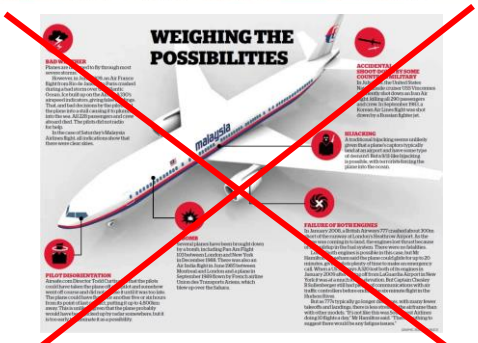
« Why does an aircraft disappear from radar? »

Paul Hopff
Attaché Dir-Gen Operations
Melsbroek, March 19th, 2016

Belgocontrol

MH370 - The trigger...



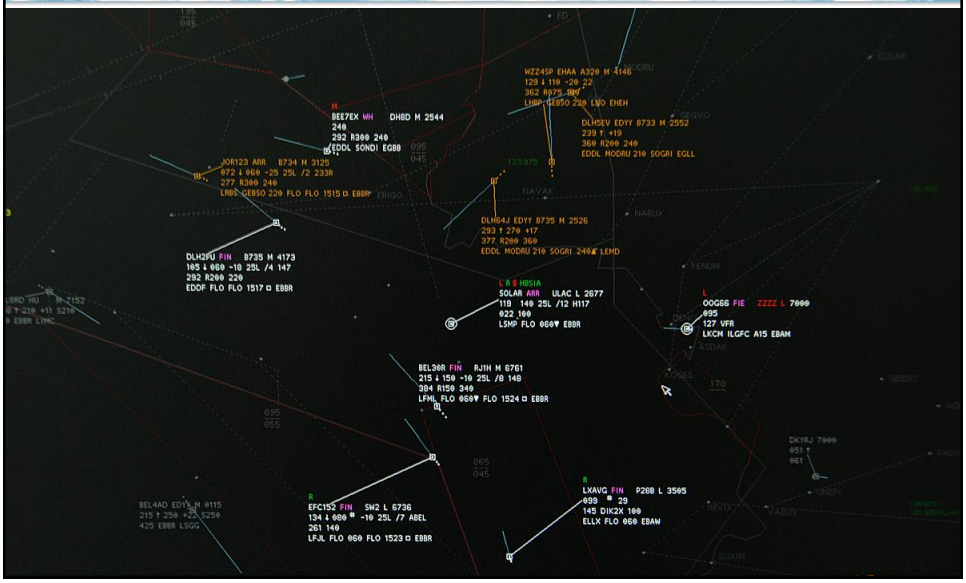
No speculations!

Many questions in the public, as well as in the aviation world...
We'll try to answer some!

On the menu... - Keywords

- Surveillance – Radar
- Aircraft Tracking
- Aircraft (wreck) Locating Techniques
- Recorder Locating Means

Surveillance

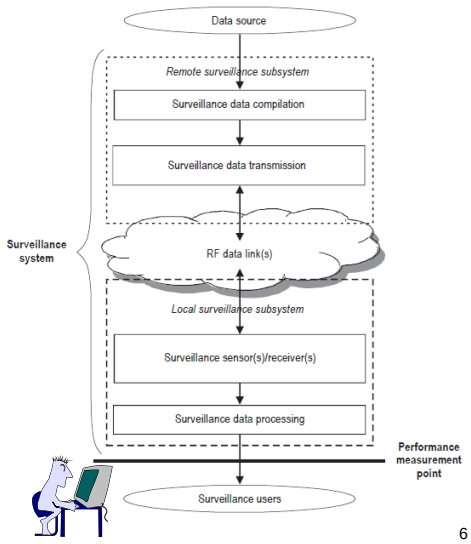


Surveillance?

- Ref. ICAO Doc 9924 (Aeronautical Surveillance Manual)
- The ability to accurately determine, track and update the position of aircraft has a direct influence on the minimum distances by which aircraft must be separated (i.e. separation standards), and therefore on how *efficiently* a given airspace may be utilized.
  - Areas without electronic surveillance:
    - ATM is reliant on pilots reporting their position verbally
    - aircraft have to be separated by relatively large distances
  - Areas where electronic surveillance systems are used:
    - the airspace can be used more efficiently by safely accommodating a higher density of aircraft through reduced separation minima.
- "Electronic surveillance systems" = **RADAR**
- Surveillance = essential **SAFETY** function in aviation and ATM!

Surveillance system?

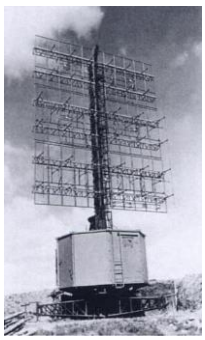
- **3 categories**
- Independent non-cooperative surveillance *(e.g. Primary radar)*
- Independent cooperative surveillance *(e.g. Secundary radar)*
- Dependent cooperative surveillance *(e.g. ADS-B)*



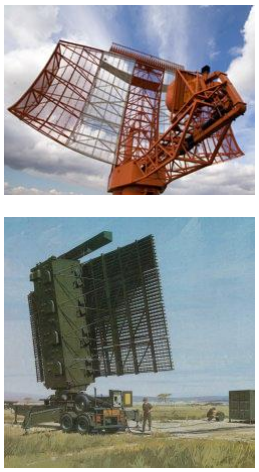
6

Primary Radar

Chain Home
(UK-1939)

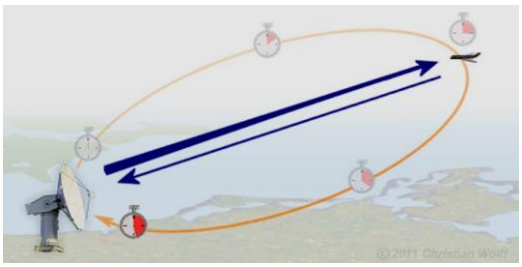


Freya
(Germany -1939)



7

Primary Radar - principle (1)



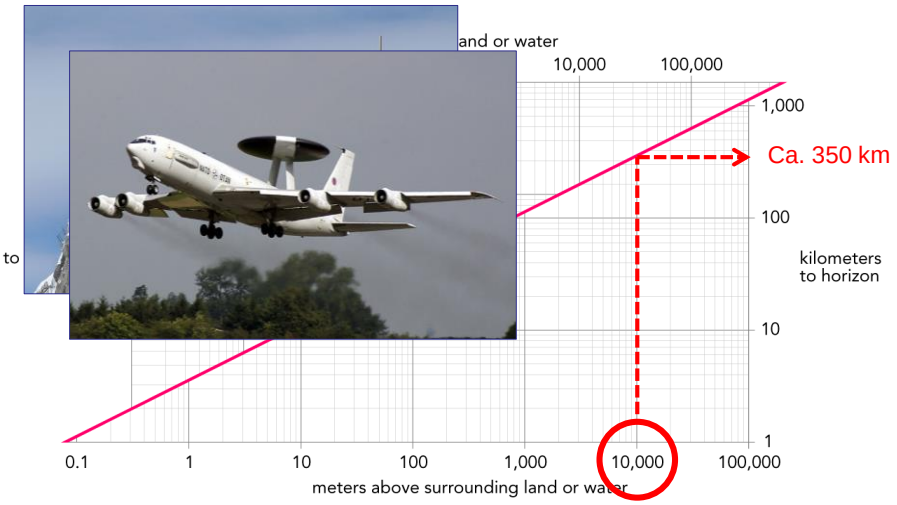
A highly directional burst of microwave energy impinges on the target. The signal *reflected* from the target aircraft is received. The time from transmission till reception of the reflection is measured, and gives the range. Knowing the azimuth angle, the *position of the target is calculated by the facility*.

- Height/altitude of the target is unknown (civil radar).
- Identity of the target aircraft is unknown.
- Line-of sight: targets beyond the horizon are invisible to radar (civil radar)!

SOME COMMON RADAR BANDS.		
HF	3 to 30 MHz	OTH surveillance
VHF	30 to 300 MHz	Long-range surveillance
UHF	300 to 1000 MHz	Long-range surveillance
L-band	1 to 2 GHz	Long-range surveillance
S-band	2 to 4 GHz	Moderate-range surveillance
C-band	4 to 8 GHz	Long-range tracking
X-band	8 to 12 GHz	Short-range tracking
Ku-band	12 to 18 GHz	High-resolution mapping
K-band	18 to 27 GHz	Police/traffic radar
Ka-band	27 to 40 GHz	Police/high-resolution mapping

8

How far is the horizon?



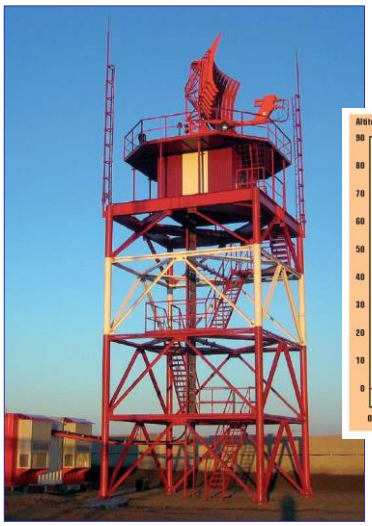
9

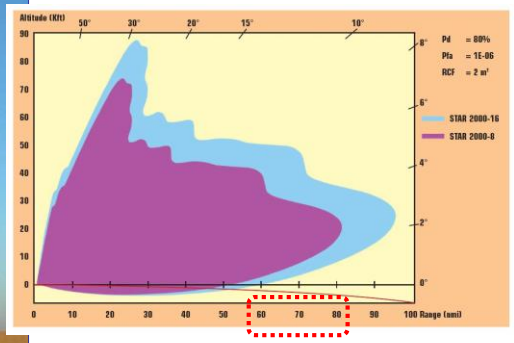
Primary Radar - principle (2)

Radar Cross Section:
σ = measure of the target's ability to reflect radar signals in direction of the radar receiver

10

Primary Radar - principle (3)

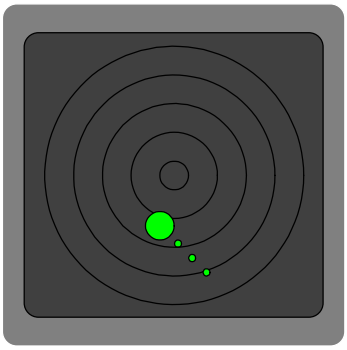


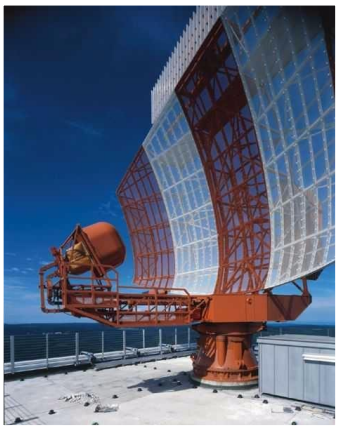


60-80 NM

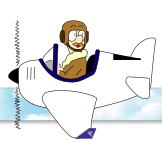
Primary Surveillance Radar (PSR)

Symbolic representation!

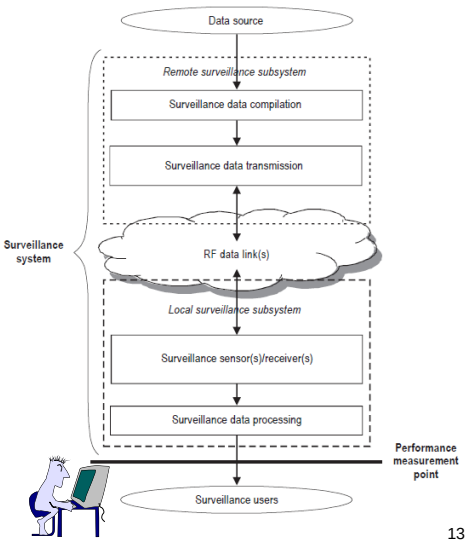




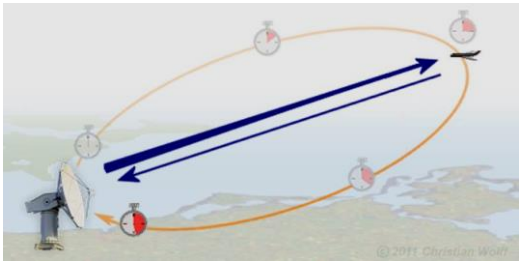
Surveillance systems



- **3 categories**
- Independent non-cooperative surveillance *(e.g. Primary radar)*
- Independent **cooperative** surveillance *(e.g. Secundary radar)*
- Dependent cooperative surveillance *(e.g. ADS-B)*



Secondary Radar - principle (1)



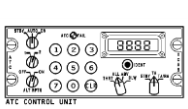
A highly directional microwave pulse is transmitted by the radar. When received by the target aircraft, an on-board system, the transponder, transmits an answer. The time from transmission till reception of the answer is measured, and gives the range. Knowing the azimuth angle, the *position of the target is calculated by the facility*.

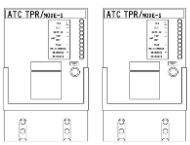
- Line-of sight: targets beyond the horizon are invisible to radar!
- Typical range: 200 NM
- The reply always contains an identification code *(Mode A).*
- The reply may contain the altitude of the a/c *(Mode C).*

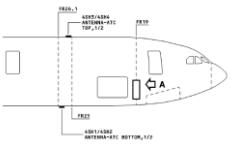
Interrogation: 1030 MHz
Reply: 1090 MHz

Secondary Radar - principle (2)

- The transmitter need be of only relatively low power compared with primary radar equipment.
- The returns, not being dependent on reflection, but consequent of a transmission from the aircraft, are of superior signal strength and improved reliability.
- The returns from the aircraft may be coded to pass flight information to the radar station.







15

Mode-A SSR

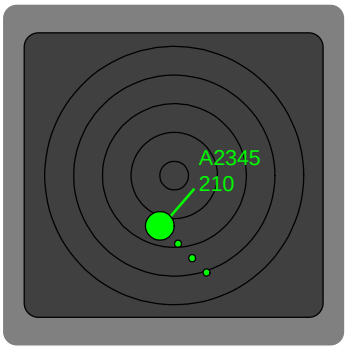
Symbolic representation!

Mode A: 4096 codes available

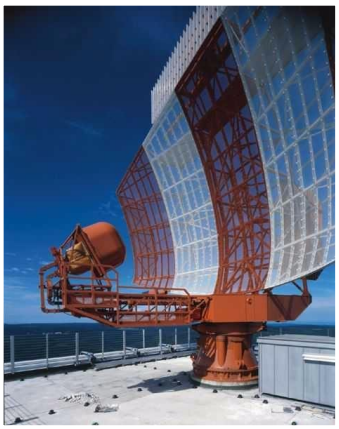
16

Mode-C SSR

Symbolic representation!



Mode C: Pressure altitude
100ft resolution



17

Secondary Radar – Mode-S

- ICAO Doc. 9924 (Aeronautical Surveillance Manual)
- The capabilities of SSR Mode S system include:
  a) accommodation of Mode A/C capabilities;
  b) reporting of pressure altitude in either 100-ft or 25-ft increments;
  c) selective interrogation of aircraft eliminating interference between closely spaced aircraft resulting in high probability of message decoding in high density traffic;
  d) protection against transmission errors by a CRC to ensure data integrity; and
  e) provision of a two-way data link between the aircraft and ground that can be used to obtain aircraft derived data.

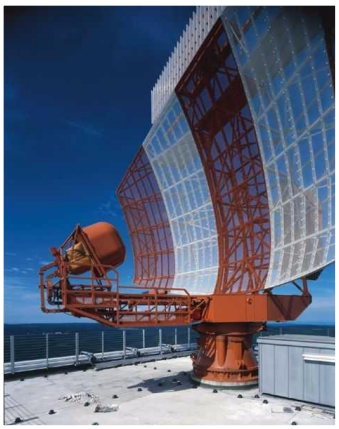
The implementation of SSR Mode S systems requires:
a) aircraft to be equipped with a functioning Mode S transponder;
b) proper configuration of aircraft installation (e.g. allocation and configuration of a unique 24-bit aircraft address, and interface with other aircraft systems).

18

Mode-S Elementary Surveillance

Symbolic representation!

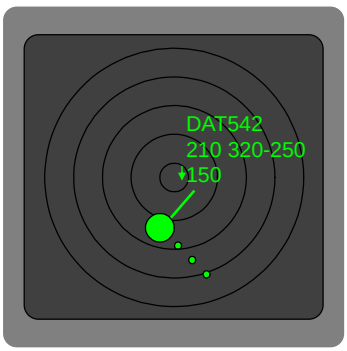
Aircraft Ident = Callsign



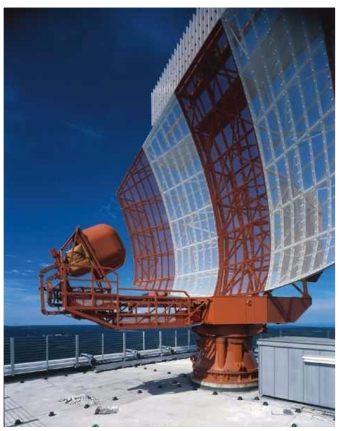
19

Mode-S Enhanced Surveillance

Symbolic representation!

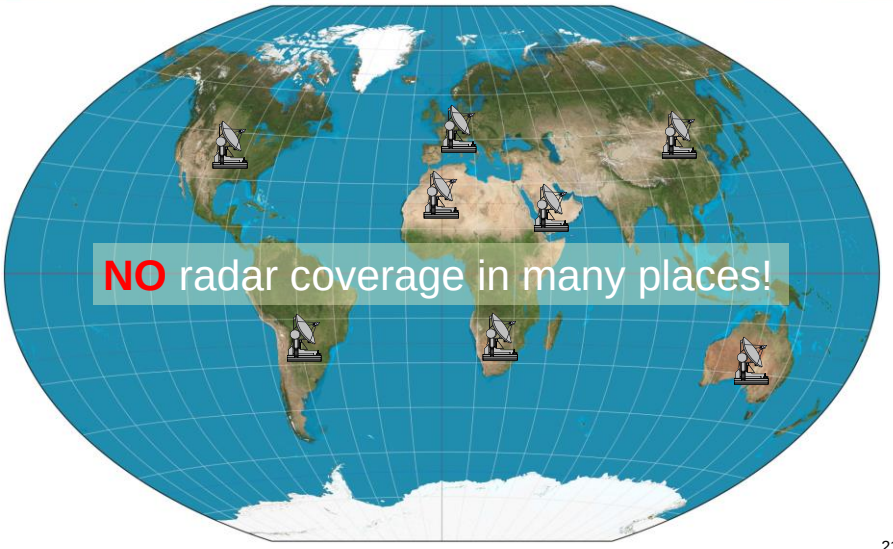


A/C Downlinked parameters



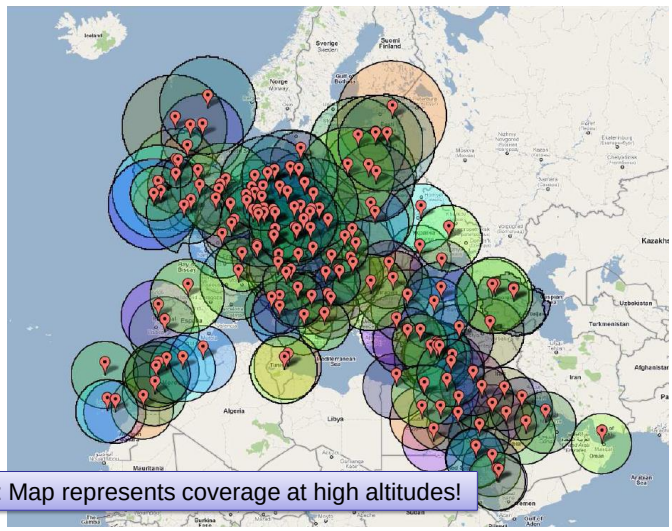
20

The world...



21

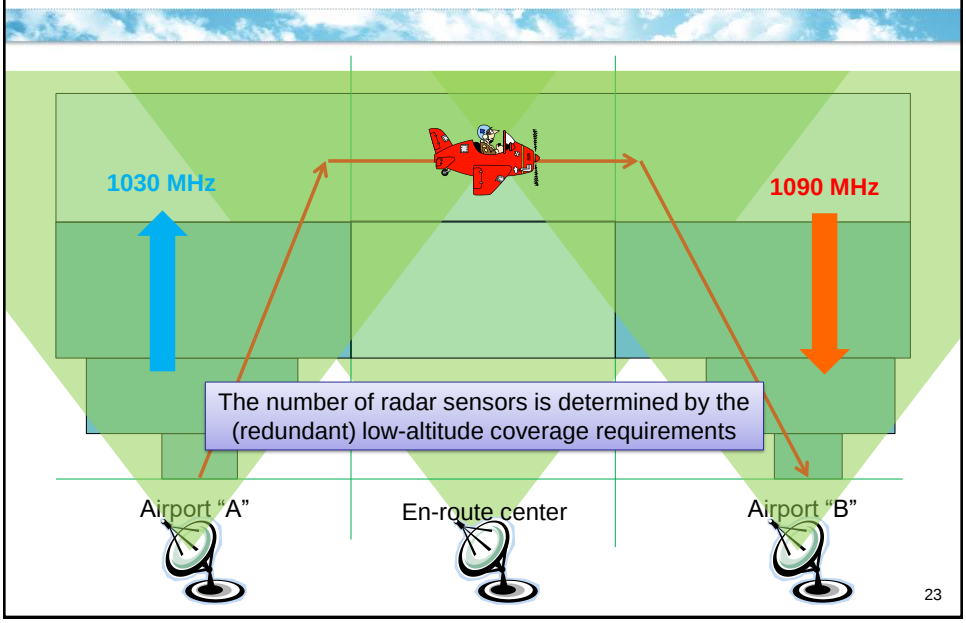
“There are too many radars!”



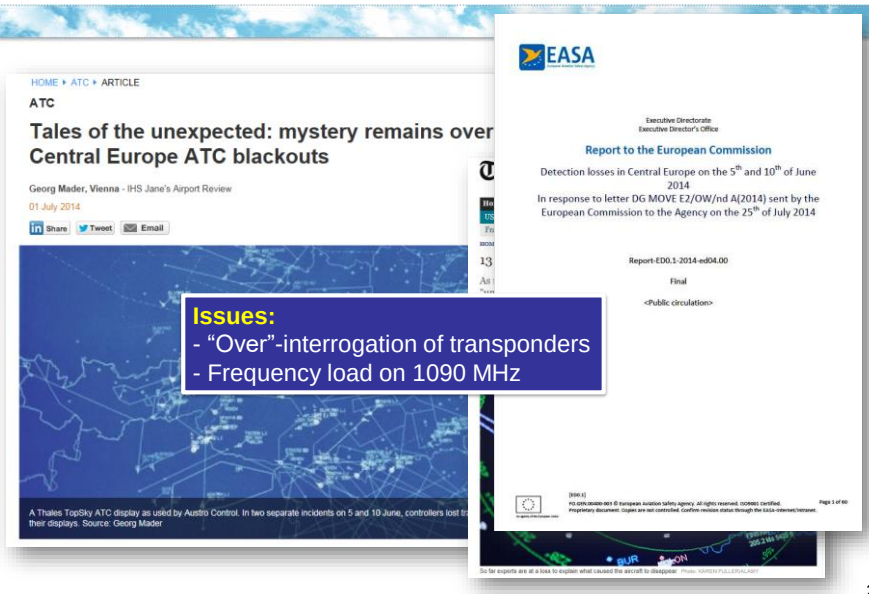
Caution: Map represents coverage at high altitudes!

22

“Are there too many radars?”



Frequency / transponder issues



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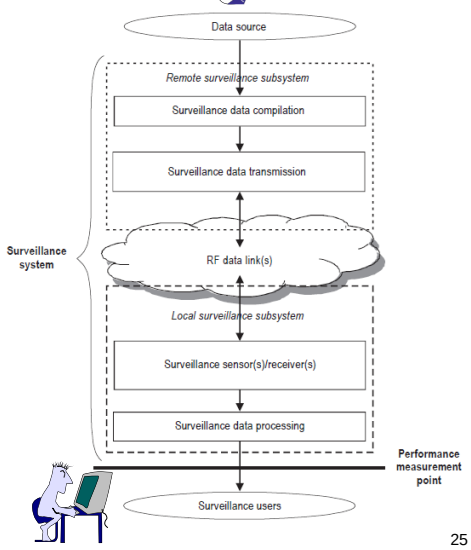
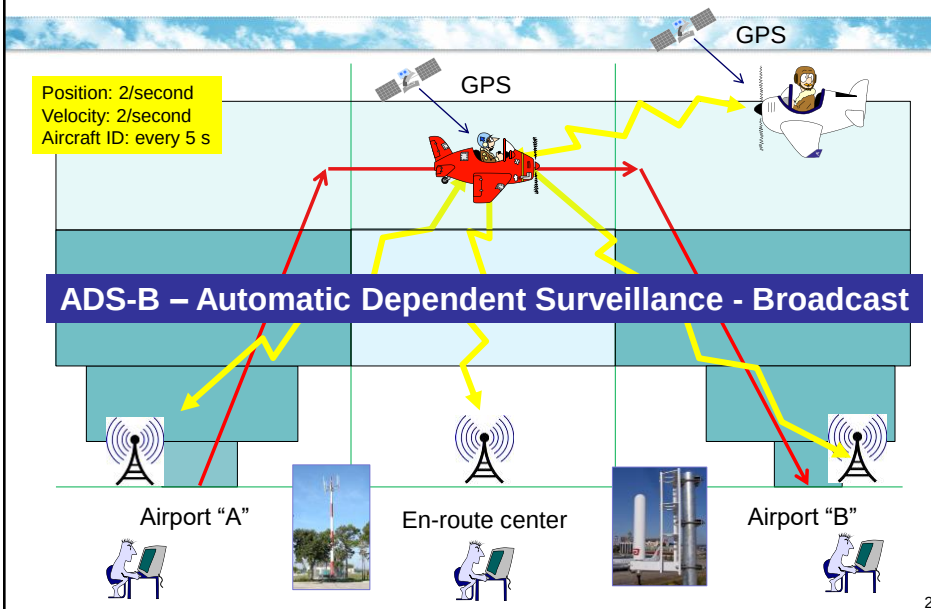


25

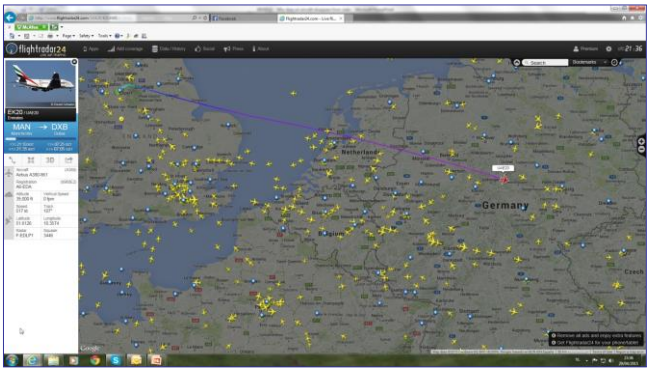
Another approach...



26

A wellknown application...

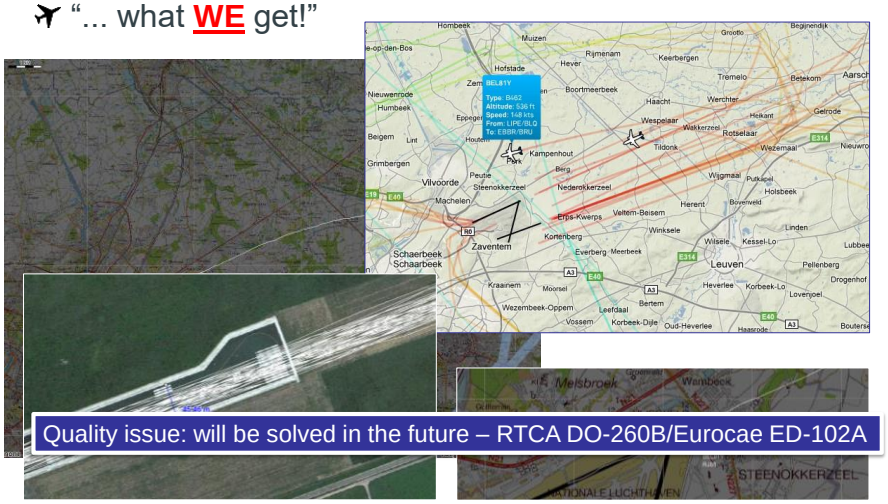
- Popular “radarsites” rely on transmitted ADS-B data.
- Only ADS-B –equipped aircraft visible!
- Today, only a minority is *ADS-B-certificated*



27

“What YOU see, is not always...”

- “... what **WE** get!”



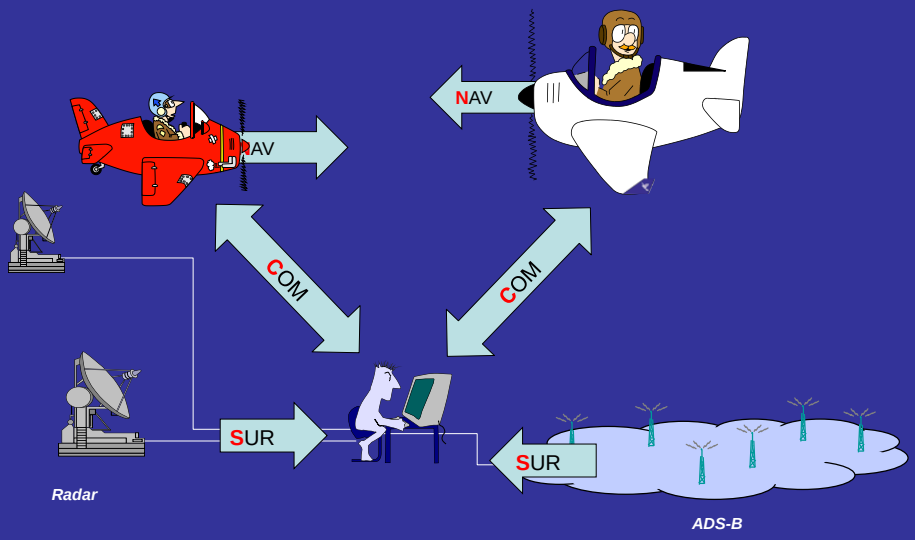
Quality issue: will be solved in the future – RTCA DO-260B/Eurocae ED-102A

28

CNS/ATM Dependency on GNSS…

Belgocontrol

ATM relies on 2 out of the 3 CNS pillars!



CNS/ATM Dependency on GNSS…

Belgocontrol

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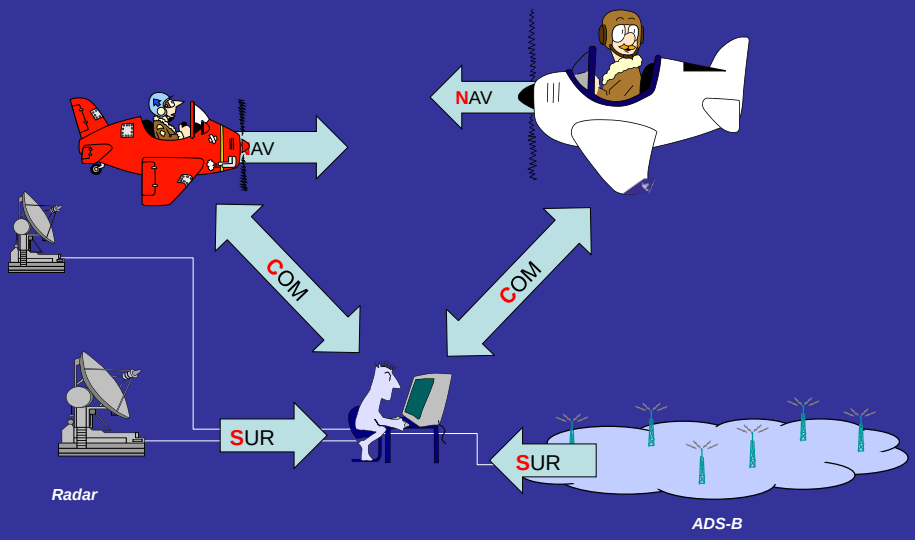
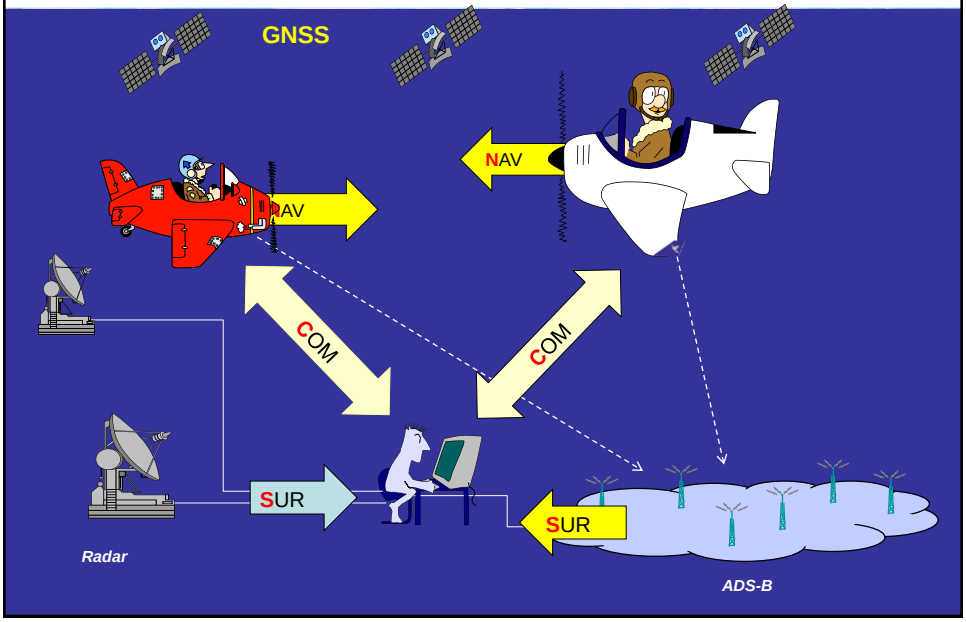
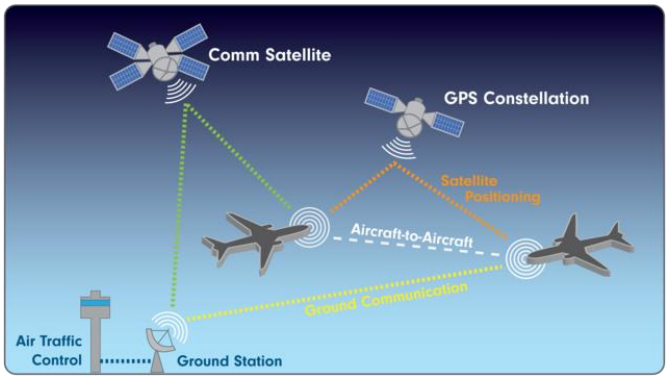


CNS/ATM Dependency on GNSS…



ADS-B - Summary

- Position information provided by target ('dependent').
- Operations rely on GNSS (GPS L1).
- Range limited to line-of-sight, unless... **Space-based ADS-B**!
- Future: ADS-B-IN applications.



32

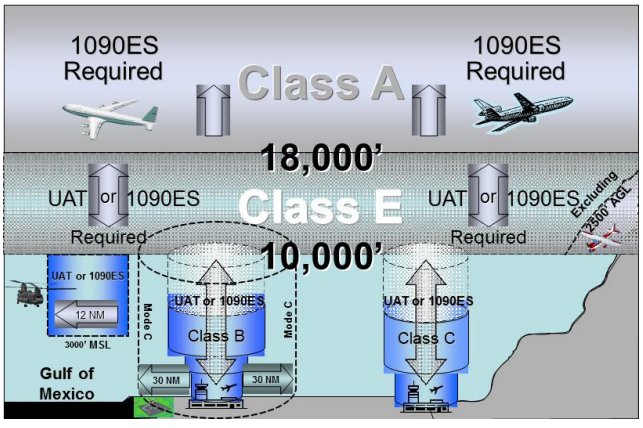
Europe – EC Regulation 1207/2011

- **For Aircraft with a Civilian Registration:**
- **ALL** Aircraft operating IFR/GAT in Europe are required to carry and operate Mode S Level 2s (i.e. with SI code capability) transponder(s) with ***Mode S Elementary Surveillance (ELS)*** capability. The applicability dates for this requirement is:
  - 8 January 2015 for "new" aircraft
  - 7 December 2017 for aircraft with an individual certificate of airworthiness first issued before 8 January 2015
- Aircraft operating IFR/GAT in Europe and with a **MTOM > 5 700 kg** or having a maximum cruising TAS > 250 knots are required to carry and operate Mode S Level 2s transponder(s) with ***Mode S Elementary Surveillance (ELS), Enhanced Surveillance (EHS)*** (for fixed wing aircraft) and ***ADS-B 1090MHz Extended Squitter*** (ES) capabilities. The applicability dates for this requirement is:
  - 8 June 2016 for "new" aircraft
  - 7 June 2020 for aircraft with an individual certificate of airworthiness first issued before 8 June 2016

Commission Implementing Regulation (EU) No 1207/2011, published on 22/11/2011;
Commission Implementing Regulation (EU) No 1028/2014, published on 26/09/2014, amending EU Regulation 1207/2011.

33

USA – 2020+ NEXTGEN



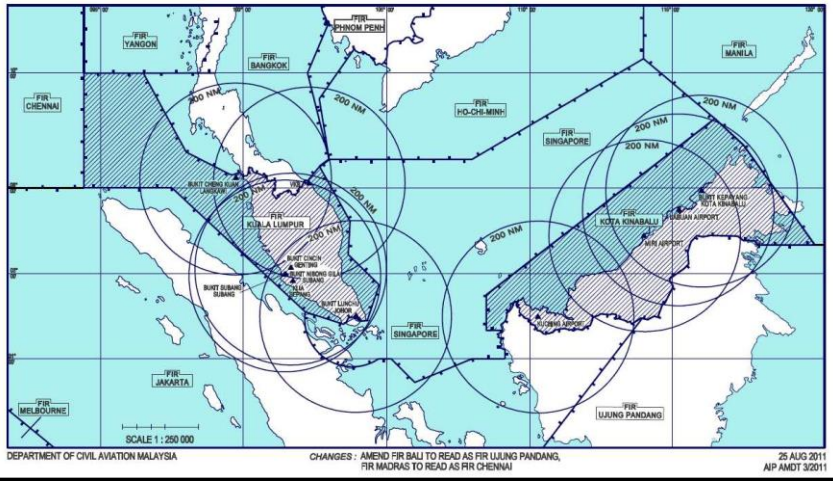
If you fly in this airspace, you must be equipped with ADS-B

Airspace	Altitude
A	All
B	From the ground up within the Mode C ring
C	From the ground up
E	Above 10,000 ft MSL but not below 2,500 feet AGL

Federal Regulations 14 CFR 91.225 and 14 CFR 91.227 contain the details.

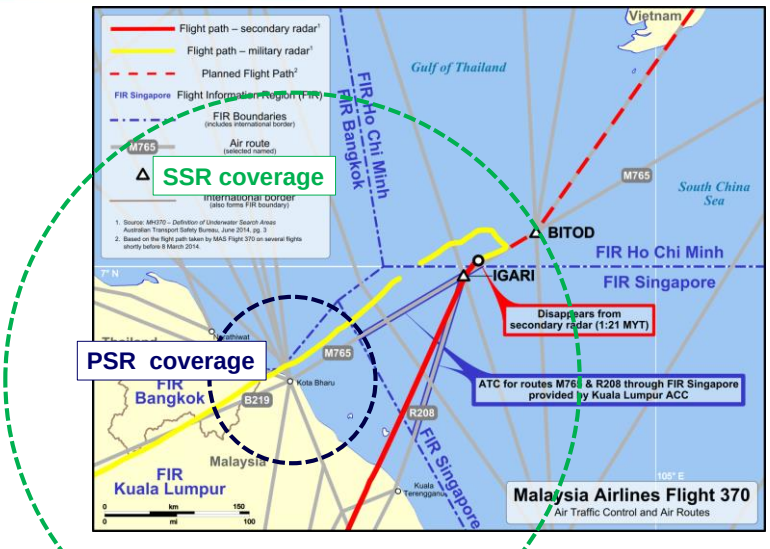
34

MH370 – Radar coverage (1)



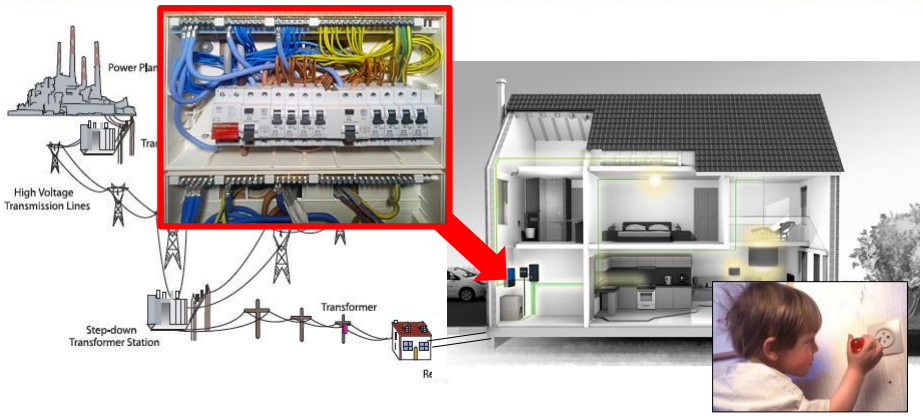
35

MH370 – Radar coverage (2)



36

Electrical networks...

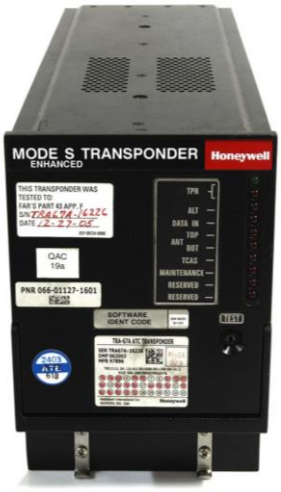


Power generation → Transport → Electr. Consumers → Users

Network protection

Electrical networks...

Essential equipment!

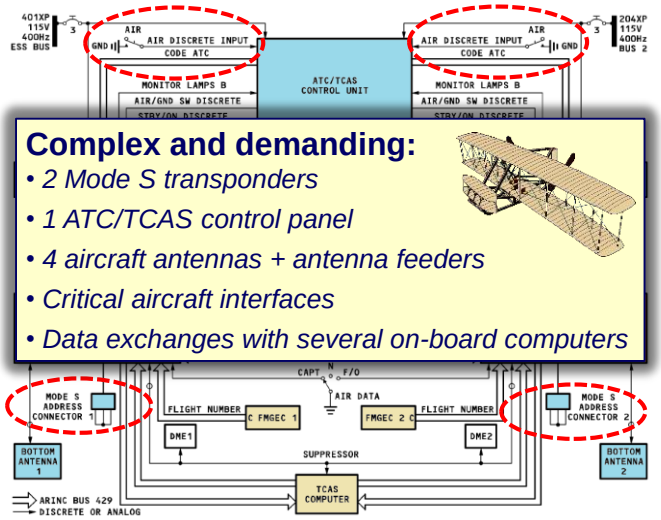


- Mode A/C SSR
- Mode S SSR
- ADS-B

- ACAS (TCAS)

39

Transponder installation...

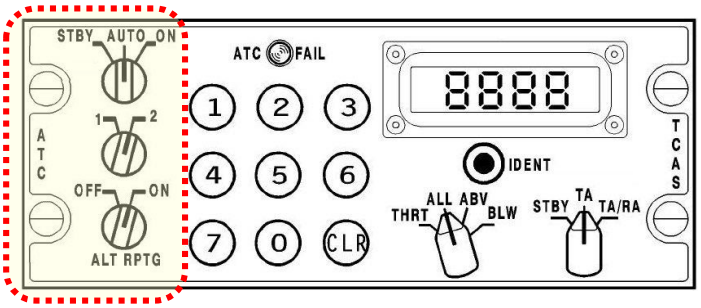


Complex and demanding:

- *2 Mode S transponders*
- *1 ATC/TCAS control panel*
- *4 aircraft antennas + antenna feeders*
- *Critical aircraft interfaces*
- *Data exchanges with several on-board computers*

40

Transponder ON/OFF?

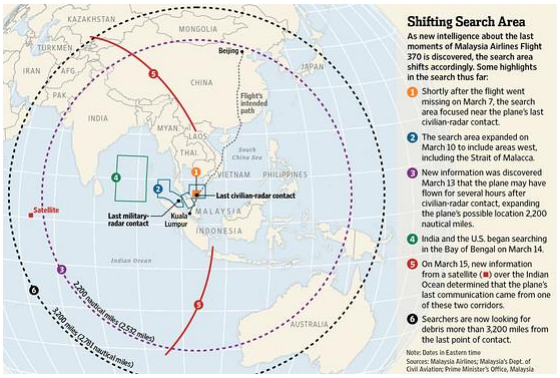


- XPDR must be “OFF” (=standby) in certain phases of flight.
- Wrong or invalid aircraft data received by ATC can give way to unsafe situations.
- Automatic mode switching (e.g. Air/Ground sensing) may fail.
- ***Pilot must have an “override” possibility!***

41

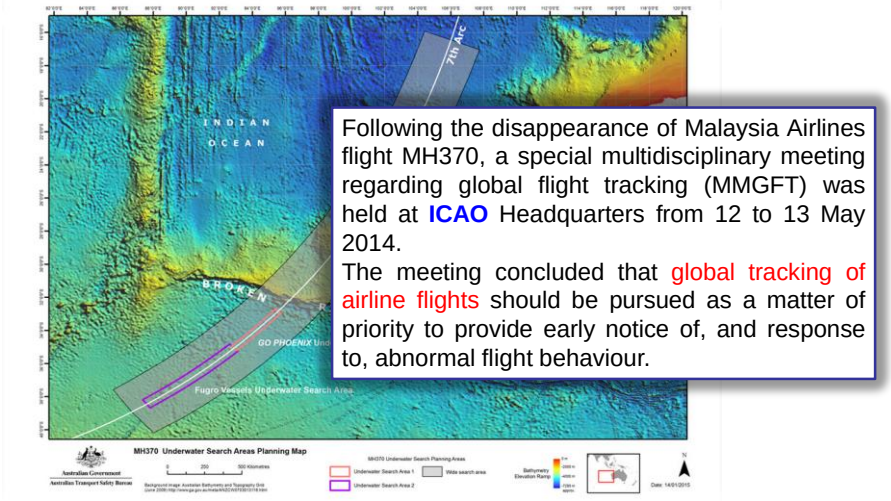
Surveillance → Tracking

- Aircraft Tracking
- Emergency Tracking
- Data Recorder Tracking



42

Where is MH370?



Following the disappearance of Malaysia Airlines flight MH370, a special multidisciplinary meeting regarding global flight tracking (MMGFT) was held at **ICAO** Headquarters from 12 to 13 May 2014.

The meeting concluded that global tracking of airline flights should be pursued as a matter of priority to provide early notice of, and response to, abnormal flight behaviour.

43

ICAO SL - Addendum to Annex 6

3.3 Aircraft Tracking

3.3.1 The operator shall establish an aircraft tracking capability to track aeroplanes throughout its area of operations.

3.3.2 The operator shall track the position of an aeroplane at least every 15 minutes for the portion(s) of the inflight operation(s) that is planned in an oceanic area(s) under the following conditions:

a) the aeroplane has a maximum certificated take-off mass of over 27 000 kg and a seating capacity greater than 19; and
b) where an ATS unit obtains aeroplane position information at greater than 15 minute intervals.

Note.— Access to ATS aeroplane position data meets aeroplane tracking requirements.

3.3.3 Recommendation.— The operator should track the position of an aeroplane at least every 15 minutes for the portion(s) of the inflight operation(s) that is planned in a remote area(s) under the following conditions:

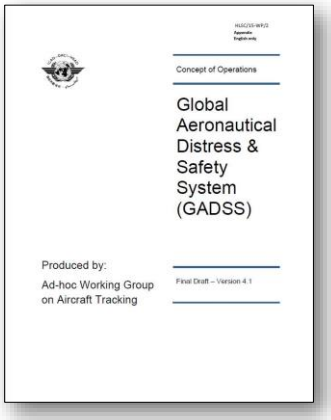
a) the aeroplane has a maximum certificated take-off mass of over 27 000 kg and a seating capacity greater than 19; and
b) where an ATS unit obtains aeroplane position information at greater than 15 minute intervals.

Note.— Access to ATS aeroplane position data meets aeroplane tracking requirements.

44

Aircraft tracking?

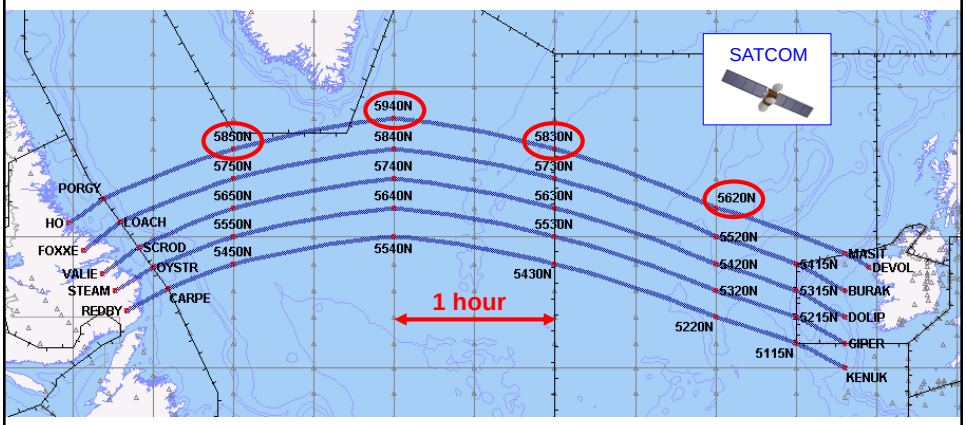
- **Aircraft Tracking.**
  A ground based process that maintains and updates, at standardised intervals, a record of *the four dimensional position of individual aircraft in flight*.
- **Autonomous Distress Tracking (ADT).**
  The aircraft capability to broadcast for distress situations, *independent of aircraft power or systems*, aircraft tracking information.



45

Aircraft Tracking – the old way...

- Example: voice reporting on HF – North Atlantic

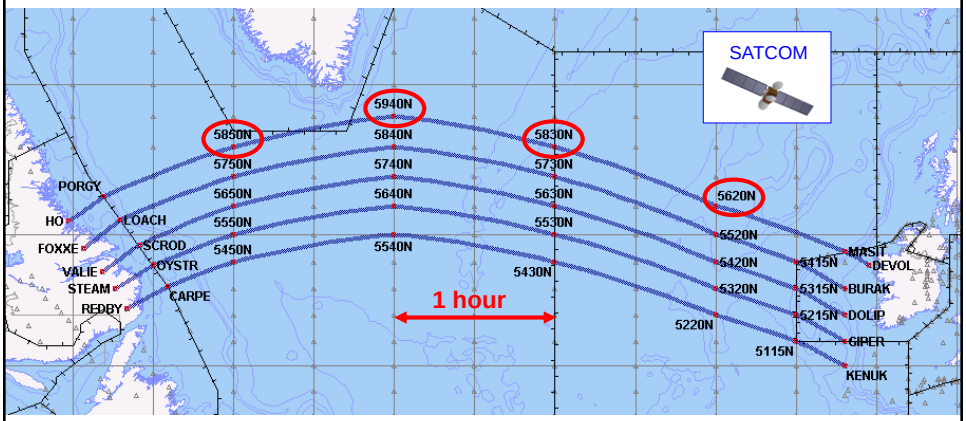


46

Aircraft Tracking – datalink (1)

Belgocontrol

Example: waypoint reporting by datalink/satcom

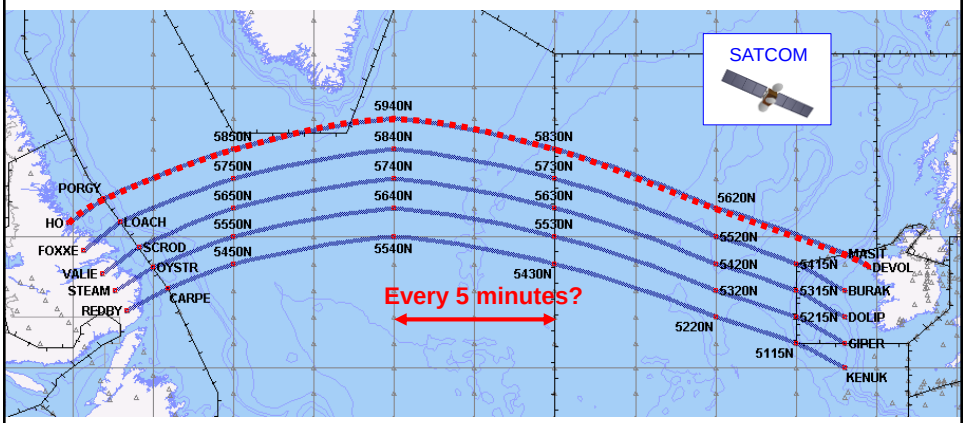


47

Aircraft Tracking – datalink (2)

Belgocontrol

Example: waypoint reporting by datalink/satcom



48

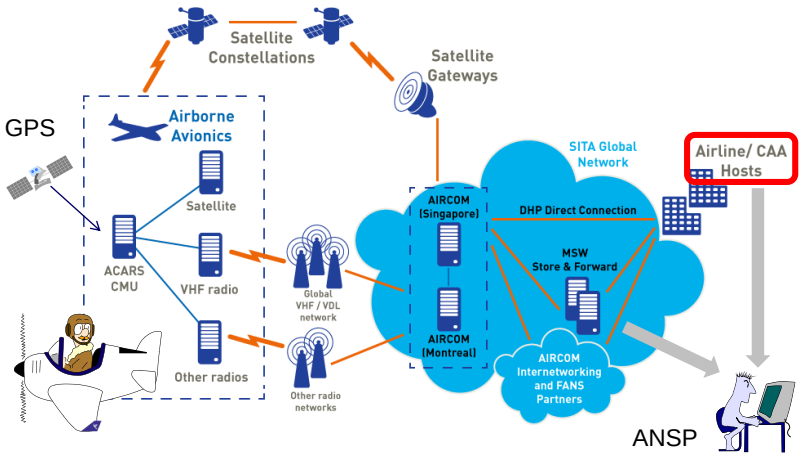
Aircraft Tracking – datalink (2)

- Example: waypoint reporting by datalink/satcom

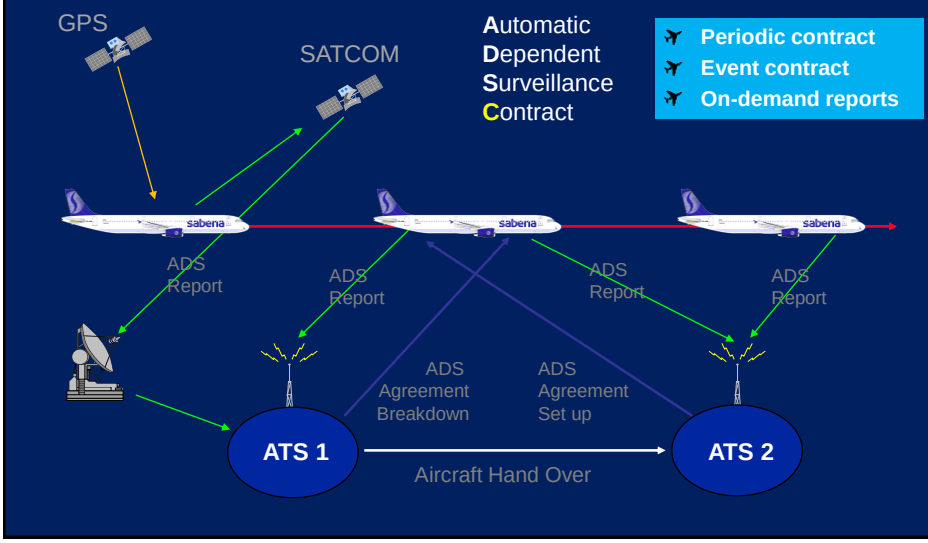
Inmarsat Aero-L: 300 bit/s throughput...

Aircraft Tracking – FMC WPR

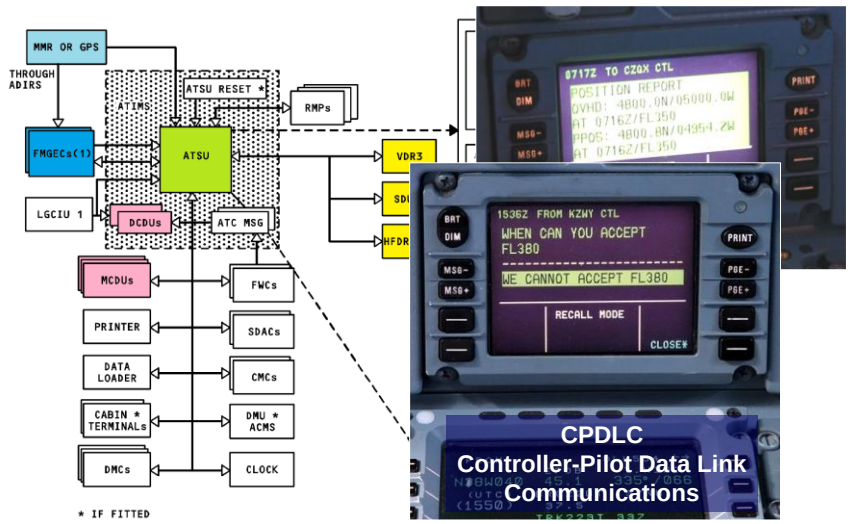
- ACARS infrastructure – SITA (alternate: ARINC)



Aircraft Tracking – ADS-C

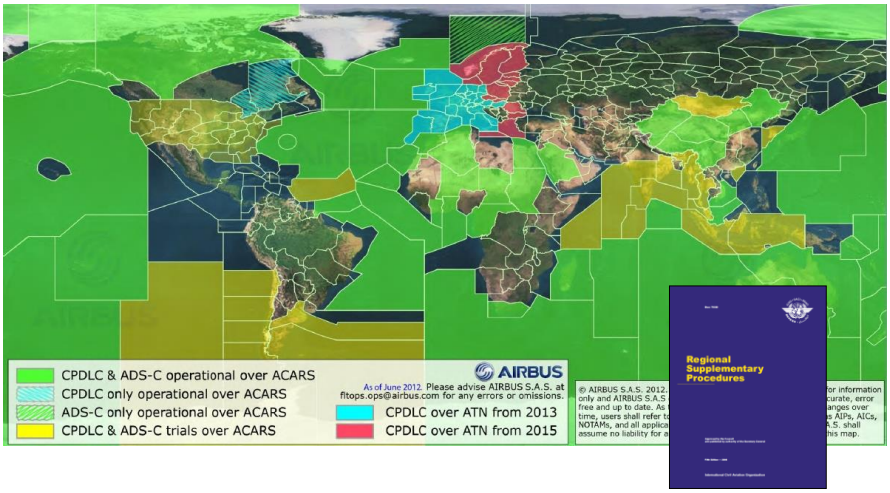


Aircraft digital communications...



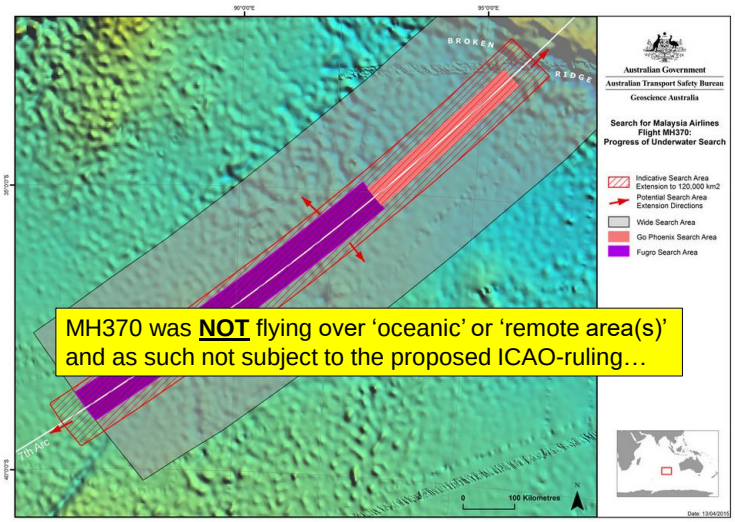
CPDLC
Controller-Pilot Data Link Communications

CPDLC & ADS-C in the World



53

Just a thought...

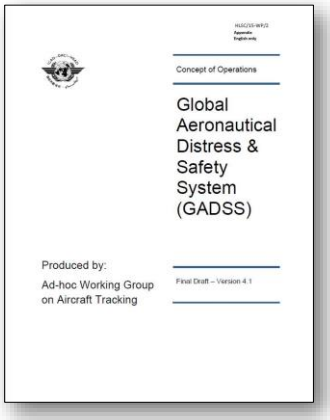


MH370 was **NOT** flying over 'oceanic' or 'remote area(s)' and as such not subject to the proposed ICAO-ruling…

54

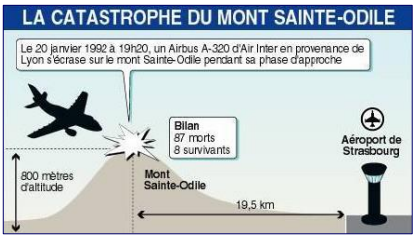
Aircraft Distress tracking?

- **Aircraft Tracking.**
  A ground based process that maintains and updates, at standardised intervals, a record of *the four dimensional position of individual aircraft in flight*.
- **Autonomous Distress Tracking (ADT).**
  The aircraft capability to broadcast for distress situations, *independent of aircraft power or systems*, aircraft tracking information.



55

Emergency Locator Transmitter



ICAO Annex 6 – Operation of aircraft

6.17 Emergency locator transmitter (ELT)

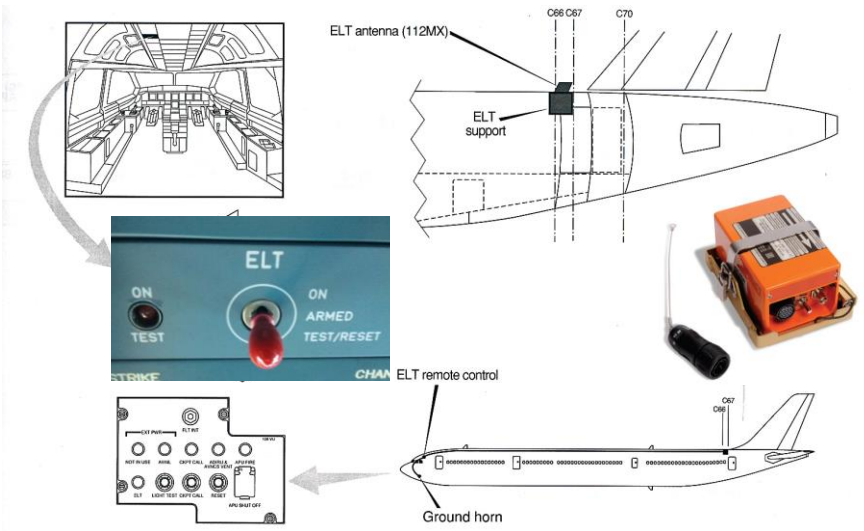
6.17.1 **Recommendation.—** *All aeroplanes should carry an automatic ELT.*

6.17.2 Except as provided for in 6.17.3, all aeroplanes authorized to carry more than 19 passengers shall be equipped with at least one automatic ELT or two ELTs of any type.

6.17.3 All aeroplanes authorized to carry more than 19 passengers for which the individual certificate of airworthiness is first issued after 1 July 2008 shall be equipped with at least two ELTs, one of which shall be automatic.

56

Emergency Locator Transmitter

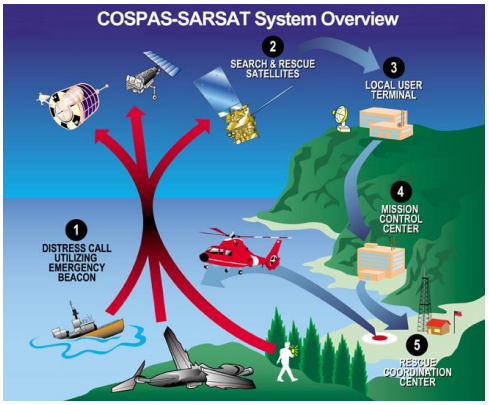


57

Emergency Locator Transmitter

ELT Battery:

- 24 hrs transmission on 406 MHz
- 30 days transmission on 121.5 MHz
- Transmission includes the unique 24-bit address code of the aircraft



The Cospas-Sarsat System includes two types of satellites:

- satellites in low-altitude Earth orbit (LEO) which form the LEOSAR System
- satellites in geostationary Earth orbit (GEO) which form the GEOSAR System

COSPAS-SARSAT.INT
International Satellite System for Search and Rescue

58

Emergency Locator Transmitter

- A review of ICAO accident records over the last 30 years indicates that of the 257 accidents, only 39 cases recorded effective ELT activation.
- ELTs were carried in 173 of these cases. This implies that of the total accidents in which ELTs were carried, *only **22.5%** of the ELTs operated effectively*

COSPAS-SARSAT.INT
International Satellite System for Search and Rescue

59

By the way...

- Even battery operated devices may cause (nasty) surprises...

60

Tracking of recorders...

- **Crash-recorders**
- SSFDR – Solid State Flight Data Recorder
  - Typical: >25 hours of Flight Data information received at a data rate from 64 up to 1024 words/second (ARINC 747).
- SSCVR – Solid State Cockpit Voice Recorder
  - 120 minutes (2 Hours) of Audio information from 4 input channels.

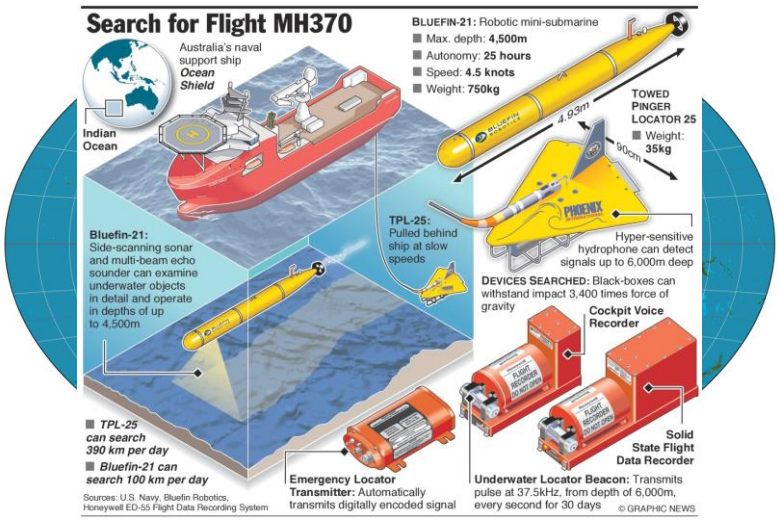
61

Tracking of recorders – ULB

- **ULB** – Underwater Locator Beacon
- A 37.5 kHz (160.5 dB re 1 µPa) pinger:
  Range: 1–2 km in normal conditions and 4–5 km in good conditions.
- A 37.5 kHz (180 dB re 1 µPa) pinger:
  Range: 4–5 km in normal conditions and 6–7 km in good conditions.
- Activated by a “water switch” – Battery power sufficient for >30 days transmissions.

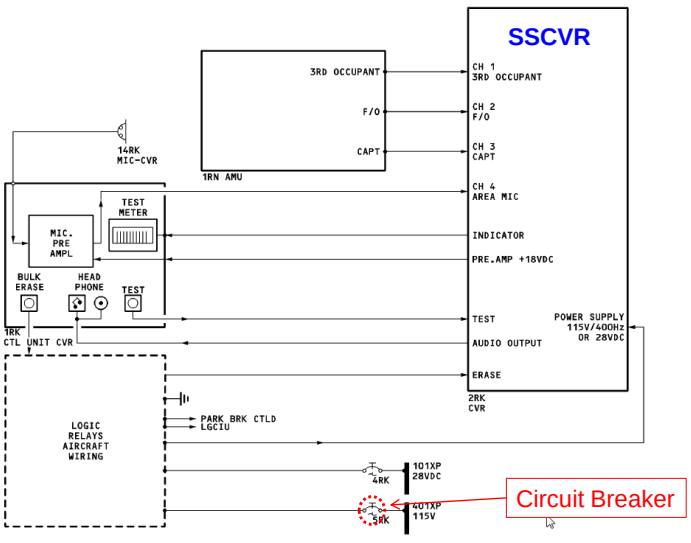
62

Tracking of MH370 recorders?



63

And... remember!



64

Conclusions

- Most parts of the world do not have any radar coverage.
- No single surveillance technology can meet all safety and security requirements.
- Thanks to SATCOM and GNSS, aircraft tracking is or can be improved.
- Distress tracking relies on ELT.
- Flight data recording: alternate paths to be explored.

65

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hop@belgocontrol.be