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Abstract

A New Mission Concept for the Space Infrared Telescope Facility

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Introduction

The Space infrared Telescope Facility (SIRTF) will be a one-meter-class cryogenically cooled infrared astronomy observatory, SIRTF will be the infrared component of NASA's family of Great Observatories, which includes the Hubble Space Telescope (HST), the Gamma Ray Observatory (GRO), and the Advanced X-ray Astrophysics Facility (AXAF). The original concept of SIRTF was to use the Space Transportation System (Shuttle) to launch the telescope into a 900 km orbit. The mission lifetime is 10 years and requires 1 to 2 Shuttle servicing missions. In late 1988, an alternative mission concept was conducted that is based on a 100,000 km altitude orbit launched by the new Titan IV/Centaur with the upgraded Solid Rocket Motor (SRMU). Mission lifetime is reduced to 5 years but because of the 2 to 3-fold efficiency gain and the improved radiation environment at the high altitude, there is an overall improvement on science return. In the fall of 1991, it became apparent to NASA and the SIRTF project that SIRTF as was conceived and designed was not commensurable with the fiscal and programmatic climate. In response to the guidance given to the project by both NASA and Congress, the SIRTF scientific and engineering teams began to develop an alternate mission which retains much of the fundamental scientific importance and promise of the original SIRTF concept while permitting significant cost savings. A two prong, approach was taken, The Science Working Group was charged to define a minimum set of science requirements and instrument complements that maintain only those capabilities which are unique to a relatively small cryogenic observatory in space, bearing in mind the complementary capabilities of other facilities (e.g., large, infrared-optimized ground-based and airborne telescopes) now expected to be operational in the SIRTF time frame. This approach led to a new complement of instruments that include wide-field imaging and moderate resolution spectroscopy at wavelengths from 3 to 200 μm. The engineering team was charged to redefine the mission concept, the telescope, spacecraft subsystems, and operations to minimize cost and complexity. The work began in March of 1992 and the engineering team emerged in July with a completely new design that uses an Atlas IIAS launch vehicle that injects SIRTF into a drifting solar orbit. The telescope and spacecraft were downsized to less than half the original size, However, the new design had to sacrifice some capabilities. The 3-axis articulating secondary is now fixed, a cold fine guidance sensor is eliminated and replaced by a much simpler quad sensor similar to the one used by ISO, and the mission lifetime is reduced to 3 years. This paper describes the solar orbit and its effect on the mission and flight system design.

Trajectory Design

One of the objectives in the process of downsizing and descoping SIRTF is to explore options of using some other orbit and launch vehicle.

The old concept of SIRTF places the telescope in a 100,000 km altitude circular high Earth orbit (HEO) with an orbital period of 4 days. This orbit is a significant improvement over the shuttle launched low Earth orbit in terms of observational efficiency, radiation and thermal environment. The Titan IV/Centaur is the only US launch vehicle that could deliver the old SIRTF to the 100,000 km orbit. The Centaur upper stage is designed to deliver payloads to a geosynchronous altitude of 36,000 km which has a transfer time of about 6 hours. The SIRTF HEO transfer requires about 19 hours. Consequently during the long coast, the Centaur requires additional batteries with associated electrical system modifications. There is also some concern over the ability of the Centaur engine to restart after the long coast because of the large ullage of the LOX tank. Some kind of mixer may have to be added to the LOX tank. All of these modifications will add to the nearly $300M cost of the Titan vehicle. Depending on whether the Solid Rocket Motor Upgrade is successful or not, the Titan Centaur can deliver a payload of about 5200 to 5700 kg to the HEO.

The next smaller US vehicle is the Atlas IIAS. The Atlas IIAS can deliver only about 1500 kg to the HEO. This would have been too much of a reduction, not to mention the problem with the long coast is still unresolved. The only way to use the Atlas is to find a new orbit that requires less launch vehicle energy to achieve. As it turns out, the two burns to achieve the HEO is equivalent to an injection energy, C_3, of 22 km^2/sec^2. By comparison, the C_3 required to send payloads to Venus or Mars is about 10 km^2/sec^2. and the energy to escape Earth is zero. At $C_3 =$ 0 km^2/sec^2, the Atlas IIAS has a payload capability of about 2500 kg, a gain of 1000 kg over the HEO. It became clear that, in order to use a smaller and cheaper launch vehicle, SIRTF has to abandon the HEO and use an escape orbit from Earth. An Earth escape orbit when viewed from the solar system is equivalent to a solar orbit that essentially flies in formation with the Earth. The solar orbit, when compared to the HEO, improves further the radiation and thermal environment, as well as viewing geometry since there is no more Earth and Moon avoidance constraints.

At one point, a libration point orbit was briefly considered for SIRTF. The L2 libration point is about one and half million kilometers from the back side of the Earth along a line joining the Sun and the Earth. An object placed at this point experiences a balance between the Sun/Earth attraction and the centrifugal force. The L2 libration point is far enough from Earth that the energy required to send SIRTF is almost the same as sending SIRTF to an escape trajectory. This point would be a good place to place SIRTF since the Sun and the Earth will always be on the same side in the sky, and the communication distance from Earth will be a manageable 1.5 million kilometers. However, the major drawback of the libration point orbit is that it requires a propulsion system and precise navigation to achieve, and that it requires continuous orbit maintenance throughout the mission. The propulsion system adds mass and complexity to the mission. Contamination of the sensitive optics of the telescope by propellants is another concern. Consequently, the 1,2 option is discarded in favor of the solar orbit option.

In the context of two-body orbital dynamics (the two bodies being the Earth and the spacecraft), an escape trajectory from Earth means that the spacecraft velocity relative to Earth approaches zero when the distance from Earth approaches infinity. In essence, when the spacecraft is far enough away from Earth, it will have the same heliocentric velocity as Earth in the solar system. If this was true, the escape orbit, which is a parabola relative to Earth, would result in the same heliocentric orbit no matter which direction we inject the spacecraft. However, the escape orbit is severely perturbed by the Sun as the spacecraft moves away from the Earth. Because of these perturbations and depending on the direction of injection, an injection energy of zero may not result in an escape trajectory.

An initial study was performed using the 3-body (Sun-Earth-s/c) dynamical system to search for proper escape trajectories from Earth by varying the injection energy and the injection direction, It was found that there are two classes of usable escape trajectories. One class has the s/c leading the Earth with the injection point on the far side (near midnight) of the Earth relative to the Sun (fig. 1). The other class has the s/c trailing the Earth with the injection point on the sun lit side (near noon).

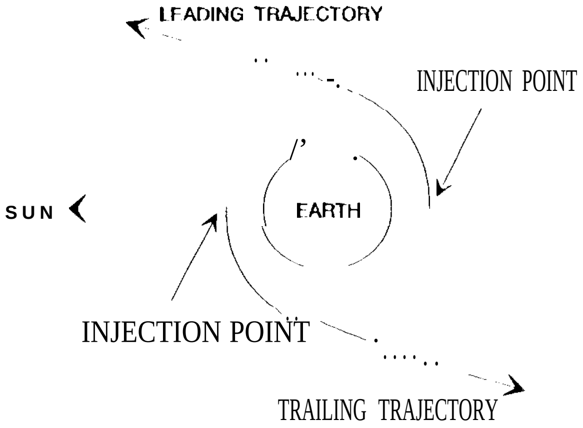

Fig. 1 Injection point geometry

Figure 2 depicts a representative trailing solar orbit for 5 years. The orbit is plotted relative to a fixed Sun-Earth line (the x-axis), The maximum distance from Earth at the end of 5 years is about 0.55 AU (82 million km), This SIRTF solar orbit is more eccentric than the Earth's orbit. Therefore, the Observatory appears to move towards the Earth at perigee and away from Earth at apogee. Figure 3 shows the geometry of the orbit for the first 60 days after launch

There is no propulsion system on SIRTF, so there is no active control of the orbit, The paper will describe the process in selecting the reference solar orbit, the minimization of drift distance, and the sensitivity of the orbit due to variations in the launch period, launch window, and injection error.

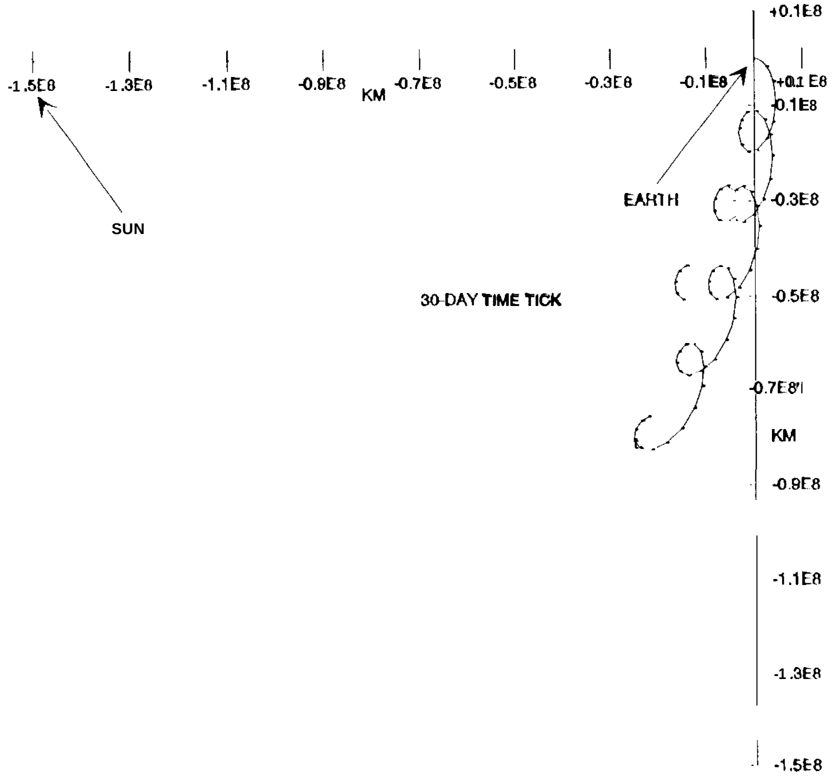

Fig. 2 5-year trailing trajectory

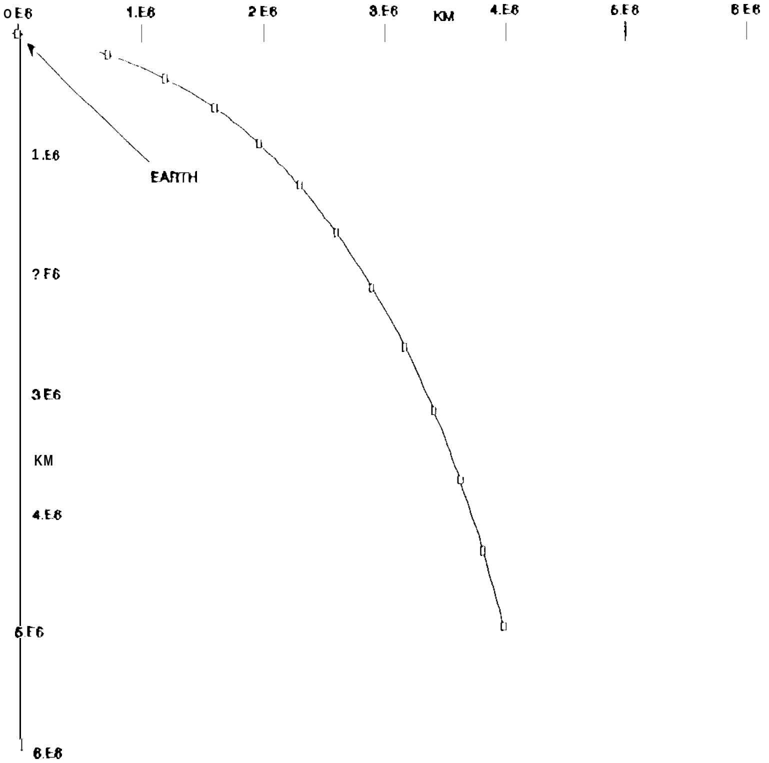

Fig. 3 Near Earth ailing trajectory