chemistry and Physics of Materials

A. Surface Physics of Metallic Surface

Submitted by
(Technical Supervisor)

Ilmars Dalins
R-RP-N, 876-1891

1. Project Data

Contract Number: NAS8-2585

Contractor: University of Alabama Research Institute
Dr. R. Mann, Principal Investigator

2. Purpose of Project. Initially the project was aimed to augment the knowledge pertaining to surface ionization process, especially as it is applied in electrical propulsion of space vehicles. Because of the subsequent change of MSFC's augment, this study was reoriented to encompass following subject matters:

a. Ultra-high vacuum techniques
b. Surface physics and its implications to space vehicle technology

Some interest has been revived lately in the surface ionization process but primarily as a problem in surface physics. The technical topics of this study have been very closely coordinated by the technical supervisor to complement his in-house activities. This coordination aspect was present at the inception of this project.

Considerable knowledge, both theoretical and experimental, exists about physical process related to surface ionization process. Consequently a review and expansion of this body of technical knowledge appears to be very desirable.

3. Technical Status. This study has accumulated considerable detail knowledge pertaining to ultra-high vacuum technology. Intricate vacuum components have been fabricated from metal, glass, and ceramics. Various limitations, advantages, and disadvantages encountered in the use of these materials have become apparent. Information gained through this study has been very valuable to the technical supervisor of this contract in aiding and consulting various hardware development programs which involve the use of molecular beams and ultra high vacuum technology and other special precesses related to electron tube technology.*

Field ion microscopy and field evaporation process has been studied. Resolution of this microscopy enabled the observations of individual atoms. It is planned to improvise this equipment to observe directly various atomic interactions in situ. The progress in this area depends upon the feasibility to fabricate certain critical components, such as a special secondary electron multiplier, etc.

Major effort has been made to develop a chopped molecular beam apparatus which operates with extreme reliability even after it has been subject to 450°C bakeout for many hours (even as much as 24) and then subsequently submerged in cryogenic liquids (liquid nitrogen or even liquid helium). The apparatus should be compact and matable with field emission microscope tubes. Various test models for components have been built and now it appears that enough information exists to build an integrated system. This will be undertaken shortly.

Some effort was devoted to evaluate the problems involved in obtaining reliable ceramic to metal seals for ultra-high vacuum applications. Further (slight) improvements in the available equipment namely a hydrogen furnace, is necessary before special (custom made) ceramic to metal seals can be fabricated in the university laboratory.

4. Major Accomplishments. Comprehensive review of the field ion microscope techniques enables certain studies of atomic interactions (important in space technology) to carry out by direct observation. This aspect is of great potential value and this technique will be used in further research of specific space physics problems.

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*Because of the preoccupation with large booster development, this technical area has been somewhat neglected by MSFC. Most studies are limited by the requirements to use commercially available equipment. The availability of this equipment is determined by commercial (marketability) consideration rather than technical.

Similarly rather novel techniques and approaches have been required in the development of the molecular beam apparatus described very generally in the foregoing section of this report. This new instrumentation appears to enable certain new avenues of research in surface physics not feasible before.

5. Problems. Several intricate technical problems have been encountered during the course of this research and successfully overcome. It appears that most of them encountered in connection with field emission microscope and molecular beam apparatus combination have been successfully overcome. The limitations of this apparatus will become more apparent when committed to use for studies of various surface physics problems. Extensive studies of desorption at high temerature will start shortly. All anticipated problems have been corrected to a reasonable degree of satisfaction. Of course this doesnot preclude that no more problems can occur in connection with studies as complex as are atomic interaction on surfaces under controlled conditions. Detailed corrections and improvements will be required also in the future.

6. Future Plans. As indicated studies will be shortly underway with the aid of special instrumentation, consisting of a specially made field emission tube combined with a special molecular beam apparatus. This tube requires special electronic circuitry which by large has been developed and tested. Further details in the direction of this research will take depends greatly upon the outcome of the performance of this new equipment. An extension for another year on this contract is requested.

7. Illustrations. None.

B. Physics of Materials at Low Temperature

Submitted by
(Technical Supervisor)

Ilmars Dalins
R-RP-N, 876-1891

1. Project Data

Contract Number: NAS8-2474

Contractor: University of Alabama Physics Department
Dr. W. G. Moulton, Principal Investigator

2. Purpose of Project. The original objective of this study was directed towards detailed investigation of Vanadium trioxide (V_2O_3) by magnetic resonance techniques. Later the objective was changed to include other materials that appear interesting from solid state physics standpoint. Thus $LaCl_3$ appeared to be quite interesting because of its isomorphic and relative structure with great deal of symmetry. Especially interesting, but less investigated, is the problem pertaining to the covalent bonding in this and similar materials.

Because difficulties were encountered in obtaining single crystals with acceptable purity and optical qualities, certain crystal growing was undertaken by university personnel. After some initial difficulties were overcome, praseodymium chloride crystals could be prepared of exceptional quality and consequently major effort of this study was made pertaining to the details of $PrCl_3$ crystal structures. The study was not only experimental but considerable comparisons with theoretical models were made.

3. Technical Status. The project has been completed in accordance with the terms of the contract (Nov. 30, 64). The final report has been submitted to MSFC. Inventory of government owned equipment is being prepared.

4. Major Accomplishments. The results of this study were published in the Journal of Chemical Physics, Vol. 41, No. 11, December 1964. The acceptance of this publication in this Journal of the American Institute of Physics is indicative of the good scientific quality of the technical work performed under this contract. Rather extensive comparisons with theoretical models, one of which was proposed by the investigators of this project, appears to be a major scientific contribution. This study describes among other things how covalent character of bonding is related to the hyperfine structure of the magnetic resonance lines.

5. Problems. The technical problems encountered during this study were successfully overcome. For the benefit of future research in this area, it seems worthwhile to mention that the difficulties encountered in obtaining crystals of acceptable quality are of considerable magnitude and certainly require very detailed attention.

6. Future Plans. Studies under this contract are complete. Future plans are uncertain in regard to continuation of this type research under a different contract.

7. Illustrations. None.

C. Interactions of Slow Electrons with Light Gas Atoms

Submitted by
(Technical Supervisor)

Ilmars Dalins
R-RP-N, 876-1891

1. Project Data

Contract Number: NAS8-11249, May 28, 1964 - June 28, 1965

Contractor: University of Alabama Research Institute
Dr. R. Mann, Principal Investigator

2. Purpose of Project. The objective of this theoretical study is to calculate as accurately as possible the inelastic scattering cross sections of low energy (100 eV or less) electrons by certain species of light atoms. Alkali atoms are being treated in the present effort. The method of predicting accurately these cross sections is of considerable importance to space technology, especially in connection with upper atmosphere research and certain plasmas.

3. Technical Status. The polarization potential of alkali atoms has been calculated from first principles. These results were presented in a paper given at the January Meeting of the American Physical Society in New York. The polarization potential is now satisfactorily understood.

4. Major Accomplishments. Detailed and rigorous calculation of the shape of the polarization potential starting with first physical principles of atomic physics is the major accomplishment up to date. Excellent agreement with experimental data indicates that part of the problem of calculating inelastic cross sections has been solved quite satisfactorily.

5. Problems. Various energy exchange effort of the electrons are now being studied in order to determine how these affect the values of the inelastic cross sections. These problems cannot be solved by direct calculation, but require close examinations of the pecularities of the electronic wave functions.

6. Future Plans. No major changes from the original objectives are anticipated. Extension of this contract for another year will be requested.

7. Illustrations. None.

D. Interaction of Electronic Current with Hypersonic Waves in Solids

Submitted by
(Technical Supervisor)

W. J. Robinson
R-RP-S, 876-7571

1. Project Data

Contract Number: NAS8-11120, September 26, 1963 - September 30, 1964

Contractor: Radio Corporation of America
David Sarnoff Research Center
Princeton, New Jersey

2. Purpose of Project. The discoveries on which this work is based are new. Both because of the novelty and frequency range of the effect, these effects open up a new area of research. Since the phenomena are new, relatively little is known about them. For this reason it is not particularly easy to predict what kind of devices can be made based on them or to be sure what the operating limits of possible devices might be. The important point at this stage is that there is good evidence for first order interaction between electrons and acoustic waves in the kmc range, and there is considerable interest in learning more about this interaction, with the idea that useful devices can be made which might operate at very high frequencies. The more there is known about these effects the more likely it is that someone will come up with an extremely simple and compact device. A generator for high-frequency oscillations and a traveling-wave amplifier can be mentioned as possible devices.

3. Technical Status. The period of performance for this contract was completed September 30, 1964. The objectives of the contract involved the following catagories: (1) the theoretical effort needed to analyze the mechanism involved in the interaction of electronic current with hypersonic waves in solids and (2) the experimental effort needed to support the theoretical analysis.

Noise spectrum measurements were made of the electrical noise in CdS in the current-satruation region. However, it has become apparent that more direct methods of observing or detecting phonons at microwave frequencies are needed. It appears that circuit effects may have distorted the measurements making their interpretation difficult. Consequently, optical methods as a means of avoiding these difficulties also become apparent.

4. Major Accomplishments. There were no significant accomplishments developed under this contract; however, several technical difficulties became apparent. Measurements with CdS crystals were not reproducible. Electron trapping was suspected and may be due to difference in impurities in each of the samples. RCA expressed no desire to get into a program of determining the impurities. They accepted the impurities content by the CdS supplier as sufficient. Dr. deKlerk at Westinghouse Research Laboratory has expressed the opinion that the mechanism involved cannot be determined until the effect of impurities on the electron-phonon interactions can be measured.

5. Problems. The results of transducer techniques are inefficient and the reasons for this are not too well understood. This has been the opinion of the RCA investigators throughout the program. In some measurements the lack of a signal may have been due to very low conversion efficience. As a possible solution to this problem we have recently let a contract to RIAS to investigate the transducer inefficiency problem.

6. Future Plans. Contract Terminated.

7. Illustrations. None.

E. Study of Impact Characteristics of Selected Non-metallic Materials in Vacuum Environment

Submitted by
(Technical Supervisor)

Stanley A. Fields
R-RP-T, 876-0582

1. Project Data

Contract Number: Not Applicable

Contractor: MSFC In-House

2. Purpose of Project. To study the effects of secondary impacts on non-metallic (stony) materials in a vacuum environment. As a result of meteor impacts on the lunar surface, material of various sizes will be ejected and impacted on the lunar surface at various velocities up to lunar escape velocity. This test program is to study the effect of such movement of material in a vacuum environment.

3. Technical Status. A slug ejector has been designed and fabricated for use in this study. The ejector is ready for assembly and checkout at the present time. This test apparatus will allow impacts to be made at velocities up to lunar escape velocity. For the extremely low velocity impacts, a special cylindrical test apparatus is being fabricated for use in an ultra-high vacuum chamber. The ultra-high vacuum chamber with an ultimate vacuum of 5×10^{-11} torr is scheduled for delivery in early 1965.

4. Major Accomplishments. The fabrication of the impact apparatus has been completed.

5. Problems. There were no problems.

6. Future Plans. After assembly and checkout of the impact apparatus, projectiles will be impacted on various types of non-metallic (stony) materials. The targets will be both solid slabs and granular. The breakage of the material, the ejecta pattern and crater formation will be studied.

The effect of movement of granular material in an ultra-high vacuum environment will be studied using the cylindrical test apparatus to tumble the material.

7. Illustrations. None.

F. Determination of the Coefficient of Friction of Metals on Non-metals at Ultra-High Vacuum

Submitted by
(Technical Supervisor)

Stanley A. Fields
R-RP-T, 876-0582

1. Project Data

Contract Number: NAS8-5415, April 27, 1964 - March 24, 1965

Contractor: Grumman Aircraft Engineering Corporation

2. Purpose of Project. To determine by a series of experiments the change in the frictional properties of a number of possible landing surfaces. Because of the lack of data available on the determination of the coefficient of friction of metal solids on granular non-metals in a vacuum environment, the initial program was formulated for the following purposes:

a. To determine whether or not high vacuum allows a significant increase in the frictional properties of granular material.

b. To provide measurements indicating the range of values obtained in an experiment and the repeatability of the experiment.

The purpose of the continuation is to determine more precisely the effect of vacuum alone on the coefficient of friction of a large sample, as homogeneous as possible in composition, size, grain geometry and texture.

3. Technical Status. The metals used in this program are aluminum 7075 and steel AISI 1020. The granular non-metallic materials are basalt and quartz in two size ranges 250μ to 500μ and 37μ to 44μ.

All tests result in an increase in the coefficient of friction of metals on non-metals from atmosphere to vacuum. The vacuum tests were made at 10^{-6} - 10^{-7} torr. The initial data indicated that the coefficient of friction of 1020 steel on basalt (250μ - 500μ) gave the lowest coefficient of friction in vacuum of 0.20.

Tests have been made to determine the repeatability of the experiments and have resulted in very good agreement between experiments. On a test series of quartz and aluminum 7075 five experiments were conducted and the maximum difference in the coefficient of friction was 15 percent.

Sufficient data will be available at the end of the current phase to separate the different variables influencing the coefficient of friction and will allow a more precise evaluation of the data taken to date.

4. Major Accomplishments. The many variables such as sequence of test, temperature, load and vacuum can be separated and the effect of each on the coefficient of friction can be determined.

5. Problems. No problems have been encountered in this reporting period.

6. Future Plans. To extend the measurements into a higher vacuum range (10^{-9} torr and greater).

7. Illustrations. None.

G. Effects of Vacuum Conditioning on the Physical Properties of Selected Materials

Submitted by
(Technical Supervisor)

Hoyt M. Weathers
R-RP-T, 876-0582

John Bensko
R-RP-T, 876-2252

1. Project Data

Contract Number: Not Applicable

Contractor: MSFC In-House

2. Purpose of Project. The intended purpose of this task was to determine how the vacuum environment affects the various bulk physical properties of certain selected silicate materials.

The ways in which this task allows possible solutions are: (1) macroscopic, bulk properties or (2) microscopic, point-to-point properties. The macroscopic approach was chosen becuase any results which may have a large scale significance should be observable. In particular, properties of bulk densities in the two environments of atmosphere and vacuum have an effect upon bearing strength and slope stability. After bulk densities have been determined, the bearing strengths will be studied experimentally.

3. Technical Status.

a. Bulk densities in atmosphere for various sizes of quartz (SiO_2) have been determined for a specific energy parameter.

b. Equipment is now available to begin the first drop tests to determine bearing strengths.

c. Natural angle of repose experiments must await the completion of "b" above.

4. Major Accomplishments.

a. Literature survey of most recent data in this area.

b. Custom equipment design and fabrication.

c. Bulk density determinations of quartz in atmosphere.

5. Problems. The problems involved in this task are:

a. It has been difficult to properly reduce in size, within graded limits, the bulk materials used in the experiment. The solution to this has been the procurement of appropriate material and additional fracturing apparatus.

b. Until recently the pressure range available has not been large enough to produce any significant results. The solution has been to increase the vacuum range by three decades.

6. Future Plans. Plans are to continue in phase one until such time as the necessary equipment is available that has been modified to work in our systems. Phase two, that of utilization of this equipment, will be started as soon as possible. Plans are to obtain more data on densities of the materials to be used in conjunction with data from bearing strength determinations. The bearing strengths will appear from penetration experiments performed both in atmosphere and at various vacuum levels.

7. Illustrations. None.

H. Research into the Suitability of Various Materials for Optical Maser Action

Submitted by
(Technical Supervisor)

Dr. J. L. Randall
R-ASTR-RP, 877-2168

1. Project Data

Contract Number: NAS8-5174, October 30, 1962 - December 31, 1964

Contractor: Linde Company
Division of Union Carbide Corporation
Indianapolis, Indiana

2. Purpose of Project. The purpose of this project is to attempt to develop new laser materials which would be more efficient and operate at wavelengths other than those presently available.

3. Technical Status. This research is conducted jointly by Linde and an in-house effort at MSFC. Spectroscopic analysis of fluorescence is made in-house at MSFC. Linde performs research leading to new potential laser materials.

4. Major Accomplishments. A new laser material, Yttrium aluminum garnet doped with neodymium ($YAG:Nd^{+3}$), has been developed. Laser operation occurs at 1.0639 microns. Up to 200 milliwatts output has been achieved in cw operation at room temperature water cooled operation. Continuing evaluation of the laser is being made at MSFC.

5. Problems. The contract has expired and a new contract is being negotiated. Work is now limited to the few rods available.

6. Future Plans. In the new contract Linde will concentrate on improvement of the optical homogeniety and quality of the rod.

7. Illustrations. None.

I. Optical Properties of Transition Ions in Crystals

Submitted by
(Technical Supervisor)

Dr. J. L. Randall
R-ASTR-RP, 877-2168

1. Project Data

Contract Number: NAS8-11200, May 13, 1964 - February 13, 1965

Contractor: University of Alabama
University, Alabama

2. Purpose of Project. The purpose of this project is to theoretically and experimentally study optical properties of some transition ions in crystals.

3. Technical Status. The fluorescence decay of Pr^{+3}, Nd^{+3}, and Sm^{+2} in $LaCl_3$ have to be measured at 77°K and 4.2°K.

4. Major Accomplishments. A time resolved spectrometer has been constructed and operates down to 4.2°K. The above listed fluorescence work has resulted in a publication in the Letters of the Journal of Chemical Physics.

5. Problems. No major problems at the present time.

6. Future Plans. Future plans call for a theoretical model to explain the obtained date.

7. Illustrations. None.

J. Research on Molecular Surface Interactions at Space Probe Escape Velocities

Submitted by
(Technical Supervisor)

James O. Ballance
R-AERO-AM, 876-2689

1. Project Data

Contract Number: NAS8-5326, May 23, 1963 - February 23, 1965

Contractor: University of Alabama
University, Alabama

2. Purpose of Project. The ultimate objective of the project is the determination of normal, tangential, and thermal accommodation coefficients at high molecular velocities as a function of surface conditions. The objective during this period was to design and construct the accelerator, complete the force probe, and the vacuum pumping system.

3. Technical Status. The force probe is complete and operates very well. No out-gassing during operation was observed. The accelerator housing is completed but needs final cleaning before use. A radiant heat degassing system is completed. The titanium pumping system has been installed.

4. Major Accomplishments. None.

5. Problems. The expected decrease in pressure with the titanium pumping system has not been realized. In fact, an increase in pressure of about one-half order of magnitude occurs when it is operated.

6. Future Plans. The experimental apparatus will be completely assembled and actual engineering measurements should be made in the next six to twelve months.

7. Illustrations. None.

K. A Determination of the Effects of Rocket Engine Exhaust Impingement on Simulated Lunar Surfaces

Submitted by
(Technical Supervisor)

Mr. R. G. Crawford
R-P&VE-SAA, 842-3300

Mr. G. B. Gerry
R-P&VE-SAA, 842-2167

1. Project Data

Contract Number: Not Applicable

Contractor: MSFC, In-House

2. Purpose of Project. Documented results of these tests are needed as soon as possible to assess the influence of landing rocket impingement on landing gear design. Of lesser importance are the additional benefits which will be gained from this testing. These benefits include determination of the motion of lunar particles which may be hazardous to the landing vehicle and to both local and distant lunar facilities.

The purpose of this task is to develop data to achieve:

a. A general evaluation of direct hot jet impingement on a variety of soils.

b. A determination of jet blown particle velocities.

c. The mass distribution of particles eroded from the simulated surfaces.

d. A determination of thermal gradients within the soil samples during and after firings.

e. A determination of facility requirements for near-vacuum-environment tests.

3. Technical Status. Initial plans to implement a test program have been completed. A series of small-scale rocket firings at various elevations (0-20 feet) above the surface of three different soil types under atmospheric conditions are scheduled to start during February, 1965.

4. Major Accomplishments. The project has not been underway long engough to produce significant accomplishments.

5. Problems. No significant problems have been encountered.

6. Future Plans. Based on knowledge gleaned from the atmospheric tests, a more comprehensive test plan will be developed. The testing in near-vacuum conditions can be better planned once a knowledge of the facility requirements associated with the impingement phenomenon have been assessed.

7. Illustrations. None.

APPLIED MATHEMATICS

Gravitation and Orbital Mathematics

A. Digital Filters

Submitted by
(Technical Supervisor)

Ronald J. Graham
R-COMP-RRF, 876-1795

1. Project Data

Contract Number: NAS8-5164, October 1, 1962 - July 31, 1964

Contractor: Auburn Research Foundation, Inc.
Auburn, Alabama

2. Purpose of the Project. The purpose was investigation and development of improved methods of numerical analysis. The areas of special interest were smoothing, differentiating, and integrating. The final end products desired were clearly defined methods developed in enough detail to be confidently applied on electronic digital computers.

3. Technical Status. The major aspects of the project have been completed. A thorough study and analysis have led to very desirable results, which are of significant benefit.

4. Major Accomplishments. Digital Filtering methods were studied. Mathematical justifications were made. Different mathematical models or filters were studied and analyzed. Techniques were developed that:

a. Smooth
b. Smooth and take first derivative simultaneously.
c. Smooth and take second derivative simultaneously.
d. Smooth and integrate simultaneously.

It was verified that digital filtering methods are very powerful and useful in developing all the above techniques.

5. Problems. No unusual technical problems were encountered.

6. Future Plans. Some other work is justifiable on error analysis and further study. Plans are to extend this task assignment for at least another year.

7. Illustrations. Contractor report from Auburn Research Foundation giving major technical accomplishments on the project is available.

B. Methods Study for the Numerical Solution of Ordinary Differential Equations.

Submitted by
(Technical Supervisor)

A. E. Anderson
R-COMP-R, 877-3945

1. Project Data

Contract Number: NAS8-11129, November 9, 1963 - November 9, 1964

Contractor: Georgia Institute of Technology
Atlanta, Georgia

2. Purpose of Project. To determine the applicability of various numerical methods for the solution of several distinct types of differential equations by investigating the results of truncation error, rounding error, and stability characteristics of various methods when applied to distinct differential equations. In particular, the basic integration methods to be studied are as follows:

a. The Runge-Kutta-Fehlberg Method
b. Cowell's Method
c. Adams' Method
d. The Lie Series
e. Runge-Kutta-Shanks Method

3. Technical Status.

a. The Runge-Kutta-Fehlberg method has been programmed in double precision for the B-5000 and applied to periodic orbits in the restricted three-body problem with excellent results.

b. A version of Cowell's method has been developed and programmed in double precision for the B-5000. The method has been applied to the restricted three-body problem. Several problems involving a kind of instability have been uncovered.

c. The Adams' method has been programmed in double precision for the B-5000, and applied to the restricted three-body problem. A unique step-size control feature has been incorporated in the program.

d. The Lie Series method has been programmed and applied to the restricted three-body problem. This method, at present, is a low-order method.

e. The Runge-Kutta-Shanks method has been programmed in double precision for the B-5000. This method has been applied to periodic orbits in the restricted three-body problem with extremely excellent results.

4. Major Accomplishments. The development of general usable programs has been one of the major accomplishments. Another major accomplishment has been the incorporation of a novel step-size control in the Adams' method which permits the use of continuous changes in step-size rather than the usual halving and doubling. A third major accomplishment has been the comparison of the various methods as to their efficiency and applicability to various types of problems.

5. Problems. Problems of accuarcy, due to limited precision, have arisen and been resolved. Questions of instability have arisen in the Cowell's method, and these questions have not as yet been fully resolved. Problems in step-size control arose continuously and were resolved. The step-size control features incorporated in the Adams' method were excellent, and the development of such features for the other methods have not as yet been resolved.

6. Future Plans. To investigate methods of step-size control which are more efficient than those currently used. To include developments in Hybrid methods, programming these methods and applying them to problems of interest. To study predictor-corrector type methods and program them for application to current problems.

7. Illustration. None.

C. Research on Numerical Integration of Second Order Differential Equations.

Submitted by
(Technical Supervisor)

A. E. Anderson
R-COMP-R, 877-3945

1. Project Data

Contract Number: NAS8-2559, February 1, 1964 - January 31, 1965

Contractor: Vanderbilt University
Nashville, Tennessee

2. Purpose of Project. Investigate methods of numerical integration that might yield increased accuracy of speed in comparison with the classical methods such as Runge-Kutta.

3. Technical Status. Professor Shanks has submitted for publication as a NASA Technical Note a report of the theoretical derivations of his integration formulas.

Professors Rodabaugh and Wesson have submitted for publication as a NASA Technical Note some results of their research on predictor-corrector methods for the numerical solution of differential equations.

4. Problems. It has been determined that an error is present in the ninth order formula of the Runge-Kutta type developed by Professor Shanks. Locating such errors poses a real problem due to the extreme complication of the conditions involved.

Choosing the best predictor-corrector for a given differential equation remains a problem. Also, the unnecessary use of computing time can be further reduced.

5. Major Accomplishments. Publication of the theoretical derivations of Shanks' integration formulas along with some new formulas from the fourth order through the eight order.

Preparation of publication of results in programming and deriving predictor-corrector methods for the numerical solution of differential equations. In addition, two students are writing Master's theses on these topics. A seminar is continuing.

6. Future Plans. To complete a ninth order formula and to carry out studies related to step-size control and error analysis with particular reference to continuing techniques.

7. Illustrations. None.

D. Research and Applications of Topological Dynamics

Submitted by
(Technical Supervisor)

H. E. Stern
R-RP-N, 876-3542

1. Project Data

Contract Number: NAS8-1646

Contractor: University of Alabama

2. Purpose of Project. To perform research in topological dynamics and the analysis of dynamical systems.

3. Technical Status. This project was started in 1961 and has continued through several extensions. Early work included the writing of a set of introductory notes to the field of topological dynamics. Other efforts have resulted in a number of papers published in various mathematical journals.

4. Major Accomplishments.

a. A seminar on nonlinear differential equations has been organized, with five persons participating. The principal topics being considered are (1) stability and Lyapunov functions, (2) the limit cycle and its generalizations, (3) stability of periodic solutions and almost periodic solutions and (4) complete stability and central theory.

b. Dr. Hsin Chu, principal investigator, attended the American Mathematical Society meeting held at Amherst, Massachusetts, August 25-28. A talk of particular interest to this contract was presented by Professor S. Lefschetz "Recent Advances in the Stability of Non-Linear Control Systems."

Dr. Chu also attended the Society meeting at Evanston, Illinois, November 27-28, where he read a paper, "A Note on Compact Transformation Groups with a Fixed End Point." This paper has been accepted for publication in the Proceedings.

c. Mr. H. C. Wasserman, a Ph. D. candidate at Wesleyan University, visited at the Research Institute from July 15 to July 30. He completed the first draft of his dissertation, "Closed Invariant Subsets of Enveloping Transformation Groups."

d. Dr. Chu's paper, "Some Inheritance Theorems in Topological Dynamics," has been submitted to the Journal of London Mathematical Society."

e. Dr. Chu has also been working on several other papers: "A Note on Distal Minimal Flows," "A Note on Complete Stability of a Non-Linear Control System," "Isotropy Subgroups of Differential Transformation Groups" and "Another Note on Transformation Groups with a Fixed End Point."

5. Problems. No unusual problems have been encountered.

6. Future Plans. Dr. Chu has proposed two possible areas in which to pursue further development of the theory and application: (1) some problems in Lyapunov theory with application to control theory and (2) the effect of the rotation of the earth's atmosphere on the motion of an artificial satellite. Current plans are to extend the contract for another year at a one-man level of effort with emphasis on the first topic.

7. Illustrations. None.

E. Synthesis of Approximate Trajectories for Low-Thrust Vehicles in Earth-Moon Space

Submitted by
(Technical Supervisor)

Joseph C. King
R-RP-N, 876-4126

1. Project Data

Contract Number: Not Applicable

Contractor: In-house

2. Purpose of Project. The present investigation is intended to develop a body of approximate trajectory data for low-thrust vehicles operating between satellite orbits of the Earth and Moon. Data of this type is needed in estimating the propulsion requirements and the performance of such vehicles, which have a significant potential for reducing the logistic problems involved in advanced lunar operations.

The approximate trajectory data obtained may be useful in generating precision trajectories based on more complicated models of the dynamical system. In obtaining precision trajectories by successive approximations, it is desirable to have good estimates of the desired initial conditions, at which to begin the interation process. The approximate results may also provide a systematic basis for short-term behavior prediction.

3. Technical Status. The potentialities of advanced, low-thrust propulsion systems for providing the logistic support of extensive lunar operations has been recognized for several years. A number of investigators have studied this application and reported their findings, and several have devoted considerable effort to the delineation of approximate trajectories. The trajectory studies have taken several rather different forms, which has resulted in a marked lack of unity in the present body of literature on low-thrust flight between the Earth and Moon. Some of the difficulty seems to lie in the absence of suitable methods for generating rigorously optimum trajectories. This situation also implies a lack of precise standards by which the various approximations can be judged.

Although a great deal of solid progress has been made over the last few years in the general field of low-thrust trajectory optimization, the methods which have been used are not immediately applicable to the Earth-Moon problem. The principal reason is that this recent work deals primarily with the physical model sometimes called the "restricted two-body problem," which has been found quite satisfactory for describing interplanetary trajectories in the sun's field (the near-planet motion is handled separately). In Earth-Moon space, however, the problem is not so readily separable into single-field sections. The apparent strategy in the Earth-Moon case would be to use a restricted three-body model of the system, but this approach in effect adds a

major complication to the type of problem which can now be handled only with some strain. So it is necessary to invoke two-body methods in the Earth-Moon case also, but the best procedures for doing so are by no means obvious. As a result, a number of schemes have been applied by various investigators, which explains the divergence of methods, noted above, which characterizes the existing literature.

The present project was undertaken as an effort to analyze the basic problem of low-thrust flight between the Earth and Moon, to review the various approaches which have been employed in approximating the trajectories, and to select a "standard' approach which offers the greatest simplicity and convenience without undue sacrifice of realism and accuracy. In endeavoring to reduce the basic problem to its simplest representation, a new method of approximation appeared which seemed unusually straightforward and praciticable. In this method, the complete trajectory is synthesized by combining several powered spirals and coasting arcs. The coasting phases are continuations of the powered segments, and they are matched and joined at their outer apsides. The junction of each pair of apsides falls on the Earth-Moon line. One type of composite synthesized by this method is illustrated in Figure 88.

4. Major Accomplishments. The new approximation method described above, referred to as "collinear matching," has been investigated numerically and found to be workable in the regions of present interest. Comparative data have been obtained (by means of the new machine program anticipated in the previous report) using an alternative approximation method based on the "activity sphere" spatial boundary. The basic results from the collinear matching method have been compared to the alternative (activity sphere) results and also to selected data reported in the literature. The comparison results were generally favorable, and on that basis the new approximation method is considered to satisfy the main study objective of determining the principal mission characteristics (propulsion requirements and flight times) by a relatively simple procedure. Further information on the method and evaluation are given in AIAA Paper 65-87, "A Natural First Approximation to Low-Thrust Trajectories Between Satellite Orbits of the Earth and Moon," which was accepted for presentation at the AIAA 2nd Aerospace Sciences Meeting, January 25-27, 1965, in New York City.

5. Problems. While it appears that no serious problems remain in the line of investigation now being concluded, the tentative nature of the above evaluations, based as they are on other approximations rather than exact trajectories, should be kept in mind. The most obvious way of providing a more reliable standard of comparison for the approximations is to compute three-body

versions of the composite (two-body) coasting arcs which have been employed. The coasting arcs are specified because they pass through the regions of strongest third-body forces. Although the machine integration of these three-body arcs is basically straightforward, it is likely that a considerable amount of searching and iteration will be required to obtain the specific trajectories needed for a thorough quantitative comparison.

6. Future Plans. As noted above, the present line of investigation is now being concluded. Several worthwhile improvements and extensions are apparent, however, and the prospects for pursuing these depend mainly on evaluations of their importance compared to other prospective study areas. No definite plans have been made at this time, but in addition to the three-body work outlined above, a systematic and rather general study of two-body approximation methods appears to be highly desirable.

A version of the technical paper cited above is expected to be published in the AIAA Journal about mid-1965.

7. Illustrations. Figure 88.

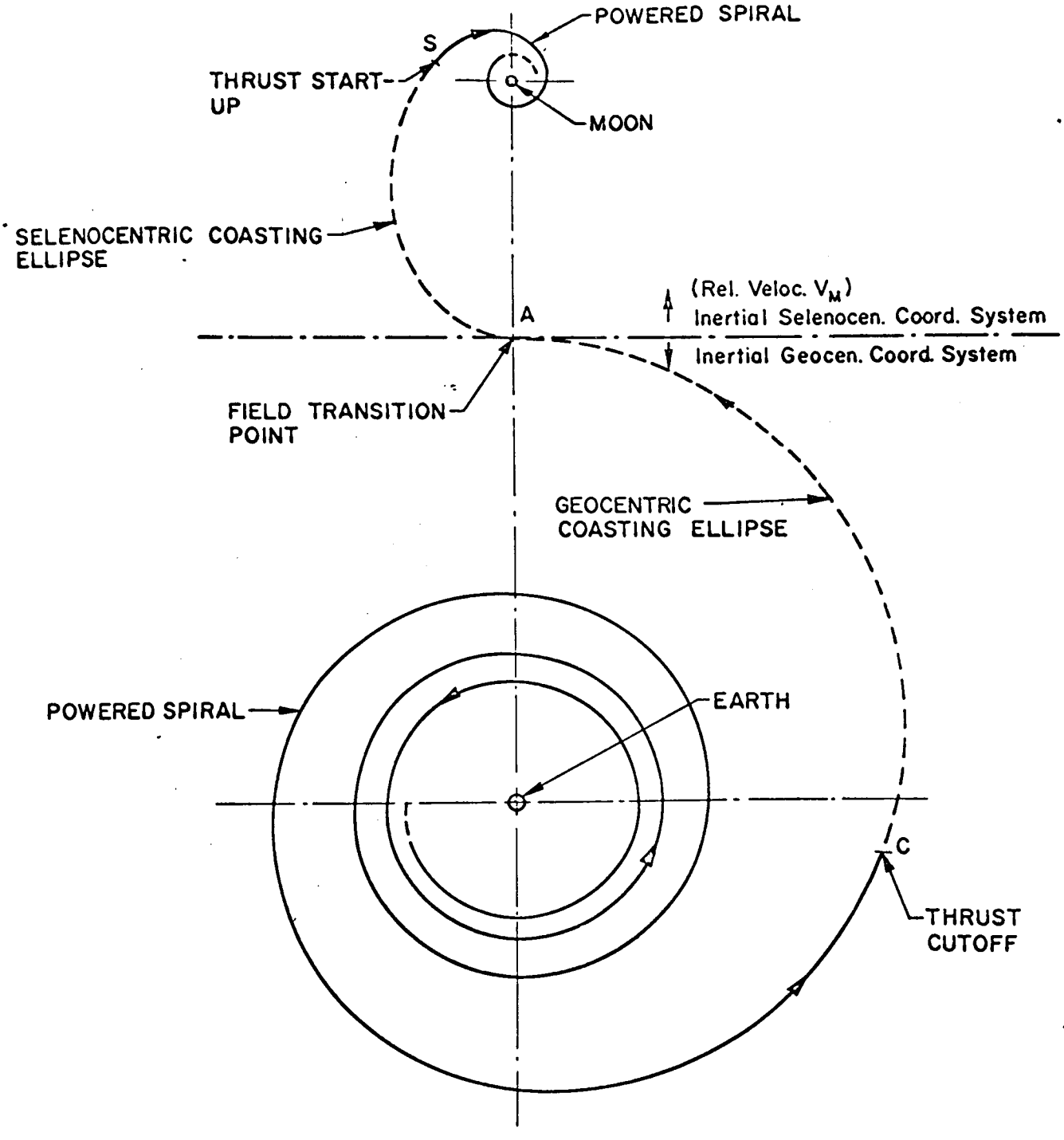

FIGURE 88. TYPICAL COMPOSITE TRAJECTORY (CISLUNAR MATCH)

F. Orbital Lifetime Study

Submitted by
(Technical Supervisor)

H. F. Kurtz, Jr.
R-AERO-FO, 876-4257

1. Project Data

Contract Number: NAS8-11121, September 26, 1963 - May 26, 1965

Contractor: Lockheed Missiles and Space Company
Lockheed Aircraft Corporation
Huntsville, Alabama

2. Purpose of Project. Develop improved techniques for the prediction of orbit lifetime and decay characteristics of vehicles of the Saturn class. Compare existing techniques and models, and use data acquired from tracking of actual orbiting vehicles to improve the accuracy of prediction. Perform lifetime analyses for future vehicles and payloads to include the optimization of orbital parameters to satisfy requirements for specific lifetime characteristics, considering vehicle performance constraints.

3. Technical Status. The development and comparison of techniques for determining lifetime confidence levels have been completed. Present efforts are centered on studying the maximization of orbital lifetime for optimized power flight trajectories, on the development and checkout of a new lifetime prediction deck and on the improvement of the atmospheric model in use.

4. Major Accomplishments. A development and comparison of various methods for determining lifetime confidence levels have been completed. Two methods investigated considered that the apogee and perigee heights are linear functions of the performance parameters and that the performance parameters are independent. These methods gave good agreement. A third method assumes that lifetime is a linear function of each independent performance parameter. This method in general gave more conservative results. The problem of obtaining the distribution function of the product of two variables in order that lifetime uncertainty due to vehicle dispersions and to prediction uncertainty might be combined has been solved. The problem of optimizing the powered flight trajectory to yield maximum orbital lifetime for a given weight

in orbit is being formulated as a Mayer Variational problem. The development of a new in-house computer program for accurate predictions is near completion with contractor assistance. Development of a new atmospheric density model is underway. This model is based on data obtained from Gemini and Saturn flights and from Discoverer data as analyzed by Lockheed of Sunnyvale. This model will account for the total heating effect of the sun as a function of time. Significant improvements in the accuracy and efficiency of making lifetime predictions have been achieved.

5. Problems. None.

6. Future Plans. The contract is being extended from May 26, 1965, for a period of six months. It is anticipated that this will be the last extension to the contract and that a final summary report will be written during this period. It is planned to continue the development of improved prediction techniques and the atmosphere model. This will be done by fully using data which are obtained on Saturn flights and by continuing to study the effects of solar activity on atmospheric density, lifetime, and decay by determining the accuracy with which solar activity can be predicted and by developing the means of using various measurements of solar activity in lifetime predictions and decay analysis. In addition, investigation will be made of the effects of solar radiation pressure, solar gravity and lunar gravity on lifetime and the techniques developed for incorporating these effects into lifetime predictions. Also a survey of information on the atmospheres of other planets will be made.

7. Illustrations. None.

Electromagnetic and Radiation Mathematics

A. Integral-of-the-Motion Method of Solving the Boltzmann-Vlasov Equations

Submitted by
(Technical Supervisor)

Robert N. Seitz
R-RP-N, 876-4126

Lawrence H. Wood
R-RP-N, 876-4126

1. Project Data

Contract Number: NAS8-11440

Contractor: MSFC In-House - Northrop Out-of-House

2. Purpose of Project. This theoretical research program is directed toward obtaining exact (nonlinear) solutions of the Boltzmann-Vlasov equations for a fully-ionized plasma. The latter equations provide a good description of low density and/or high temperature plasmas. They may be applied to most space plasma problems such as the calculation of satellite potentials, the calculation of potentials on celestial bodies and the distribution of charged particles in the Earth's magnetic field. They are also applicable to thermonuclear plasmas and to virtually all electron tube devices. Exact nonlinear solutions have been obtained for a number of steady-state problems including cylindrical thermionic diodes and planar and cylindrical plasma diodes. One simple time-dependent problem has also been solved exactly.

A colateral purpose has developed in the course of this project. This is the development of a self-programming computer system to reduce the time required to program and debug scientific problems from weeks to minutes. This effort has arisen because the computer program has consistently proven to be the major bottleneck in the generation of data for papers and reports.

3. Technical Status. Nothing has been done with the Boltzmann-Vlasov equations pending the development of the new computer system.

The Autoprogrammer system permits the user with no prior computer experience to enter and solve mathematical equations in the format and syntax of mathematics just as the equations appear in a textbook. For example, a function such as the error function can be entered as

$$2/\sqrt{\pi} \int (0,x) \exp(-x^2)\, dx$$

and can be programmed in less than 30 seconds. A typical station in the system utilizes 2 large keyboards, a cathode ray storage oscilloscope, and an electric typewriter. The large keyboards are used for the entry of the most common operations and functions such as plus, minus, exponentiation, integration, and partial differentiation. The typewriter is used to type out a hard copy of the program as the user pushes buttons on the keyboard. The typewriter is also utilized to call forth up to 4000 mathematical functions and operators from a

library. The cathode ray oscilloscope provides 2-dimensional and 3-dimensional perspective displays of curves as well as alphabetical and decimal data. The oscilloscope also possesses a stylus which the user employs to enter graphical data into the computer.

The system lends itself very well to multistation operation by scientists and engineers and provides an enormous improvement in turn around times, comparing to conventional computer systems the way a telephone compares to a telegraph. It is believed that this system will greatly expedite the solution of the Boltzmann-Vlasov equations.

4. Major Accomplshiments. The computer system has been brought nearly to the point at which it is a major tool and not a toy. An effort is being made to incorporate all of the operations and capabilities to Fortran IV into the system so that it will have at least the full flexibility of Fortran. The cathode ray scope and keyboards are currently being fabricated and should be ready for checkout within the next few weeks.

5. Problems. Two principle problems have appeared. One is that of getting adequate computer capability from this years funds. This requires a sizeable lead time and an RFQ must be issued to secure such a computer system. As a result, a new computer system does not appear to be feasible before the end of this fiscal year. In order to provide a stop-gap computational capability, the Computation Laboratory has furnished a remote terminal which will be tied into a Univac 1107 computer. The other problem concerns the magnitude of the effort required to develop the new computer system. This has proven to be a sizeable undertaking. Accordingly, an effort is being made to build up a small working group to implement the development of the new system. This will be conducted in conjunction with the Computation Laboratory at MSFC, thereby augmenting the available research funds.

6. Future Plans. The immediate future plans are concerned with completing the development of the system to the point at which it becomes a working tool. At that time, research on the Boltzmann-Vlasov equations will resume. This should take place within the next reporting period. Thereafter, an effort will be made to automate the numerical analytical operations and to provide symbol manipulation capabilities - that is, algebraic manipulation differentiation integration.

7. Illustrations. None.

Geophysical and Planetary Mathematics

A. Search for Good Algorithms for Practical Solutions to Discrete Optimization Problems

Submitted by
(Technical Supervisor)

A. E. Anderson
R-COMP-R, 877-3945

1. Project Data

Contract Number: NAS8-11189, February 1, 1964 - January 31, 1965

Contractor: The University of Tennessee
Knoxville , Tennessee

2. Purpose of Project. To find and program, for a computer, some good algorithms for solving in a practical way certain types of discrete optimization problems.

3. Technical Status. Experimentation is being done to determine, if possible, where to concentrate the most computing attention in sequencing problems. Also, some work is being done on some optimal partitioning problems.

4. Major Accomplishments. Programs have been written detecting local areas in a discrete space which (heuristically speaking) would be expected to give the best results from intensive computation. Experiments have been made with encouraging results.

5. Problems. No major problems encountered.

6. Future Plans. To extend the methods into areas of quadratic and other types of nonlinear programming.

7. Illustrations. None.

FLUID PHYSICS RESEARCH

Thermodynamics and Transparent Properties

A. Nonequilibrium Gas Kinetics

Submitted by
(Technical Supervisor)

Gerhard B. Heller
R-RP-T, 876-4024

Henry A. McGee
R-RP-T, 876-4024

1. Project Data

Contract Number: NAS8-11242, June 8, 1964 - 10 months

Contractor: Georgia Institute of Technology
Atlanta, Georgia

2. Purpose of Project. The purpose of the research project is to advance the knowledge in nonequilibrium kinetics. Kinetic phenomena in the gas phase are significant considerations in various fields like high speed aerodynamics, combustion, rarefied gas dynamics, meteorology, and electric propulsion, such as the arc engine or thermion engine. It also provides better theoretical knowledge of the processes occurring in the upper atmosphere due to combustion products of Saturn vehicles. Kinetics studies under this task include both physical phenomena of momentum, heat and mass transfer and chemical phenomena.

The approach is to derive the general differential equations which describe the interactions, to use theoretical or experimental potentials, and to solve individual interactions by Monte Carlo methods. Computer experiments of molecular and atomic interactions will be carried out.

3. Technical Status. The basic differential equations have been written. By using a moving coordinate system, the number of independent variables has been reduced to nine. Presently the best possible set of variables is being determined. The equations are being programmed for the 7094 computer of the Computation Laboratory.

4. Major Accomplishments. See Technical Status.

5. Problems. A serious problem is the availability of the exact potentials. So far only the hydrogen potentials are well enough known from quantum mechanical derivations. In other cases approximations like Lennard-Jones potentials will be used as a first cut at the problem.

6. Future Plans. A study is underway for experimental verification of the theoretical results. Two approaches are pursued: (1) tie-in to experiments carried out by Dr. Frary on upper atmosphere kinetics at RPL, (2) specific kinetics experiments designed to verify specific results of the theory and to provide inputs presently not available.

7. Illustrations. None.

SECTION V. NUCLEAR ELECTRIC SYSTEMS

ELECTRIC PROPULSION

Component Technology

A. Study of Electrically Propelled Cargo Vehicles for Sustained Lunar Supply Operations

Submitted by
(Technical Supervisor)

Joseph C. King
R-RP-N, 876-4126

1. Project Data

Contract Number: NAS 8-11207, June 3, 1964 - September 3, 1965

Contractor: General Electric Co.
Missile and Space Div.
Philadelphia, Pa.

2. Purpose of Project. To determine the applicability and the optimum operating modes of electrically propelled Earth-Moon shuttle vehicles for logistic support of advanced lunar operations. The main purpose of the study is to present the major design choices (that is, mission profile, trip time, I_{sp}) in their proper perspective, defining the consequences of various selections and providing a rational basis for system optimization.

3. Technical Status. Prior to the initiation of the present contract, the potentialities of electrically propelled vehicles in the lunar supply operations had been fairly widely recognized, but the technical aspects had not been investigated in depth. Several technical papers have been published on the general feasibility and mission potential of this application, and a moderate amount of trajectory analysis has been carried out. The present contract was intended to proceed from that point to develop a detailed and reliable appraisal of applicability of electric propulsion to the lunar supply mission, in terms of the technical capabilities which are now emerging.

The initial approach to the study was to develop a generalized analysis of the lunar supply problem based on a reusable vehicle or propulsion module. The results of the analysis were developed in parametric form, from which major performance characteristics and cost relationships can be determined for various state-of-the-art assumptions. This particular phase of the work now appears to be essentially complete, and it is now possible to make rational selections of design characteristics and operating modes for detailed analysis and preliminary design studies.

4. Major Accomplishments. A number of significant findings have been established in the initial phase of this study. Among these findings are the following:

a. The relative advantages of the electrically propelled vehicles over the anticipated alternative systems have been reaffirmed. Payload multiplication factors of 2 1/2 and estimated operating cost reductions of 40 percent, compared to all-chemical systems, are typical of nearer-term applications.

b. Single-use electric vehicles have proved to be of definite interest, at least for applications based on the expected initial technical capabilities.

c. The availability of propellants derived from lunar minerals would be definitely advantageous. The reuse of lunar surface-to-orbit vehicles is not particularly attractive without lunar propellants.

5. Problems. No particular problems have arisen in the study work itself. The technical problems in implementing the mission under study, however, are quite substantial. The most difficult of these problems appear to concern the required nuclear power supplies: the lengthy and expensive R&D programs necessary for their development and the problems involved in achieving the long lifetimes and low specific weights needed for high performance and operating economy.

6. Future Plans. Although the major portions of the parametric and mission mode analyses have now been completed, it will be desirable to supplement and refine these analyses from time to time as further information is derived rom other phases of the study. Most of the future work, however, will consist of more detailed analyses of the various elements of the application, such as the powerplant, the spacecraft, and the operational plans and procedures. Such detailed analyses will provide further information on how the various design choices will affect the main indices of merit for the application: performance, weights, time phasing, cost, and reliability.

7. Illustrations. None.

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SEMI-ANNUAL PROGRESS REPORT

PART I

OART PROGRAM

SUPPORTING RESEARCH PROJECTS

(July 1, 1964 to January 1, 1965)

Edited by

Harry J. Coons, Jr.

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Houston, Texas

Director, NASA, Michoud Operations (2)
New Orleans 26, Louisiana

Director, NASA, Western Operations (2)
Santa Monica, California

Scientific and Technical Information Facility (25)
Attn: NASA Representative (S-AK/RKT)
P. O. Box 57
Bethesda, Maryland

Air Force Materials Laboratory
Research and Technology Division
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base, Ohio
Zip Code 45433