Shuttle Guidance Navigation and Control Subsystem Redesign

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GN&C

- Guidance
  - Determining where you want to go
- Navigation
  - Determining where you are
- Control
  - Getting from where you are to where you want to go

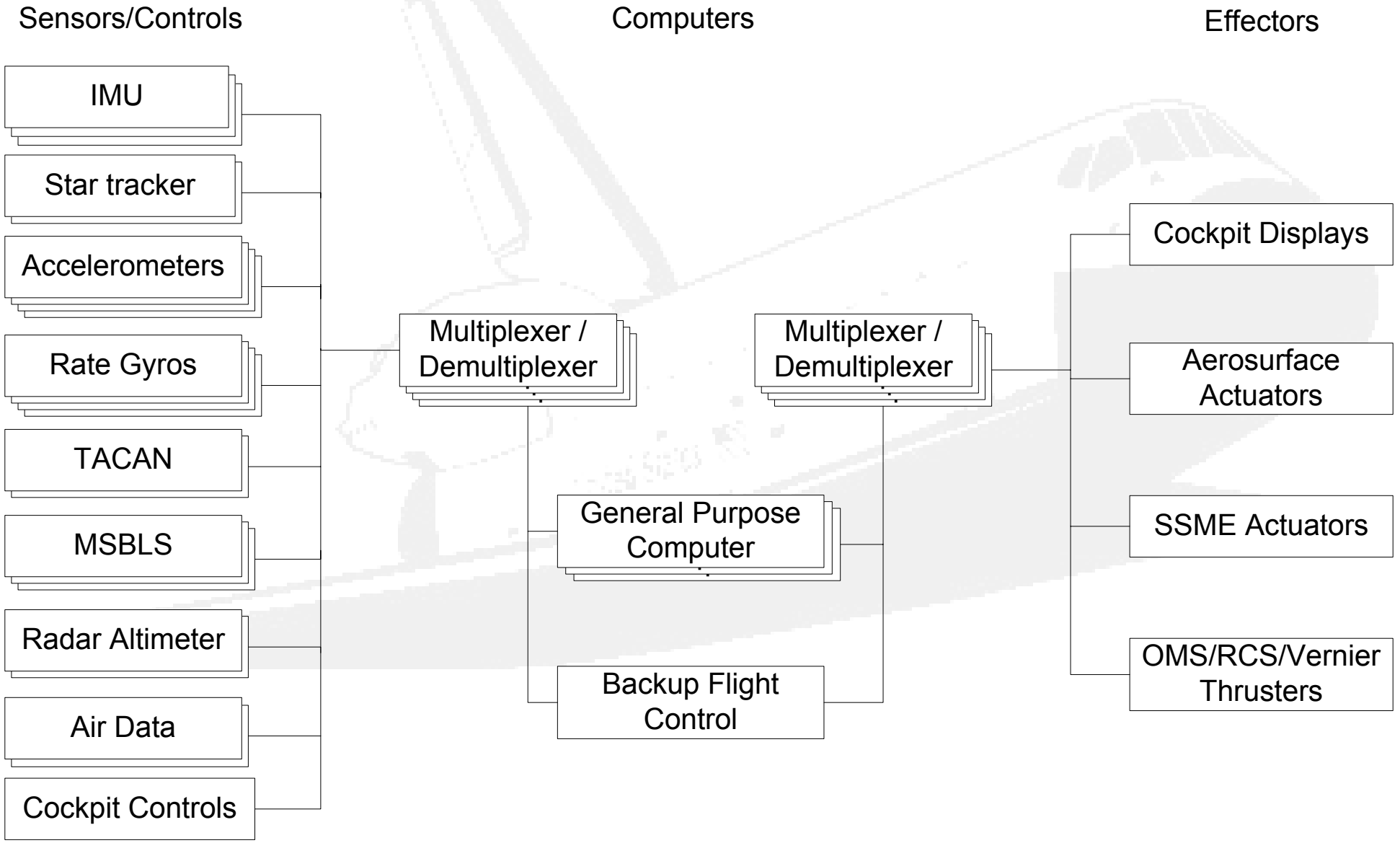
Overview

- Major modification - Integration of GPS
- Hardware Trade Study
- Recommendations
- Performance Gain

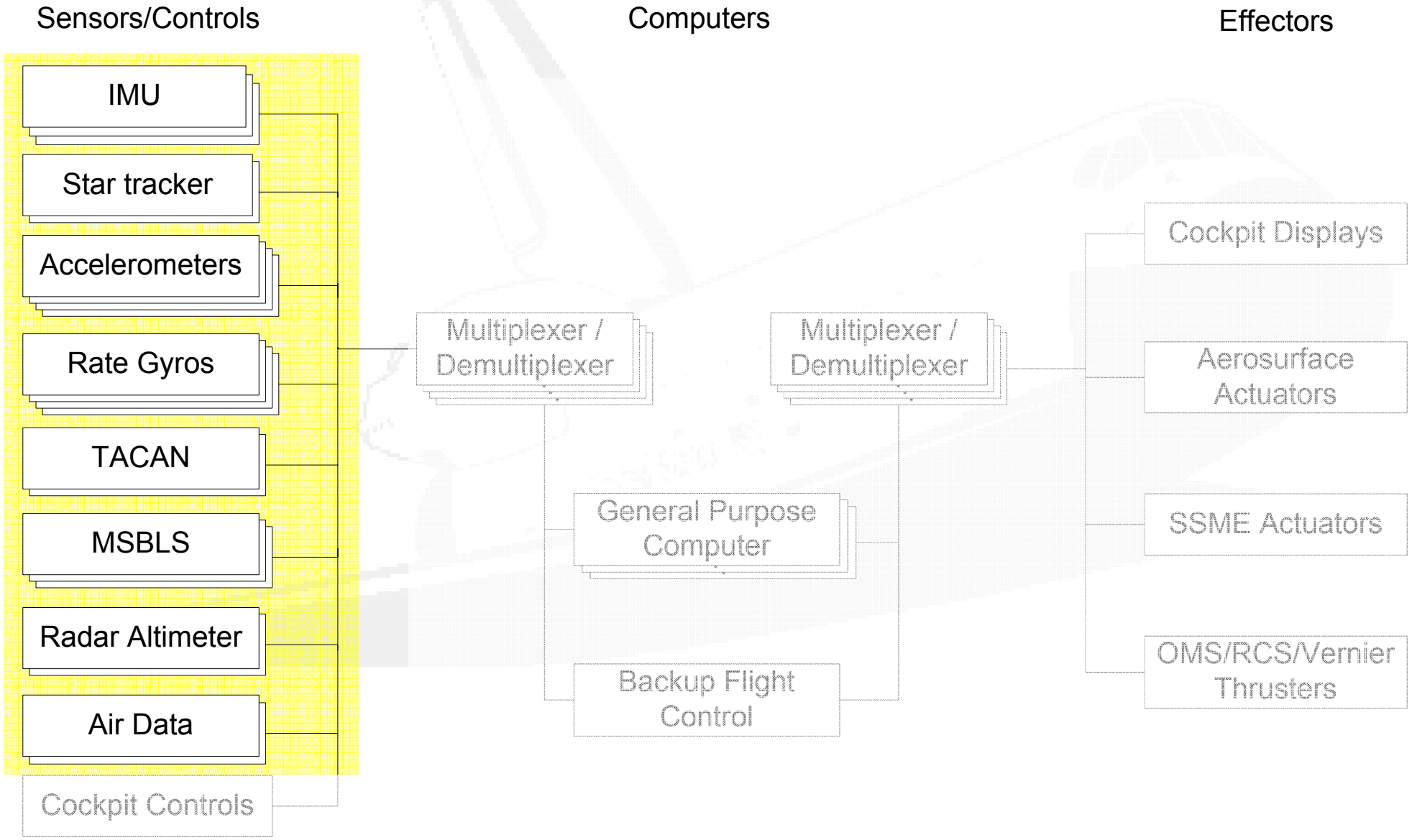
Redesign Constraints

- Figures of Merit
  - Cost (Don't have prices, but do have weight)
    - Maintainability – Space qualified hardware, fewer components
    - Lifetime Cost – Software support
  - Performance
    - Redundancy – Same criteria as original
    - Robustness
    - Power

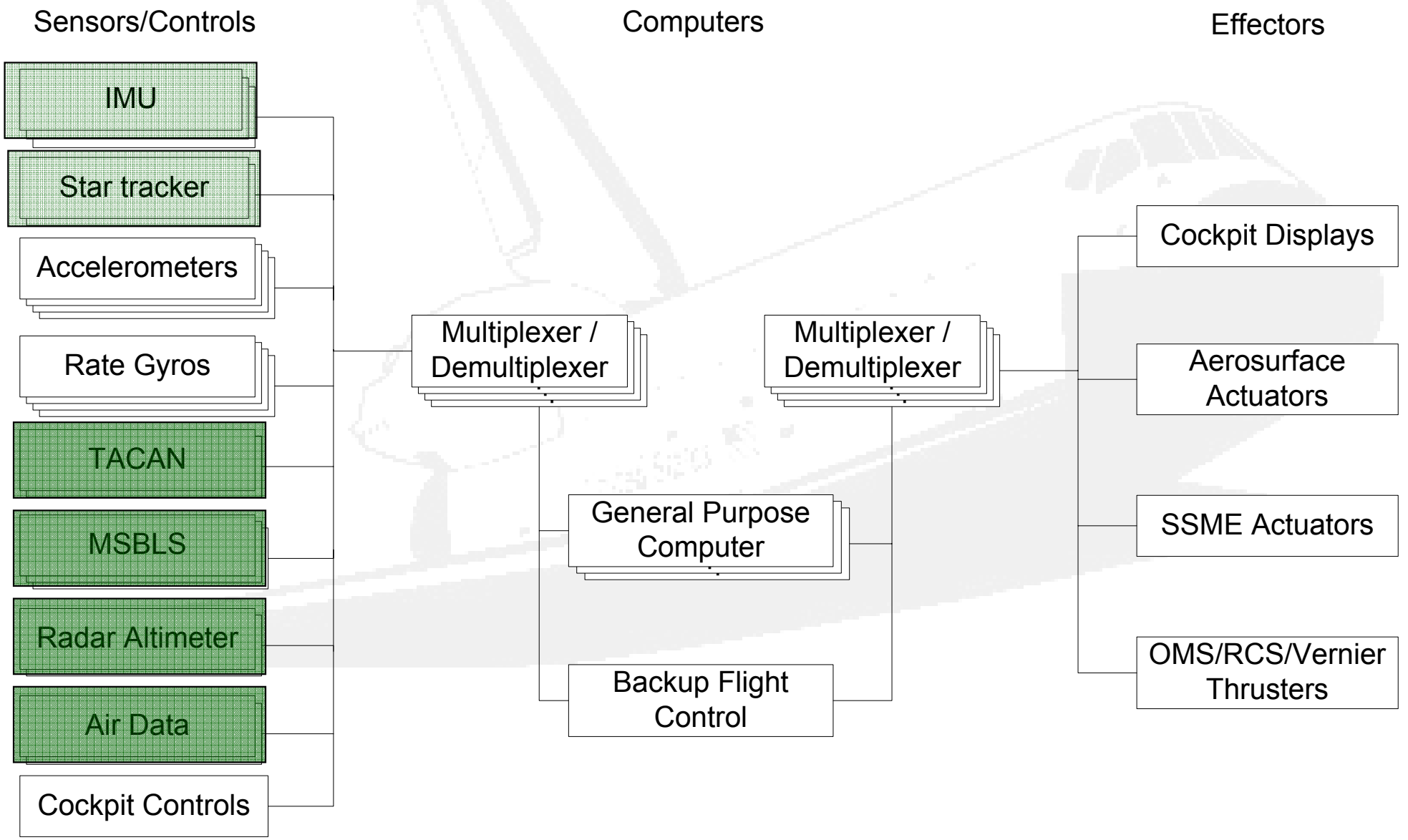
Current System Diagram



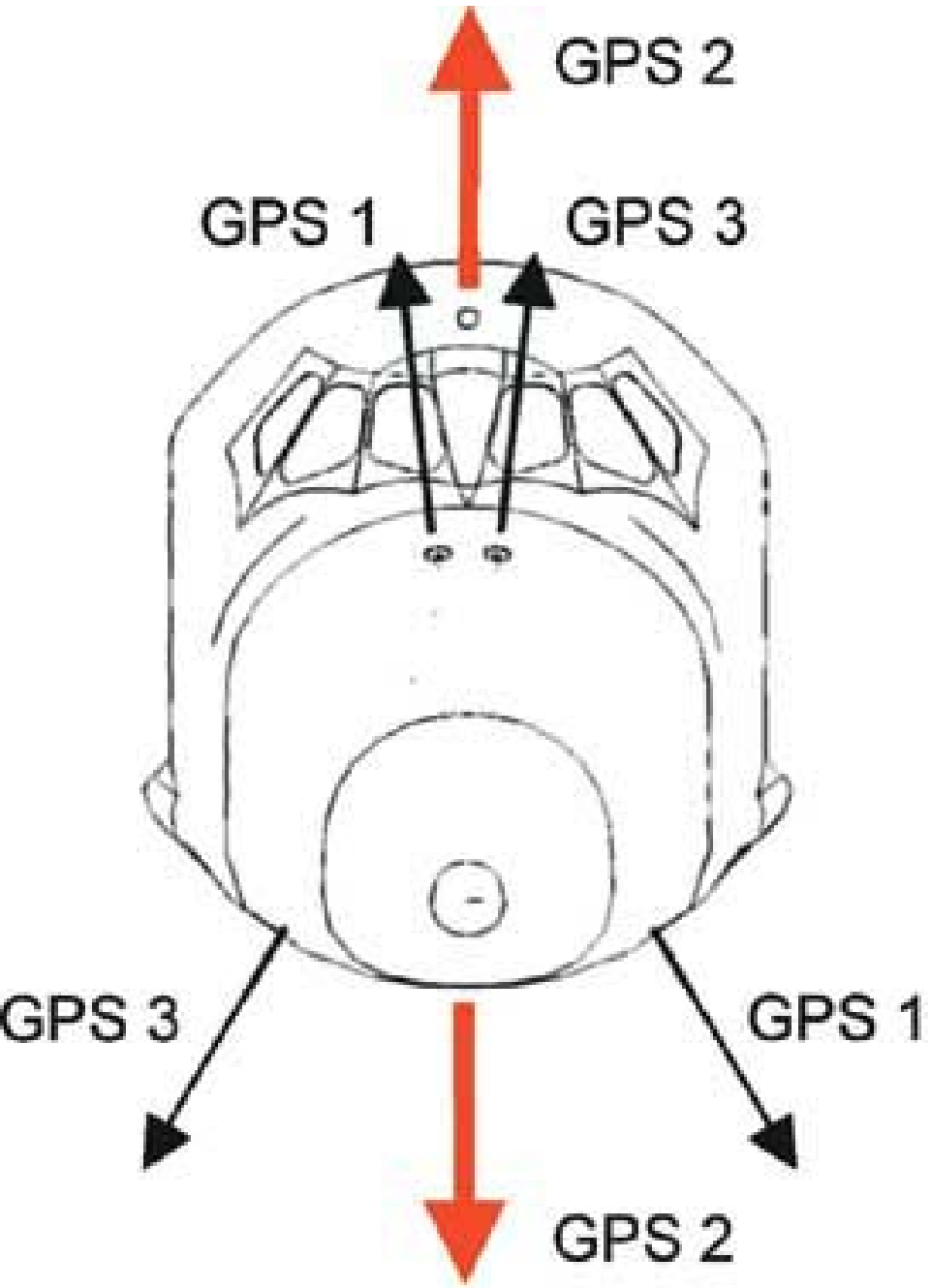
Redesign Focus

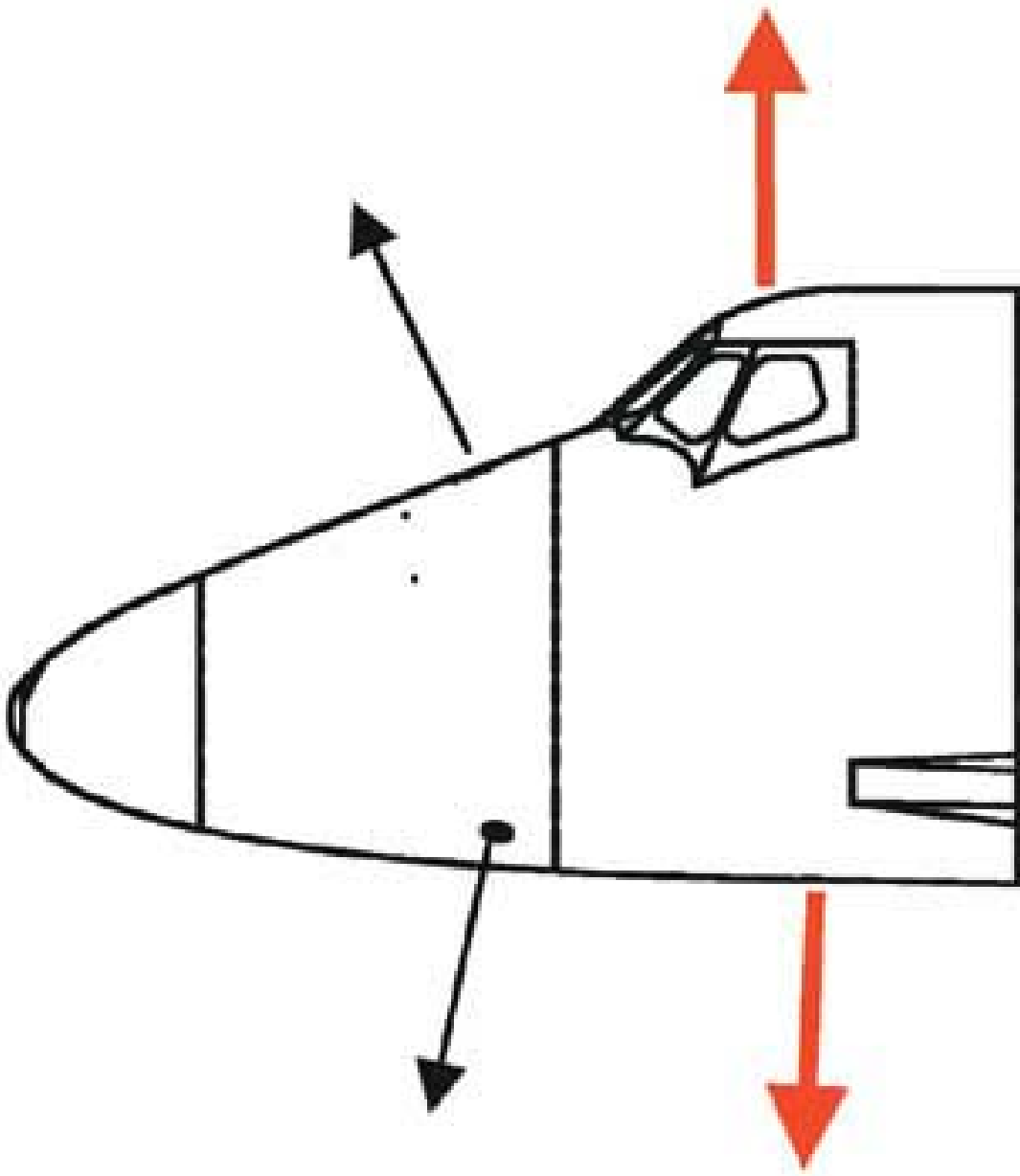


GPS Impact

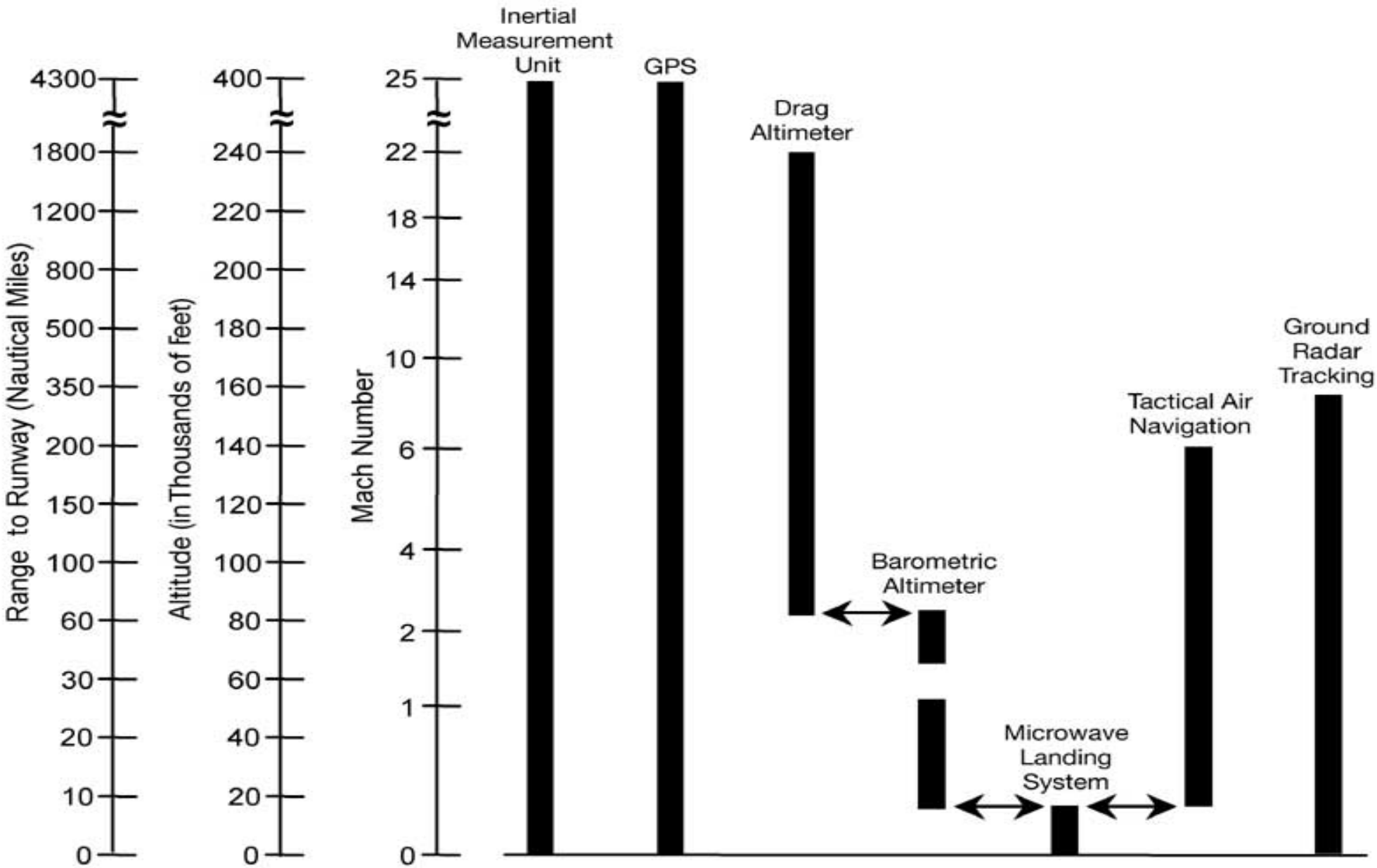

Sensors/Controls
Computers
Effectors
IMU
Star tracker
Accelerometers
Rate Gyros
TACAN
MSBLS
Radar Altimeter
Air Data
Cockpit Controls
Multiplexer / Demultiplexer
Multiplexer / Demultiplexer
General Purpose Computer
Backup Flight Control
Cockpit Displays
Aerosurface Actuators
SSME Actuators
OMS/RCS/Vernier Thrusters

GPS Antenna Locations

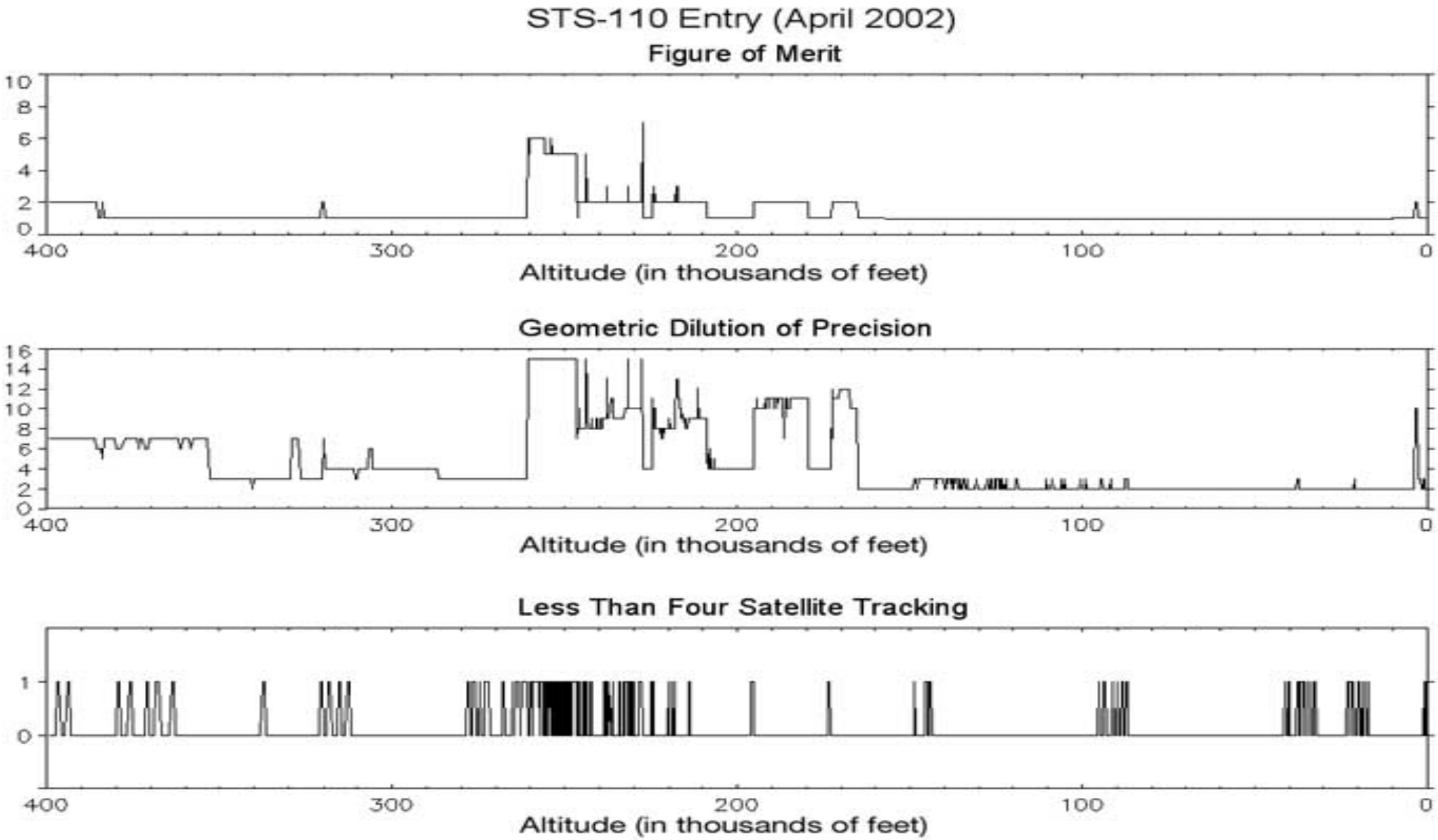




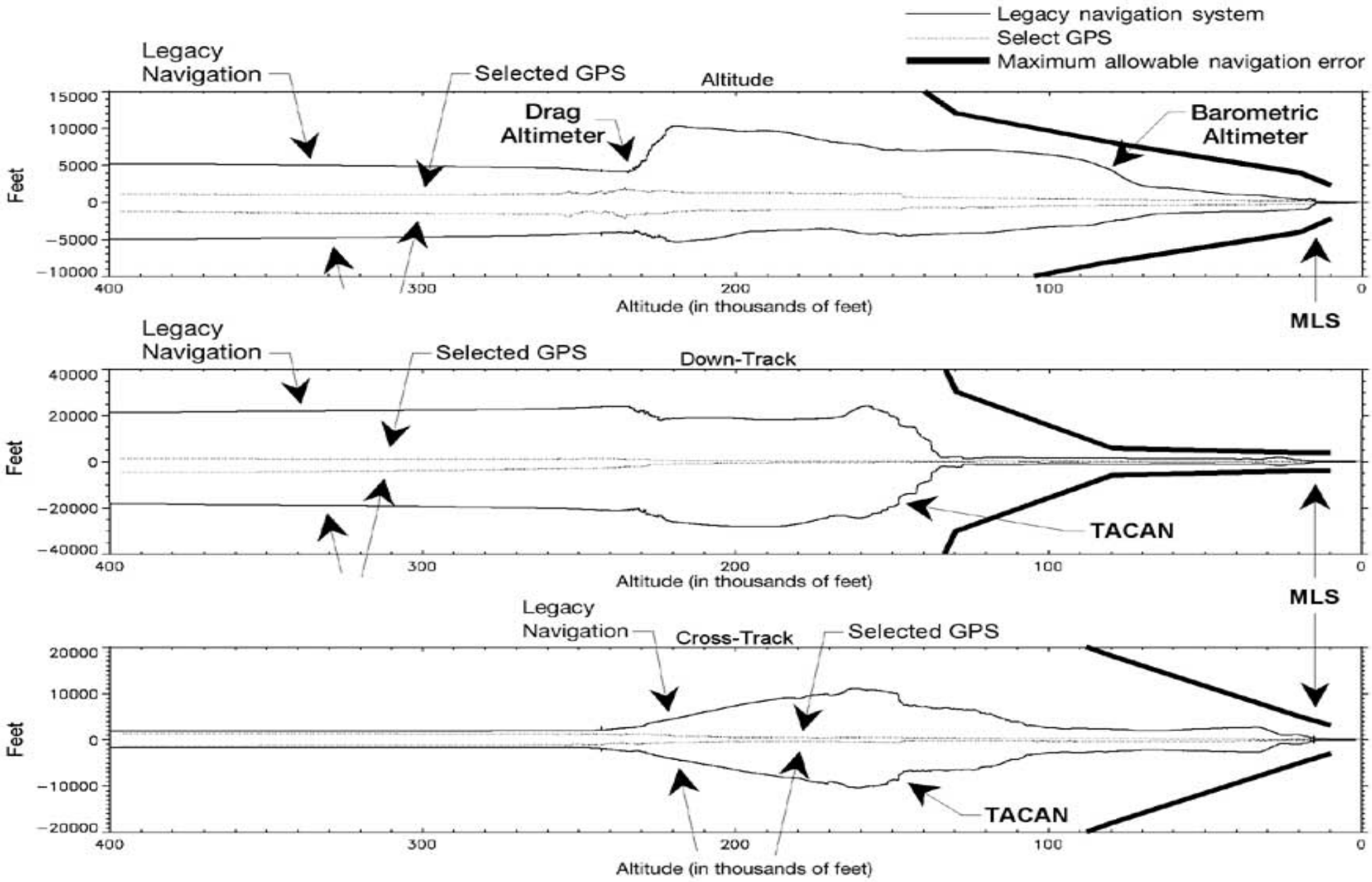
Instrumentation Used on Entry



GPS Performance During STS-110



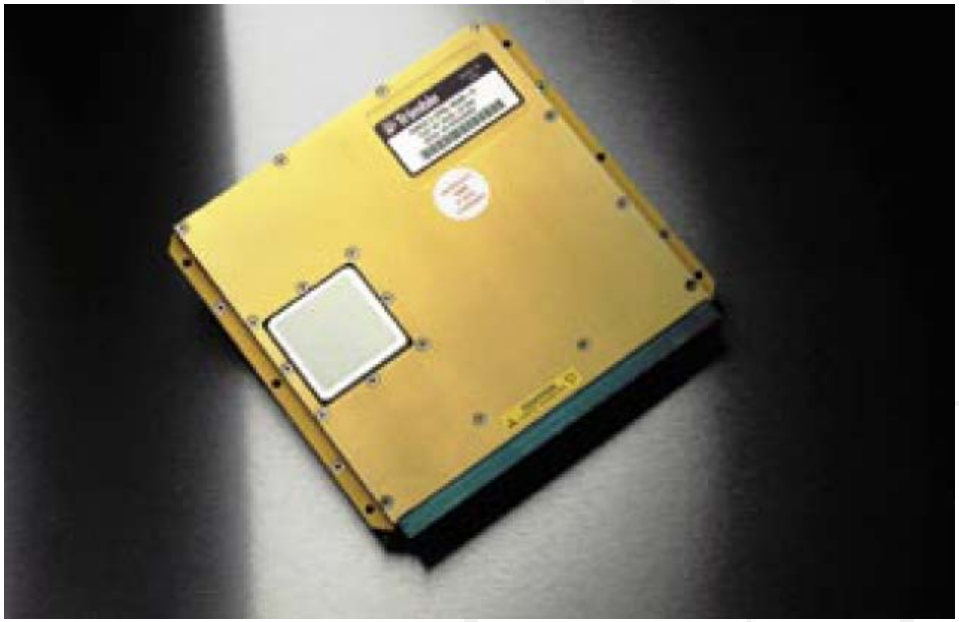
GPS Solution vs. Legacy System



GPS Trade Study

Unit	GPS	MAGR	Navstrike24	Force5	GPS/ IMU	SIGI	H-764 ACE
Pos. Accuracy (m) Vel. Accuracy (m/s) Time		< 15 < 0.1 < 100ns	< 3 < 0.07m/s < 30ns RMS	< 16 < 0.4 < 100ns		<50 <0.3 <155ns	<10 <0.05 <?
Size (in)		3.2x6.8x12	3.5x3x0.75	5.9x5.7x0 .6		7x7x9.8	7x7x9.8
Weight (lb)		12.3	0.5	0.94		21	18.5
Power (W)		115V/ 400Hz or 28V DC	4	16 (max) 8.5 (norm)		34 - 45	40
Space Qualified		*flew on shuttle	Unknown	x		x	
Track Record		x	x	x		x	Unknown
Availability		x	x	x		x	x

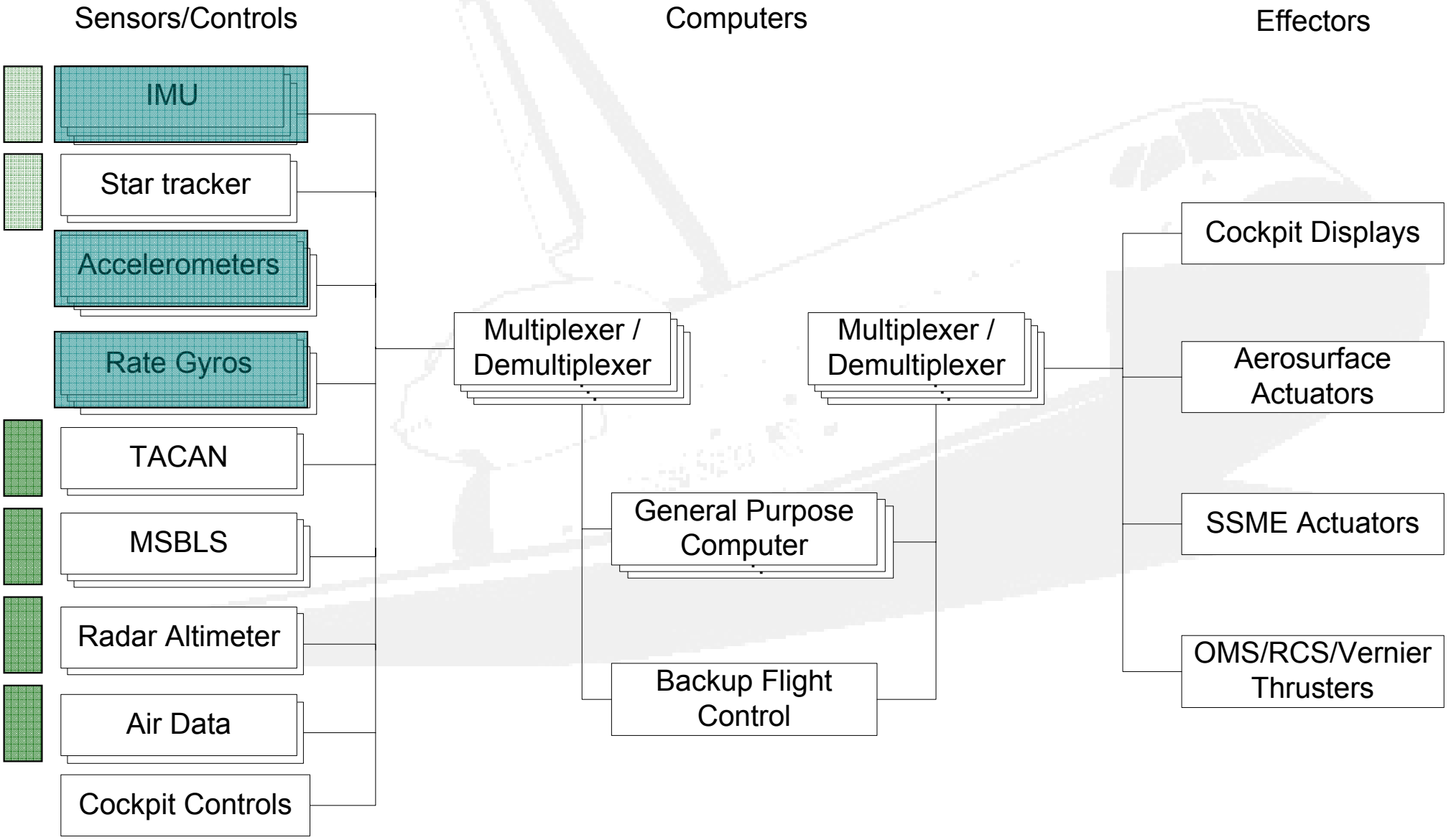
GPS Trade Study Result



Trimble Force 5

- SIGI – Promising but exact specifications were unavailable for IMU component
- NavStrike – Highly accurate but not space qualified. Design for short mission length could imply reliability/robustness issues.
- MAGR – Not space qualified, though flown on Shuttle (as test article).
- H-764 ACE – Not space qualified. JPALS design.

Hardware Trade Study
IMU



IMU TRADE	MIMU	LN200S
<u>Accuracy (1-σ)</u> Bias (deg/hr) Scale Factor (ppm) Ang. random walk (deg/rt(hr))	 0.005 1 0.005	 1 100 0.07
Size (in)	9.17x6.65	3.5x3.4
Weight (lb)	10.4	1.65
Power (W)	32	12
Space Qualified	x	x
Track Record	x	x
Availability	x	x

IMU Trade Study Result

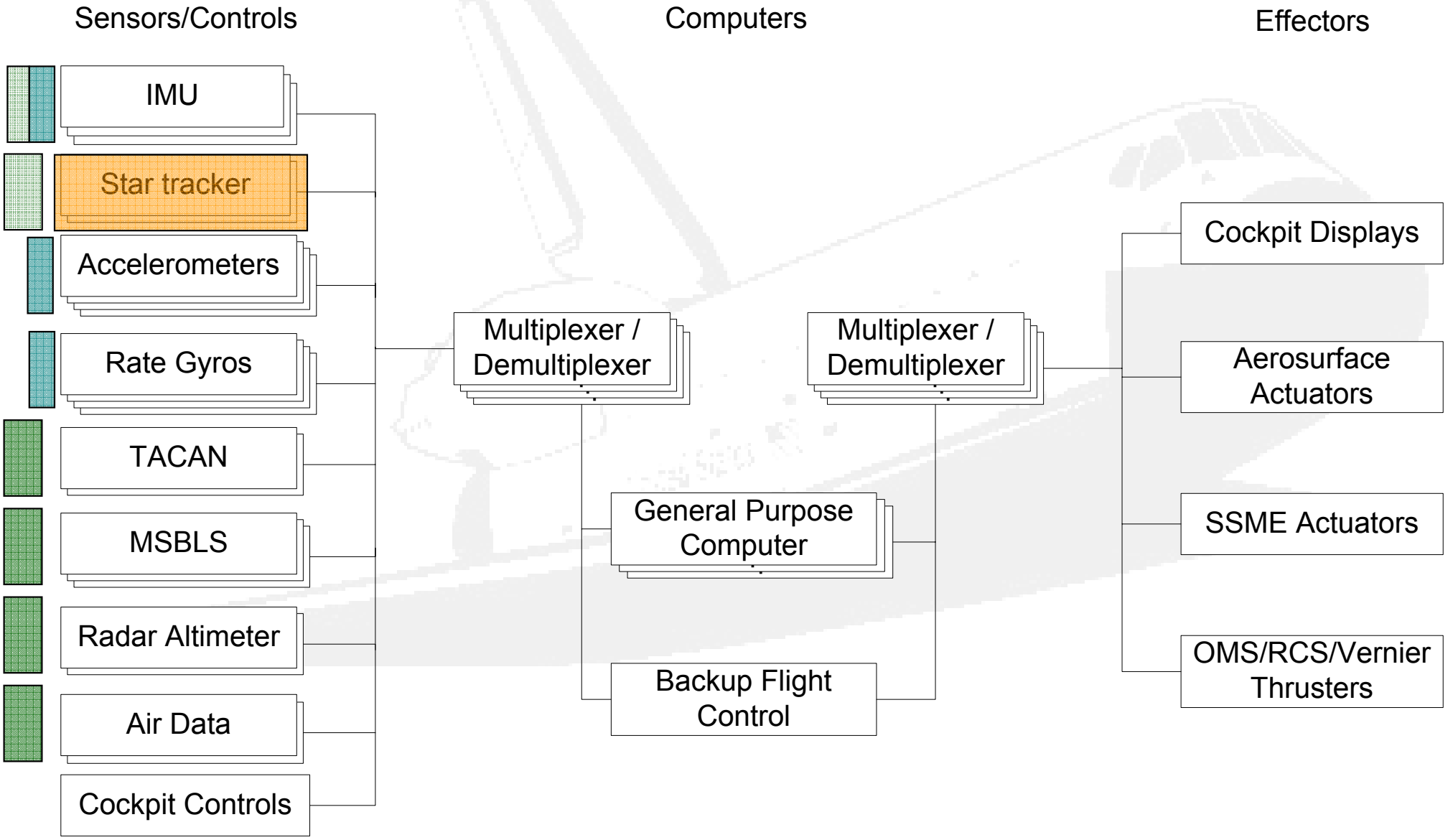
Honeywell MIMU

- Better performance that LN200S
- Space Qualified
- Light Weight

MEMS considerations

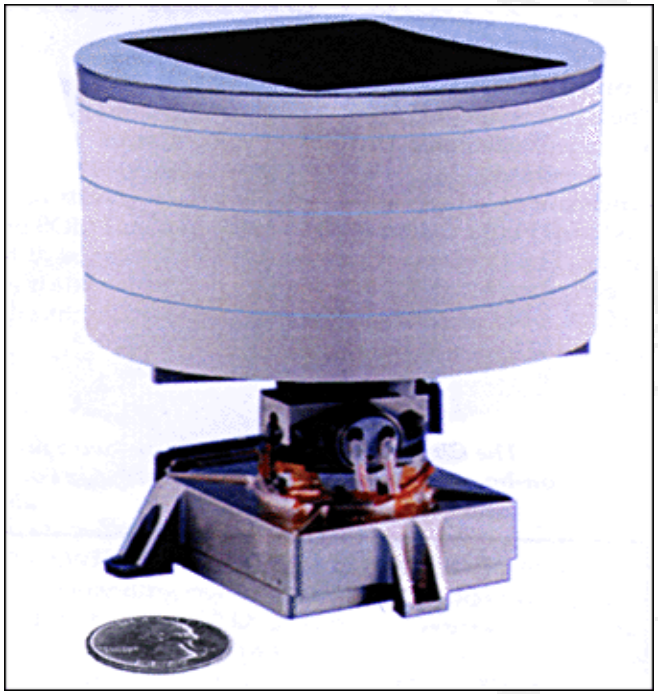
- Extremely light weight, low power
- Promising performance, but unproven
- Thermal problems

Hardware Trade Study
Star Tracker



Star Tracker Trade	**Therma HE 5AS**	**EMS Tech. CALTRAC**	**Sodern SED16**	**Tech. U. Of Denmark ASC**	**LLNL STSC**	**Ball Aero CT633**	**Crisa A-STR**	**Draper ISC**	**Draper SISC**
Accuracy (arcmin) **Pitch** **Yaw** **Roll**	 0.017 0.017 0.083	 0.3 0.3 0.1	 0..25 0.25 1.0	 0.017 0.017 0.083	 0.516 0.516 1.55	 0.1 0.1 0.5	 0.2 0.2 1.6	 6 6 6	 0.6 0.6 0.6
Field of View (deg)	22X22	36X27	25X25	18X12	28.9X43.4	20X20	16.4X16.4	21X21	21X21
Sensitivity (magnitude)	Mv6	Mv7	?	Mv8	Mv4.5	Mv4.5	Mv5.5	Mv5.5	Mv5.5
Max ang. rate (deg/s)	0.16	4	10	7	?	0.8	0.5	40	40
Weight (lb)	6.6	7.5	6.7	1.9	0.5	5.5	17	6.5	6.5
Size (in)	10.2x7.6x1.3	12.6x6x6	6.7x6.3x11.5	5x5x5	4.7x4.7x5.5	5.6x5.3 dia	5.6x5.3 dia	6x6.25 dia	6x6.25 dia
Power	9W	14W	7.5W	8.2W	4.5W	9W	21W	3.5W	3.5W
Lost in Space	X	X	X	X	X	X	X	X	X
Space Qualified	X	X		X	X	X		X	X
Track Record	X	X		X	X	X			
Availability	X	X	X	X	X	X			

Star Tracker Trade Study Result

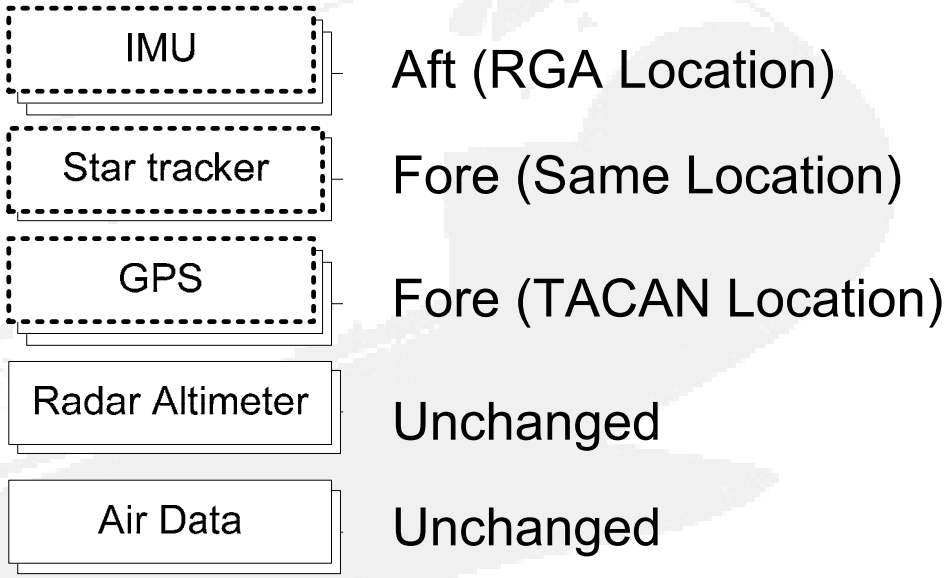


Lawrence Livermore National Labs - STSC

- Largest FOV
- Lightest
- Space qualified and available
- Good track record
- Second-lowest power consumption

Summary

Sensors/Controls	Replaced with
IMU	MIMU
Star tracker	STSC
Accelerometers	MIMU
Rate Gyros	MIMU
TACAN	FORCE 5
MSBLS	FORCE 5
Radar Altimeter	Unchanged
Air Data	Unchanged



Conclusions

- Weight savings of over 140 lbs
- Volume reduction of at least 4.5 cubic feet
- Significant power savings
- Cost savings
  - Cost-to-orbit is $4,700 per lb in 2002 dollars
  - Amounts to a savings of at least $660,000 per launch