Ghost is in the Air(Traffic)

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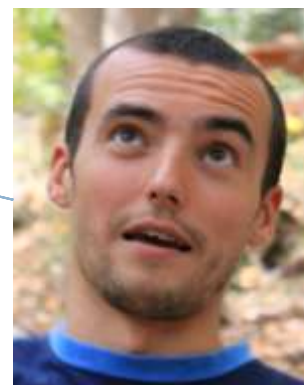
Mifare Classic MFCUK

Interest in avionics

Hacking MFPs + PostScript



http://andreicostin.com/papers/
http://andreicostin.com/secadv/

Administratrivia #0
DISCLAIMER

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- Reader takes full responsibility whatsoever of applying or experimenting with presented material
- Authors are fully waived of any claims of direct or indirect damages that might arise from applying the material
- Information herein represents author own views on the matter and does not represent any official position of affiliated body

- **tldr;**
- **DO NOT TRY THIS AT HOME!**
- **USE AT YOUR OWN RISK!**

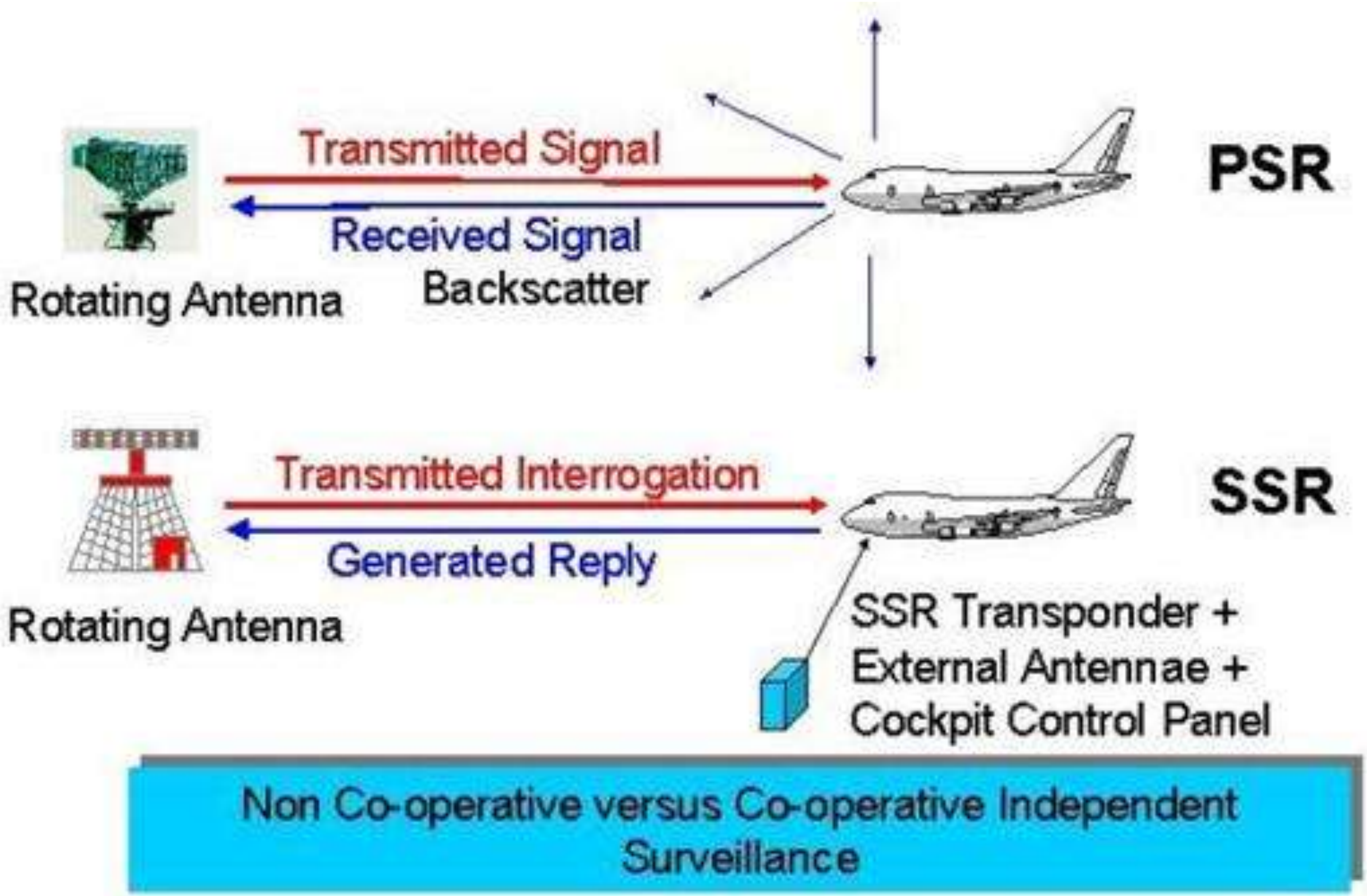
Agenda

1. ATC Today (SSR)
2. Today's Problems
3. ATC "Tomorrow" (ADS-B)
4. "Tomorrow"s Problems
5. Exploit scenarios & Demos
6. Solutions and take-aways

ATC Today…


AIR TRAFFIC CONTROL
What my friends think I do
What my mom thinks I do
What society thinks I do
POLICE
What pilots think I do
What I think I do
What I actually do

How do radars work without ADS-B?



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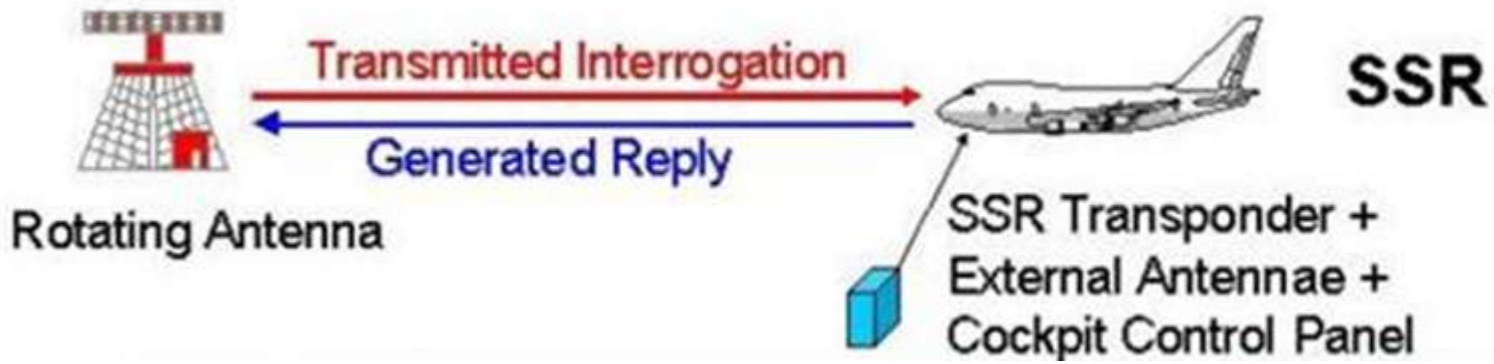
SSR transmits basic *solicited* data



- SSR is solicited type of communication
  - Solicitation via XPDR
  - Solicitation via voice VHF
- Example of data from SSR XPDR:
  - Aircraft Address
  - Altitude
  - Code (squawk)
  - Angles (Roll/Track)

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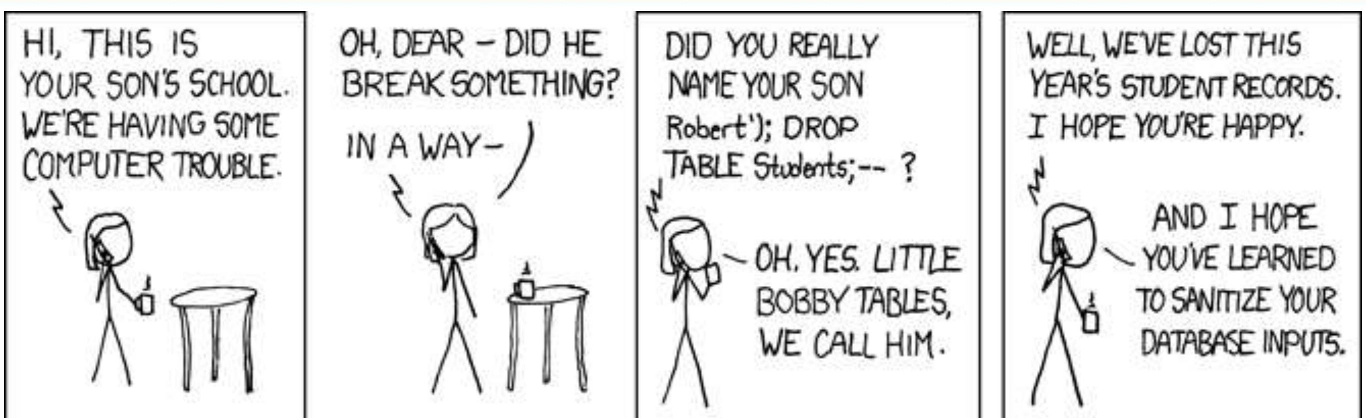
Inputs are not robust enough

> **!** Don't add any leading zeros, hyphens, dashes or spaces to the FLTID.

To allow correlation of a FLTID to a flight plan, the FLTID must match the Aircraft Identification (ACID) entered in Item 7 of the Flight Notification.

> **!** If you enter either of these codes incorrectly, ATC might not be able to see your aircraft, or might confuse it with another. You could also affect other systems, like TCAS. The codes are flight critical information, so enter them carefully.



Input mistakes have severe implications

When making routine code changes, you should avoid inadvertent selection of codes 7500, 7600, or 7700 thereby causing momentary false alarms at automated ground facilities. For example when switching from code 2700 to code 7200, switch first to 2200 then 7200, NOT to 7700 and then 7200.

This procedure applies to nondiscrete code 7500 and all discrete codes in the 7600 and 7700 series (i.e., 7600-7677, 7700-7777) which trigger special indicators in automated facilities. Only nondiscrete code 7500 will be decoded as the hijack code. An aircraft's transponder code (when available) is utilized to enhance the tracking capabilities of the ATC facility, therefore you should not turn the GTX 320 to SBY when making routine code changes.

Important Codes

- **1200**—The VFR Code for any altitude.
- **7600**—Loss of Communications.
- **7500**—Hijacking (Never assigned by ATC with
her aircraft is subject to unlawful interference).
- **7700**—Emergency (All secondary surveillance
times).

Important Codes

Following is a list of important codes:

- 1200 – VFR code in the U.S. (refer to ICAO standards for VFR codes in other countries).
- 7000 – VFR code commonly used in Europe (refer to ICAO standards).
- 7500 – Hijack code.
- 7600 – Loss of communication code.
- 7700 – Emergency code.
- 7777 – Military interceptor operations code (NEVER SQUAWK THIS CODE).
- 0000 – Code for military use in the U.S.

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ADS-B is a $billions world-wide effort from 2002…

FAAXX704: Automatic Dependent Surveillance-Broadcast (ADS-B)

Investment Description: The Surveillance and Broadcast Services (SBS) program office is implementing Automatic Dependent Surveillance-Broadcast (ADS-B), a surveillance system designed to provide improved air traffic information for pilots and air traffic controllers. ADS- More...

FY2012 (CY) Spending: $301.52 M

Time frame of investment: 2006 - 2035

Status: Continued, Major

• Projects • Current Exhibit 300 • FY12 Exhibit 300 • Contracts • Baseline Change History • Evaluation History

EXHIBIT 300 UII 021-142305975

Section C: Summary of Funding (Budget Authority for Capital Assets)

1.

Table I.C.1 Summary of Funding

	PY-1 & Prior	PY 2011	CY 2012	BY 2013
Planning Costs:	$9.9	$0.0	$0.0	$0.0
DME (Excluding Planning) Costs:	$710.7	$179.8	$288.0	$272.1
DME (Including Planning) Govt. FTEs:	$28.6	$6.3	$6.8	$4.5
Sub-Total DME (Including Govt. FTE):	$749.2	$186.1	$294.8	$276.6
O & M Costs:	$11.0	$5.0	$6.4	$7.9
O & M Govt. FTEs:	$2.6	$0.3	$0.4	$0.2
Sub-Total O & M Costs (Including Govt. FTE):	$13.6	$5.3	$6.8	$8.1
Total Cost (Including Govt. FTE):	$762.8	$191.4	$301.6	$284.7
Total Govt. FTE costs:	$31.2	$6.6	$7.2	$4.7
# of FTE rep by costs:	202	38	38	24
Total change from prior year final President's Budget ($)		$0.0	$-2.0	
Total change from prior year final President's Budget (%)		0.00%	-0.66%	

US GOV ITDashboard - FAAXX704 (ADS-B)

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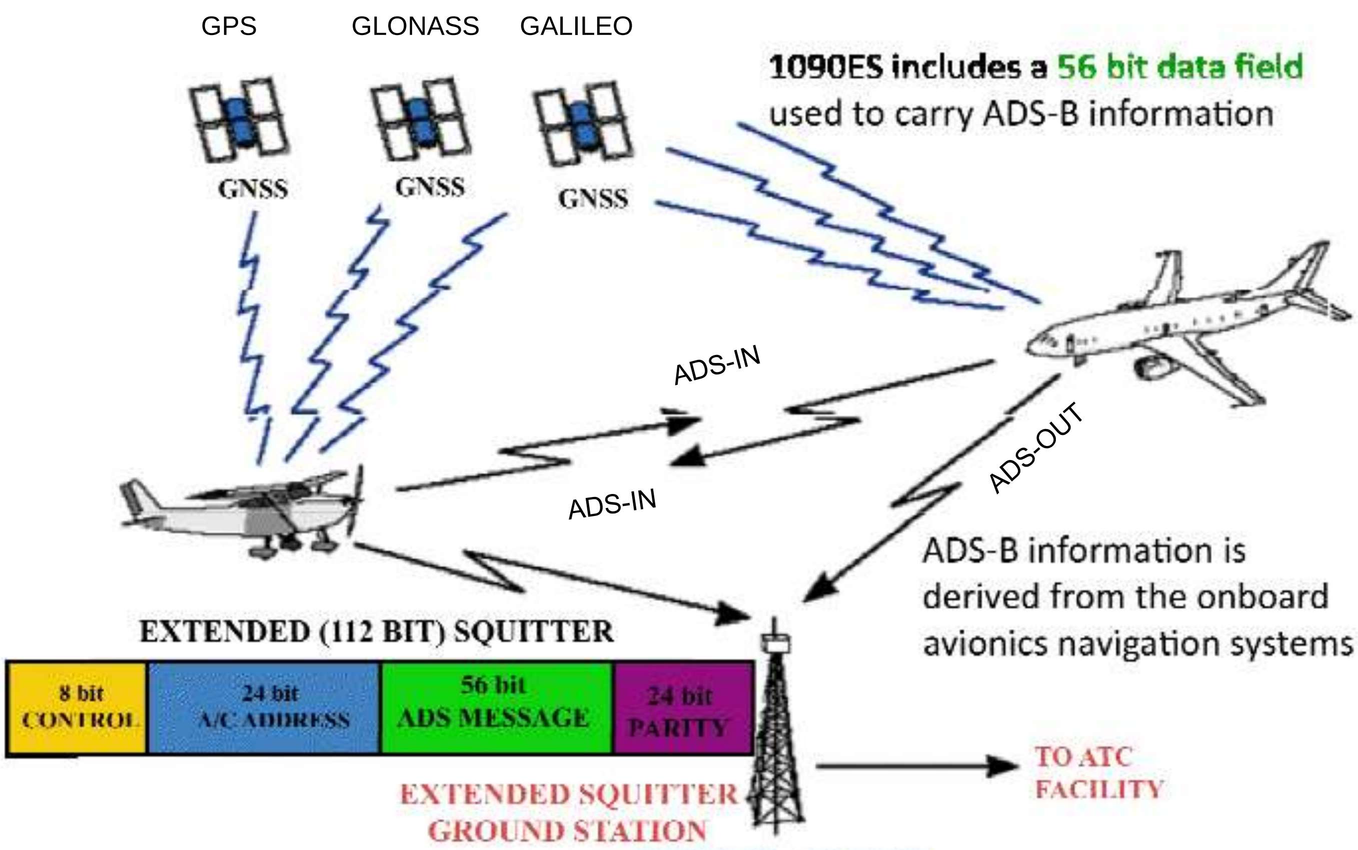
How does ADS-B work? – *Architectural* view

Guidance for the Provision of Air Traffic Services Using ADS-B for Airport Surface Surveillance

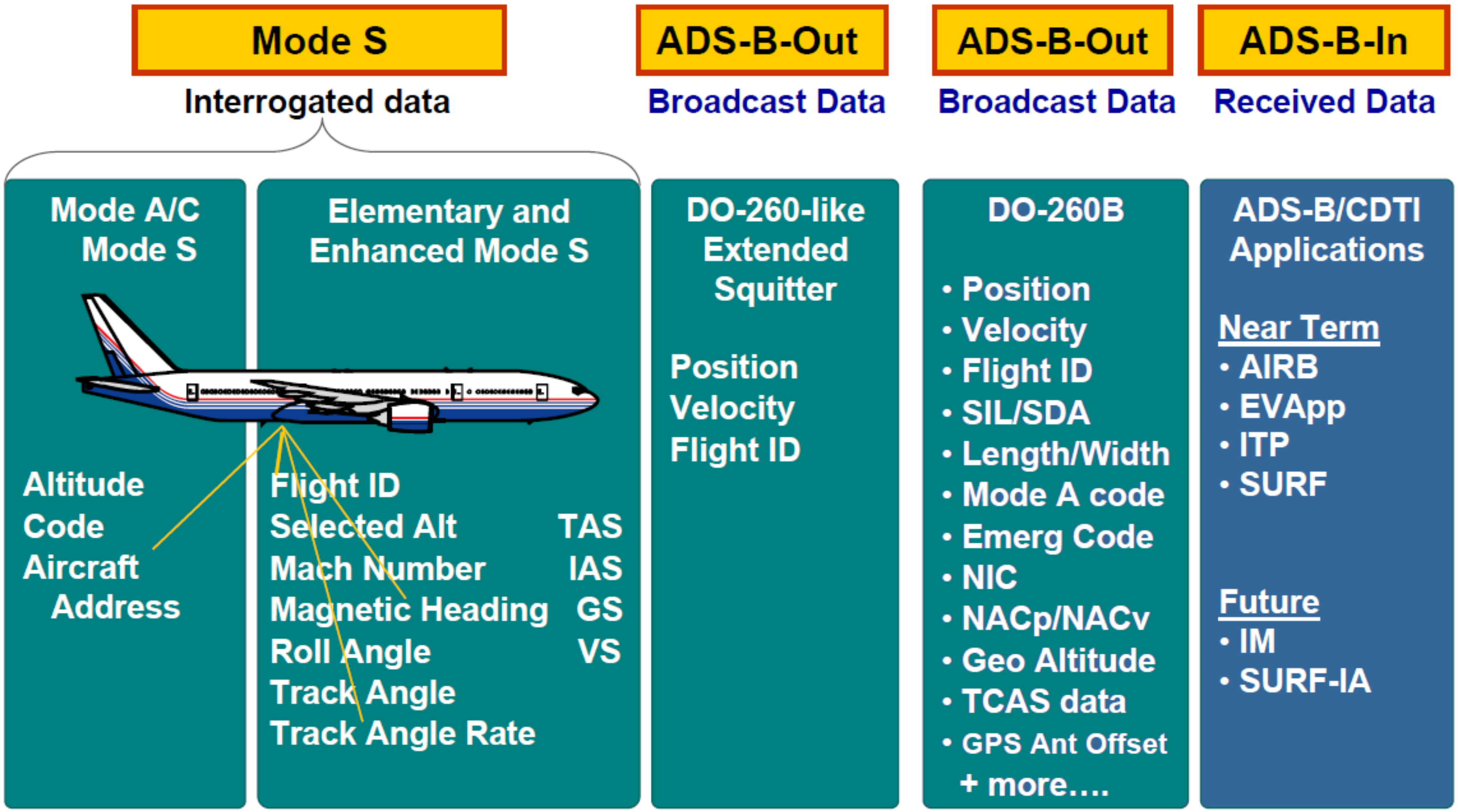
Guidance for the Provision of Air Traffic Services Using ADS-B for Airport Surface Surveillance

2.1.1 ADS-B Out and ADS-B IN



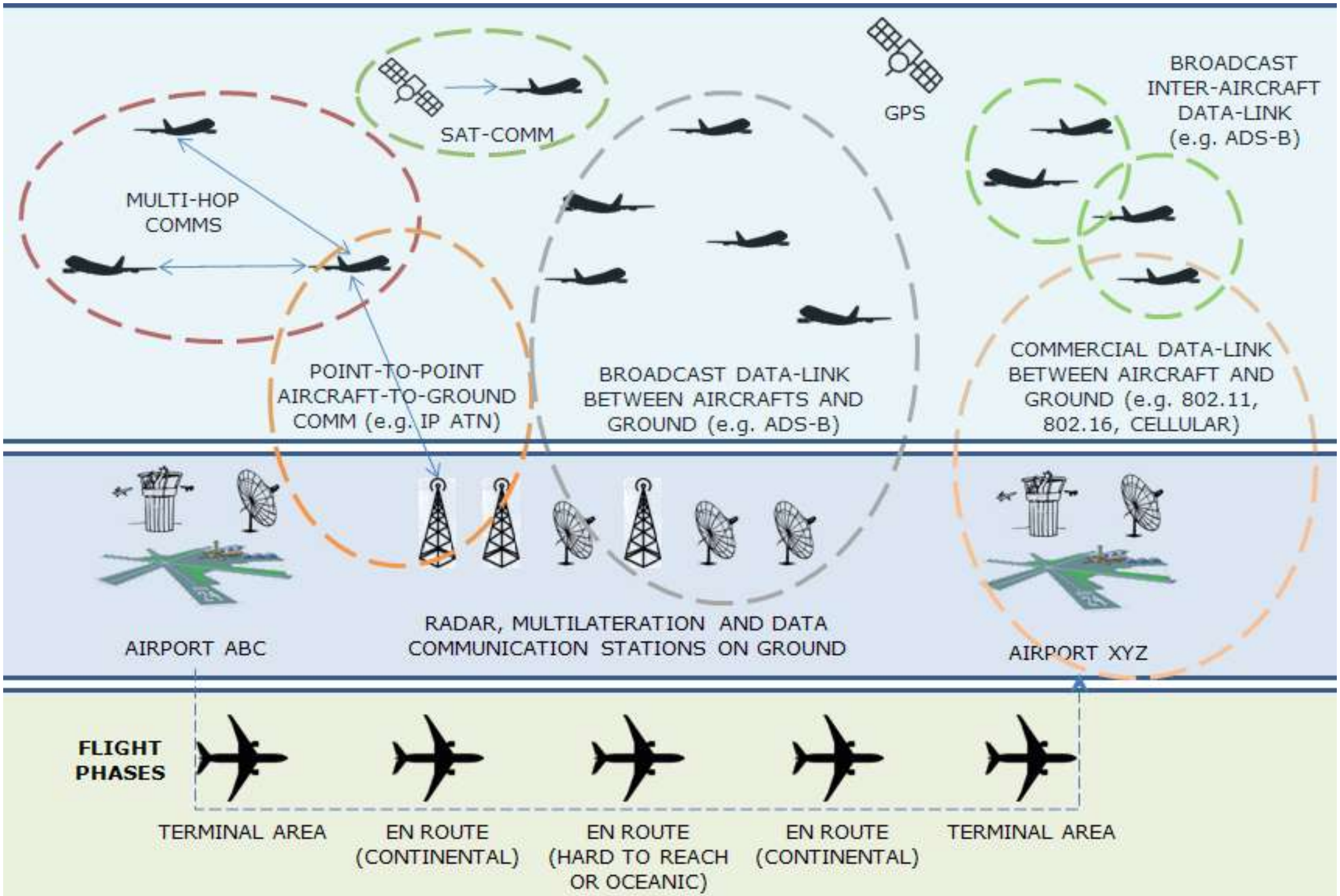
ADS-B Out and ADS-B In – Simplified Functional Diagram

ADS-B – INsideOUT…



- ADS-B is being used over 2 existing technologies:
  - Mode-S – 1090 MHz (replies) and 1030 MHz (interrogation)
    - PPM @ 1 Mbps
  - UAT (Universal Access Transceiver) – 978 MHz (replies)
    - CP-2FSK @ 1.041667 Mbps (modulation index h >= 0.6)

ATC Tomorrow – NextGen, ATC/M and eAircrafts



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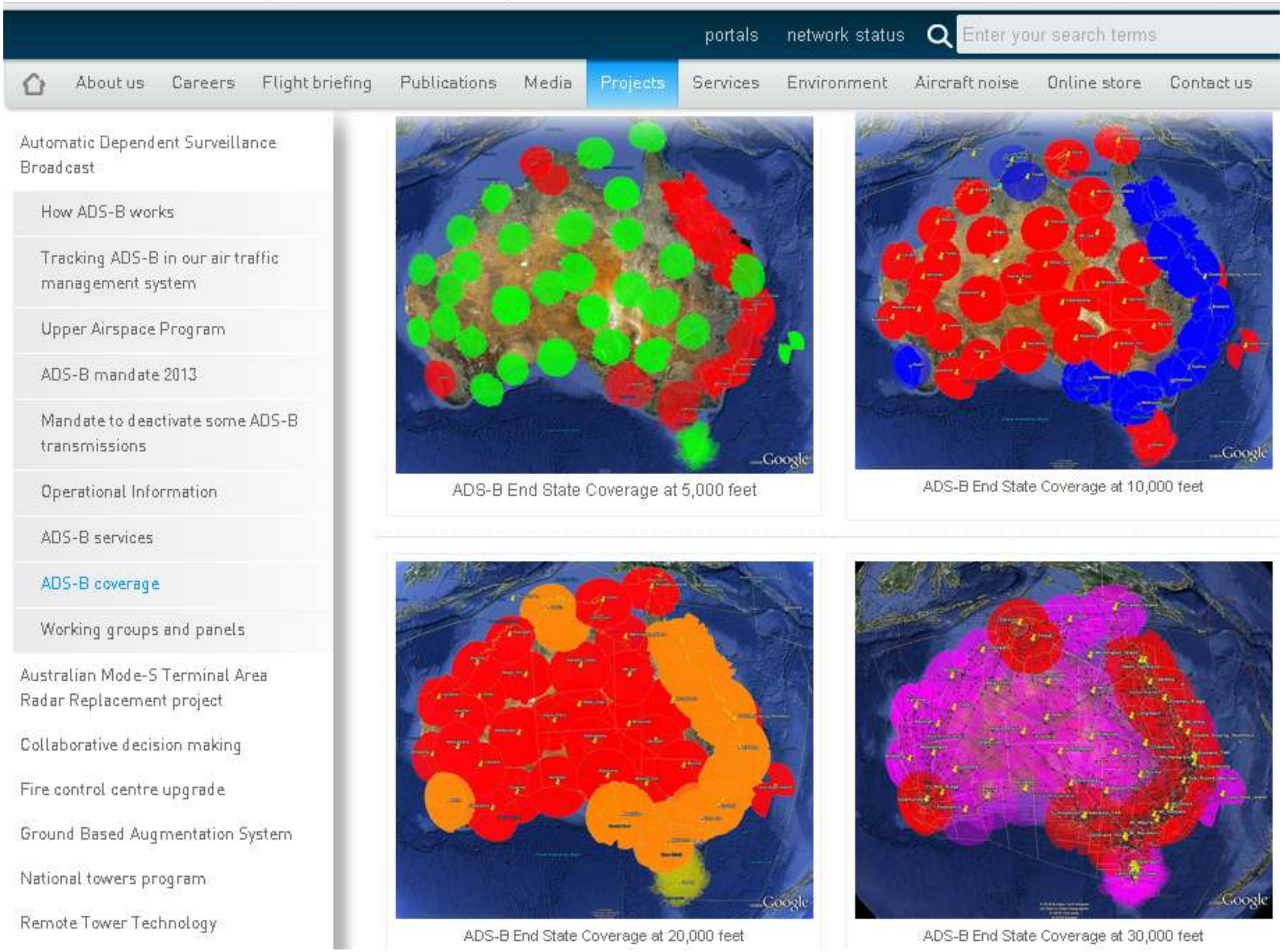
ADS-B Deployment Map – Australia

www.airservicesaustralia.com/projects/ads-b/ads-b-coverage/



Australia Airservices ADS-B Coverage Map

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ADS-B Deployment Map – USA

FAA NextGen Technologies Interactive Map (ADS-B)

How does community get this data?

Summarized list of enthusiast-level ADS-B radar receivers

AirNav RadarBox

PlaneGadgets ADS-B

miniADSB

Mode-S Beast with miniASDB

Aurora Eurotech SSRx

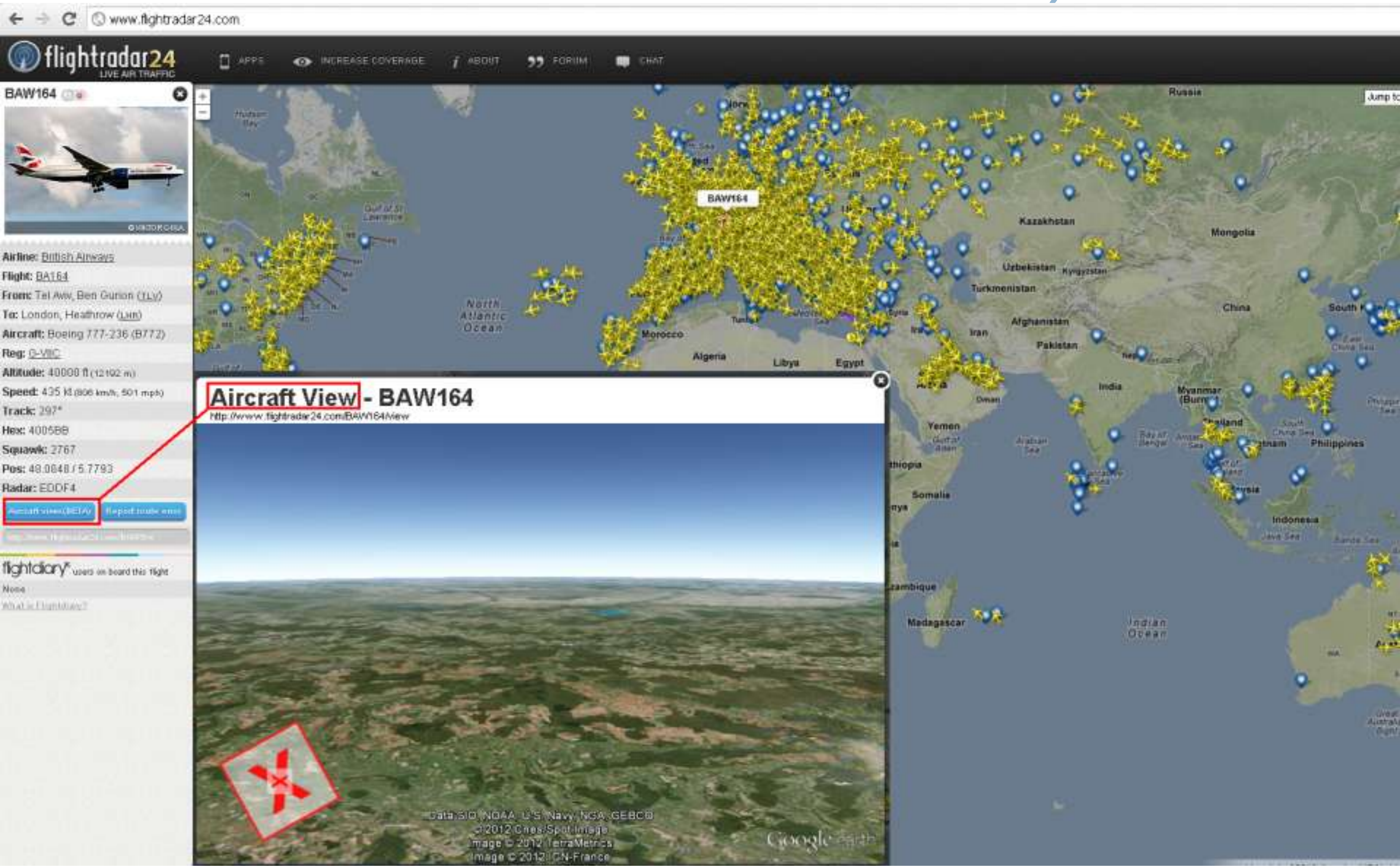
Funkwerk RTH60

Kinetic SBS

microADSB USB

microADSB-IP BULLION

How does ADS-B look like? – *Community* view



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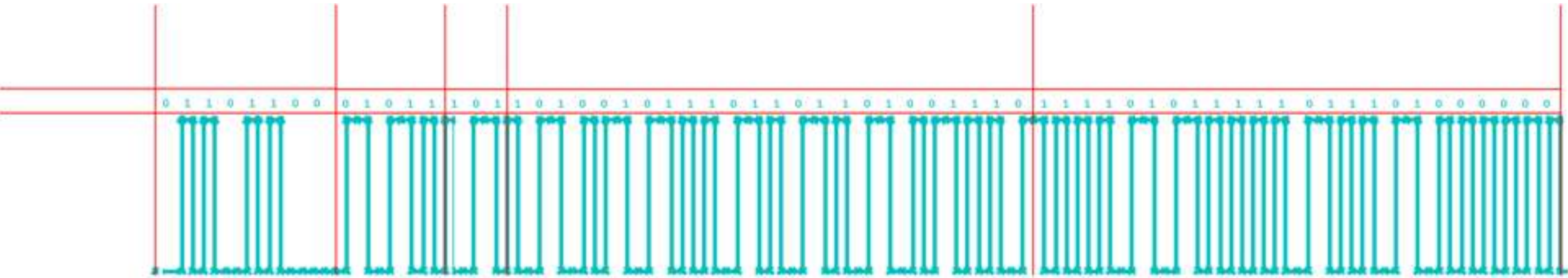
ADS-B frame – modulation, format, security



- Frames encoded in
  - Pulse-position-modulation (PPM)
  - 1 bit = 1 us
  - Shared-medium (**no CA/CD**), theoretical bandwidth 1 Mbit/sec

ADS-B frame – modulation, format, security

- Frames encoded in
  - Pulse-position-modulation (PPM)
  - 1 bit = 1 us
  - Shared-medium (**no CA/CD**), theoretical bandwidth 1 Mbit/sec
- Frames composed of
  - A preamble
    - 8 bits for TX/RX sync
  - A data-block
    - 56 bits for short frames
    - 112 bits for extended/long frames
    - Mandatory to have
      - 24 bits ICAO address of aircraft
      - 24 bits error-detection parity

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ADS-B frame – modulation, format, security

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ADS-B Main Threats – Summary

ADS-B Threat	Fail / warn / ok
Entity/message authentication	
Entity authorization (eg. medium access)*	
Entity temporary identifiers/privacy	
Message integrity (HMAC)	
Message freshness (non-replay)	
Encryption (message secrecy)	
Massive public DBs with private detail*	

Potential mitigations exist… but are not public

- Mode-4/Mode-5 IFF Crypto Appliqu**é**
  - 2-Levels Crypto secured version of Mode S and ADS-B GPS position
  - Defined for military NATO STANAG 4193
  - Enhanced encryption
  - Spread Spectrum Modulation
  - Time of Day Authentication
  - Level1:
    - Aircraft Unique PIN
  - Level2:
    - Level1 + other (unknown for now) information
  - Apparently based on **Black** & **Red** keys crypto

- ADS-B also specifies, but not details available about crypto/security:
  - DF19 = Military Extended Squitter
  - DF22 = Military Use Only

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ADS-B – Adversary Model – *By role*

- Pilots
  - Bad intent
  - (Un)Intentional pranksters
- Pranksters
- Abusive users/organizations
  - Privacy breachers – eg. Paparazzi
  - Message conveyors
- Criminals
  - Money (more likely). Eg.: Underground forums with “Worldwide SDRs for hire” – potentially very profitable underground biz (think sniff GSM)
  - Terror (less likely)
- Military/intelligence
  - Espionage
  - Sabotage

Example: *internal prankster* attack

- **Already happening** – Callsigns/FlighIDs used in real-life!
- Check them on Google or RR forum

	A				B
1	MATTSUXX	A20	: N229!	vest Airline	)7/11 17:57:04
2	BUTTSEXX	A2F	N290S'	est Airlines	7/11 01:27:28
3	MATSUUXX	A2F	X N292	west Airline	'07/11 03:29:55
4	MATTSUXX	A31	: N297!	ed Express	)7/11 16:39:11
5	HIDAD	A31	IIDAD		
6	BALLSLAM	A21	- N23!	west Airlin	06/06 18:21:05
7	BUTTPUMP	A2F	) - N29	west Airlir	/06/06 07:17:47
8	YOUSUCK	A33	- N308!	vest Airline	06 09:22:03
9	BUTTSEXX	A2F	120 201	5:19 BUTTSE	
10	ABBAROCK	A22	120 201	3:09 ABBAR	
11	NO2OBAMA	N38	MA		
12	FAYISGAY	N8C			
13	WOLYSAID	N45			
14	ATCFAIL	N71			
15	BIGBOOBS	N72			
16	GETAJOB	N83			
17	NOFATCHK	USA	3 NOF		
18	VOTEUNUN	VOT	B8 - N:		
19	VOTENOO	VOT	can Ea	at probably	
20	PHATCHIX	PHA	) - N29		
21	DUMBPILT	DUN	OJO - A	ISW	
22	JETSBLOW	JETS	9 / N2!		
23	JOHNRULZ	JOH	V (A30:		
24	KELYSMLS	KEL	' (A305	niles, or Ke	You be the judge.
25	SOFAKING	SOF	B - N2!		
26	FATIGUE	FAT	ntal Ex		
27	LADYGAGA	LAD	32 / N2	on Aug 7 &	
28	SEXY1215	C-FI			
29	YOUWIN	N23	– send	YOUWIN" 8	l"
30	BULLSHIT	N5C			
31	GOINHOM	N15			
32	THEMOLE	N78			

Example: *external abusers* + public data correlation

Strategically positioned

Have a well-defined target

Poses inexpensive devices

Can publicly access private details (why is this allowed?!)

en.wikipedia.org/wiki/Aircraft_registration

- Searchable worldwide registration database
- Aruba Aircraft Register
- Australian Aircraft Register
- Austrian Aircraft Register
- Belgian Aircraft Register
- Brazilian Aircraft Register
- British Aircraft Register
- Canadian Aircraft Register
- Danish Aircraft Register
- Dutch Aircraft Register
- Dutch Historic Aircraft Registers
- Finnish Aircraft Register
- French Aircraft Register
- Guatemalan Aircraft Register
- Indian Aircraft Register
- International Registry of Mobile Assets, pursuant to the Cape Town Treaty
- Irish Aircraft Register
- Latvian Aircraft Register
- Lebanese Aircraft Register
- Luxembourg Aircraft Register
- New Zealand Aircraft Register
- Norwegian Aircraft Register
- Singapore Aircraft Register
- South African Aircraft Register
- Swedish Aircraft Register
- Swiss Aircraft Registry
- United States Aircraft Registry
- Article 20 of the Convention on International Civil Aviation
- Annex 7 to the Convention on International Civil Aviation
- Supplement to Annex 7 of the Convention on International Civil Aviation

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Public access, seriously? USA (FAA)

Federal Aviation Administration

Aircraft Inquiries

- N-number
- Serial Number
- Name
- Make / Model
- Engine Reference
- Dealer
- Document Index
- State and County
- Territory and Country
- Pending / Expired / Canceled Registration Reports
- Recent Registration
- N-number Availability
  - Request A Reserved N-Number
    - Online
    - In Writing
  - Reserved N-Number Renewal
    - Online
  - Request for Aircraft Records
    - Online
- Help
  - Main Menu
  - Aircraft Registration
  - Aircraft Downloadable Database
  - Definitions
  - N-Number Format
  - Registrations at Risk
  - Contact Aircraft Registration

FAA Home » Licenses & Certificates » Aircraft Certification » Aircraft Registration » Aircraft Inquiry » N-Number Inquiry

Warning:

NOTICE
The FAA Registry will be performing maintenance on its web servers beginning Saturday, July 21st.
This website will be unavailable from 06:00 AM CDT Saturday morning through 11:30 PM CDT Sunday night.
We apologize for the inconvenience.

FAA REGISTRY

N-Number Inquiry Results

N1 is Assigned

Data Updated each Federal Working Day at Midnight

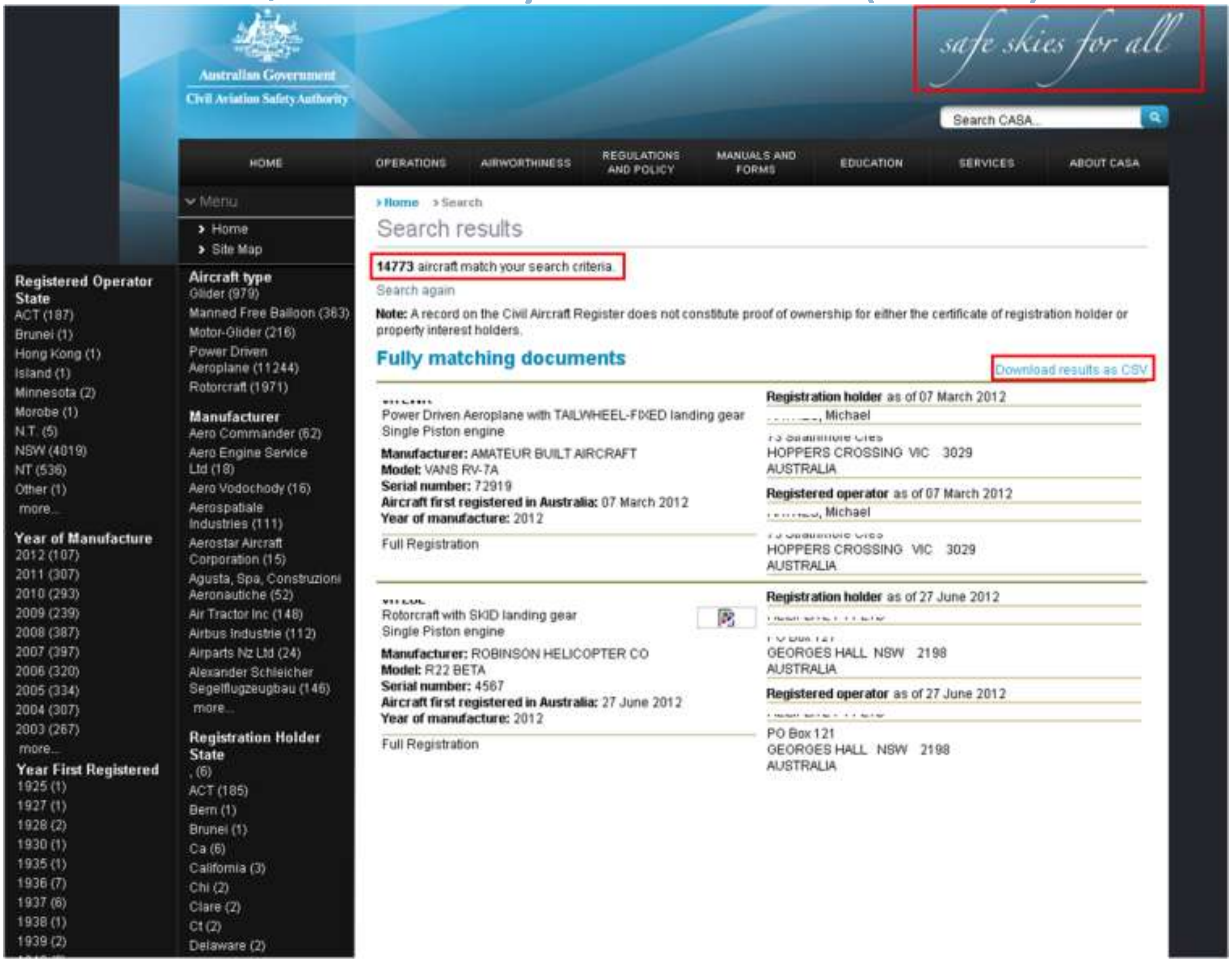
Download the Aircraft Registration Database (39 MB)
Aircraft Certificate Expiration Date has been added to the Master Download file.

Aircraft Description			
Serial Number	1071	**Type Registration**	Government
Manufacturer Name	GULFSTREAM AEROSPACE	**Certificate Issue Date**	02/14/1990
Model	G-IV	**Expiration Date**	12/31/2013
Type Aircraft	Fixed Wing Multi-Engine	**Status**	Valid
Pending Number Change	None	**Type Engine**	Turbo-fan
Date Change Authorized	None	**Dealer**	No
MFR Year	1988	**Mode S Code**	50000001
		Fractional Owner	NO

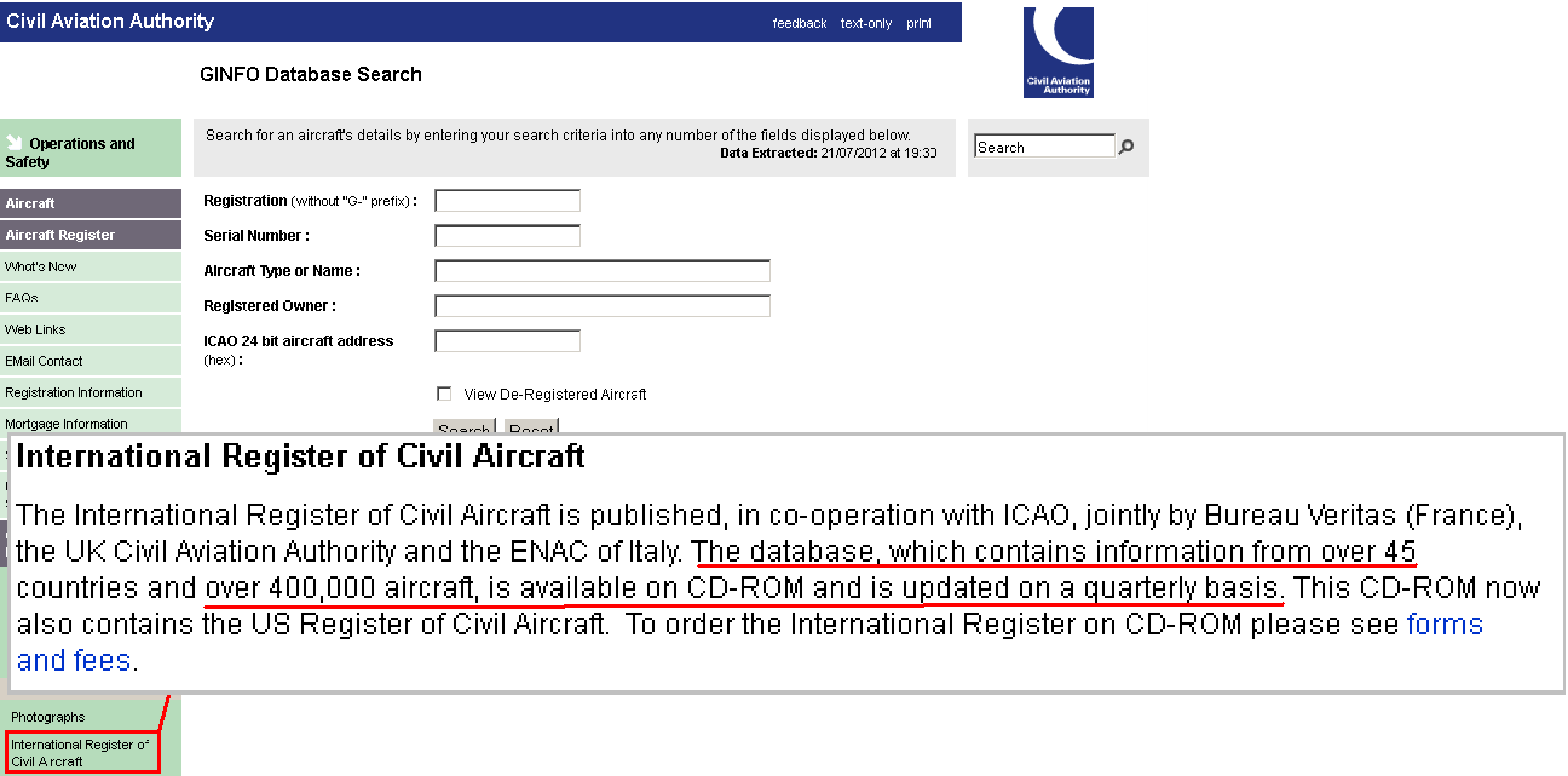
Registered Owner			
Name	FEDERAL AVIATION ADMINISTRATION		
Street	NATL FLIGHT PROGRAM OVERSIGHT OFC		
	6125 SW 68TH ST RM 137N		
City	OKLA CITY	**State**	OKLAHOMA
County	OKLAHOMA	**Zip Code**	73169-1225
Country	UNITED STATES		

Airworthiness			
Engine Manufacturer	ROLLS-ROYC	**Classification**	Standard
Engine Model	TAY MK 610-8	**Category**	Transport
		A/W Date	09/09/1988

Public access, seriously? Australia (CASA)



Public access, seriously? UK (CAA)



Civil Aviation Authority feedback text-only print

Civil Aviation Authority

GINFO Database Search

Operations and Safety

Aircraft

Aircraft Register

What's New

FAQs

Web Links

EMail Contact

Registration Information

Mortgage Information

Photographs

International Register of Civil Aircraft

Search for an aircraft's details by entering your search criteria into any number of the fields displayed below.
Data Extracted: 21/07/2012 at 19:30

Search

Registration (without "G-" prefix) :

Serial Number :

Aircraft Type or Name :

Registered Owner :

ICAO 24 bit aircraft address (hex) :

View De-Registered Aircraft

Search Reset

International Register of Civil Aircraft

The International Register of Civil Aircraft is published, in co-operation with ICAO, jointly by Bureau Veritas (France), the UK Civil Aviation Authority and the ENAC of Italy. The database, which contains information from over 45 countries and over 400,000 aircraft, is available on CD-ROM and is updated on a quarterly basis. This CD-ROM now also contains the US Register of Civil Aircraft. To order the International Register on CD-ROM please see forms and fees.

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ADS-B – Adversary Model – *By location*

- Ground-based
  - Easier to operate (win criminals)
  - Easier to be caught (win agencies)
  - Easier to defend or mitigate against (win agencies)
    - Eg. Angle of arrival, time-difference of arrival

- Airborne
  - Drones
  - UAV
  - Autonomously pre-programmed self-operating checked-in luggage:
    - Pelican case, barometric altimeter, battery, embed-devs, GPS, RF…
  - Possibly could work around angle of arrival
  - Could pose more advanced threat to ADS-B IN enabled aircrafts
  - **Important:** not extensively modeled in the attacker & threat modeling of Mode-S/ADS-B

Potential for DoS on ATC human-resource

- Attack:
  - Based on “Fake airplane injection into ATC” attack
  - Mitigation: there is a *mostly manual* procedure for an ATC operator to check a flight number against flight plans and flight strips (*flight strips is so 1900*, really!)

- Twist1:
  - Inject 1 mln fake airplanes, both valid and invalid flight plans, filed by different flight plan systems
  - Result: Potential human-resource exhaustion

- Fixes:
  - Have fully e-automated flight plan exchange and cross-checks
  - **Better, solve ADS-B insecurities and *potential* is nullified**

Potential for DoS on ATC flight-space resource

- Attack:
  - Similar to “DoS on ATC human-resource”

- Twist1:
  - Fake planes scattered on *wide geographic area* of responsibility of “victim ATC”
  - The area of ghost/fake/unidentified aircraft/object is in “flight quarantine”
    - Separation are increased, all normal routes deviated
    - General rules are in ICAO 4444 + country specifics
  - This is done for safety reasons (eg. ASSET methodology) to avoid disasters
  - A potentially wide geo-area affected in terms of air-traffic – nightmare!

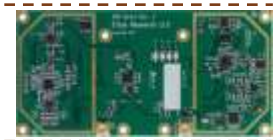
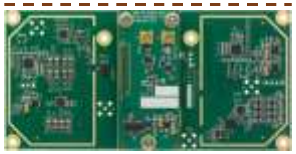
- Twist2:
  - Fake a copy of a genuine aircraft within it’s own area of separation
  - Will generate a Short Term Conflict Alert (STCA)

- Fixes:
  - Locate and turn-off attacker RF emitter (but what if it’s a drone?)
  - **Better, solve ADS-B insecurities and *potential* is nullified**

Potential for DoS on ADS-B IN aircrafts

- Attack:
  - Based on “Fake airplane injection into ATC” attack
  - Mitigation: unknown, perhaps similar to ATC semi-auto/semi-manual flight plan cross-check
- Twist1: Inject fake airplanes (1…1 mln) into ADS-B IN capable aircrafts
  - Assumption: Target aircraft lacks good connectivity and automated cross-check protocols for flight plan lookup and validation (compared to ATC)
  - Result: Total uncertainty in received data, i.e. data is useless…
- Fixes:
  - Have real-time critical data exchange and verification capability on eAircrafts
  - Have fully e-automated flight plan exchange and cross-checks
  - **Better, solve ADS-B insecurities and *potential* is nullified**

Hardware setup

Hardware		Functions	Price
SDR USRP1		Main RF support	700 USD
SBX		ADS-B **OUT**/IN (attack)	475 USD
WBX		ADS-B **OUT**/IN (attack)	450 USD
DBSRX2		ADS-B **IN** (verify)	150 USD
Plane Gadget		ADS-B **IN** (verify)	~245 USD
Attenuators Cables		Limit output **(SMA cable)**	<10 USD

Alternative SDRs   Alternative ADS-Bs

ADS-B Message Replay
Quick reference

- Capture ADS-B data:
  - UHD-mode
    - *uhd_rx_cfile.py --spec B:0 --gain 25 --samp-rate 4000000 -f 1090000000 -v ~/CAPTURE_adsb.fc32*
  - Pre-UHD-mode
    - *usrp_rx_cfile.py*

- Replay the *captured* data:
  - UHD-mode
    - *tx_transmit_samples --file ~/CAPTURE_adsb.fc32 --ant "TX/RX" --rate 4000000 --freq 1090000000 --type float --subdev B:0*
  - Pre-UHD-mode
    - *usrp_replay_file.py*

ADS-B Message Injection
Quick reference guide

- ADS-B data crafting
  - Tweak the captured data
    - Load I/Q data: *d_cap = read_float_binary('~/CAPTURED_adsb.fc32')*
    - Modify the samples: *d_cft = adsb_randomize(d_cap)*
    - Write back I/Q data: *write_float_binary(d_cft, '~/CRAFTED_adsb.fc32')*
  - Generate the data
    - MatLab – *modulate(adsb_frame, fc, fs, 'ppm')*
    - GNUradio – write native C++ block

- Transmit the *crafted* data:
  - UHD-mode
    - *tx_transmit_samples --file ~/CRAFTED_adsb.fc32 --ant "TX/RX" --rate 4000000 --freq 1090000000 --type float --subdev B:0*
  - Pre-UHD-mode
    - *usrp_replay_file.py*

ADS-B Message Analyze/Visualize/Plot Quick reference guide

- GNURadio ModeS tests:
  - Pre-UHD-mode (by Eric Cottrell):
    - *gr-air/src/python/usrp_mode_s_logfile.py*
  - UHD-mode (by Nick Foster):
    - *gr-air-modes/python/uhd_modes.py –a –w –F ~/CRAFTED_adsb.fc32*

- GNURadio:
  - *gr_plot_psd_c.py -R 4000000 ~/CAPTURE_adsb.fc32*
  - *gr_plot_psd_c.py -R 4000000 ~/CRAFTED_adsb.fc32*

- Octave + gnuplot:
  - *n_samp = 500000*
  - *trig_lvl = 0.01*
  - *d_cap = read_float_binary('CAPTURE_adsb.fc32', n_samp)*
  - *axis ([0, n_samp, -trig_lvl, trig_lvl])*
  - *plot(arr)*

Code showcase

adsb_modes_crc.py

```python
def adsb_112bits_crc(adsb_payload_11_bytes):
    POLY = 0xFFFA0480

    data = \
        (adsb_payload_11_bytes[0] << 24) | \
        (adsb_payload_11_bytes[1] << 16) | \
        (adsb_payload_11_bytes[2] <<  8) | \
        (adsb_payload_11_bytes[3] <<  0)

    data1 = \
        (adsb_payload_11_bytes[4] << 24) | \
        (adsb_payload_11_bytes[5] << 16) | \
        (adsb_payload_11_bytes[6] <<  8) | \
        (adsb_payload_11_bytes[7] <<  0)

    data2 = \
        (adsb_payload_11_bytes[8] << 24) | \
        (adsb_payload_11_bytes[9] << 16) | \
        (adsb_payload_11_bytes[10] <<  8)

    logging.info('init dataX', hex(data), hex(data1), hex(data2))

    result = 0x00000000

    for i in range(0, 88):
        logging.info('data', hex(data))
        if (data & 0x80000000) <> 0:
            data = data ^ POLY
            logging.info('data (if)', hex(data))

        data = data << 1
        logging.info('data (<<)', hex(data))

        logging.info('data1', hex(data1))
        if (data1 & 0x80000000) <> 0:
            data = data | 1
            logging.info('data (if)', hex(data))

        data1 = data1 << 1
        logging.info('data1 (<<)', hex(data1))

        logging.info('data2', hex(data2))
        if (data2 & 0x80000000) <> 0:
            data1 = data1 | 1
            logging.info('data1 (if)', hex(data1))

        data2 = data2 << 1
        logging.info('data2 (<<)', hex(data2))

    result = result ^ data
    logging.debug(hex(data >> 8), hex(result >> 8))

    return result >> 8
```

Demo showtime

- http://www.youtube.com/zveriu

Agenda

1. ATC Today (SSR)
2. Today's Problems
3. ATC "Tomorrow" (ADS-B)
4. "Tomorrow"'s Problems
5. Exploit scenarios & Demos

Solutions and take-aways

High-level perspective – Timelines

- SDR Community
  - 1988 (Peter Hoeher and Helmuth Lang) - SDR prototype
  - 1991/1992 (Joseph Mitola) - SDR theory and paper
  - October 2003 (Ettus) - USRP1 available $US750
  - September 2008 (Ettus) - USRP2 available $US1700 (http://www.ruby-forum.com/topic/165227)
  - 13 Jan 2010 (Ettus) - WBX Tranceiver board available (http://lists.gnu.org/archive/html/discuss-gnuradio/2010-01/msg00146.html)
  - 23 Mar 2011 (Ettus) - USRP N200 $US1500 and USRP N210 $US1700 available (http://lists.ettus.com/pipermail/usrp-announce_lists.ettus.com/2011-March/000007.html)
  - 15 Apr 2011 (Ettus) - SBX Tranceiver board available (http://lists.ettus.com/pipermail/usrp-announce_lists.ettus.com/2011-April/000008.html)
  - February 2012 (Antti Palosaari) - RTL-SDR discovered (http://thread.gmane.org/gmane.linux.drivers.video-input-infrastructure/44461/focus=44461)
- ADS-B Standartization/Regulatory
  - Jul 2002 (FAA) - Federal Aviation Administration (FAA) announced a dual link decision using 1090 MHz ES for air carrier and private/commercial operators of high performance aircraft and UAT for the typical general aviation user as media for the ADS-B system in the United States (http://www.faa.gov/news/press_releases/news_story.cfm?newsId=5520&print=go)
  - March 2003 - First ADS-B demonstrations (AOPA for CAP)
  - April 2003 (RTC) - DO-260A "Minimum Operational Performance Standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services – Broadcast (TIS-B)"
  - Jul 2004 (RTC) - DO-282A "Minimum Operational Performance Standards for Universal Access Transceiver (UAT) Automatic Dependent Surveillance – Broadcast."
  - 2004 - US Development & testing stations deployed
  - 2007 - Early estimates stated the cost to equip a general aviation aircraft ranged from $7,644 to $10,920 for ADS-B Out and from $10,444 to $29,770 for ADS-B Out and ADS-B In, depending on aircraft type.
  - 2009 - US Ground segment implementation and deployment
  - 2009 - Assuming 2009 market prices for individual system components, a UAT retrofit was estimated at $18,000 and new at $25,000. For a 1090ES retrofit $4,200 and new at $18,000.
  - Dec 2009 - Australia in world first for nationwide ADS-B coverage
- Research community
  - Jan 2001 - An Assessment of the Communications, Navigation, Surveillance (CNS) Capabilities Needed to Support the Future Air Traffic Management System
  - Oct 2001 - Vulnerability accessment of the transportation infrastructure relying on GPS
  - 2002 - Validation techniques for ADS-B surveillance data
  - 2003 - GPS integrity and potential impact on aviation safety
  - Sept 2004 - Aircraft ADS-B Data Integrity Check
  - 2008/2009 - Vast security research on Future eEnabled Aircraft and their support infrastructure
  - Oct 2010 - Identification of ADS-B System Vulnerabilities and Threats
  - 2010 - Assessment and Mitigation of Cyber Exploits in Future Aircraft Surveillance
  - 2010 - Visualization \& Assessment Of ADS-B Security For Green ATM
  - 2011 - Security analysis of the ADS-B implementation in the next generation air transportation system
  - Oct 2011 - Aircraft Systems Cyber Security
  - Oct 2011 - On the Requirements for Successful GPS Spoofing Attacks
  - Jul 2012 - Practical setups and demonstrations on ADS-B attacks (BH12US, DC19)

ADS-B Security Solutions

- Solutions could include:
  - Verifiable multilateration (MLAT) with multiple ground-stations, but:

> Guidance Material on Surveillance Technology Comparison
>
> **7.11 VERIFICATION OF ADS-B**
>
> Some commentators have promoted the use of multilateration as a means of ensuring the validity of received ADS-B data. Technically this is possible. Radar could also be used to verify the integrity of ADS-B data. If radar and/or multilateration in **all** areas of ADS-B coverage is required, then the most advantages of ADS-B are significantly diminished and the ADS-B deployment becomes unlikely. Verification could perhaps be achieved at major airport hubs aimed at detecting non compliant
>
> *Edition 1.0* *September 2007* *Page 41*

  - "Group of aircrafts" concepts
  - AANETs should inspire from VANETs solutions
  - Lightweight PKI architectures and protocols. Our thoughts:
    - FAA, EUROCONTROL, CASA as CAs
      - CAs root keys installed/updated during ADS-B device mandatory certification process
      - HMAC on each broadcast message
        - Every broadcast a subset of HMAC bits

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Take-aways

- ADS-B is a safety-related mission-critical technology

- Yet, ADS-B **lacks minimal security** mechanisms
  - This poses direct **threat to safety**

- ADS-B **costs tremendous** amount of money, coordination, time
  - Yet, ADS-B is defeated in practice with
    - FOSS or moderate-effort custom software
    - Relatively low-cost SDRs hardware

- ADS-B assumptions are not technologically up-to-date
  - Doesn’t account users will have easy access to RF via SDRs
  - Doesn’t account users will have easy access to UAV, drones, etc.

- **SDRs** and their decreasing price **are not** the problem

ADS-B is flawed and is the actual root-cause problem

References (academia, standards, reports)

enough and sufficient to induce potentially dangerous safety and operational perturbances in a multi-million technology via the exploitation of missing basic security mechanisms such as message authentication at least.

REFERENCES

[1] K. Sampigethaya, R. Poovendran, L. Bushnell, *Assessment and Mitigation of Cyber Exploits in Future Aircraft Surveillance*, Aerospace Conference (AC), 2010 IEEE

[2] K. Sampigethaya, R. Poovendran, *Visualization & Assessment Of ADS-B Security For Green ATM*, Digital Avionics Systems Conference (DASC), 2010 IEEE/AIAA 29th

[3] K. Sampigethaya, R. Poovendran, L. Bushnell, *A Framework for Securing Future e-Enabled Aircraft Navigation and Surveillance*, AIAA Proceedings, 2009

[4] K. Sampigethaya, R. Poovendran, S. Shetty, T. Davis, C. Royalty *Future E-Enabled Aircraft Communications and Security: The Next 20 Years and Beyond*, Proceedings of the IEEE, Vol. 99, No. 11, November 2011

[5] K. Sampigethaya, R. Poovendran, *Privacy of future air traffic management broadcasts*, Digital Avionics Systems Conference, 2009. DASC '09. IEEE/AIAA 28th

[6] K. Sampigethaya, R. Poovendran, L. Bushnell, *Secure Operation, Control, and Maintenance of Future E-Enabled Airplanes*, Proceedings of the IEEE, Dec 2008

[7] K. Sampigethaya, R. Poovendran, *Security and Privacy of Future Aircraft Wireless Communications with Offboard Systems*, Communication Systems and Networks (COMSNETS) 2011, IEEE

[8] K. Sampigethaya, R. Poovendran, L. Bushnell, *Secure Wireless Collection and Distribution of Commercial Airplane Health Data*, IEEE Aerospace and Electronic Systems Magazine, 2009, 34(7): 14. 20

[9] L. Kenney, J. Dietrich, J. Woodall, *Secure ATC surveillance for military applications*, Military Communications Conference, MILCOM 2008, IEEE

[10] D. McCallie, J. Butts, R. Mills, *Security analysis of the ADS-B implementation in the next generation air transportation system*, International Journal of Critical Infrastructure Protection, No. 4 (2011), Pag. 7887

[11] J. Krozel, D. Andrisani, M. A. Ayoubi, T. Hoshizaki, C. Schwalm, *Aircraft ADS-B Data Integrity Check*, AIAA Aircraft Technology, Integration, and Operations Conf., Chicago, IL, Sept., 2004

[12] A.C. Drumm, E.M. Shank, *Validation techniques for ADS-B surveillance data*, Digital Avionics Systems Conference, 2002. Proceedings. The 21st

[13] S. Thompson, D. Spencer, J. Andrews, *An Assessment of the Communications, Navigation, Surveillance (CNS) Capabilities Needed to Support the Future Air Traffic Management System*, Project Report ATC-295, 10 January 2001, Massachusetts Institute Of Technology, Lexington, Massachusetts

[14] B. Nuseibeh, C.B. Haley, C. Foster, *Securing the Skies: In Requirements We Trust*, Computer, IEEE Journals & Magazines, Sept. 2009

[15] B. Nuseibeh, C.B. Haley, C. Foster, *Securing the Skies: In Requirements We Trust*, Computer, IEEE Journals & Magazines, Sept. 2009

[16] L. Purton, H. Abbass, S. Alam, *Identification of ADS-B System Vulnerabilities and Threats*, Australian Transport Research Forum, Canberra, October, 2010

[17] Federal IT Dashboard - An Official Website of the United States Government *FAAXX704: Automatic Dependent Surveillance-Broadcast (ADS-B)*, www.itdashboard.gov/investment?buscid=3

[18] Federal Aviation Administration (FAA), *Air Traffic Bulletin, Special Issue 2005-3, August 2005*, www.faa.gov/air_traffic/publications/bulletins/media/atb_aug_05.pdf

[19] *DO-282B, Minimum Operational Performance Standards for Universal Access Transceiver (UAT) Automatic Dependent Surveillance-Broadcast (ADS-B)*, RTCA Paper Number 190-09/SC186-286, RTCA DO-282B, 2009

[20] *DO-249, Development and Implementation Planning Guide for Automatic Dependent Surveillance Broadcast (ADS-B) Applications*, RTCA DO-249

[21] *DO-260A, Minimum Operational Performance Standards for 1090 MHz Automatic Dependent Surveillance Broadcast (ADS-B) and Traffic Information Services (TIS-B)*, RTCA DO-260A

[22] *DO-242A, Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B)*, RTCA DO-242A

[23] *DO-263, Application of Airborne Conflict Management: Detection, Prevention, & Resolution*, RTCA DO-263

[24] DoT, FAA, Technical Standard Order, *Airborne Navigation Sensors Using The Global Positioning System (GPS) Augmented By The Wide Area Augmentation System (WAAS)*, TSO-C145a

[25] End to- End System Preliminary Hazard Analysis Matrix of Scenarios, *FAA Capstone Safety Engineering Report #1 ADS-B Radar-Like Services*, Volume 2

[26] Electronic Code of Federal Regulations, Title 47: Telecommunication, *PART 15RADIO FREQUENCY DEVICES, Subpart BUnintentional Radiators*,

[27] Surveillance and Conflict Resolution Systems Panel (SCRSP), *Civil-Military Interoperability with Military Mode S Format 22*, SCRSP/WG-A/B, Montreal, 26th to 7th May 2004,

[28] R.D. Grappel, R.T. Wiken, *Guidance Material for Mode S-Specific Protocol Application Avionics*, Project Report ACT-334, Lincoln Laboratory, MIT,

[29] RTCA Special Committee 209 ATCRBS / Mode S Transponder MOPS Maintenance, *Proposed Change to DO-181D and ED-73C for Higher Squitter Rates at Lower Power*,

[30] Jim McMath, *Automated Dependent Surveillance - Broadcast Military (ADS-M)*,

[31] Vincent Orlando, *Extended Squitter Update*, adsb.tc.faa.gov/WG3_Meetings/Meeting1/1090-WP-1-01.pdf

[32] N. O. Tippenhauer, C. Ppper, K. B. Rasmussen, S. Capkun, *On the Requirements for Successful GPS Spoofing Attacks*, CCS11, October 1721, 2011, Chicago, Illinois, USA

[33] E. Lester, J. Hansman, *Benefits and incentives for ADS-B equipage in the national airspace system*, MIT ICAT Report, ICAT-2007-2, 2007

[34] W. Ochieng, K. Sauer, D. Walsh, G. Brodin, S. Griffin, M. Denney, *GPS integrity and potential impact on aviation safety*, The Journal of Navigation Vol. 56, 2003

[35] H.R. Zeidanloo, *Botnet Command and Control Mechanisms*, ICCEE '09, Second International Conference on Computer and Electrical Engineering, 2009

[36] Yuanyuan Zeng, Kang G. Shin, Xin Hu, *Design of SMS Commanded-and-Controlled and P2P-Structured Mobile Botnets*, WiSec'12, April 1618, 2012, Tucson, Arizona, USA

[37] C. Xiang, F. Binxing, Y. Lihua, L. Xiaoyi, Z. Tianning, *Andbot: Towards Advanced Mobile Botnets*, LEET'11, 4th Usenix Workshop on Large-Scale Exploits and Emerging Threats, 2011, Boston, Massachusetts, USA

[38] A. Khalili, J. Katz, W.A. Arbaugh, *Toward secure key distribution in truly ad-hoc networks*, Proceedings of IEEE Symposium on Applications and the Internet Workshops, 2003

[39] M. Toorani, A. Beheshti, *LPKI - A lightweight public key Infrastructure for the mobile environments*, 11th IEEE Singapore International Conference on Communication Systems, 2008

[40] Ki-Woong Park, Hyunchul Seok, Kyu-Ho Park, *pKASSO: Towards Seamless Authentication Providing Non-Repudiation on Resource-Constrained Devices*, AINAW Advanced Information Networking and Applications Workshops, 2007

[41] B. Kadri, M. Feham, A. M'hamed, *Lightweight PKI for WSN uPKI*, International Journal of Network Security, 2010

[42] Righter Kunkel, *Air Traffic Control: Insecurity and ADS-B*, DefCon 17, Las Vegas, USA,

[43] Righter Kunkel, *Air Traffic Control Insecurity 2.0*, DefCon 18, Las Vegas, USA,

[44] Brad Haines, *Hacker + Airplanes = No good can come of this*, Confidence X, 2012, Krakow, Poland,

[45] *A comprehensive summary of existing radio-enthusiasts-level ADS-B devices*, www.andreicostin.com/papers/AdsbComprehensiveDeviceList.xlsx

[46] RadioReference Community Forum, *Dodgy callsigns from flights*,

[47] GNU Radio, *A free & open-source software development toolkit that provides signal processing blocks to implement software radios*, gnuradio.org

[48] CGRAN, *Comprehensive GNU Radio Archive Network*, www.cgran.org

[49] Ettus Research, *USRP (Universal Software Radio Peripheral)*, www.ettus.com/product/details/USRP-PKG

[50] Ettus Research, *SBX 400-4400 MHz Rx/Tx transceiver daughterboard*, www.ettus.com/product/details/SBX

[51] Radar Gadgets, *Plane Gadget ADS-B Virtual Radar*, www.radargadgets.com

[52] Mini-Circuits, *VAT-10W2+ SMA Fixed Attenuator*, 217.34.103.131/pdfs/VAT-10W2+.pdf

[53] Discovery Tech News, *Iran's Military Hacks U.S. Stealth Drone*, news.discovery.com/tech/irans-military-hacks-us-stealth-drone.html

[54] BBC Tech News, *Researchers use spoofing to 'hack' into a flying drone*, www.bbc.com/news/technology-18643134

[55] SWISS Magazine, *Eco-care reaches new (flight) levels*, May 2012, Pag. 94

[56] NewScientist Tech, *Air traffic system vulnerable to cyber attack*, www.newscientist.com/article/mg21128295.600-air-traffic-system-vulnerable-to-cyber-attack.html

[57] USA TODAY 27 May 2011, *Air France jet's final minutes a free-fall*, www.usatoday.com/news/world/2011-05-27-air-france-crash_n.htm

[58] Bureau d'Enquètes et d'Analyses (BEA), *Final Report On the accident on 1st June 2009 to the Airbus A330-203 registered F-GZCP operated by Air France flight AF 447 Rio de Janeiro - Paris*, http://www.bea.aero/en/enquetes/flight.af.447/rapport.final.en.php

[59] Garmin, *Garmin GDL 90*, www8.garmin.com/specs/gdl90_0903.pdf

[60] FreeFlight Systems, *Freeflight 1201, 1204, 1203 GPS/WAAS SENSOR SYSTEMS*, www.freeflightsystems.com/docs/FFS_GPS_WAAS.pdf

[61] Eric Cottrell, *GNURadio 'gr-air' module - pre-UHD-mode Mode-S/ADS-B demodulator and decoder*, github.com/russss/gr-air

[62] Nick Foster, *GNURadio 'gr-air-modes' module - UHD-mode software-defined radio receiver for Mode S transponder signals, including ADS-B reports from equipped aircraft*, github.com/bistromath/gr-air-modes

[63] [Discuss-gnuradio] A Chunks to Symbols Related Question, *GNURadio PPM native transmitter block implementation hints*, lists.gnu.org/archive/html/discuss-gnuradio/2012-01/msg00144.html

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References (related talks)

- 22C3 – I see airplanes
- DefCon17 – Air Traffic Control: Insecurity and ADS-B
- DefCon18 – Air Traffic Control Insecurity 2.0
- GRConf2011 – ADS-B in GnuRadio
- DefCon20 – Hacker + Airplanes = No Good Can Come Of This

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