NEW FISTA MEASUREMENT PLATFORM

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ABSTRACT

The very successful FISTA I airborne infrared measurement aircraft ceased measurements in Oct 1993 with the retirement of the ‘A model’ turbojet NKC-135A. An NKC-135E turbofan was modified and the first flight of FISTA II was on May 11, 1995. A description of the layout and capabilities of FISTA II is presented. The initial capability includes the previous FISTA I instruments. Planned upgrades in 1995-96 will provide digital recording, extended infrared capability, and calibrated visible region imaging. Space has been reserved to accommodate other government or industrial contractors who are encouraged to use the platform.

INTRODUCTION

The Flying Infrared Signatures Technology Aircraft (FISTA) program started in 1974 to provide calibrated infrared measurements of aircraft in order to understand the phenomenology of aircraft signatures. This data was also used as the basis for the development and validation of the Spectral and Inband Radiometric Imaging of Targets and Scenes (SPIRITS) computer simulation model. The FISTA program has provided a large volume of spectral, spatial, and temporal data on aircraft, missiles, many surface targets, and extensive background measurements. The program used the dedicated NKC-135A FISTA I aircraft, serial number 553120, as its measurement platform until its retirement in October 1993 as part of an Air Force plan to retire all turbojet ‘A’ model KC-135s. The turbofan aircraft NKC-135E, serial number 553135, at Edwards AFB with a window configuration similar to the old FISTA is the replacement platform. This aircraft, FISTA II, has been modified and completed test flight certification on 11 May 1995 to continue infrared and visible region measurements.

FISTA II PLATFORM

The NKC-135E, serial number 553135 shown in Figure 1, has 20 windows on the right side of the fuselage. All but one window have 12.5 inch diameter clear aperture which are either filled by clear 0.75 inch thick lexan windows or accept instrument mounts. The window layout is illustrated in Figure 2. The 6.5 inch diameter window number 1 on the forward portion of the fuselage, where it curves in towards the nose, allows viewing slightly across the nose of the aircraft. About seven instruments can be operated at one time, allowing a wide range of spectral, spatial, and temporal data to be collected simultaneously.

Figure 1 FISTA II, KC-135E, S/N 53135, With Twenty Special Windows

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Approved for public release; distribution umlimited. Revised August 1995.
OASD-PA 17 Aug 95, SAF/PAS 95-0795, AFMC 95-2281, ESC 95-1080, HO 332-95.
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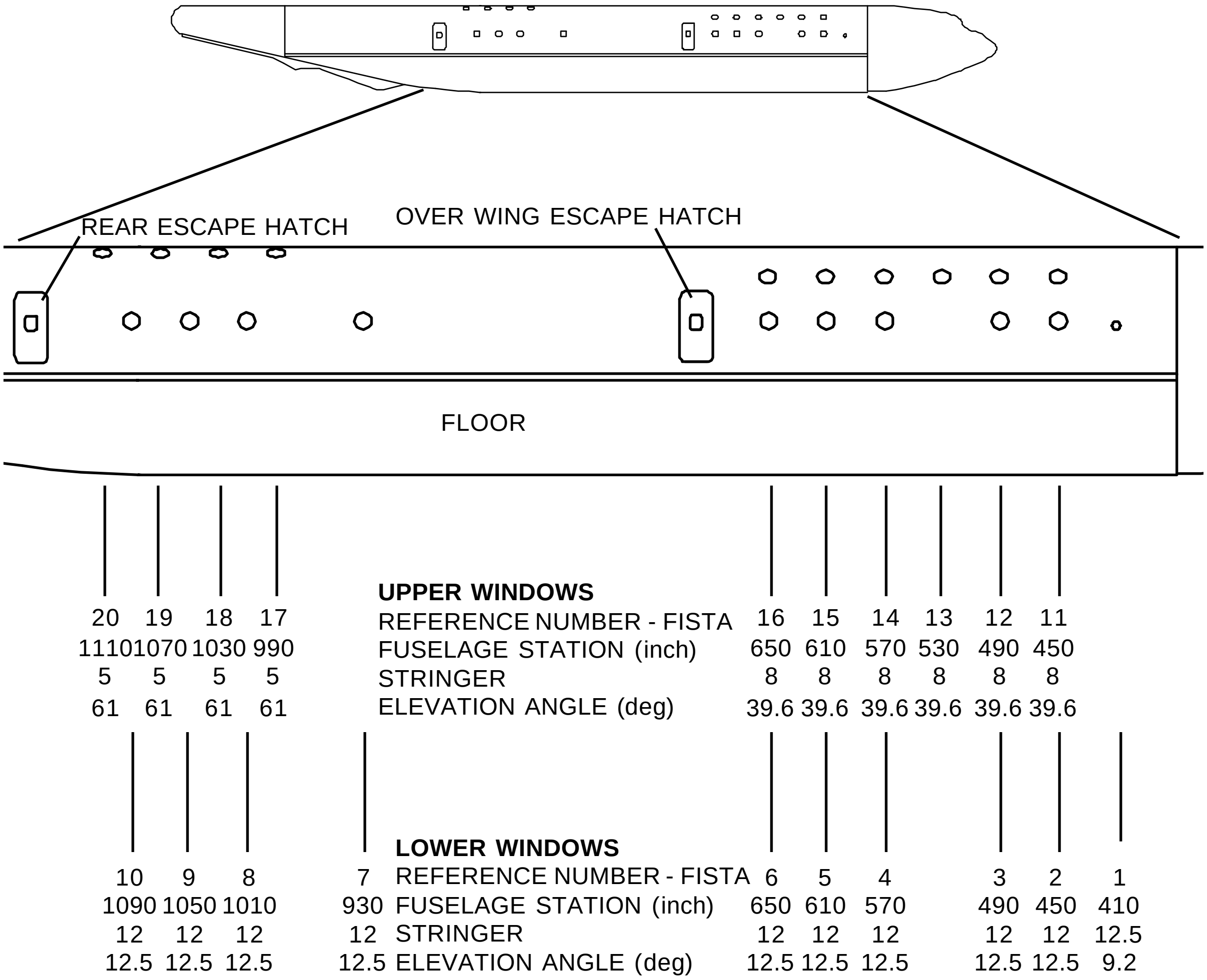

Window FISTA #	Prime Forward and Side	Prime Aft	Alternate 1	Alternate 2	Upgrade
1	Spectra 102	-	Spectra 105	Spectra 102	LIDAR
2	Spectra 105	-	Imager LWIR	Imager MWIR	Spectra 105
3	Imager MWIR	-	Spectra 103	Spectra 105	Imager MWIR
4	Imager LWIR	Spectra 102	Imager MWIR	Imager LWIR	Imager LWIR
5	Spectra 103	-	Spectra 102	Spectra 103	Spectra 103
6	Radiometer	Radiometer	Radiometer	Radiometer	Radiometer
7	-	Imager MWIR	-	-	-
8	-	Imager Visible	-	-	-
9	-	Imager LWIR	-	-	-
10	-	Spectra 105	-	-	-
13	Metric Visible	Metric Visible	Metric Visible	Metric Visible	Metric Visible

Figure 2 Twenty Instrumentation Windows in FISTA II and Typical Instrument Configurations

The widows are grouped in four zones. Windows 1 through 6, with optical centerline at 9.2 and 12.5º elevation angle are forward of the wing and allow unobstructed viewing to side, forward, upward, and downward directions. Viewing to the aft is partially blocked by the wing. This group, identical to those on the old FISTA, is the primary location for side and tail aspect measurements of aircraft in flight. Windows 7 through 10, also at 12.5º elevation, allow unobstructed viewing of targets to the rear of the aircraft, particularly down looking views at off-nose aspects. These window positions were not on the old aircraft. Windows 11 through 16, with optical centerlines at 39.6º elevation, can be used primarily to track strategic and theater missiles high in the sky. They are also used to provide test control and safety monitoring and can also accept horizontal mounts with reduced aperture for measurement of coaltitude targets. Windows 17 through 20, at 61º elevation angle, can be used for vertical viewing into space or for limited viewing to the left (the target's right side). The fuselage stations, stringer locations, and elevation angles of the normals to the windows (for level flight) are given in Figure 2. The typical fields of regard from a forward 12.5º elevation window are illustrated in Figure 3. Similar sets of angles can be covered from the windows at 39.6 and 61º elevation giving viewing access into the hemisphere on the right side of the aircraft and limited viewing to the left. Additional flexibility can be achieved with a mount that gives a 6.5 inch aperture in a 12 inch window with its axis cocked at 30º to left or right and up or down from the normal centerline.

Internally the floor layout of the aircraft is configured, as shown in Figure 4, to take maximum advantage of the windows for instrument operation. The shaded areas marked forward and rear instrument windows and sensors, allow clear access to installed instrumentation. There are 14 standard 19 inch (wide) instrumentation 'PRESS' racks in which the control instrumentation is installed. A double width console rack #14 holds the Edwards AFB instrumented refueling boom control and monitor equipment. The solid circles are cryogenic storage tanks for liquid nitrogen or helium required to cool the optical instrument heads. Seating for 21 persons, technical and ground support crew, is provided in the rear for takeoff and landing.

The typical instrument mounting in Figure 5 can be installed into any 12.5 inch clear diameter window. A small or large rotatable eyeball assembly can mount directly into the window and allow the instrument to be trained to about 22º in any direction from the centerline. A 45 or 55º periscope mirror assembly can be inserted through the eyeball aperture and be easily rotated through 360º to allow tracking of targets above, behind, below, and forward of the FISTA. Two crash restraint arms (one shown) hold the instrument for takeoff and landing. Counter balance bungee cords support nearly all instrument weight in-flight and allow ease of tracking for the operator. As each instrument is often required to view different parts of the target each system is independently tracked by an operator. A sensor mount with periscope in a small eyeball is shown in Figure 6.

The instrumentation racks, Figure 7, are designed for aircraft use and have a sloped back that allows them to be mounted close to the fuselage, giving a wide center isle in the aircraft. Four bolts tie it to a floor plate allowing easy removal. All cables pass through a quick disconnect panel at the top of the rack. An instrument being tracked and its associated control rack is shown in Figure 8. A representative set of rack functions is shown at the top of Figure 4. Five racks are reserved for general use of government or industry programs that desire to participate in measurements or to test or demonstrate new equipment.

Measurement systems are best be designed to operate on standard aircraft power, single or three phase 400 Hz 115 Vac. A few kilowatts of 60 Hz 115 Vac is available. Liquid nitrogen, LN_2, is stored in cryogenic tanks and is transferred by hand held dewars. If extensive cooling is required the LN_2 can be fed directly to the installation. Defrost heaters located near each windows keep windows free of condensation. A six channel interphone system plus aircraft radio monitoring is provided at all tracking and operator positions.

The suite of instruments currently available are listed in Table 1. This includes 3 interferometric spectrometers with high spectral resolution (up to 1 wavenumber), spatial imagers covering the short through longwave infrared with selectable filter bands, a dual channel cryogenically cooled radiometer, and documentation cameras and videos. Space has been allocated to install a lidar that could view in nearly any direction, including a forward view to sample ahead of the aircraft for correlation with other onboard sampling. Plans are being made to cover the visible and ultraviolet regions with calibrated spatial measurements. Nearly all recording will be digital, with dedicated systems for spatial imagers and multi-gigabyte optical or hard disks in computers for spectral and temporal systems. All systems can be quickly mounted and demounted to enable flexible setup to meet the needs of any application and give versatile configuration capability to meet customer or experimenter needs.

Instrument sensitivity is important in determination of applications that FISTA can support. In Table 2 data on maximum instrument sensitivity of the primary IR sensors is provided in equivalent RMS noise. The peak-to-peak noise levels are three times greater. In many cases reduced sensitivity is desired for such targets as sun, earth backgrounds or engine hot parts. In these cases narrow band filters, neutral density filters, or aperture stops are installed to reduce the response uo to many orders of magnitude. The interferometers

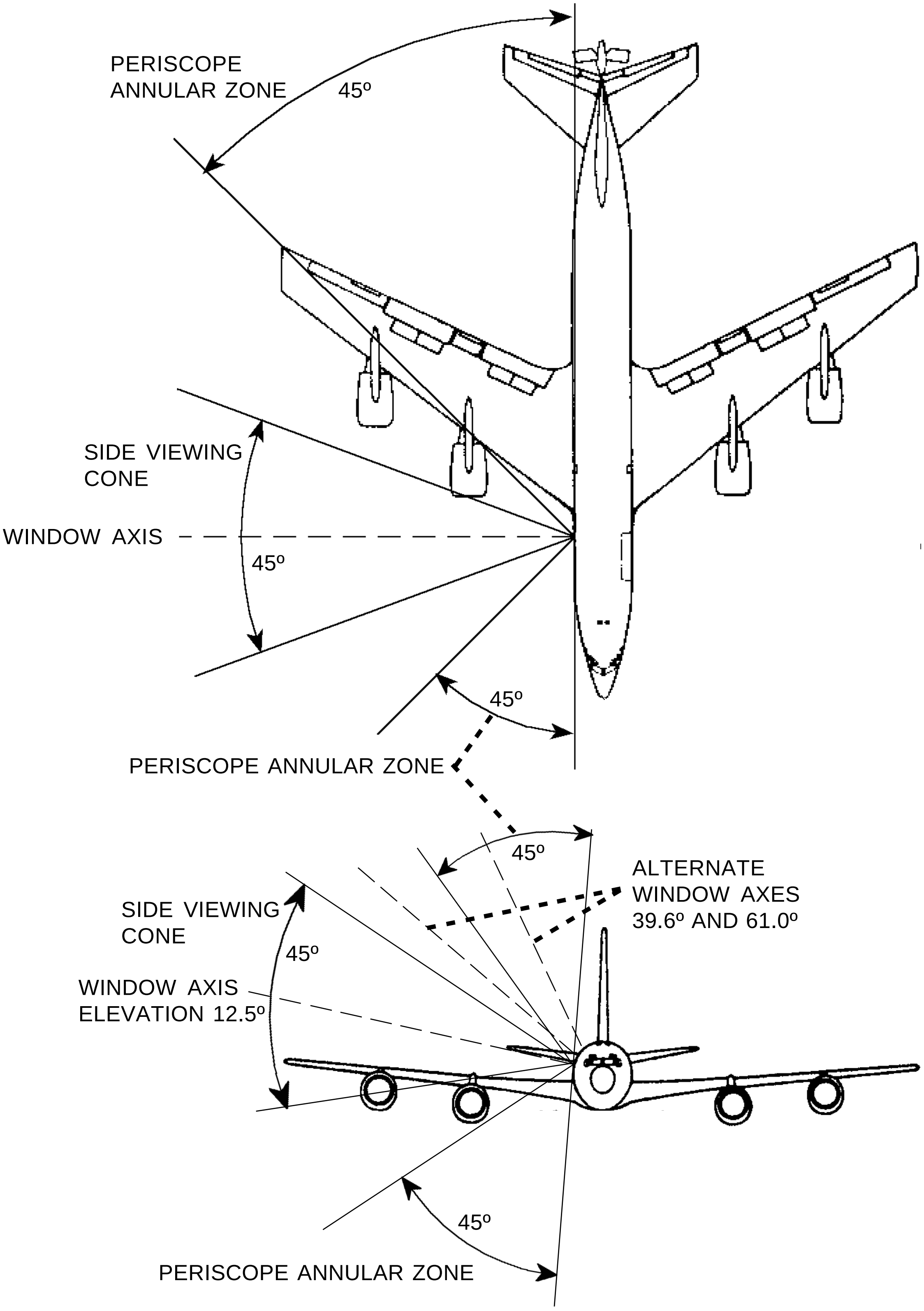

Figure 3 Primary Regions Viewable to Side and With Periscopes From a 12.5º Elevation Window. Similar Ranges of Viewing can be Achieved From the 39.6 and 61º Elevation Windows. By Observing With FISTA in a Bank Many Other Zones can be Viewed.

Rack Functions

Rack # 1 & 2	LIDAR or Other User*
Rack # 3 & 4	Visible, Documentation
Rack # 5	Imager MWIR (SAIRS)
Rack # 6	Amber (MWIR Trackers)
Rack # 7	Power Distribution
Rack # 8 & 9	Spectral Systems (102, 103, 105, & radiometer)
Rack # 10	Mission Coordinator, GPS, Range
Rack # 11	Imager LWIR (FLIR)
Rack # 12	Other Users*
Rack # 14	Aerial Refueling
Rack # 15 & 16	Other Users*

* Racks installed as required.
Power, intercom, etc., available

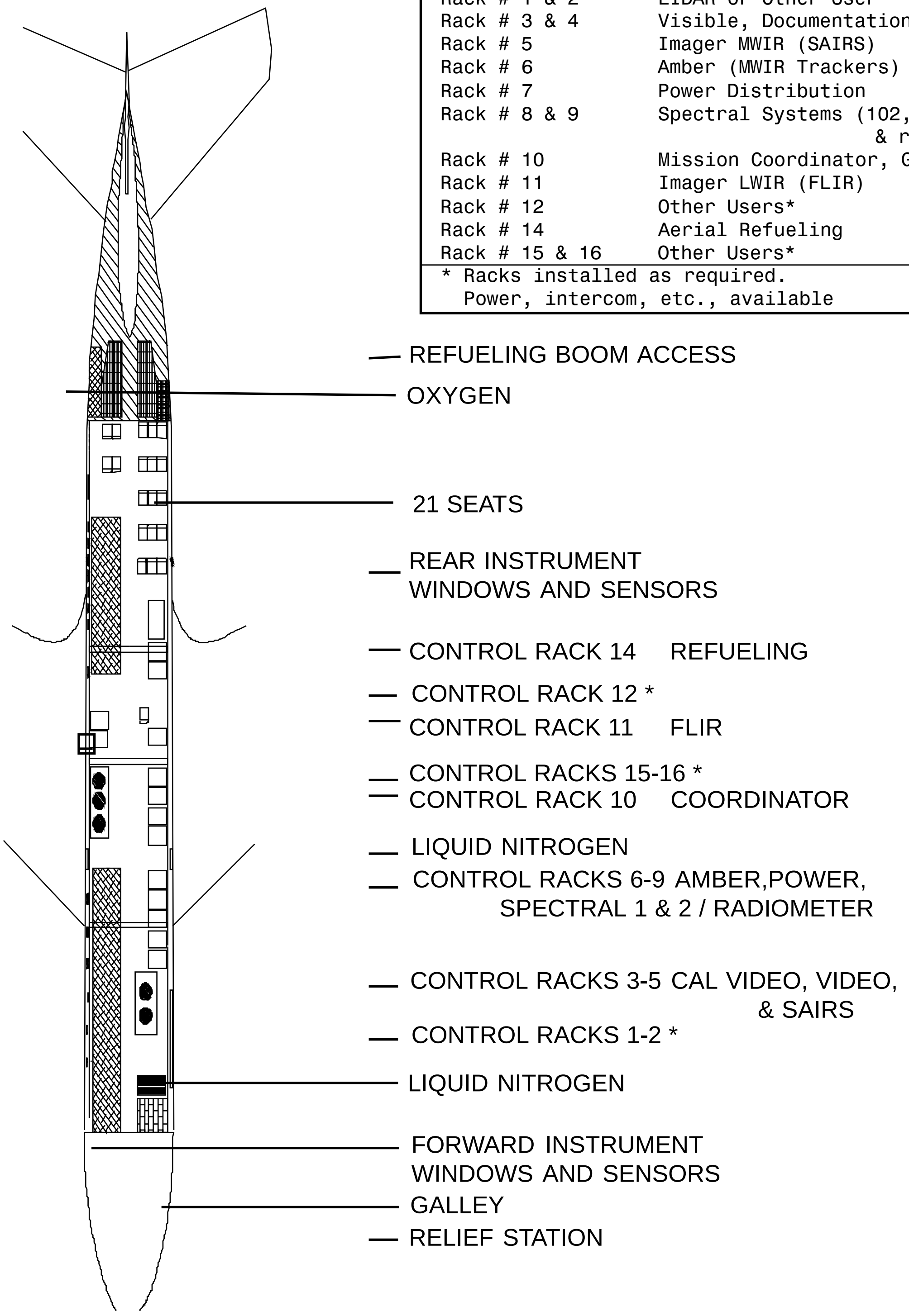

Figure 4 Floor Layout and Rack Functions of FISTA II

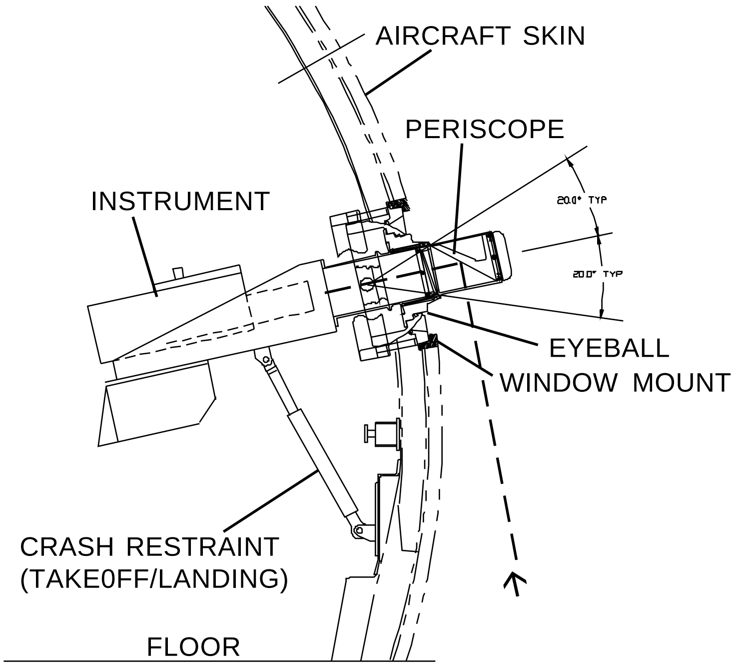

Figure 5 Typical Instrument Mount to Trainable Eyeball and Rotatable Periscope Mirror, Here Viewing Down

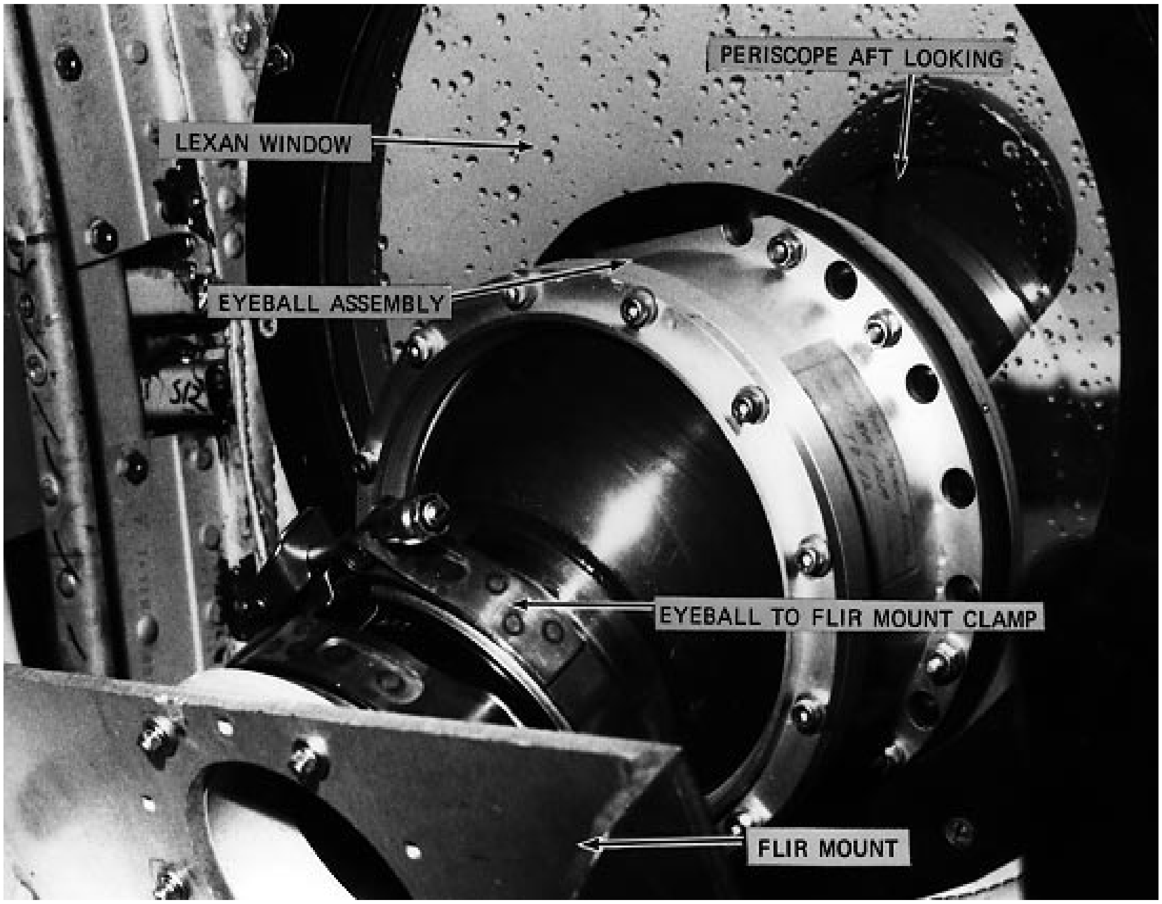

Figure 6 The Trainable Eyeball Assembly With a Rotatable Periscope Mirror That Allows Viewing Forward, Aft, Up, and Down

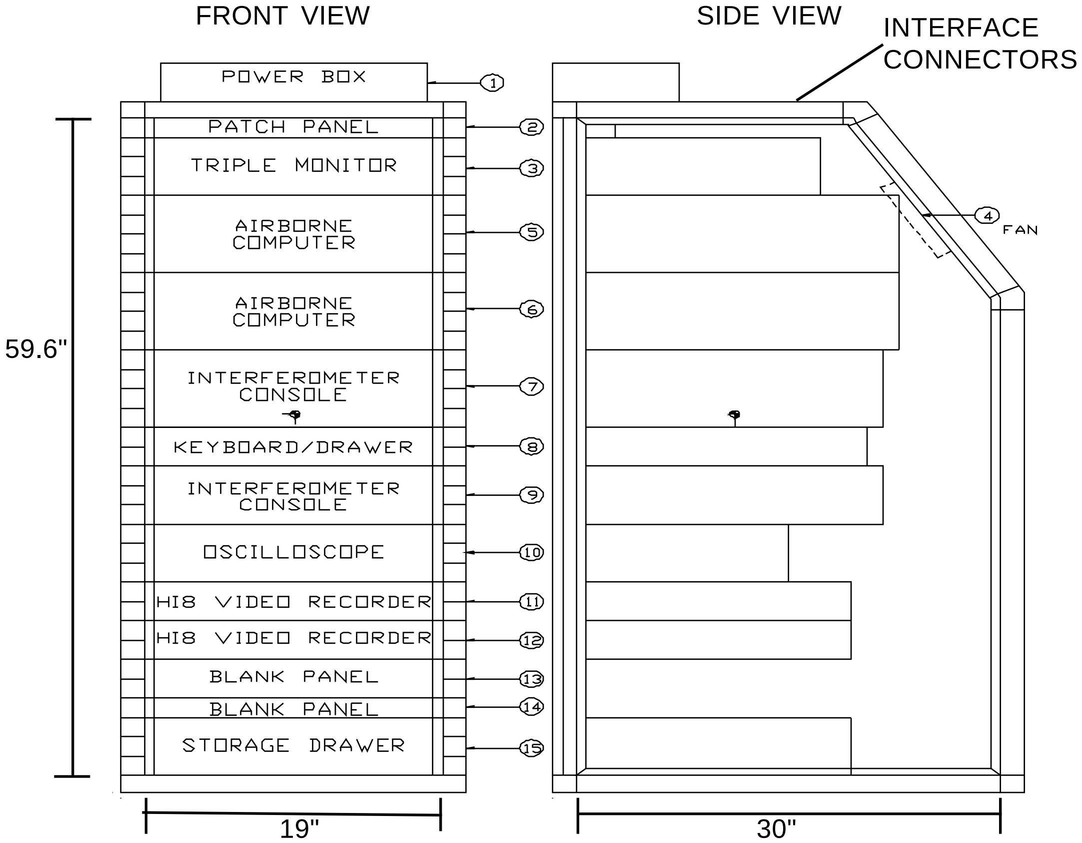

Figure 7 Standard 19 inch Panel Instrumentation Rack With Typical Control Units

Figure 8 An Instrument on FISTA II, (A) Sensor Being Tracked, and (B) The Control Console

Table 1 FISTA Measurement Instrumentation

INSTRUMENT	WAVELENGTH	FIELD-OF-VIEW	RESOLUTION	DETECTOR	SCAN
INTERFEROMETER SPECTROMETERS					
102	1.3 - 3.3 µm	1° CIRCLE	3.8 cm^{-1}	InAs (77K)	1.5 sec
103	2.0 - 7.0 µm	0.5° SQUARE	0.95 cm^{-1}	HgCdTe(77K)	1 sec
105	2.0 - 5.4 µm	1° CIRCLE	0.95 cm^{-1}	InSb (77K)	1 sec
IR IMAGERS					
FLIR	5.0 - 14.0 µm	4.0 x 6.9°	0.5 mrad	HgCdTe(77K)	16 msec
FLIR w/Telescope	5.0 - 14.0 µm	1.1 x 1.9°	0.15 mrad	HgCdTe(77K)	16 msec
SAIRS (100mm)	2.0 - 5.0 µm	5.6 x 7.3°	0.4 x 0.8 mrad	PtSi (77K)	33 msec
SAIRS (200mm)	2.0 - 5.0 µm	2.8 x 3.7°	0.2 x 0.4 mrad	PtSi (77K)	33 msec
MAVIS	0.35- 0.75 µm	7.2 x 5.4°	100mm LENS	GaAsP MicroChan	33 msec
AMBER	3.0 - 5.0 µm	2.5 x 2.5°	0.1 mrad	InSb (77K)	<33 msec
LLLTV (1)	0.4 - 0.7 µm	7.0 x 5.0°	100mm LENS	NaKCaSb	33 msec
LLLTV (2)	0.4 - 0.7 µm	5.0 x 3.0°	150mm LENS	NaKCaSb	33 msec
RADIOMETER					
DUAL (1)	4.0 - 5.0 µm	1° CIRCLE	1 msec	InSb (77K)	500 Hz
DUAL (2)	7.5 - 11.6 µm	1° CIRCLE	1 msec	HgCdTe (77K)	500 Hz
DOCUMENTATION SYSTEMS					
CCD Television A	0.5 - 1.1 µm	18x24°/6x8°	25/75 mm lens	Si	16 msec
CCD Television B	0.5 - 1.1 µm	24x32°/1x2°	15/300 mm lens	Si	16 msec
CAMERAS 1VN 16mm	visible	44x69°	10 mm lens	film	1 to 25/sec
CAMERAS 1VN 16mm	visible	09x14°/3x5°	50-150 mm lens	film	1 to 25/sec

Table 2 Instrument Sensitivity

INSTRUMENT	BAND	FOV	WAVELENGTH	RESOLUTION	NESR/wavenumber	NESI/wavenumber
	micrometer	sr	micrometer	cm^{-1}	$w.cm^{-2}.sr^{-1}.cm$	$w.cm^{-2}.cm$
SPECTRAL INTERFEROMETER						
102	1.3 - 3.3	$2.80x10^{-4}$	at 2.7	3.80	$5.4x10^{-10}$	$1.5x10^{-13}$
	"	$2.80x10^{-4}$	at 1.7	3.80	$1.8x10^{-9}$	$5.0x10^{-13}$
103	2.0 - 7.0	$1.10x10^{-4}$	at 5.1	0.95	$3.6x10^{-8}$	$4.0x10^{-12}$
	"	$1.10x10^{-4}$	at 2.5	0.95	$1.4x10^{-7}$	$1.5x10^{-11}$
105	2.0 - 5.4	$3.20x10^{-4}$	at 5.0	1.20	$1.9x10^{-8}$	$6.0x10^{-12}$
	"	$3.20x10^{-4}$	at 2.5	1.20	$1.3x10^{-7}$	$4.0x10^{-11}$
INSTRUMENT	FILTER	PIXEL FOV	WAVELENGTH	BAND WIDTH	NER/micrometer	NEI/micrometer
		sr	micrometer	micrometer	$w.cm^{-2}.sr^{-1}$.µm-1	$w.cm^{-2}.µm^{-1}$
THERMAL IMAGING						
SAIRS 100mm	1	$3.20x10^{-7}$	2.00- 2.89	0.89	$4.5x10^{-8}$	$1.6x10^{-14}$
	2	$3.20x10^{-7}$	3.29- 3.75	0.46	$1.8x10^{-7}$	$5.9x10^{-14}$
	3	$3.20x10^{-7}$	3.81- 4.44	0.63	$3.9x10^{-7}$	$1.2x10^{-13}$
	5	$3.20x10^{-7}$	3.53- 4.25	0.72	$1.9x10^{-7}$	$6.1x10^{-13}$
	6	$3.20x10^{-7}$	4.63- 4.97	0.34	$2.3x10^{-6}$	$7.2x10^{-13}$
	8	$3.20x10^{-7}$	3.65- 4.11	0.46	$4.0x10^{-7}$	$1.2x10^{-13}$
FLIR Telescope	5	$5.64x10^{-8}$	8.29- 9.51	1.22	$2.4x10^{-5}$	$1.3x10^{-12}$
	6	$5.64x10^{-8}$	9.62-11.04	1.42	$1.7x10^{-5}$	$9.7x10^{-13}$
	7	$5.64x10^{-8}$	11.20-12.74	1.54	$3.3x10^{-5}$	$1.9x10^{-12}$
	9	$5.64x10^{-8}$	7.80-13.18	5.38	$5.8x10^{-6}$	$3.3x10^{-13}$
MAVIS 100mm	3	$1.40x10^{-8}$	0.49- 0.57	0.08	$4.4x10^{-10}$	$6.2x10^{-18}$
RADIOMETER						
DUAL1	1	$3.20x10^{-4}$	10.17-12.08	1.91	$8.2x10^{-10}$	$2.6x10^{-13}$
	2	$3.20x10^{-4}$	8.17- 9.40	1.23	$1.5x10^{-9}$	$4.8x10^{-13}$
DUAL2	3	$2.60x10^{-4}$	3.78- 4.73	0.95	$6.0x10^{-9}$	$1.6x10^{-12}$
	4	$2.60x10^{-4}$	3.31- 3.88	0.57	$1.2x10^{-8}$	$3.2x10^{-12}$

measure their data as a function of frequency and conequently the noise is linearly related to the frequency or wavenumber. Their sensitivity is reported in noise equivalent spectral radiance (NESR) and irradiance (NESI) per unit wavenumber (cm^{-1}). The spectra can be coadded and the noise level is then reduced by the factor $\sqrt{n}$ where n is the number of spectral scans added together. The thermal imagers and radiometer operate in bands selected by optical filters and noise equivalent radiance (NER) and irradiance (NEI) are in units per micrometer (µm) per sensor pixel. Pattern noise and related issues are not included and are relatively small in these systems. The SAIRS thermal imager can also operate with a 200 mm lens that reduces the field of view by a factor of 4. The FLIR can operate without the telescope with a field of view of $1.7x10^{-7}$ sr.

FISTA MEASUREMENTS

The FISTA program, in coordination with the 452 Flight Test Squadron, Edwards AFB, provides experiment advice and flight test planning for missions and makes measurements for or with the customer. In many situations the FISTA program provides, analysis, interpretation, and simulation model development, in addition to measurement and calibration of data. If a SPIRITS (SPectral and Inband Radiometric Imaging of Targets and Scenes) target module is requested, the FISTA program can make the extensive calibrated measurements required to support model development and provide from this, a SPIRITS target module, a report describing the measurements and analysis, and a database of measurements in an appropriate format (for instance, AIMG, Air Force Information Warfare Center Measurement Guide). The development of a SPIRITS model requires a full understanding of the plume, hot parts, and airframe (hardbody) behavior as well as their interaction with the environment and backgrounds. To support this analysis, an extensive capability has been developed at the Phillips Laboratory, Geophysics Directorate. A few samples of data types are illustrated here. A more complete summary of these processes is available to qualified requestors.

High resolution spectra provide detailed information on radiation from plume species, hot parts temperatures, and atmospheric transmission and radiance, that is required to understand the physical processes responsible for the observed behavior. A measurement of a rocket plume at 53 seconds after lift-off in the midwave infrared, shows the primary radiating species in Figure 9 . Spatial images are made in many infrared bands using switchable filter wheels on the SAIRS and FLIR imagers. A calibrated SAIRS measurement is shown in Figure 10A. The average radiances of shadowed fuselage and backgrounds are obtained from within the boxes superimposed in Figure 10B. To obtain the radiant intensity of more complex shapes the image can be displayed above a selected threshold level so that the radiance above that threshold, within the selection box, can be determined. This process, shown in Figure 10C, illustrates the measurement of a sunglint patch, and in Figure 10D an engine plume radiant intensity. The vertical line on Figure 10E gives the line plot of radiance shown in Figure 10F, where some of the prominent features are marked.

The radiometer has two optical channels to measure the temporal variation of a source as illustrated in Figure 11 from the midwave infrared channel.

A major advantage with the simultaneous spectral, spatial, and temporal measurements, in addition to the different phenomenology that each addresses, is that agreement between the independent calibrations of the different systems provides a high level of confidence in the accuracy and consistency of the measurements. The FISTA not only provides calibrated measurements, but also provides to the customer an analysis and explanation of the phenomenology being observed. This can also be incorporated in the SPIRITS model, which is based on physics in the infrared, and thus provides a powerful tool for infrared simulation. This model, once calibrated and validated against target measurements, has the potential to predict signatures for systems in the design phase from which design changes and optimizations can be performed before construction of a prototype.

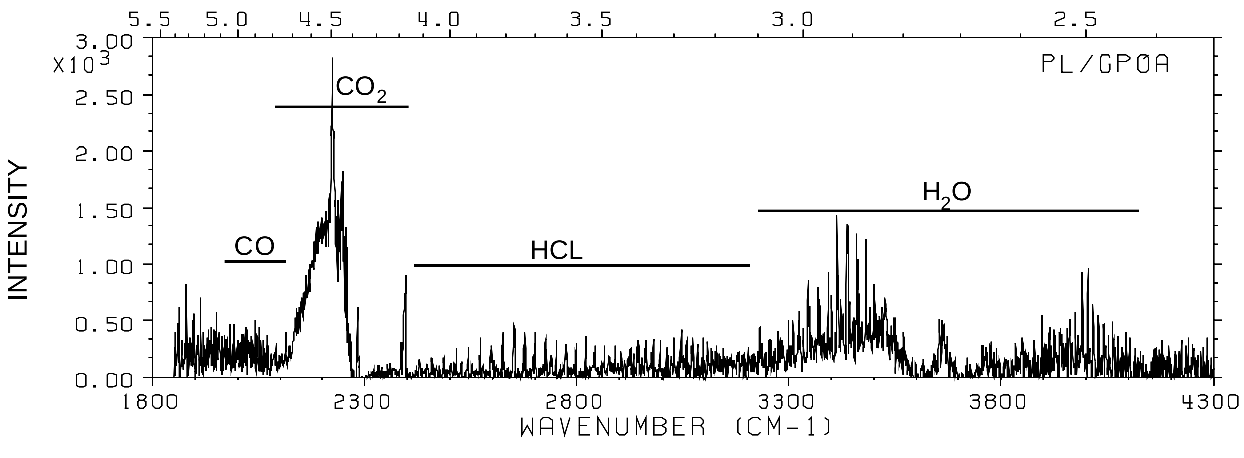

Figure 9 Spectrum of a Rocket Engine Measured by FISTA in the 2.55 to 5.40 µm Band

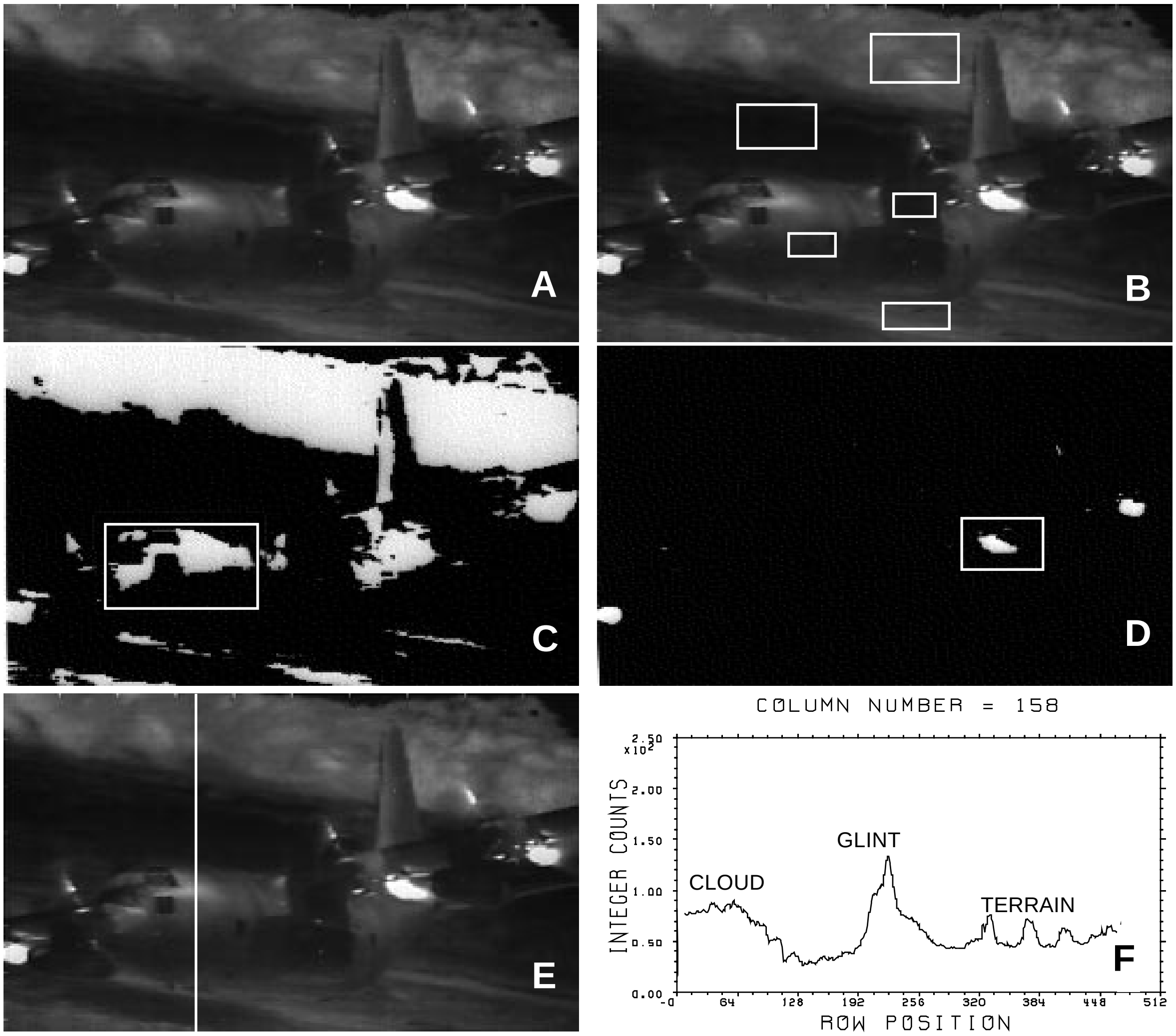

Figure 10 A SAIRS Infrared Image of an Aircraft Illustrating Methods of Analysis, (A) Measured Image, (B) Boxes for Radiance Averages, (C) Thresholded Image and Box Selection for Sunglint, (D) Threshold Image and Box Selection for Plume Radiant Intensity, (E) Vertical Line for Line Radiance Plot and (F) Line Plot From Image E Showing Some Components

A calibrated SAIRS infrared measurement is shown in Figure 12A and a SPIRITS computer generated image with the same radiance scale is shown in Figure 12B. This illustrates the power of the SPIRITS model in providing accurate simulation. The program is being upgraded as models for new targets are developed. Recently, time average and static propellers with propeller sunglints have been added. Wings, flaps, and cargo doors can be set at any position. Careful measurement of high bypass turbofan engine plumes has shown that the current standard plume flowfield model, SPF, is not adequate for some aircraft plume modeling. A muti-flow version with internal plume turbulence has been added to provide an acceptable level of modeling. The SPIRITS model is primarily designed as a fast operational tool, rather than a detailed research code, and thus can perform hundreds of computations from many target viewpoints in a variety of environments for threat and survivability analyses. To meet this objective, the code is designed to run fast without unduly compromising precision and accuracy.

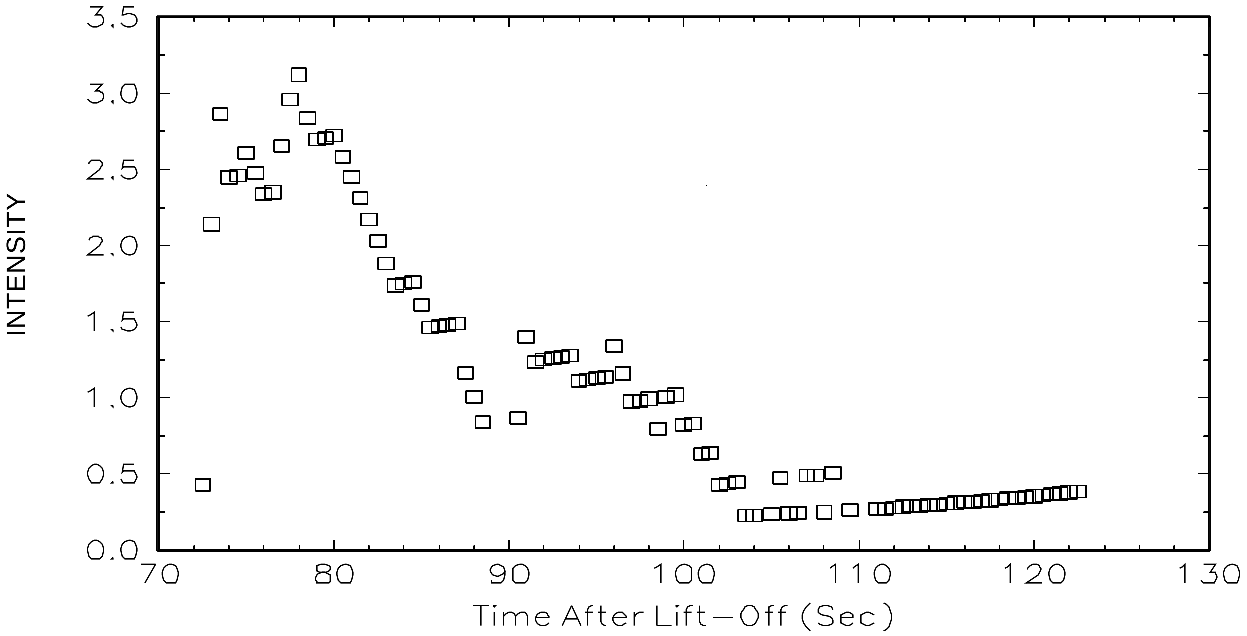

Figure 11 Radiometer Measurements in the Shortwave Infrared

Another important part of the FISTA program is the provision of support measurements. Upper air weather sounding balloon data, surface weather readings, general weather conditions, target flight parameters and engine operating conditions, the observers viewing aspect, range to target, sun position, and many other relevant parameters are collected so that thorough analysis can be performed. This data is assembled into a database program that can be easily queried for analyses tasks. Filter programs are also developed to provide the data in a transfer format for easy import into customer databases.

As the surface finish of the target plays a major role in determining its contrast signature, a considerable effort is required to establish the optical properties of the paints and metallic surfaces. The spectral directional reflectance, Figure 13, and bidirectional reflectance distribution functions at selected wavelengths, Figure 14, of aircraft surfaces are measured independently of the flight test and quantified into a parameterized model so that the SPIRITS code correctly predicts the surface radiance, including the reflected components from the surrounding environment. This understanding has been used to advise customers on appropriate types of aircraft surface finishes to minimize their contrast signature in specified scenarios.

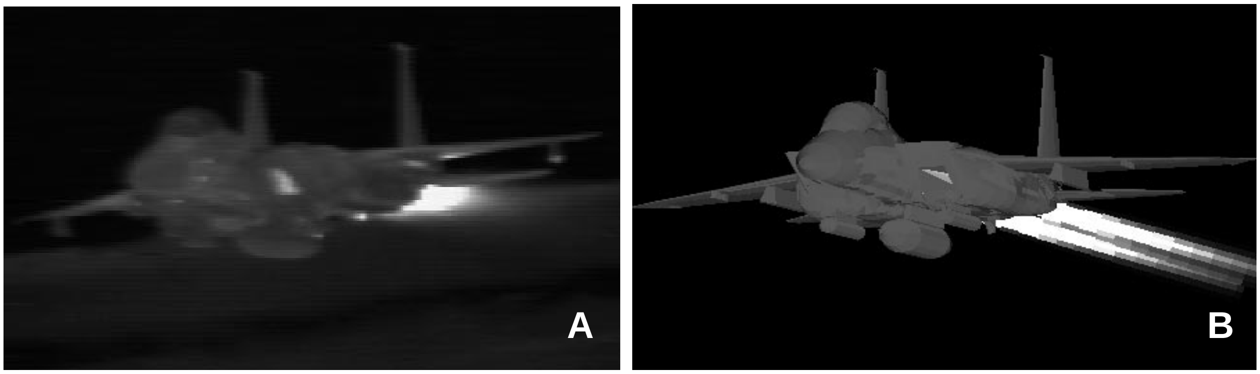

Figure 12 Comparison With Same Intensity Scales of, (A) FISTA Measurement, and (B) SPIRITS Model

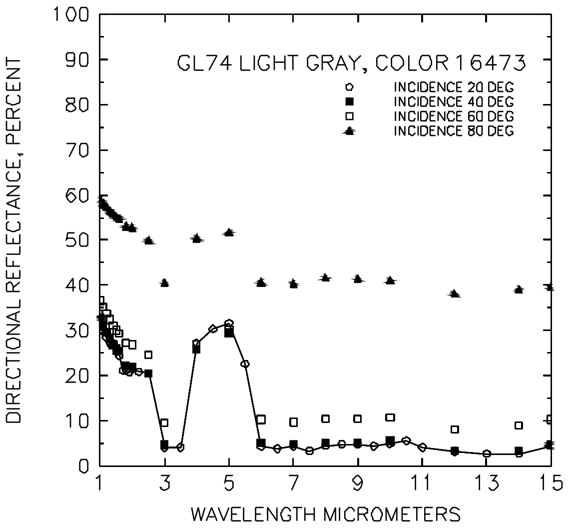

Figure 13 The Spectral Directional Reflectance of Paint GL74, Color 16473, Gloss Light Gray

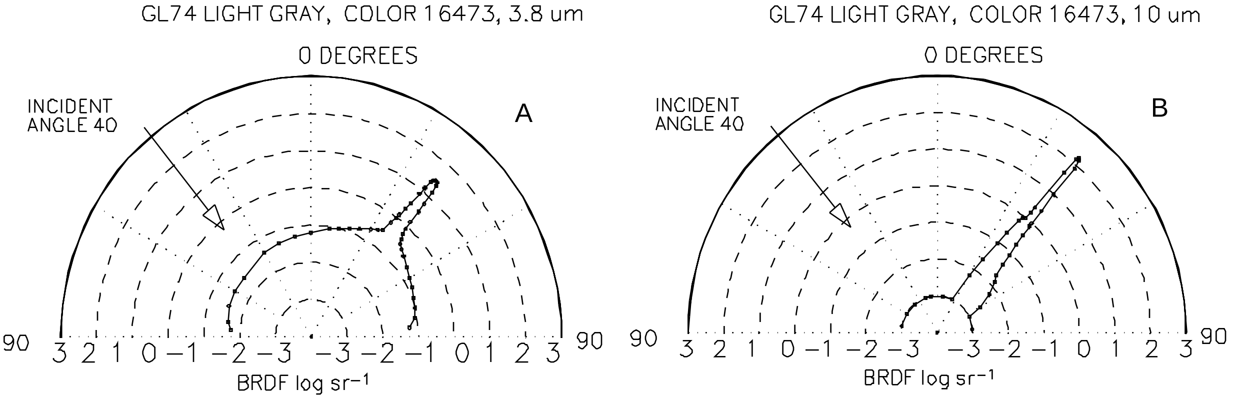

Figure 14 The Bidirectional Reflectance Distribution Function in the Plane of Incidence for Paint GL74, Color 16473, Gloss Light Gray, (A) At 3.8 µm, and (B) At 10 µm

FISTA SUMMARY

The FISTA II aircraft is designed to exceed the measurement capability of the old FISTA I aircraft by providing a more complete range of measurement geometries. In addition to the original spectral, spatial, and radiometric capability, an expansion into calibrated measurement in the visible is in development and near infrared and UV coverage is planned. Provisions for a versatile lidar sampling system are included in the aircraft layout. Space has been designed and reserved to accept government and industry users of the aircraft that increases the utility of the platform. Potential users can contact PL/GPOA as shown below. All measurements will continue to be accurately calibrated to meet the user needs for data to support the development of signature prediction models and to understand target performance.

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