FUEGO Airborne Signal/Noise Study using LWIR Microbolometer Array Cameras

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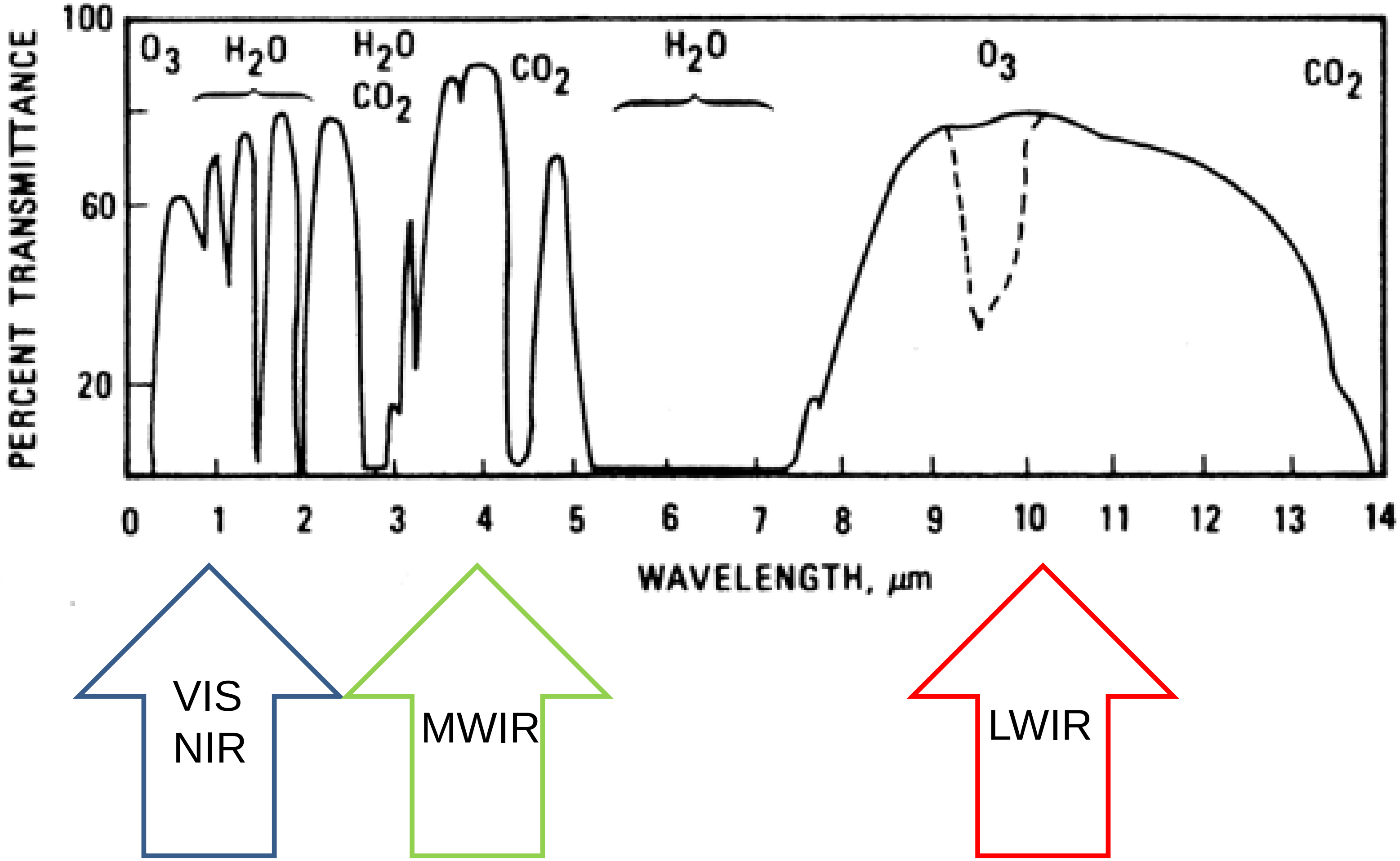
Artwork: Robin E Lafever

Background: NASA photo

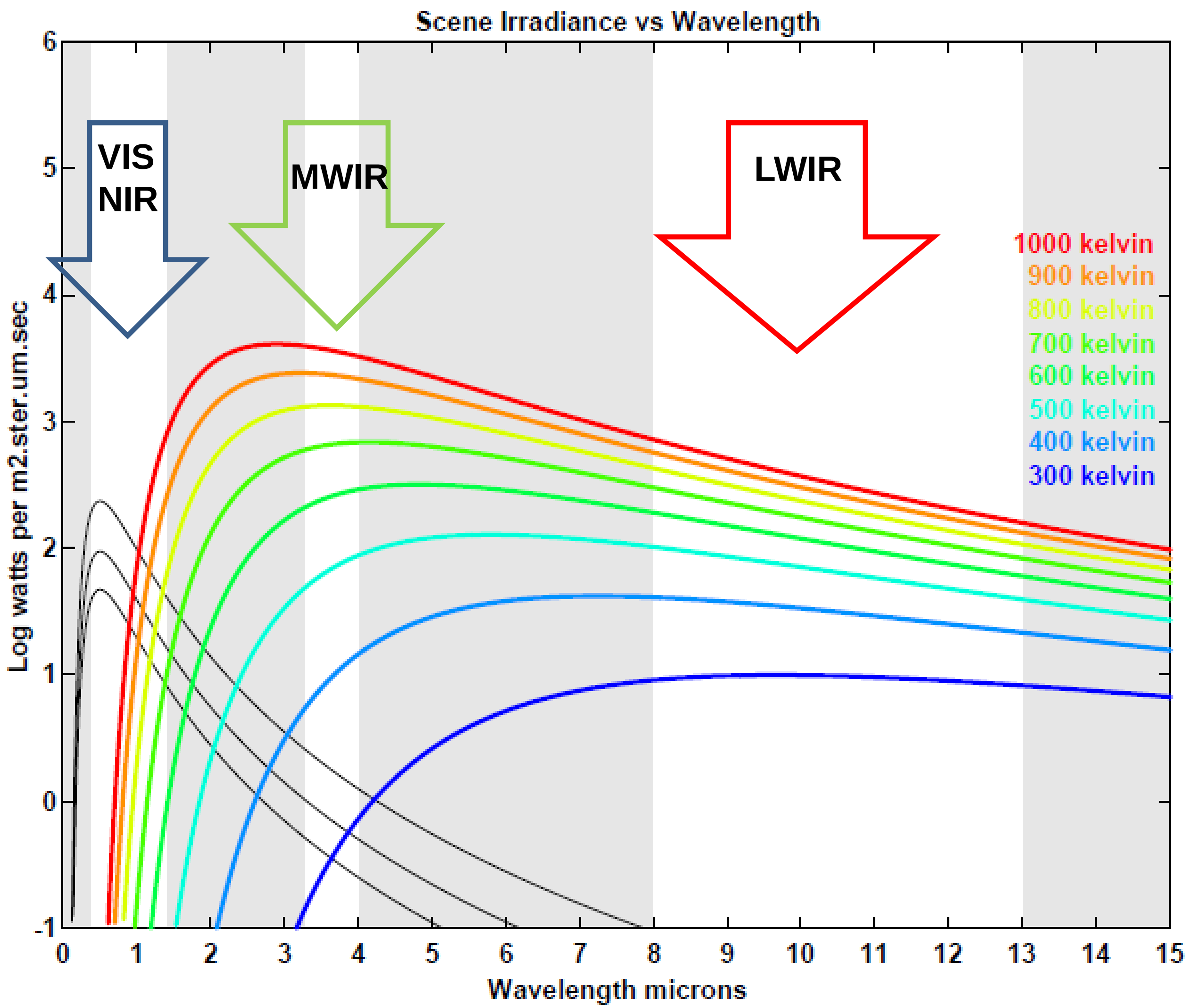
Atmospheric Transmission vs Wavelength

http://www.fao.org/docrep/003/t0355e/t035



Irradiances in Three Wavebands

Black: Noon Earth, Albedo=0.1, 0.2, 0.5
Blue: 300K, ε=1, Earth day or night
Other colors: Fire signatures increasing effective temperatures



VIS:
- Excellent scene context
- Excellent angular resolution
- Huge applications & market
- Cheap lenses & sensors
- But ... little or no fire signal

MWIR:
- Best possible fire S/N ratio
- Good angular resolution
- But...cooled sensors
- And... heavy, bulky, hungry
- Tiny market
- Still most costly technology

LWIR
- OK fire S/N ratio
- Variety of lenses and sensors
- Midsize market
- Not too costly

Microbolometer-Array Cameras for the LWIR

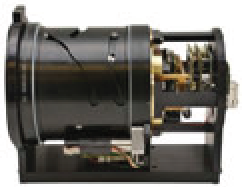
Example: Atom 1024: amorphous Silicon

Camera body: 70mm cube, 230 grams
1024 x768 pixels; each 17μm square
noise = 0.05 kelvin RMS;
LWIR 8-13 μm thermal band
2W electrical power; Ops -40C to +60C
14 bit CameraLink input/output

many lenses...

50mm f/1.0
HFOV=20°
Manual focus

50mm f/1.2
HFOV=20°
Fixed focus athermal



15-100mm f/1.4
HFOV=9.9-68°
Continuous zoom
motorized focus

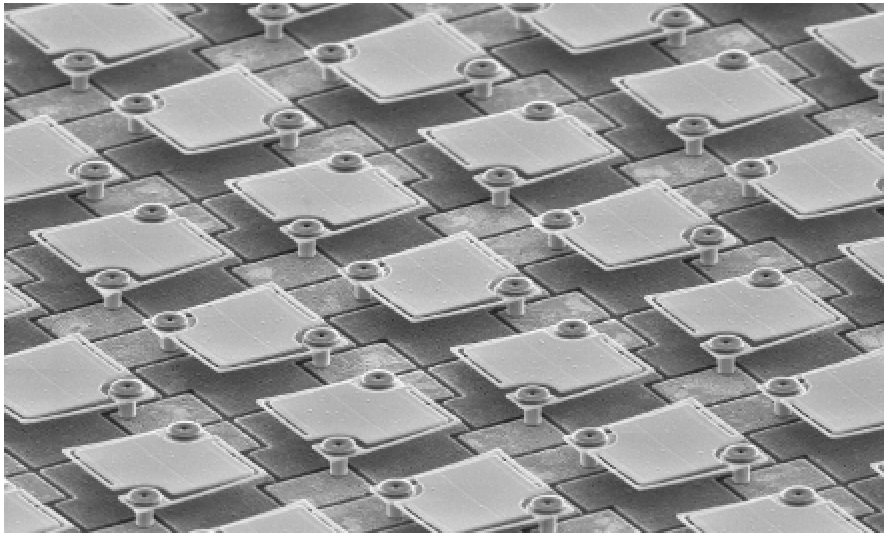
25-150mm f/1.4
HFOV=6.6-40°
Continuous zoom
motorized focus

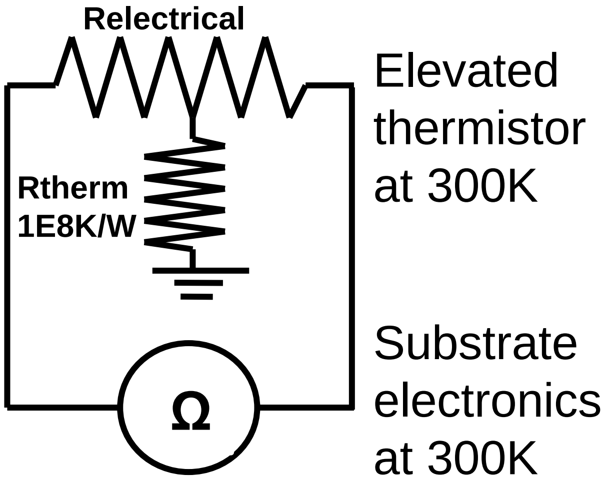
25-225mm f/1.5
HFOV=4.4-40°
Continuous zoom
motorized focus

A Warm Microbolometer Model

based on the CEA LETI/IR-FPA model

NEDT, K	0.054
Pixel, µm	17
EBW, Hz	100
Rth, K/W	1.0E+08
TCR, per K	0.03
TempResponsivity V/K	0.011
therefore Vnoise, V	5.94E-04
FillFactor	0.60
Absorption Effic	0.60
PowerResponsivity V/W	4.0E+05
NEP=Vn/R, W	1.50E-09
D*, cm √Hz/W	1.13E+07
Becker, S., et al Proc SPIE 8541 (2012).	





Observatory Assumptions for LWIR S/N Estimates

LWIR Mission Assumptions		
Payload altitude, km	20	
Cloud conditions	clear	
Operating wavelength, µm	10	
Operating bandpass, µm	4	
Fire effective temperature, K	800	
Fire irradiance, w/m²µm.ster	237	<< Planck law

Results: Four Alternative Lenses

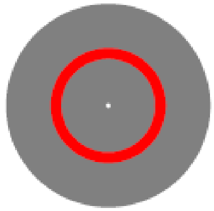
Camera and Lens Assumptions				
Pixel size, µm	17			
Pixels per array side	1000			
Throughput, filter * QE	0.3			
Lens aperture, mm	40	50	60	100
Lens focal length, mm	80	100	120	200
Pixel size on ground, nadir, m	4.3	3.4	2.8	1.7
Diffraction diameter, nadir, m	12.0	9.6	8.0	4.8
Sampling, pixels per diffraction diam	2.8	2.8	2.8	2.8
Angular field, degrees	12.1	9.7	8.1	4.8
Linear field at nadir, km	4.25	3.40	2.83	1.70
Tview one pass at nadir, 150kts, sec	57	45	38	23
Pushbroom width, ten cameras, km	71	45	34	18
Warm-camera Microbolometer Array				
Exposure time, s	0.01			
Assume D* (cm rootHz/W) =	1.00E+07			
Noise bandwidth, Hz	100			
NEP, watts/pixel	1.7E-09	1.7E-09	1.7E-09	1.7E-09
Filled-pixel fire signal, watts	1.4E-08	1.4E-08	1.4E-08	1.4E-08
Signal to noise ratio, one exposure	8.4	8.4	8.4	8.4
Signal to noise ratio, one pass	348	311	284	220

Trying four f/2 lenses

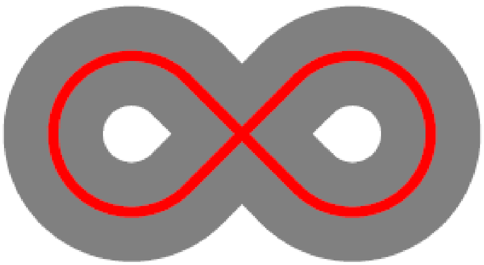
These are fabulous signal-to-noise ratios: reliable fire detection

A Few Airborne Surveillance Flight Patterns

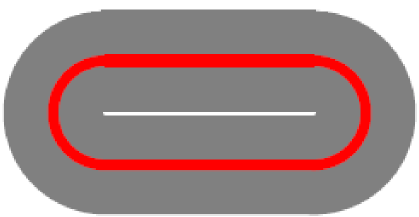
Gray: Survey Region   Red: Flight Path



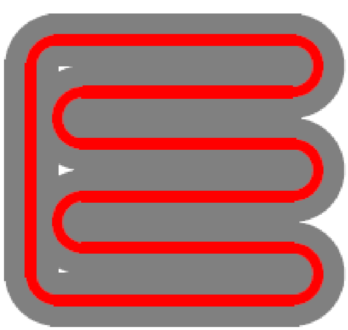
Circles: continuously on a single target.
If swath=30km & radius=15km, circum=90km



Eights: frequent returns to one spot but also some upwind & downwind coverage



RaceTracks: dense coverage but also extended downwind coverage



Boustros: completely reprogrammable in NS and EW coverage but area has a direct cost to reobservation frequency

Moving Platform OK?

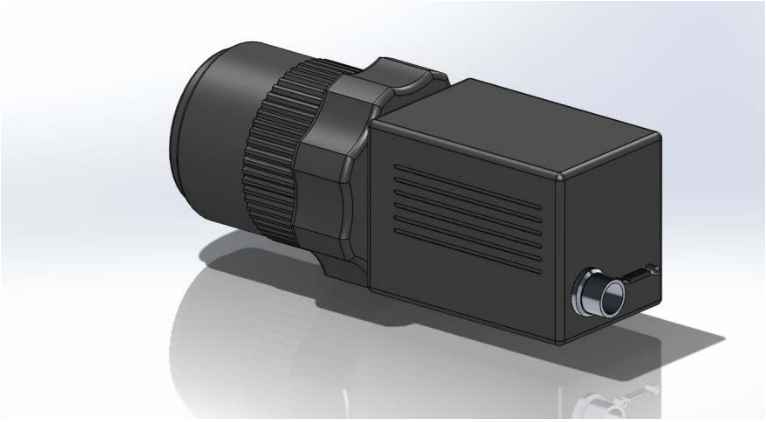
	100 Knots (50m/sec)	150 Knots (75m/s)	200 Knots (100m/s)
Single-frame ground motional Blur at Texp=0.01s	0.5m OK	0.75m OK	1m OK
Scene revisit time at 90km flight path complete circuit	30 minutes	20 minutes	15 minutes
Image coadding time per visit at 3km view along flight path	1800 frames Huge S/N ratio	1200 frames Huge S/N ratio	900 frames Good S/N ratio

Yes ... Moving Platform is OK

Payload Concept from Robin Lafever

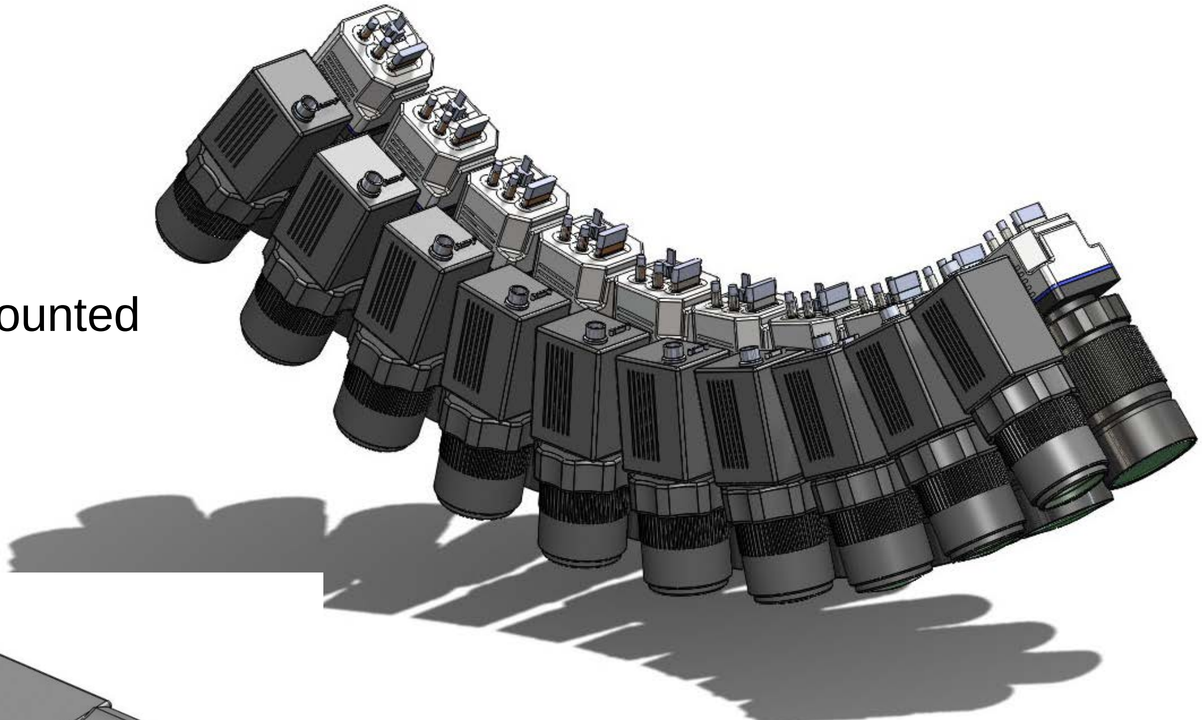
Basic Instrument components:

MWIR Camera based on ATOM 1024
with generic lens attached

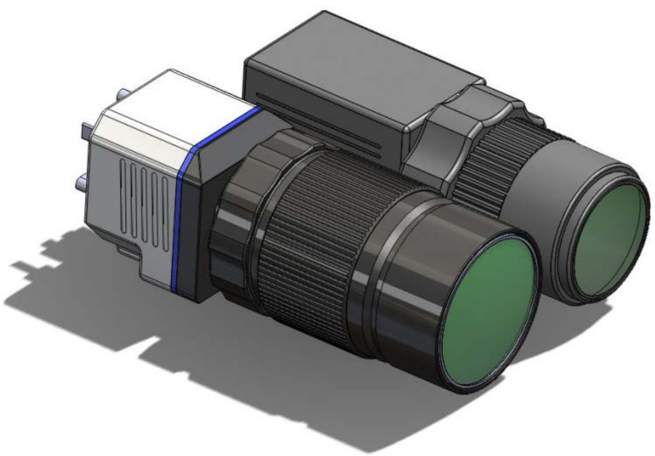


VIZ Camera based on GOBI frame
with generic lens attached

Payload Concept   Instrument Array

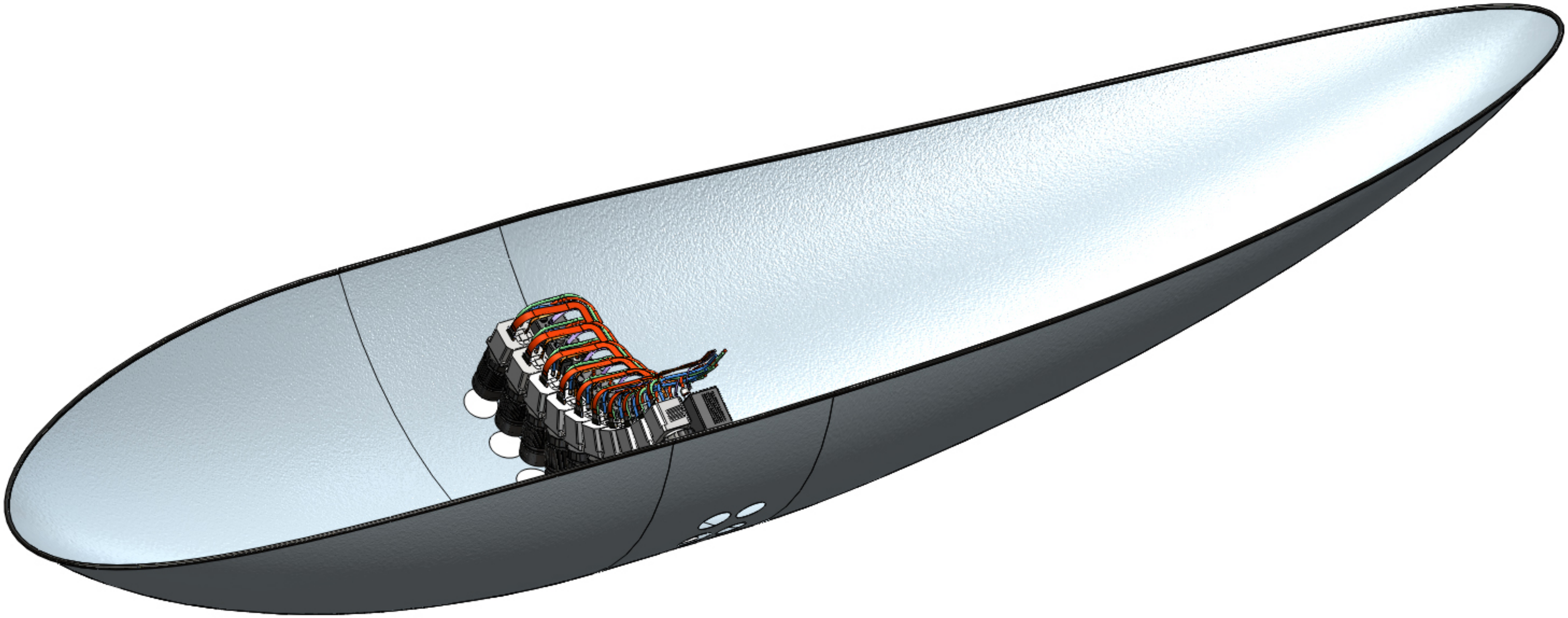


10 Camera pairs are mounted
at 9 degree pitch

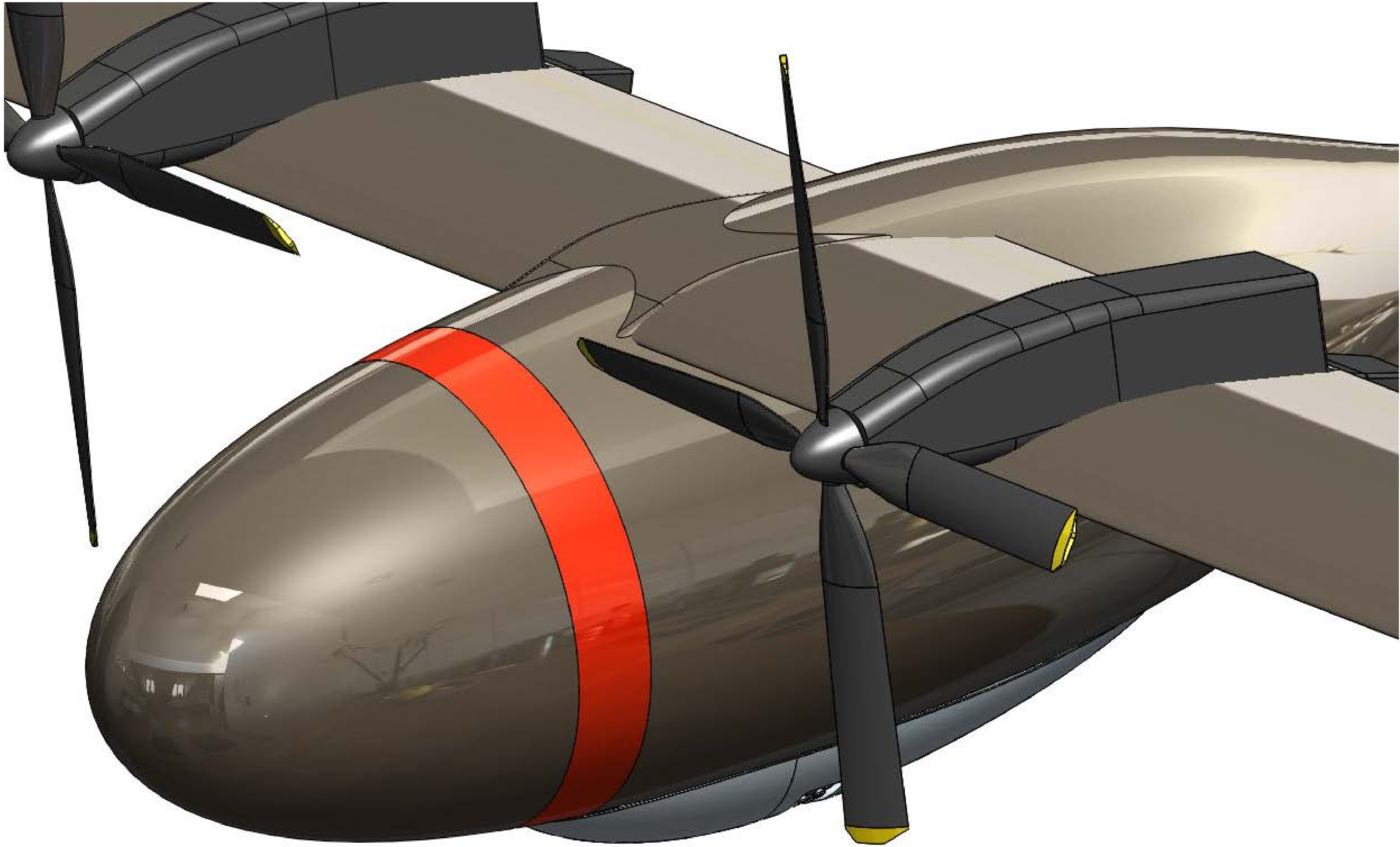


Payload Concept ‘Canoe’

A ***Canoe*** is an instrument carrier bay that is mounted to the

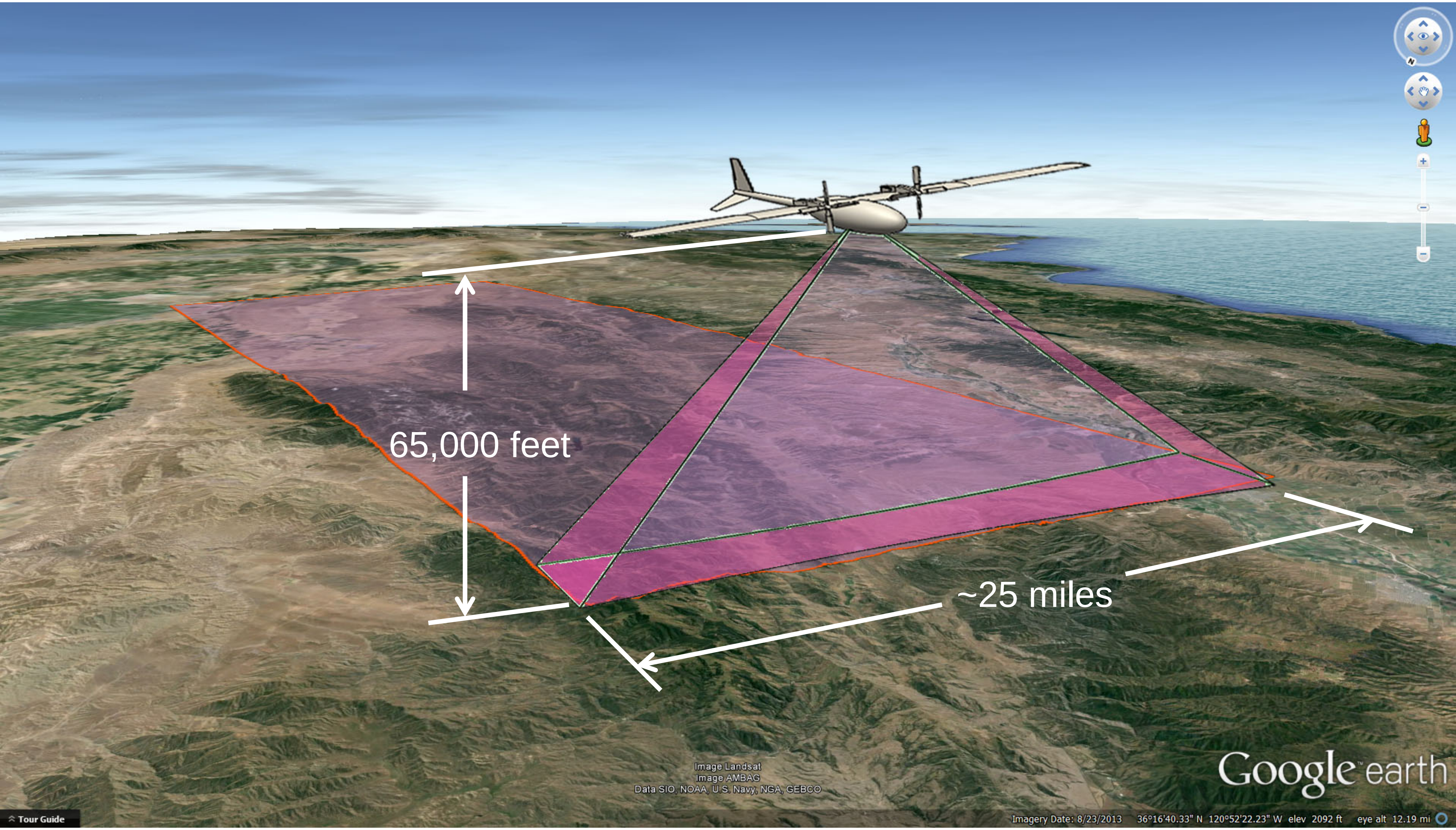


Camera array is mounted in its canoe with downlooking views in a pushbroom port-to-starboard arrangement.

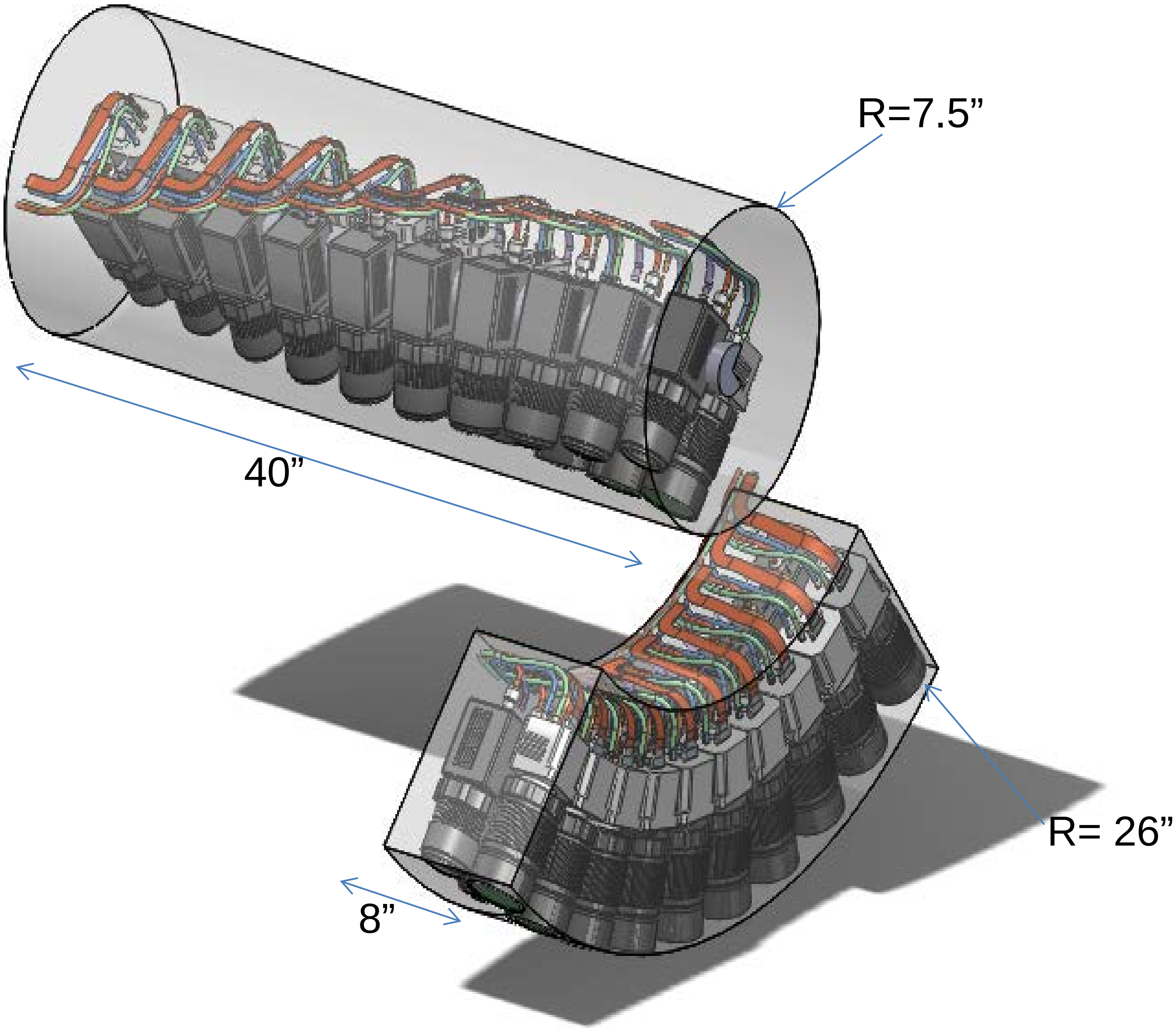


Airborne platform with Canoe

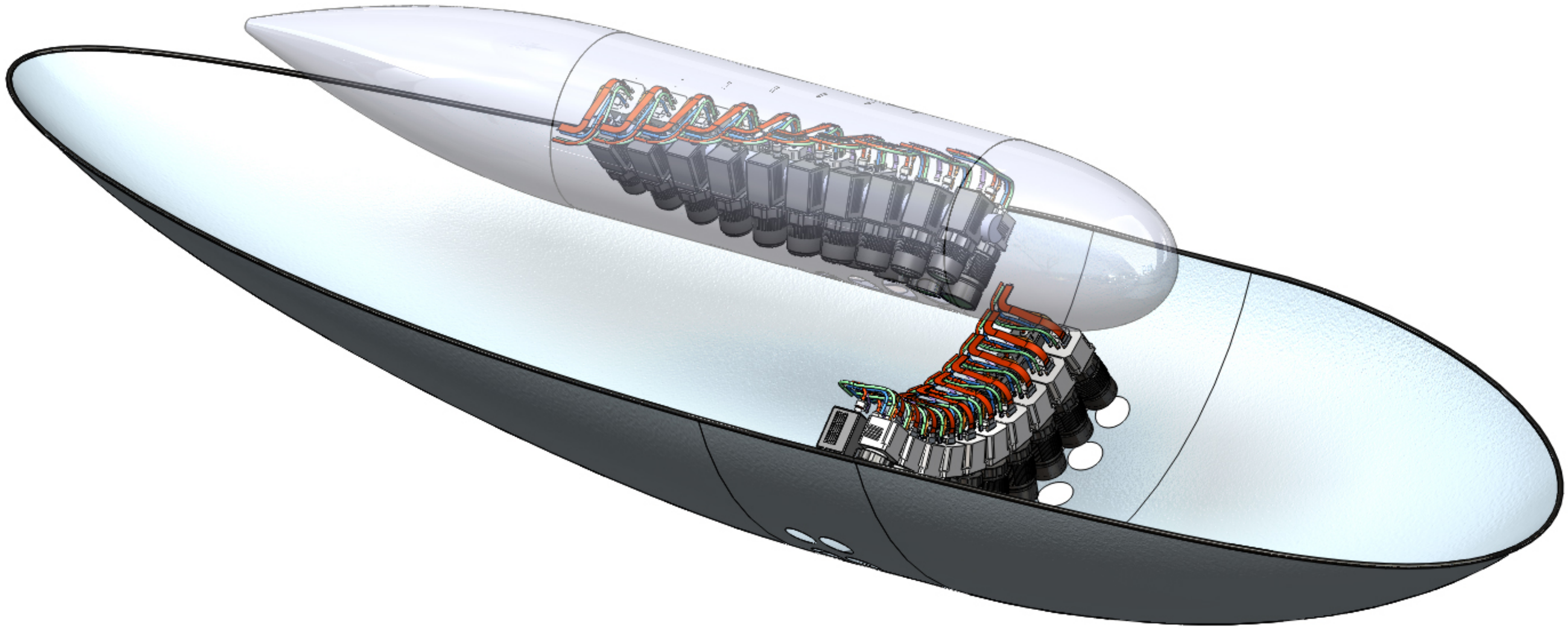
Nominal scan profile



Alternate packaging options

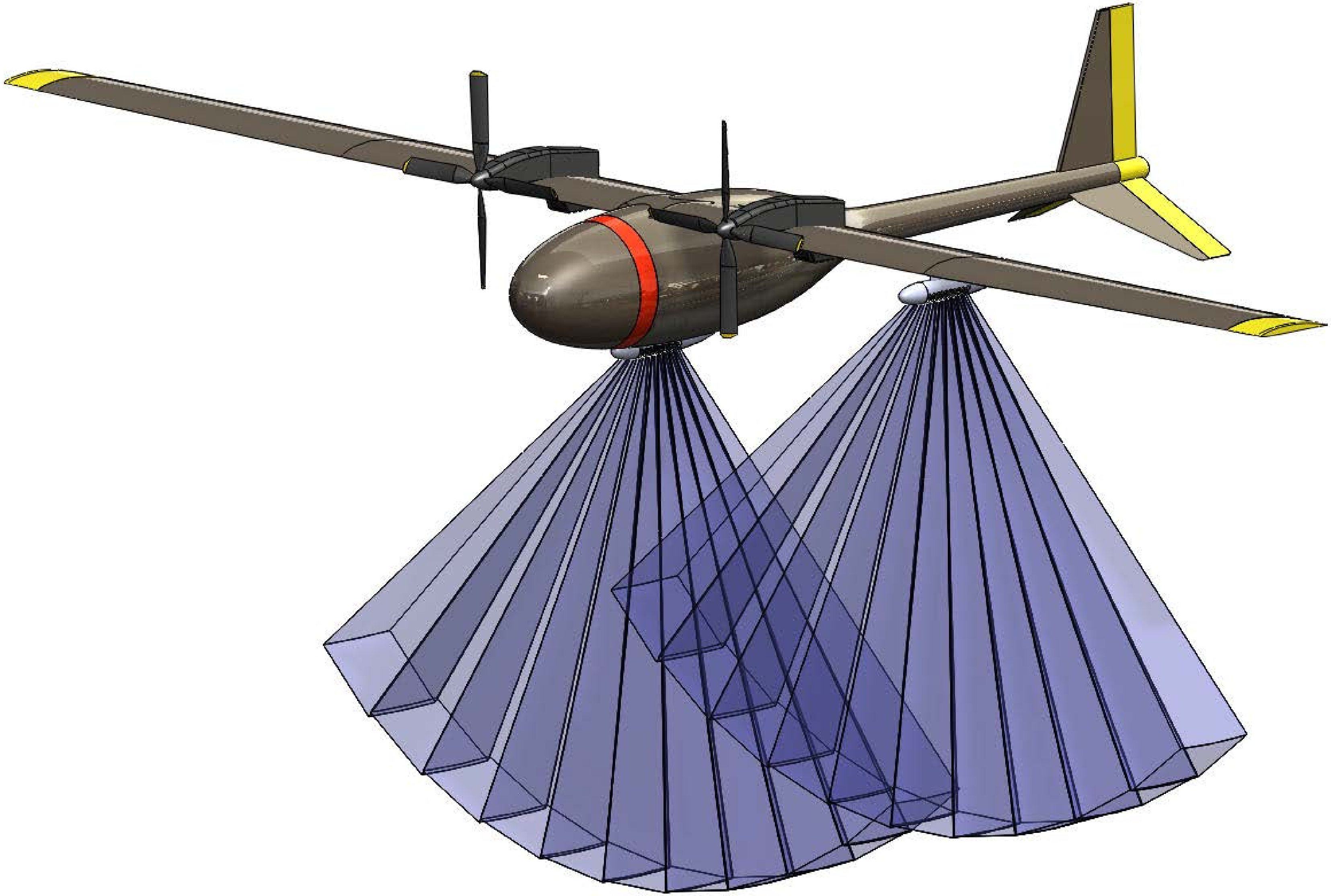


Alternate packaging options --- Canoe Vs Pod



Alternate packaging options

Canoe and Pod have similar Observation patterns



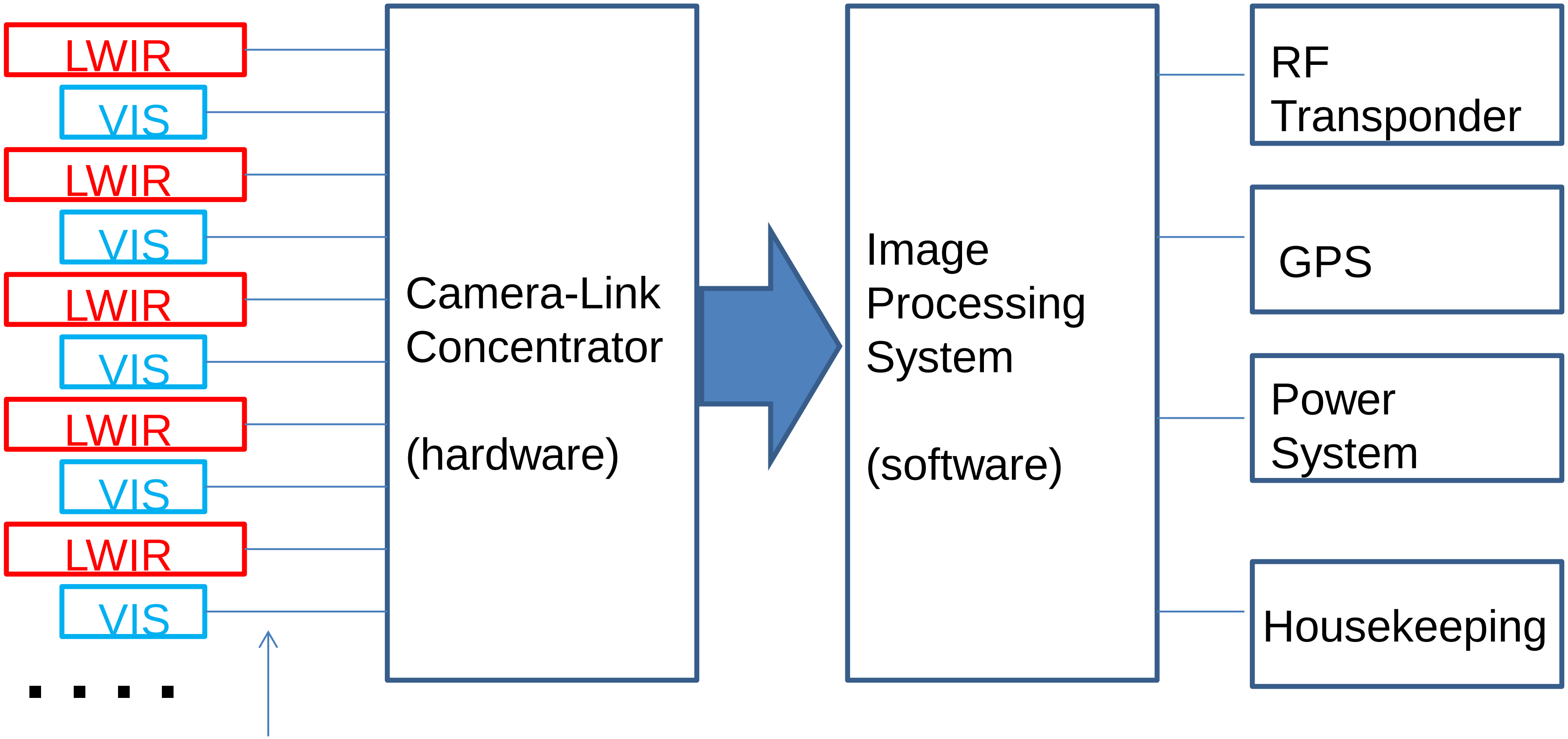
Data Processing Tasks

- *Gather raw images the IR and the VIS cameras*
- *Gather time critical ancillary data*
  - *GPS, vehicle attitude, yaw rates*
- *Clean, remap, coadd pixel data onto geospatial grid*
- *Detect & classify unusual features*
- *Create a list of hotspot groups with thumbnails*
- *Downlink hotspot list with engineering data*
- *Receive list and evaluate engineering data*
- *Prioritize hotspot list as to urgency*
  - *Hotspots growing? heating up? moving?*
  - *Requires real time GIS support*
- *Distribute to firefighting team as appropriate*

FLIGHT

GROUND

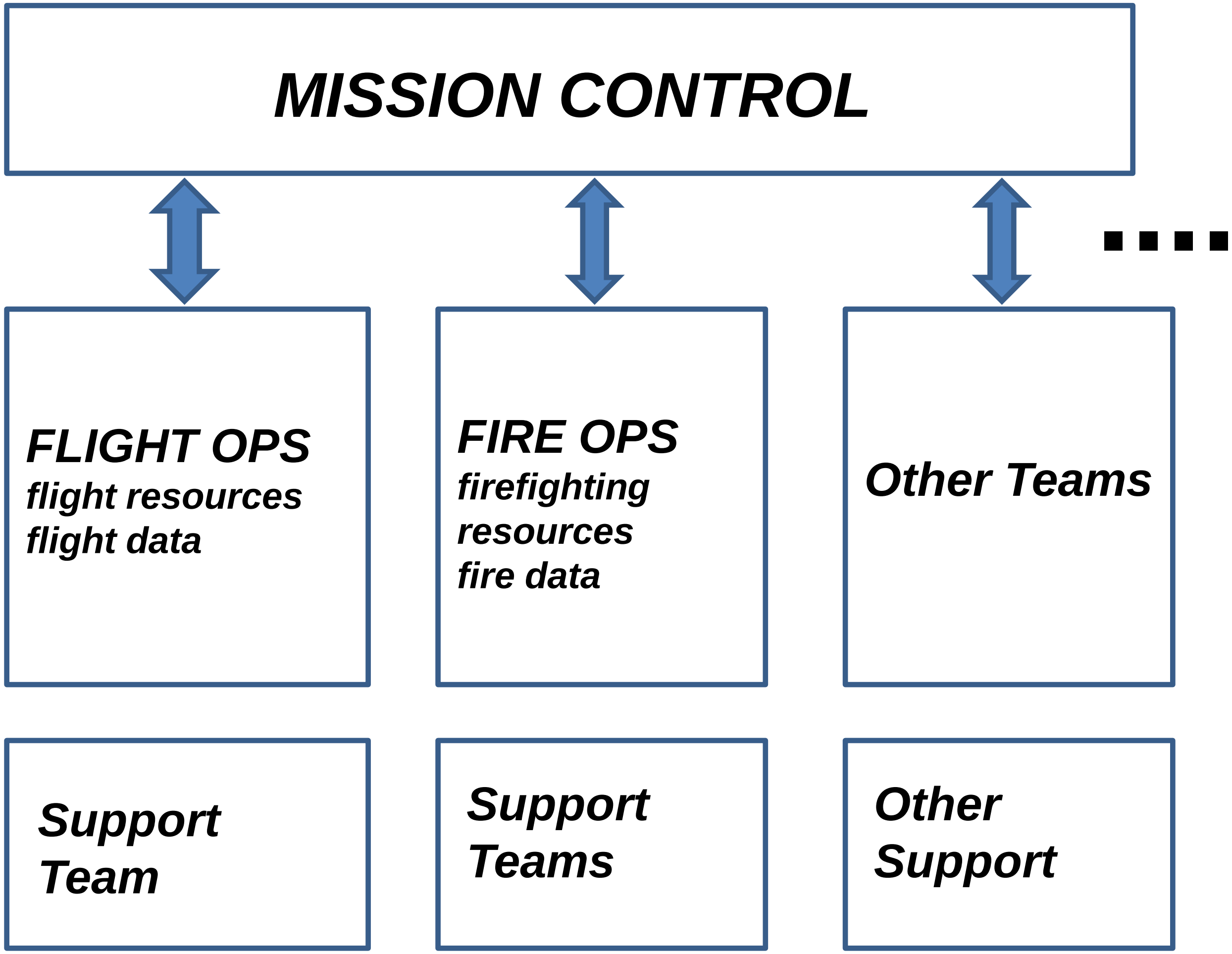
Flight Systems Overview



INPUT raw data from cameras:
Each camera: 1MPix, 2 bytes/pix
At 30 frames/sec: 60MB/sec
20 cameras together: 1.2GB/sec

OUTPUT useful data to downlink:
Each hotspot: 6kBytes
100 hotspots/minute: 10kB/sec
One scene map/minute: 16kB/sec

Ground Systems Overview



Shovel Ready?

------VIS Cameras with Lenses---------

Allied Vision Technologies: Mako, Guppy, ...
Imaging Source: 8 models, moho or color
Sony: ~80 models; monochrome, color
Thor Labs: ~ 12 models, monochrome
Basler: ~ 7 models, mono and color
PixelLink: 5 models various interfaces
JAI –PULNiX family: 8 models, mono, color
... too many more to list

-------LWIR Cameras with Lenses--------

SpectralCameras “Gobi-640” A-Si, 17um, 50mK
DRS “UC640-17” VOx 17um 50mK
Jenoptik “VarioCam” 1024x768 50mK 1100g
ICI “7640 P-series” 640x480, VOx, 40mK, 1W, USB.
Sofradir “Atom-1024” A-Si, 17um, 54mK, 2W, GigE
FLIR “Quark-640” VOx, 17um
Selex-Galileo “Alice-640” VOx

---IR Lens and WindowSuppliers-----

ElectroPhysics / Sofradir / IRCores
Edmund Optics
FLIR Systems / Indigo Operations
Jenoptik Optical Systems Division
New England Optical Systems
NovoTech Incorporated “Ocelot” series
Ophir Optics

Field Testing Possibilities

**** Mountaintop tripod setup viewing test burn area***

**** Manned rental helicopter patrolling test burn area***

**** Remote-control UAV patrolling test burn area***

Example aircraft from UAVfactory.com (U.K.)   camera pod from ISPoptics.com (Latvia)

Conclusions and Future Work

- ***Microbolometer LWIR cameras appear to do the job!***
- ***Cameras, lenses, software drivers all available***

- ***Hardware R&D effort: high throughput concentrator***
- ***Still needed: ground & field validation of SNR assumptions***
- ***Still needed: image fusion & coadding software***
- ***Still needed: hotspot detection & extraction software***
- ***Still needed: guidance by the firefighting community***
- ***And of course: engineering support and a student!***