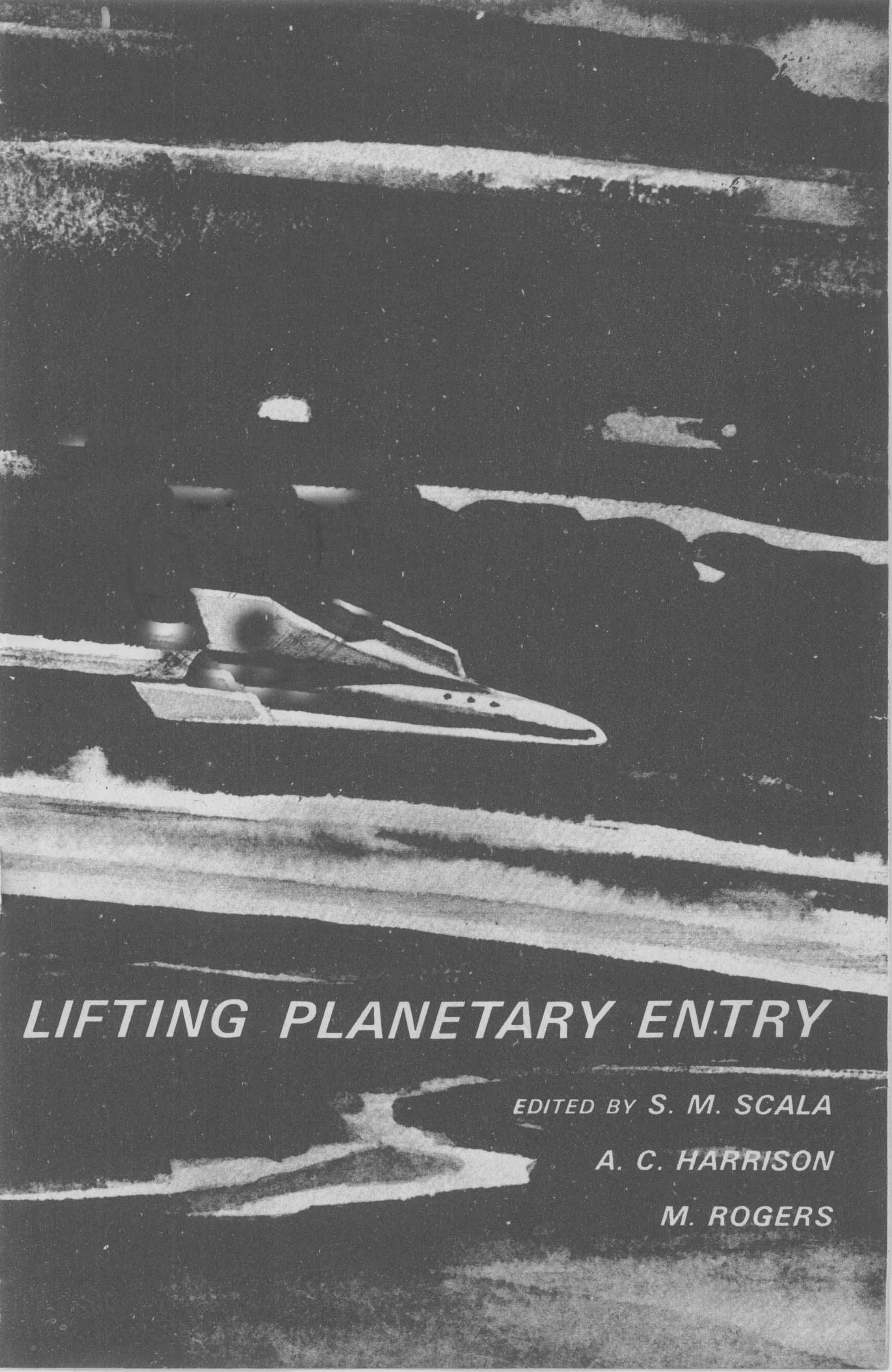

LIFTING PLANETARY ENTRY

EDITED BY S. M. SCALA
A. C. HARRISON
M. ROGERS

PREFACE

Recent successes of the aerospace industry in manned space flight have been spectacular, but the coming to maturity of space technology will be reached only when man can enter a planetary environment from space and land with precision at a site selected at his discretion.

A body of fundamental knowledge underlies and parallels the recent accomplishments, but it is scattered throughout the literature of the disciplines involved. It was believed that a special symposium would serve to correlate at least a part of this knowledge and, at the same time, provide source material on the various fundamental aspects of the dynamics of manned lifting planetary entry with the aim of identifying those which require further research and understanding.

As a result, the Air Force Office of Scientific Research and the General Electric Space Sciences Laboratory co-sponsored a Symposium which was the third in a series on fundamental aspects of the aerospace disciplines. The first, "Physical Chemistry in Aerodynamics and Space Flight", was held in Philadelphia, Pennsylvania, in September, 1959. The second, titled "The First International Symposium on Analytical Astrodynamics", took place in Los Angeles, California, in June, 1961. At this third symposium, held in Philadelphia, Pennsylvania, in October, 1962, a total of 34 papers were presented; of these, 32 were submitted -- along with two new papers for publication in these proceedings. Because the number of papers is large, a summary of their contents would be too lengthy to include in this preface. We will, however, describe the inter-relationships among the six subject areas.

The first session dealt with Planetary Atmosphere Models which, of course, are needed to predict the nature of the environment to be encountered by a space vehicle. In fact, it might be said that a fundamental difficulty is involved in attempting the design of a space craft capable of entering a planetary atmosphere unless the vertical structure of that atmosphere is known. Hence, it must be supposed that unmanned space craft and unmanned space probes will obtain this information prior to man's flight to the neighboring planets.

Once the nature of the atmosphere is known, one may proceed to a determination of the conditions produced by its interaction with the space craft, namely the Aerodynamic Plasma which is formed by shock-wave heating of the gas. This was the subject of the second session.

When the thermochemical state of the gas which envelops the vehicle in the shock layer has been determined, a means of utilizing these boundary conditions must be derived so as to predict the magnitude of the aerodynamic and radiative heating. One may then proceed to determine an optimum family of trajectories which will minimize the time-integrated aerodynamic and radiative heating, along with thermal shield requirements, while providing maximum payload, range and cross-range maneuverability. The title given to such investigations is Energy Management, subject of the third session.

A problem of increasing importance is that of the vehicle structural response to the heating load, particularly when the spacecraft has relatively thin lifting surfaces in which deformation of the structure due to heat load effects will influence aerodynamic performance. This involves both weak and strong coupling; thus, the term Aerothermoelasticity is to be distinguished from aeroelasticity, in which such thermal coupling is either extremely weak or non-existent. In the fourth session, a series of four papers was presented, dealing with the full spectrum of aerothermoelastic effects arising from weak to strong thermal coupling.

On the second day of the Symposium, the attendees were fortunate to have as their invited speaker at an evening reception General James Ferguson, United States Air Force Deputy Chief of Staff for Research and Technology, who presented the latest official views of the Air Force on the importance of the military in space to ensure that space will indeed be used for peaceful purposes.

Although the hypersonic interaction problem may be considered to be the major one in the design of hypervelocity space craft, the vehicle eventually must decelerate and land at a predetermined site. Consequently, the subject of Low Speed Aerodynamics was appropriate to this Symposium to extend its coverage to a complete understanding of the aerodynamic interaction problems. In the fifth session, papers were presented on a wide range of configurations which can be used for the terminal phase of re-entry. The paper by Mr. Lesko was not actually presented orally at the Symposium. However, it complements the papers that were presented, and is included in this volume since, in fact, it had been originally scheduled for presentation.

In the final session on Hypervelocity Flows, a number of papers were presented that dealt with the more rarefied aspects of hypervelocity phenomena, including molecular interactions between gases and solids, and effects of surface on thermal accommodation, the subjects of the papers by Professors Hurlbut and Wachman, respectively. Aerodynamic heating and mass transfer cooling were also considered.

In the following pages, it will be seen that this symposium has addressed itself successfully to a wide range of problems in those technical specialties which define the present state of the art and hence help to chart the various paths for future research and development.

Since man is undoubtedly going to participate to a greater extent in space activities in the future than he does at present, with a greater frequency of flights and a wider variety of missions, it seems that an over-all philosophy should also be developed. In particular, one may ask if a reasonable goal might be to develop a multi-purpose vehicle that is capable of satisfying the needs of a variety of future missions, both in terms of flexibility of operation and adaptability to mission objective. That is, can a vehicle be designed so that with essentially minor refurbishment, in terms of time and cost, it could cope with the environment associated with a wide range of space and entry flight conditions? Clearly, this objective can be established only after sufficient additional knowledge is generated so that realistic systems trade-offs can be carried out.

Those who participated in the Symposium are indebted to the members of the Committee, which included, in addition to the Editors, R. L. Bisplinghoff, K. L. Coulson, N. Dow, H. W. Emmons, D. C. Hazen, J. Kaplan, W. C. King, W. G. Vincenti, W. R. Warren, and P. P. Wegener. Among the many who assisted the Committee during the three days of the Symposium, special mention must be given to B. J. Compton, E. H. Deal, J. E. Friedman, P. H. Jensen, T. Palandro, E. Rothouse, S. J. Sutton, and J. H. Wood, along with Bonnie Baumgartner, Jane Doolittle, Jan Decker, Kay LaCombe, Ronnie Meehan, Mary Mellon, Renie Rosetta, Barbara Speeney, Barbara Tenaro, Carol Tison, Marge Weston, and Joanne Zinchak.

The Editors especially wish to thank Mr. P. H. Jensen, who accumulated the manuscripts and illustrations for this volume, carried out much of the actual editing, arranged for authors' review of the proofs, and served as liaison with the publisher's production staff. Likewise, special thanks are due Mr. P. A. Bertolino, who conceived and created the artwork which appears on the dust jacket, the frontispiece, and the six breaker pages.

King of Prussia, Pennsylvania
May, 1963

S. M. Scala
A. C. Harrison
M. Rogers

WELCOMING ADDRESS

by

Dr. Knox Millsaps, Executive Director

U.S. Air Force Office of Scientific Research

It is indeed a great pleasure for me to welcome you this morning on behalf of the sponsors of this symposium, the General Electric Company and the Air Force Office of Scientific Research. AFOSR is very happy to join with industry in sponsoring this symposium on Dynamics of Manned Lifting Planetary Entry, since the subject is perhaps a neglected area of research in the United States.

Great interest is shown for this symposium, as evidenced by the large number of participants present here today. It is most unfortunate that limitations of space and time have precluded the attendance of more researchers and the acceptance of additional papers. As we all know, the communication of research ideas and results is becoming an ever growing problem. We are trying desperately to alleviate this situation. Easing of this difficult matter can be accomplished by publishing in the established technical journals and by participating in scientifically sponsored meetings such as this one, in order to make the invaluable information to be presented available to possible users quickly and widely. I have been solemnly assured that the proceedings will be available in approximately six months.

I see by the agenda that we start from the earth but rapidly take our leave to look at Mars and Venus. From the outset, we can see the new problems posed by man's venture into space. New methods of "energy management" will be investigated, for this promises to be a fertile field for future analyses and tests. Yet, no one field of science can claim a monopoly on this venture. Throughout this journey, old problems in interdisciplinary regimes will be tackled and dragged into our storehouse of understanding. But, what is more important, we will become acquainted with new scientific phenomena to add to our ever-increasing thirst for exploring the vertical frontier and to increase our knowledge of the environment that future generations might inhabit.

I shall not detain you longer from this fascinating journey, but I would like to end my remarks by congratulating the present contributors for their parts in this symposium. I further

wish that each one of you will broaden and strengthen your personal contacts and that you will leave this symposium with a full sense of accomplishment and a little measure of cordial hospitality from GE and AFOSR.

WELCOMING ADDRESS

by

Dr. Richard Porter

General Electric Company

As you must surely know, Philadelphia is one of the most fitting places in the United States to hold a scientific meeting such as this, for it was here, during the middle of the 18th century, that the young operator of a printing establishment, in hot pursuit of scientific knowledge, risked electrocution and once chased a whirlwind on horseback until it sent branches and tree trunks swirling about his head.

In 1743, he looked forward to seeing an eclipse of the moon, only to be disappointed when one of those unbridled storms, a "Nor'easter", enveloped Philadelphia in rain and clouds. Through correspondence with friends in Boston, he learned that they had enjoyed a fine view of the eclipse. Although the Massachusetts city was directly upwind from Philadelphia, the storm had not reached there until some hours later. This was startling, for it had been assumed that Northeasters move, with the wind, toward the southwest. The young man drew upon his knowledge of whirlwinds and suggested that such storms were huge cyclones, brewed in the Gulf of Mexico, rather than in the North Atlantic. He calculated that this one had travelled from Philadelphia to Boston at 100 miles an hour. This early enquirer into the science of meteorology was, of course, Benjamin Franklin, then 37 years old. Franklin used the only vehicle then at his disposal for studying atmospheric electricity, the kite, in which activity he was joined by Dr. Alexander Wilson of Glasgow, Scotland, who sent up a thermometer in a kite in 1749, and obtained the first upper-air temperatures. By the end of the century, a new vehicle was available, the balloon, by means of which the French scientist Joseph Gay-Lussac ascended, in 1804, to a height of some 23, 000 feet. Limited by the physiological weaknesses of man (hypoxia) to an altitude of some 29, 000 feet, the French came up with the idea of unmanned sounding balloons, carrying self-recording instruments to read temperature, pressure, and humidity. It must have been quite a sight to see these balloon watchers galloping about the countryside, trying to keep track of a speck in the sky in order to be able to recover the instruments, without which, of course, the ascent would be only a waste of time. However, even this crude device was responsible for the discovery of the stratosphere, where the temperature suddenly began to level off, or even to rise.

In 1875, a Dutch instrument maker devised a method for transmitting instrument readings by wire and, by 1917, this was applied to instruments suspended by a kite — shades of Franklin! Finally, in the 1920's the development of radio opened the way to a still more practical method, and experimenters in both Europe and America began to send up radio transmitters with their data. Now, with the aid of rockets, satellites, and a variety of other vehicles and techniques, the meteorologist has become the atmospheric scientist, and is rapidly reaching for the moon in the most literal sense. Ben Franklin would have been proud of us, I am sure.

Even in the political field, he seems to have some words for us today: "Experience keeps a dear school, but fools will learn from no other". And again, "They that can give up essential liberty to obtain a little safety deserve neither liberty nor safety". It does not seem inappropriate that his famous bust by Houdon is enscribed with the lines, "He snatched the lightning from Heaven and the scepter from tyrants".

So, I welcome you to the City of Franklin, and the Birthplace of Independence. As Winston Churchill once remarked, the United States is a land of free speech. Nowhere is speech freer!

Gentlemen, we offer you our most cordial and frank hospitality, and when you are ready to leave, we hope you will be glad that you have come.

LIST OF CONTRIBUTORS

Bachynski, M. P., RCA Victor Research Laboratories, Montreal, Canada

Barth, C. A., Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California

Benson, B. R., Hypersonic Flight Section, Flight Branch, Flight Dynamics Laboratory, Aeronautical Systems Division, USAF, Wright-Patterson Air Force Base, Ohio

Bisplinghoff, R. L., Director, Office of Advanced Research and Technology, National Aeronautics and Space Administration

Bortner, M. H., Space Sciences Laboratory, Missile and Space Division, General Electric Company, Valley Forge, Pennsylvania

Breene, R. G., Jr., Consultant, Physical Studies, Inc., Centerville, Ohio

Brodwin, M., Gas Dynamics Laboratory, Northwestern University, Evanston, Illinois

Brown, G. A., Associate Professor of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts

Brull, M. A., Professor of Applied Mechanics, University of Pennsylvania, Philadelphia, Pennsylvania

Buck, M. L., Hypersonic Flight Section, Flight Branch, Flight Dynamics Laboratory, Aeronautical Systems Division, USAF, Wright-Patterson Air Force Base, Ohio

Cambel, A. B., Gas Dynamics Laboratory, Northwestern University, Evanston, Illinois

Cavoti, C. R., Space Sciences Laboratory, Missile and Space Division, General Electric Company, Valley Forge, Pennsylvania

Cloutier, G. C., RCA Victor Research Laboratories, Montreal, Canada

Diederich, F. W., Research and Advanced Development Division, AVCO Corporation, Wilmington, Massachusetts

Dixon, S. C., NASA Langley Research Center, Hampton, Virginia

Emmons, H. W., Professor, Harvard University, Cambridge, Massachusetts

Ferguson, Lt. Gen. James, USAF Deputy Chief of Staff for Research and Technology

Gaines, L. M., North American Aviation, Incorporated, Los Angeles Division, Los Angeles, California

Garber, A. M., Re-entry Systems Department, Missile and Space Division, General Electric Company, Philadelphia, Pennsylvania

Giragosian, P. A., Advanced Program Department, Aircraft-Missiles Division, Fairchild Stratos Corporation, Hagerstown, Maryland

Groves, G. V., Department of Physics, University College, London, England

Guy, L. D., NASA Langley Research Center, Hampton, Virginia

Hacker, D. S., Armour Research Foundation, Chicago, Illinois

Hazen, D. C., Professor, Princeton University, Princeton, New Jersey

Hoffman, W. D., Advanced Program Department, Aircraft-Missiles Division, Fairchild-Stratos Corporation, Hagerstown, Maryland

Hurlbut, F. C., University of California, Berkeley, California

Johnston, E. W., North American Aviation, Incorporated, Los Angeles Division, Los Angeles, California

Kaplan, J., Professor of Physics, University of California, Los Angeles, California

Kaplan, L. D., Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California

Kemper, C. A., President, Joseph Kaye and Company, Incorporated, Cambridge, Massachusetts

Lafazan, S., Gas Dynamics Section, Aerospace Corporation, Los Angeles, California

LeCat, R., Grumman Aircraft Engineering Corporation, Bethpage, Long Island, New York

Lenard, M., Space Sciences Laboratory, Missile and Space Division, General Electric Company, Valley Forge, Pennsylvania

Lesko, J. S., Aero-Space Division, The Boeing Company, Seattle, Washington

Levine, P., Research and Advanced Development Division, AVCO Corporation, Wilmington, Massachusetts

Marrone, P. V., Cornell Aeronautical Laboratory, Buffalo, New York

McDermott, D. P., Department of Physics, University College, London, England

McMullen, J. C., Advanced Space Projects Department, Missile and Space Division, General Electric Company, Philadelphia, Pennsylvania

Nagamatsu, H. T., General Electric Research Laboratory, Schenectady, New York

Nardone, M. C., Space Sciences Laboratory, Missile and Space Division, General Electric Company, Valley Forge, Pennsylvania

Nelson, H. C., Research and Advanced Development Division, AVCO Corporation, Wilmington, Massachusetts

Neumann, R. D., Hypersonic Flight Section, Flight Branch, Flight Dynamics Laboratory, Aeronautical Systems Division, USAF, Wright-Patterson Air Force Base, Ohio

Nicolet, M., Director, Centre National de Recherches de l'Espace, Brussels, Belgium

Nighan, W. L., Gas Dynamics Laboratory, Northwestern University, Evanston, Illinois

Nolan, E. J., Re-entry Systems Department, Missile and Space Division, General Electric Company, Philadelphia, Pennsylvania

Radbill, J. R., Space Sciences Laboratory, North American Aviation Company, Downey, California

Schilling, G. F., The Rand Corporation, Santa Monica, California

Seager, D. B., External Aerodynamic Research, Lockheed Aircraft Corporation, Lockheed, California

Sheer, R. E., Jr., General Electric Research Laboratory, Schenectady, New York

Sieron, T. R., Hypersonic Flight Section, Flight Branch, Flight Dynamics Laboratory, Aeronautical Systems Division, USAF, Wright-Patterson Air Force Base, Ohio

Singer, S. F., National Weather Satellite Center, United States Weather Bureau

Smith, A. M., Advanced Space Projects Department, Missile and Space Division, General Electric Company, Philadelphia, Pennsylvania

Treanor, C. E., Cornell Aeronautical Laboratory, Incorporated, Buffalo, New York

Vachon, D. N., Advanced Space Projects Department, Missile and Space Division, General Electric Company, Valley Forge, Pennsylvania

Vincenti, W. G., Professor, Stanford University, Stanford, California

Wachman, H. Y., Space Sciences Laboratory, Missile and Space Division, General Electric Company, Valley Forge, Pennsylvania

Warder, R., Gas Dynamics Laboratory, Northwestern University, Evanston, Illinois

Wegener, P. P., Professor, Yale University, New Haven, Connecticut

Weil, J. A., General Electric Research Laboratory, Schenectady, New York

Welsh, W., Gas Dynamics Section, Aerospace Corporation, Los Angeles, California

Wilson, L. N., Armour Research Foundation, Chicago, Illinois

CONTENTS

AERODYNAMIC PLASMAS

ENERGY MANAGEMENT

AEROTHERMOELASTICITY

LOW SPEED AERODYNAMICS

PLANETARY ATMOSPHERE MODELS

Introductory Remarks

by

Joseph Kaplan

I am reminded of a symposium, held in 1956, which concerned itself with planning scientific instrumentation for use with artificial earth satellites. The participants of this meeting were engineers and scientists who had come together to discuss a subject which seemed quite remote at that time. In the audience were many of my colleagues and former students, and I could not help the feeling that I was back in my classroom at UCLA, lecturing about the high regions of the earth's atmosphere, then far beyond the reach of man. Yet, this distant realm was now to become accessible to direct exploration through instrumentation carried by a completely novel tool: LPR, the Long-Playing Rocket, as we had dubbed the artificial satellite program for the International Geophysical Year.

Today, only six years later, the topic of this symposium has a remarkably wider scope. The subjects under discussion will be the characteristics of the atmospheres of other planets as well as of the earth, and the tool, the spaceprobe, has become a very long-playing vehicle, intended to carry man together with his instruments into space. Again, among the participants of this symposium are many former students of mine. They, together with their colleagues in many fields, are the ones who will discuss our present state of knowledge of the highest regions of the earth's atmosphere, and the atmospheres of planets millions of miles from here.

It seems natural to open a symposium on the problems of manned entry into planetary atmospheres with questions about what we know about the physical environments of the planets we seek to reach. The authors in this section, among the foremost experts in their fields, will review and discuss our present information about the composition, structure, and geophysical aspects of planetary atmospheres. But they will also stress the uncertainties and lack of knowledge which still exist. In this section, then, an attempt will be made to provide the fundamental source material and to lay the foundation for the sessions to follow. In some cases, not enough