

# The Laser Communications Relay Demonstration Experiment Program

David J. Israel

*NASA Goddard Space Flight Center, 8800 Greenbelt Rd., Greenbelt, MD 20771,  
Tel: 301-286-5294, [David.J.Israel@nasa.gov](mailto:David.J.Israel@nasa.gov)*

Bernard L. Edwards

*NASA Goddard Space Flight Center, 8800 Greenbelt Rd., Greenbelt, MD 20771,  
Tel: 301-286-8926, [Bernard.L.Edwards@nasa.gov](mailto:Bernard.L.Edwards@nasa.gov)*

John D. Moores

*Massachusetts Institute of Technology Lincoln Laboratory, 244 Wood Street, Lexington, MA  
02421-6426, Tel: 781-981-7600, [Moores@ll.mit.edu](mailto:Moores@ll.mit.edu)*

Sabino Piazzolla

*NASA Jet Propulsion Laboratory, 4800 Oak Grove Dr., Pasadena, CA 91109,  
Tel: 818-354-4086, [Sabino.Piazzolla@jpl.nasa.gov](mailto:Sabino.Piazzolla@jpl.nasa.gov)*

and

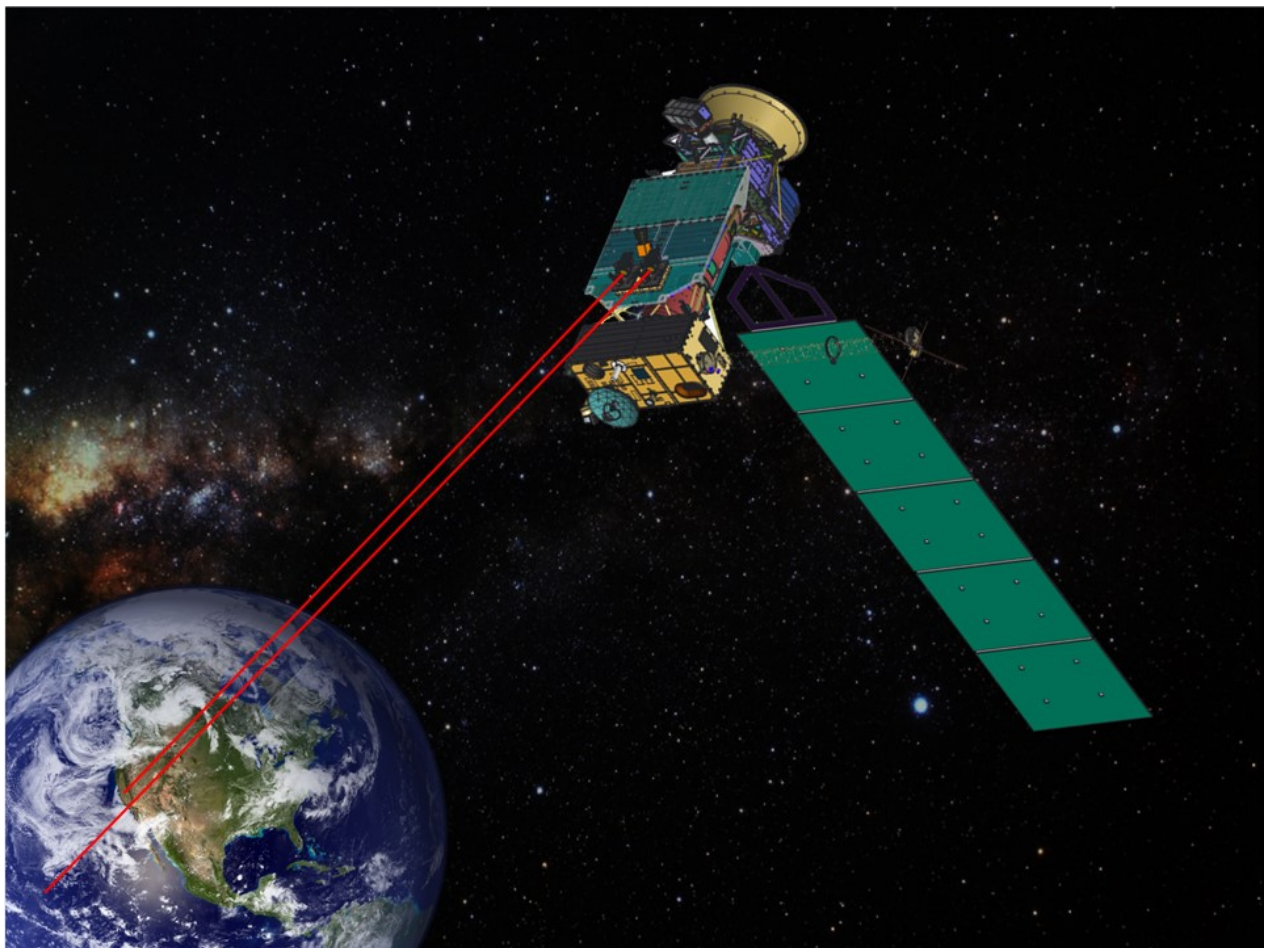
Scott Merritt

*NASA Goddard Space Flight Center, 8800 Greenbelt Rd., Greenbelt, MD 20771,  
Tel: 301-286-0050, [Scott.A.Merritt@nasa.gov](mailto:Scott.A.Merritt@nasa.gov)*

**This paper elaborates on the Laser Communications Relay Demonstration (LCRD) Experiment Program, which will engage in a number of pre-determined experiments and also call upon a wide variety of experimenters to test new laser communications technology and techniques, and to gather valuable data. LCRD is a joint project between NASA's Goddard Space Flight Center (GSFC), the Jet Propulsion Laboratory (JPL), and the Massachusetts Institute of Technology Lincoln Laboratory (MIT LL). LCRD will test the functionality in various settings and scenarios of optical communications links from a GEO payload to ground stations in Southern California and Hawaii over a two-year period following launch in 2019. The LCRD investigator team will execute numerous experiments to test critical aspects of laser communications activities over real links and systems, collecting data on the effects of atmospheric turbulence and weather on performance and communications availability. LCRD will also incorporate emulations of target scenarios, including direct-to-Earth (DTE) links from user spacecraft and optical relay providers supporting user spacecraft. To supplement and expand upon the results of these experiments, the project also includes a Guest Experimenters Program, which encourages individuals and groups from government agencies, academia and industry to propose diverse experiment ideas.**

## Introduction

With constantly advancing space applications, radio frequency (RF) communications links are not expected to be able to fully support the needs of human exploration and advanced instruments aboard science missions. Optical communications offer a solution to these needs, enabling greater data rates than RF systems at the same mass and power. In fact, optical communications could provide up to 100 times the data rates of today's RF systems, transforming and revitalizing the possibilities for advancement and discovery. Furthermore, optical communications capabilities have various added benefits, including resolving RF's issues with limited spectrum allocation and constrained bandwidth. The National Aeronautics and Space Administration (NASA) is developing the Laser Communications Relay Demonstration (LCRD) mission as a testbed for bidirectional optical communications and associated communication techniques, including adaptive optics, symbol coding, link layer protocols and network layer protocols. LCRD will conduct experiments on optical communications links from geosynchronous orbit for at least two years, with the goal of responding to growing needs for enhanced communications technologies and developing affordable optical assets for both deep space and near-Earth enterprises. This paper provides a high-level overview of LCRD's architecture and possible experimentation ideas. For more detailed explanations or to learn about proposing experiments, find the LCRD Introduction for Experimenters document at [lcrd.gsfc.nasa.gov](http://lcrd.gsfc.nasa.gov).



*Figure 1. LCRD consists of a flight segment and a ground segment that will demonstrate two simultaneous bidirectional optical links.*

## LCRD Architecture

LCRD has a flight segment and a ground segment (see Figure 2 below).

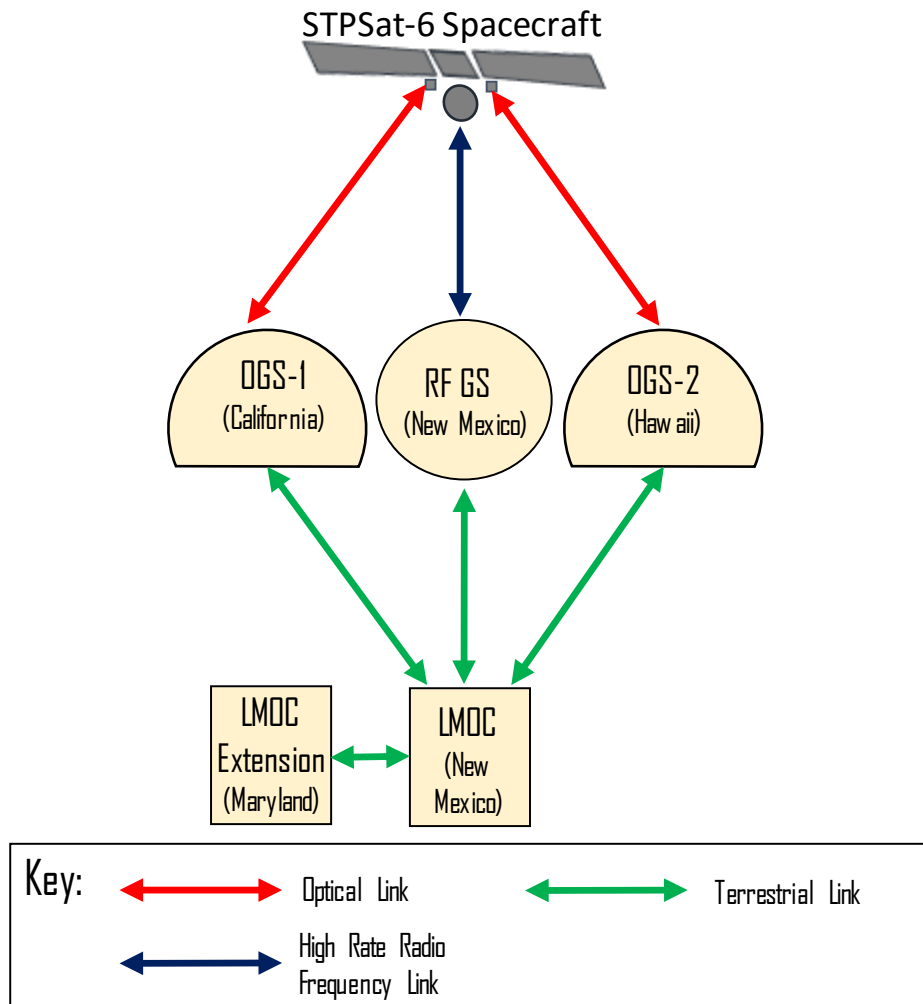


Figure 2. The LCRD mission's primary architecture is depicted above.

The flight segment will be aboard the Air Force Research Laboratory's Space Test Program Satellite-6 (STPSat-6) spacecraft, and will consist of the LCRD flight payload and a High-bandwidth Radio Frequency (HBRF) terminal provided by the spacecraft. The forward and return links of an optical relay service may be supported by any combination of an optical or Ka-band trunkline, depending on the scenario. One of the LCRD flight payload's optical space terminals may be used to provide the trunkline for full rate (up to 1.244 gigabits per second) forward and return links. The HBRF terminal will support LCRD Ka-band communications for space-to-ground trunklines. On the forward link, this RF trunkline can support one or two users at 32 megabits per second (Mbps) for each user. On the return link, the RF trunkline can support one user at a data rate of up to 622 Mbps, or two users at a data rate up to 311 Mbps. Data can pass through the HBRF terminal to get to or get down from the optical space terminals. The HBRF terminal is connected to LCRD's space switching unit (SSU), which will switch incoming data according to the frame header, process commands to the payload and send down the payload's telemetry data. This unit can switch data between optical and RF links. The space segment also includes two optical space terminals

(OSTs), which each include a telescope that can transmit optical signals. The OST modems support Pulse Position Modulation (PPM) and Differential Phase Shift Key (DPSK) waveforms on forward and return links, and controller electronics for pointing, tracking, and acquisition and thermal control. They have Built-In Test functions that enable simple calibrations and internal modem or payload loopback testing (for simplified internal testing and calibration). The modem can also generate test pattern data frames for use in direct downlink return service.

LCRD's ground segment consists of two optical ground stations: OGS-1 at the Jet Propulsion Laboratory's Optical Communications Telescope Laboratory (OCTL) facility in California, and OGS-2 in Hawaii. These ground stations can communicate with both of the OSTs on the flight segment. The optical ground station subsystems include an optical telescope assembly, ground modem, coder/decoder (CODEC), user services gateway, user element simulators (including a user mission operations center (MOC) and a user platform simulator), and an atmospheric channel monitoring system. The ground segment also has an RF ground station and the LCRD Mission Operations Center (LMOC), including the LMOC Extension (LMOC-E).

## **Dynamic LCRD Elements Applicable to Experiments**

LCRD experimenters can utilize the relay demonstration's robust architecture to perform experiments involving features on the ground and in space. The LCRD elements, as demonstrated in the configuration above, can serve various roles to cater to experiment needs. Below are descriptions of various functions each LCRD element can assume. For more details, refer to the LCRD Introduction for Experimenters document at [lcrd.gsfc.nasa.gov](http://lcrd.gsfc.nasa.gov).

**The LCRD flight segment's primary function** is to employ its optical space terminals to serve as a relay between a user leveraging optical communications links and a ground station. In this case, OST-1 or OST-2 would provide a forward/return optical link to the user, and the other optical terminal could have a link to one of the optical ground stations (OGS-1 or OGS-2). Conversely, an RF trunkline could be made available between the HBRF terminal on the space segment and the RF ground station.

**This flight segment can also function as an optical relay between user spacecraft**, with each LCRD optical space terminal providing forward/return optical links to two different user spacecraft. In this scenario, the space-based HBRF terminal could also transmit and receive data to and from the RF ground station.

Additionally, the **LCRD flight segment can serve as a Direct-to-Earth (DTE) user**. The flight segment would receive simulated, user-formatted data streams from one of the optical ground stations to one of the optical space terminals, or from the RF ground station to the onboard HBRF terminal. Then, the flight segment would simulate a DTE user downlink by sending this data to an optical space terminal to be downlinked to OGS-1 or OGS-2, which would be scheduled and configured to support the transmission. Alternatively, an optical uplink from OGS-1 or OGS-2 to a DTE user could be similarly simulated.

**LCRD's optical ground stations could also serve various roles** to meet experiment configuration requirements. They can function in their primary roles as optical ground stations, providing optical trunklines for relay scenarios or forward and return links for DTE demonstrations. Or, one of the OGSs could function as a user spacecraft by using optical links in either direction to communicate with an optical space terminal. In this case, the optical ground station would interface with the flight segment to produce and receive user data using its user element simulators, the User Platform Simulator and the User Mission Operations Center Simulator (UMS). The OGS could also enable the LCRD flight segment to simulate a DTE user by employing its user element simulators to send and receive simulated data to and from the flight segment.

Finally, **the LCRD RF ground station could also simulate various roles** aside from its primary function as the ground station supporting forward and return RF trunklines to and from the onboard HBRF terminal. The RF ground station could also enable the LCRD flight segment to simulate a DTE user by sending

simulated DTE data to the HBRF terminal. Furthermore, the RF ground station could function limitedly as an optical relay user spacecraft if other assets are preoccupied by providing simulated user data to the flight segment's HBRF terminal. In this case, the ground station would only simulate part of the link (not the optical modulation, wavelength, etc.).

## Experiments

LCRD serves as a platform for diverse experimentation of optical links and associated elements. For experimentation purposes, LCRD's flight and ground segment elements can play various roles in a relay scenario.

For instance, suppose a relay user would like to test the feasibility of an optical relay provider in supporting a user spacecraft (see figure 3 below), including meeting the needed data rates, view periods and latency requirements.

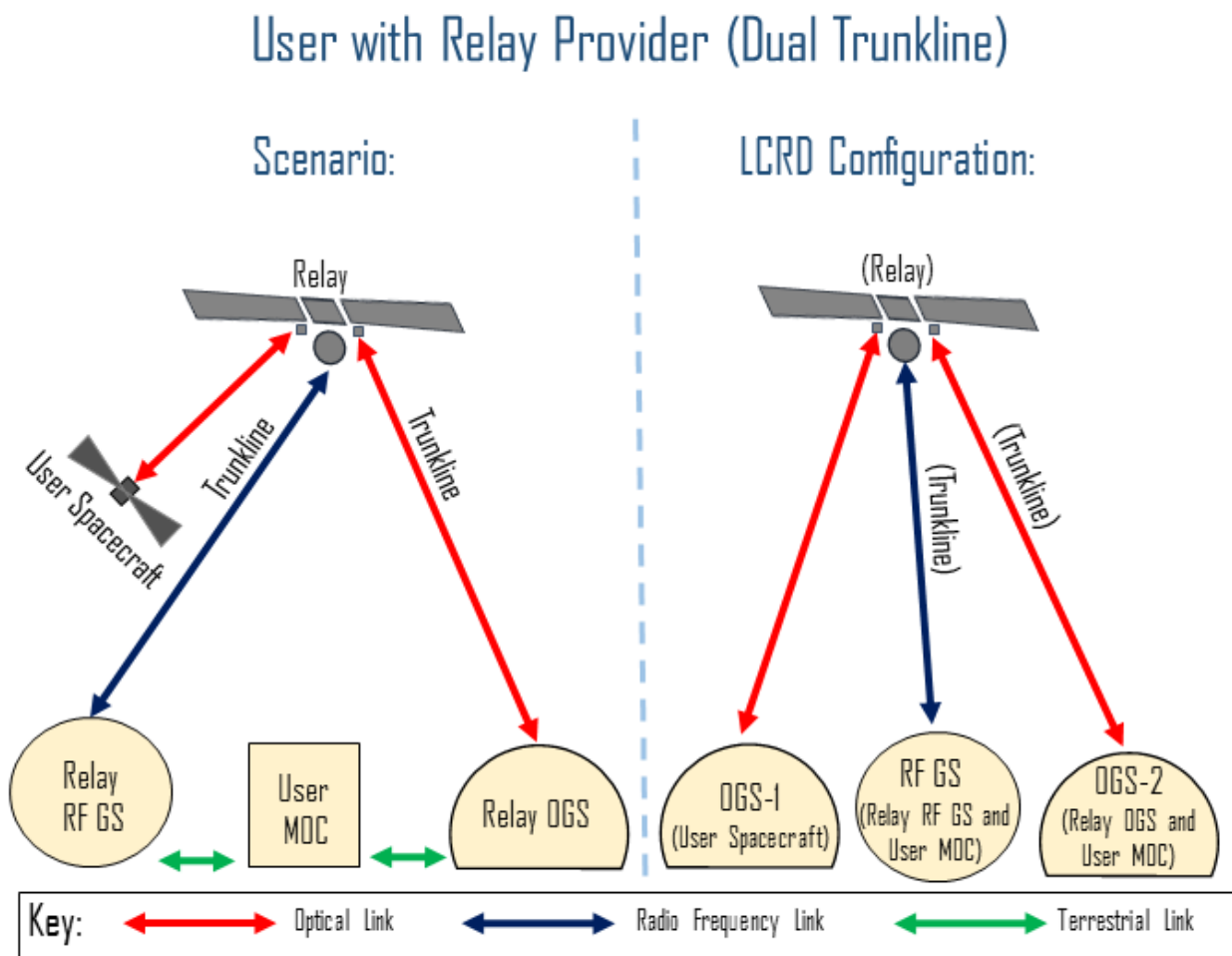


Figure 3. Example LCRD experiment configuration (on right) to simulate a scenario involving a single user spacecraft communicating with a relay provider (on left).

In the example configuration in Figure 3, the OGS-1 ground station in California functions as the user spacecraft for this scenario, communicating with the LCRD flight segment, which functions as the data relay spacecraft, using optical links. In this scenario, OGS-1 (the user spacecraft) produces data using its user platform simulator to model information specific to the spacecraft, such as data rates, data volume, types of data and view periods. The LCRD flight segment communicates with OGS-1 using one of its optical space terminals. It also transmits data to and from the ground at OGS-2, which functions as the relay's optical ground station, using an optical link from the flight segment's other OST. Furthermore, the flight segment communicates with the radio frequency ground station using its onboard HBRF terminal. Either way, a ground station that provides a trunkline (radio frequency or optical) uses its UMS to function as the User MOC. If both optical and radio frequency links are used simultaneously, the UMS at both stations will be coordinated to meet the experiment's requirements.

This experiment configuration is designed to support multiple scenarios. For instance, it can be used to show that an optical relay using optical links could support a user spacecraft with specific characteristics, like a science mission requiring a particular daily volume, by configuring OGS-1 subsystems to simulate that user's data. In that case, an optical trunkline between an optical space terminal and OGS-2 could demonstrate whether required data volumes can be achieved in a given time period. To make the experiment more realistic, the contact schedule would be based on the mission's expected orbit, and could be altered based on weather conditions that would create contact outages and limited space relay availability due to other users requiring support.

The configuration described can also support an experiment testing LCRD's capability to adhere to real-time data delivery requirements: Real-time user data required could be transmitted to/from Earth using an RF link, while the rest of the data could be transmitted using an optical trunkline.

Furthermore, relay users can test their space- or ground-based optical communications systems to determine LCRD compatibility. In this case, an OGS would simulate the user, while one OST communicates directly with the user system (not depicted in the configuration above).

## **The Proposal Process**

The LCRD Guest Experimenters program is available to potential experimenters from academia, government, industry and abroad. NASA can support experiments involving proprietary data as necessary.

Potential experiment proposers can find details about proposal requirements and the proposal process at [lcrd.gsfc.nasa.gov](http://lcrd.gsfc.nasa.gov). The LCRD team is available to translate experiment goals into a proposal that could be supported by LCRD's capabilities.

Experimenters whose proposals have been accepted will work with designated LCRD experiment coordinators to refine the proposal and determine all requirements. The coordinators will also work with the experimenters to develop a schedule of experiment activities. NASA will give experimenters data related to the experiment, as was specified in the proposal, once the experiment is complete.

## Conclusion

The experiment configurations and architecture descriptions described in this paper are broad overviews of LCRD's capabilities. For more details about any of the information mentioned above, refer to the LCRD Introduction for Experimenters document at [lcrd.gsfc.nasa.gov](http://lcrd.gsfc.nasa.gov), or contact LCRD Principal Investigator Dave Israel at [david.j.israel@nasa.gov](mailto:david.j.israel@nasa.gov).

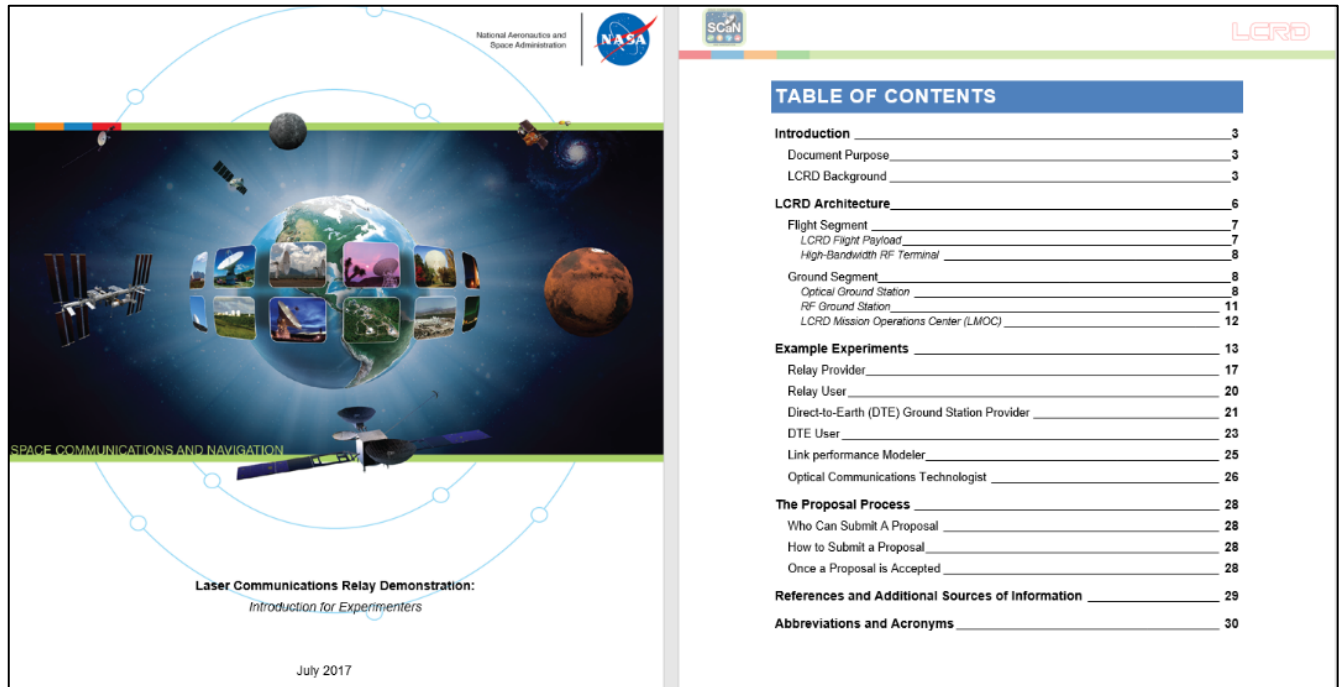


Figure 4. Cover and Table of Contents of the "Laser Communications Relay Demonstration: Introduction for Experimenters" Document

## References

- 1 "Laser Communications Relay Demonstration Introduction for Experimenters." Exploration and Space Communications Division, NASA. <https://esc.gsfc.nasa.gov/media/413>.
- 2 Israel, David J. "Considerations for an Earth Relay Satellite with RF and Optical Trunklines." American Institute of Aeronautics and Astronautics, *34th AIAA International Communications Satellite Systems Conference, Cleveland, Ohio*, 17 Oct. 2016. [ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160012468.pdf](https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160012468.pdf).
- 3 Israel, David J., et al. "Laser Communications Relay Demonstration (LCRD) Update and the Path towards Optical Relay Operations." Institute of Electrical and Electronics Engineers, *2017 IEEE Aerospace Conference, Big Sky, Montana*, 4 Mar. 2017, [ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170002019.pdf](https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170002019.pdf).
- 4 Laser Communications Relay Demonstration Homepage. NASA. <https://lcrd.gsfc.nasa.gov/>.><https://esc.gsfc.nasa.gov/node/100>.
- 5 SCA Homepage. NASA. <https://www.nasa.gov/directorates/heo/scan/index.html>.
- 6 Space Technology Mission Directorate Technology Demonstration Missions Website: Laser Communications Relay Demonstration (LCRD). NASA. [https://www.nasa.gov/mission\\_pages/tdm/lcrd/index.html](https://www.nasa.gov/mission_pages/tdm/lcrd/index.html).