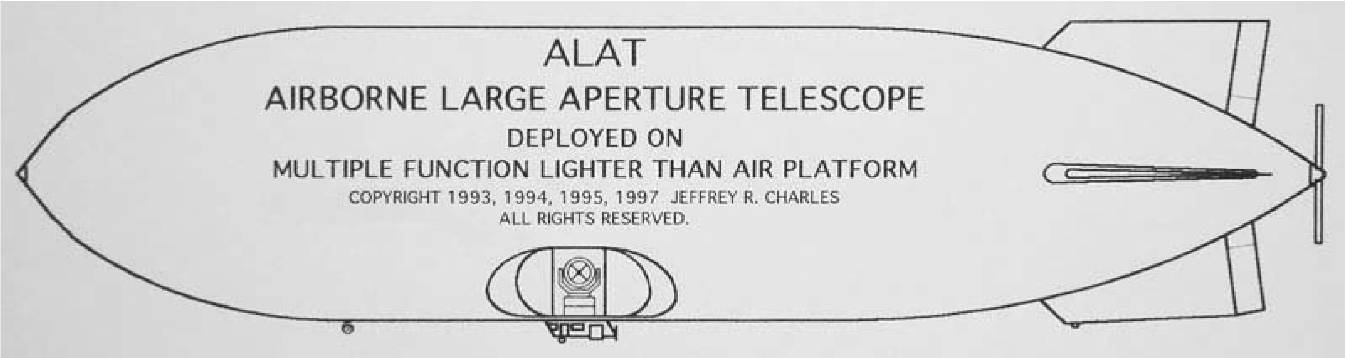
ALAT
Airborne Large Aperture Telescope



Jeffrey R. Charles

Document converted to HTML on June 12, 1996.
Published (sans drawings) on versacorp.com web site in 1996.
Drawing figures (most of which were published in 1995) posted on web in 2003.
1997 updates to proposed designs and minor updates about status of other platforms posted in 2003.

Airborne Large Aperture Telescope (ALAT)

Instrumentation and applications relating to an airborne large aperture telescope which is envisioned to reside on a multiple function lighter than air platform, as presented at the JPL Advanced Concepts Program Mini conference for "Innovative Space Mission Applications for Thin Films and Fabrics" on May 8, 1995 and published in the proceedings. ALAT was first presented as part of my ARDOC (Airborne Relay for Deep-Space Optical Communication) presentation at JPL's "Seminar 331" on December 8, 1993. Some data from the earlier presentation has been added to this file. Even though this material was presented at JPL and subsequently proposed for JPL/NASA Project(s), it was all conceived and developed with my own time and resources, with some being conceived and developed during years I was not working at JPL..

Contents:

ALAT

Airborne Large Aperture Telescope

ABSTRACT

A multiple function telescope for astronomical observation and other applications, residing on a multiple function lighter than air platform which is also suitable for:

ARDOC - Airborne Relay for Deep-Space Optical Communication
STRATOCOM (TM) - Stratospheric Observation and Communication
HOST - High Precision Orbital Debris and Satellite Tracking
HIAA - High Resolution Imaging and Astrometry of Asteroids
Instrumentation and applications to be proposed for JPL/NASA Project(s)

Investigator: Jeffrey R. Charles

Abstract for ALAT & Related Concepts:

A multiple function lighter than air robotic platform which is capable of residing in the lower stratosphere for an extended period of time would be an elegant solution for a variety of long standing research and communications problems. Such a platform would be invaluable to the continued pursuit of many disciplines, including astrophysics, high resolution imaging and ranging of satellites and orbital debris, air and space communications utilizing weather dependent frequencies (including optical), atmospheric research, commercial broadcasting, cellular communications, regional position information (including "smart maps" for automobiles), and surveillance. The platform can house inflatable structures which would serve both as ballonets and as reflectors for power collection, communications, and radio astronomy. Additionally, the platform could be used for educational payloads and as a high altitude test bed for materials and instrumentation.

The Airborne Large Aperture Telescope (ALAT) is envisioned to be a multiple function optical telescope (or series of telescopes) which will reside on a high altitude lighter than air robotic platform. The large aperture (~2-3 m) of the telescope and the altitudes at which it operates (~16-22 km) will allow it to perform nearly as well as a space based telescope, yet have many additional advantages, including lower cost, accessibility for maintenance & upgrading, the ability to perform long integrations over a large portion of the sky, and mobility to facilitate strategic positioning for specific events such as eclipses, occultations, or communications. ALAT is the cost effective way to provide the high performance telescopes required for expanded research on a global scale.

Thin Film / Fabric Structural Material Application Concept Summary

Objectives:

- Reliable communication and astronomical observation in "weather dependent" frequencies (including optical) at a lower cost than space telescopes or space antennas.
- Maintenance of long duration (or continuous) observation capability; a single deployment will facilitate many observations.
- Transportability of large instruments for observations of localized events such as solar eclipses or grazing occultations.
- Low cost per function by integrating multiple scientific and commercial payloads on one platform.

Benefits of a Multiple Function LTA Platform:

MULTIPLE FUNCTIONS = LESS COST PER FUNCTION, ENABLING MORE CUSTOMERS TO AFFORD TO IMPLEMENT THEIR PROGRAMS, SUCH AS:

- Astronomical observation, benefiting astrophysics.
- Optical space communication relay (ARDOC) benefiting space missions, military.
- High resolution imaging/ranging of satellites & debris, benefiting space missions and the military.
- High altitude atmospheric & environmental observation, benefiting everyone.
- Optical and other surveillance, benefiting the police, DEA, military.
- Forestry, mapping, etc., benefiting civil development and the environment.
- Security of optical transmissions, benefiting the police and military.
- Public cellular communications, benefiting everyone.
- Public broadcasting, benefiting everyone.
- Deep space RF applications (using inflatable communication & observation reflectors) benefiting astrophysics (space missions & radio astronomy).
- Beamed power development and use, benefiting communications, scientific research, and travel.
- Regional position reference (smart maps, etc.) benefiting motorists, police.

Performance Features:

Multiple Function Lighter Than Air Platform;
Why Use a Lighter Than Air Platform?

- Deployable at 0~23 km altitude, but usually deployed at 16~21 km altitude (depending on latitude and other conditions).
  - Above most clouds and turbulence.
  - Less power (~75 kW SHP in lowest 98.5% winds) required to maintain station at ~21 km due to lower average wind speed.
- Does not require continuous motive power to remain airborne; can stay up for weeks; longer than an airplane.
- Less vibration than an airplane.
- Low air speed:
  - Reduces boundary layer effects on payload.
  - Eliminates need to fully enclose telescope.
  - Facilitates larger aperture and greater sky coverage
- Airship hull can serve as or house an inflatable antenna and/or solar/beamed power reflector = large reflector size at less cost.
- Platform potentially has larger payload capacity than an airplane, allowing it and its instrumentation to be used for multiple applications: Atmospheric observation, environmental study, mapping, surveillance, deep space communications, domestic communications, broadcasting, etc. = less cost per function and a wider range of customers.
- Large size and potentially continuous presence = public visibility.

Performance Features:
Why an Airship Instead of a Conventional Balloon?

- Reliable recovery of payload and lifting gas = less risk and lower long-term cost.
- Ability to maintain constant position in spite of prevailing wind simplifies command and data transmission, facilitates arraying, and allows use for commercial broadcasting & communications, atmospheric study, surveillance, and other applications.
- Ability to maintain constant attitude facilitates extended observations and simplifies tracking routines.
- Transportable and controllable - can be deployed at a specific time and place for observations of rare events.
- Storage and rapid deployment from existing airship hangars - payloads can remain relatively undisturbed between missions.
- Not subject to limitations of a tether. Platform is free to drift during observations or to maintain a specified station.

Performance Features:
Airborne Large Aperture Telescope

- Unaffected by most cloud cover - one airborne telescope can have the same availability as multiple ground stations.
- Facilitates serious astronomical observation from nearly anywhere in the world regardless of weather conditions.
- Perpetual good "seeing" at altitude = high resolution
- Reduced effects from atmospheric scattering, absorption and emission, particulates, moonlight, and man made light sources.
- Potential for night and day observation = better utilization
- Provides many of the observational advantages of a space telescope, yet is less expensive and is accessible for servicing and upgrading.
- Facilitates airborne optical communication research and development.
- Large aperture facilitates use as an airborne relay for deep space optical communication (ARDOC).
- Fewer real and perceived environmental issues and related legal delays than ground based stations.

Airborne Large Aperture Telescope (ALAT)

Performance Features:

Airborne Large Aperture Telescope & LTA Platform; Combined Performance Features & Specifications

- Platform dimensions for existing hangars & reasonable drag coefficient: Diameter = 40 meters; length = 182 meters; total volume = 170,000 cubic meters; available lifting gas volume = 165,000 cubic meters; total lift @ sea level = 154 metric tons.
- Preliminary mass properties estimates (metric tons):
  Composite structure & rigging=7; envelope > 4; ballonets=1; primary propulsion=3; secondary propulsion=0.5; power generation=3; flight management & avionics=0.3; two telescopes=3; telescope and T&C instrumentation with environmental control=1.1. Total = 22.9
  The probable ceiling for the specified platform and proposed payload if built with existing technology will probably be at ~0.15 density, or ~16 km altitude. This altitude in the upper tropopause is below most of the equatorial ozone concentration, but it is also below some cirrus clouds and the turbulence ceiling of powerful storms. This will impose certain restrictions:
  - The mid-latitude jet stream (i.e. polar front jet stream) will have to be avoided, limiting long term platform deployment to polar regions and/or latitudes within ~35 deg. of the equator.
  - Large equatorial storm systems will have to be avoided.
- It is preferable to deploy ALAT in the lower stratosphere (20-23 km altitude) anywhere in the world. This is above convection and nearly all types of clouds. A ceiling of ~23 km (for reliable use at 20~22 km) is the goal which should ultimately be achieved. This presents additional challenges:
  - Rarefied air and corrosive chemicals at high altitude increase cost of achieving a higher ceiling.
  - Lifting gas volume / platform ratio will have to be increased; for the same payload mass, total platform volume may have to be increased ~250% over that shown above. Payload and support structure mass is critical.
  - Noctilucent clouds can still influence observations.
  - Plasma events above storms may be observed from the platform, but their influence on the platform and its payloads is largely unknown.
- Preliminary mass properties estimates for additional functions when integrated into ALAT and its platform:
  - Airborne Relay for Deep-Space Optical Communication (ARDOC)=0.3; High Precision Imaging & Ranging of Satellite & Orbital Debris Tracking (HOST)=0.1; high altitude atmospheric & environmental observation=0.3; optical and other surveillance (0.75m aperture)=0.5; forestry & mapping=0.1; secure air-ground optical communications=0.2; public cellular communications (STRATOCOM (TM))=0.4; public television and other broadcasting=0.3; deep-space RF communications with inflatable reflectors > 0.5; beamed power development & use=0.6; regional position reference (smart maps, etc.)=0.2. Overall mass is several tons lighter if airship is tethered or if telescope suspended under it.

Airborne Large Aperture Telescope (ALAT)

Thin Film / Fabric Structural Material Application Concept Summary:

Design Characteristics

- Manufacture and storage in existing airship hangars will substantially reduce cost but will limit platform size and payload capacity.
- Non rigid or semi rigid airship with composite payload support structure which may include a partial keel.
- Remote control & programmable robotic operation at high altitude, pilotable at low altitude.
- Multiple internal gas bags and ballonets for trim and altitude control.
- Lift from helium. In-flight renewal of helium from other vehicles is being considered, as is supplemental lift from hydrogen in external balloons or isolated internal gas bags. Beamed power can be used to electrolyze condensed or stored water.
- Inflatable structures inside hull can serve as antenna reflectors, solar and beamed power concentrators. Concepts such as using rigging and an outer protective envelope to prevent surface deformation and provide tension and stability are applicable to "stand alone" inflatable structures.
- Telescopes probably mounted on platform structure under protective covers; deployable telescope array structures and arrayable platforms have been considered.
- Primary propulsion at rear to preserve laminar flow; some vectored thrust available near instrumentation gondola below envelope. Primary propulsion will almost certainly be from electric motors. Solar and / or beamed power may be used if missions are long. Limited propulsion provided by a "conventional" high altitude engine. Steam power is being considered due to low boiling point of water at high altitude.

Thin Film / Fabric Structural Material Application Concept Summary, continued:

Environment Description:

- **Launch**
  - Ground level winds pose risk, especially near hangar.
  - Air pollution can potentially damage platform, etc, while in storage.
- **Ascent**
  - Jet stream will carry the platform downwind during ascent, it must then fly to its intended station
  - Temperature extremes during ascent can range from ~45 deg. C to -85 deg. C.
- **Use conditions on station**
  - Ozone, volcanic material, and other corrosive or eroding elements @ 21 km (or at lower altitudes if platform deployed near the poles)
  - Direct and reflected UV
  - Low ambient temperatures and daily thermal cycling
  - Station keeping against wind requires power - site selection is important, particularly if platform is deployed at lower altitudes.
- **Typical mission duration: ~1-9 weeks. Operational lifetime: ~20 years.**

Major Structural / Material / System Challenges

Design:

- Development of a *suitable* LTA platform that will withstand the ~20:1 change in atmospheric pressure (~12:1 if deployed from the South American altiplano) that would be encountered during ascent to ~21 km.
- Optimization of telescope and platform to ameliorate boundary layer and thermal effects on "seeing" and platform performance.
- Optimization of platform for long endurance flight; integration of beamed power systems; provision for adequate shielding of other systems.
- Minimizing altitude change due to day/night temperature change.
- Minimizing mass of platform, telescope and mirror.
- Integration of platform control, payload tracking routines, GPS, and DGPS.
- Determination of appropriate emphasis on LTA platforms and payload capability (i.e. quantify feasibility; identify and prioritize "customers" and their payload requirements; determine the optimum quantity and location of platforms and control stations required to better satisfy current and future commercial and research needs).
- Determination of optimum deployment altitudes and latitudes.
- Ground launch and recovery site selection based on existing infrastructure, fiscal and mission requirements, and political stability.

Major Structural / Material / System Challenges

Materials:

- Minimizing mass of platform (optimizing material mass/strength ratio).
- Selection of materials and techniques to minimize long term effects of high altitude atmospheric chemistry (ozone, etc.) and erosion on various platform and payload materials; particularly the telescope mirror coatings. Possible mirror coatings include Rhodium or Gold.
- Long term resistance to direct and reflected UV.
- Retention or renewal of lifting gas (minimizing permeability to Helium).
- Minimizing deformation of inflatable reflectors.
- Resistance to effects of low temperatures and thermal cycling

Major Structural / Material / System Challenges

Demonstration, phase 1:

- Ground based demonstration & materials testing
- Research activities: Feasibility study, material & design studies, weather studies, thorough documentation, definition of phase 2, phase 2 implementation plan.
- Demonstration activities: Acquisition of two or more small (~20 cm aperture) telescopes, testing and demonstration of telescope imaging, tracking, & communication routines, concurrent with materials testing and the development of flight management, telemetry & command, & other subsystems.
- Ground based demonstration: 20 cm aperture demonstration system testing and imaging of astronomical and terrestrial objects and satellites, followed by reflecting laser pulses off of a suitable satellite and detecting & verifying the returns; then repeating the above experiments with the telescope and its mounting positioned on actuators that will simulate the motion of an aircraft.
- Physical testing of design and materials: Design, construction, and testing of a full scale lightweight composite 2.5~3 meter telescope and mounting (sans optics) with all pointing controls and actuators. Testing assisted by small mirrors and lasers. Operating this mounting on a proper test bed in windy conditions should identify many problems and facilitate their solution. (Construction of full size mounting could be deferred to a later phase).
- Long term chemical testing: Includes testing of mirror coatings and other materials for erosion and oxidation in a quasi-wind tunnel with an ozone environment.

Airborne Large Aperture Telescope (ALAT)

Major Structural / Material / System Challenges

Demonstration, phase 2:

- Limited airborne demonstration
- Research activities: Advanced feasibility studies, detailed weather studies and materials analysis, identification and analysis of major challenges, identification and prioritization of customers and their requirements, mission definition, frequency allocation, conceptual system design, site selection, identification of probable suppliers & industry partners, cost estimates, phased prototype implementation plan.
- Demonstration activities: Use an existing well maintained blimp at ~2 km altitude. A blimp better simulates many anticipated high altitude LTA platform conditions and offers many of the same advantages, such as long flight duration and a low air speed which will facilitate "outside" deployment of the telescopes. The demonstration will ultimately involve imaging of astronomical and terrestrial objects from an airborne platform. Satellite tracking with both telescopes will follow, one goal being to facilitate uninterrupted tracking (i.e. a smooth transition between telescopes) when possible. A simplified air-space optical communication demonstration may be possible by repeating the laser demo.
- Airborne demonstration instrumentation: 2 small (20 cm 50%) aperture tracking telescopes equipped for imaging and collimated ~532 nm to 2000 nm laser projection will be mounted below and to either side of the blimp envelope.
- Comments: The blimp demonstration will allow the development of mission and control hardware, software, and procedures; but will not subject the hardware to the degree of ozone, etc., and low temperature that will be encountered at 16~21 km. Extrapolating from small scale low altitude demonstration data will not address many issues including platform resonance and maintenance of an accurate mirror figure. An additional phase could include the building and testing of a small high altitude LTA platform for two or more ~20 cm +/- 50% aperture telescopes.

Airborne Large Aperture Telescope (ALAT)

Major Structural / Material / System Challenges

High Resolution Imaging and Air to Retroreflector Satellite Demonstration Hardware:

- **20 cm +/- 50% aperture tracking telescope with a steering mirror or an equivalent means of high frequency precision pointing. Telescope also equipped for imaging and collimated ~532 nm to 2000 nm optical communication laser projection & reception. (Twin synchronized telescopes if budget permits).**
  - Primary mirror = F/1.5; Cassegrain focus = F/13; Secondary obstruction = 18% of diameter.
  - Focusing telecompressor = 0.8x to 0.95x
  - Wide field imaging telecompressor = 0.25x
  - Fields of view = 0.04 deg. & 0.3 deg; 5 deg. & 50 deg. with attached video finders.
  - Mounting = 3 Axis. Azimuth = 1020 deg. travel; Elevation = 240 deg. travel; Cross axis = 60 deg. travel. This mounting configuration will allow the telescopes to maintain a satellite track regardless of the airborne platform orientation.
- **Telemetry and command links.**
- **On board memory and dedicated air to ground RF links for payload.**
- **Possible low to medium altitude platforms:**
  - Kuiper airborne observatory - includes telescope. (Remarks: Kuiper subsequently out of service.)
  - SOFIA Airborne Telescope – includes 2.5 meter telescope (In 03, deployment scheduled for 2006)
  - Existing blimps – telescope(s) probably below and to side of envelope. This is the most likely demonstration platform because it better simulates anticipated LTA platform conditions and offers many of the same advantages, such as long flight duration and a low air speed which allows "outside" deployment of the telescopes.
- **High Altitude Platforms:**
  - SR-71 Aircraft - Reliable recovery but limited sky coverage & greater expense.
  - Balloons - Good sky coverage but higher risk to payload and subject to spinning.

Major Structural / Material / System Challenges

Simplified Experimental Imaging, Tracking, and Optical Communication Demonstration:

- The demonstration will ultimately involve imaging of astronomical and terrestrial objects with small telescopes from an airborne platform. To demonstrate feasibility of an airborne relay for deep-space optical communication, or ARDOC, satellite tracking and a simplified air-space optical communication demonstration will follow. Active space borne optical communication systems are not readily available; therefore, a passive space borne retroreflector (such as that on Lageos) will be utilized for the near term. As necessary studies are completed and a platform has been selected that is compatible with fiscal and mission requirements, it is envisioned that a small scale system test would progress as follows:
- Acquisition of telescope, instrumentation, and software.
- Ground testing of telescope imaging, tracking, and communication routines involving imaging of astronomical and terrestrial objects; concurrent with platform flight management and RF link development.
- Ground based satellite tracking and system testing, followed by laser pulses off of a suitable satellite and detecting and verifying the returns.
- Repeat the above experiments with the telescope and its mounting positioned on actuators that simulate the motion of an aircraft.
- Repeat the above experiments with the telescope and its mounting temporarily installed in a suitable aircraft. Additional activities could include imaging of planets, satellites, and terrestrial objects from the platform for public relations, possibly during network coverage of sporting events from the same LTA platform if lifting capacity permits.
- Repeat the above experiments with the telescope interfaced to an RF relay, memory, etc., in the aircraft. Originate RF transmissions or pulses from the ground, optically re-transmit the information to an orbiting retroreflector, optically receive the reflected information, then re-transmit it to the ground with the RF link & verify accuracy.

Airborne Large Aperture Telescope (ALAT)

Proposed Payloads and their Locations on the Actual Multiple Function ALAT Platform:

- **3 TO 3.5 METER TELESCOPE(S) (On top, lower sides, or on a controllable array assembly which can be rotated to protect telescopes).**
  - Primary Mirror = F/1.0; Cassegrain Focus = F/15.
  - Focusing Telecompressor = 0.6x to 0.8x.
  - Wide Field Imaging Telecompressor = 0.2x.
  - Fields of View = 0.016 deg. & 0.08 deg. with 12 mm CCDs.
  - Field Acquisition Fields of View = 50 deg., 4 deg., & 0.3 deg.
  - Mounting = Altitude / Azimuth with Optional 3rd Cross Axis.
  - Used for observation, surveillance, tracking, ranging, & deep-space optical communication.
- **20 CM CORONAGRAPH**
  - Enhanced by nearby deployment of an optional small opaque robotic LTA device to create an artificial "eclipse" (should be effective at ~21 km altitude).
- **0.5 to 0.75 meter air to air & air to ground OPTICAL COMMUNICATION & SURVEILLANCE TELESCOPE (Below middle front).**
  - Can theoretically resolve license plate numbers from up to 40 km.
  - Primary Mirror = f/1.0 to f/2.0; Cassegrain Focus = f/6 to f/15.
  - Mounting = Inverted Alt/Azimuth with Optional 3rd Cross Axis.
- **RF RELAY TRANSCEIVER** (Below center or inside)
- **DEEP SPACE COMMUNICATION AND OTHER ANTENNA(S)**
  In addition to utilizing conventional antennas, sections of the airship hull can serve as inflatable antenna reflectors or the hull can enclose inflatable antennas nearly as large as its diameter. This will shield them from deformation by the wind and other forces. Steerable feed allows antenna pointing without changing platform orientation. Uses include communications, radio astronomy, and orbital object imaging/ranging. Concept can also be applied as a means to concentrate beamed power in order to permit use of a smaller and lighter beamed power collector (rectenna).
- **BEAMED POWER** (Below or inside middle front or rear of platform).
- **CELLULAR TELEPHONE, BROADCASTING**
- **REGIONAL POSITION REFERENCE** (and automobile, etc. tracking sensors)

Airborne Large Aperture Telescope (ALAT)

Disadvantages of a Large Lighter Than Air “Airship" Platform:

- Requires large structure for fabrication, maintenance & storage
- Vulnerability to surface winds and jet stream related turbulence
- Platform development and fabrication cost.
- Lightweight payload development cost.
- Power or tether required to maintain platform altitude & location
- Requires FAA and FCC clearances.
- Platform motion complicates pointing and tracking routines.
- Atmospheric effects at 16~21 km can influence some aspects of payload performance.

What Else is Being Done or Proposed Now (1995)?

- Ground based optical telescopes - subject to cloud cover.
- Proposed ground based optical communication network - subject to cloud cover
- Kuiper airborne observatory - medium aperture, lower altitude, short time aloft.
- Proposed SOFIA 2.5 meter telescope in a 747 - less time aloft than an airship.
- Proposed microwave powered airplanes (JPL, Canada) - low payload capacity.
- Air force air to satellite O.C.D. - medium aperture, limited range.
- Proposed Polar Stratospheric Telescope (POST) - tethered @ ~30K', limited to deployment near polar regions.
- HALROP (proposed Japanese solar powered airship) - a platform that may be adaptable to ALAT.
- Balloon and rocket borne telescopes - short time aloft, stabilization difficult.
- Hubble space telescope - expensive, difficult to service.
- Proposed deep space optical communication relay satellite(s) - expensive.
- Various other proposed inflatable antennas and structures. (Most are for space missions).

Airborne Large Aperture Telescope (ALAT)

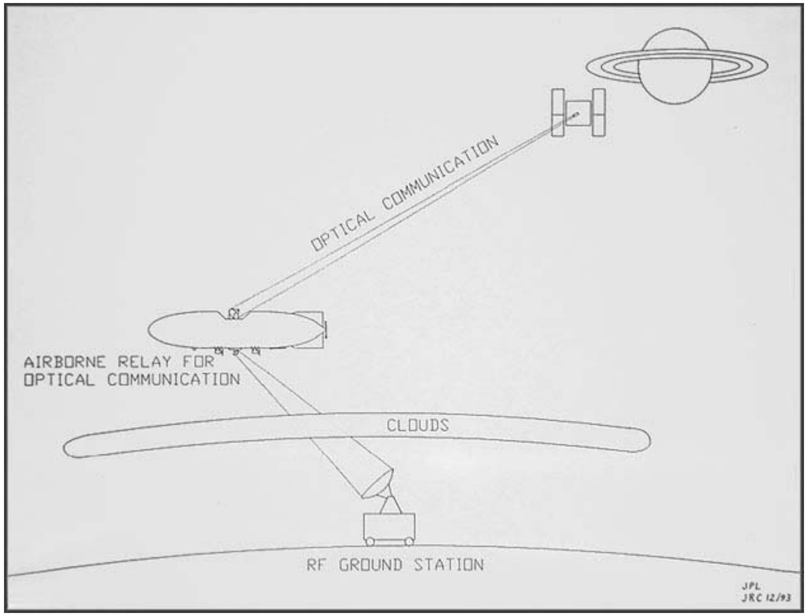
Additional "Spin-off" Technology and Applications:

- Long endurance lighter than air platform research.
- Test bed for inflatable structure research and development.
- Test bed for high altitude instruments, power plants, propulsion.
- Platform and telescope mounting can be used to facilitate other temporary or permanent scientific and commercial payloads.
- Inflatable structure concepts applicable to ground, air, and space based structures. Small to very large (>100 meter) precision inflatable antennas with lifting gas assisted adaptive surfaces can be deployed at various altitudes in the atmosphere or under inflatable covers at terrestrial sites. The antenna weight is supported mostly by lifting gas. Under some conditions, liquid (such as water) can be used to assist in positioning the antenna. In the case of terrestrial sites, liquid can also be used for partial support, particularly if the antenna is surrounded by a nearly spherical outer envelope.
- Steerable antenna feed concepts can be applied to rigid fixed dish antennas of either wide or limited scan range.

ARDOC

Airborne Relay for Deep-Space Optical Communication

Presented at JPL Seminar 331 on December 8, 1993



Investigator:

Jeffrey R. Charles

Most related drawing figures are combined with those of a subsequent ALAT presentation.

ARDOC

Airborne Relay for Deep-Space Optical Communication

Abstract:

Airborne Large Aperture Multiple Function Telescope having means to perform reliable two way optical communication with satellites and exploratory spacecraft. Data from optical communication is stored on board the airborne telescope platform and relayed to a ground station in an appropriate RF band.

ALAT and ARDOC Introduction (from Draft 4, 1993)

ALAT – Airborne Large Aperture Telescope
A multiple function telescope for astronomical observation and other applications including:
ARDOC – Airborne Relay for Deep-Space Optical Communication
ALAT resides on a multiple function lighter than air platform which is also suitable for:
Stratcom – Stratospheric Observation and Communication

Investigator: Jeffrey R. Charles

Introduction: A Controllable airborne lighter than air platform which is capable of residing in the lower stratosphere for an extended period of time would be an elegant solution for a variety of long standing research and communications problems. Such a platform would be invaluable to the continued pursuit of many disciplines, including astrophysics, high resolution imaging of satellites, air and space communications utilizing high frequencies affected by weather (including optical communications), atmospheric research, commercial broadcasting, cellular communications, regional position information (including “smart maps” for automobiles), and surveillance.

The Airborne Large Aperture Telescope (ALAT) is a multiple function telescope (or series of telescopes) which will reside on a high altitude lighter than air robotic platform. The large aperture (~2-3 m) of the telescope and the altitude at which it operates (~16-22 km) allows it to perform nearly as well as a space based telescope, yet have many additional advantages, including lower cost, accessibility for maintenance and upgrading, the ability to perform longer integrations over a large portion of the sky, and the ability to be positioned for specific events such as eclipses, occultations, or optical communications. ALAT is the cost effective way to provide the high performance telescopes required for expanded research on a global scale.

The ARDOC Concept:

Multiple Function High Altitude Lighter Than Air Platform

on which resides a

Large Aperture (3 Meter) Multiple Function Telescope

which is capable of

Astronomical Observation

High Resolution Imaging of Satellites

Deep Space Optical Communication

Typical Applications for Airborne Platform

- Optical Communication
  - *Relayed optical communication with deep space objects (spacecraft)*
  - Direct optical communication with ground (weather permitting) for security
- Scientific
  - Astronomical observation
  - Measurement of high altitude environmental phenomena
  - Characterization of atmosphere for RF communications
- Law Enforcement and Military
  - Surveillance
  - High resolution imaging of satellites
- Public Service
  - Cellular phone service and commercial broadcasting
  - Regional position reference

Types of Airborne Platforms

- Lighter Than Air (LTA)
  - Non-Rigid (e.g. blimp or balloon)
  - Semi rigid
  - Rigid (e.g. dirigible)
- Lifting Body Airship (e.g. lighter than air assisted)
- Low air-speed high altitude airplane
- High air-speed high altitude airplane

Why Lighter Than Air?

- Does not require continuous motive power to remain airborne
- Can stay airborne longer than an airplane - missions can last several weeks - potentially a “permanent” high altitude platform
- Less vibration than an airplane
- Low air speed reduces boundary layer effects in the optical path and reduces aerodynamic stress on payloads outside the aircraft. This eliminates the need to fully enclose the telescope, permitting a larger aperture and greater sky coverage
- Potentially larger payload capacity than an airplane, permitting multiple payloads = less cost to fly each payload
- Large size and potentially continuous presence = public visibility = possibility of selling advertising space to offset costs

Why an Airship Instead of a Conventional Balloon?

- Reliable recovery of payload and helium = less risk and lower long-term cost
- Ability to maintain constant position in spite of prevailing wind simplifies command and data transmission and facilitates use for commercial broadcasting and communications, atmospheric study, surveillance, and other applications.
- Ability to maintain constant attitude facilitates extended astronomical observations and simplifies tracking routines and cable wrap design
- Transportable and controllable - can be deployed at a specific time and place for observations of rare events
- Storage and rapid deployment from existing airship hangars - payloads can remain relatively undisturbed between missions.
- Longer time aloft

Implementation of the Total System - Platform

- Robotic = Unmanned at altitude. Controlled from a ground station
- Semi-rigid or non-rigid LTA airship with payload support structure
- 180 m length, 40 m diameter for 16 km altitude; 250% volume if 22 km
- Propulsion by electric propellers below hull and at rear center. Low boiling point at altitude may permit use of steam turbines
- Power from conventional fuel and/or beamed power, solar power
- Lift from helium. Additional lift possible by using beamed power to electrolyze condensed or stored water to obtain hydrogen
- Operational altitudes and latitudes:
  - Low cost: 16 km altitude between 35 deg. N. and 35 deg. S. latitudes (upper tropopause). Below ozone concentration but also below some cirrus clouds and turbulence ceiling of powerful storms.
  - Preferable: 20-22 km altitude anywhere in the world (lower stratosphere). Above all convection. Above all clouds except noctilucent clouds. Rarified air and corrosive chemicals increase cost.

Proposed Payloads and Their Locations

- **3 TO 3.5 Meter Optical Communication and Observational Telescope(s) - On top**
  - Primary Mirror = F/1.0; Cassegrain Focus = F/15.
  - Focusing Telecompressor = 0.6x to 0.8x.
  - Wide Field Imaging Telecompressor = 0.2x.
  - Fields of View = 0.016 deg. & 0.08 deg. with 12 mm CCDs.
  - Field Acquisition Fields of View = 50 deg., 4 deg., & 0.3 deg.
  - Mounting = Altitude / Azimuth with Optional 3rd Cross Axis.
- **0.5 to 0.75 meter air to air & air to ground Optical Communication and Surveillance Telescope - Below middle front**
  - Can theoretically resolve license plate numbers from up to 40 km.
  - Primary Mirror = f/1.0 to f/2.0; Cassegrain Focus = f/6 to f/15.
  - Mounting = Inverted Alt/Azimuth with Optional 3rd Cross Axis
- **RF Relay Transceiver - Below center or inside**
- **Deep Space Communication and Other Antenna(s)**
  - In addition to conventional antennas, the airship hull can serve as an antenna reflector, or the hull can house inflatable antenna. This concept can also be applied as means to concentrate beamed power. This will permit a smaller and lighter beamed power collector to be used.
- **Beamed Power – Below middle rear**
- **Cellular Telephone, Broadcasting**
- **Regional Position Reference**

Technical Challenges / Areas for Research

- Minimizing atmospheric chemistry effects
- Determining optimum altitude and latitude, etc, range
- Optimizing telescope / platform configuration to minimize boundary layer effects
- Development of light weight telescope and mirrors capable of withstanding the effects of widely variable atmospheric pressure and temperature
- Incorporation of real-time GPS and platform sensor information with telescope pointing and tracking algorithms
- Quantity, location, and configuration of ground stations, if fixed

Disadvantages of an Airborne Telescope and Relay Platform

- Maintenance and storage of airborne platform
- Development costs for platform
- Maintaining platform altitude and location when needed
- Locating and tracking spacecraft
- Requires FAA and local FCC authorizations

Notes about selected developments since ARDOC AND ALAT material was first presented:

- Development of a High Altitude Airship (HAA) has been funded by the U.S. missile defense agency. Some of the proposed HAA platforms are larger than the minimum size proposed for ALAT. Therefore, some of the airborne platforms developed under the program may be applicable to ALAT and ARDOC. This funded platform development has the potential to radically reduce the cost of implementing an airborne large aperture telescope having functions that facilitate an airborne terminal for optical communication (ATOC).

Selections from other 1993 ALAT and ARDOC documents - 1

Preliminary proposal for the development and implementation of ARDOC:
Airborne Relay for Deep Space Optical Communication
Conceived and presented by Jeffrey R. Charles
Draft 3. Sept 25, 1993

Primary Objectives:

- Reliable tow way optical communication with satellites and exploratory spacecraft, accomplished with the benefit of a a high altitude airborne optical transceiver, which in turn communicates with a ground station via RF.
- An airborne optical relay will permit optical communication with spacecraft regardless of weather conditions. The optical relay would generally operate at altitudes greater than 20 km, where it would not be obscured by clouds.
- Further, such a system offers the advantage of portability, low cost, and easy accessibility for servicing and upgrading. Since sensor performance is constantly being improved, the ability to upgrade the system is an important factor.

Selections from other 1993 ALAT and ARDOC documents - 2

Preliminary proposal for the development and implementation of ARDOC
by Jeffrey R. Charles. Sept 25, 1993 (continued)

Comments Regarding RF Hardware:

- While a large antenna would not be required for communication between the ground and ARDOC, there are some advantages in using ARDOC in the vicinity of a large antenna. When necessary, a large antenna could receive an RF beacon or reflection from the spacecraft, then the spacecraft position could be communicated to the airborne relay. Since an interplanetary spacecraft cannot be seen optically unless it has a suitable optical beacon, it is necessary to offset the telescope from a star or planet in the same field of view. Using an antenna would provide some redundancy in acquiring the spacecraft signal and/or maintaining the general tracking direction. The ARDOC tracking routines can use feedback from the platform to compensate for the changing platform position and orientation.

Advantages of an Airborne Relay for Deep Space Optical Communication:

- Unaffected by cloud cover = reliable communication
- More usable in daylight than ground stations due to darker sky background at altitude
- Supplements other optical communications, providing a backup system for use when:
  - Ground based optical communication systems are under the clouds
  - Bad “seeing” interferes with ground based reception
  - Daytime sky brightness interferes with ground based reception
  - Atmospheric scattering of light from a nearby star or planet interferes with reception
  - Other optical communication systems are down due to malfunction of maintenance
  - Limited memory on a micro-spacecraft will not allow it to delay sending required data and no eligible ground stations are on the side of the earth toward the spacecraft.
- Less hardware and new infrastructure than what is required for multiple ground stations:
  - Utilizes existing airports, antennas, etc.
  - Only a small antenna required for communication
  - Telescope aperture can be reduced due to high altitude
  - Developmental experiments do not require time on ground observatory telescopes
- Transportable – can quickly be moved to critical communication areas or positioned in a “night” location which will optimize the reception of optical communication by the spacecraft.
- Accessibility for servicing and upgrading
- Less expensive than a relay satellite and allows a more constant transmitter pointing reference for the spacecraft.

Selections from other 1993 ALAT and ARDOC documents - 3

STRATCOM

Stratospheric Observation and Communication
Jeffrey R. Charles October 21, 1993

High altitude Multiple Function Lighter than Air Platform

Why Lighter than air?
- LTA airship does not require continuous motive power to remain airborne.
- Can stay airborne longer than an airplane.
- Has the possibility of being a “permanent” high altitude platform if appropriately serviced or multiple units are used.
- Low air speed eliminates need to fully enclose telescope behind an optical dome, turret, or window. This in turn allows more payload mass to be dedicated to the actual telescope, facilitating a larger aperture at less cost.
- Public visibility.

Why a Multiple Function LTA Airship?
- Multiple function telescope and ARDOC are on top of the airship hull (for sky coverage), making it top heavy or unstable if constructed for maximum lift. Unconventional hull shapes generally have a less favorable cost/lift/mass relationship.
- Other payloads and functions can be below hull to counterbalance telescope without adding useless mass or decreasing sky coverage.
- Broad spectrum of prospective customers / backers:
  - High altitude atmospheric and other experiments
  - Beamed power development
  - Cellular telephone and television, etc. transponders, translators, etc.
  - Multiple function telescope(s) for observation and communication.

Why a Large Aperture Multiple Function Telescope?
- More capability = more potential users / backers
- Required for high optical communication bit rates beyond Mars
- Many advantages of a space telescope yet is serviceable and costs less
  - Not affected by cloud cover
  - Minimal atmospheric scattering, sky brightness, & particulate influence
- Multiple units facilitate more observations than a single space telescope
- Can be easily transported to “remote” observing sites for eclipses, etc.
- Less new infrastructure & environmental impact than multiple ground stations

Illustrations:

The following illustrations show the development of the concept and related "spin-off" technology. To allow a long mission duration and minimize boundary layer effects on the payload, all airborne embodiments utilize lighter than air platforms. Airplanes with adequate lift require substantial power and forward air speed in order to fly. This causes undesirable boundary layer effects and makes the aircraft more difficult to track; and tracking can be important for optical and some other communications, or in beaming power. Flying rotors (variants of the helicopter) can remain in a fixed location but can require a lot of power. The necessity to "de-spin" the payload on a flying rotor also adds complexity. Since the stability of the telescope is very important, it is either attached to the airship structure or suspended below widely separated support points. The concept has evolved considerably since conception, resulting in "spin-off" applications and technology that will benefit other fields. The drawing and illustration list is shown below.

- Illustration of the ALAT Platform
- Illustration of ARDOC (Airborne Relay for Deep-Space Optical Communication)
- Original ALAT Conceptual Drawing; Arrayable LTA (Lighter Than Air) Platform Unit with Telescope
- Second Conceptual Drawing; LTA Platform with Multiple Payloads
- Third Conceptual Drawing; LTA Platform with Internal Inflatable Reflector
- Detail of Steerable Feed Inflatable Antenna Concept
- Ground Based Steerable Feed Antenna with 110 deg. Fully Illuminated Scan Range (based on inflatable version)
- Ground Based Steerable Feed Antenna with Limited Scan Range
- Airborne or Spaceborne Inflatable Antenna with Inflatable Spherical Enclosure
- Large Ground Based Inflatable Antenna with Inflatable Spherical Enclosure under an Inflatable Dome Housing
- Proposed Small Aperture Optical Communication Demonstration Instrument (from 1993 ARDOC presentation)

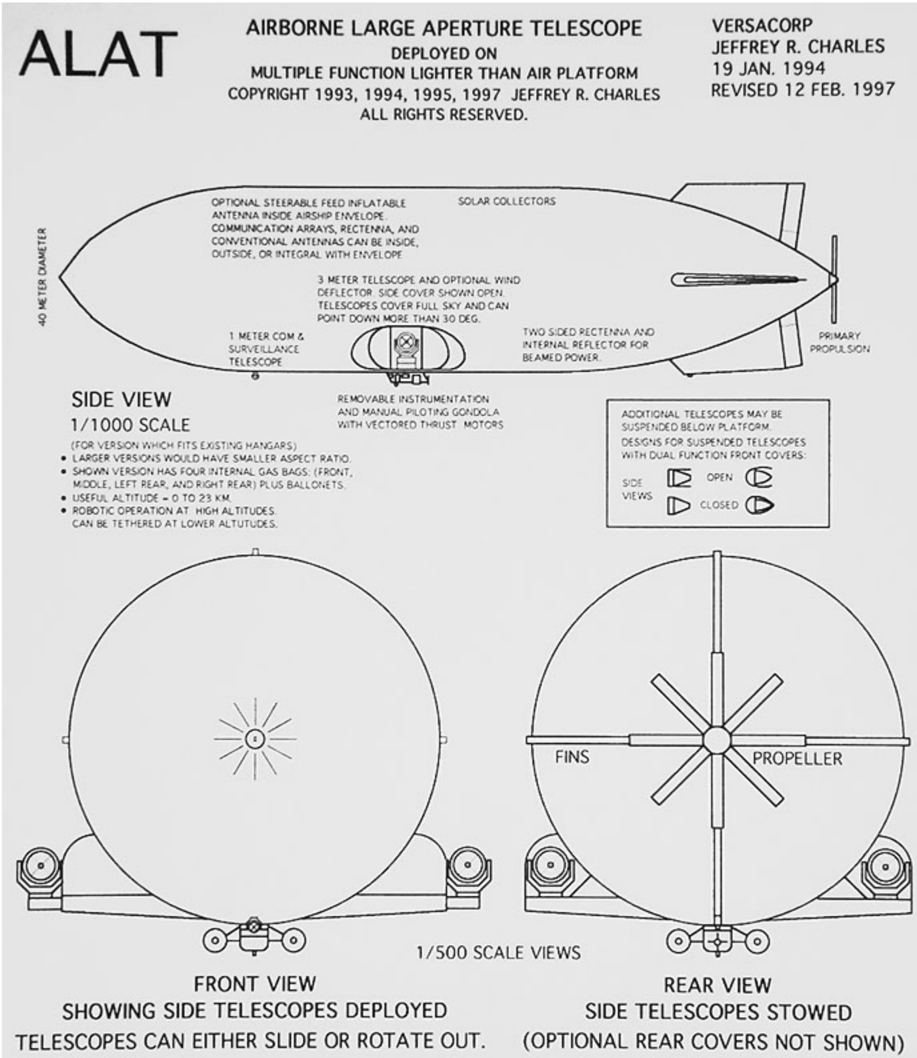
ALAT

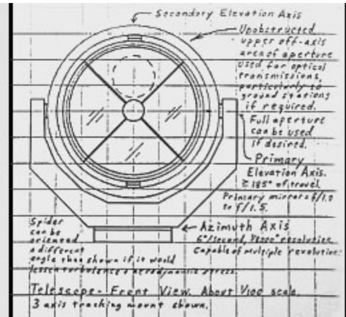
Airborne Large Aperture Telescope

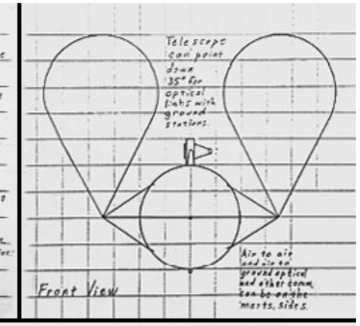
Illustrations

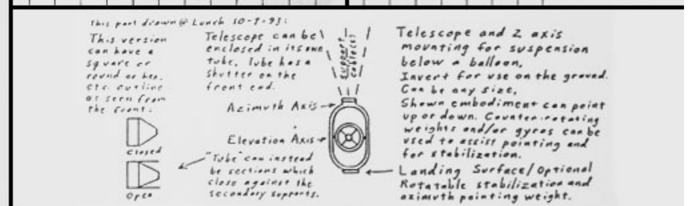
Jeffrey R. Charles

ALAT Platform, Telescope, Optical Communication Relay, and Antenna (1993-1997 versions)

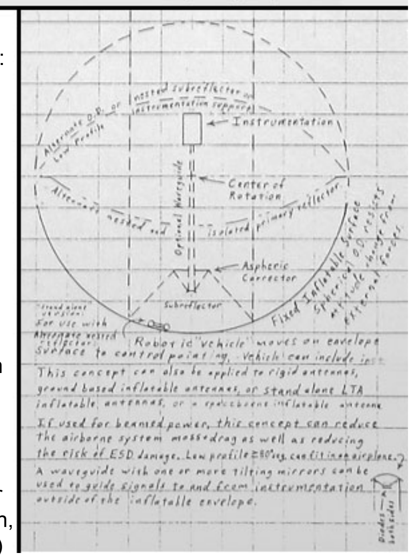






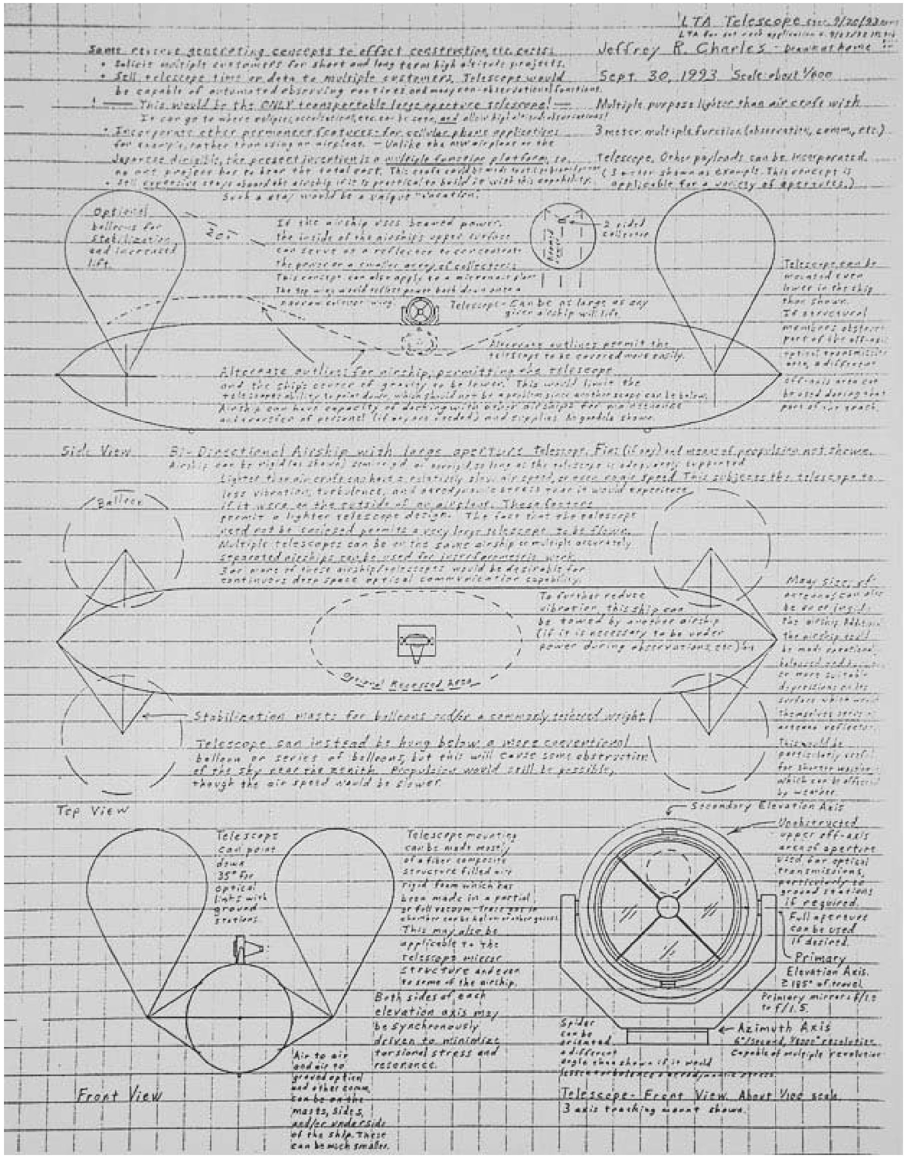


Airborne Large Aperture Telescope (ALAT) features: Left: High altitude multiple function LTA airborne platform supports one or more integrated and/or suspended telescopes. Top Center: 1993 concept drawing for on board large aperture (3.5m) telescope and Airborne Relay for Deep-Space Optical Communication (ARDOC). Top Right: Optional balloon array for additional lift. Right: More designs for suspended telescopes. Lower Right: Steerable feed inflatable antennas for beamed power, observation, and communication. (1994)

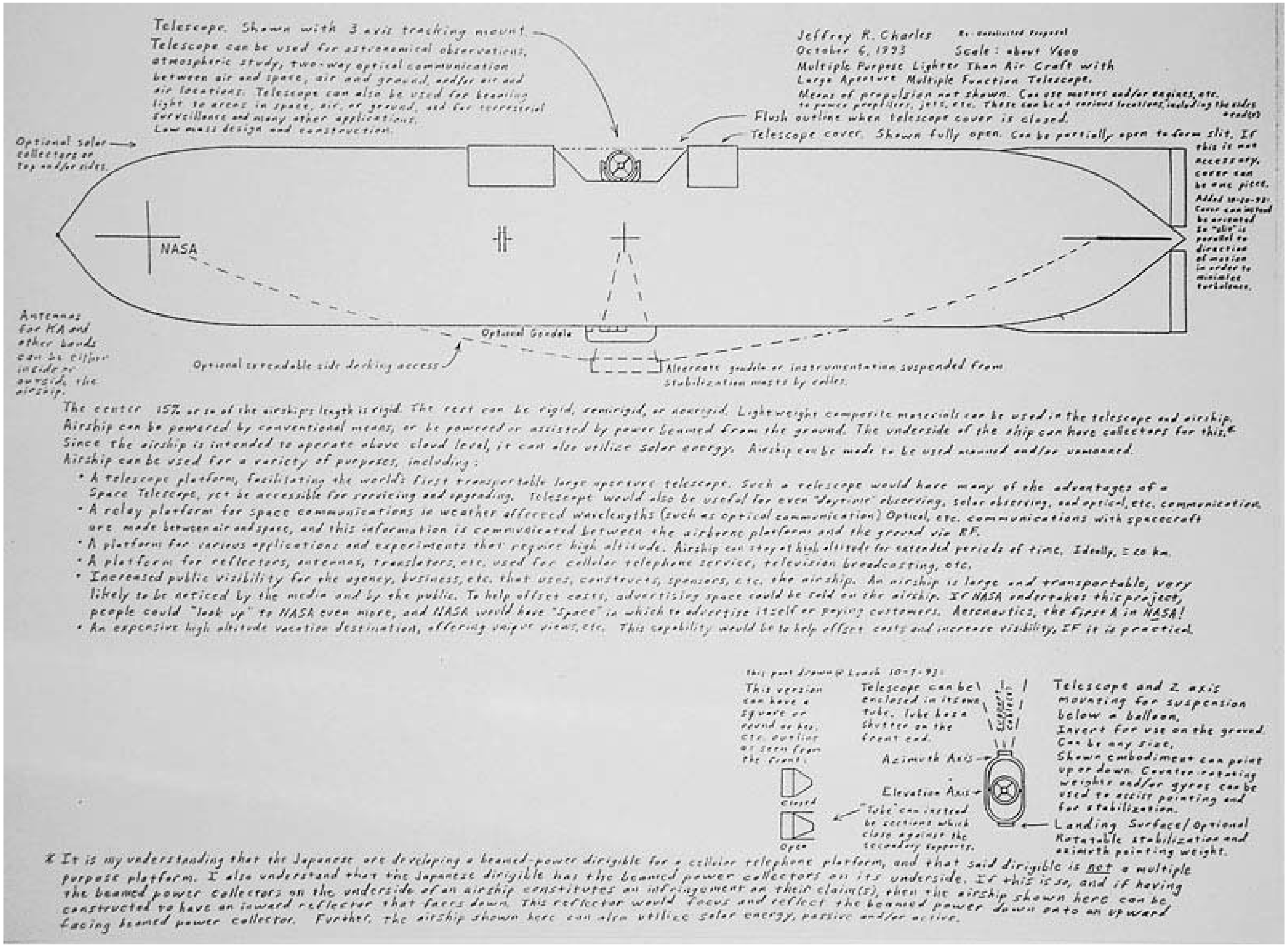


ALAT was first proposed to JPL by J. Charles in 1993, but was not funded. Follow up development has been performed by Versacorp.

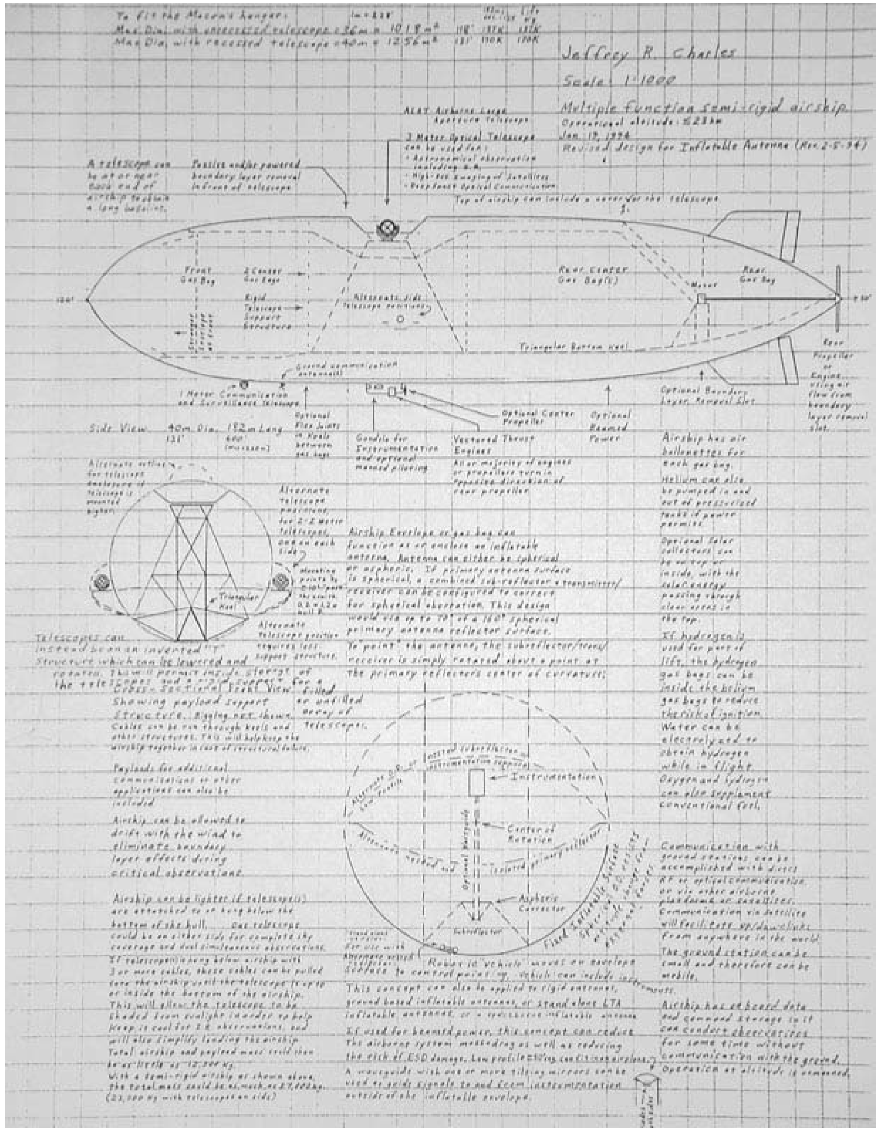
ALAT: First Concept Drawing (Sep. 1993)



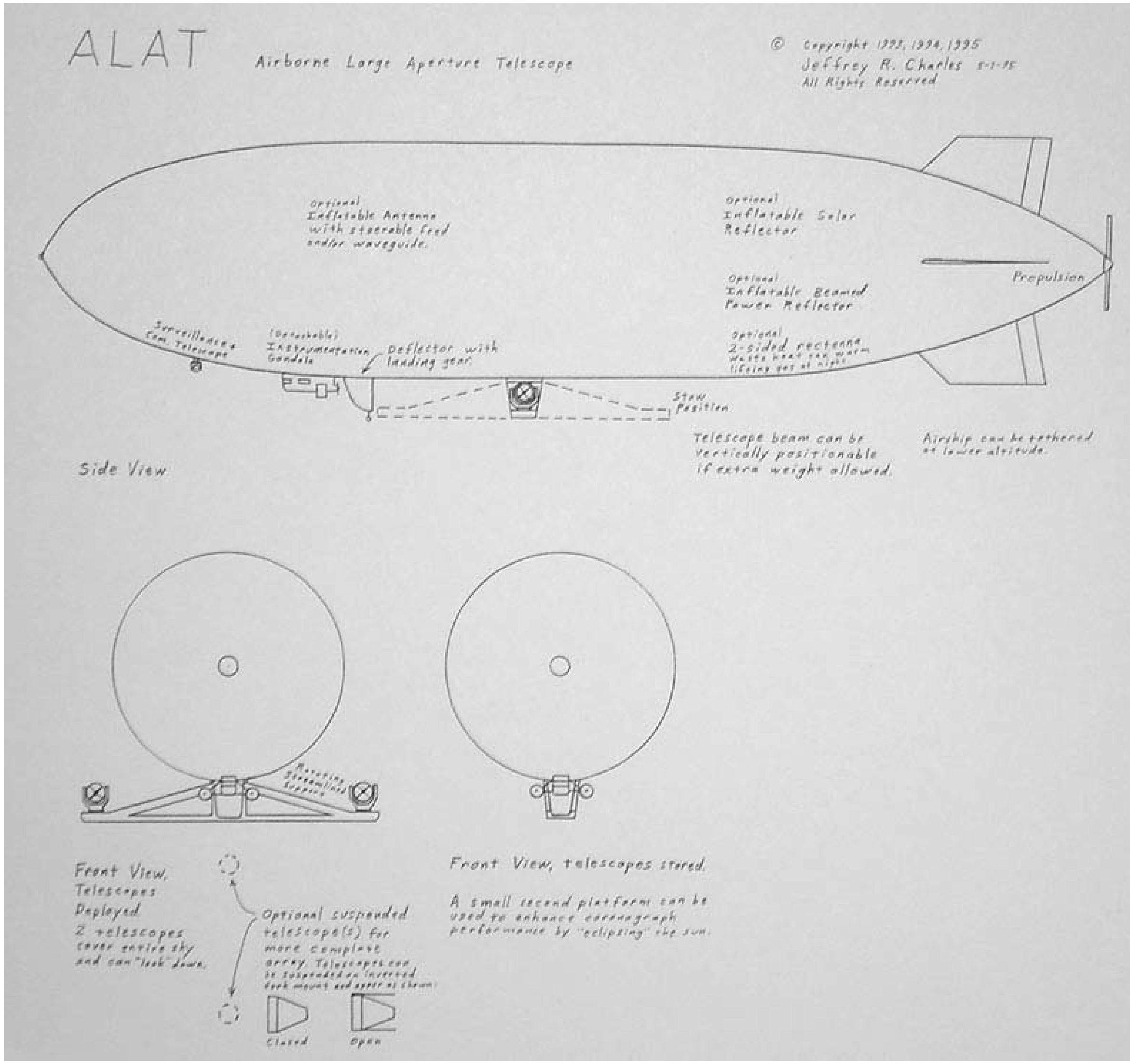
ALAT: Second Concept Drawing (Oct. 1993)



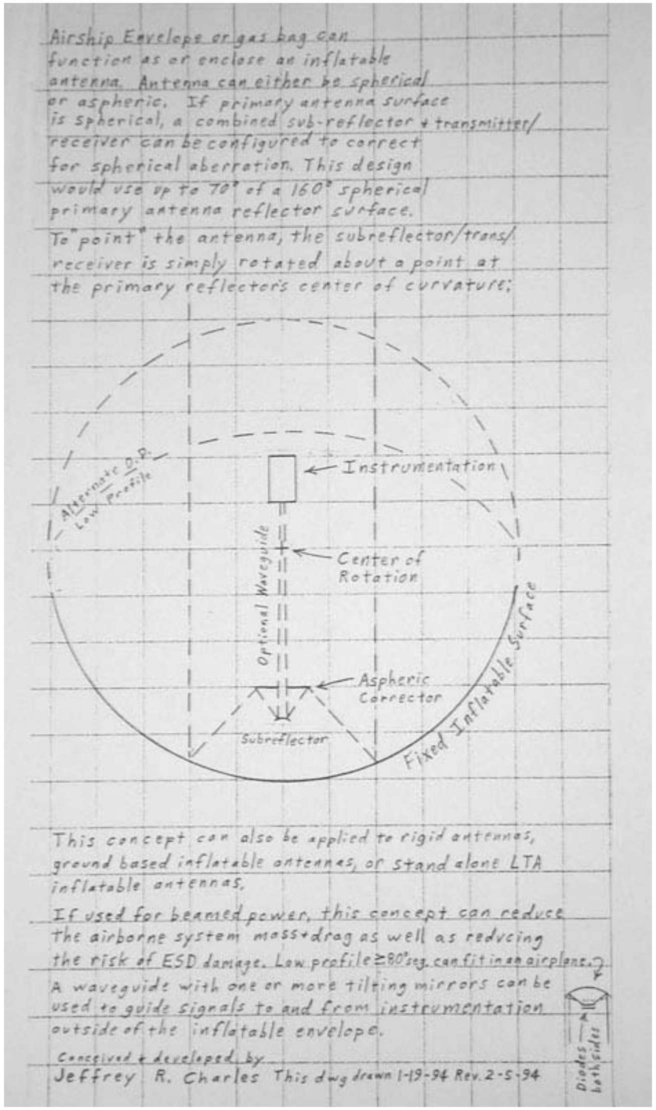
ALAT: Third Concept Drawing (Jan. 1994)

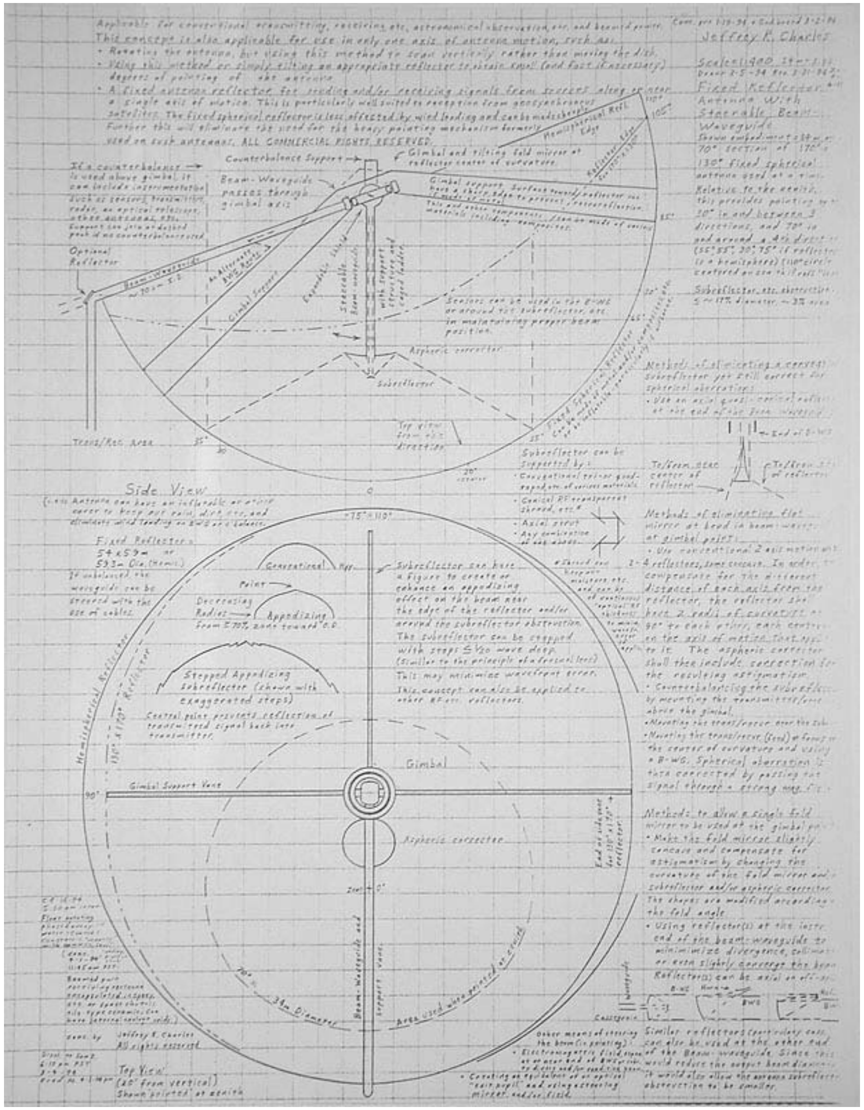


ALAT: Fourth Concept Drawing (May 1995)

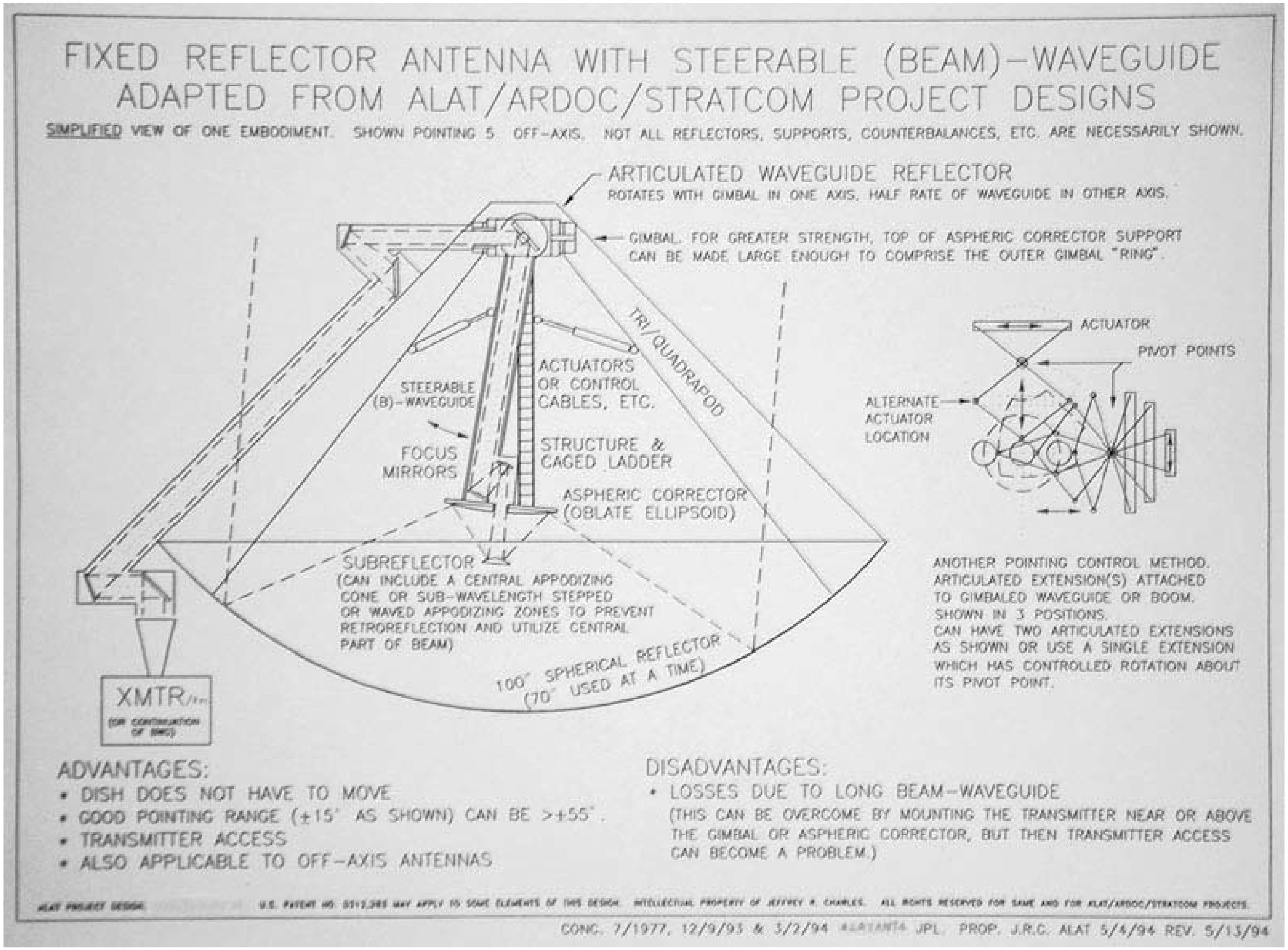


ALAT: Internal and External Inflatable and Rigid Steerable Feed Antennas (Jan. and Mar. 1994)

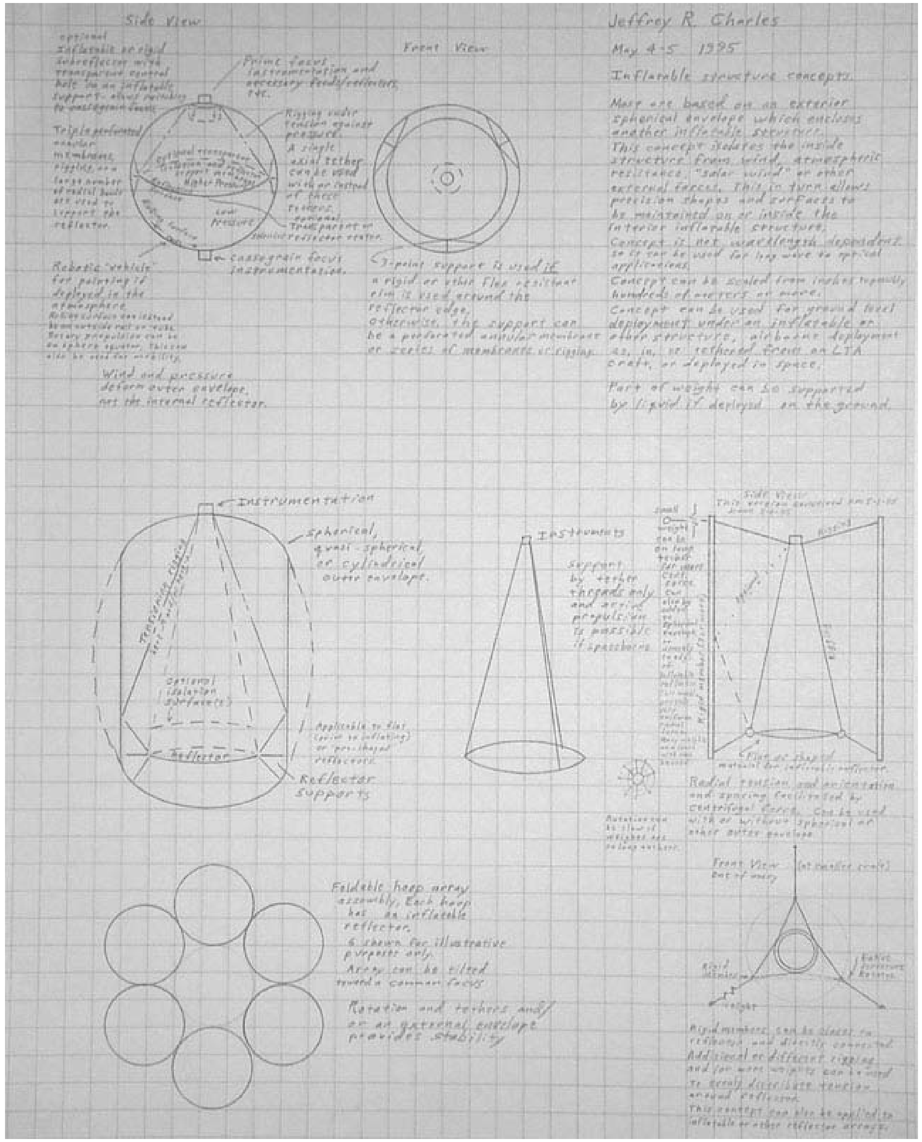




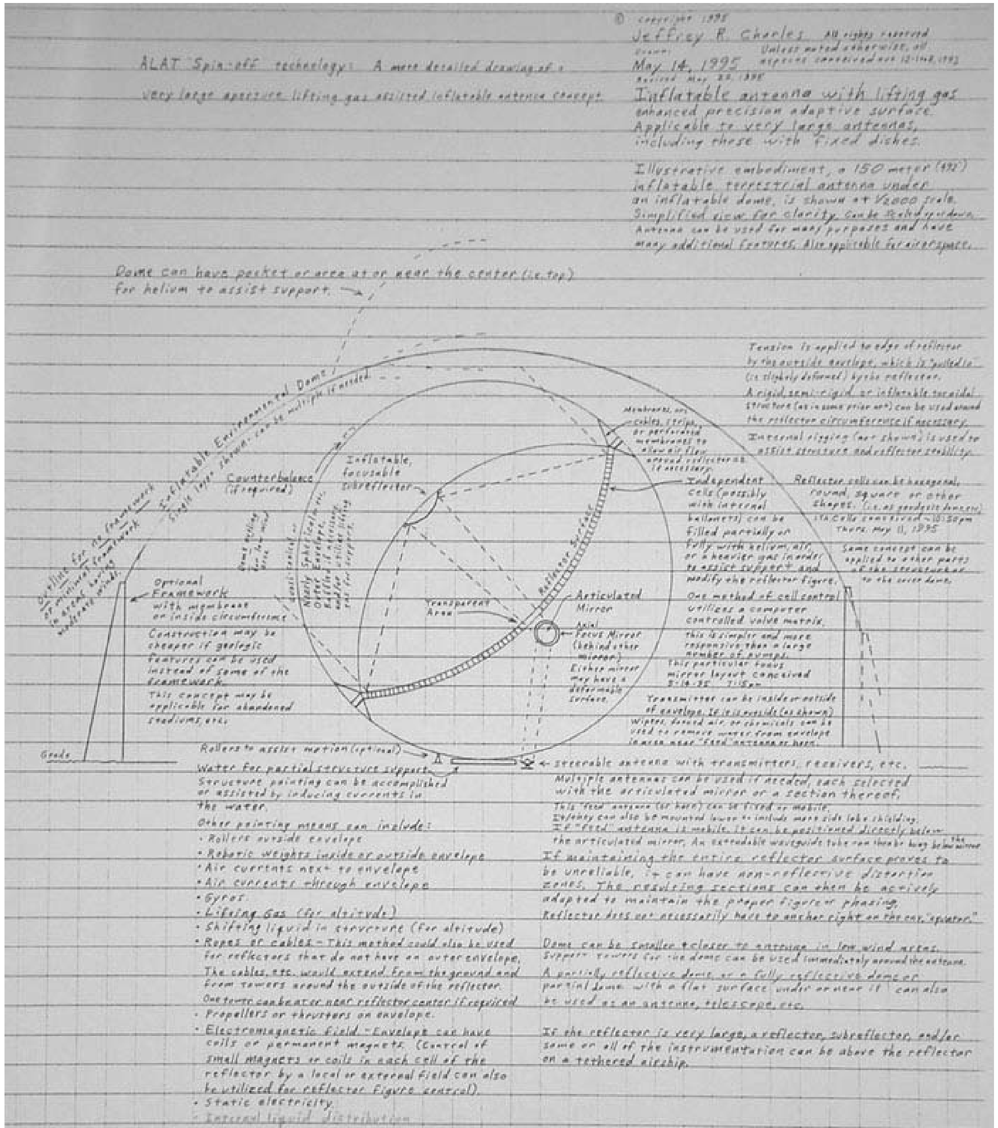
ALAT: Steerable Feed Antenna (May 1995)



ALAT: Inflatable Antennas for Ground, Water, Air, and Space Deployment (May 1995)

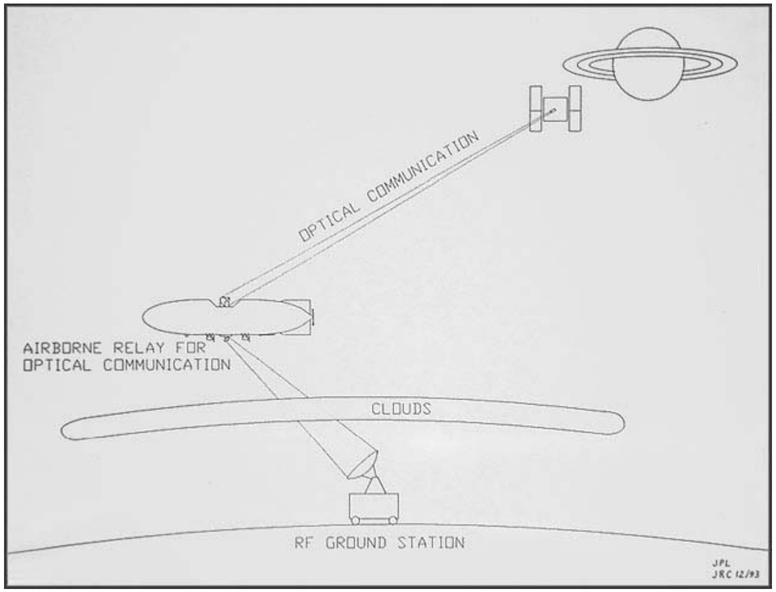


ALAT: Large Inflatable Antenna (May 1995)

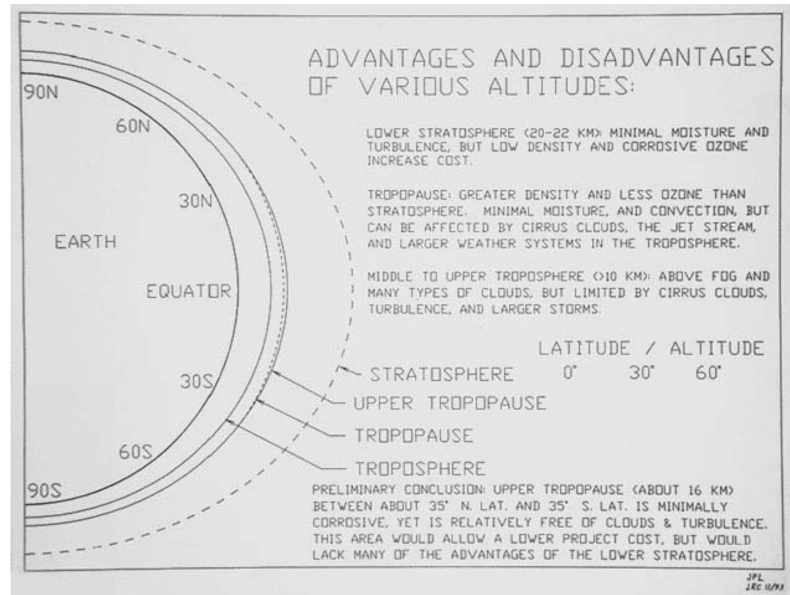


Spin-off technology from LTA platform development – large inflatable antennas. This drawing is from Jeffrey R. Charles' 1995 "Airborne Large Aperture Telescope" (ALAT) paper. The paper was published in proceedings of JPL "Innovative Space Mission Applications for Thin Films and Fabrics" conference of 8 May, 1995. ALAT is envisioned as a system for astronomical observation and relayed optical communication that is deployed on one or more a Multiple-function Lighter-than-Air Platform (MLAP) that is developed in partnership with private industries that utilize it for their commercial payloads. ALAT and related concepts were first promulgated as HALAT (High Altitude Large Aperture Telescope) in 1993.

ALAT / ARDOC Concept Drawing (Dec. 1993), Atmospheric Data (Dec. 1993)

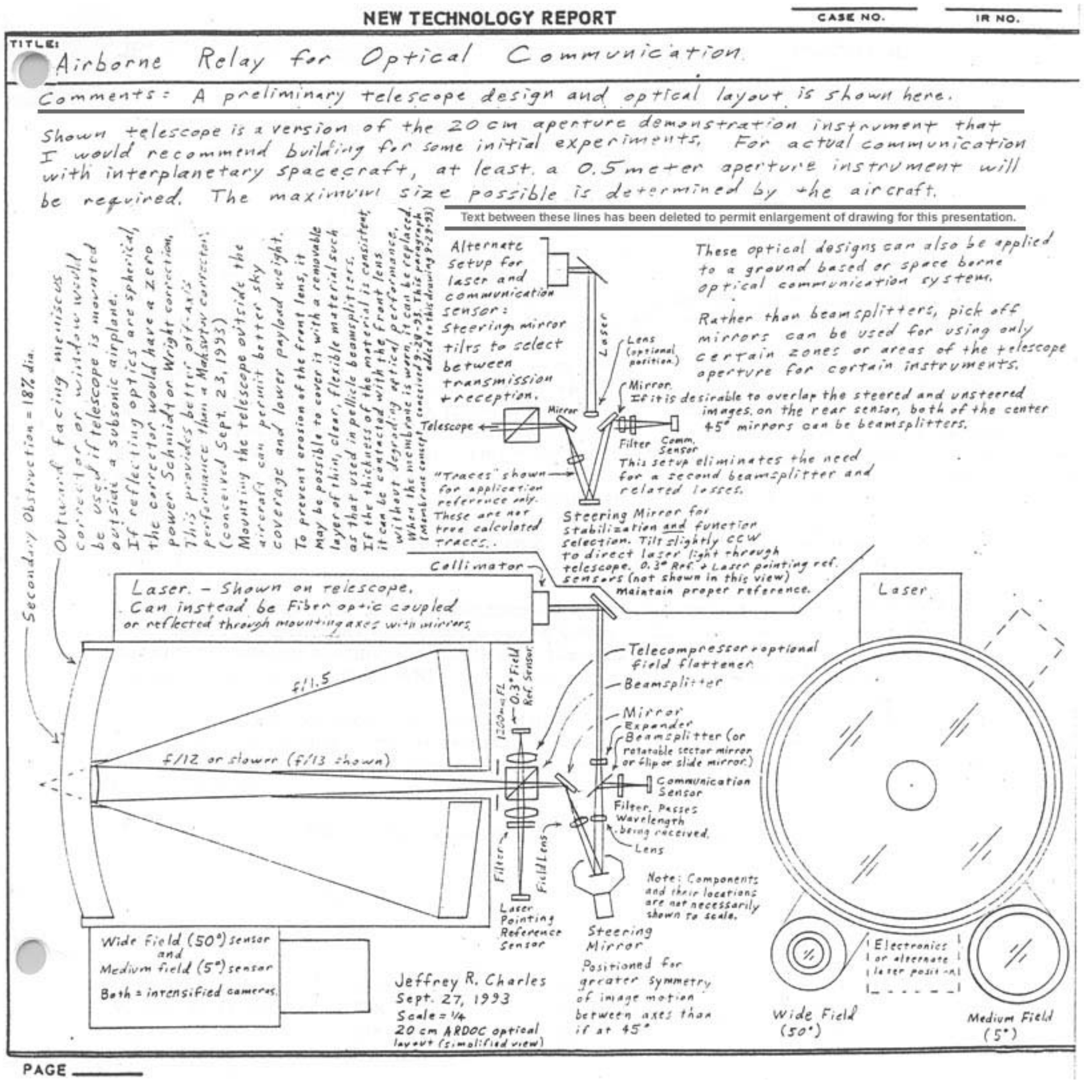


Airborne Relay for Deep-Space Optical Communication (ARDOC), 1993



Airborne platform location trades.

Airborne Relay for Deep-Space Optical Communication (ARDOC) Demonstration Instrument (Sep. 1993)



J. Charles' 1993 concept for small aperture airborne optical communication demonstration instrument. This is the instrument design initially proposed for the Airborne Relay for Deep-Space Optical Communication (ARDOC) demo.

The 1993 optical communication demonstration instrument initially conceived for ALAT / ARDOC (illustrated at left) has selectable fields of view of 0.3 and 0.04 degrees.
The baseline 1995-1997 version of the full size ALAT system has a pointing accuracy goal of 0.06 arc seconds (based on better than 0.03 arc second pointing knowledge) and specifies 0.27 arc seconds as attainable. The 0.06 arc second figure should be possible for at least pointing stability. It assumes use of a 2,000 x 2,000 pixel detector (12 x 12 mm format, 6 micron pixel size) that provides a field of view (FOV) of 0.96 arc minutes at the ALAT telescope's Cassegrain focal surface. Pointing stability of 0.06 arc seconds corresponds to 12.5 microns (about 2 pixels) on the detector. Currently (in 2003), it should be possible to attain pointing stability and accuracy better than 0.06 arc seconds. If motion prediction (beyond simple point ahead based on feedback from a previous guiding sample) is used, it may be possible to improve stability by a factor of two or so.
The overall tracking scenario for ALAT assumes use of a separate (and smaller) acquisition instrument on the main telescope mount. Acquisition has a safe mode FOV of 50 degrees (provided by a relatively small optical system), a science and communication acquisition FOV of 4 degrees (at least 10 cm aperture, for acquisition of a planet or reference stars), and a tracking acquisition FOV of 0.3 degrees (at least 20 cm aperture, to get the downlink source somewhere on the receive detector). The main 3 meter f/14.3 telescope has science FOVs of about 0.96 arc minutes (Cassegrain focus plus weak fine focusing optic) and 4.8 arc minutes (with 0.2x focal reducer), either of which can correspond to the tracking FOV. The main telescope can also have (as an optional configuration) a 0.3 degree acquisition FOV, provided by 0.42x focal length reduction optics and a very large 7.2 x 9.6 cm (6x8k pixel) sensor accessible by a remote controlled flip mirror or fixed or flip beamsplitter. (Large 6x8 or 7x9k sensors with pixels up to 12 um have been made by American Digital Imaging (ADI), and one 7x9k CCD sensor was used at Mt. Hopkins Observatory.) The optional high resolution sensor and large FOV provides an acquisition and pointing knowledge accuracy (including pointing by reference star) of 0.135 arc seconds per 12 um pixel (on 6x8k sensor), which should provide feedback for acquisition pointing better than 0.27 arc seconds, and even better tracking accuracy.

Referenced Weather Data

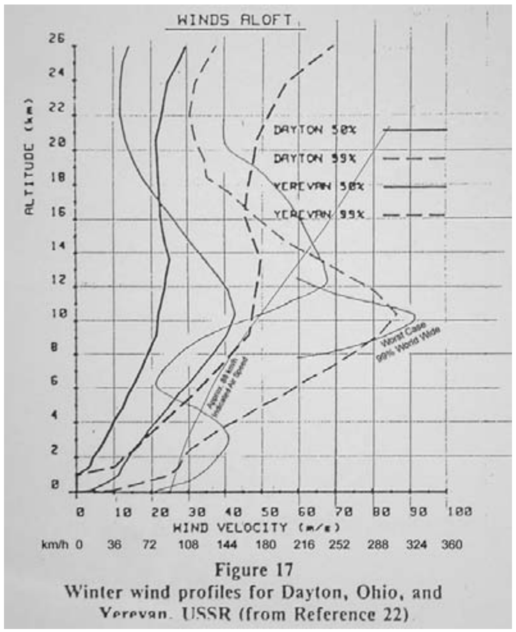
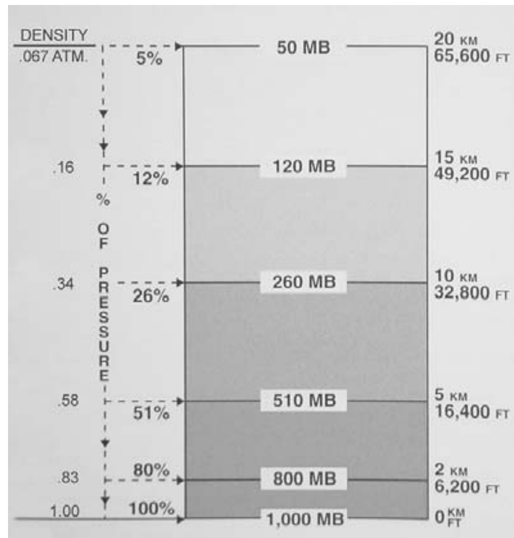


Figure 17
Winter wind profiles for Dayton, Ohio, and Yerevan, USSR (from Reference 22)

Wind Speed at two locations, with Indicated Air Speed Profile



Air Density at Different Altitudes

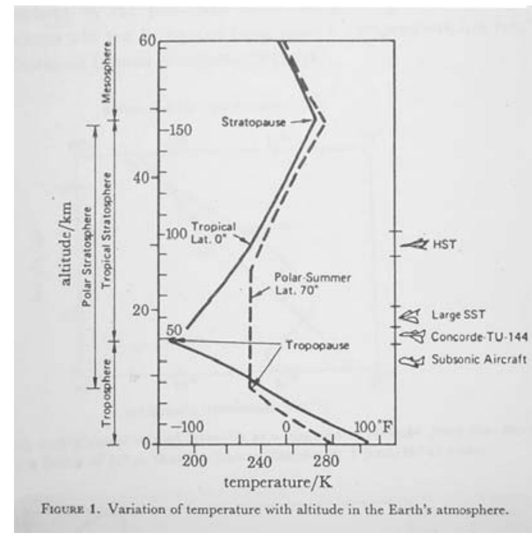


FIGURE 1. Variation of temperature with altitude in the Earth's atmosphere.

Atmospheric Temperature at Different Altitudes