Assessment of Free-Space Lasercomm For DOD's T&E Applications

H. Hemmati, J. Charles, and S. Piazzolla
Jet Propulsion Laboratory
4800 Oak Grove Dr. 161-135
Pasadena, CA 91109
hamid.hemmati@jpl.nasa.gov

ABSTRACT

For test and evaluation of airplanes, it is desirable to telemeter large volumes of data to the ground. This telemetry has generally utilized RF communication systems, which have relatively low data rates, and, due to limited spectrum availability, imposes limitations on the number of simultaneous communications in a given region. Appropriate application of optical communication technology is expected to provide higher data rate capability without the spectrum limitations of RF systems, facilitating simultaneous telemetry of more data from a greater number of aircraft. This paper reviews our recent brief study to assess the insertion of free space lasercom to DOD Test and Evaluation applications.

INTRODUCTION

We studied the applicability of free-space optical communications to telemetry downlink challenges for DOD Test and Evaluation flights (T&E). One such challenge is that aircraft flight-testing is often restricted to a few users on a given day due to the limited frequency bandwidth available. Flight-testing of advanced avionics system requires enhanced data-rates that are not supportable with current capabilities. To identify the proposed solutions, JPL conducted a trade study to identify the application of an Optical Communication System to aeronautical platforms. As an outcome, the study provided a design for a lasercomm system that will support Aeronautical Testing. Several technical issues were addressed in order to propose solutions that maximize overall system performance.

Objectives of the study were to determine the DOD T&E applications (and what range conditions) in which laser communications technology be effectively utilized, and to quantify the potential benefits to:

* Provide high bandwidth telemetry from airborne and space-borne sensors, instruments, and platforms under test.
* Alleviate issues associated with restricted spectrum allocation limitations given the anticipated increasing need for wider bandwidth test telemetry data links, via Optical Communication data-rate enhancement by at least an order of magnitude.

Figure (1) pictorially shows the downlink from the plane and the uplink beam from the ground terminal to the plane.

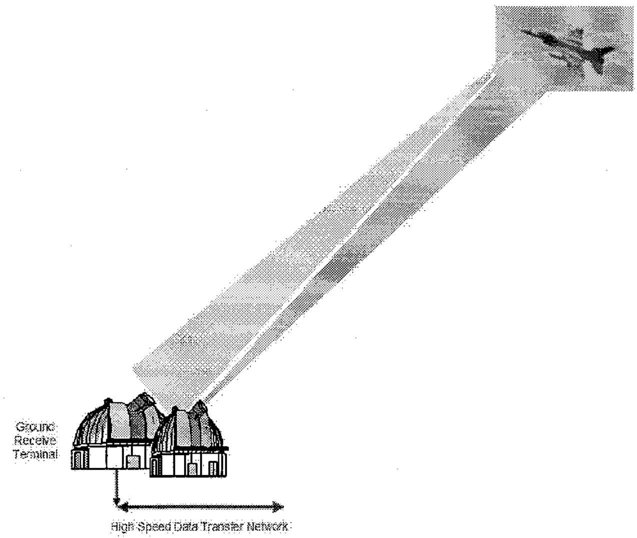

Figure 1. A cartoon of the optical link to ground

REQUIREMENTS:

These high level requirements for the link include:

Maximum range from airborne platform to ground receiver:

> 450 km for low data rate, experimental links

> 100 km for the store and burst transmit mode; rates ≥100 Mega-bits/sec (Mbps)

Telemetry data-rate:

> 0.1 Gbps (downlink only)

> 10 Mbps for long range and experimental links

Link availability:

The minimum requirement is that the total volume of data optically communicated throughout a given test flight will average at least the same data volume that could be communicated on the same flight with the existing RF downlink. The maximum data rate of the current RF system is 12Mbps, so a 100Mbps optical system would have to be available for at least 12% of the total flight time to meet the requirements.

Elevation angle to air platform:

Near horizontal link (close to and as low as 0°)

If ground terminal is elevated (on a tower, hill, mountain, or air platform, some experimental links may have a slight negative elevation angle

Aircraft platforms:

We examined a number of aircrafts including: the DC-8 and F-15, F-18 were examined for several characteristics, including vibration, while the B1-B, C-12, F-16, F-22, KC-135, and two UAVs were evaluated only for transmitter placement and tracking rates option because sufficient timely vibration characteristics were not available.

IMPLEMENTTAION CHALLENGES

The following is a list of major issues that were studied:

- Atmospheric turbulence effects on the downlink beam and its contribution to limiting the communication range
- Atmospheric absorption and scattering for the near-horizontal link
- Background light at low elevation angles
- Laser beam pointing and limits of beam-divergence leaving the transmitter
- Eye-safety on the ground.

SUMMARY OF ANALYSIS
Analysis performed in the study provided additional information about optical link performance drivers, and defined a general range of conditions in which a successful optical link would be possible. For example, it is anticipated that high bandwidth (>100 Mbps) optical communication links exceeding 240 Km are possible (at least under favorable conditions), assuming the communicating aircraft is at sufficient altitude to achieve a reliable line of sight.

Range for air-to-ground link is limited primarily by atmospheric absorption and scattering. Heavy fog and dust storm would be most troublesome, but are not expected to occur frequently in anticipated demonstration regions. To address link interruptions potentially caused by these and other factors, the high data rate of the optical communication system would be used for high rate burst communications while the optical link is established.

The maximum range is driven in large part by elevation angle, local geography, and earth curvature. Therefore, greater range is typically achievable from a higher flight altitude. Maximum range is also driven by transmitter beam-width. Analysis indicates that a data-rate in the gigabit per second regime is possible, when a transmitter having 200-urad beam width is used in conjunction with and a high altitude receiver (e.g. an airborne receiver at ~ 6km altitude).

Atmospheric scintillation has a significant influence on optical links. The aperture averaging phenomenon very effectively mitigates the atmospheric scintillation effects encountered in near-horizontal links encountered here, reducing the need for multi-beam transmission or adaptive optics.

Simple moderate data rate optical terminals having moderate beam divergence angles (several mrad but still sub-degree) may utilize GPS and Inertial Navigation Sensor-assisted beam pointing in conjunction with high laser transmit power to satisfy most requirements on beam-pointing, except during heavy aircraft maneuvers.

SUMMARY OF STUDY CONCLUSIONS:

Optical Communication will provide spectrum relief for telemetry from Department of Defense (DOD) Test and Evaluation (T&E) flights.
Optical Comm is also capable of providing substantially faster data rates than current radio frequency telemetry systems. Several aspects of T&E operations were considered

in this study, the purpose of which is to assess feasibility of free-space Lasercom to DOD T&E applications.

The study concluded that Optical Communication technology is suitable to most DOD T&E scenarios and is applicable to majority of airplanes. Given a minimum data-rate of 100 Mbps and 15 km altitude for the plane, ranges exceeding 240 km are possible at low elevation angles with a variety of host platforms.

Data-rates exceeding 1 Gbps are possible for air-to-ground link, with a transmitter capable of narrow-beam pointing and a receiver located at a high altitude (particularly a balloon borne RCVR at > 6 km altitude).

POINTING AND TRACKING, PHYSICAL LINK RANGE LIMITATIONS

The optical link range is influenced by a number of factors other than turbulence. These other factors include obstructions by the earth, due to curvature or local features such as mountains or bluffs. For a long-range link, even a low obstruction near the link path perigee point (illustrated below) can significantly influence the link range. In addition, the effects of turbulence in the link path perigee regime can be more problematic than turbulence near the ground receive terminal, due in large part to the distance that can exist between the link path perigee point and the receiver.

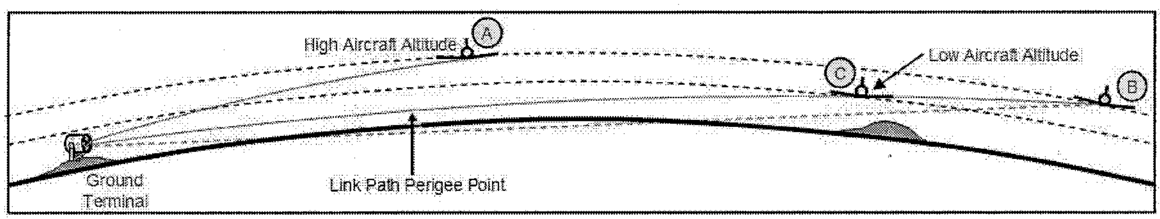

Figure 2. Illustration of the Link Path Perigee Pont for a Long range optical Link. For shorter links, the perigee point is usually right at the receiver.

Maximum link range is driven in large part by minimum elevation angle (A vs. B). Greater range is typically achievable from a higher flight altitude (B vs. C). For airplane-to-ground downlinks studied here, ranges up to 240 km are possible.

Figure (3) shows the additional line of sight visibility that can be gained when the receiver terminal (whether it is on a mountain or an air platform) is located at a higher elevation than the surrounding ground. The higher elevation makes it possible for the terminal to have a slightly negative elevation angle and thereby cover additional range around the earth's curvature. The link path is then lowest at a point (referred to here as a perigee point) that is between the terminals, where the path is tangent with the local curvature of the earth. It is important to note that theoretically having the line of sight shown on the graph does not necessarily mean that the link can be closed. This is because atmospheric conditions, particularly in the region of the perigee point, can attenuate and scatter the optical signal. The graph above assumes that the ground between the transmitter and receiver is at sea level, and does not account for atmospheric refraction. In reality, atmospheric refraction would increase the line of sight range, while higher ground elevation between the terminals, if near the perigee point, would reduce the line of sight range.

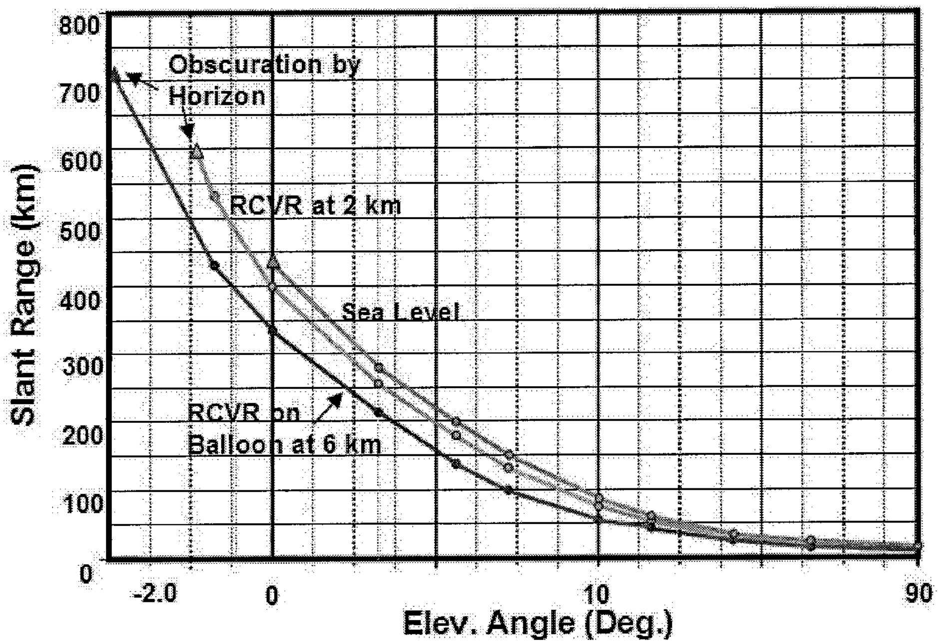

Figure 3. Geometrical slant range as a function of elevation angle for differing receiver station altitudes.

In conclusion, analysis indicated that downlink ranges on the order of a few hundred kilometers at shallow elevation angles and with data-rates of at least 100 Mbps and potentially much higher assuming a 1-meter receiver on the ground.

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