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Chapter 24

Giuseppe Colombo and Space Activities in Huntsville, Alabama*

Charles A. Lundquist†

Abstract

Giuseppe Colombo was an outstanding space scientist acting on the world stage, as has been emphasized by previous authors. Colleagues from his native Italy have honored him on several occasions. Other authors have summarized well his activities in the United States at the Smithsonian Astrophysical Observatory (SAO) and at the Jet Propulsion Laboratory. Less well known are his important interactions with the NASA Marshall Space Flight Center (MSFC) and the space community in Huntsville, Alabama. On 27 June 1961, within a month after his arrival in the United States as a visiting scientist at SAO, he visited the Marshall Center. By that time, the Huntsville space team had launched and analyzed data from six satellites. During his Marshall visit, Colombo met with scientists who were then coping with attitude determinations for these early satellites. He quickly perceived that satellite attitude calculations constituted a new class of practical mechanics problems that fit his expertise. He promptly wrote several papers on satellite attitude problems. In 1974, Colombo was a prime advocate of the scientific and operational potential of tethered satellites. Colombo and SAO colleagues wrote a seminal paper on tether concepts and dynamics which they

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presented to personnel at the Marshall Center. Thereafter, a Marshall-SAO collaborative study of tether utilization began that progressed vigorously for several years with Colombo as a prime participant. The ultimate result was a joint U.S.–Italian tethered satellite project that flew twice on the Space Shuttle in 1992 and 1996. Through many contacts with MSFC and other NASA organizations, Colombo became very knowledgeable about U.S. space capabilities.

His fertile mind frequently identified opportunities to apply these capabilities to various innovative objectives, and he often published these ideas. His productive life was cut short by his death on 20 February 1984.

Background

On 4 October 1957, when the first artificial satellite was launched, Giuseppe Colombo had just observed his 37th birthday on 2 October. He was then a full Professor of Mechanics at the University of Padua in Italy. The beginning of actual space operations brought many applied mechanics topics to a new level of reality. These space mechanics topics were naturally of great interest to Professor Colombo.

As part of the U.S. participation in the International Geophysical Year (IGY), the Astrophysical Observatory of the Smithsonian Institution (SAO) was funded to establish an optical capability to observe the positions of artificial satellites as they orbited the Earth and to use such observations to determine the mechanical motions of the satellites. The observations had to be global, and therefore sites with Baker-Nunn satellite tracking cameras were established cooperatively in many nations as part of the IGY. Also, SAO invited qualified scientists from around the world to spend time at its headquarters in Cambridge, Massachusetts, to participate in the analysis and interpretation of satellite orbital mechanics. Giuseppe Colombo, better known by his nickname, Bepi, eagerly accepted this invitation. In June 1961 he arrived in Cambridge for the first of many periods of residence at SAO,[1] Figure 24–1. His part-time association with SAO continued for the rest of his life.

By June 1961, the von Braun team, first as part of the Army Ballistic Missile Agency and after 1 July 1960, as the NASA Marshall Space Flight Center, had successfully launched and managed the data analysis from six scientific satellites.[2] On 27 June 1961, Bepi Colombo traveled from Cambridge to visit the Marshall Center and to get a first hand introduction to satellite operations.[3] Thus he began another relationship that continued for the rest of his life.

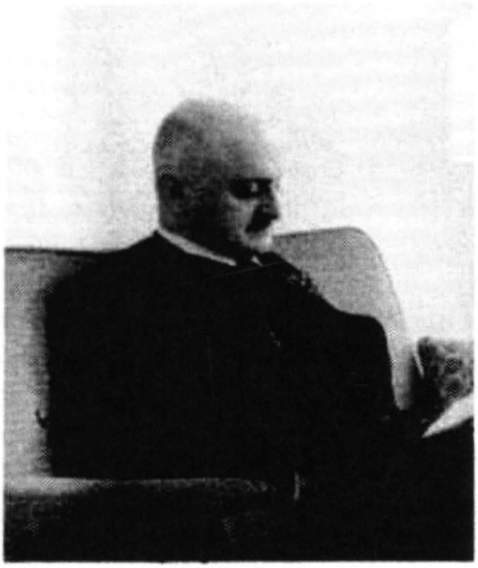

Figure 24–1: Giuseppe Colombo on arrival at SAO. Credit: SAO.

Satellite Body Motions

When Bepi Colombo made his first visit to the Marshall Space Flight Center (MSFC) on 27 June 1961, Explorer XI had been in orbit exactly two months, and the operation of the satellite was in full swing. To track the satellite, to receive housekeeping and scientific telemetry, to transmit operational commands, and to record the signal strength of the received radio signal from the satellite, MSFC operated a ground station on Green Mountain in Huntsville, Alabama. A visit to the station was on the agenda for Colombo. The visit gave him real-time insight into the scope of ground based support of an operational satellite in orbit.

Even more important for Colombo were his discussions with the scientists at the MSFC Space Sciences Laboratory. There, a team of analysts had the responsibility to determine the orientation of the Explorer XI body as a function of time and provide this information to the scientific investigator team of Dr. William Kraushaar at the Massachusetts Institute of Technology. The Huntsville team had previously determined the orientation of Explorer IV.[4] The scientific mission of Explorer XI was a pioneering scan of the sky for astronomical sources of gamma rays. The satellite was a long body with the last stage rocket from its launch still attached, Figure 24–2.

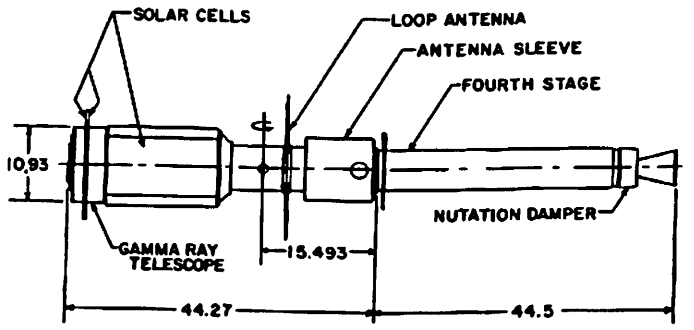

Figure 24–2: Explorer XI, dimensions in inches. Total mass 95.1 lb. Credit: SAO.

The gamma-ray detection equipment had a field of view along the symmetry axis of the satellite looking out the end opposite the expended rocket case. Immediately after being launched, Explorer XI was spinning at about 400 revolutions per minute about its symmetry axis.

Experience with earlier satellites had taught the Marshall team that dissipation of rotational kinetic energy by flexing of satellite components would soon transform the body motion of such a satellite into a propeller-like spin about an axis of maximum moment of inertia perpendicular to the symmetry axis.[5] To assure a prompt transition to this motion, a nutation damper had been included in the satellite design to augment energy dissipation.

An orbiting body in a propeller-like spin is subjected to a number of torques that cause a precession of the direction of the spin axis. Most importantly, a satellite with a permanent or induced or current-generated magnetic moment is subjected to torques as it travels through the Earth's magnetic field. Also, all satellites are subjected to gravity gradient torques. Still further, non-uniform satellite surface areas can result in aerodynamic and solar radiation pressure torques. Describing the rigid body motion of an actual satellite and fitting the description to observations is a complicated applied mechanics problem. The team at the Space Sciences Laboratory was grappling with this problem for Explorer XI when Colombo visited. He immediately appreciated that here was a very interesting specific applied mechanics problem but also that the general problem for any satellite deserved a comprehensive treatment. These problems fit his talents well, and he left Huntsville with a determination to attack these problems.

Back at SAO, Colombo soon completed two special reports on the motion of satellites about their center of mass: for Explorer IV dated 18 July 1961,[6] and for Explorer XI dated 23 May 1962.[7] He continued refinement of the Explorer XI analyses and in 1964 coauthored a report, with P. Higbie of the Explorer XI MIT investigator team, which identified the thermal expansion effect on the moments of inertia and the rotational period of the satellite.[8]

In 1963, after further communications with personnel from the Marshall Center and following periods of residence in Padua, he wrote a comprehensive review paper on satellite body motions, which was presented at a conference on Gyrodynamics of the International Union of Theoretical and Applied Mechanics.[9] As examples, the paper cited observed motions of Explorer XI, Tiros I, Solar Radiation I and Vanguard II. This chapter illustrates Bepi's passion for applied problems, rather than for abstract mathematical developments.

During the later years of the 1960s, Earth satellite launches became commonplace. Meanwhile, Colombo's personal contacts at MSFC became very preoccupied with the challenges of the Apollo program, which put the first humans on the Moon in 1969. During the early 1970s, space stations, such as Skylab, with human crews, began orbiting the Earth. Despite the much larger sizes, the motions of the bodies involved in these advancing missions involved the same principles as those recognized for the smaller satellites of the early space age.

Advanced Concepts

Colombo became very knowledgeable about U.S. space capabilities through his continuing interactions with the Marshall Center and other NASA organizations. Often his fertile mind identified opportunities to apply these capabilities to various innovative objectives, and he often published these ideas. Also, he became a conduit to Europe for information on advanced concepts being studied at the Marshall Center and elsewhere in the United States.

An example of the latter role is his lecture at the International School of General Relativistic Effects in Physics and Astrophysics at the "Ettore Majorana" Centre for Scientific Culture in Erice-Trapani-Sicily in 1977.[10] He spoke on "Advanced Technologies in Space and Opportunities for Gravity Experiments." He presented a review of a number of potential experiments, proposed by various authors, which were then under discussion in the Marshall Center environment. An example is a gravity wave antenna whose supporting structure would be fabricated by a "beam machine" being designed by a Marshall engineer, Erich Engler, to fit in the Shuttle cargo bay. The machine would be fed strip metal from large rolls and would form this material into long beams in a continuous process. The critical features of the resulting structure are that it would have dimensions of a kilometer, be capable of supporting a ton of mass at each corner and have its longest resonant period in the minutes range.

On another occasion, Bepi Colombo and Mario Grossi, his frequent collaborator, suggested a technology for modifying atmospheric conditions, which they presented at the 1976 International IEEE/AP-S Symposium.[11] They argued that it would be feasible to put a solar power facility in a synchronous orbit and equip the satellite with a 22.2-GHz transmitter tuned to the water vapor absorption line. They asserted that the solar facility and the transmitter could be designed to have an output power of about 10 Gw in a beam a fraction of a degree wide. The beam could be steerable toward any region on the Earth's surface within line of sight. The power density in the antenna beam can reach levels of 100 to 1,000 W/m^2 at the Earth's surface.

Colombo and Grossi argued further that a substantial amount of the beam energy is transferred to the atmosphere through absorption by atmospheric water vapor, cloud water droplets and rain droplets. They calculated that this atmospheric heating is capable of elevating the temperature of a 2 km^3 column of air by 1° C in one minute. They observed that various significant meteorological consequences appear possible, such as the dissipation of fog layers, the prevention and modification of hail storms and the amelioration of severe atmospheric pollution. This remains an interesting project option for eventual implementation by MSFC. Perhaps, sometime in the future, the old saying that "Everybody talks about the weather but no one does anything about it" will no longer be true.

Tether Systems

The mastery of spacecraft technology allowed the measurement of natural fields and pertinent environmental phenomena around the Earth to become the subject of intense study. A national effort with the acronym, AMPS, was organized by MSFC, under the leadership of Dr. Rick Chappell, to study the atmosphere, magnetosphere, and plasmas in space. At the same time, after Skylab, the attention of planners at MSFC turned to missions for the Space Shuttle, whose development was in progress. AMPS investigations were among the many possible objectives of instrumentation to be carried by the Shuttle.

Thus in September 1974, Colombo and three senior colleagues at SAO were motivated to promote the concept of a tethered subsatellite to be deployed from the Space Shuttle.[12] As first author, G. Colombo, saw that a tethered satellite would invoke mechanical problems not previously addressed. A second author was E. M. Gaposchkin, who was an expert on determining the details of the gravity field of the Earth.[13] The third author was M. D. Grossi, who had been involved in AMPS topics, such as radio propagation in the magnetosphere.[14] The final author was G. C. Weiffenbach, who had extensive experience with satellite design, construction and operation.[15] Figure 24–3 illustrates the concept proposed in reference [12].

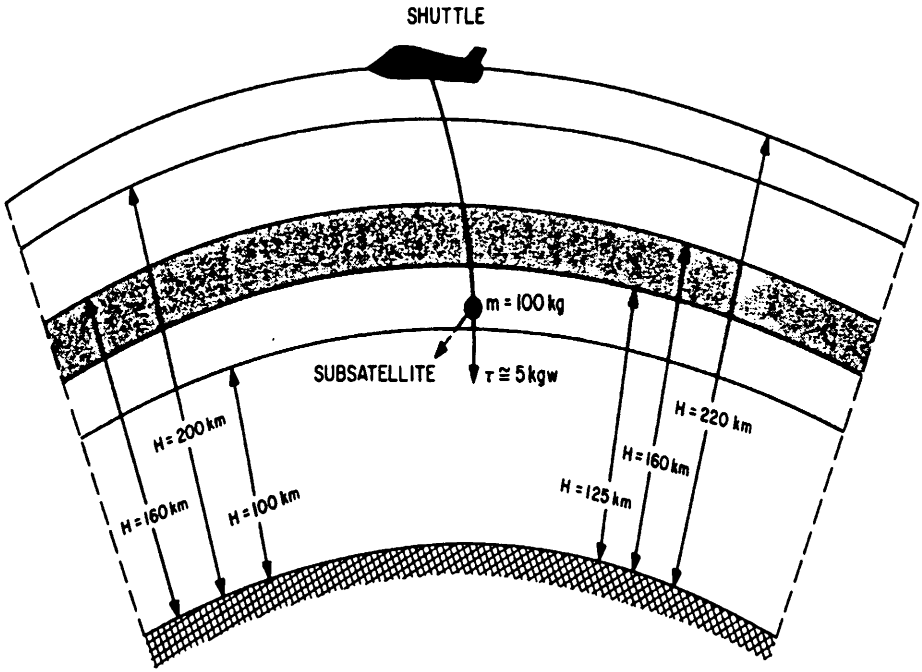

Figure 24–3: Proposed Skyhook concept. Credit: NASA MSFC.

Prior to reference [12], there was a small, scattered and rather unappreciated literature on tethered spacecraft.[16] However, reference [12] was the first fairly detailed discussion of the mechanics of two spacecraft connected by a long cable or tether. The SAO authors promptly made a presentation of the tether concept to representatives of Marshall Center management. A subsequent result at MSFC was establishment of an AMPS Tethered Subsatellite Working Group. The Working Group had representatives from the Science and Engineering Directorate and the Program Development Office. Organizing the work of the group was the responsibility of the Space Sciences Laboratory under the leadership of Dr. Mathias Siebel, who was a member of the Laboratory Directorate. An objective of the group was to assess whether a tethered subsatellite should be recommended to MSFC as a NASA project. Further tethered subsatellite discussions with Drs. Colombo and Grossi took place at MSFC in November 1974.

Beginning in early 1975, the Tethered Subsatellite Working Group had a series of meetings where the results of several studies by group members were presented and discussed. For example, a typical subject (addressed by Chris

Rupp) was the algorithm for the tether tension control mechanism on board the Shuttle. On 16 May 1975, Dr. Ernst Stuhlinger, MSFC Associate Director for Science, sent a letter to Dr. Weiffenbach, Associate Director for Geoastronomy of the recently organized Harvard-Smithsonian Center for Astrophysics. The letter described the activities to date of the MSFC working group. Subsequently, on 28 July 1975, Drs. Colombo and Grossi came to Huntsville to participate in the sixth meeting of the Working Group. At the meeting the results of the group to date were reviewed. The favorable results justified continued work toward a NASA project and interactions with NASA Headquarters intensified.

By 30 March 1976, a tentative project schedule was formulated. The Phase A conceptual design of the tethered satellite system would be completed by the end of fiscal year 1976. A Phase B effort would be completed during FY77, and Phase C/D would begin in FY78. MSFC, SAO and other participants in the project intensified their work to complete the required Phase A documents by the end of the fiscal year.

Further definition of roles for the project was provided in a memo dated 23 August 1976, from John Yardley, Associate Administrator, Office of Space Flight (OSF), NASA Headquarters. It stated "OSF will accept responsibility for the system definition, development and operation with users responsible for definition, development and flight activities of mission peculiar hardware."

The Phase A report was ready for review by mid-October 1976. It was published in December 1976.[17] This document was supported by two reports from SAO.[18,19] Meanwhile, as work continued into FY77, on 20 January, a "mid-term" review was held between MSFC and SAO. Bepi Colombo had a 30-minute summary presentation on the agenda. Figure 24–4 illustrates the configuration envisioned at that time.

It was clear at this time that the Shuttle-borne subsatellite proposed by Colombo and his associates had been embraced by NASA and the NASA engineering organizations were already busy defining the project. In essence, Bepi Colombo had acted as an extension of the Marshall Center during the conception of the project.

To the scientists who expected to use a tethered satellite for research objectives, a public gathering devoted to discussion of these uses now seemed timely, and a Workshop on the Uses of a Tethered Satellite System was organized in May 1978 with joint sponsorship by the Marshall Center and the University of Alabama in Huntsville.[20] The diverse topics discussed were geomagnetic field mapping, analysis of magnetometer data, gravity gradient determination, need for measurements in the lower atmosphere, interaction of a tethered satellite with the atmosphere, measurement of reactive neutral constituents in the thermosphere, mass spectrometer measurements, atmospheric electrification, chemical releases, aerodynamic effects, the electrodynamic tether, interactions with the ionosphere and a look for large body plasma flow interactions. Bepi Colombo was an author on two of the presentations.

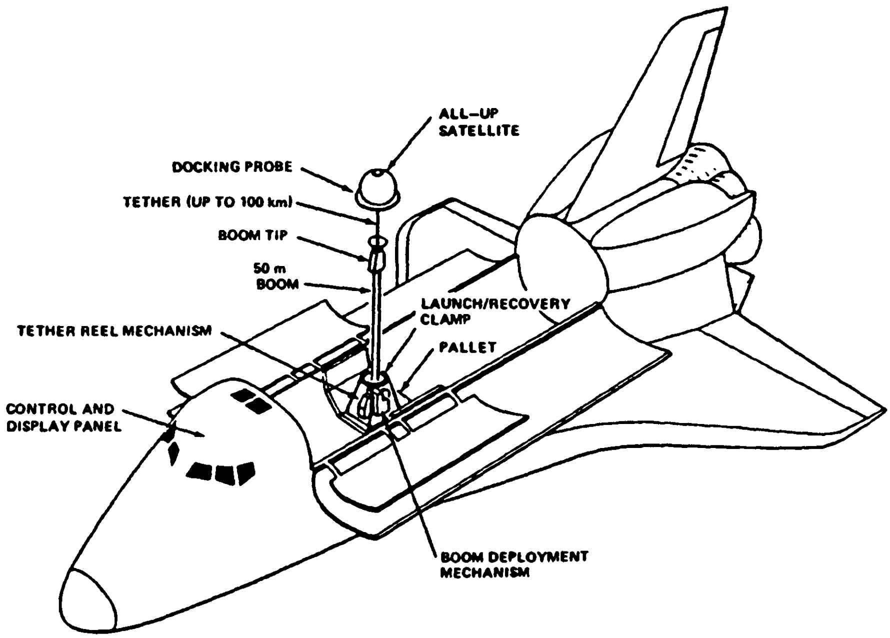

Figure 24–4: Phase-A tether system concept in the Shuttle.

During the late 1970s the first launch of the Space Shuttle was delayed, but it launched successfully in 1981. During this time, work also continued on the tethered subsatellite project, but details of this development are outside the scope of this chapter. However, the fulfillment of the tether project had to wait for confidence in Shuttle operations to mature to the extent that a mission such as a tethered satellite was acceptable.

Further, the proposal arose that the subsatellite might be sponsored by Italy, and that the United States would be responsible for the tether mechanism. Of course, Colombo was a proponent of this option. Finally, on 7 March 1984, NASA Administrator James M. Beggs and Professor Ernesto Quagliarello of the National Research Council of Italy signed two Memoranda of Understanding in Rome.[21] The two separate agreements established the development of the tethered satellite system and the launch of the Laser Geodynamics Satellite-2. Colombo also had a hand in the latter project, but not the seminal role he had in the first. The NASA Marshall Center was responsible for the U.S. part of both joint projects.

Finale

In June 1983, another Applications of Tethers in Space Workshop was held in Williamsburg, Virginia.[22] The workshop was again organized and cosponsored by the Marshall Center with NASA Headquarters. Recognizing that a formal U.S.–Italy agreement was pending signature, representatives from Italy described the status of the subsatellite development in Italy. Likewise, attendees from the United States presented the status of the tether mechanisms.

Professor Giuseppe Colombo was the Guest Dinner Speaker at the workshop. He gave an insightful talk on "Where Are We Going with Tethers?"[23] As always, he was looking forward. At the event, Philip Culbertson, Associate Deputy Administrator, awarded Professor Colombo the NASA Gold Medal for Exceptional Scientific Achievement. Sadly, Bepi and his close colleagues knew at the time that he was seriously ill and this was probably his last tether conference.

Bepi Colombo's productive life was cut short by his untimely death on 20 February 1984, in Padua, Italy. This preceded by just two weeks the signing of the U.S.–Italy tether agreement, which he had done so mush to promote. The Italian tethered satellite eventually was deployed from two U.S. Space Shuttle missions.[24]

As the above text demonstrates, the Huntsville, Alabama, space community had benefitted greatly from his innovative approach to space science.

Of course, Bepi's home nation has honored him in many ways.[25] Likewise, other organizations in the United States, with whom he had associations, have expounded on his technical contributions and his warm friendship: SAO[26] and JPL.[27] With his passing, the space community around the world suffered a painful loss, but all can commend the many contributions he made to science and technology.

Acknowledgments

It is a pleasure to thank the Archives and Special Collections Division of the Library at the University of Alabama in Huntsville for access to Archives collections and for other help. The UAH Space Archives has a very extensive collection of documents from the tether activities at MSFC. After Professor Colombo's death, further advanced tether concepts were promoted by Dr. Robert Forward. The UAH Archives also have the works of Dr. Forward. Thanks are also due to the NASA Scientific and Technical Information Help Desk and to the Marshall Center History Office.

References

[1] Staff writer, "The Observatory Welcomes Giuseppe Colombo," *SAO News*, Vol. I, No. 1, p. 2, Cambridge, Massachusetts, June 1961.

[2] Charles A. Lundquist, "Progress in Design and Implementation of Scientific Spacecraft," *Space Research, Proceedings of the First International Space Science Symposium*, H. K. Kallmann Bijl, editor (Amsterdam: North Holland Publishing Co., 1960) p. 540.

[3] Charles A. Lundquist, *1961 Appointment Calendar*, Marshall Space Flight Center, Alabama, 27 June 1961.

[4] C. A. Lundquist, R. J. Naumann and S. A. Fields, "Recovery of Further Data from 1958 Epsilon," in *Space Research Vol 2*, Jager, Moore and Van de Holst, editors (Amsterdam: North Holland Publishing Co., 1962).

[5] William Beller, "S-15 May Solve Cosmic Ray Riddle," *Missiles and Rockets*, 16 February 1961 pp. 25–26.

[6] Giuseppe Colombo, "On the Motion of Satellite 1958 Epsilon Around Its Center of Mass," *SAO Special Report No. 70*, 18 July 1961.

[7] Giuseppe Colombo, "On the Motion of Explorer XI around Its Center of Mass," *SAO Special Report No. 94*, 23 May 1962.

[8] Giuseppe Colombo and P. Higbie, "Thermal Effect on the Rotational Period of an Artificial Satellite," *SAO Special Report No. 166*, 30 November 1964.

[9] Giuseppe Colombo, "The Magnetic Torque Acting on Artificial Satellites," Proceedings of the Conference on Gyrodynamics, IUTAM, Celerina, 20–23 August 1962. In *Kreisel Probleme Gyrodynamics*, H. Ziegler, editor (Berlin: Springer-Verlag, 1963).

[10] Giuseppe Colombo and Charles A. Lundquist, "Advanced Technologies in Space and Opportunities for Gravity Experiments," *Proceedings of the International School of General Relativistic Effects in Physics and Astrophysics: Experiments and Theory*, J. Ehlers editor (Munich: published by Max-Planck-Institut for Physik und Astrophysik, 1977).

[11] M. D. Grossi and G. Colombo, "Atmospheric Modification by a High-Power Microwave Beam at 22.2 GHz (Water Vapor Absorption Line)," *Harvard-Smithsonian Center for Astrophysics Preprint Series No. 617*, 13 October 1976.

[12] G. Colombo, E. M. Gaposchkin, M. D. Grossi and G. C. Weiffenbach, *Shuttle-Borne "Skyhook": A New Tool for Low-Orbital-Altitude Research* (Cambridge, Massachusetts: Smithsonian Institution Astrophysical Observatory, September 1974).

[13] e.g. E. M. Gaposchkin, editor, "1973 Smithsonian Standard Earth," *SAO Special Report No. 353*, 28 November 1973.

[14] e.g. Mario D. Grossi, "Guided Propagation of Radio Waves in the Ionosphere," *NATO-AGARD Lecture Series No. 41* (Eindhoven, Netherlands: 25 June 1970).

[15] e.g. George C. Weiffenbach, "A Constellation of Passive Laser Retroreflector Satellites for High Accuracy Dynamic and Geometric Geodesy," *XV General Assembly of the International Union of Geodesy and Geophysics* (Moscow: August 1971).

[16] e.g. J. D. Isaacs, A. C. Vine, H. Bradner and G. E. Bachus, "Satellite Elongation into a True 'Sky-Hook'," *Science*, Vol. 151, p. 682, 11 February 1966.

[17] Preliminary Design Office, Program Development Office, MSFC, *Shuttle/Tethered Satellite System Conceptual Design Study*, NASA TMX-73365, December 1976.

[18] G. Colombo, D. A. Arnold, J. H. Binsack, R. H. Gay, M. D. Grossi, D. A. Lautmen and O. Orringer, "Dumbbell Gravity-Gradient Sensor: A New Application of Orbiting Long Tethers," *SAO Reports in Geoastronomy No. 2*, June 1976.

[19] M. Dobrowolny, G. Colombo and M. D. Grossi, "Electrodynamics of Long Tethers in the Near-Earth Environment," *SAO Reports in Geoastronomy No. 3*, June 1976.

[20] S. T. Wu, editor, *UAH/NASA Workshop on the Uses of a Tethered Satellite System*, University of Alabama in Huntsville, 2–3 May 1978.

[21] "NASA, Italy Sign Satelite Memoranda," *Marshall Star*, 14 March 1984, p. 2.

[22] Ivan Beckey and William R. Marshall, General Co-Chairmen, *Workshop Proceedings, Applications of Tethers in Space, Vol. 1 and 2*, Williamsburg, Virginia, 15–17 June 1983, produced by the NASA Center for Aerospace Information (CASI).

[23] Giuseppe Colombo, "Where Are We Going in Tethers," *Workshop Proceedings, Applications of Tethers in Space, Vol. 1 of 2*, Williamsburg, Virginia, 15–17 June 1983, NASA-CR-171196, produced by the NASA Center for Aerospace Information (CASI), pp. 3-129 to 3-134.

[24] Luigi Bussolino, "TSS-1, Tethered satellite deployed from the Space Shuttle," Paper IAC-12-E4.3A.03, presented at the Forty-Sixth History Symposium of the International Academy of Astronautics, 1–5 October 2012, Naples, Italy. Published as Chapter 23 in this volume.

[25] e.g. Facolta di Ingegneria, Istituto de Meccanica Applicata Alle Macchine, Universita di Padova, *Giuseppe Colombo un Uomo Rivolto Futuro*, Atti del Convegno Tenuto a Padova, il 20 febbraio 1985.

[26] Ibid. 25, G. B. Field, F. A. Franklin, M. D. Grossi, E. Lorenzini and I. I. Shapiro, "Prof. Giuseppe Colombo with the SAO," p. 77.

[27] Ibid. 25, John D. Anderson, "Mariner Venus/Mercury and the Years 1970-1975," p. 69.