EARTH SYSTEM SCIENCE AT 20 ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

BYRON D. TAPLEY
INTERVIEWED BY REBECCA WRIGHT
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WRIGHT: Today is January 12, 2010. This oral history with Dr. Byron Tapley is being conducted in Austin, Texas for the NASA Headquarters Earth System Science at 20 Oral History Project.

This interview is part of a series that is gathering experiences from those who significantly were involved in the efforts to launch and foster the concept of Earth System Science. Interviewer is Rebecca Wright, assisted by Sandra Johnson. Thank you again for finding time in your busy, busy schedule to talk with us today. We'd like for you to start by telling us how you first got involved in your field of expertise.

TAPLEY: My introduction into the space research field came as Sputnik was launched in [October 4, 1957]. I had just finished my academic work, accepted an appointment at the University of Texas [UT, Austin, Texas] in the field of Engineering Mechanics, after performing my doctoral research on the plastic deformations of materials under high strain rates.

When the Sputnik was launched, the university decided that it would be appropriate to introduce a space-related course in aerospace engineering. I was approached by the Chair of the Aeronautics Department about teaching the course. I decided that, if I were going to make this change, I wanted to develop a complete program, rather than just one course.

The university agreed that I would develop a program in the field of astrodynamics, as a part of what became the aerospace engineering department. It was a big change to leave an active and mature program of research to initiate a program with a clean sheet of paper. This proved to be a very big challenge. There was no academic capability on campus. No curricula and no students at that point, and actually no one to have an intellectual discussion about space issues. There was considerable interest and excitement in the student body and after a couple years the first set of Ph.D. candidates began to mature and the program began to take on a life of its own, and a number of leading engineers and scientists at various NASA and other government centers, academic institutions and space related industrial firms passed through the academic program on the way to their numerous accomplishments.

My early research was related to the theory of low thrust transfer trajectories, which was of interest in the early design concepts for interplanetary exploration missions The early research came out of a early meeting with Dr. C.R. [John] Gates who was in charge of Section 312 at the Jet Propulsion Laboratory. This section had the responsibility for developing the guidance and orbit determination algorithms to support the unmanned lunar missions in the early decade of space exploration. In addition to encouraging NASA to provide the first research grant that I obtained, Dr. Gates provided an introduction to a number of pioneers in the space field including, Bill Melbourne, Carl Salloway, Tom Hamilton, Harry Lass. I spent summer periods with this group during the first decade of my career and I learned a great deal from their collective expertise. The connection with JPL [Jet Propulsion Laboratory, Pasadena, California] has been a long and close relation because of the intellectual interest and the fact that so many students have initiated their careers there.

The first topic of low-thrust trajectory analysis proved an interesting path. The technology for conducting the missions failed to mature and the concept has never played a very large role in the missions for interplanetary exploration. However, as the basis for initiating a space related curriculum, it proved an excellent choice in that the topics of orbit determination, guidance and navigation, and trajectory optimization were all encountered as an integral part of the study. Courses in each of these disciplines were added to the curricula and a good part of the period between 1965 and 1975 was spent studying various parts of this field. The first group of very good students matured during this effort and most migrated to JPL to take on increasing responsibilities during the subsequent decades.

Around 1968, we were approached by Gene [Eugene L.] Davis at the NASA Johnson Space Center to assist with developing orbit determination capabilities for the manned exploration program. We began working on the development of batch estimation techniques and Kalman filter techniques for navigation of Earth-orbiting satellites, and extended some of the effort into the early Apollo program, with the navigation related to lunar exploration.

In the early part of the 1970s program, we initiated application of the Precision Orbit Determination [POD] capability Geodynamics Program at the NASA Goddard Space Flight Center [GSFC, Greenbelt, Maryland], to participate in the analysis of some of the first satellite laser ranging [SLR] being collected under a program put in place by NASA Goddard. Dave Smith who was in charge of the geodynamics program at NASA GSFC was interested in looking at how the sequential processing or the Kalman filtering of the laser data would essentially compare with what would be done with the traditional analysis results that NASA Goddard acquired using their GEODYN [software] program.

This essentially led forward to our first exposure to satellite acquired geodynamic-tracking data. We essentially began to develop our own software systems to process that data. This activity led to developing a software system called UTOPIA, the University of Texas Orbit

Processor Incorporating statistics Analysis, the first of a long line of software systems that we developed to look at the solid Earth dynamics and the Earth System Science type applications.

This capability allowed us to propose for a mission called GEOS-C [Geodynamics Experimental Ocean Satellite]. It was one of the first satellite altimeter missions. Our proposal was accepted and we joined the science team for this mission. We began to analyze the altimeter data in combination with the satellite laser ranging data. This data combination stimulated the analysis that we performed at the University of Texas during the subsequent decades. And it was through this analysis that we began to have a significant input into the NASA Earth System Science program.

The first major step occurred in 1977. At this time, the Seasat mission was being developed at JPL as the first microwave remote sensing satellite and its primary focus was on studying the oceans. The objectives of the mission were to make the first global measurements of the ocean surface and the surface winds in the microwave frequency range. The all weather and global nature of the altimeter, synthetic aperture radar and scatterometer data promised a significant advancement in our understanding of the ocean dynamics. Of these sensors, the radar altimeter required an accurate orbit to utilize the measurements.

I was approached by George [H.] Born, who was in charge of the Seasat data system with the question of whether I would take on the management of a GPS [Global Positioning System] instrument team. The instrument would have been the first GPS reviver to fly on a satellite. I was tasked with assisting in the delivery of the accurate orbits required to apply the Seasat altimeter measurements. I agreed to the assignment. Early on it was apparent that there were a host of issues related to the technology that required resolution.

The manufacturer fell behind schedule, overran the budget and the project finally decided to eliminate the instrument. At that point there was a problem with the Altimeter/Precision Orbit Determination team. Although the implementation was through JPL, Seasat was a joint NASA-DoD [Department of Defense] satellite. The Altimeter/POD Team was composed of a contingent of NASA and DoD members with strongly differing opinions on the mission implementation of the altimeter measurement. The nature of the team interactions suggested that an individual that was not in either camp should act as a leader of the team, so I was asked to take on that activity. The decision to act as the Altimeter/POD team leader turned out to be a very important step in setting the direction for the research that I, and the Center that evolved from the research, conducted during the next three decades. This activity was centered on a strong collaboration with two of my early students George H. Born and Bob E. Schutz.

As mentioned earlier, George was a former student that completed his graduate work in the late ’60s, and migrated through NASA JSC to JPL. He was one of the early vanguards of the numerous students that joined JPL after completing their graduate studies. Bob joined the faculty at the University [of Texas] after completing his academic studies. The problem of determining accurate orbits for altimeter satellites provided a collaborative bond for our interactions during the next three decades. The knowledge gained in these studies was the basis for our manuscript on *Statistical Orbit Determination*.

The Seasat altimeter evolved and had another significant connection. The altimeter instrument leader, who was the engineer in charge of the altimeter fabrication, was Bill [William F.] Townsend. Bill joined NASA HQ [Headquarters, Washington, DC] and was part of the management structure that implemented the remarkable successful follow-on satellite altimeter missions. He later advanced to Deputy Director of Goddard Space Flight Center and served as

[NASA] Acting Associate Administrator for Earth Science. There was significant and enjoyable interaction with Bill throughout each of these phases.

The Seasat activity actually was an extremely important mission in terms of demonstrating the capability of the satellite laser ranging-radar altimeter connection. The requirement for precise positioning of the satellite, in order to be able to use radar measurement, was a requirement to contend with. The effort that we made to satisfy this requirement turned out to be a major factor in developing a capability that, over the ensuing decades, has been a recognized standard of our program and that's the ability to compute orbits very accurately or the development of the precision orbit determination area.

When I began involvement with the Seasat mission, one could make height measurements with the altimeter at the sub-decicentimeter accuracy level, but the best orbits had accuracies at five meters. With this level of orbit accuracies, one could not use the use the altimeter measurements of the ocean surface to meet the oceanographers needed.

The Seasat effort was relatively short lived. The Seasat launch placed a really remarkable suite of instruments on orbit, but after an exciting start, the satellite failed 90 days into orbit due to a significant short in the power system. There was a solar power panel slip ring design problem that had been identified in the military applications at Lockheed Martin but the information hadn't been passed to the civilian applications area. Although the short caused failure of the satellite, during the 90 days in orbit, we did get enough information on the altimeter to know that we had a very powerful measurement technique. We immediately set out on an effort to develop a program to fly a mission using an altimeter and focused on an accurate measurement of the ocean surface topography.

Stan Wilson joined NASA Headquarters to take over the oceanography program. In one of his early actions, he convinced Bill Townsend to move from the NASA Wallops Island Facility [Virginia] to the Headquarters program to take responsibility for the mission that we were trying to initiate to continue the altimeter measurements that we had started with Seasat.

This effort continued during a several year formative stage to define a mission concept called TOPEX for Ocean Topography Experiment. Although it was proposed during early budget preparation activities, it was successful. For the 1983 NASA budget submission, an agreement to team with CNES [Centre National dUEtudes Spatiales or National Space Study Center, France] and make it a joint NASA-CNES mission was completed, and this arrangement led to a mission start.

The effort associated with the TOPEX/Poisedon Mission, which was the bi-lateral mission name, consumed most of my attention during the period between 1983 and 1992. The Precision Orbit Determination Team that I led was charged with delivering an orbit whose accuracy would not limit the accuracy of the altimeter height measurement. The altimeter was designed to measure the height with a precision less than three centimeters. To be able to use these measurements for oceanographic studies, an orbit accurate to five centimeters in the radial component was required. At this point, the best orbit accuracies were on the order of five meters in the radial component, and increasing the accuracy from five meters to five centimeters required making advances to allow a two orders of magnitude reduction in accuracy. We recognized this task as a significant challenge.

After considerable initial study, we agreed to commit to a ten-centimeter radial orbit accuracy. We had assembled an astrodynamics team composed of members from JPL, NASA

Goddard and UT to conduct the required effort. So the better part of the 1980s decade was focused on defining and satisfying the requirements for computing accurate satellites orbits.

Early in the investigation, errors in the Earth geopotential model were identified as one of the limiting error sources. The better part of the ten-centimeter error budget that we committed to satisfy was responsible for errors in the gravity model. In an alternate effort, we had been encouraging NASA to initiate an effort to improve the Earth's gravity model. While there was a recognized need for improved shortwave length effects in the existing models, it was assumed that the long wavelength content, which is of primary concern for satellite orbit determination, was reasonably well known. While this was not correct for our requirements, it was true for most of the other stated needs and, since one could not measure the short wavelength gravity signals from satellite altitude, most of the NASA funding for gravity model development was being eliminated. This had a significant impact on the significant space geodesy effort at NASA GSFC, where the NASA Gravity Model development effort was centered.

In a highly serendipitous development, Bill Melbourne, Jim Marsh and I attended a meeting in San Matteo, Italy, to propose that the GPS receiver that we were developing for TOPEX be added to the ERS-1 instrument. The European Remote Sensing, ERS-1, satellite would implement the first European satellite altimeter. The GPS receiver that we proposed would be the first satellite born high accuracy receiver. Our proposal was not successful, because the German PRARE receiver had already been selected. After the meeting was over, we offered to drop Stan Wilson, who was the Oceanography program manager at Headquarters, off at the Milan airport. Bill, Jim and I were going to drive overnight from Milan across to Toulouse [France] where the four of us would meet the next day with members of the French Space Agency, CNES, to discuss tracking systems for the proposed TOPEX/Poseidon mission.

As it turned out, we managed to miss Stan's plane connection. He noted, with some concern, that he had funded three of the world's best navigators to work on the POD problem, but they couldn't navigate to the airport in time for his plane connection. But in any event, as the situation evolved, he had no choice but ride with us during our overnight journey.

So during the overnight drive, we had a captive audience in which the problems with the gravity model errors and the impact on the TOPEX mission were discussed for an extended period. Stan sat through this lengthy discourse without comment. I was not sure whether or not he was attentive to the message, but shortly after we returned to the US, Stan asked Bill Townsend to get with TOPEX project manager Charlie [Charles] Yamarone [Jr.] at JPL to put in place funding to improve the gravity model. Although TOPEX was an oceanography mission, the geodetic measurement requirements associated with the gravity model and reference frame are fundamental building blocks for an accurate measurement, and the gravity model development initiated by Stan, Bill and Charlie as a result of this chance contact had very broad importance to the Space Geodesy community. A significant portion of our knowledge today can be traced to this event.

We implemented the gravity model improvement effort as a collaboration between UT and Goddard. The plan was to develop a series of models that we called the Joint Gravity Model, joint for UT-Goddard Gravity Model. There were three models developed during this effort: JGM-1, JGM-2, and JGM-3. The JGM-1 and JGM-2 model developments were executed at GSFC with UT supporting the effort. UT took the lead in developing JGM-3. The JGM-3 model incorporated the first of the satellite acquired GPS tracking data. Although JPL completed the GPS receiver development and we launched it, the Air Force was restricting use of the signals to military applications only. After lengthy discussions we negotiated an agreement by which the signal denial would be turned off during three 10-day periods. The satellite ground track covers the Earth's surface once every 10 days, so the 10-day interval for the GPS tracking gave global coverage in each of the 10-day intervals.

We took the data from the three 10-day periods and combined it with the information used to develop the JGM-2 gravity model to develop an extremely good model for the TOPEX mission. In fact the JGM-3 proved to be the best model for precision orbit determination for most satellites until 2002, when we began to get the first results from the GRACE [Gravity Recovery and Climate Experiment] mission. The gravity model effort started for TOPEX led to our being in a good position to propose a gravity mission as a response to the call for this first Earth System Science Pathfinder mission.

In a follow-up effort, I collaborated with Goddard on a gravity mapping mission called GAMES that had a pair of satellites orbiting, one behind the other, in the same orbit plane. The gravity information was to be inferred from accurate intersatellite measurements of the relative motion of the two satellites. The intersatellite distance was measured using a laser link between a passive trailing satellite and an active leading satellite. This mission was given serious consideration, but as with numerous other proposed missions in the two decades beginning around 1980, this mission was not implemented. A few years after the GAMES mission was rejected, the call for the first Earth System Science Pathfinder mission came out.

JPL approached me about essentially collaborating with them on a concept similar to GAMES that involved an accurate microwave ranging measurement with two active co-orbiting satellites. I also got a call from Goddard about the same time about collaborating on a mission involving a gravity gradiometer that had been under development. At this point, we'd been trying to get a gravity mission since it was first recommended in 1967. All of the missions proposed in the 1980s and 1990s were not successful.

It is interesting to note that when TOPEX was finally selected in 1983, there was a mission called Geopotential Research Mission, which was in strong competition for a mission start. The Geopotential Research Mission established measurement concept was proposed for GRACE, but the mission was to fly at a much lower altitude and would be much more expensive than the GRACE mission turned out to be.

Regarding the selection in 1983, we argued in a mission review at NASA Headquarters that, since the ocean is changing with respect to time and the gravity field is fixed, (conventional knowledge referred to the gravity as a onetime measurement and you are done) we should do the TOPEX mission first and then follow up in a few years with a gravity mission. Shortly after TOPEX was accepted, we had the first Space Shuttle disaster [January 28, 1986, STS 51-L, *Challenger*], which delayed most mission implementations for several years. It delayed the TOPEX launch until 1992 and it eliminated any chances of getting the GRM [Geopotential Research Mission] gravity mission selected. The GRM team was finally disbanded in 1986.

For the GRACE proposal, we took the base intersatellite measurement approach from GRM and upgraded the concept by bringing the GPS receiver on board to satisfy the orbit determination and time synchronization requirements that were a challenge for GRM. We raised the altitude to increase the mission life and we added an accurate accelerometer to measure the surface forces due to drag and radiation pressure. This eliminated the costly and mission life limitations associated with the drag-free concept adopted for GRM. This allowed fairly low-cost mission implementation mode that had the potential for a long mission life. We proposed a teaming arrangement with German colleagues at the GeoForschungsZentrum [GFZ] in Potsdam, Germany. Under the direction of my colleague, Christoph Reigber, they had flown an earlier single satellite gravity and geomagnetics mission called CHAMP [Challenging Minisatellite Payload] which would provide most of the satellite technology and the accelerometer needed for GRACE. We formed a team to develop the proposal for the GRACE mission. We were successful in that proposal, and it led to a really remarkable approach for measuring the Earth's gravity field.

The mission concept proposed to measure the Earth's gravity field at monthly intervals. Since the gravity field is determined by the Earth's mass distribution, changes in the monthly gravity fields are caused by changes in the Earth's mass distribution. This realization allowed the focus on measuring the mass exchange between the oceans, atmosphere and land surface as a consequence of the Earth's dynamic system interactions. The major component of the signal observed by GRACE is water moving about. Rather than focusing on only the fixed or stationary gravity field, we proposed to look at the time-variable nature of gravity also.

We had been measuring the long-wavelength components of the time variable gravity using satellite laser ranging to a series of spherical satellites called cannonball satellites—LAGEOS-1 [Laser Geodynamics Satellite], LAGEOS-2—since the launch of LAGEOS-1 in 1978. LAGEOS and Starlette [Satellite de Taille Adaptée avec Réflecteurs Laser pour les Etudes de la Terre], which was launched by CNES, were round balls with optical retro reflectors spread over their surface. We mostly focused on the time-variable nature of the J2 coefficient, which is mostly related to the oblate nature of the Earth (e.g., the polar diameter is less than the equatorial diameter). We measured the annual variations and observed that the annual variations appeared to be caused by both geophysical and climate related effects.

We didn’t fully understand the climate connection at that point, but we knew that there was annual variability in gravity field at the long-wavelength components. This was one of the important topics for study that we highlighted in this GRACE mission proposal. Not only would we do the mean field, but we would study the time variable nature as well. As we noted, gravity comes into play in a number of ways. The mean field is important in the satellite altimeter missions such as TOPEX and the Jason follow-on missions, both for computing the orbits and to define the ocean surface geoid to which the altimeter measurement is referenced.

Also the surface that one uses to reference the altimeter measurement against, to get the quantity of interest to the oceanographers, is the dynamic ocean topography. This quantity is the difference between the sea surface height that the altimeter measures and the marine geoid. The water would go to a surface that’s defined by the gravity over the ocean (the marine geoid), if the effects of the Earth’s rotation and the effects of atmospheric pressure and winds were not present.

The altimeter measurement is extremely difficult because the dynamic ocean topography has signals with amplitudes of about one meter, but the actual shape of this ocean’s mean surface has variations with amplitudes as large as 100 meters. That is, there are 100-meter highs and lows at various points over the ocean surface, where the water departs from the best fitting ellipsoid by as much as 100 meters below it and/or 100 meters above because of the internal mass distribution of the Earth. So you’re looking at a one-meter dynamic ocean topography signal and imbedded in a marine geoid with100-meter level variations. At the time of launch of the TOPEX mission, the errors in the gravity field were such that small errors in that marine geoid totally dominate the dynamic topography signal.

At the time of the GRACE satellite launch, we had ten years of very accurate altimeter measurements of the ocean surface, but they could not be used to determine the general ocean circulation because the errors in the gravity field hid the dynamic ocean topography signal. As we noted, one of the objectives of the GRACE mission was to get a very accurate mean sea surface to allow full use of the altimeter-defined measurements. The other was to look at temporal variations in the gravity field and relate that to mass flux going on in the Earth's dynamic system. That mass flux is mostly water moving around. Some of the signal is related to long-term trends while other signals have a seasonal variation that repeats from year to year at yearly intervals. The measured phenomena with long term trends are related to ice mass loss in the polar regions and the signals present in the rebound of the North American continent after the unloading of the ice following the last ice age (e.g., the glacial isostatic adjustment).

The more interesting activity is the ability to be able essentially to look at the water in most of the major river basins in the world, and look at the seasonal changes in this water. That's both surface water and subsurface water; the subsurface being the large-scale continental aquifers, and the water changes in those are fairly interesting topics, and of quite a bit of concern at the present time.

We also proposed some breakthrough measurements such as the ability to use the mass measurements of the column including the ocean and the atmosphere as an indicator of the ocean bottom pressure. By using these measurements to infer change in the ocean bottom pressure, one deduces information about the ocean bottom currents in the deep oceans.

There has been a number of really very interesting measurements that have come out of the GRACE-related activities. It's evolved from the concept of a gravity mission into one of a mass flux mission, in which the mass flux is mostly water, although, as we noted, phenomena such as the glacial isostatic adjustment can be observed. You also see large episodic changes. One gravity signal in this category is related to the [2004 Indian Ocean] Andaman-Sumatra Earthquake. You see a very sharp difference in the gravity field before and after that Earthquake occurred.

WRIGHT: Speaking of GRACE, I believe it was selected in May of 1997 and it launched in 2000. Can you share some of those interactions of getting it to that selection process and then its launch?

TAPLEY: The GRACE mission was the first one of the Earth System Science Pathfinder [ESSP] missions accepted. It was submitted as a response to the first call for ESSP mission. The Earth System Science Pathfinder Program was to select innovative low-cost missions that could be placed on orbit rapidly. Further, the mission manager of the program could be outside NASA and, under this approach, an academician could be responsible for the entire program.

In the teaming arrangement, we proposed what was to be demonstrated as a very good concept. Under the teaming concept, JPL would be responsible for the mission implementation, including the satellites and the instrument compliment, UTCSR [University of Texas Center for Space Research] would be responsible for the data system and for the overall mission management, GFZ would be responsible for the German contributions to the mission, which included the satellite launch and the mission operations. Ab [Edgar S.] Davis, who ended up being the proposal project manager, and Mike [Michael M.] Watkins, who later became the project scientist, were very influential in maturing the concept. Mike Watkins was one of our students who after completing his Ph.D. degree had joined JPL. While at CSR, Mike had supported our effort on the proposed GSFC GAMES gravity mission that I mentioned earlier. Mike had been involved in simulations that we performed to support this proposal so he had a good understanding of the nature of the mission concept. He was also involved in the SLR studies of time variable gravity.

Ab had been involved in developing accurate GPS ranging systems, so he understood the nature of intersatellite ranging measurement. As I mentioned earlier, the Geopotential Research Mission had developed and demonstrated the concept of using the accurate phase measurement to do the "micron level ranging" between the two satellites. We essentially adopted the intersatellite range measurement concept that had been developed for the Geopotential Research Mission.

We had available all of the technology developed for all the missions that were proposed, but were not successful in the 1970s and '80s. A concept called gradiometry, in which one measures the gradients directly, had gone forward. ARISTOTELES was a joint ESA [European Space Agency]-NASA mission that was given a great deal of consideration in the mid 1980s, but wasn't accepted. In the development effort for this mission, the gradient measurement was obtained as the difference between accelerometers located at different points on the same satellite. The differential acceleration contains the signal associated with the gravity gradient that one wants to measure. As a consequence of developments related to this mission, the technology for accelerometers had been advanced extensively in France at ONERA [Office National d'Etudes et Recherches Aerospatiales, French Aerospace Lab].

Rather than use the GRM concept—in which they were going to put a lot of propellant on board the satellites and fly the satellites so that a proof mass in the center was shielded by the actual shape of the satellite for any surface forces associated with radiation pressure or atmospheric drag, the so-called pea in a pod version. That is a hard requirement to satisfy. In addition to the difficult control requirements, a great deal of propellant is required to maintain this condition at the approximately 170 km altitude proposed for the mission. This fact necessarily limits the life of mission. Rather than adopt this concept, we chose to use a three-axis accelerometer to measure the surface forces directly. We got a very accurate three-axis accelerometer from CNES, and specified that it be located at the center of mass of the satellite to eliminate the effects of the rotational accelerations. With that accelerometer measurement sensitive to the surface forces only, we could use the high accuracy intersatellite ranging measurements to focus on the gravitational effect. That idea allowed us to design a concept with a multi-year mission life and focus on long-term gravity changes.

With the POD requirements and timing requirements satisfied by tracking with the GPS satellites, another major problem for GRM was eliminated. The development of the GPS system, the development of the accelerometer, the adoption of the formerly developed intersatellite ranging system that had been developed for GRM, allowed us to apply existing technology to implement a micron level intersatellite ranging system.

With the measurement concept in hand, we needed a satellite bus that would satisfy a number of demands to be sure that the high accuracy ranging measurement was not corrupted. The demanding requirements on the satellite buses included high structural and thermal stability to ensure that the micron level ranging accuracy is not influenced. A micron is about a tenth the size of a human hair, and we’re measuring at distances on the order of 200 kilometers. Anything that happens on the satellites is a potentially troublesome source of error in measurement. We leveraged some extremely difficult arrangements on requirements on the actual satellites.

In the first ESSP proposal call, the dollar value of the missions was really limited. You could either bid for the first mission with a $60 million cap or the second mission, which was to be launched at $90 million cap. We clearly needed at least $90 million, so we bid for the second mission. But to buy two satellites buses, build two paradigm-shifting type intersatellite ranging measurements, provide the accelerometers to measure the surface force measurements, and launch the two satellites for $90 million was an extreme challenge. In the innovative teaming arrangement we proposed, we would buy the satellites from Daimler Space Systems (which later became Astrium) in exchange for the satellite launch and the mission operations.

Astrium had demonstrated a satellite bus for the CHAMP [Challenging Mini-Satellite Payload] mission, which could be modified to meet the GRACE mission demands. It had accommodated an earlier version of the ONERA accelerometer that we wanted to use. JPL had provided a GPS receiver for the CHAMP mission, so this element had been accommodated on the proposed satellite bus.

In deciding to buy the satellites from a foreign vendor (in this case Astrium [EADS, European Aeronautic Defense and Space Company]), we proposed that the German Space Agency [German Aerospace Center, DLR (Deutsches Zentrum für Luft-und Raumfahrt)] agree to launch the satellites. There was a strong interest at the German Space Operations Center in operating the satellites, so we agreed to this element of the collaboration. The important thing for us was the launch vehicle. That was a tall pole in proposal "tent." With that arrangement, we could submit a proposal, which would allow us to stay under the cap, but just barely. We proposed a cost of $87 million, but with essentially no reserves in the budget.

In the first scenario that went forward on this, they essentially took the initial proposal and screened those for possibilities to allow one to go back and prepare a more definitive proposal. In that first proposal screening, I understand that we were almost at the bottom of the ranking. There were approximately 45 or 46 proposals submitted and we ranked somewhere in the 30s. Some of the negative ranking was associated with a lack of belief in the proposed teaming arrangement.

The scenario in Germany was uncertain, because a number of the DLR staff that interacted directly with NASA was saying that DLR was not going to do this mission. Other individuals in Germany were pushing the mission. So we were involved with the ones that wanted to do the mission in preparing the proposal.

There was also uncertainty associated with whether or not we could implement what GRM had proposed for a 1983 cost that was an order of magnitude larger. We did make the first cut. They did request that we prepare the second version of the proposal. Early on in the rankings for the second version, we advanced into the upper ten, and were ranked somewhere around seven.

I was told later that in the final selection process that a fairly important factor in our selection was the strong endorsement of Bill [William M.] Kaula, who is one of the eminent names in satellite geodesy and in gravity model development. Bill had been the project scientist for the GRM, so he clearly understood the nature of the measurement and the importance of the results if we were successful.

He also had chaired the highly important 1967 Williamstown Conference. The report from this conference made the recommendations that provided the basis for most of the geodetic and oceanographic missions that were implemented in the 1970s and 1980s. The altimeter missions were recommended in this report, and, to go along with the altimeter missions, a dedicated gravity-mapping mission was proposed. So Bill clearly knew that among the suite of missions recommended in the Williamstown Conference Report, a gravity mission had not been implemented. He had chaired a couple of other major studies and had been pushing NASA very strongly for the entire timeframe to actually do a gravity mission. I think he saw this as a chance to finally implement a credible gravity mission.

He was influential in arguing the importance of doing the mission, provided that the technical story came together. After extensive deliberation, we actually became one of the three that were selected. In that process they selected two missions and one alternate or backup in case either of the first two failed in the implementation process. If either of the missions has problems with either cost or schedule, the plan was to cancel the mission and look to implementing the third mission. An interesting and perhaps important side note is the selecting official for the first ESSP selection was Bill Townsend, with whom I had had a number of years of interactions during the TOPEX mission and after in his management role at GSFC. That Bill would be responsible for setting our first gravity model effort in place under the TOPEX mission framework and that he would be the official to set GRACE on its historic course is a sense of personal pleasure.

At the time we were selected the actual feeling at Headquarters was that we weren’t going to be successful, because the NASA selection didn’t commit DLR. We were selected provided that DLR actually agreed to provide the launch. In other words, we had a mission concept that proposed elements that NASA would do and other elements that DLR would accomplish, and if either one of those were not present, then we had no mission.

The official stance of DLR indicated that we had difficulties. In the mission concept we proposed, as the PI [principal investigator], I had the ability to make all the final management decisions. I was responsible to NASA for all elements of the mission. In the teaming arrangements, a colleague Chris [Christopher] Reigber agreed to be the Co-PI and to assume responsibility for the German elements of the proposal. Chris was a very well established geodesist and geophysicist in Germany and was the PI on the CHAMP mission. Chris, in addition to having outstanding scientific and engineer credentials, was extremely astute in the political ramifications in Germany. His capable efforts in the political community were extremely important in the final success of our efforts.

In addition to Chris, the other individual that was very important in getting the mission in place was Ab Davis. Ab had spent an extended period in Germany working with Chris at GFZ in implementing the GPS receiver on CHAMP. He used this period to establish contact with the accelerometer group at ONERA. During this period, he also established a friendly relation with the CHAMP satellite provider, which we turned to for the GRACE satellites. As a consequence, he understood very well the requirements for the teaming arrangements.

Through the combined efforts of Astrium [then Daimler Space Systems] and Chris in approaching the ministry that funds DLR, DLR was encouraged to go forward with the mission. Even with worst early prognostications, the collaborative MoU [Memorandum of Understanding] between NASA and DLR for the GRACE Mission was signed. As we found later, there were two internal reasons for the ministry support in Germany. Astrium wanted to build the satellites. They had a very good bus. They were trying to get the bus established with NASA as a credible vehicle for future business, so they gave us a very good price for building the satellites. In a development that proved important, they agreed to build them at a firm fixed price, which was fairly important to us since we had no reserve, and if there were cost overruns, we ran the risk of cancelation.

As follow-on to the success of the GRACE mission, Astrium has been able to get their Flexbus, as they named the bus used for GRACE, selected for a number of subsequent missions. They accomplished their objectives. But it is important to note that they did an incredible job in building the GRACE satellites and delivered for the cost that they had agreed to. There were a couple of design changes made late in the fabrication phase, which added additional cost.

We were extremely lucky in that we actually negotiated the price in terms of German marks, which later became Euros. Most of the payments were made during a timeframe in which the dollar strengthened against the euro, so that the cost in dollars was less than we anticipated. We were able to cover some of the cost growth in other elements of the development by this international fluctuation in the dollar. There was some risk though, because the dollar value could have declined. We were carrying some reserve for the dollar fluctuation, which we were able to apply in other areas.

The other interaction involved the launch vehicle. We proposed the mission expecting that we DLR would provide the Cosmos Russian launch vehicle, since this vehicle had been used to launch CHAMP. We didn’t know that another group inside Germany that was working on a commercial venture with the Russians. This interaction led to the decision to launch the GRACE satellites on a launch vehicle called the Rockot, which was provided by the Eurockot Consortium.

When this was first announced, I indicated that I did not want to provide the first satellites for launch on a new launch vehicle. I was assured that there were other commercial customers and that the launch vehicle would be used a number of times prior to the GRACE launch. It turned out that their industrial customer was the Iridium [satellite constellation], and shortly after making the announcement related to GRACE, Iridium went bankrupt. All of a sudden, the GRACE satellites are first in line.

As preparation for the Iridium launches, Motorola [Inc.] had negotiated a test flight, which was not conducted, and they turned over the actual module that they were going to fly on the Rockot for a demonstration test for GRACE. The first two stages of the Rockot were military missiles that had a long very successful launch record. We weren’t worried about the first two stages. We were worried about the third stage, referred to as the Breeze, that was a new development and had never been flown. It was developed for injecting commercial payloads into orbit. To demonstrate the Breeze, the Rockot Corp. took the two Motorola demonstration payloads, configured them to simulate the GRACE mission, and actually flew a preliminary demonstration GRACE launch. In this demonstration, they launched the Breeze into a GRACE orbit; the Breeze then injected the two payloads into orbit, and finally the Breeze deorbited, effectively simulating the requirements that we had for the GRACE mission.

The test was very successful and we got the actual loads and vibration information that we could use to support our design and test program. With that successful test, we agreed to the Rockot launch vehicle. As a final point, the Rockot launch of the actual GRACE satellites was perfect, and 45 minutes after the launch the two GRACE satellites and the Breeze were mapped by the German military radar as they made their first orbit over the German Space Operations Center in Oberpfaffenhofen, Germany.

The mission cost growth exceeded the $90 million cap by approximately $7 million. Most of this overrun was due to a set of Red Team Reviews and additional testing required by the agency to move away from the “faster better cheaper” implementation mode that evolved as a consequence of the two Mars Mission failures around 2000. But we were able to get the two satellites on orbit and get them in an operational mode for cost on the order of $100 million NASA dollars. There was probably another equivalent $50 million provided by the collaborative agreement with DLR, so the overall mission cost for the two satellites on orbit was approximately $150 million.

Present time now, we're approaching 10 years in orbit. The last Senior Review extended the mission out to 2015. There is concern as to whether the components on the satellites will last that long. They're aged and the batteries are giving us problems. There's a few other things giving us problems, but the mission to date has provided a remarkable dataset in place. The data has led to a paradigm shift in how we view observations of the Earth system dynamics.

WRIGHT: Has it met your expectations?

TAPLEY: We were pretty sure that the fundamental baseline requirement that the mission had to satisfy, the determination of an accurate long wave mean field, would be satisfied. We believed that if we collected global data for a period of two to three months, we would meet this requirement. That turned out to be correct. The first gravity model, based of 111 days of data, provided a gravity model that allowed determination of the general ocean circulation features from the decades long sequence of satellite altimeter measurements. So the first 111 days worth of data in the mission essentially gave us that very significant dramatic result.

The more difficult objectives associated with the mass flux measurement was a more significant challenge. To validate these measurements interactions with the oceanographic, cryospheric and hydrology communities was required. The hydrology community was a new community in the gravity applications area. They understood what we were talking about in general but they didn't understand how to use the global gravity coefficients that we were distributing as the primary data product. After extensive interactions a procedure for satisfying their requirements has been developed.

Recent investigations show applications of the data for seasonal river basin water balance, changes in lake impoundment, change in underground aquifers and drought monitor indices. After the slow start, the community has just really embraced the measurements. There was a very interesting AGU [American Geophysical Union] report that came out in December [2009] showing the depletion of the water in the San Joaquin Valley Aquifer in Central California. This water depletion is important, since a significant portion of the agricultural produce consumed in the US is dependent on the water from this aquifer.

There was another investigation that focused on an aquifer in India that provides water for most of the Indian population. You have a very large population where the underground water is going down very rapidly due to agriculture applications. So there are a lot of these application-related issues that are satisfied by the GRACE ability to sense underground water change. These results, along with other important climate-related measurements, suggest that the GRACE observations need to be continued. There are plans for a GRACE Follow On Mission, but it is scheduled to launch after the likely end of the current GRACE mission. One of the things we're working on now is trying to establish a bridge mission to the next mission to keep the measurements going.

But, with regard to your question, I would say that the ability to accurately observe a wide range of Earth System processes has been rewarding—to see the wide ranges of communities utilizing the data for applications that we didn't originally anticipate is very rewarding. We knew we could measure the global signal with unparalled accuracy, but we didn't fully understand all the ways the measurements would be used.

We think we're at the point now where the measurements from GRACE are ready to be ingested into models to assist the prediction process. That's one of the more difficult challenges facing the Earth System research. When you assimilate global measurements into the accurate models for the Earth Dynamics processes and use those models for improving the forecast, then you not only help the overall operational areas, such as weather predictions, but the climate predictions where the long-term forecast accuracy is under considerable scrutiny.

There have been some really nice additional results in the climate arena. The altimeter measurement that we discussed above provides one example. By using the global altimeter measurements for one 10-day ground track repeat cycle, one can measure the average or mean global sea level. This quantity is related to the volume of water in the ocean. By repeating the measurements at ten-day intervals, you can observe a change in global mean sea level. The global sea level change is currently recognized as an important climate signal and has an important connection to the GRACE mission.

We've been able to accurately measure the sea level change since the beginning of the TOPEX mission. The original average of the global altimeter measurements was used to calibrate the bias in the altimeter measurement. If one can use other measurements to determine the bias, then the global average of the altimeter measurements during a given repeat cycle can be used to observe the mean seas level. This concept was first proposed by Bob Stewart during a collaborative between Bob, George Born, and I in determining procedures for calibrating the TOPEX altimeter bias calibration.

One of the things that we were concerned with was understanding the various error sources in the altimeter measurement. Bob noted that if we successfully calibrated the altimeter measurement and accounted for all the other error sources, then the remaining signal would be due to sea level change, and that this could be an important signal for study, in its own right. So we proposed in this 1983 paper, as an aside comment, that one of the things we could do with global measurements of a properly calibrated altimeter would be to measure the global sea level and its changes. One did not have a set of altimeter measurements to test this concept, so the idea lay dormant for a while. In 1987 there was a call from NASA looking for climate related measurements. Wes [Wesley T.] Huntress drafted the call and was the program manager for the effort. I submitted a proposal to evaluate the use of the altimeter measurement record as a means of sensing climate change.

This was the first study devoted to using satellite altimeter measurements to observe global sea level change. The first test of this concept was performed using GEOSAT altimeter measurements and the results were not positive. The altimeter was a single frequency altimeter with uncertain accuracy, and associated orbits were not accurate enough to allow a credible measurement of sea level change. I initiated a study of the problem with a few Ph.D. candidates. We conducted both simulated studies to look at the issues that limited our ability to make this measurement as well as attempts to use the data for recovery of the ocean circulation. One of the students in this initial study was Steve Nerem, who has devoted a significant part of his career to the question of Global Sea Level Changes and is one of the current authorities on this effect. His work is currently referenced as the NASA standard sea level measurement.

With the TOPEX/Poseidon mission, the accurate altimeter measurements and the accurate orbits allowed an accurate measurement that has been maintained for almost 20 years and is one of the fundamental climate change measurements.

Although we could make the measurement, understanding the nature of the temporal variations was a much bigger problem. We know that there are two effects present in the sea level change. Temperature change will cause sea level change due to the water expansion, and if you add mass (water) to the ocean, the sea level will change. We know the polar ice caps and continental glaciers are melting; the water released in this melt ends up in the oceans. We also believe that the climate is warming up and the water should be warming as a consequence. We know that both of these effects are underway, but we do not know how much of the sea level rise is due to ocean water heat increase and how much is the effect of the addition of water from the melting glaciers.

The interesting thing is that GRACE will measure mass changes in the ocean, but it’s not sensitive to temperature changes. The temperature changes will not have an associated mass change and the mass change is the gravity signal that GRACE can measure. So by using the altimeter measurements of the global ocean surface topography, the total sea level change can be observed. By flying GRACE, you observe the mass change component. What’s left over is the temperature component, so those two measurements allow you to separate the steric or the temperature-driven component of sea level rise from the mass driven component. The mass changes are due to water that’s actually being added, which is fairly important in trying to understand from a climate point of view what is influencing the sea level change. To help close the global mass change budget, GRACE also measures the mass loss by the glaciers, which should be most of the mass added to the ocean. Agreement with these two GRACE measurements is a confirmation of the GRACE measurement accuracy.

I've been fortunate to participate in a number challenging missions and it has been a great pleasure to see the successful application of the measurements from these missions. It was very exciting in the 1970s to begin the work with the LAGEOS laser ranging and it was more challenging to address the requirements of the TOPEX mission. But GRACE I think probably has been perhaps the most rewarding of all the missions that I've been privileged to be associated with.

WRIGHT: Sounds like it keeps providing you more information to benefit from.

TAPLEY: Yes. I think we're still finding new ways that we can use the measurements. It's an extremely important interdisciplinary mission. GRACE is the only mission with the ability to directly measure the regional mass flux. Most of the other missions measure radiometric (reflectance) or metric (height) properties in one form or another and, where required, these measurements are used to make inferences about the mass flux. But GRACE measures the effect of the mass itself. So it's a very good complement to most of the other measurements.

GRACE in combination with the SAR [Synthetic Aperture Radar] radar missions, the altimeter missions and the satellite laser ranging missions, as well as results from a number of the hydrology related missions, provides the basis for a wide range of inter-disciplinary studies. One example is found in the ICESat [Ice, Cloud,and land Elevation Satellite] mission, which implements a laser altimeter to measure the ice sheet topography. From these measurements one can determine the change in the ice sheet volume. The SAR missions will measure surface velocity. GRACE will measure the mass changes, so together they give a complete picture. There will be missions to measure soil moisture, which along with the total subsurface water change observed by GRACE will provide essential information on the water budget.

WRIGHT: You used the word interdisciplinary. Let's talk about the whole concept of Earth System Science. How are the benefits that GRACE is providing for us working with the other concepts, how are you able to help the other disciplines within Earth System Science with the work that you're doing?

TAPLEY: In the GRACE proposal we described an interdisciplinary climate-related mission. The name GRACE is an acronym for Gravity Recovery and Climate Experiment. We actually proposed several paradigm shifting climate related measurements for the GRACE mission. The ability to infer mass change below the Earth's surface was a paradigm shifting capability that had not been provided by any other mission.

In response to the interdisciplinary related capabilities, the mass flux measurement concept evolved from an extension of a program initiated under the Earth Observation System, the EOS program. I led an interdisciplinary EOS science investigation proposal, which was selected to look at the integration of data from the EOS measurement suite with the objective of focusing on the Earth system dynamics. I proposed an investigation that would study a number of the topics that GRACE is addressing.

The EOS implementation was delayed and the data needed to accomplish the investigations was never provided, but we did perform a number of simulated investigations and we did use the time variable gravity measurements observed by the LAGEOS satellites to begin initial studies that were very beneficial to the GRACE mission. We actually understood a lot of the inter-disciplinary applications that GRACE addressed when we proposed the GRACE mission. In the GRACE proposal, we outlined contributions to oceanography, hydrology, cryology and contributions to geophysics. We also proposed some paradigm shifting measurements, such as inferring the deep ocean currents and the change in underground continental aquifers.

In oceanography we focused on providing the mean ocean geoid to allow determination of the general ocean circulation from the satellite altimeter measurements, we described changes in the mean sea level, and we proposed inferring the ocean bottom pressure changes as a means of inferring deep ocean currents. The GRACE measurement component was viewed as an essential augmentation to other measurements and, without GRACE, an important part of the overall puzzle would not be measured. So in the initial context, GRACE was always viewed as having a strong interdisciplinary thrust in the Earth System Science context. Early on in the GRACE mission, we argued that GRACE is an essential member of the satellite suite that NASA provides to observe the Earth’s dynamic system. In all of the base objectives of the Earth science program, there is a place where the mass and the mass flux provided by GRACE are essential to the scientific interpretation. The mass flux taken by itself usually won’t solve the problems, but it is a very important piece of the puzzle. You usually can’t solve the problem without understanding the associated mass and mass flux.

So the measurement of gravity has evolved from what was viewed in a fairly narrow context as a geodetic measurement, the mean gravity (or static) gravity field, into one that’s really central to in the climate change considerations. It is being recognized as one of the significant climate parameters that we should to be measuring.

WRIGHT: What do you see that needs to happen in the next 20 years in the field of Earth science?

TAPLEY: The transition in the NASA mode of operation is undergoing some interesting perturbations. NASA, from the beginning, has had a mission of developing new technology and providing new proof of concepts. It uses the missions as a rationale for the technology development. The idea of repeating a measurement that you've already demonstrated has been a big problem for them. It's has been a problem for management in deciding what NASA should do, and it's been a problem in terms of resource allocation since they are always budget limited, and repeating a previous measurement means that you will not be able to do some new measurement.

However, we find ourselves at the present time with a serious need of having observations of climate related quantities that extend over multi-decade time frames. The satellite role in making many of these measurements is crucial, because the satellite measurements are the only acceptable way of getting global near-synoptic measurements. The accuracy of these measurements and the global nature of those measurements are extremely important for climate change studies. NASA is the only agency that has demonstrated the capability and the will to this role.

NOAA [National Oceanic and Atmospheric Administration] could improve the operational-related measurements to meet the climate needs, but they have not delivered the measurements with the precision and accuracy associated with NASA products. So at the present, the issue of maintaining continuity of some important measurements has not been resolved and some of the quantities that we've talked about such as the sea level measurement has become a global climate change indicator, and maintaining a continuous measurement is fairly important.

The sequence of mass flux measurements coming out of GRACE has the potential for becoming such an important data record, if we can continue the measurement sequence after the current GRACE mission. But the issue of how NASA responds to the need for measurement continuity to support climate change studies is a difficult one to address. Either the NASA mission needs to be enlarged to allow the agency to address these issues, or their needs to be another agency put in place and charged task.

On another front, the missions themselves are getting extremely expensive. All of them are in the few hundreds of millions of dollars to billions of dollars. We can't do very many missions under this cost profile. In the technology development mode, NASA needs to develop the ability to get the critical measurements in a cheaper way. One proposed technology that may come into play is associated with the smaller satellite implementation. The nanosatellites have been fabricated and orbited, but the requisite technology base to use them is not in place. Actuators, thrusters, instruments and power supplies are needed for the nanosatellite regime. If these technology demands can be met, then clusters of satellites that allow you to distribute the required measurement functions can be discharged in a more cost friendly implementation. Development along these lines is one way in which we have the potential for essentially making the measurement systems more robust and to provide them at a lower cost. I think there will be considerable effort in this direction in the future.

The one measurement sequence where the US seems to be lagging is in the radar measurement area. We demonstrated the first satellite radar capability on Seasat in 1977, but we haven't had another dedicated polar orbiting radar on orbit since that time. We've done short-term radar demonstrations such as the SRTM [Shuttle Radar Topography Mission]. However, none of the proposed dedicated radar missions have been successful. All of the other nations have. Canada, Germany, Japan, and ESA all have flown dedicated satellite radar missions. I believe that this situation will be remedied in the current decade.

Looking down 20 years and trying to use the history to project forward 20 years is a risky venture. But if I looked at where we are now, one of the key problems that we need to solve is how we maintain, hand off, operate satellites in a way to continue some of the high-quality measurements sequences. Future requirements will require that we use cluster and constellations of satellites to satisfy increasing demands for higher spatial and temporal resolution (or coverage). Development of the nanosats may be one way of satisfying these requirements, so I see development in this area.

WRIGHT: Since you looked forward, let me ask you to look back. What do you believe to be some of the greatest accomplishments of the last 20 years since Earth System Science has developed and evolved?

TAPLEY: The development of the metric range measurement accuracy, which allowed us to define the shape of the Earth, the reference frame used to describe changes, the dynamic properties on and inside the Earth, is one of the major accomplishments. The measurement accuracy, the metric/measurement accuracy, has gone down from the five-to-ten-meter level in the mid-1970s to the micrometer level today, with the nanometer level accuracy just over the horizon.

The ability to define positions in a geocentric reference frame, to be able to observe changes in this reference frame, allows the ability to study tectonic deformations, land subsidence, and the ability to observe the millimeter scale movement of the Earth's center of mass as various dynamic processes occur, represents one of the great achievements of the past few decades. The development of laser and microwave ranging systems with the measurement accuracy required to perform these studies has been one of the biggest accomplishments in our ability to study the Earth, and an extremely important point in being able to figure out how you're going to conduct studies.

The idea of making micron-level measurements over a distance of 200 kilometers was a concept that was proposed in the '70s and early 80s timeframe. We are demonstrating these measurements on GRACE today.

Another success lies in our ability to put these measurements together and to look at the whole Earth system, at one time, with this level of precision, and it gives you a new way to view the Earth and to understand what's going on both in scientific and in application terms. This global, near synoptic measurement capability brought forward by the satellite platform has allowed Earth system studies to be conducted in a completely different context.

Some of the unique investigations include the ability to measure the mean sea level change with the millimeter level precision, to use the ocean surface topography measurements to infer the general circulation, to infer changes in the deep ocean bottom currents, to observe changes in the mass of the polar ice caps, and to measure changes in ground water aquifers throughout the world. These are all views of the Earth that are completely new, very important, confirm studies that people have conjectured about for long periods, and allows us to quantify the processes that are underway.

Out of all this we begin to get both the database and the confidence in the database to think about assimilation of the measurements into the models. I fail to include this area in the accomplishments of the next 20 years. I do think that during the next 20 years we're going to achieve the capability to assimilate the satellite data into the models, improve the model fidelity and use the improved predictions to understand multi-decadal climate trends. That's the next significant step in using the satellite data. In addition to the predictions of future trends, ingesting the satellite data into models allows the models to extrapolate the satellite information to a higher spatial and temporal resolution.

Satellites are limited to observing phenomena only when they overfly it. But the models allow you to assimilate the measurements and then extrapolate spatially and temporally between the subsequent views so that you can "observe" the phenomena at more frequent intervals. I think evolving our current capabilities could be one of the biggest steps forwards in being able to understand the Earth. It'll help improve the physical principles on which the models are based. Then once the physics is right, the initialization and steering provided by the satellite observations will allow the prediction modes to be conducted with the requisite accuracy.

WRIGHT: Let me switch subjects as our time starts to close, because I wanted you to have an opportunity to talk to us for a few minutes about the fact that you have worked 50 years in your field. During that time period you founded the Center for Space Research for the University of Texas at Austin. Share with us why you felt that was a good thing for the world, for us to have the center.

TAPLEY: For most of my early career, I operated in the individual faculty member, graduate student mode. This is the way most faculty members want to work. That's the best way to conduct a teaching-research relation. Although I did not want to get into administration, I did agree to serve as the chair of the Aerospace Engineering and Engineering Mechanics Department for the 11-year period between 1966 and 1977. During that time period, we organized an informal institute for advanced studies in orbital mechanics. The institute was organized primarily because the Air Force was willing to provide funding for an institute to study astrodynamics. A colleague that we had hired by the name of Professor Victor Szebehely had brought the Air Force funding with him. We put reports out under the institute name for about 10 years, but it had no management structure within the university.

In 1982 or 1983 there was a move on campus to form a space-based research center. I worried about the direction that the proposed management was going, and what impact it might have on what we were doing. At that point, we had a pretty healthy program underway. We'd already done the Seasat mission and were involved in the formative stages of the TOPEX mission.

To protect the thrust that we had developed, I decided it would be best to propose that we become an organized research unit. So we put the proposal in place and formally organized it at that point. We were assigned to the Bureau of Engineering Research, primarily because most of the faculty came from the Aerospace Engineering Department. From the beginning, the center has evolved with a strong interdisciplinary focus. We've had good collaboration with astronomy, collaboration with physics, with the natural sciences including the geography and geophysics group, and more recently with the Jackson School [of Geosciences, The University of

Texas] in terms of the geophysical-related areas.. It's evolved into an internationally recognized an interdisciplinary research unit.

Because of the success of the LAGEOS efforts, the TOPEX mission, this EOS interdisciplinary research grant, the ICESat mission and the GRACE mission, we have had a very productive three decades of activity. The research effort has allowed us essentially to establish collaborative relations with a number of internationally recognized research groups, such as GFZ Potsdam, Shanghai Observatory, etc.

The organized research unit also provided a basis for larger student involvement and a place of employment, once they'd finished their academic work. A major factor in our success has been our ability to keep some of our best graduates active to allow them to continue their research. So it turned out that forming the organized research unit was an important step in the evolution of our program. We've extended the center not only in the space geodesy area, but also into a number of other satellite remote sensing areas that we have not discussed. We have established the capability for receiving satellite data in a direct broadcast mode. In addition to supporting research, we use the data in teaching and in a number of other areas such as regional hazard monitoring.

Gordon Wells, who is one of the key individuals in this effort, is a lead member of the governor's Division of Emergency Management. He plays an important role in the states response to natural and manmade disasters such as hurricanes, floods, fires, etc. We also are the home for the multi-university Texas Space Grant Consortium. It's an outreach type program that NASA funds. Under the center's effort, we prepared the proposal for this program in 1980 and have been involved with its efforts since that time frame. I was the PI and Steve Nichols was the

Co-PI on the proposal. Steve was influential in establishing and actually chairing the first national space grant organization.

So the Center for Space Research has been a good way to combine our interest in space research and exploration with our interest in teaching in one unit. The general thrust has been a campus-wide focus for both space research and space applications, and the academic components that are associated with this effort.

WRIGHT: In your spare time you currently serve on the NASA Advisory Council [NAC].

TAPLEY: Yes.

WRIGHT: Is that a relatively new role for you or is that something you've been doing for a while?

TAPLEY: No, I think I went on this—time gets by on that. I don't actually remember. It must have been two years ago in January. I've been involved in a number of advisory positions over the years. I've bumped around a couple times. At one point I looked fairly carefully at taking the Associate Administrator role for Earth Science when Charlie [Charles F.] Kennel left. In fact Bill Townsend actually moved into the position. GRACE was at a point where it was critical for me to not make this move. I really did want to participate in the GRACE mission. This fact, coupled with some family medical problems, prevented me from making this move.

But the NAC role required a smaller time commitment and it does give you the chance to provide advice that can have an impact. Although you do not have the ability to make decisions, you can have an input to put the thought process. It’s rewarding to be able to work at that level.

I did a fair amount of alternate advisory work in the late ’80s and up through the middle of the ’90s for the National Academy [of Sciences] in which I was a member of the Space Science Board and Chaired the Committee on Earth Science. During this time, the EOS mission suite was going forward and we were able to provide advisory oversight to this process. It’s been interesting to see how the NASA side of the advisory process evolves. Both activities are rewarding as long as you feel that your efforts are making a contribution.

[End of interview]