

SESAR JU Digital Transformation Webinars: Communication, Navigation and Surveillance



From Barometric to Geometric Altimetry

October 22, 2020



Pressure-based altimetry



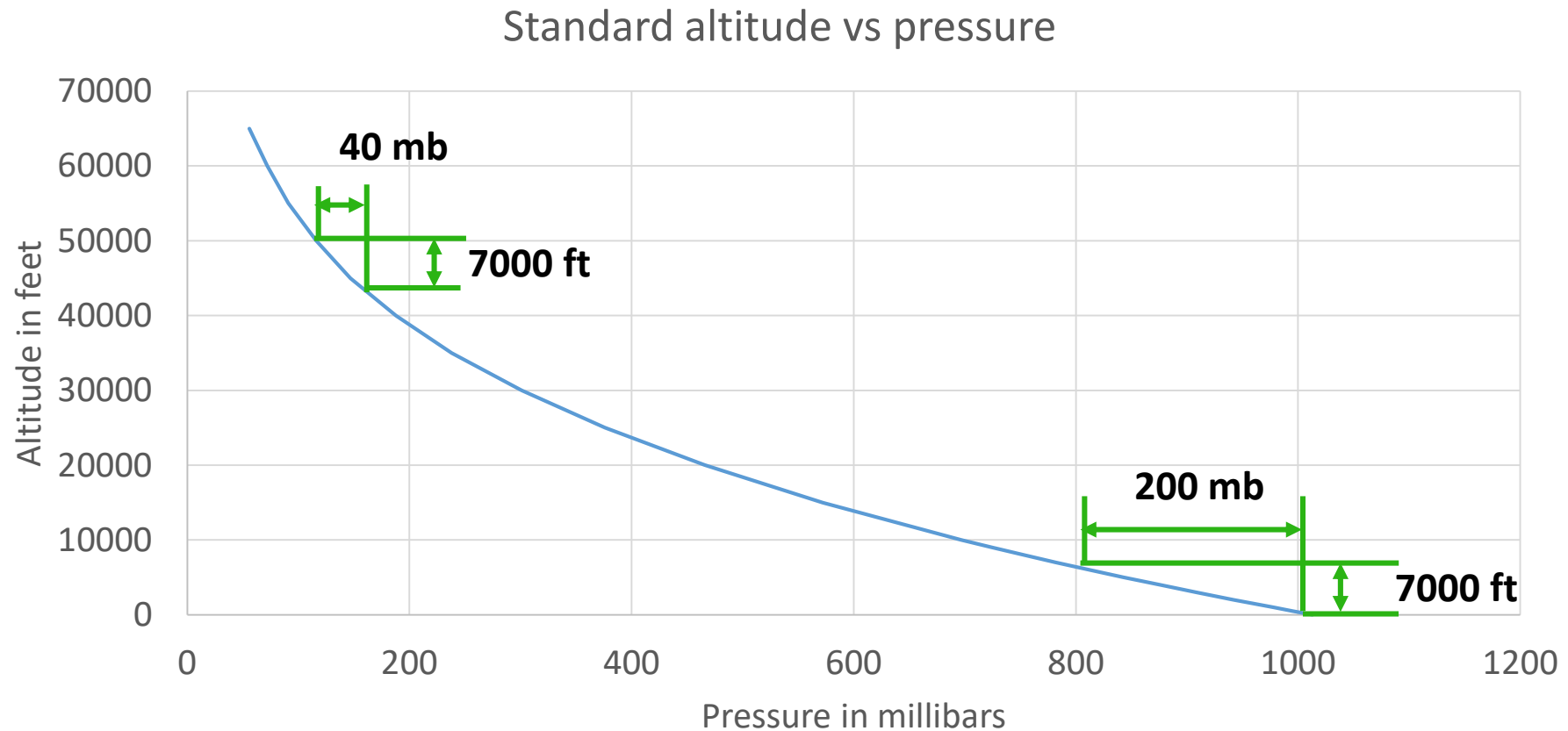
*Walter Kollsman
an inventor
1928*

What a hassle

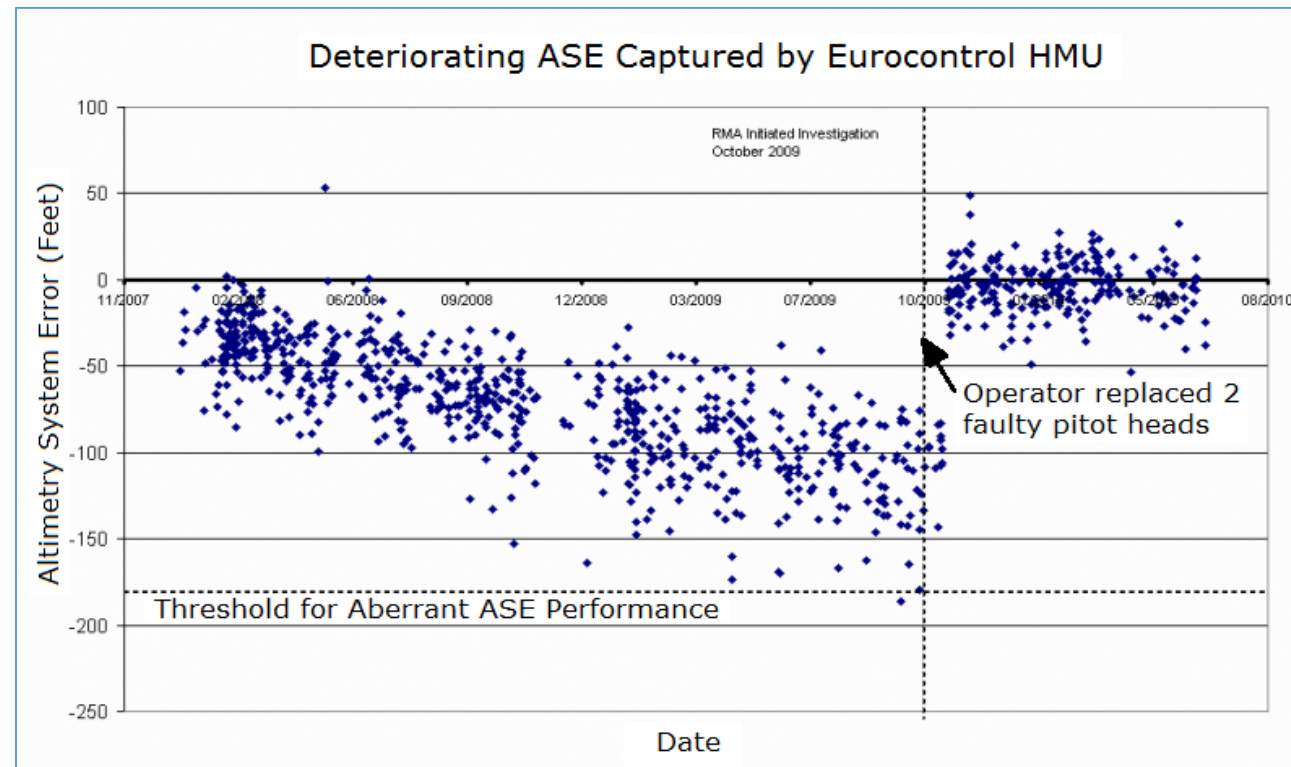
- » Less precise with altitude
- » Independent height-measuring for RVSM
- » Altimeter settings
- » Vigilant inspection
- » Aircraft design
- » Cold temperature corrections
- » Transition altitudes
- » Numerous other limitations



Decreasing precision with altitude



Height measuring units (HMU)



Annex 6, 7.2.7: “...a minimum of two aeroplanes of each aircraft type grouping of the operator have their height-keeping performance monitored, at least once every two years...”

Altimeter settings

- Thousands of reporting stations around the globe
- Height above the ground measurement depends on surface pressure
- Without the altimeter setting at the destination, minimums increase depending on the distance to the source of the altimeter setting

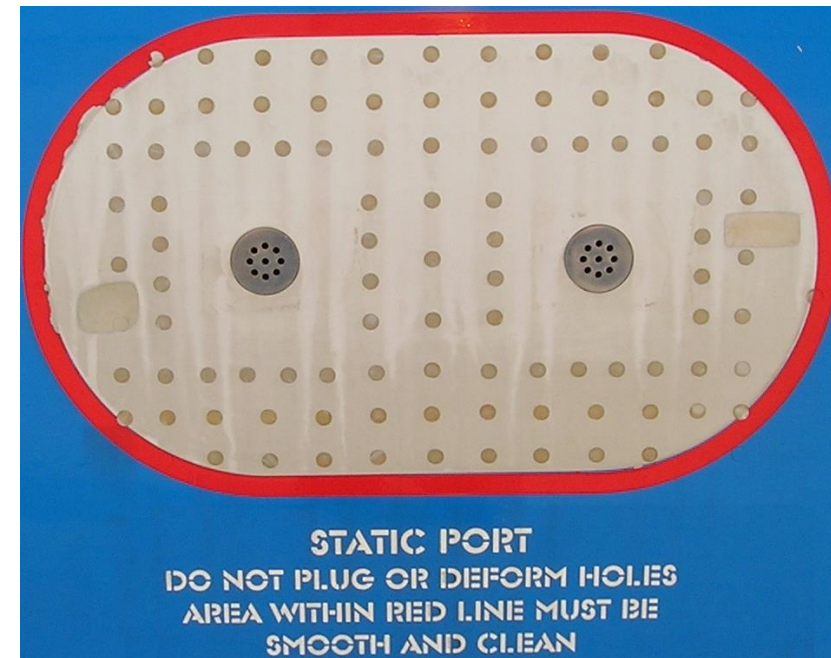
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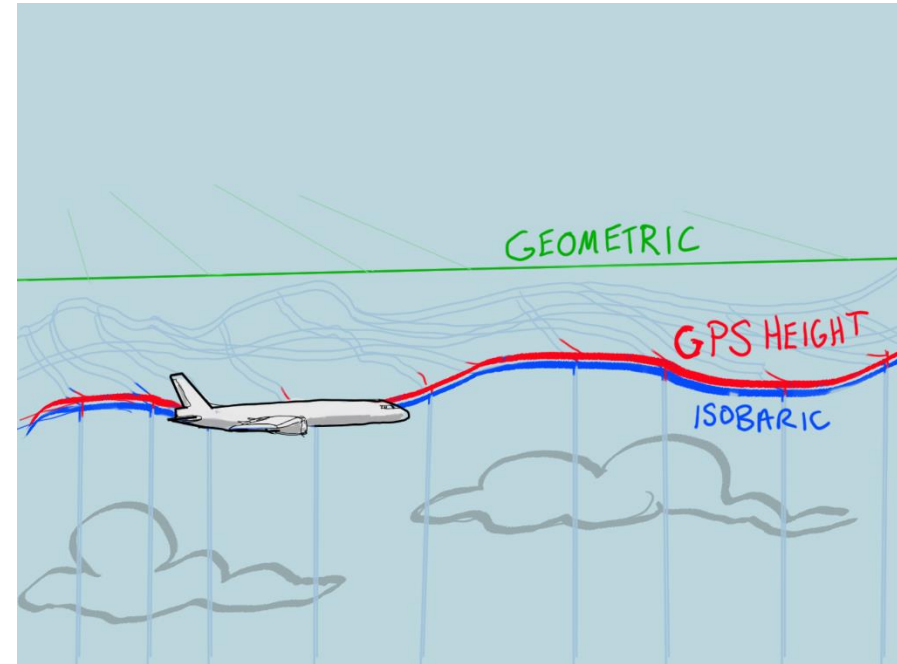
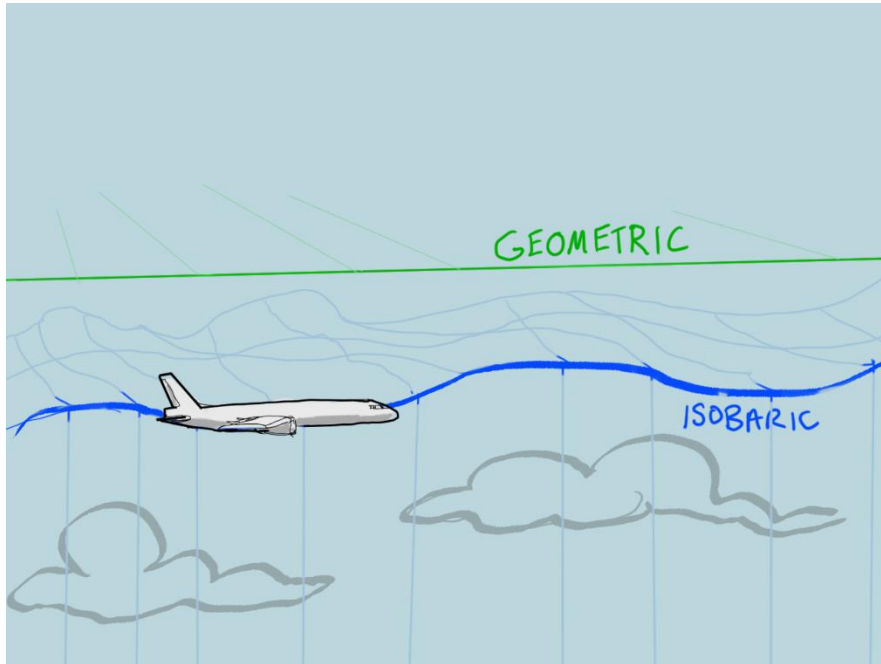
QNH is rounded down to the next whole millibar and reported as a four figure group preceded by Q. If the value is less than 1000mbs then the first digit will be 0.

Maintenance and design nightmare

- » Vigilant inspection of static ports – insects, paint, dirt, etc.
- » De-icing critical
- » Deice chemicals must not be sprayed directly into ports
- » Aircraft surface design
 - » **Significant design challenge**
 - » **To become RVSM compliant, some aircraft had to be re-skinned, others retired**



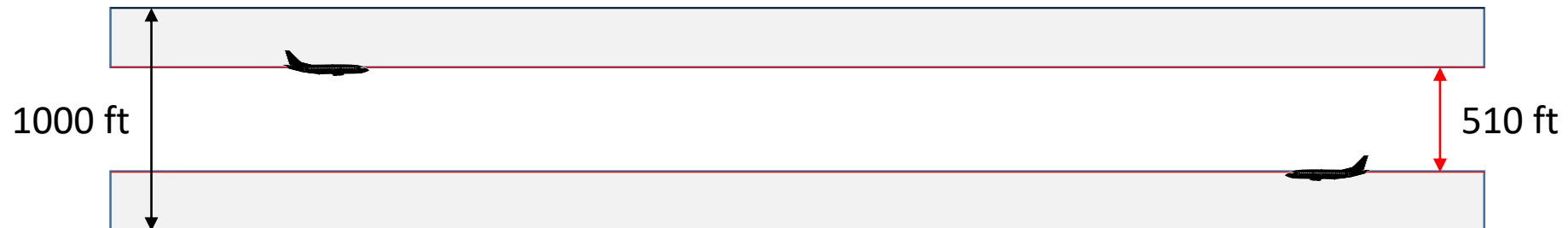
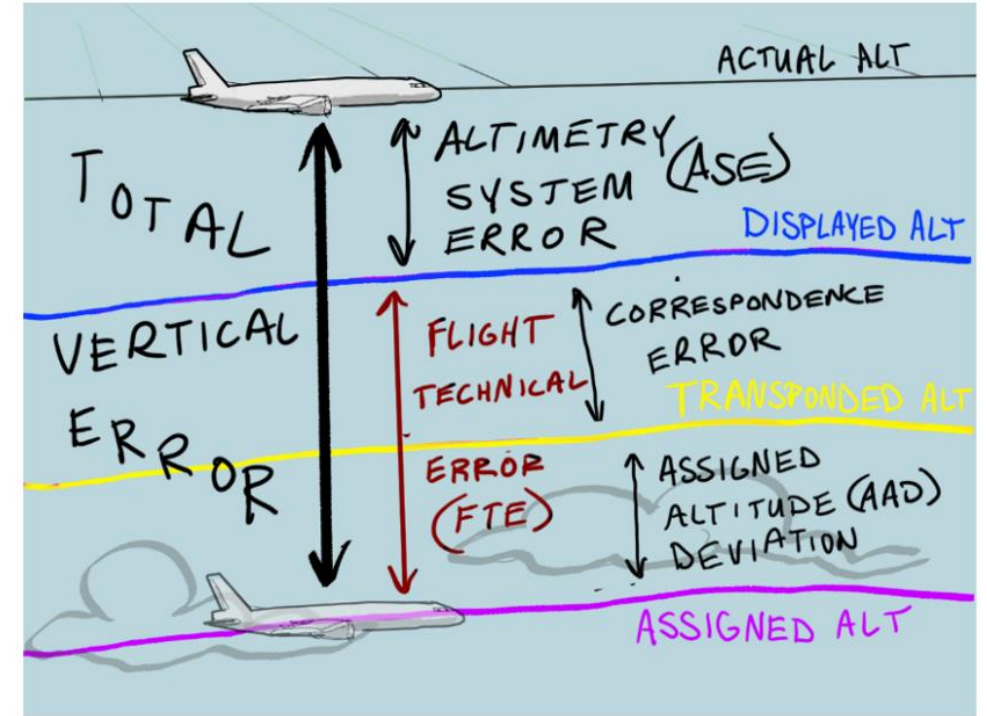
Climbing and descending in level flight



Source: RVSM Aircraft Monitoring and How it Enhances Airspace Safety, CSSI Inc, Jun 28 2017

Altimetry system error

- Altimetry System Error (ASE) is the difference between the instrument displayed pressure altitude and the actual altitude flown.
- To be compliant with international standards, the ASE of an aircraft must be less than 245 ft.



Source: RVSM Aircraft Monitoring and How it Enhances Airspace Safety, CSSI Inc, Jun 28 2017

Why 1000 ft?

- » Easy to say
- » Altimeter buffer
- » Created 60+ years ago
- » Based on statistical probabilities of collision including altimetry error tolerances
- » SESAR research R-WAKE project: If altimetry were more precise wake category medium aircraft could be separated by just 500 ft



Alternative to pressure

GNSS – Global Navigation Satellite System, such as GPS

Geometric altitude – Actual height above a reference datum

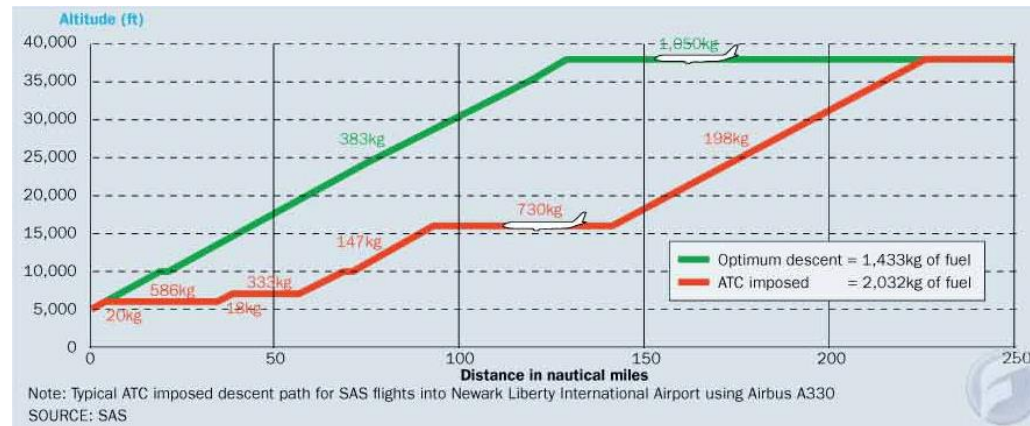
GNSS-based altimetry – Using satellites to determine geometric altitude



Trajectory-based operations

“The use of barometric altimetry...reduces the potential of the trajectory based operations capabilities. However, geometric altimetry could be used to improve...these aspects.”

-- *Analysis of the geometric altimetry to support aircraft optimal vertical profiles within future 4D trajectory management, Javier García-Heras, Francisco Javier Sáez Nieto, Air Navigation Research Group, Polytechnic University of Madrid, Spain, May 2011*



GNSS-based altimeter limitations

- Need at least 4 satellites in sight with good geometry
- GNSS vertical 50% less accurate than lateral
- Subject to outages
- Constellation degradation
- Space weather disturbances

www.navcen.uscg.gov/?Do=constellationStatus

Home	DGPS Advisories	GPS Constellation Status	MSI Data Downloads	GPS Testing Notices	LNMs	Almanacs	Nav Rules	AIS
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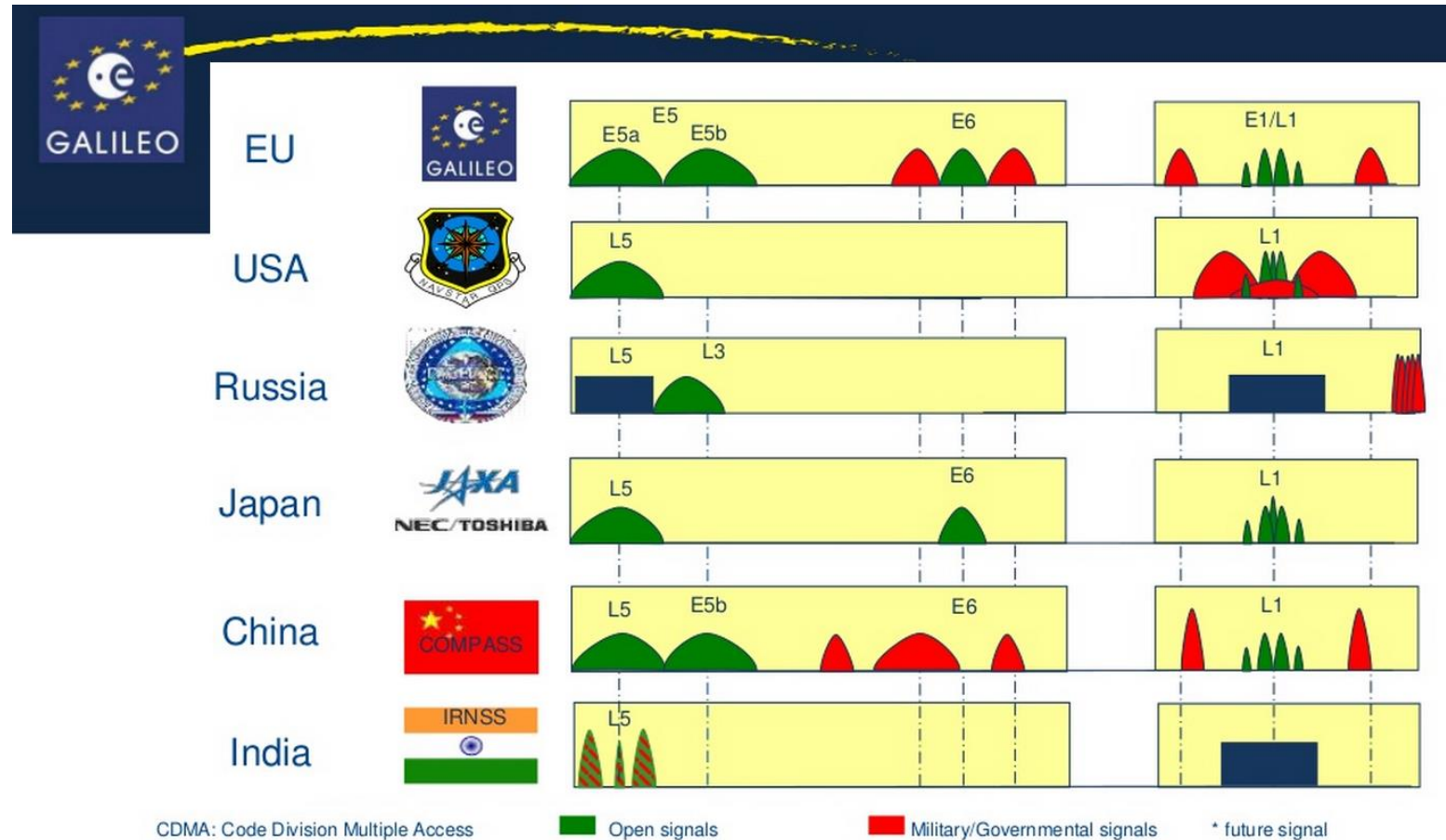
GPS CONSTELLATION STATUS FOR 03/07/2015

Plane	Slot	SVN	PRN	Block-Type	Clock	Outage Date	Nanu-Type	Nanu-Subject
A	1	65	24	IIF	CS			
A	2	52	31	IIR-M	RB			
A	3	64	30	IIF	RB			
A	4	48	7	IIR-M	RB			
A	6		8		CS			
B	1	56	16	IIR	RB			
B	2	62	25	IIF	RB			
B	3	44	28	IIR	RB			
B	4	58	12	IIR-M	RB			
B	6	69	3	IIF	RB			
C	1	57	29	IIR-M	RB	12 MAR 2015	FCSTDV	2015015 - SVN57 (PRN29) FORECAST OUTAGE JDAY 071/0400 - JDAY 071/1600
C	2	66	27	IIF	RB			
C	3	59	19	IIR	RB			
C	4	53	17	IIR-M	RB			
F	5	26	26	IIA	CS	05 JAN 2015	UNUSUFN	2015004 - SVN26 (PRN26) UNUSABLE JDAY 005/1750 - UNTIL FURTHER NOTICE
							DECOM	2015005 - SVN26 (PRN26) DECOMMISSIONING JDAY 006/2200
F	6	43	13	IIR	RB			

Source: Preliminary Assessment of Surveillance Alternatives for Upper Class E Traffic Management (ETM), April 2019



Frequencies of GNSS



Fiammetta Diani, European GNSS Agency, 5 Nov 2014

GPS III



In 2000, the U.S. Congress authorized GPS III:

- Broadcast on the L2 frequency (1227.6 MHz)
- Will be fully operational by 2021
- Provides improved accuracy and availability for all users, an easy-to-track signal, and is a defense against localized interference

Two civilian frequencies transmitted from one satellite enables removal of the ionospheric delay error for that satellite:

- Without that, a GPS receiver must use ionospheric corrections from another source (such as a Satellite Based Augmentation System)
- Advances in technology for both the GPS satellites and the GPS receivers have made ionospheric delay the largest source of error in the signal

Source: https://en.wikipedia.org/wiki/GPS_Block_III

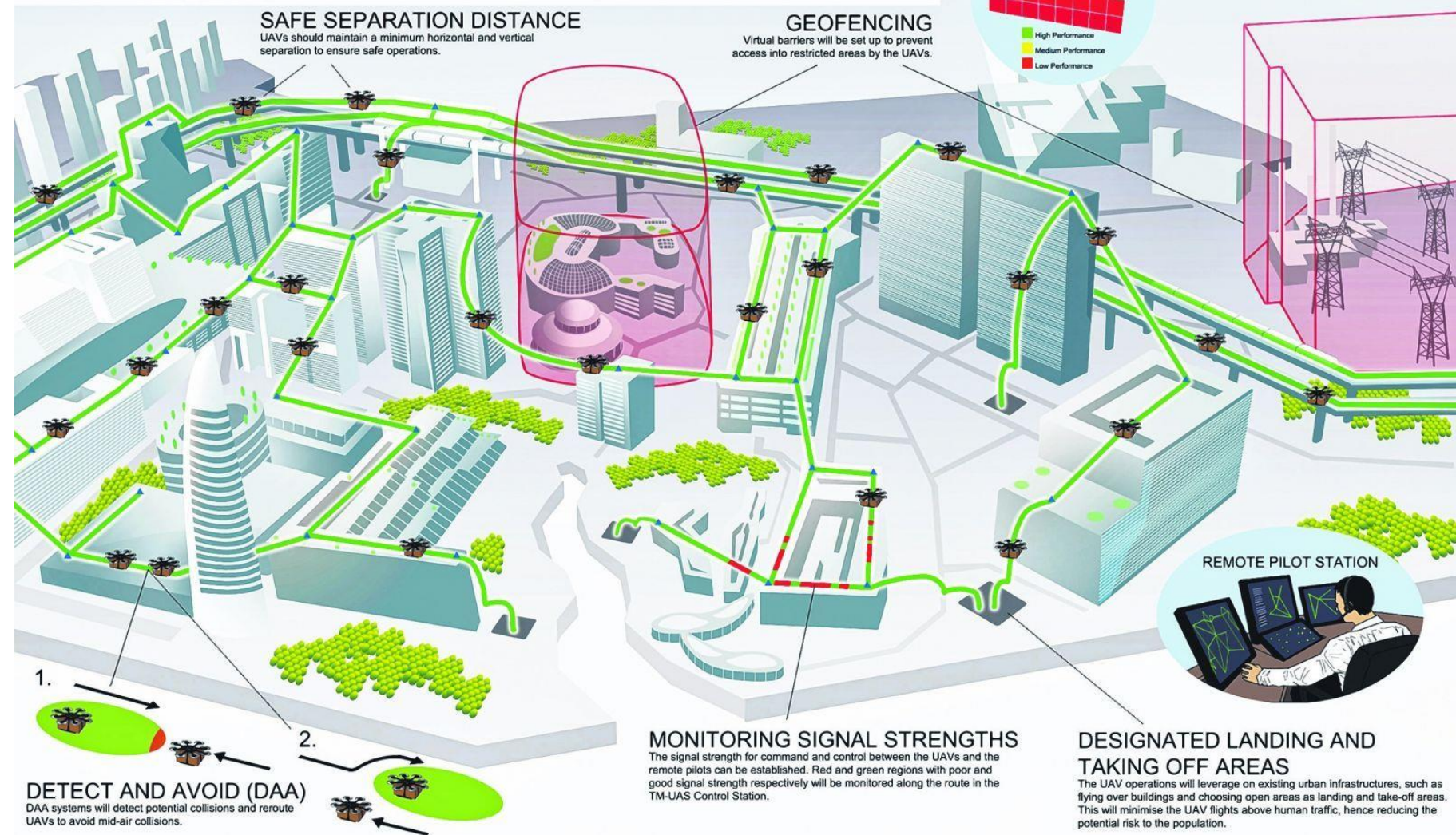


Advanced Air Mobility (AAM)

Source:
Nanyang Technological University, Singapore (NTU Singapore)
<https://www.innovationtoronto.com/2016/12/singapore-developing-drone-air-traffic-control-systems/>

NTU's Traffic Management of Unmanned Aircraft Systems (TM-UAS) Programme

The skies will in the future be filled with Unmanned Aircraft Vehicles (UAVs, or commonly known as drones) for delivery, inspection, rescue and surveillance purposes. With the increasing density of UAV operations, it is important to have an efficient and safe traffic management system to ensure the urban airspace can be utilised optimally with population's safety. Nanyang Technological University's scientists from Air Traffic Management Research Institute (ATMRI) is aiming to free up the urban airspace for UAV operations, developing technologies such as traffic management control, smart routing and collision avoidance.



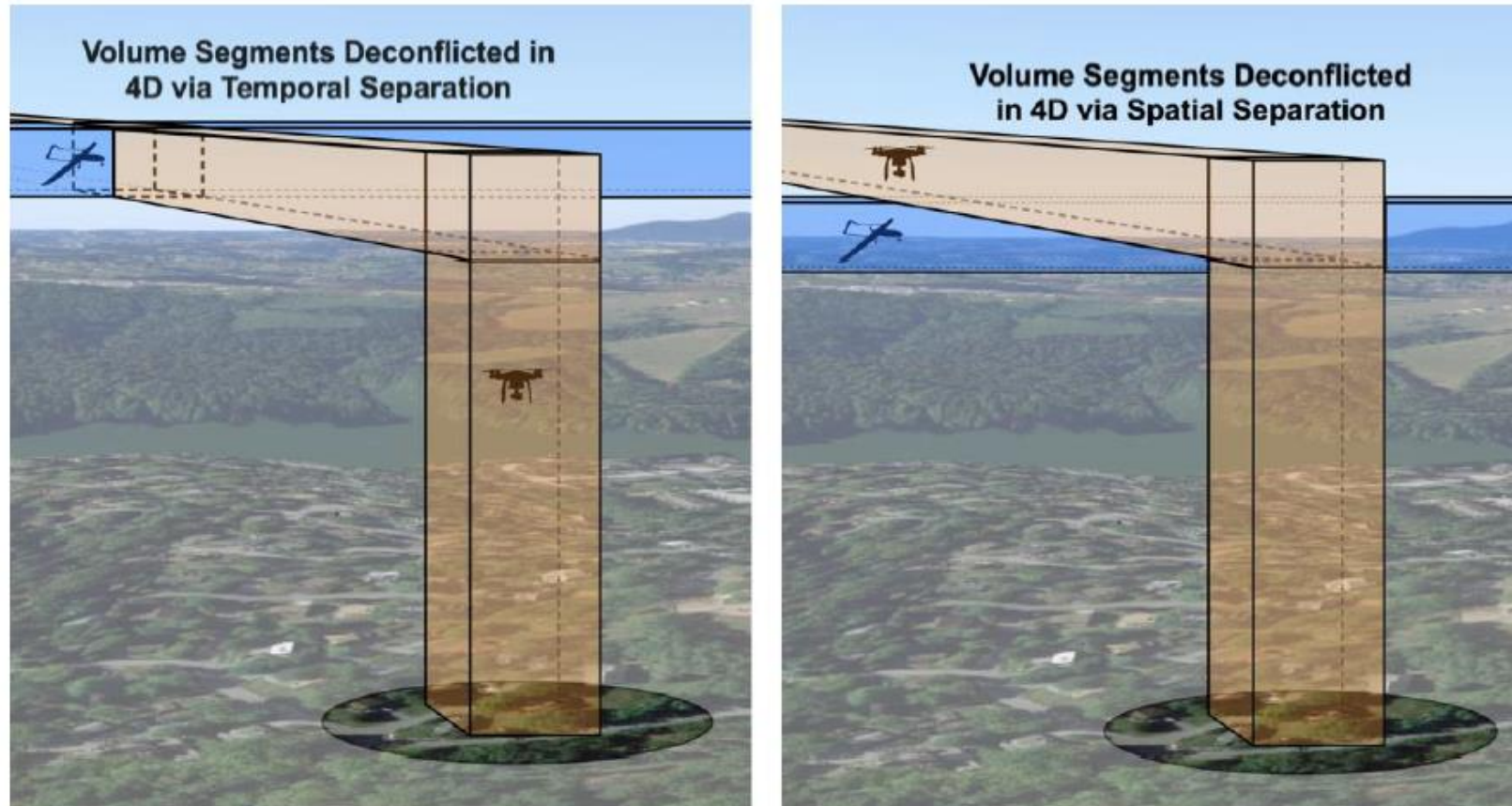
The diagram illustrates the vertical structure of U.S. airspace and the regulatory requirements for drone operations. The sky is divided into several colored layers representing different airspace classes:

- Class E:** The layer immediately above the surface, extending up to 400 feet AGL. It is shown in a light blue color.
- Class G:** The layer below Class E, extending from the surface up to 400 feet AGL. It is shown in a darker blue color.
- Class B, C, D, & E (SFC):** The layer above Class E, extending from 400 feet AGL up to the base of Class B airspace. It is shown in a light blue color.
- Class B:** The layer above Class B, C, D, & E (SFC), extending from the base of Class B up to the base of Class A. It is shown in a light blue color.
- Class A:** The layer above Class B, extending from the base of Class A up to the top of the atmosphere. It is shown in a light blue color.

A dashed horizontal line at 400 feet AGL separates the surface-based airspace (Class E and G) from the enroute airspace (Class B, C, D, & E (SFC) and Class A). The ground level is depicted with silhouettes of various structures, including a farm, a small town, and a city skyline. A drone is shown flying at a low altitude, with a line indicating its flight path. Text at the bottom explains that UTM operations are conducted up to 400 feet AGL within U.S. airspace, and operators must obtain airspace authorization from ATC for flight within/into controlled airspace.

- Source: FAA Unmanned Aircraft Systems (UAS) Traffic Management (UTM) Concept of Operations, v2.0, March 2020

FAA deconfliction concepts



Source: FAA Unmanned Aircraft Systems (UAS) Traffic Management (UTM) Concept of Operations, v2.0, March 2020

High altitude operations

Vehicles operating in upper Class E:

- sophisticated high altitude, long endurance (HALE) vehicles
- unmanned free balloons
- airships
- supersonic/hypersonic aircraft
- Space launch and re-entry

These vehicles:

- perform research
- enable broad coverage services
- enable supersonic and space travel



Source: https://www.faa.gov/uas/advanced_operations/upper_class_etm/

Can you imagine?

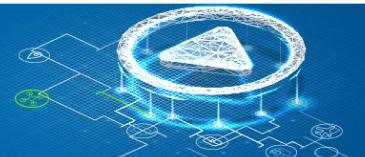
- Elimination of transition altitudes and altimeter settings, a huge burden to ATC and a significant cause of level busts and controlled flight into terrain
- Improvement of airspace efficiency and capacity by increasing the number of altitudes and reducing airspace used by procedures
- Support for trajectory-based operations
- Elimination of altimeter-related cold temperature corrections
- Elimination of out-of-tolerance altimeter setting issues between sectors
- Elimination of the need for ANSPs to maintain pressure reporting stations
- A massive undertaking affecting every single aircraft in the world

Questions?

This material was originally presented by IFATCA at the Annual Conference in Sofia, Bulgaria, April 2016:

<https://www.ifatca.org/wp-content/uploads/wp-archive/2015-sofia/B.5.6-WP87-Concept-of-GNSS-based-altitude-pdf.jpg>

Extra slides



German Aerospace Center (DLR) concept

- The challenge: manage and monitor UAS with diverse characteristics safely together with other users
- Concept not limited to implementations in Very Low Level (VLL) airspace but in all categories of airspace, with both manned and unmanned aircraft
- In U-space, maximum altitude:
 - **rural areas - 500 ft**
 - **urban areas - 1000 ft above the highest obstacle.**
- SESAR predicts over 400,000 commercial drones in Europe by 2050.
- A recent DLR patent enables the presentation of conflict-free trajectories involving multi-dimensional optimization criteria and high traffic densities.

Source: DLR Blueprint, Concept for Urban Airspace Integration, December 2017

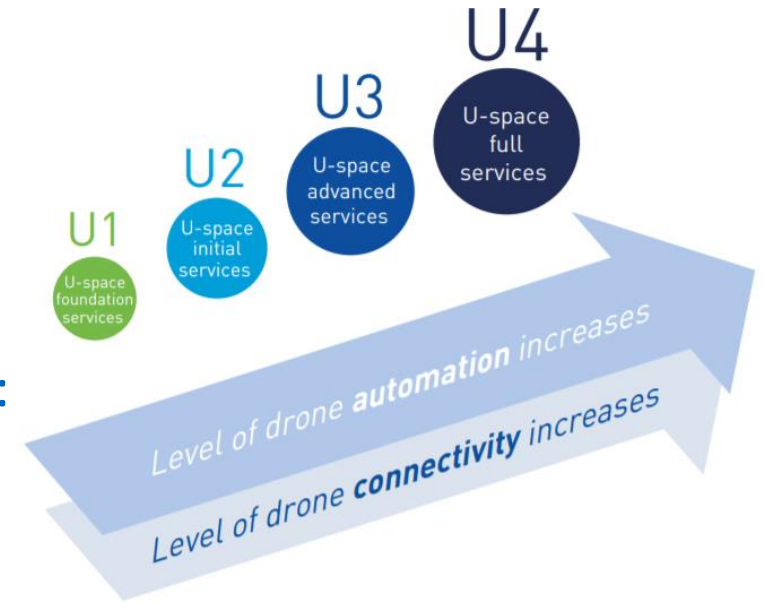
SESAR U-space concept

U-space is a set of new services and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones. These services rely on a high level of digitalisation and automation of functions, whether they are on board the drone itself, or are part of the ground-based environment. U-space provides an enabling framework to support routine drone operations, as well as a clear and effective interface to manned aviation, ATM/ANS service providers and authorities. U-space is therefore not to be considered as a defined volume of airspace, which is segregated and designated for the sole use of drones. U-space is capable of ensuring the smooth operation of drones in all operating environments, and in all types of airspace (in particular but not limited to very low level airspace). It addresses the needs to support all types of missions and may concern all drone users and categories of drones.

Source: U-Space Blueprint, SESAR Joint Undertaking, 2017

U-space implementation phases

- U1 E-registration, e-identification and geofencing
- U2 Management of drone operations:
 - **flight planning**
 - **flight approval**
 - **Tracking**
 - **airspace dynamic information**
 - **procedural interfaces with air traffic control.**
- U3 Advanced services support complex ops in dense areas:
 - **capacity management**
 - **assistance for conflict detection**
 - **automated 'detect and avoid' (DAA) may be available**
- U4 Full services:
 - **interfaces with manned aviation**
 - **very high level of automation, connectivity and digitalisation for both drone and U-space system**



Source: U-Space Blueprint, SESAR Joint Undertaking, 2017

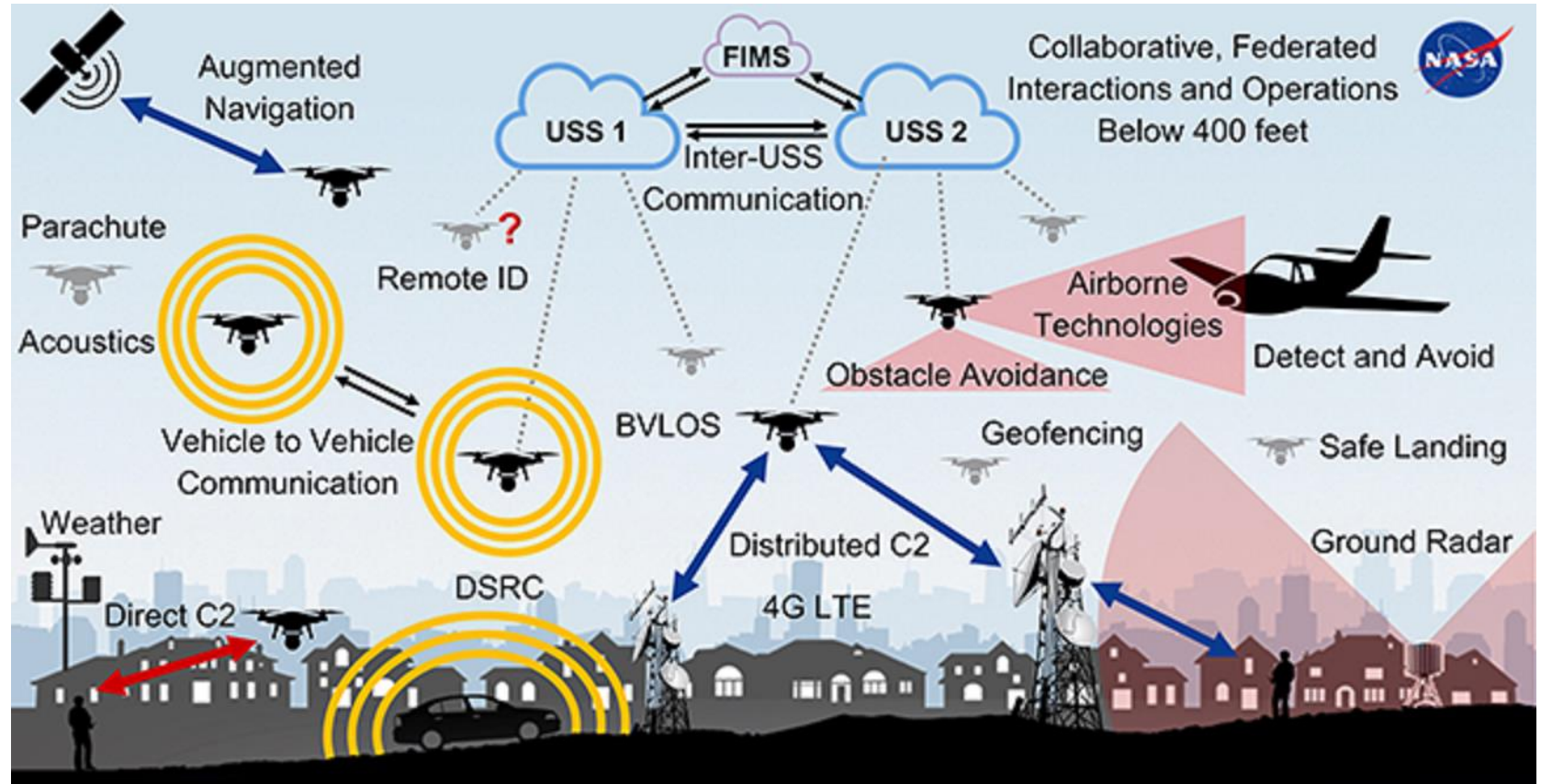
FAA UAS Traffic Management (UTM) concept

- Users supply services under FAA regulation
- Community-based, cooperative traffic management system
- Based on information sharing between operators, vehicles and FAA
- Operators share flight intent with each other and coordinate to de-conflict
- Communication and coordination through a distributed information network, not between pilots and air traffic controllers via voice.
- FAA provides real-time airspace constraints and operators remain within these constraints without direct ATC services

Source: FAA Unmanned Aircraft Systems (UAS) Traffic Management (UTM) Concept of Operations, v2.0, March 2020

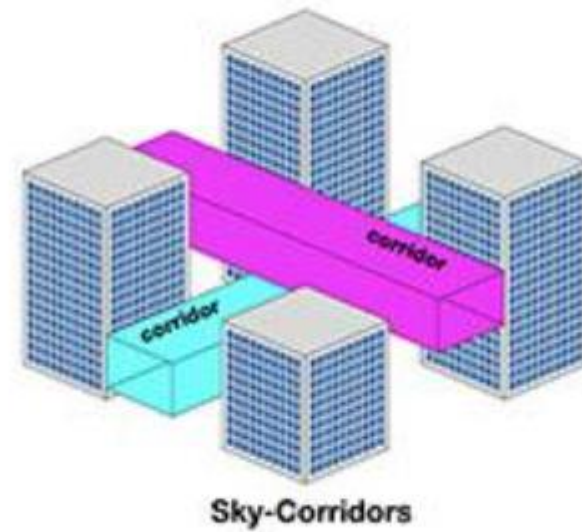
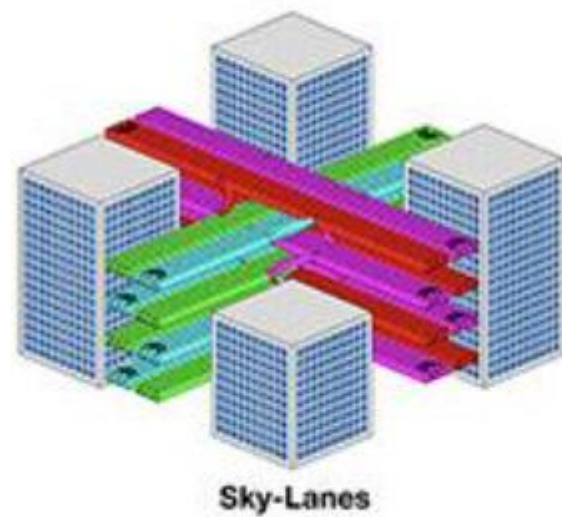
UAM

- BVLOS: Beyond Visual Line of Sight
- C2: Command and Control
- DSRC: Dedicated Short-range Communications
- FIMS: Flight Information Management System
- Remote ID: Remote Identification
- USS: UAS Service Supplier



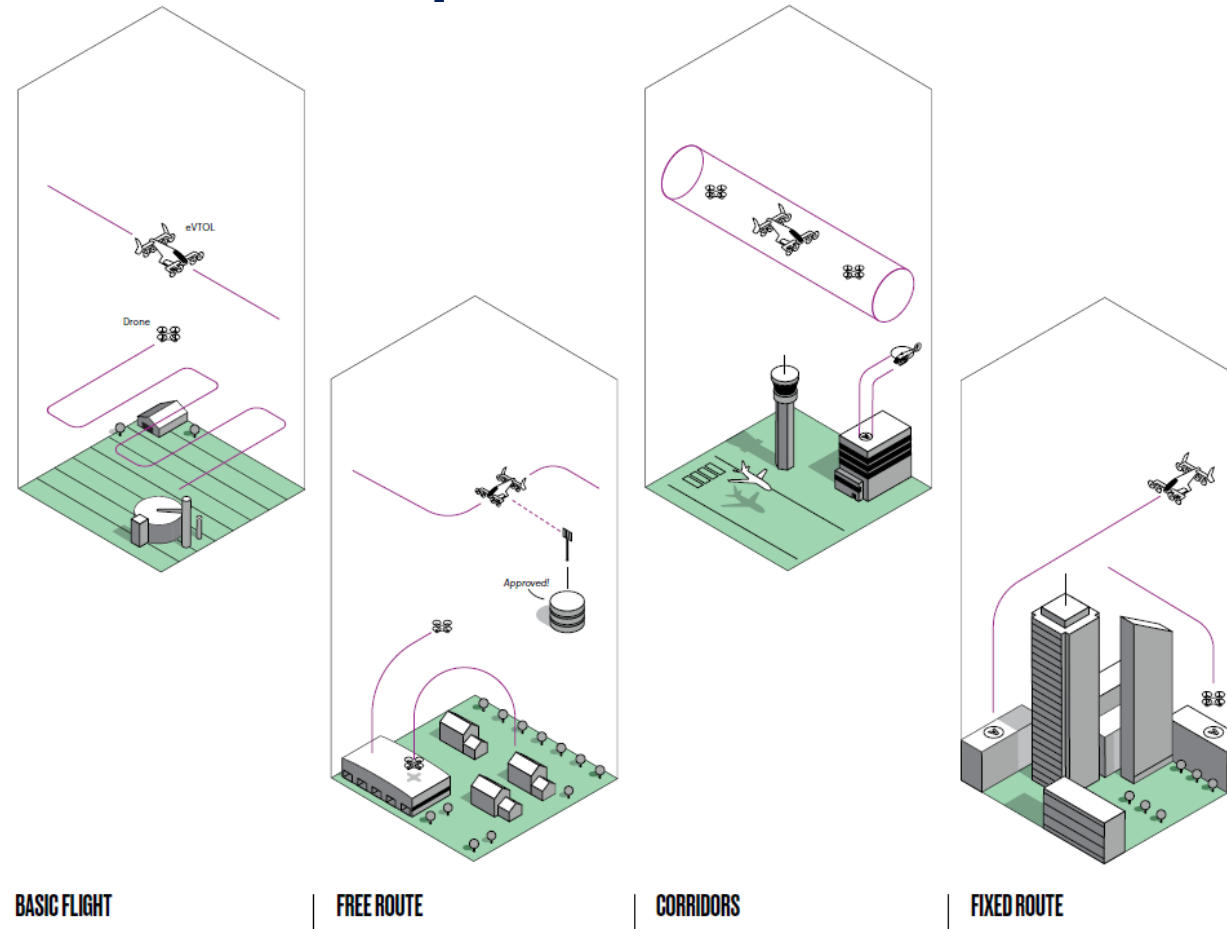
Source: <https://utm.arc.nasa.gov/index.shtml>

Sky lanes



Source: <https://aviationweek.com/aerospace/aircraft-propulsion/deciding-rules-road-urban-uas> (Jan 26 2017)

Operational concepts



Source: Airbus Blueprint for the Sky, 2018

Altimetry system error

Error Values

If the aircraft values from the RVSM monitoring test results are within the accepted tolerance range, the aircraft is considered in compliance for RVSM flight.

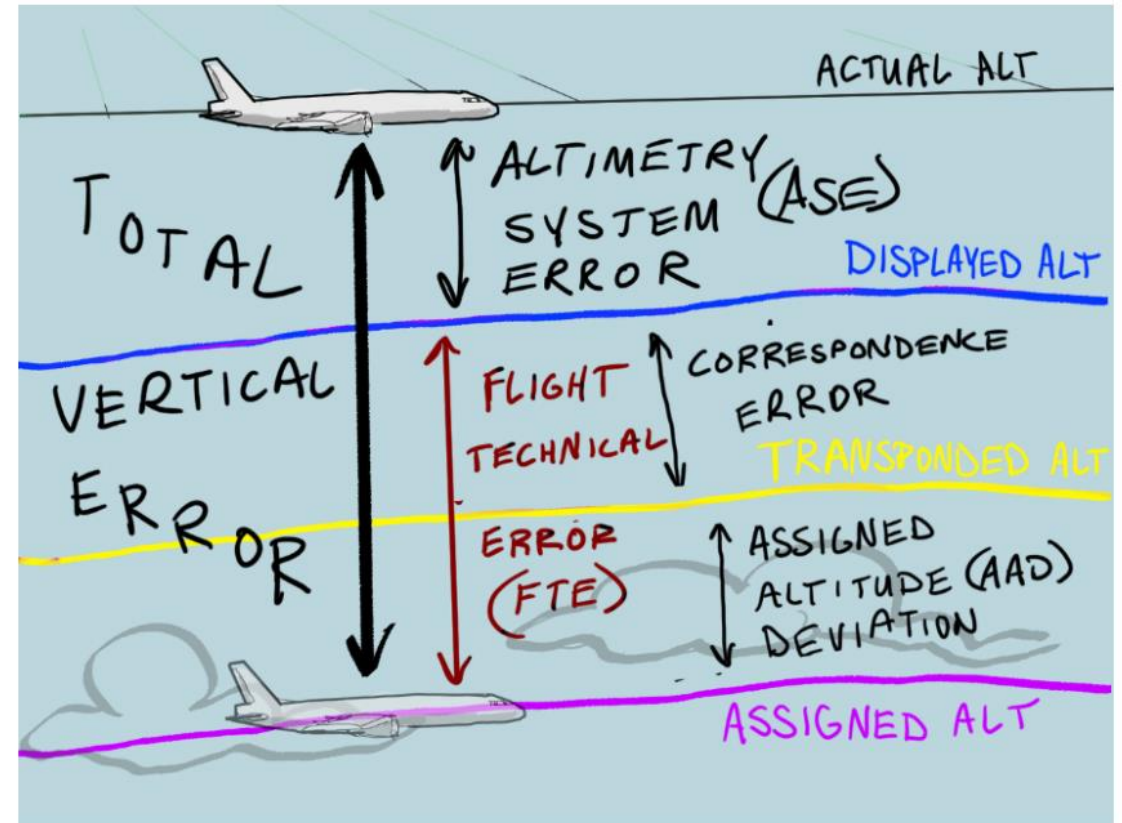
Altimetry System Error (ASE) is the difference between the instrument displayed pressure altitude and actual altitude flown. The tolerance for ASE is 75 m or 245 ft.

Total Vertical Error (TVE) is the difference between the actual altitude flown and the assigned pressure altitude. The tolerance for TVE is 90 m or 300 ft.

Assigned Altitude Deviation (AAD) is the difference between ATC assigned altitude and the altitude flown transponded or provided from the aircraft equipment. The tolerance for AAD is 90 m or 300 ft.

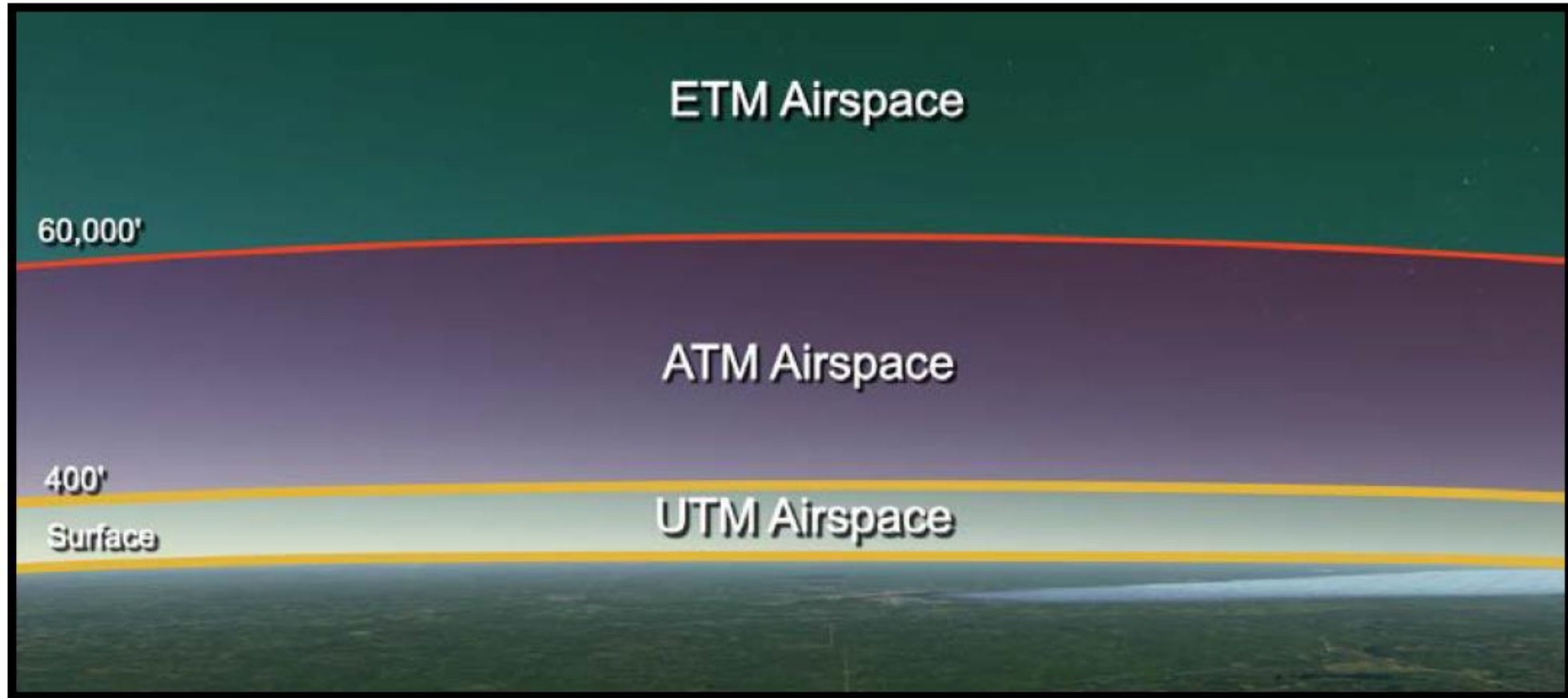
WRITTEN BY
CSSI RVSM

Bobby Miller III
Aviation Safety
RVSM at CSSI, Inc.



Source: RVSM Aircraft Monitoring and How it Enhances Airspace Safety, CSSI Inc, Jun 28 2017

Expanding airspace



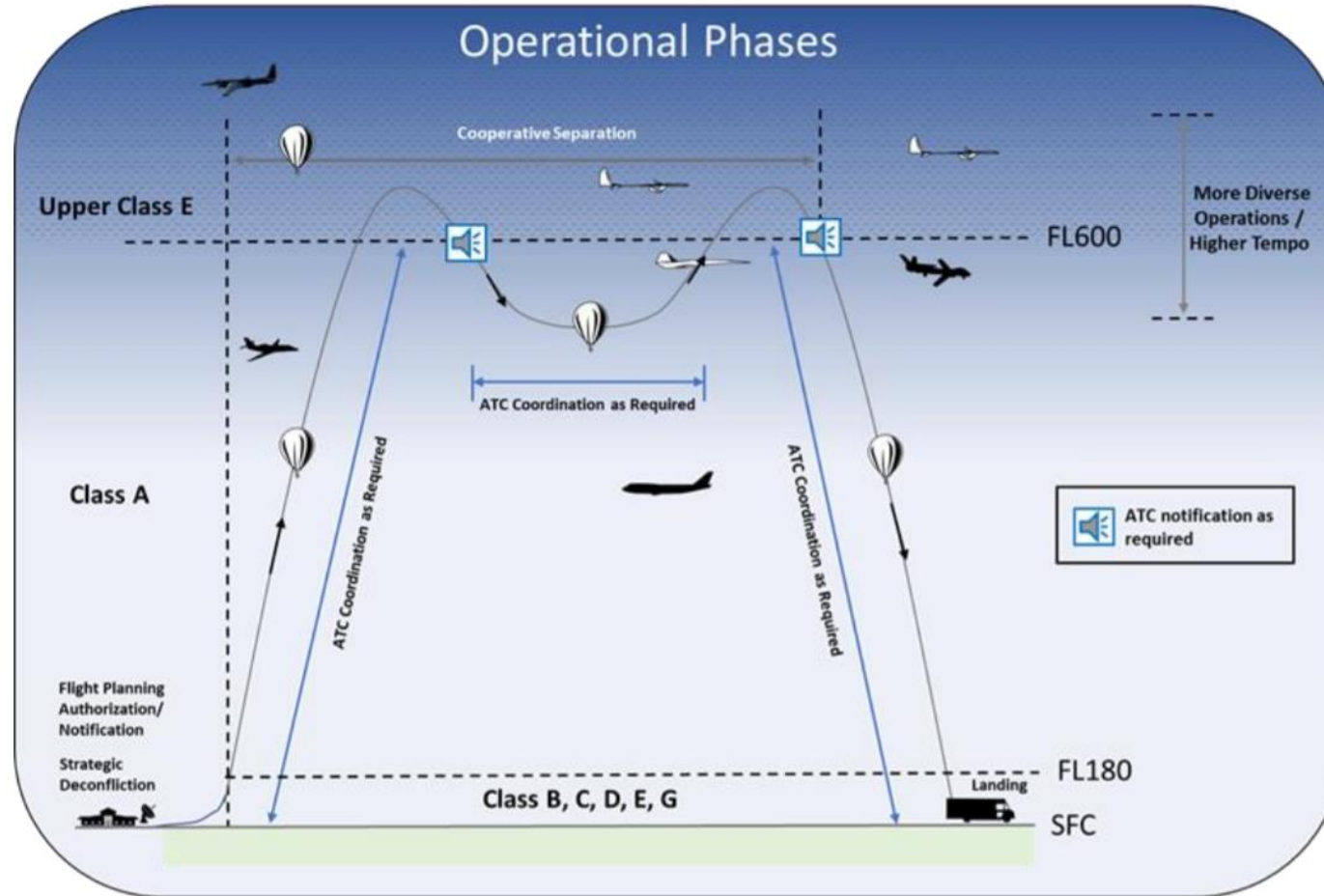
Source: Preliminary Assessment of Surveillance Alternatives for Upper Class E Traffic Management (ETM), April 2019

High altitude performance

- Commercial pressure altimeters may not provide useful barometric altitude information above 60,000 ft
- In current version 2 1090ES ADS-B transponders, geometric altitude is reported as a difference relative to pressure altitude (e.g., +500 ft relative to 30,000 ft)
- Version 3 1090ES ADS-B will be availability of absolute geometric altitude.

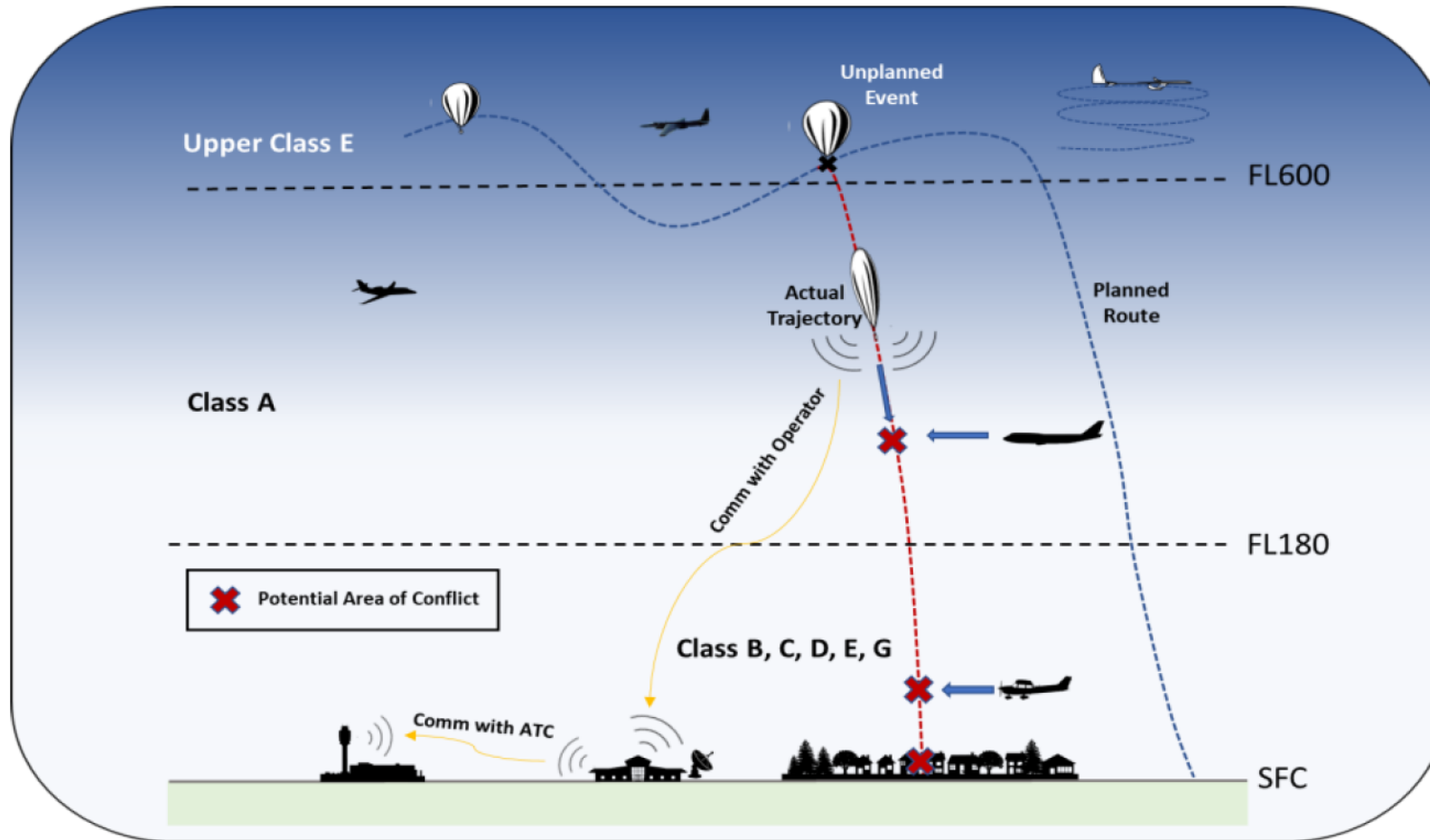
Source: Preliminary Assessment of Surveillance Alternatives for Upper Class E Traffic Management (ETM), April 2019

Upper Class E Traffic Management (ETM)



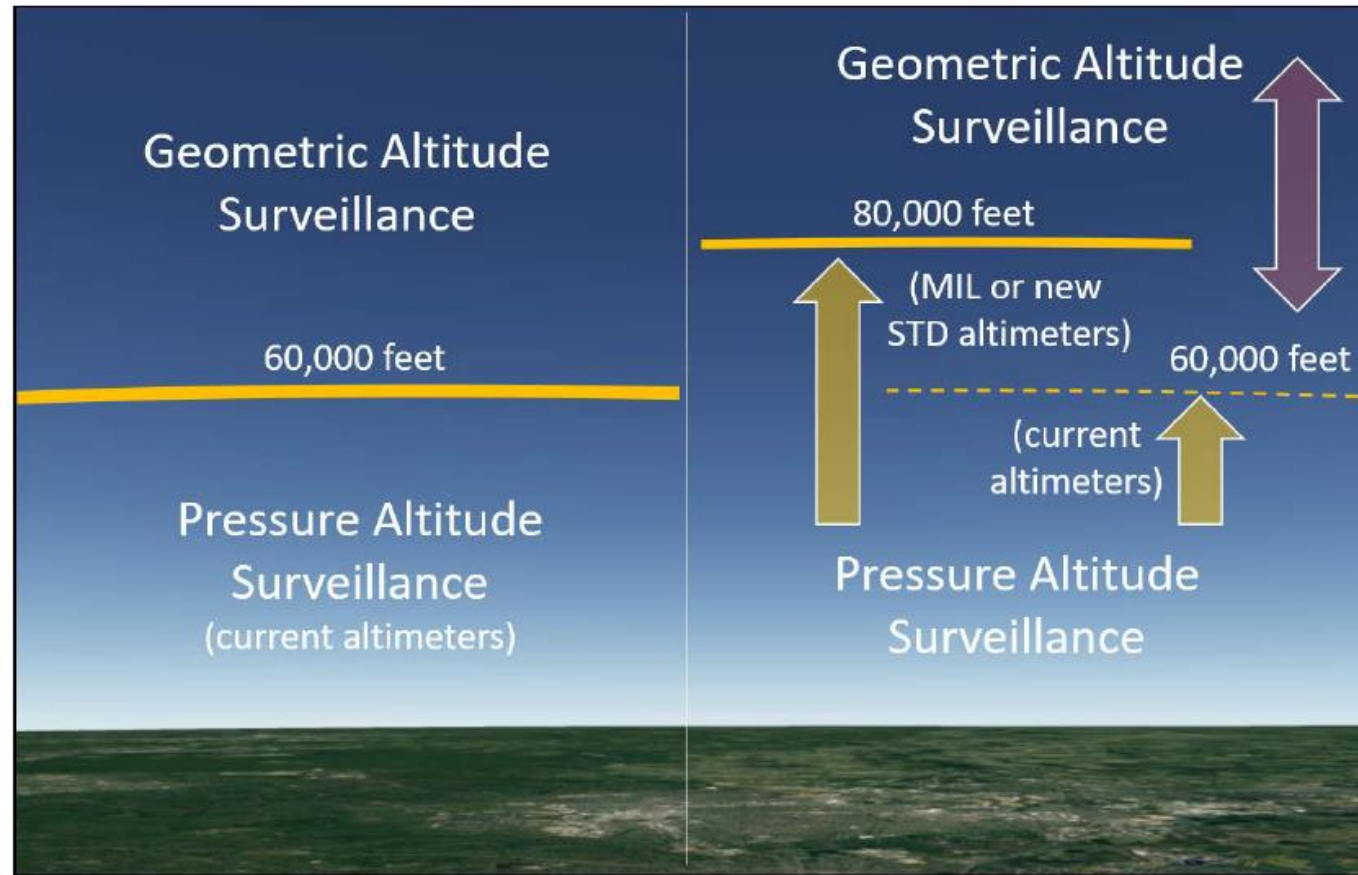
Source: FAA Upper Class E Traffic Management Concept of Operations

Unplanned transit from ETM airspace



Source: Preliminary Assessment of Surveillance Alternatives for Upper Class E Traffic Management (ETM), April 2019

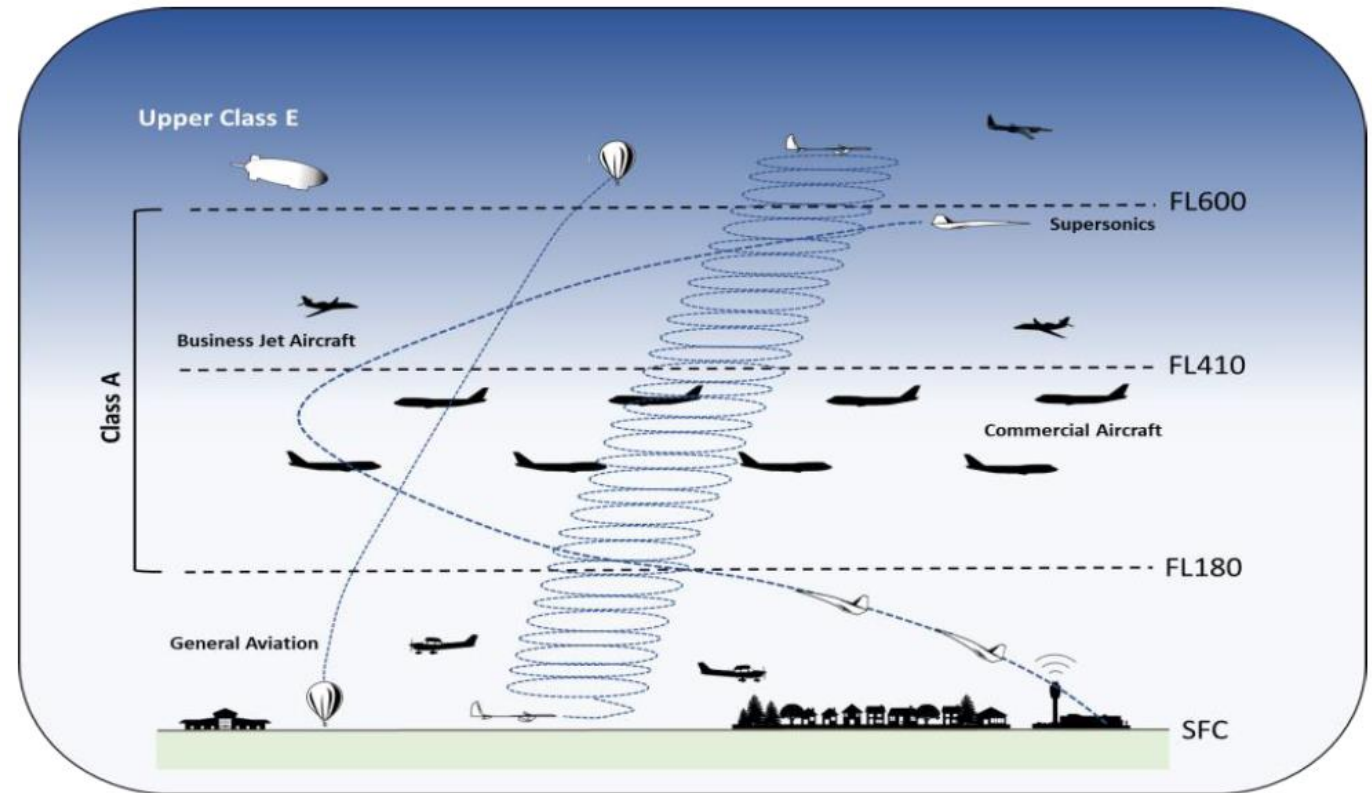
Altimetry options



Source: Preliminary Assessment of Surveillance Alternatives for Upper Class E Traffic Management (ETM), April 2019

Transit to and from ETM airspace

- Many flight plans will contain waypoints and lat/longs that could exceed character or route limits
- Flight plans that exceed 24 hours may time out
- ATC needs Unmanned Aircraft Systems (UAS) contingency plans
- Trajectories are uncertain and require frequent updating and modification
- UAS unable to “sense and avoid” and have difficulty getting to FL180



Source: Preliminary Assessment of Surveillance Alternatives for Upper Class E Traffic Management (ETM), April 2019

High altitude users

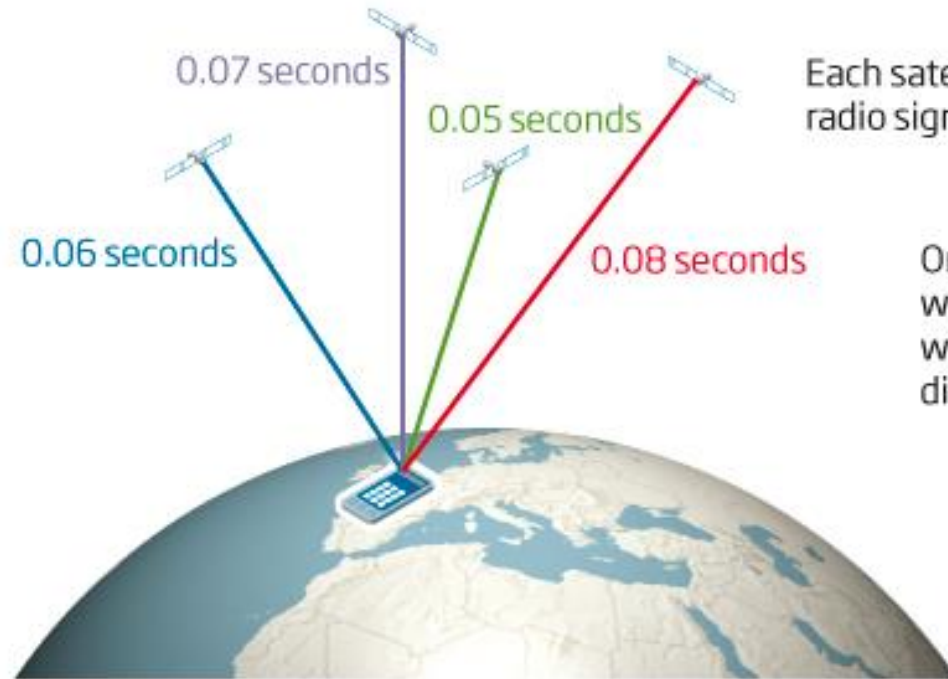


Source: Existing and Emerging Communication Technologies for Upper Class E Traffic Management (ETM), March 2020

Satellite nav and altitude

How GPS works

©NewScientist



Each satellite is continually sending out weak radio signals with its position and the exact time

On Earth, a receiver will compare the time when the signal was sent with the time it was received. This is used to calculate distance from the satellite

After correcting for errors, the receiver uses the signals from four or more satellites to calculate its position in 3D. This is called trilateration

Today's use of geometric altitude

- Terrain Avoidance Warning System (TAWS) cross-checks
- GNSS landing systems
- ADS-B Out message (ICAO ADS-B WG)
- SASP recommends it to replace HMU
- Paragliders
- Google Loon

GPS technical limitations

- Need at least 4 satellites in sight with good geometry
- GNSS vertical 50% less accurate than lateral
- Subject to outages
- Constellation degradation
- Space weather disturbances

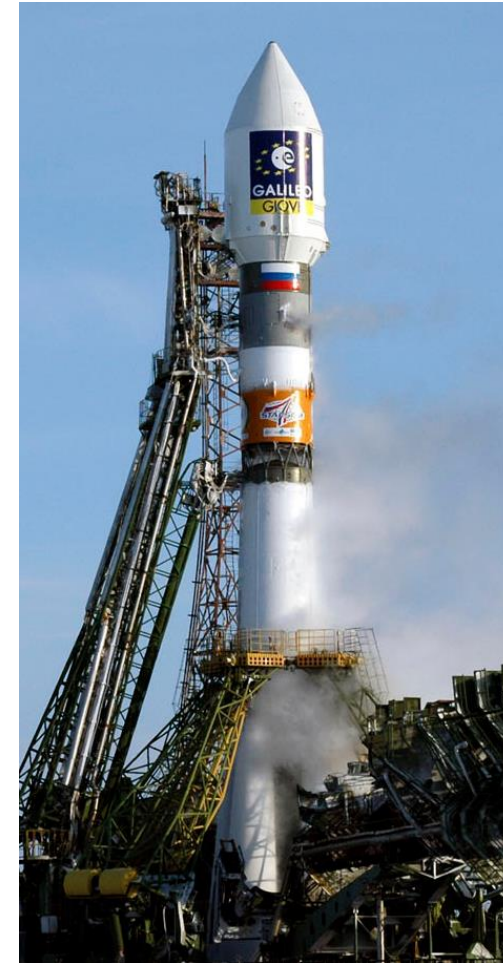
GPS regulatory limitations

- Coordinating Committee for Multilateral Export Controls (COCOM) placed restrictions on GPS receivers, which may stop working:
 - **an altitude greater than 59,000 ft or**
 - **velocity greater than 1000 knots (kts).**
- COCOM restrictions may be interpreted loosely or conservatively
 - **Some will function above 59,000 ft as long as the velocity condition is not triggered**
 - **Others will cease to output GPS state solutions if either condition is triggered**
- These constraints are to prevent foreign adversaries from using GPS for weapon system navigation and impact both 1090ES and UAT ADS-B
- Unrestricted GPS receivers do exist and have been used to test prototype ADS-B installations for ETM operations

Source: Preliminary Assessment of Surveillance Alternatives for Upper Class E Traffic Management (ETM), April 2019

Improving vertical accuracy

- Augmentation
 - GBAS
 - SBAS
 - ✓ WAAS (USA)
 - ✓ EGNOS (EU)
 - ✓ QZSS (Japan)
 - ✓ Others (India, China)
- Additional constellations
 - Galileo (EU)
 - GLONASS
 - Compass / BeiDou 2



EU-US agreement on GPS-Galileo

ARAIM Technical Subgroup (SG): July 1, 2010

- Multi-constellation concept to support air navigation worldwide
- Advanced RAIM (ARAIM)
 - **Multiple constellations**
 - **Ground system broadcasts corrections**
- LPV-200: Vertical guidance 200-foot altitudes
- ARAIM SG goal: LPV-200 at every airport in the world

ADS-B security

- ADS-B is susceptible to jamming and spoofing
 - **ADS-B jamming is most likely to occur as interference with GPS signals**
 - **Spoofing is possible through creation of false GPS signals or transmission of false ADS-B messages**
- Current ADS-B avionics standards do not mitigate these vulnerabilities
- Radar and other techniques provide validation of ADS-B messages in the SBS system to mitigate such vulnerability
- ADS-B is susceptible to GPS disruptions from solar storms or human action (e.g., anti-satellite, or ASAT, weapons)

Source: Preliminary Assessment of Surveillance Alternatives for Upper Class E Traffic Management (ETM), April 2019

Space launch vehicle tracking

- Radar tracking of current space operations extremely limited
- SSR transponder not required
- Primary method of surveillance is operator telemetry
- Some vehicles equipped with special transponders are tracked by military radar



Source: Preliminary Assessment of Surveillance Alternatives for Upper Class E Traffic Management (ETM), April 2019

High altitude performance

- Air data computers not required to operate above 50,000 ft; required performance is uncharacterized
- Concorde was certified to operate at 60,000 ft
- Barometric altitude provided by most commercial systems is not useful above 60,000 ft
- F-15s were certified to fly at FL800 with restrictions
- Error band increases significantly (e.g., ± 850 ft at 80,000 ft)

Source: Preliminary Assessment of Surveillance Alternatives for Upper Class E Traffic Management (ETM), April 2019

High altitude users

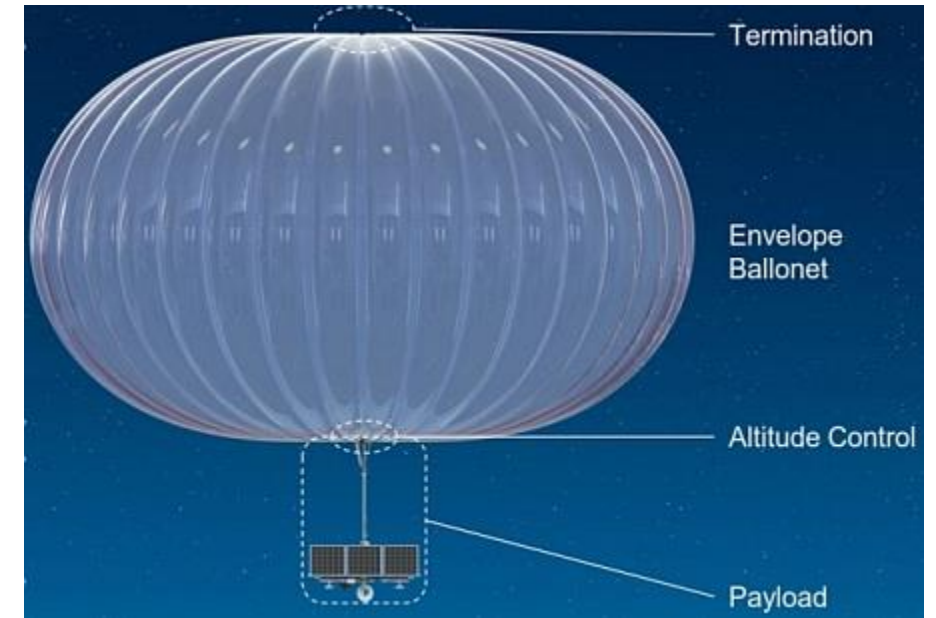
- Supersonic passenger aircraft, Mach 1.0-2.5, FL 550 to 70,000 ft
- Solar powered, High Altitude Long Endurance (HALE) fixed wing aircraft between FL 600 and 90,000 ft for three to six months
- Unmanned Free Balloons (UFB) up to 160,000 ft
- HALE balloons
- HALE airships, up to FL 600



Source: Existing and Emerging Communication Technologies for Upper Class E Traffic Management (ETM), March 2020

Loon

- Loon currently logs about 400,000 flight hours each year—about 100,000 in United States oceanic airspace annually.
- 75% occur between FL500 and FL600 with clusters of 50-plus balloons.
- As of late 2019, launching dozens per week, with the goal of millions of flight hours with hundreds of vehicles.



Source: Upper E Traffic Management (ETM) Tabletop 2 Summary, NASA Ames Research Center, December 12, 2019

Sceye TV 17

- Helium-filled, remote-controlled airship
- Not operational today
- FL640-FL650
- High-accuracy track predictions using observed conditions
- ADS-B for surveillance



Source: Upper E Traffic Management (ETM) Tabletop 2 Summary, NASA Ames Research Center, December 12, 2019

AeroVironment Hawk30

- Telecommunications base, delivering connectivity to remote areas
- Cylindrical ascent/descent (mission and wind dependent) up to about FL600
- Climb and descent rate is approximately 100 feet/minute, 8 hours to level
- ADS-B for surveillance
- Voice comm with ATC via control center
- GPS for navigation



Source: Upper E Traffic Management (ETM) Tabletop 2 Summary, NASA Ames Research Center, December 12, 2019

Airbus Zephyr

- Currently provides broadband communications and collects research data in Australia
- Conventional takeoffs and landings via slow cylindrical ascent and descent, 100-150 feet/minute) to operational levels above FL550.
- Vulnerable to environmental impacts
- Limited maneuverability
- Can usually maintain altitude if necessary
- Surveillance by ADS-B
- Comm via ground control center landline



Source: Upper E Traffic Management (ETM) Tabletop 2 Summary, NASA Ames Research Center, December 12, 2019

Northrop Grumman's Global Hawk

- Similar to large manned aircraft but controlled by a remote pilot at an operations center
- Support military operations, conducting research and surveillance missions out of restricted airspace
- 30 minutes to reach FL500+ at speeds of up to 360 knots
- Ascent/descent typically via a spiral climb
- Can maneuver as needed via manual adjustment by the remote pilot



Source: Upper E Traffic Management (ETM) Tabletop 2 Summary, NASA Ames Research Center, December 12, 2019

HAPSmobile Sunlider

- Japanese venture
- Successful flight to 62,500 ft on October 7, 2020



Source: <https://www.cnet.com/news/this-massive-drone-beamed-broadband-from-the-sky-in-a-key-test/>

Others

- Aurora Odysseus
- Aerion AS2 Supersonic Business Jet

Source: Upper E Traffic Management (ETM) Tabletop 2 Summary, NASA Ames Research Center, December 12, 2019

