FIVE MILLION FLIGHT HOURS CONTINUOUS RECEPTION OF ACAS-COMMUNICATIONS AND REPORTING OF ACAS/TCAS-INTERVENTIONS IN THE GERMAN AIRSPACE

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Abstract
In the SATT-Project the IfEV of the Technical University of Braunschweig developed an ACAS Monitor Station which receives since April 2007 the 1030/1090 MHz Secondary Surveillance Radar- and ACAS-Communications in the north German Airspace. Since August 2008 five additional stations spread over Germany receive the ACAS-Communication in the German Airspace and transmit that to the institute continuously. The monitoring software keeps track on the status of all Mode S-Aircraft in range and automatically compiles reports on Resolution Advisories by Airborne Collision Avoidance Systems (ACAS). Twenty months of continuous recordings cover more than 5 000 000 flight hours of ACAS-equipped Aircraft till August 2009. The compiled reports of every event describe precisely timestamped the Traffic Situation before the delivered Resolution Advisory, the Resolution Advisory itself, and the reaction of the aircraft. In a first rough average the system detects 3 Events per day in Germany, respectively one Event per 5000 flighthours, and in one of seven cases a non-standard-conform reaction of a German or international aircraft.

1 ACAS-MONITORING

Sponsored by the German Department of Economy and Technology the IfEV of the Technische Universität Braunschweig developed an experimental 1030/1090MHz-receiver station listening into the SSR-Mode S- and ACAS-communication of aircraft in the north German airspace [6]. The station observes the collision alerts and the vertical Resolution Advisories (RA) issued by the Airborne Collision Avoidance System (ACAS). The observations are completed by a detailed description of the traffic situation before the ACAS intervention and the actual reaction of the aircraft.

During August 2008 this experimental system got a considerable enhancement by 5 additional 1030/1090MHz-receiver stations industrially produced by Thales. Two of them were installed as a modified more powerful version in Braunschweig, one looking into the west, the other into the east of north Germany. Together with the three others in Frankfurt, Stuttgart and near Munich, they cover essential parts of the German airspace and receive the communication of 600 to 800 airliners simultaneously during the day. All the stations transmit the received data via net to the Braunschweig Institute. The developed signal evaluation software fuses all messages due to their time stamps of arrival, collects all aircraft data available in a data knowledge base and selects ACAS-relevant information into a report about every detected threat.

During about 5 million flighthours observed by this ACAS-Monitorsystem we see about 3 ACAS-interventions per day or one per 5000 flighthours of ACAS-equipped aircraft. Every ACAS-Event-Report describes in plain text and a Diagram the communicated messages like the resolution messages (UF 16-30), the corresponding coordination replies (DF 16-30) and the resolution advisory broadcast (UF 16-31) versus time of arrival in a station. The software also checks the standard conformity of every received message and its logical sense for validation.

For the time 3min before until 3min after an observed ACAS-Event the frequent altitude reports (DF 00) of the aircraft involved were taken from the data base to describe precisely their altitude tracks versus the same time interval. The Mode S-addresses of aircraft are used to print also their tailnumber, aircrafttype and airline into each report. If ADS-B is available, the horizontal situation and horizontal distance versus time is plotted.

Most of the ACAS-events observed above FL100 are vertical encounters, i.e. at least one aircraft descends or climbs and levels off just above or under another aircraft close to legal vertical separation minima. This counts as safe in ICAO-minimum separation standards, but if the controller or the pilot fails or misunderstands, then the chance to resolve the threat is already lost. Human doing is considered to fail in 1 of 10 000 service actions. Consequently 5000 flighthours times 10 000 could then create one potential midair collision per 50 million flighthours. That shows that the ICAO`s target level of safety: 1 collision per 10^9 flighthours is not jet reached.

The precise altitude tracks show also that in 6 of 7 ACAS-events the aircraft follow promptly and precisely the Resolution Advisory of its ACAS-system. In 1 of 7 observed cases, however, the aircraft does not follow at all or hesitates or even reacts too strong potentially endangering others. Therefore a couple of German Airlines got test-wise event reports in the past, if their aircraft were involved. Our work got also general support by the European Agency for Aviation Safety EASA and the German Department of Transportation.

2 ACAS EVENT STATISTICS

1582 ACAS events were detected during the whole 28 month experiment. 555 Events were detected from April 2007 to August 2008 only by the Braunschweig-Station in the North German Airspace. Since the installation of all the five Stations in August 2008 we saw 1027 further ACAS-Events in the German Airspace till the end of August 2009. In the mean the system collects 3 events per day or one event per ca. 5000 flight hours depending on the season. In 703 events only one airplane became known, since no mutual communication could be monitored, because the unknown participant is either out of range or is not equipped with ACAS. In 879 events communications of both airplanes were recorded. In 340 events both planes were equipped with ADS-B, so their horizontal tracks and distance can be reconstructed without radar data.

All results exclude intentional encounters between military aircraft (training) or scientific DLR-aircraft. These are no subject of any review and statistic.

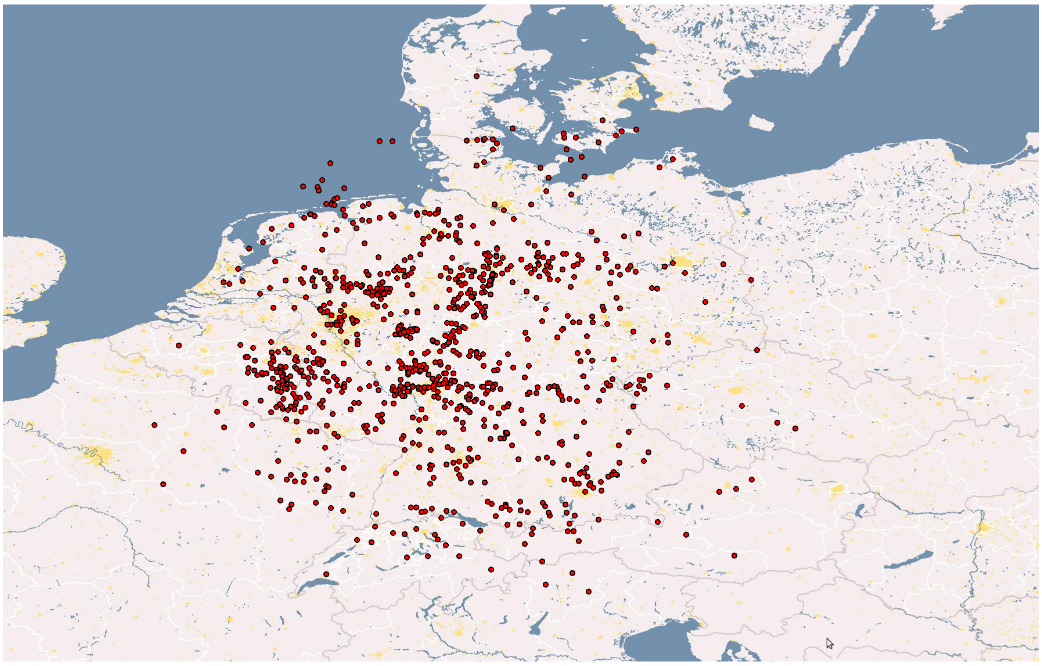

Figure 1 - Positions of ACAS-Events with ADS-B equipped Aircraft

Figure 1 shows the locations of the 961 Events in which at least one aircraft sends its position by ADS-B. This of course includes also Events in which only one of the participating aircraft could be identified. One aim of the SATT project, was to identify airspaces with frequent ACAS interventions. Figure 1 shows in some areas certain aggregation.

3 ACAS-EVENTS – EXAMPLES

Together with each ACAS-Event a plain text list of received ACAS messages, an altitude profile and the ADS-B track (if available) of the involved airplanes are compiled into a Event-report. Below some example Events are described. The Mode S-addresses of the airplanes were partly blanked out.

3.1 Example 1: Climbing Plane in Conflict with Cruising Plane

Received ACAS Messages

Each event report includes all corresponding ACAS messages. Below the exchanged data is summarized. Each message was repeated several times, however its shown only once here:

```
3C.. UF1631: ARA: Corrective, Downward, Speed limit
3C.. UF1630 to 39..: RAC: Do not pass below
39.. DF1630: Confirmation RAC: Do not pass below
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Altitude Profile

An excellent altitude profile (better than radar), with several updates per second, is acquired by monitoring the DF00-messages. The ACAS-Monitor Software ACASMON stores the altitude profiles and positions of all airplanes in range. For the complete description of ACAS events, the relevant altitude profiles and the tracks are automatically put into the event description.

Figure 2 shows the altitude profile versus time (time in minutes since midnight UTC). This diagram is presented here as it is automatically outputted by ACASMON on every event. The thick red or green lines show the altitudes of the airplanes (left y axis).

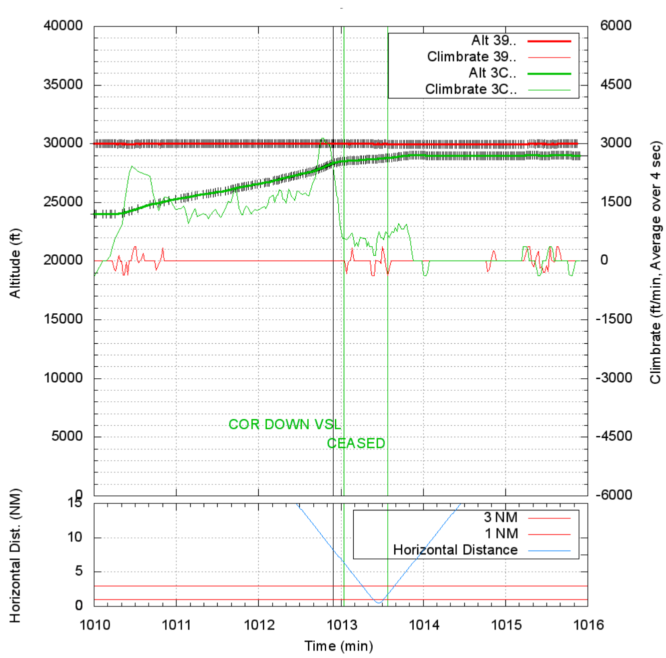

Figure 2 - Altitude profile of example event 1

The small black dashes on the altitude plots are timestamps of the received altitude reports which form the plot. The red plane is all the time within reception range, here about 40 altitude measurements per minute were received. A radar would only take 12 or less measurements. The track of the green plane starts on the edge of the reception range – but still 21 altitude reports per minute were received. The thin red or green vertical lines show the computed climb or descent rates (right y axis).

The vertical lines mark the arrival times of ACAS-relevant messages, but only messages with new information are plotted, repeated messages with old information are not plotted again. In the example the black line marks the first received ACAS message, but this message did unfortunately not contain the issued RA itself. The green line marks the first message containing information on the RA-type. The RA was *corrective(COR), upward sense (UP), vertical speed limit (VSL)*. This message was repeated several times, but is not plotted again. The final message *ceased* tells that the RA on 3C.. was terminated. The ACAS on 39.. did not issue a RA to its pilot.

Since both airplanes were equipped with ADS-B, the distance between both planes could be calculated and indicated below the diagram as a blue line in Figure 2 above. It shows the horizontal distance drops clearly below 1 NM.

ADS-B Tracks:

If the airplanes are equipped with ADS-B, ACASMON also extracts the ADS-B positions, tracks and puts the track into the event description (Figure 3) The blue and purple lines connect both aircraft positions during the transmission of the first and the last ACAS message. The arrows mark the directions of the flight.

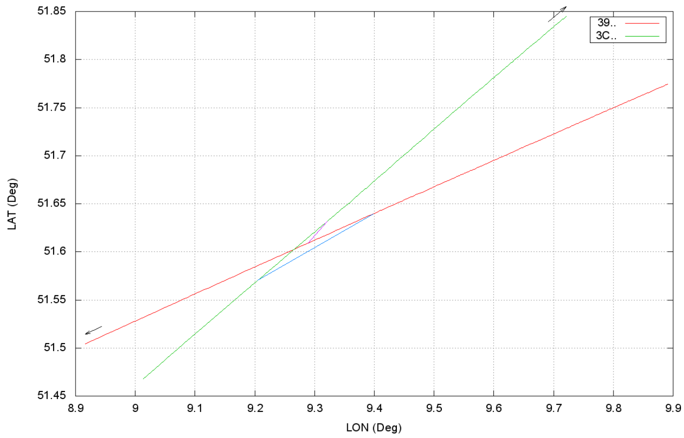

Figure 3 - Horizontal track of example event 1

Observations:
3C.. is closing on 39.. with a high climb rate. The ACAS on board of 3C.. detects a conflict and issues an RA first. This is reasonable since the ACAS on the maneuvering plane (3C..) ought to react first. 3C.. does (almost perfectly) level off as indicated by the RA.

3.2 Example 2: Fast Descend Provokes Conflict

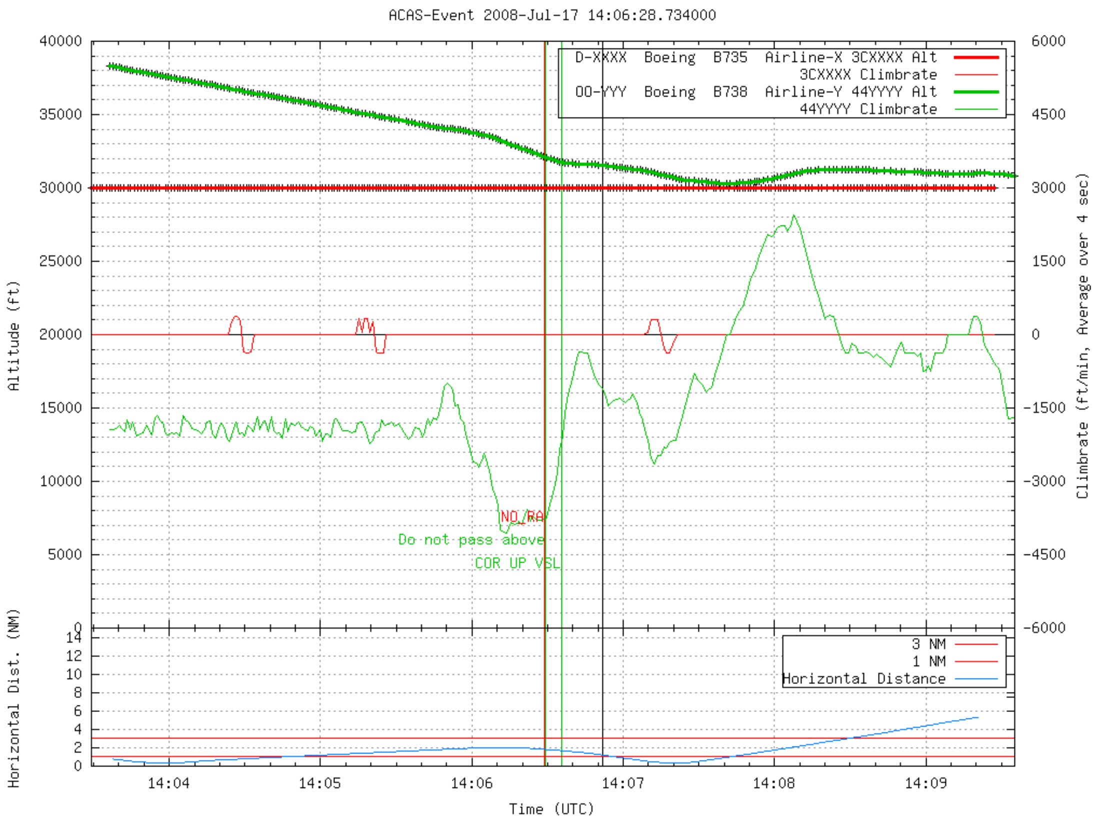

Figure 4 - Altitude profile of example Event 2

Received ACAS Messages

The ACAS messages corresponding to that event report are:

44YYYY UF1631: ARA: Corrective, Upward, Speed limit
44YYYY UF1630 to **3CXXXX**: RAC: Do not pass above
3CXXXX DF1630: Confirmation RAC: Do not pass above, No RA

Altitude Profile

Figure 4 shows the automatically computed altitude profile versus time. **44YYYY** descends with 4 000 ft per minute (thin red line, right y axis), which forces ACAS to interrupt this early. **44YYYY** does level-off promptly after the ACAS-intervention, and therefore the ACAS on board of **3CXXXX** does not have to intervene at all.

ADS-B Tracks

Again both plans are equipped with ADS-B and the horizontal tracks are shown in Figure 5.

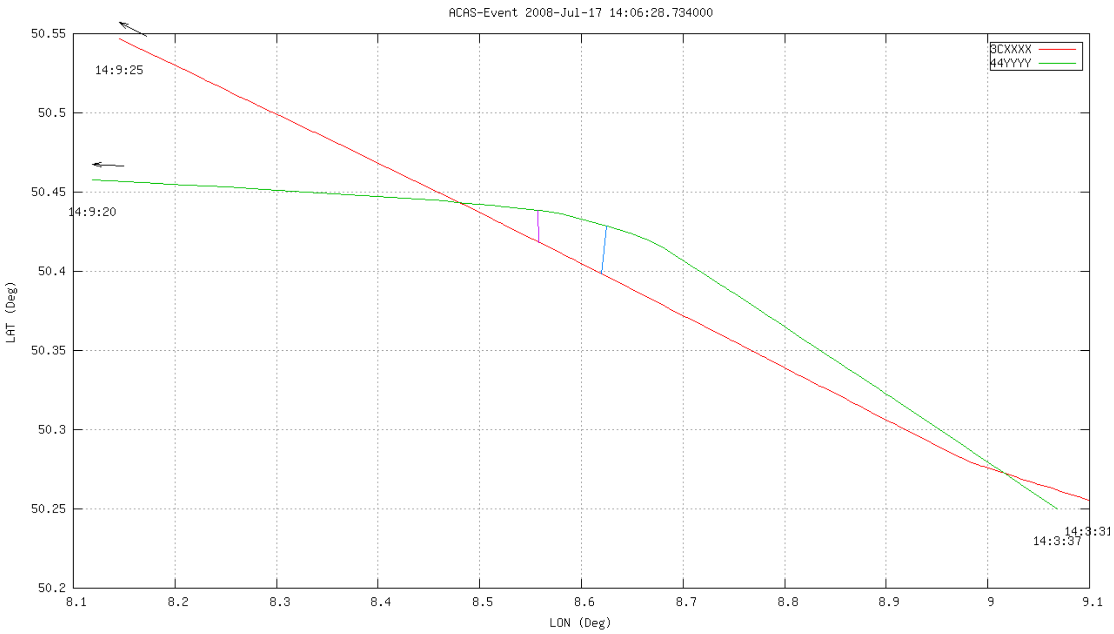

Figure 5 - Horizontal track of example Event 2

BFU-Bulletin:

This Event is one of the very few Events in which the German Bundesstelle für Flugunfalluntersuchung – BFU (German Federal Bureau of Aircraft Accidents Investigation) started an investigation and published a Bulletin [9]. The following text is a complete copy of the bulletin in German:

17.07.2008 1607 Uhr (MESZ) Schwere Störung eines deutschen Lfz. im Inland ohne Verletzte. Ort: Düsseldorf (NRW)

LFZ.1: Boeing **B737-500** Während des Reisefluges in Flugfläche FL300 kam es zu einer Annäherung an eine im Sinkflug befindliche **B737-800**. Der geringste Abstand der Luftfahrzeuge betrug laut Radardaten 2,1 NM lateral bzw. 300 ft vertikal.

LFZ.2: Boeing **B737-800** Während des Sinkfluges kam es zu einer Annäherung an eine in Flugfläche FL300 fliegende **B737-500**. Der

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geringste Abstand der beiden Luftfahrzeuge betrug 2,1 NM lateral
bzw. 300 ft vertikal.
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The English translation would be (translation by Jens Gottstein, not by BFU):

```
17.07.2008 1607 (CEST) Serious incident of a German Aircraft within
Germany without injuries. Location: Düsseldorf

Aircraft 1: Boeing B737-500 During levelflight on flightlevel FL300
occurred an encounter with a descending B737-800. The minimum
distance of the aircraft, according to radar data, was 2.1 NM
laterally and 300 ft vertically.

Aircraft 2: Boeing B737-800 During the descent occurred an encounter
to a B737-500 at flight level FL300. The smallest distance between
the two aircraft was 2.1 NM laterally and 300 ft vertically.
```

Observation:

ACAS-Monitoring gives a complete insight into the traffic situation before the ACAS-intervention, documents the RA, and shows the reaction of the aircraft. In this case the short bulletin does not give any further details on the operational situation, the adequacy of the ACAS-RA and the reaction of the pilots although this encounter was classified as a serious incident.

3.3 Example 3: A More Complicated RA

This event is much more complicated than the others above. Here the ACAS-devices in both planes issue incompatible Resolution advisories first. While coordination the ACAS-devices recognize the incompatibility, one device reverses its resolution Advisory within the next second.

Altitude Profile

Figure 6 shows the automatically computed altitude profile versus time. Both planes are descending from 5000ft, while the horizontal distance is vanishing too. After both planes decent below 4000ft ACAS intervenes.

The ACAS on board of **3CYYYY** issues the RA *Corrective* ***Upward*** *Positive Altitude Crossing* RA to its pilot, which means "Climb and cross the altitude of the intruder!". This RA is coordinated to the ACAS-device of **3CXXXX**, which at first accepts the RA and communicates that itself has *No RA*.

A second later the ACAS-device of **3CXXXX** issues an RA itself to its pilot: *Corrective* ***Upward*** *Vertical Speed Limit*. But the *Upward* RA is not compatible to the RA in **3CYYYY**. As a last resort, the ACAS-Algorithm resolves incompatibilities by selecting the RA of the aircraft with the lower Mode S-Address, **3CYYYY** has to withdraw its RA and select the compatible RA *Corrective Downward Positive*, i.e. "Descend!". ACAS labels the RA as a *Sense Reversal.*

Both pilots follow promptly their RAs: **3CXXXX** levels off and **3CYYYY** descends with 2500ft/min. Until after 15 seconds RA of **3CYYYY** was reduced to *Corrective Down Vertical*, which was also followed promptly. After another 15 seconds the RAs in both planes are *Ceased*.

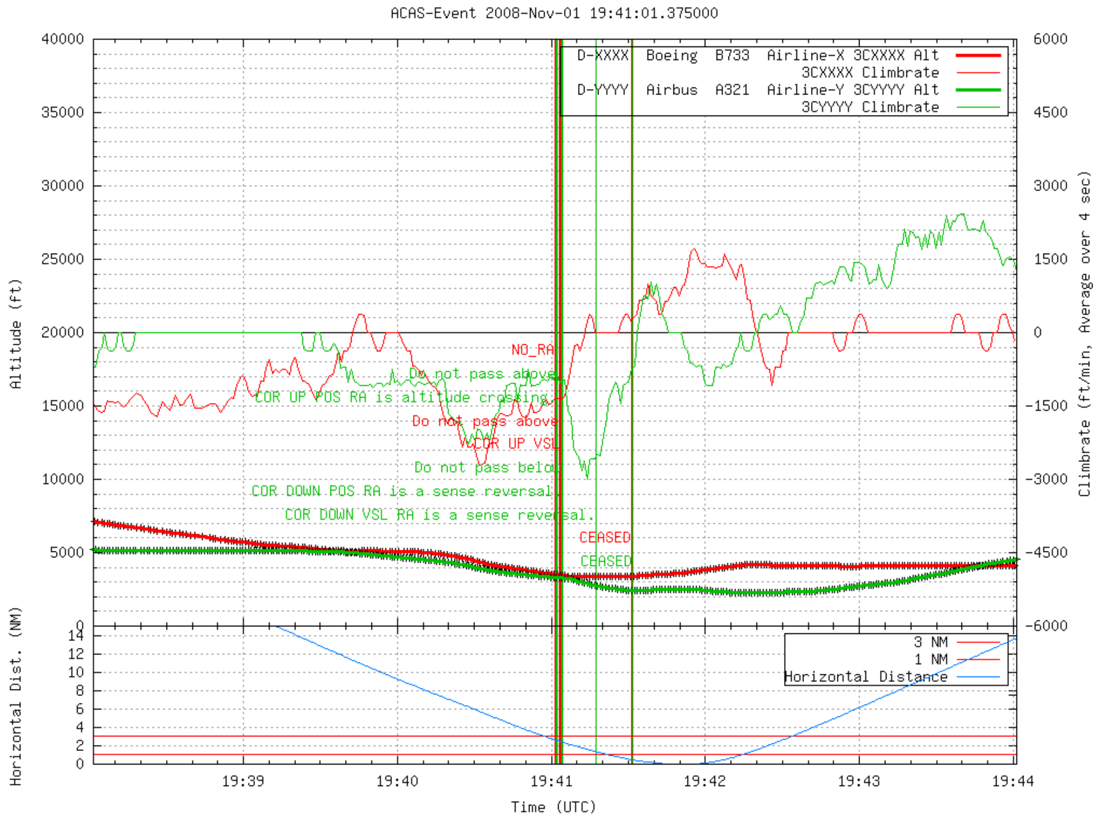

Figure 6 - Altitude profile of example Event 3

ADS-B Tracks

Again both plans are equipped with ADS-B and the horizontal tracks are shown in Figure 7 on a map of the Frankfurt Region. The blue line marks the position of both planes when the first RA was issued, the violet line marks the positions of the planes when the RA ceased.

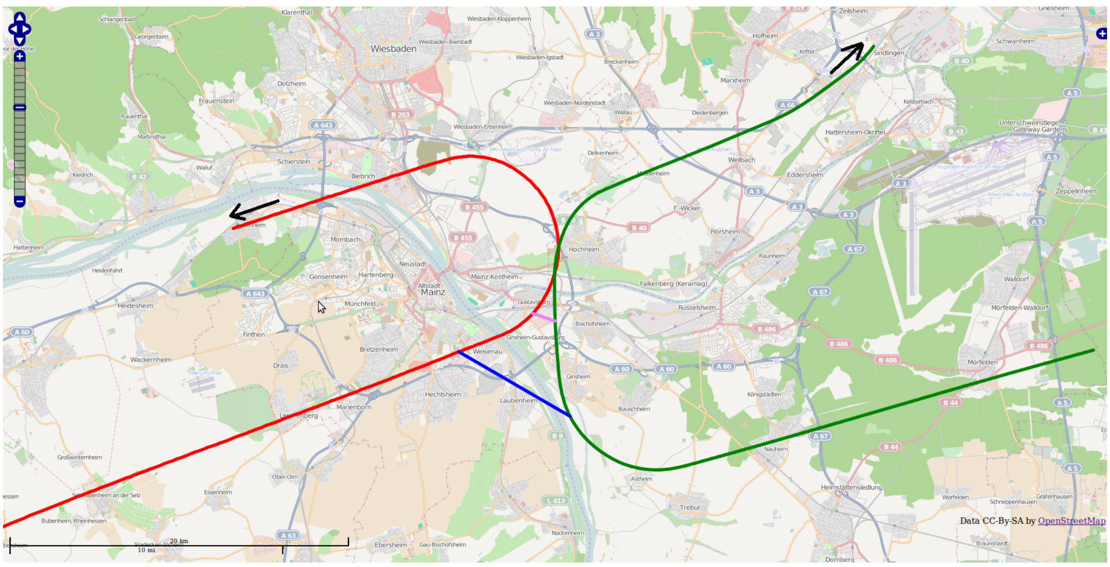

Figure 7 - Horizontal track of example Event 3

BFU-Bulletin:
Also this particular Event was investigated by BFU and published in the Bulletin [10]. The BFU published a short Bulletin as for Event 2 and a even long 2 pages version.

The Bulletin states, that **3CXXXX** was in final approach on runway 07R, **3CYYYY** was coming downwind leg and turning into base leg to runway 07L when both TCAS alert due to the threatening crossing on about the same altitude. The Bulletin is in close similarity to the ACAS-Monitoring-Event-Report. The Bulletin explains the operational background. While ACAS-Monitoring describes complete and precisely the vertical and horizontal tracks, illustrating the actual reaction of aircraft, together with the complete ACAS-intervention and coordination process. The different Resolution Advisories and other details, obvious from the Event-Report, are partly confirmed by the Bulletin.

Obviously the combination of both, the textual Bulletin an the graphical Event-Report, could yield a much deeper insight into the incident, and gives the opportunity to learn.

3.4 Example 4: Exaggerated Reaction on RA

Received ACAS Messages
This ACAS-Communication is very complicated, therefore the exchanged data is extremely shortened here:

```
4843.. UF1631: ARA: Corrective, Upward, Speed limit
                 and assigned RAC: Do not pass below

4844.. DF1630: ARA: Corrective, Downward, Speedlimit
             and assigned of RAC: Do not pass above
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Altitude Profile

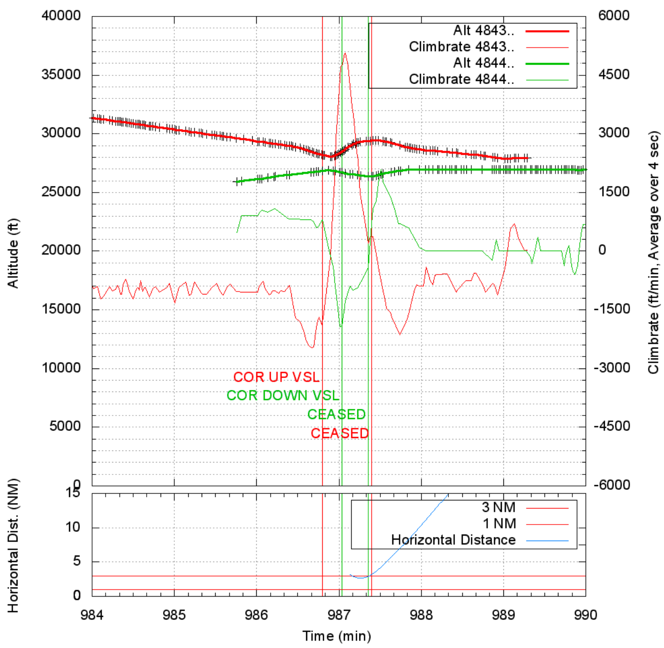

Figure 8 - Altitude profile of example Event 4

Figure 8 shows the automatically computed altitude profile versus time. 4843.. is descending and 4844.. is climbing. The event took place ca. 200NM from the ground station at the edge of the reception range. So the tracks are not as good as in the previous examples. But as soon as the planes enter the reception range, the tracks have ca. 20 plots per minute.

Both ACAS intervene. 4844.. got a *corrective (COR), downward sense (DOWN), vertical speed limit (VSL)* RA (green lines) and did not just level off but went into a short descent. 4843.. received a *corrective (COR), upward sense (UP), vertical speed limit (VSL)* RA (red lines) and did also not just level off as adviced but went into a strong climb with 5000 ft/min. Both planes were equipped with ADS-B. But correct horizontal tracks could only be established after the event had already started. Below the altitude graph the distance is plotted as it was available.

Observations:

Both ACAS respond. 4843.. and 4844.. react on the RA excessively strong - instead of leveling off, they descent and/or climb. 4843.. climbs against its RA-instruction even with 5000 ft/min, which could endanger other passing airplanes.

4 CONCLUSION - REVIEW OF THE EVENTS

The ACASMON software extracts ACAS-Events from listening into the Mode S transmissions. ACASMON does this by building up a knowledge base on the status of every airplane in range. The Mode S formats UF16-30, UF16-31 and DF16-30 [2] are used to recognize ACAS-Events and to extract the contained ACAS Resolution Advisories. The additional processing of RA-Downlink-Radar-Reports is in development. This way the extracted ACAS-Events form an objective collection to answer unambiguously the following questions:

Why does the airborne collision avoidance system ACAS intervene at all? In what traffic situations does it intervene?

In nearly all observed encounters one of the two airplanes climbs or descends, while the other one is cruising. In fewer encounters both airplanes climb or descent. In 50% of the observed events, the climbing or descent rates are extremely high. (2500 ft/min up to 5000 ft/min)

Is the indicated Resolution Advisory and the coordination with the other plane appropriate to the traffic conditions and conform to the ACAS standard?

In the cases, in which one airplane was cruising and the other was climbing or descending, the ACAS in the climbing/descending plane fortunately intervenes first. So the maneuvering airplane could correct its maneuver and the other one could continue reasonably its level flight.

What was the reaction on a Resolution Advisory (RA)?

It was observed that the RAs were promptly followed in 6 out of 7 cases. In the few other cases the reactions were late, adverse or even exaggerated.

The automated ACAS-Event-Reports cannot explain the operational background on board and with respect to the traffic situation. This operational background can only be described by pilot- or controller-reports which are collected by the German Luftfahrtbundesamt (LBA) and the BFU, if investigated. So far the combination of all these reports promise synergies to understand all sources of midair collision risks, which is the task of our work.

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