SPECIAL REPORT

Losing Aircraft in the Space Age

Malaysia Airlines Flight MH370 illuminates the links between air and space

Losing an Aircraft in Today's World

By Stuart Baskcomb

Like many people, I have discussed the MH370 loss with colleagues and friends fairly regularly over the past weeks. It never takes long for one of us to ask how we can lose an aircraft in today's world where surveillance is never far from peoples' minds, but for its ubiquity rather than its absence.

> *There were 11 accidents over water since 2009, but only 1 black box recovered*

The previous high-profile loss, Air France flight 447 in June 2009, started a push for new technology and regulations. However, because of the relatively low probability of losing an aircraft, perhaps global tracking has not been considered urgent or received the strong financial and political incentives and concerted effort needed to make it ubiquitous. The lack of urgency would seem to fly in the face of the historical record: there have been eleven accidents over water since June 2009 and only one of the black boxes has been recovered! Following the disappearance of MH370, it looks like the momentum for change has finally arrived.

Today's Tracking Technology

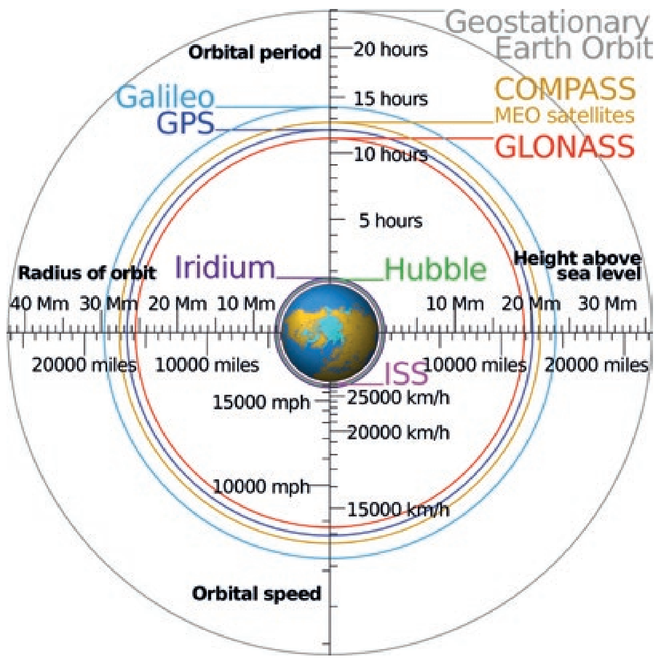
Aircraft today already carry equipment to determine their own positions via GNSS (Global Navigation Satellite System) and ELTs (Emergency Locator Transmitter). One such GNSS, GALILEO, will also include SAR (Search and Rescue) receivers to improve coverage/response time and location accuracy of ELTs.

In anticipation of future regulatory mandates (e.g. 2017 in Europe), over 90% of all commercial aircraft are also already fitted with equipment for ADS-B (Automatic Dependent Surveillance-Broadcast). ADS-B transponders connect with the relevant avionics systems (GNSS, pressure altimeters, etc.) and regularly broadcast the aircraft's positional information, readable by anyone with the right receiver. Currently, the receivers are ground-based and therefore cannot provide coverage in remote oceanic and continental regions.

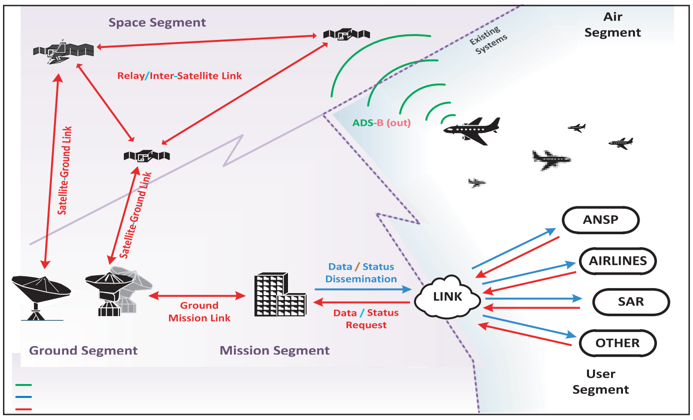
Both MH370 and AF447 were equipped with ADS equipment. The MH370 broadcasts stopped for some reason, possibly disconnected intentionally (pilots can pull circuit breakers as part of their fault-finding and isolation procedures). But even with regular positional broadcasts from the AF447, it took nearly two years of searching and a bit of luck – assumptions revisited, "friendly" seabed terrain – before it was discovered. The AF447 was previously the most expensive aviation search operation, with an estimated final bill of $44 million. This is the same estimated cost for the first month of the MH370 search and, as of the time this goes to press, there is still no end in sight. With two Australian ships costing over $850,000 a day for example, it is difficult to even guestimate the final bill.

For next generation ADS-C (C for Contract), satellite technology is already in place and offered by companies such as Inmarsat. It can help with tracking but its main purpose is maintenance support. Aircraft require a modem onboard, but can transmit much more than just positional data. ADS-C presents the heady prospect of on-ground experts assisting the aircrew in real-time and maybe even preventing an accident in the air. However, cost can become an issue for airlines, especially for very frequent transmissions.

Space-based technology can already play a role in capturing the position of all aircraft anywhere in the world using existing aircraft equipment. Future upgrades may make that role a more prominent one.



Aircraft take advantage of LEO, MEO, and GEO satellite systems to stay in touch and on-track. – Credits: Cmglee Geo Swan/Wikipedia



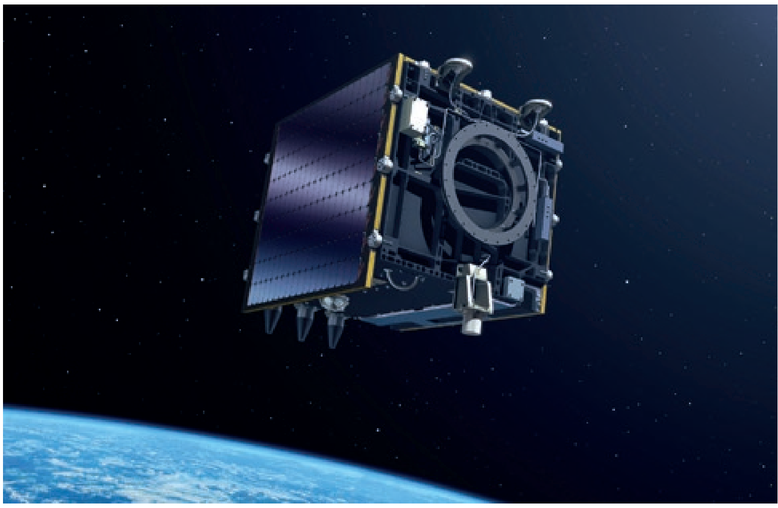
Space-based Automatic Dependent Surveillance-Broadcast keeps aircraft connected where there are no ground receivers in range. Credits: TAS-B

Tomorrow's Tracking Technology

ADS-B receivers installed on satellites will allow aircraft positions to be tracked in areas that are out of range from today's ground stations.

A recently-formed consortium (too young for an official name yet) is developing an ADS receiver payload as part of a European ADS-B satellite constellation. This organization includes Thales Alenia Space Deutschland (TAS-D), SES TechCom, and German Aerospace Center DLR. TAS-D holds all the patents for satellite ADS-B equipment and plans to market a solution by 2020.

Hannes Griebel, Head of the Satellite ADS-B Development Program at TAS-D, told me that they currently plan a dedicated satellite constellation with ADS-B as the primary payload. "This is more expensive, but preferred from a certification point of view. For example, would a satellite with a failed secondary payload be replaced if the primary is working fine?" Griebel also told me that the real challenge has been the environment. For example, the receiver needs to "degarble" all the overlapping messages received from multiple aircraft: "Imagine you are stood in the pitcher position of a baseball stadium. Now try to listen to every conversation between all the spectators." The computing power needed to degarble is nothing compared to a gaming PC. However, your gaming PC would not work for long, if at all, in space.

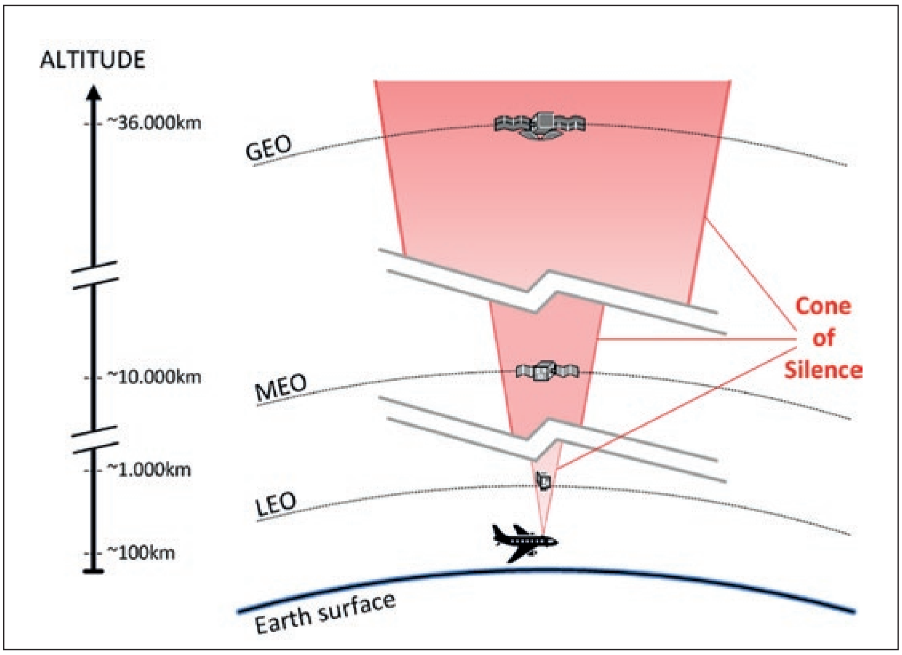


Proba-V carries the first satellite ADS-B receiver and antenna array. – Credits: ESA

The real challenge is operating an ADS-B receiver reliably in space

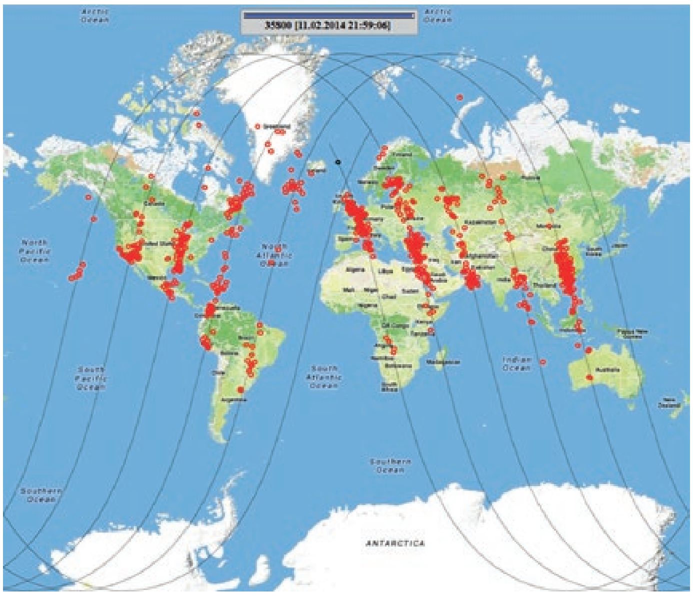
DLR is currently one year into a two-and-half year flight test program with the very first satellite ADS-B receiver and antenna array onboard ESA's Proba-V satellite. According to Toni Delovski, DLR's ADS-B-over-Satellite Project Manager, the testing has so far been a success and "proof of concept" for ADS-B receivers in a LEO satellite system has been achieved.

Using existing aircraft transponders is key to getting space-based ADS-B off the ground. This presented one challenge



The transmission dead-space directly above an aircraft, known as the Cone of Silence, increases in radius with altitude. This creates a gap that becomes increasingly disruptive the further the receiver is from the transmitter, with a receiver altitude of 36,000 km effectively suspending radar transmissions for 10 hours. – Credits: DLR

A Beijing-bound flight operated by Malaysia Airlines disappeared from air-traffic control radar on March 8, 2014 about an hour after taking off from Kuala Lumpur. Just a few minutes after the reassuring "Good night Malaysia" was heard from the cockpit, someone or something disabled the Aircraft Communications Addressing and Reporting System (ACARS) as well as the aircraft's radar transponder. The plane never checked in with controllers after entering Vietnamese airspace and what was supposed to be a rather uneventful flight turned into the biggest aviation mystery of all time.



Testing with Proba-V's ADS-B has provided proof of concept for the satellite-receiver approach. – Credits: DLR

I was surprised by the maturity of the technology already available

with respect to the "cone of silence," the area directly above an aircraft where its transponder signal cannot be seen. Delovski explained to me how DLR's experiments on ESA's Proba-V have characterized the cone of silence: "A LEO satellite traveling at 7km/s at an orbit of between 600 and 700km above sea level closes the gap so quickly that the delay in receiving data is negligible." That gap expands as the distance between the receiver (satellite) and transmitter (aircraft) increases and as the relative velocity between receiver and transmitter decreases. This constraint provides LEO satellites with one advantage over using a GEO satellite system which is at a greater distance and relies on the aircraft's velocity alone to close the gap. At the GEO satellite orbiting height of 36,000km, the gap would be a not-insignificant ten hours.

After initially leading the ADS-B space race, Europe is now playing catch-up. In America, Aireon is scheduled to launch Iridium NEXT's LEO satellites between 2015 and 2017. These will include ADS-B receivers (based on TAS-D's patented design), albeit as a secondary payload. Such competition is both financially and technologically advantageous for the airline industry: two independent systems offer a back-up option, as well as choice.

The Hurdles of Global Tracking

Providing coverage of the remote parts of the Earth is one challenge that satellite technology can solve. There are others.

According to a recent European Union report, the cost of satellite data transmission is around $0.50 per message (a decrease of 90% since 2009) and is expected to become cheaper. The cost of a position report via the Iridium network can be as low as $0.05 per report, using a GNSS sensor by Spidertrack, for example.

The size of a potential aviation disaster search area drives how frequently an aircraft should broadcast its position. AF447 was actually close enough to land to be reporting its position every ten minutes. The ACARS messages received before the incident reduced the effective reporting frequency to five minutes. However, the search area was still 17,000 square kilometers and it took nearly two years of searching! A positional accuracy of 6 nautical miles is the expected minimum to be required from regulatory bodies and this will require a reporting frequency of around one minute. DLR's testing on ESA's Proba-V has shown the update rate of satellite ADS-B can achieve this comfortably. In order to have reliably good data, a downlink every fifteen seconds is being proposed. In addition, Griebel advised, the raw data received by a satellite ADS-B every second or less can be analyzed following an incident to provide a more precise search area.

With nearly 100,000 flights every day, what about bandwidth? According to Griebel, this is not even a concern in high density air traffic areas (where ground-based systems are operating satisfactorily anyway), let alone in the low density areas where satellite ADS-B will excel: "A single downlink (one aircraft) is only about 200 bytes of data. Existing phone services require much greater capacity."

However, if the aircrew can disconnect the system, all this capability will not avoid a repeat of the MH370 case. One solution here is an RLS (Return Link Service) which could allow the satellite control center to remotely switch on the aircraft transponder when required. However, this would need a change in aircraft systems and therefore will need to be mandated before it becomes reality. And before it can be mandated, it will need to be argued that the increased risk of a pilot-independent system on every aircraft is outweighed by the advantage of mitigating the rare event of a deliberate disconnection.

What's Next?

The political will in the face of the public attention to the MH370 loss, on top of the multi-million dollar search cost, has certainly helped push the introduction of aircraft tracking up the agenda. ICAO is leading the regulation aspects and held a Special Meeting on Global Flight Tracking of Aircraft in May 2014. Whilst regulations must remain unbiased to the type of technology to be used as means of compliance, space-based technology will play a key role in the solution.

I started my research for this article with the surprise shared by many, of how we can lose an aircraft today. Maybe working inside the industry meant I was not quite as surprised as the general public. However, what has surprised me more is the level of maturity of the technology already available and (sometimes) in use. This provides a great foundation to make the necessary improvements and evolve with the emerging satellite technology.

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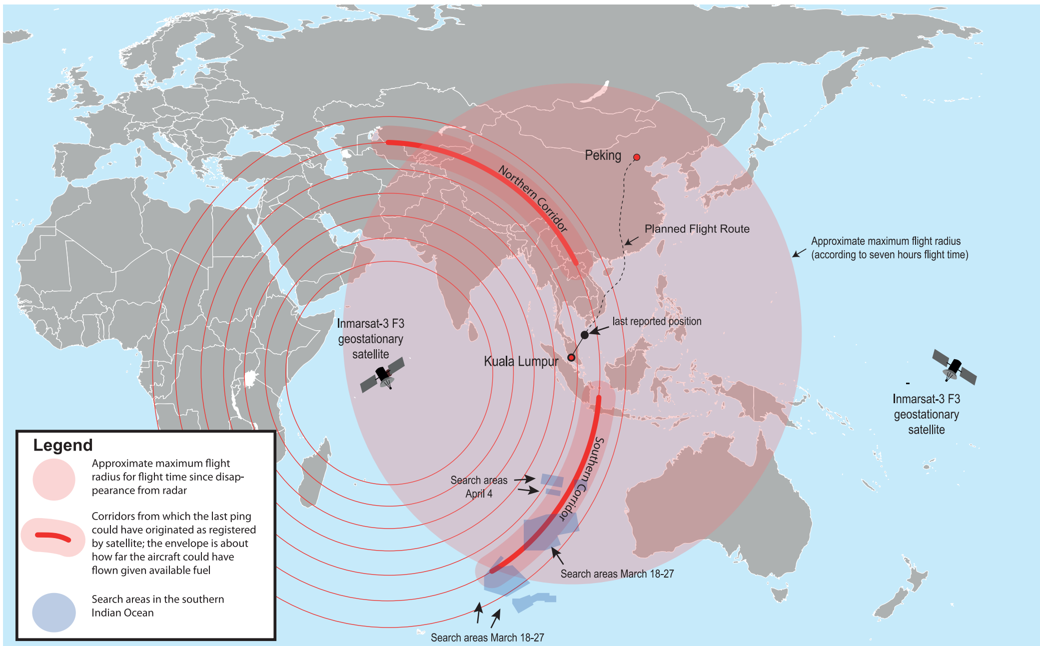
Inmarsat: Arming Against Tragedy

By Tereza Pultarova

> *"There is no need to wait for another technology, we can provide basic tracking with what we have today"*
>
> *Inmarsat COO Ruy Pinto*



The evolution of the MH370 search area. – Credits: Furfur and Pechristener/Wikipedia with translation by A. Klawitter

All eyes were on British satellite operator Inmarsat when it announced results of a never-done-before analysis at the end of March 2014. Looking at regular pings between Inmarsat's network and the still airborne MH370 – a sort of confirmation of being aware of each other's existence – the company's analysts managed to determine the approximate location of the last received ping. Despite the fact that the exchange didn't contain any location data, Inmarsat considerably reduced the size of the enormous haystack in which search teams from more than 20 countries were looking for the symbolic needle – the remnants of a Boeing 777-200ER.

"We looked at the Doppler effect, which is the change in frequency due to the movement of a satellite in its orbit. What that then gave us was a predicted path for the northerly route and a predicted path for the southerly route," Chris McLaughlin, senior vice president of external affairs at Inmarsat, told Guardian in March. "That's never been done before; our engineers came up with it as a unique contribution. Subsequently, we worked out where the last ping was, and we knew that the plane must have run out of fuel before the next automated ping," he said.

The doomed MH370 was carrying Inmarsat's equipment supporting the company's Classic Aero service. A standard in aviation, Classic Aero enables transmission of data from the Aircraft Communications Addressing and Reporting System (ACARS) via Inmarsat's geostationary satellite constellation. The data usually include information about the plane's onboard systems, its altitude, heading, speed, and location.

In case of the ill-fated MH370 someone or something disabled ACARS about an hour after take-off. The regular data transmission ceased; however, the system itself kept synchronizing with the satellites on a regular basis as long as the computer remained powered.

In an interview with Guardian, Chris McLaughlin likened Classic Aero to a smartphone and ACARS to an app – even with the app disabled, the phone keeps performing some regular functions.

Satellite operator Inmarsat kept receiving regular pings from Flight MH370 for about eight hours after it went silent, meaning the aircraft must have remained airborne with at least some electrical systems functioning. The telecommunications company later performed an unprecedented data analysis that helped narrow down the area of the probable crash in the southern Indian Ocean.

Free Satellite Tracking for Everyone

Since MH370's disappearance, Inmarsat has kept a high profile. In early May, ahead of a meeting organized by the International Civil Aviation Organization (ICAO) to discuss global aircraft tracking, Inmarsat announced it will offer a basic free tracking service via its satellite fleet to all aircraft around the world already carrying its equipment.

"There is no need to wait for another technology," Inmarsat's Chief Operations Officer Ruy Pinto told E&T Magazine in May. "We can provide solutions that are available today. Most of the technology has been available since the Air France tragedy in 2009 and what we are trying to do now is to remove what some may consider a commercial barrier to speed up the uptake of satellite-based positioning services in the aviation community."

Some 11,000 transoceanic airplanes around the world, nearly 90 percent of the global long-haul fleet, already carry Inmarsat's gear – either Classic Aero or its more powerful and modern sibling Swift Broadband.

While Swift Broadband offers aircraft positioning services by default, Classic Aero would require a software upgrade. Inmarsat offers to pay for that upgrade and says there is no additional investment required on the part of the airlines.

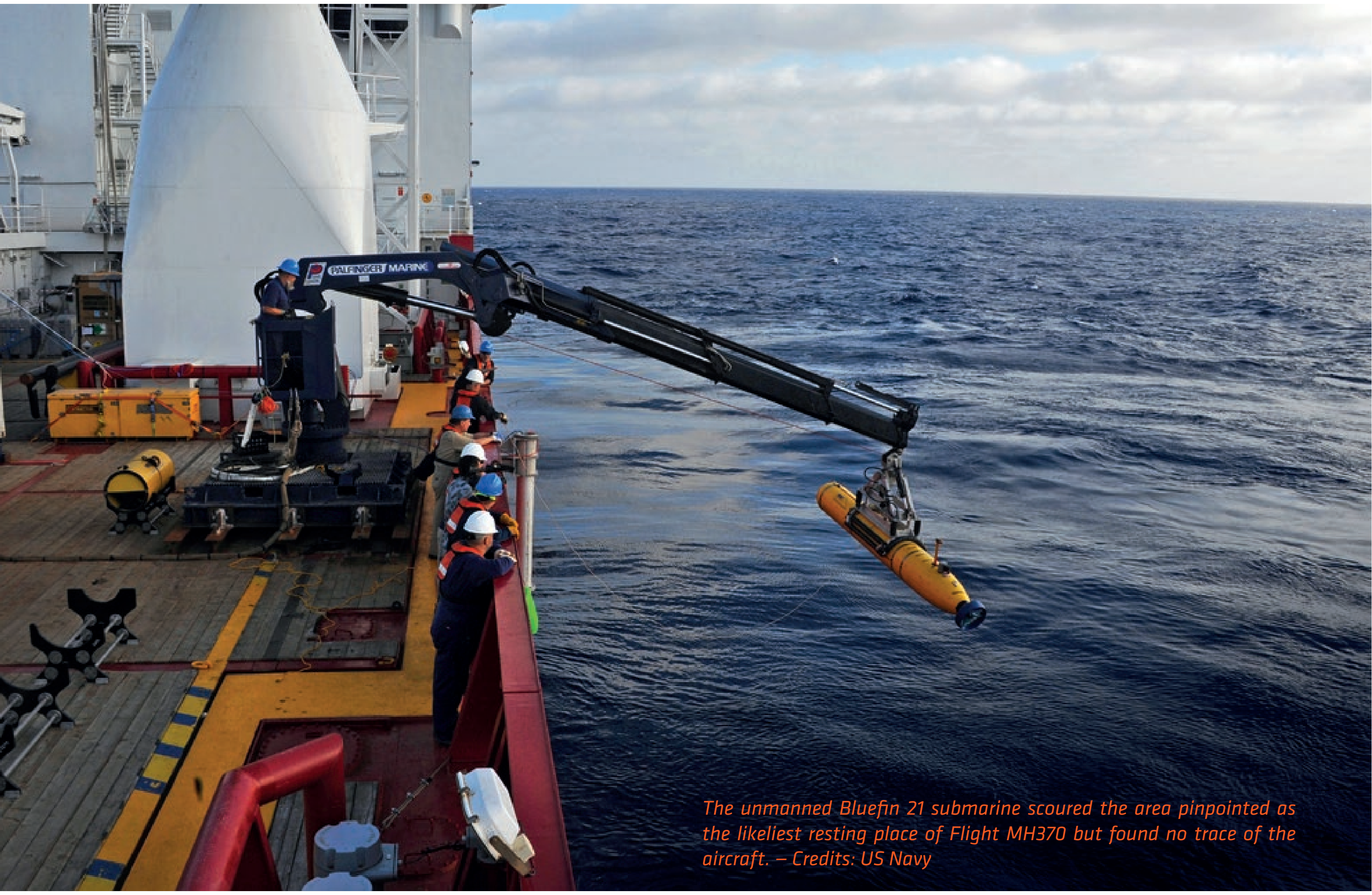
Swift Broadband, awaiting certification next year, is usually carried on top of Classic Aero. Aircraft traveling on busy transatlantic routes between Europe and North America are mandated to use satellite tracking systems, such as those provided by Swift Broadband. In the rest of the world, however, the decision is mostly upon the airlines and their willingness to invest.

Inmarsat is now working with ICAO, a UN body responsible for developing aviation standards and regulations, and the International Air Transport Association representing industry members to determine how frequently the free positioning data should be transmitted to ensure ground controllers have sufficient control over the aircraft's whereabouts.

Satellites offer not only global coverage but also system redundancy

"We think that every 15 minutes would be a reasonable interval for a free tracking service," says Pinto. "The bandwidth available on both Classic Aero and Swift Broadband would be more than enough to accommodate such a service. Where there may be a need for some upgrade is Inmarsat and its distributors who would have to upgrade some of their ground systems to be able to provide the data seamlessly to the airlines."

Unlike conventional radar-based tracking, Inmarsat's satellites offer not only global coverage but also system redundancy – the company has enough satellites in orbit to cover for any unexpected failures without customers noticing.



The unmanned Bluefin 21 submarine scoured the area pinpointed as the likeliest resting place of Flight MH370 but found no trace of the aircraft. – Credits: US Navy

Streaming Black Box Data

Inmarsat, confident in its capabilities, has gone even further and proposed using its existing systems to address another painful problem that has come to light in the wake of the MH370 loss.

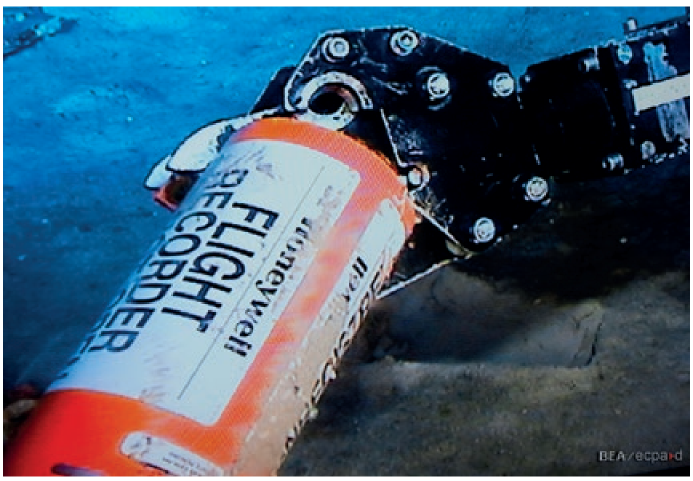
To understand the causes of most aviation disasters, investigators need to get hold of flight data recorders and cockpit voice recorders, better known as black boxes. Those two shoebox-sized devices usually hold all keys to explaining the most mind-boggling disasters. Unfortunately, as the case of French AF447 in 2009 as well as the recent MH370 have shown, those vital keys could lie buried at the bottom of the ocean at depths of several kilometers.

With AF447, it took search and rescue teams two years to retrieve the black boxes from the bottom of the Atlantic Ocean. The situation around MH370 portends that the recorders may not be discovered at all.

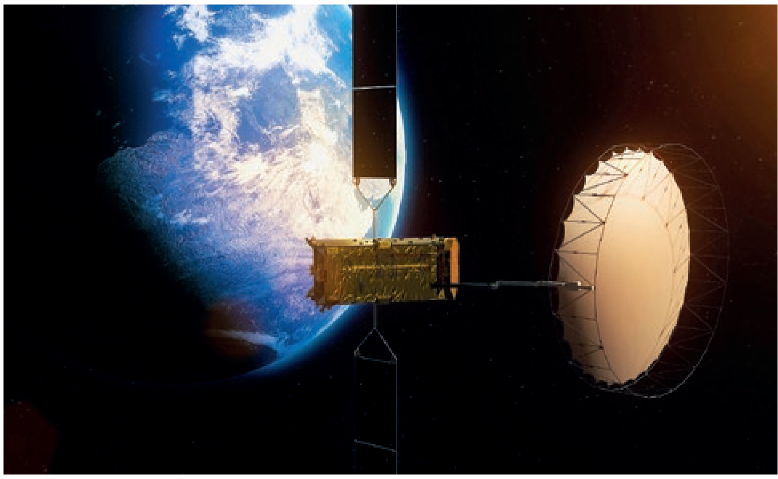
To help searchers in their efforts, the black boxes are equipped with locator beacons transmitting an acoustic signal on frequencies between 10 and 40 kHz. The signal propagates in water and can be intercepted at distances up to ten kilometers – that's obviously not much if you need to scour thousands or even tens of thousands of square kilometers of the ocean and only have 30 days to do so as black box batteries are designed to last exactly that long.

In the search for AF447, the signals were not intercepted at all and sophisticated mathematical analysis had to be employed to determine the location of the aircraft's wreckage. In the case of MH370, the search teams had a bit more luck – several signals consistent with those of the black boxes were intercepted towards the end of the 30-day period of the beacon's battery life. In spite of that, underwater search of the area pinpointed as the most likely resting place of the aircraft rendered no positive results.

A sensible approach to prevent such a scenario from repeating in future would be to stream some black box data in real time via satellites to provide investigators with vital clues immediately after an accident.



The flight data recorder of French Flight AF447, which was lost in 2009. The precious black box was retrieved two years later from a depth of nearly 5km. – Credits: BEA ecpad



Alphasat, one of the latest additions to Inmarsat's geostationary satellite fleet. – Credits: ESA

> *"We are transmitting black box data only after a trigger by some unexpected changes to the airplane status, so bandwidth is not an issue"*
>
> *Inmarsat COO Ruy Pinto*

The technology enabling such streaming exists and the only thing seemingly holding it back are standards and regulations.

"We are now working with the regulatory bodies such as ICAO and IATA, as well as with the airlines, trying to define that service, the subset of data to be streamed, and how it could be implemented in Classic Aero and Swift Broadband," Pinto told E&T Magazine.

"Swift Broadband would obviously allow transmitting a bigger set of data than Classic Aero, but both are sufficient to provide a basic service, which, however, would not be a part of the free tracking offer."

According to Inmarsat's proposals, the data wouldn't be streamed continuously but only after a trigger signaling unusual behaviour of the aircraft. Such a trigger could be either conveyed by the aircraft's onboard computers or by ACARS. Apart from system failures, situations such as sudden veering off course could activate the emergency data transmission.

Data from both the flight data recorders and cockpit voice recorders would be streamed in such situations. The latter, however, poses certain privacy concerns as pilots may not be particularly keen on the prospect of their superiors possibly eavesdropping on them.

However, Inmarsat believes that potential data misuse shouldn't be a showstopper. "We would have to invest into and adapt our systems to address the privacy concerns. Either the data could be automatically erased after a certain time or it could have a very limited access and not be available to normal operations," Pinto told E&T Magazine. "There are ways in which you can address privacy concerns, similar to secure connections that you can see on the Internet. However, these mechanisms would have to be mandated by the regulation."

Obviously, Inmarsat is not the only company that could possibly provide such services. Its competitors, American Iridium and United Arab Emirates Thuraya, will most likely delve into black box data streaming as well.

Cospas-Sarsat: Life-Saving Beacons Fail to Save

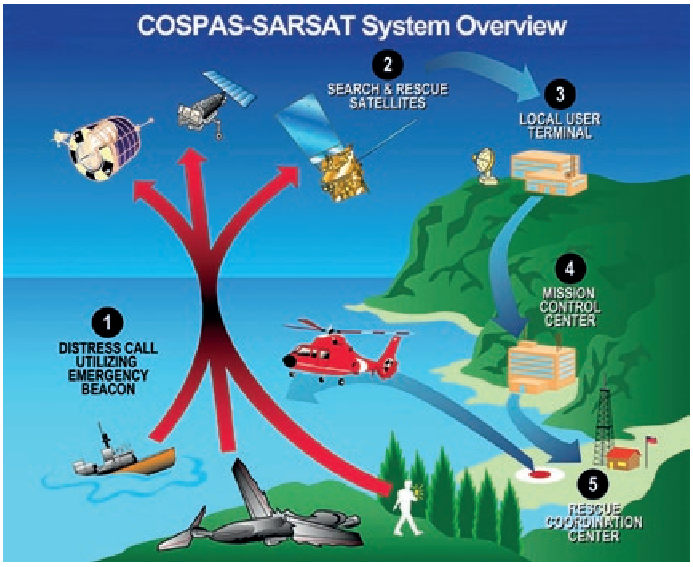
By Tereza Pultarova

There were four of them aboard the ill-fated Boeing 777-200ER: a portable device – to be triggered manually from the cockpit, a fixed gadget in the rear of the aircraft that activates automatically upon impact or when in contact with water, and two additional devices at the emergency slides. At least two of those Emergency Locator Transmitters were supposed to transmit the 406MHz frequency signal used by the international Cospas-Sarsat search and rescue constellation to locate and assist vehicles or individuals in distress. But the SOS signal from the missing Malaysia Airlines Flight 370 never came.

Since its inception in the late 1970s, the Cospas-Sarsat program, currently operating search and rescue devices aboard six low Earth polar orbiting and six geostationary satellites, has helped to save the lives of about 35,000 people around the world.

Though the majority of accidents resolved with the contribution of Cospas-Sarsat happen to ships cruising the world's oceans, about 13% of the SOS calls come from aircraft accidents.

"Cospas-Sarsat has been instrumental in the location and rescues involving about 25 aircraft with over 10 passengers aboard," says Steven W. Lett, Head of Secretariat at Cospas-Sarsat. "The reason that this number is not greater is because most large aviation accidents happen near airports, or are easily seen in urban or suburban areas, so satellite-derived alert and location data is unnecessary," he says, explaining that the constellation more frequently contributes to the rescue of small aircraft that more commonly disappear above uninhabited areas and are not as carefully tracked as large commercial jets.



A scheme of the Cospas-Sarsat system. – Credits: NOAA

Hijack or Beacon Malfunction?

According to recommendations of the International Civil Aviation Organization, all aircraft flying over the oceans and remote land areas should be equipped with at least two Emergency Locator Transmitters. The ultimate enforcement of that recommendation, however, is in the hands of regional civil aviation authorities.

Unfortunately, as the case of MH370 shows, having the beacon installed doesn't necessarily save the situation. Following the aircraft's disappearance, some speculated the plane might have been hijacked and have landed, taking the missing emergency beacon signal as evidence. Experts were sceptical about such an explanation, saying it wouldn't have been the first case of an Emergency Locator Transmitter malfunction.

In fact, as Cospas-Sarsat confirmed, when the Air France Flight 447 crashed in the Atlantic in 2009 killing all 228 passengers and 12 crew members aboard, its Emergency Locator Transmitter didn't produce any signal either.

"While aircraft emergency locator transmitters (ELT) are built to very rugged specifications, there are risks of failure that are difficult to avoid," Lett explains. "One of those explanations is the detachment of the ELT antenna from the airframe in a crash. Without an antenna, the ELT cannot transmit effectively. Also, like almost any other radio equipment, an ELT cannot transmit under water. The water absorbs the signal."

> *"While ELTs are rugged, there are risks that are difficult to avoid"*
>
> *Steven Lett, Cospas Sarsat*

It takes about 50 seconds after the ELT activation to commence the emergency signal transmission, as the transmitter's electronics need to stabilize first.

"There were cases in the past when a helicopter or an airplane simply sank like a stone and the beacon didn't have a chance to activate," Milan Cermack, CEO of Swiss company Applied Space Technology and adjunct professor at the International Space University in France and Memorial University in Canada, told E&T Magazine after the MH370 disappearance.

Designs exist allowing the beacon to detach from the sinking wreckage and remain floating on the water's surface in order to commence and continue the emergency signal transmission. However, until the as-yet unexplained loss of the Malaysian plane, there was no substantial push in the aviation community to implement such solutions in commercial airliners.

Cospas-Sarsat says the next generation of its beacons would be able to begin transmission within three seconds, improving the chances of fast sinking vehicles being located.

Rescue Goes International

The International Cospas-Sarsat Programme was founded in 1979 by Canada, France, the United States, and the former Soviet Union. Since then, more than 20 countries have joined the program as ground infrastructure providers, with a further eleven states using the system's services.

The system of search and rescue payloads piggy-backing on meteorological satellites consists of GEOSAR and LEOSAR segments. LEOSAR comprises six satellites in low Earth polar orbits. As the low Earth orbit (LEO) satellites don't provide constant coverage of the whole globe, the system is reinforced by six geostationary satellites forming the GEOSAR. These satellites don't allow independent beacon position determination but bring the advantage of complete global coverage.

Although some of the modern beacons are able to transmit their exact location using GPS coordinates, the Cospas-Sarsat beacons are usually located by analyzing the Doppler Effect affecting the beacon's frequency as intercepted by the LEOSAR satellites.

> *When AF447 crashed in 2009, its ELT didn't produce any signal either.*

Satellite-enabled Emergency Locator Transmitters are mandatory on most aircraft. – Credits: Cosy-ch/Wikimedia

"Independent calculation of a beacon's location presently requires signal reception by LEOSAR satellites and, at any given instant, those satellites cover only a portion of the Earth," Lett explains. "The GEOSARs provide continuous global coverage between approximately ±70 degrees latitude, but they cannot be used to independently calculate a beacon location."

To improve coverage, Cospas-Sarsat is currently in the process of placing additional search and rescue instruments on medium Earth orbit (MEO) satellites to be launched as part of the GPS, Galileo, and GLONASS constellations.

"MEOSAR will provide constant global coverage with dozens of satellites, allowing precision independent-location calculation, without a location needing to be reported by the beacon, with only a single signal burst from the ELT," Lett explains. "That means a high probability of detecting and locating a beacon within a few seconds of activation with increasing precision of location over time."

As the causes of the MH370 disappearance are not known, it is hard to establish why the emergency beacon failed. Cospas-Sarsat said that according to available data, the ill-fated aircraft must have traveled within the range of two GEOSAR satellites, with EUMETSAT's Metop-A and Metop-B LEO spacecraft passing over the region around the time of the crash. With MH370 already the second case of a large aircraft disaster suffering an apparent beacon malfunction, there certainly may be reason to give the beacons another look.

Most accidents of large commercial aircraft happen in the vicinity of airports, thus Emergency Locator Transmitters usually don't play a crucial role in locating the disaster. – Credits: James Gordon

The disappearance of Flight MH370 spurred conspiracy theories. With the complete lack of hard evidence about the ultimate crash, some thought the plane might actually have landed. One piece of information in particular was frequently pointed to as a proof for such a scenario – the fact that the plane's Emergency Locator Transmitter, designed to activate upon impact, failed to send an emergency message.

Eyes in Space: When Satellites Search for a Plane

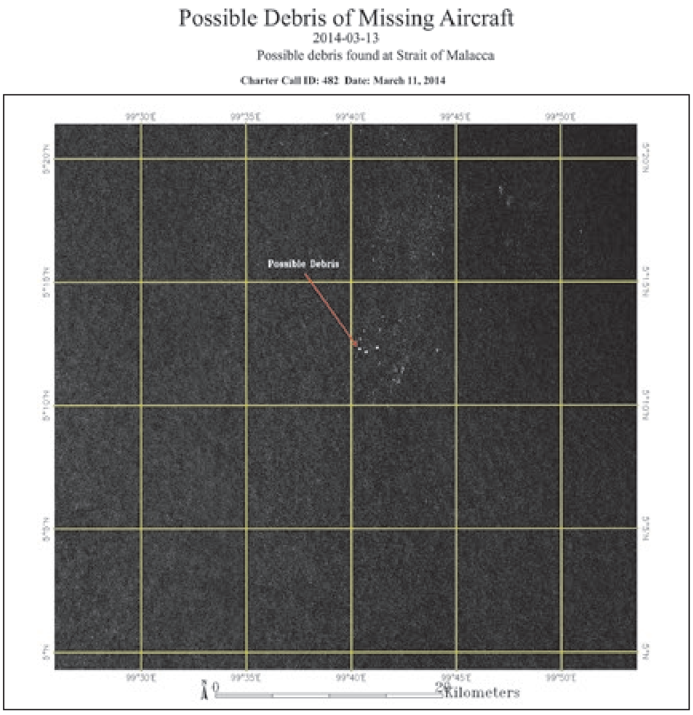
By Merryl Azriel

It turns out that satellites are not well suited to spotting aircraft.

A little thought will reveal that this is not an entirely surprising conclusion. Aircraft are small and fast. They are not constrained to defined routes. To effectively find a given plane, mid-flight, without advanced notice, one would need to effectively image the entire globe, constantly, at high resolution.

"[It is] extremely difficult to task a satellite for capturing an image over a flying object without knowing several hours in advance its exact location," says Hervé Jeanjean, Earth Observation Expert at French space agency Centre National d'Etudes Spatiales (CNES). "And even though an image is taken over an aircraft, it is almost impossible to identify the type of aircraft. It would require an extremely powerful system with a huge constellation of several hundred of satellites able to refresh observations every 10 to 30 minutes and everywhere at a resolution below one meter." That pairing of refresh rate and resolution simply does not exist in today's satellite fleet.

> *"This is the first time that the Charter was activated for a missing aircraft"*
>
> *Chaohui Guo , CNSA*



This TerraSAR-X image acquired March 13, 2014 was provided under the International Charter Space and Major Disasters. It highlights the challenge of spotting debris in the ocean's vast expanse.
Credits: DLR, Astrium Services/Infoterra GmbH

Where to Search

It's somewhat easier to locate the wreckage of an aircraft than it is to find the aircraft whole and in flight. Assuming the absence of highly active seas, wreckage does not move too quickly. Fuel and oil that leak out of the aircraft can spread in a large slick that can be captured via radar. But as the disappearance of Malaysia Airlines Flight 370 on March 8, 2014 showed all too well, there remains the problem of where to look.

"You have to decide whether you look at a big area with a lower spatial resolution or at a small area with higher spatial resolution," says Jens Danzeglocke of the Earth Observation Division at German Aerospace Center DLR Space Administration. He refers to radar satellites such as TerraSAR-x, Radarsat-2, and the newly-launched Sentinel-1 that have the ability to image at multiple resolutions – but not all at the same time. "This is quite a problem when you want to make radar observations in a case like the one of the missing airplane. On the one hand, floating debris of the plane will not be very big, so you might not be able to find it using a low spatial resolution. On the other hand you do not really know where to search."

Jeanjean highlights the same problem. Take, for example, a satellite such as Pléiades which collects sub-metric optical imagery. "Pléiades' acquisition capacity is about 1 million km²/day/satellite," he explains. When it comes to a vast ocean search, that barely scratches the surface.

Space and Major Disasters

This was exactly the challenge that puzzled the International Charter Space and Major Disasters. The Charter is "a worldwide collaboration among space agencies to make satellite data available for the benefit of disaster management authorities during the response phase of an emergency," explains China National Space Administration (CNSA)'s

Executive Secretariat representative Chaohui Guo. Interested space agencies (primarily) are Charter Members who volunteer their space assets for use during an activation. Authorized Users, such as civilian disaster response agencies, activate the Charter when they need to call on Members for assistance.

On March 11, 2014 the China Meteorological Administration activated the Charter with respect to the disappearance of MH370. From the very first, this was an unusual activation. “The Charter was activated more than 480 times in the past 14 years, but this is the first time that the Charter was activated for a missing aircraft,” says Guo. “Usually, the Charter covers major natural disasters such as floods, earthquakes, forest fires, landslides, etc.” Technological disasters are provided for in the Charter, but such activations are uncommon and are almost always related to oil spills.

“The Charter has created scenario guidelines for these kinds of disasters, but we do not have a scenario guideline for missing aircraft,” explains Guo. After all, how do you ask for images of a disaster when you don’t know where the disaster is?

That uncertainty was why it took four days after the disappearance for a Charter activation to be requested and accepted. When the first estimates as to the aircraft’s location were available, the Charter Members thought they might have a hope of quickly locating the missing craft. But the area of interest kept changing – and growing – as time went on. “Because of the quite large and indefinite area, the areas of interest were difficult to define, especially when the search area was over the south Indian Ocean,” Guo says.

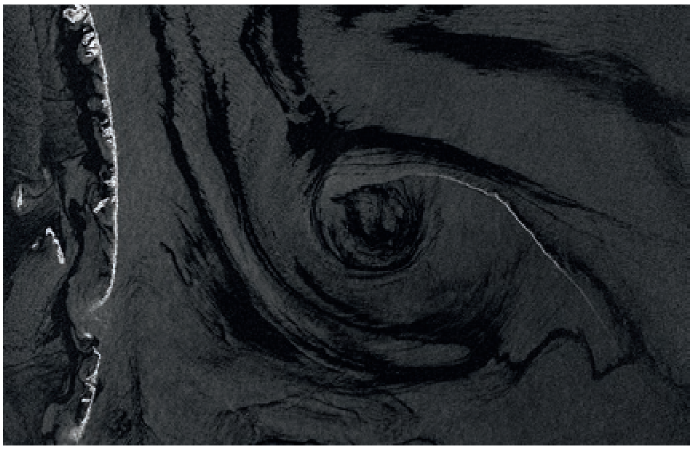
No Plane in Sight

Although some agencies continued to provide imagery through May 1, the activation was formally closed on March 25. As of the time of writing, the plane’s location remains undiscovered.

So did something go wrong in this case or were there simply no clues to find? “To our knowledge, all has been done to the maximum extent possible,” says Jeanjean, but Secure World Foundation’s Brian Weeden isn’t so sure. In a panel discussion held May 8 on the role of satellites in aviation safety, Weeden pointed out that there is little-to-no public information about the ability of military satellites to detect aircraft like MH370. With governments loathe to reveal their capabilities, it could be in their interest to refrain from divulging any details about what they can and cannot see.

“It is unlikely that [Earth observation] satellites will be able to better track aircraft in the near future”

Hervé Jeanjean , CNES



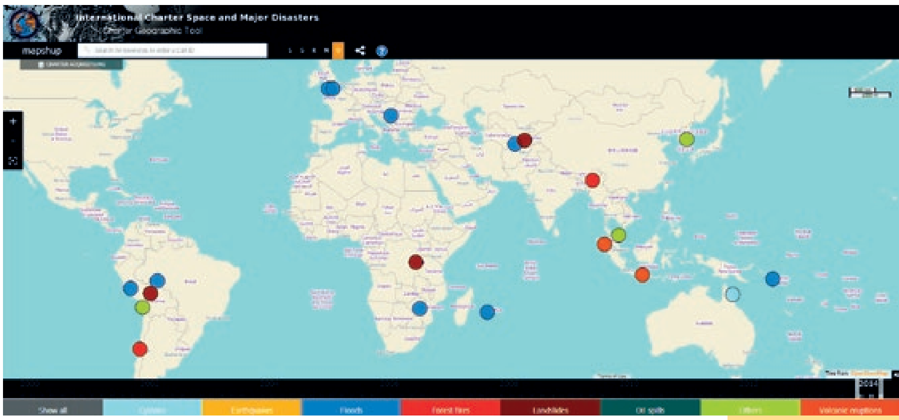
This TerraSAR-X radar image of the 2010 Deepwater Horizon oil slick is more typical of the events for which the International Charter Space and Major Disasters is activated. – Credits: DLR

It seems unlikely that secret military satellite images exist that pinpoint the location of MH370. If there are, the Charter won’t tell us – it consists of Earth observation missions from the civilian world employing civilian, or at most dual-use, satellites.

The International Charter Space and Major Disasters is not the only intergovernmental mechanism to call on space assets after a disaster. “In Europe, the Copernicus program is operating a service for managing emergency situations with the provision of damage-extent maps over areas affected by disasters,” says Jeanjean. Other initiatives using satellite-based Earth observation data include SERVIR in the US, Sentinel Asia, and the UN-Spider platform.

But no matter how much data one can gather, physical and technological limits still apply. “With respect to Earth observation from space, it is unlikely that satellites will be able to better track aircraft in the near future,” says Jeanjean. “In most cases, getting an image for a non-predictable event is opportunist.”

We tend to think of satellites as the “eye in the sky” watching everything on Earth’s surface, but as the still-mysterious disappearance of MH370 demonstrates, satellites can’t, in fact, see it all.



2014 Charter activations throughout the world by classification. Credits: OpenStreetMap/International Charter Space and Major Disasters

Three days into the search, China, the home country of the majority of the doomed aircraft’s passengers, requested activation of the International Charter Space and Major Disasters, hoping satellites could capture the aircraft’s wreckage. However, none of the objects spotted by the satellites, floating in the southern Indian Ocean, have been confirmed to have originated from the missing aircraft.

Staying in Touch

By Nikita Marwaha
Graphic Design by Kristhian Mason
Technical Advice from Vito Mitaritonna

Aircraft communication with satellites takes place both from the air and the ground. Ground stations relay signals to and from the aircraft – allowing the satellite to communicate with the plane and consequently determine its location. A telecommunication satellite can "see" in an arc that stretches north and south of its fixed position – yet without GNSS data the satellite can only say how far away the plane's electronic "ping" is, not where it is coming from.

Global Navigation Satellite Systems (GNSS)

GPS and other GNSS are used to show pilots the position of their aircraft on a map. There are two GPS receivers on a plane, the left and right receivers, which are independent and supply very accurate positional data to the Flight Management Computer (FMC). In the event of a failure of the GPS system, the Inertial Reference System (IRS) calculates data including the airplane's position, acceleration, track, vertical speed, ground speed, wind speed, direction, and attitude for the FMC.

GPS satellite. – Credits: NASA

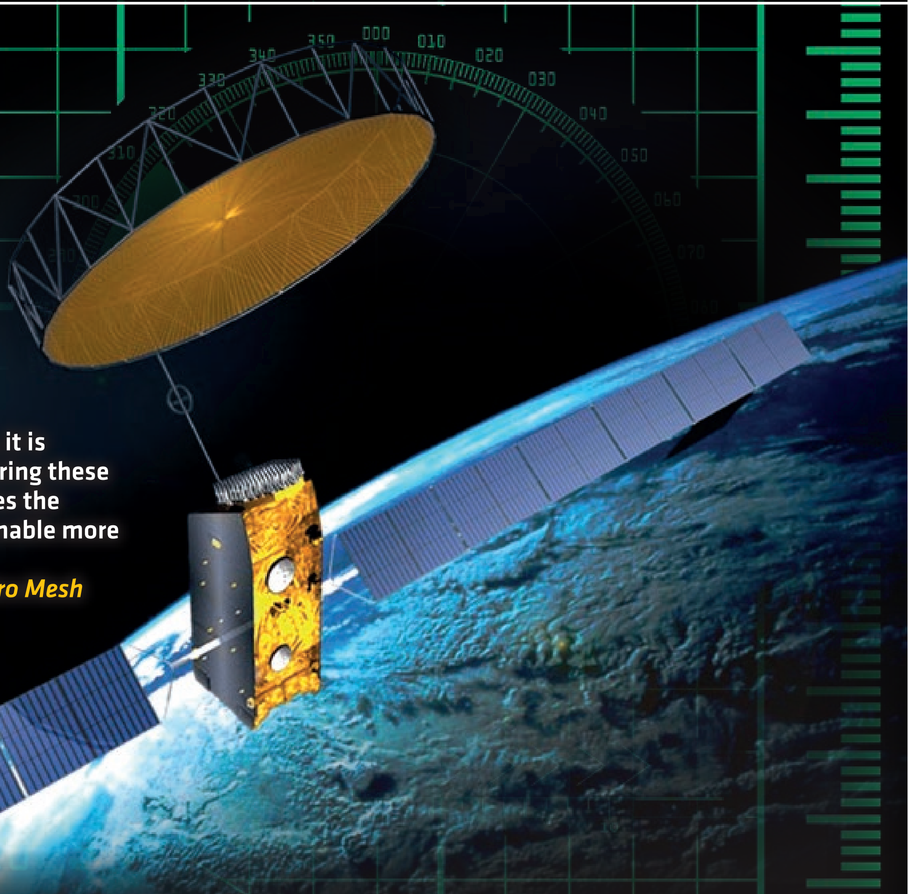
Radar

Primary radar detects and measures the approximate position of aircraft using reflected radio signals sent via radar. Secondary radar relies on targets being equipped with a transponder and requests additional information from the aircraft such as its identity and altitude.

Primary radar. – Credits: Bukvoed/Wikipedia

Satcom

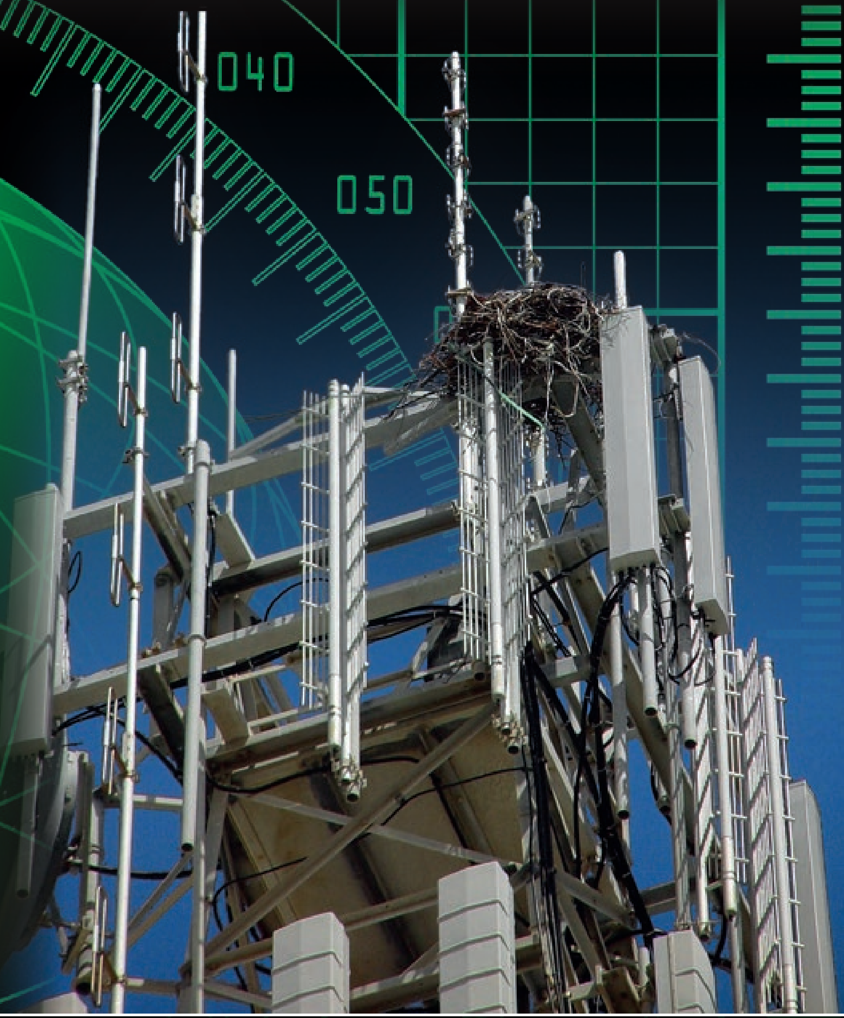
Aircraft use satellites to stay in touch when out of reach of ground networks. Communication satellites in low Earth orbit (LEO) or geosynchronous Earth orbit (GEO) can serve this purpose. Polling signals are sent from the ground station to the satellites, which relay them to the aircraft. When an aircraft responds, it is known as a "handshake." Information transferred during these communications contains a unique code that identifies the plane, determining approximate aircraft location to enable more efficient communication delivery.



GEO satellite Inmarsat 4 with Northrop Grumman Astro Mesh Deflector. – Credits: Inmarsat

Radio

High frequency radio is used to keep in touch with air traffic control and other aircraft once an aircraft is more than 240km (150 miles) out to sea, since radar coverage fades.



Radio antenna. – Credits: Leon Brooks/public-domain-image.com

Making Air Travel Safer with Satellites

By Colin Brace and Phillip Keane

In all of the mystery surrounding the disappearance of Malaysia Airlines Flight 370, one thing can be said for sure: that the flight lost all contact with Air Traffic Control (ATC) approximately 38 minutes after takeoff from Kuala Lumpur. At 1:19 am local time the last voice contact was made with the aircraft. The final words from the cockpit were a brief farewell from the aircrew: "'Good night Malaysian three seven zero."

> *"The way air traffic is managed has not progressed"*
>
> *del Rio Herrero , ESA*

In a time of increasing connectivity, it may seem peculiar that ATC systems still rely on radio communications alone. The European Space Agency is one organization that is looking towards a more integrated and autonomous solution that could reduce the risk of such communications losses and increase efficiency of ATC systems in the future.

Outgrowing Radio

On a busy day, more than 33,000 flights cross European airspace," points out Oscar del Rio Herrero, of the European Space Agency. "These numbers are expected to steadily increase. By 2030, the number of yearly controlled flights is estimated to reach 17 million, with 55,000 flights criss-crossing the continent on busy days. But while the number of flights is steadily growing," he adds, "the way air traffic is managed has not progressed as quickly."

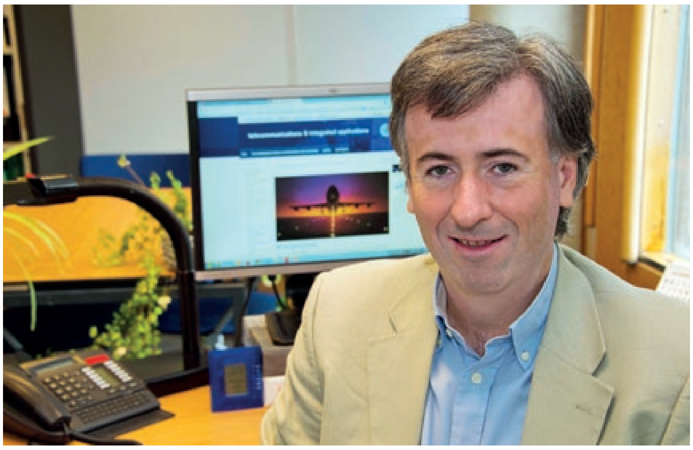
Air traffic management (ATM) is handled today, as it has been for many decades, by radio contact between pilots and air traffic controllers. Aircraft are tracked by radar when over land and in coastal areas, and flight paths are negotiated by radio. However, once an aircraft heads out over the ocean ATM is no longer possible until it reenters continental airspace. This means that flight paths cannot be easily adjusted in response to weather and other factors, and that wide buffers must be maintained between aircraft flying in a given oceanic corridor.

Another limitation is that management of European air traffic, like that of much of the world, has not yet been fully integrated. The continent's ATM is organized on the basis of more than sixty different sectors, all controlled individually, meaning it is highly fragmented. Forecasted growth is threatening to saturate the current system.

Time to Modernize

In recognizing the need to modernize Europe's ATM, the European Commission initiated the Single European Sky (SES) Policy. Part of the policy includes its technological pillar – the Single European Sky ATM Research Programme (SESAR). SESAR aims to develop a high-performance ATM system to enable the safe and environmentally-friendly development of air transport. It will represent a major paradigm change, as ATM would henceforth be managed through data links with air traffic controllers, with voice as a backup. SESAR's ambitious goals are to save between 8 and 14 minutes of flight time per flight, as well as up to 500 kg of fuel and up to 1575 kg of CO_2 emissions on average. The organization also aims to cut ATM service costs by half.

Iris is intended to provide a validated satellite-based communication solution in support of European air traffic management. – Credits: ESA



Oscar del Rio Herrero of ESA's Iris program. – Credits: Anneke Le Floc'h/ESA

Established in 2007, Iris is the European Space Agency's program to develop a comprehensive satellite ATM system for SESAR based on a global communication standard. It is a long-term undertaking with significant challenges.

"There are two aspects which make this such a complex endeavor," says del Rio Herrero. "First, you have many ATM stakeholders. You have the airspace users – the airlines – as well as service providers, the various regulatory entities, and the industry associations, all of whose requirements need to be considered. The second is the safety dimension," he continues. "This is of course extremely important, but it does make the process time-consuming. International standards govern everything that is airborne."

"ATM depends on standards, used worldwide," del Rio Herrero explains. "It's what makes moving forward such an exciting and difficult challenge."

At the technical level, Iris requires innovative developments to meet the stringent performance requirements of future ATM safety communications. "This means an extremely robust communication system with guaranteed service under all flight conditions on a 24/7 basis," he says.

> *"Robust satellite communications will open up a world of possibilities"*
>
> *del Rio Herrero , ESA*

There are also the business constraints of the airlines, which require drastically reducing the costs of aircraft terminals and communication services when compared to today's most advanced satellite communication technology. "Airlines do not want safety equipment that requires major modifications during the aircraft's operational lifetime, which is on average about 25 years," del Rio Herrero observes.

Satellite ATM for All

In April 2014, British satellite operator Inmarsat announced that it will be offering a free global airline tracking service over the Inmarsat network, riding a wave of renewed interest in improving aviation safety following the loss of flight MH370. "Since it is estimated some 80% of the commercial airline fleet traversing the world's oceans is already using Inmarsat's satellite services for fleet management, this is a first important step toward the universal adoption of satellite-based ATM," says del Rio Herrero.

As part of incrementally working towards the long-term Iris goals, ESA is already working with Inmarsat in the Iris Precursor communications service to adapt the widely-used SwiftBroadband system to provide initial ATM services over continental airspace. The target date for the deployment of this interim solution is 2018. The Iris Precursor will then evolve into the full Iris service by 2028, in line with long-term objectives of SESAR, to enable full 4D trajectory management over all airspaces across the globe. By then, digital data links between controllers and cockpit crews are expected to become the standard, with voice communications kept as backup.

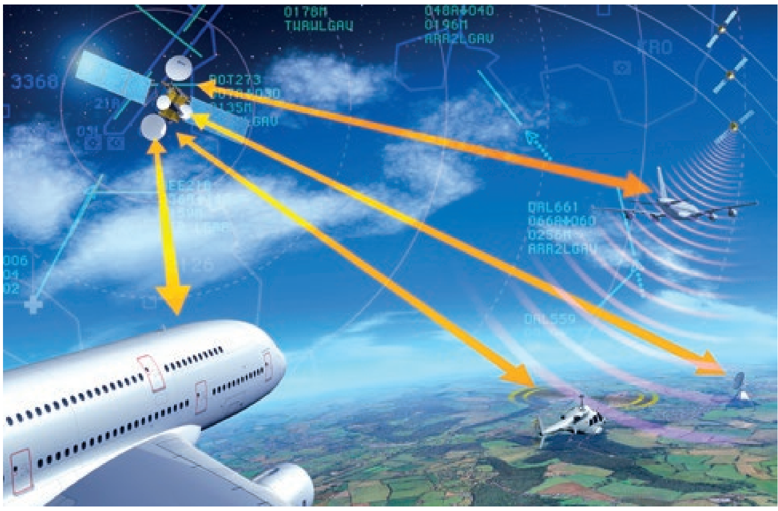
del Rio Herrero believes that commercial airlines will eventually have two satellite links. The first will be a lower-speed but extremely robust L-band link for mission-critical communications related to ATM. The second will be a much faster but less robust Ka- or Ku-band link which will be used for non-critical traffic, including passenger broadband services (on-board WiFi).

"Robust satellite communications will open up a world of possibilities," says del Rio Herrero. "It will enable all kinds of interesting ATM applications improving capacity and safety, and reducing costs and emissions."

A Connected MH370

What impact would Iris have had on the mystery of MH370? If nothing else, the proposed new system could have maintained contact with the flight as it left Malaysian airspace. Beyond that, nothing is certain, but the advantages of a satellite based ATC system seem extensive nonetheless. Use of real-time, four dimensional trajectory management will allow operators to save fuel, money, and time while increased safety can be assured for both pilots and air crew. Air Traffic Controllers already carry extremely high workloads in what is arguably one of the highest pressure careers out there; any system that streamlines the process and allows staff to focus on other critical tasks is a good thing.

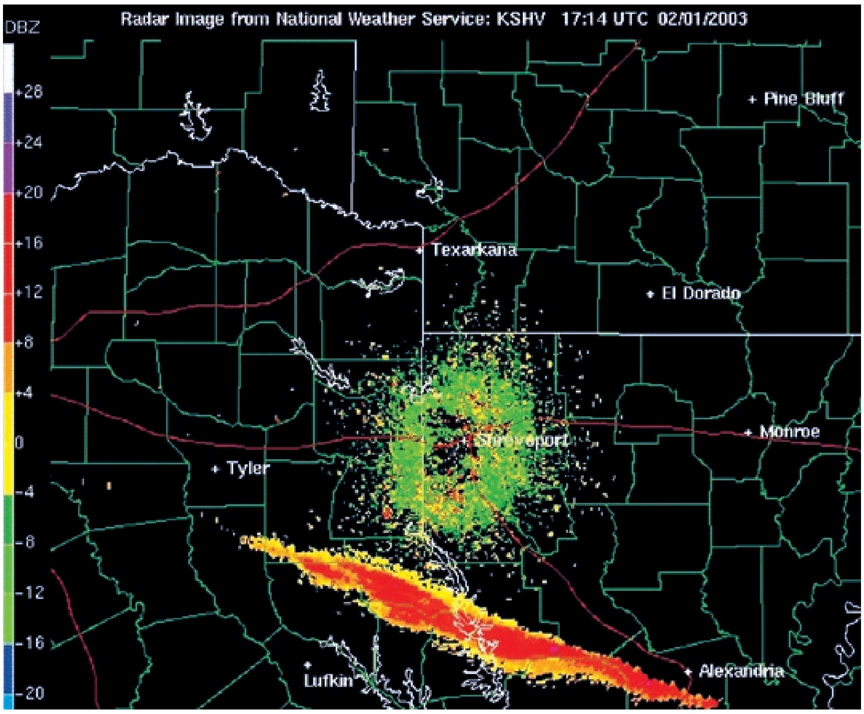
Colin Brace is a writer and editor for ESA's Telecommunications and Integrated Applications Directorate.



Establishing satellite communication and data link standards will bring about a paradigm shift in air traffic connectivity. – Credits: ESA

Space Debris and Meteorite Forecast for Safer Aviation

By Matteo Emanuelli



Columbia debris (in red, orange, and yellow) detected by National Weather Service radar over Texas and Louisiana. The airliners were not aware of falling fragments and risked collisions. – Credits: National Weather Service

As many as nine civil aircraft flew through Columbia's falling debris field

An international group of researchers is developing an unusual forecasting tool – a program that would be able to predict where and when a meteorite or a reentering satellite could hit an aircraft. As fictional as it may sound, the risk of an object from space striking a commercial airliner while hurtling through the atmosphere, though slim, is realistic and capable of producing the most catastrophic consequences.

Being well aware that even the least probable of possibilities can sometimes become a reality (such as aircraft disappearing under mysterious circumstances), a team of experts led by the International Association for the Advancement of Space Safety (IAASS) has launched a project called ADMIRE for Aviation - (Space) Debris and Meteorites Integrated Risk Evaluation. Its goal is to make space debris and meteorite forecasting an integral part of aviation safety procedures, similar to detailed weather information.

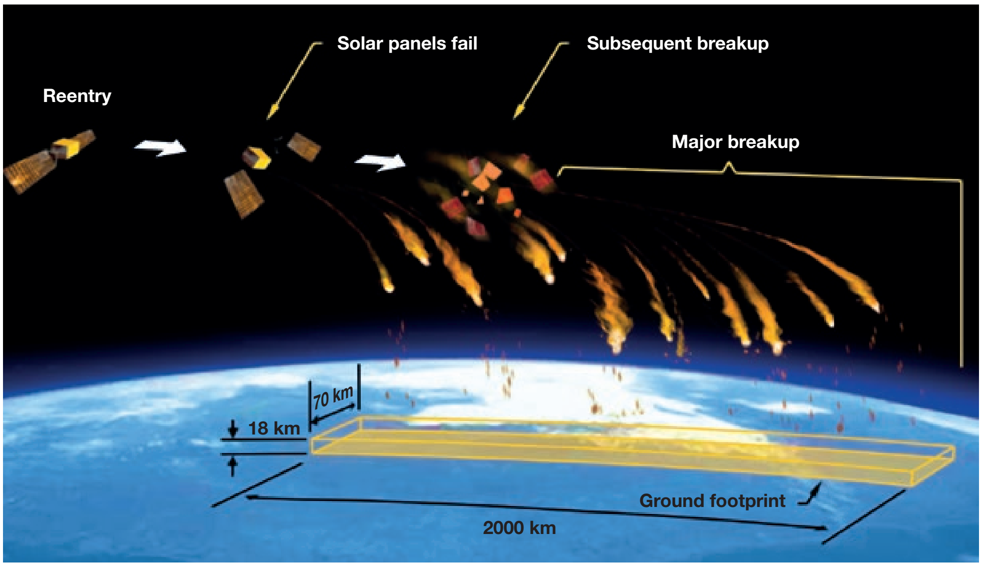
"The Shuttle Columbia's falling debris in 2003 was a serious and real risk for aviation," said Tommaso Sgobba, head of the ADMIRE project and IAASS Executive Director. "That close-call highlighted the need to understand and manage the weekly risk of space reentries."

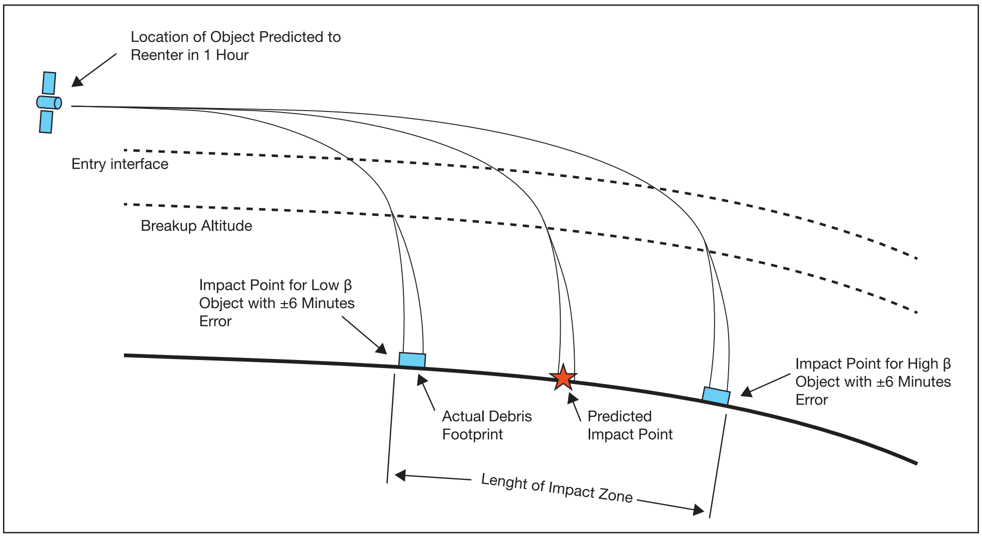
The risk posed by space debris and meteorites to air traffic is generally perceived to be very low, therefore there have been few attempts to properly quantify it. However, there have been moments when major tragedy was avoided by no more than sheer luck. On December 19, 1996, a Chinese passenger plane was forced to make an emergency landing after the exterior glass of the cockpit window was cracked by an unidentified flying object at an altitude of 9,600m. More recently, on March 27, 2007, an Airbus A340 of LAN Airlines spotted wreckage from what was thought to be the Russian Progress 23P cargo ship reentering the atmosphere. The aircraft, flying between Santiago, Chile, and Auckland, New Zealand, was carrying 270 passengers. The pilot estimated the debris was within 8km of the aircraft and reported hearing a sonic boom as it passed. Russian authorities dismissed the space debris hypothesis, instead blaming a meteorite. Either one could have been fatal.

The Shuttle Columbia Disaster and Its Heritage

Talk with anyone in the reentry safety business and it will not be long until the Shuttle Columbia disaster comes up.

A few months after the accident, NASA Administrator Sean O'Keefe testified before the US Senate that "in as much as this was tragic and horrific for the loss of seven very important lives, it is amazing that there were no other collateral-damage efforts as a result of it. No one else was injured."





Above: Dimensions of airspace affected by a spacecraft reentry event.
Below: Possible downrange impact points from observation prior to breakup. Since debris travels at orbital speed (~7.6 km/second), there is an uncertainty in the reentry point of approximately ±2740 km. However, without special tasking, good estimates of final orbits are generally not computed within one hour of reentry even to this precision. – Credits: IAASS

Air traffic collision risk from debris and meteoroids has never been quantified

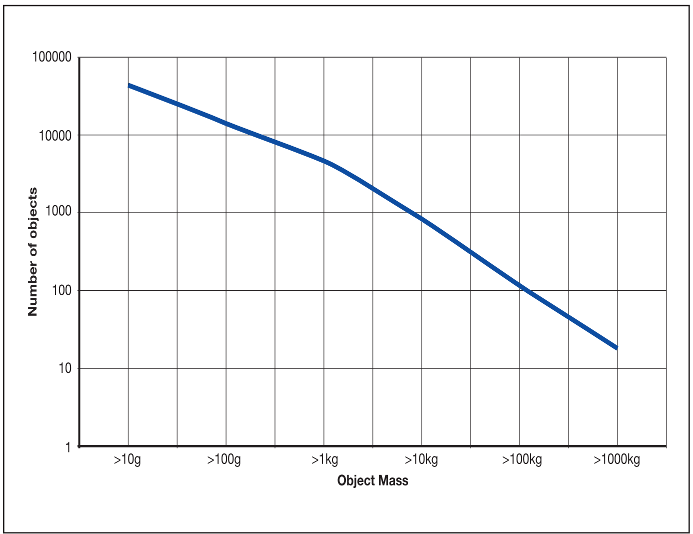
In fact, in the 40 minutes required for the majority of the debris from Columbia to fall to the Earth's surface, as many as nine civil aircraft flew through the falling debris. Although no damage to any of those aircraft was reported, a study conducted by ACTA, Inc. of Torrance, CA showed, using data retrieved from the accident investigation, that the probability of one of these aircraft being struck by a piece of falling debris could have been as high as 1 in 10 to 3 in 1,000. The analysis assumed, per current standards, that any impact anywhere on a commercial transport by debris of mass above 300 grams would produce a catastrophic accident: all people onboard would be killed.

The Shuttle Columbia tragedy began at about 60km of altitude and led to a "progressive breakup" in which primary structural failure was followed by smaller pieces (thermal tiles, fragments of the cargo bay doors, etc.) continuing to shed off of larger pieces (landing gear, turbo pumps, etc.) during the fall. Large pieces were less susceptible to wind and drag, falling down quickly and reaching the ground within three to five minutes. Smaller pieces became instead entrained in the wind as they fell and some of them even developed a small amount of lift. As a result, these pieces took about 40 minutes to reach the ground. Although small and light, some of these pieces were large enough to substantially damage aircraft. Smaller pieces, assumed to be harmless to aircraft, remained airborne for over two hours.

The Columbia accident highlighted the need to select vehicle reentry trajectories that minimize the risk to ground populations and the need to take measures to keep air traffic away from falling debris. Moreover, it started a chain of events that demonstrated the need for a deliberate, integrated, and international approach to public safety during reentry operations, particularly for the management of air traffic and space operations. Prior to this accident, neither the Federal Aviation Administration (FAA) nor NASA took active precautions to protect uninvolved aircraft from the potential hazards of Shuttle debris during a planned reentry.

Meteorites

Space debris are not the only objects entering the atmosphere. About 30x10^6 to 40x10^6 kg of outer space matter is intercepted each year by our planet. Most of this material vaporizes when it goes through the atmosphere. Although the reentering space debris flux is better known than entering meteorite flux, the space debris reentry risk is lower. It has been estimated there are 13,680 atmosphere entries of potential dangerous-for-aviation meteorites while there are "only" 2,267 space debris reentries. "The explosion of stony meteoroids in the upper layers of the atmosphere produces a high number of smaller debris which have high density and velocity," says Bruno Lazare, Safety Advisor at CNES. "The fragmentation of space debris is less energetic and creates generally a lower amount of small objects. Furthermore, artificial objects are less massive and have lower terminal velocity than meteorites."



Annual meteorite flux, which is the frequency of falling meteorites, is estimated as a function of their mass. These values are based on the analysis of meteorites found on accumulation sites and on the analysis of data recorded by observation cameras. – Credits: IAASS

"The impact of the Columbia accident on aviation safety cannot be overstated," says Dr. Paul Wilde, FAA technical advisor, who provided technical support to the Columbia Accident Investigation Board. "In the wake of the accident, multiple US agencies collaborated to develop consensus based aircraft protection standards and models to characterize aircraft vulnerability to launch and reentry debris."

Following the Colombia accident, the FAA established procedures to be used as a real-time tactical tool in the event of a Columbia-like accident to identify how to redirect aircraft around space vehicle debris. The tool developed for the purpose was called Shuttle Hazard Area to Aircraft Calculator (SHAAC). SHAAC used a simplified Shuttle debris catalog to predict the size and location of debris footprint providing information to define the airspace containing the falling fragments.

Although the Shuttle retired from service in 2011, the procedure developed for it can be reused for the increasing number of commercial space transportation systems that will carry out routine suborbital operations, launches to orbit, and orbital reentries in the coming years. Across this range of vehicles, the available reaction time between space vehicle breakup and entry of debris into the US National Air Space (NAS) can range from zero (if the vehicle is in the air traffic environment at the time of the failure) to upwards of 90 minutes (if the vehicle is nearly in space and at orbital speed at the time of failure).

Air traffic operators will require dependable information and procedures to cope with the sudden onset of such an event and with the short lead-time that will be available until debris enters the airspace. To address those operational needs, FAA has been working on a systematic, standardized space vehicle debris threat management process that can be applied to the variety of space vehicles that will eventually operate in the NAS in the US.

A 300g object hitting a commercial aircraft would produce a catastrophic failure

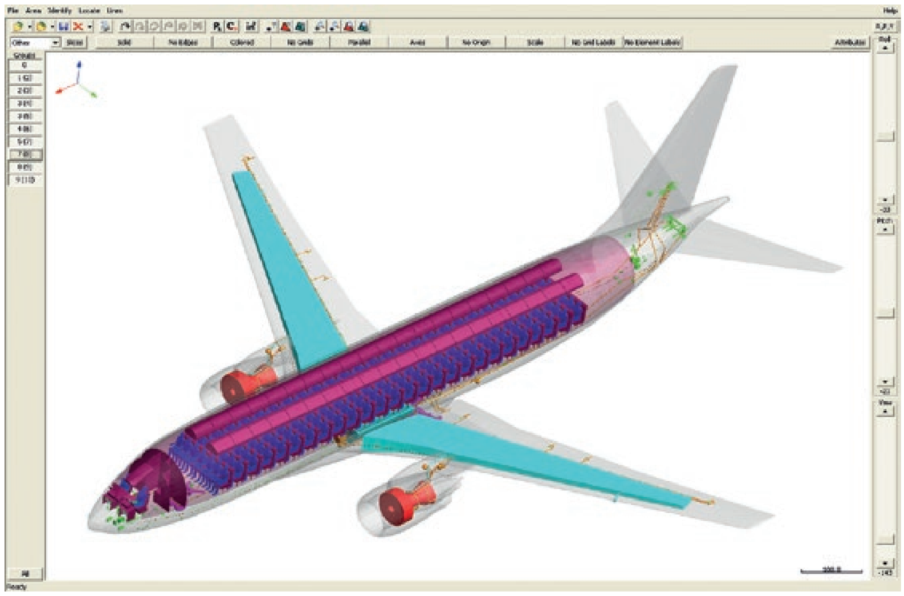
Forecasting Space Debris Reentries

The procedures established after the Space Shuttle Columbia accident to clear the airspace in case of a space vehicle breakup are only feasible for controlled reentries such as those typically performed for crewed missions, or at the end of mission by cargo vehicles that carry spare parts, consumables, and other items to the International Space Station. In such cases, specific maneuvers are planned either to bring the vehicle intact to a preplanned location, at sea or on land, or to direct the debris field, following fragmentation/explosion, away from inhabited areas, such as into the South Pacific Uninhabited Area.

According to The Aerospace Corporation, there are about 100 large man-made space objects that reenter the Earth's atmosphere randomly each year and then fragment and explode during the atmospheric descent. Forecasts of the time and location of such uncontrolled reentries may have errors of several thousand kilometers and are available only minutes before reentry.

In addition to large objects, there are several thousand of smaller space debris, results of on-orbit fragmentations due to explosions or collisions that reenter annually. Very little is known about them in terms of further fragmentation or demise.

Dr. Russell Patera of The Aerospace Corporation analyzed the risk from falling space debris to passengers aboard commercial aircraft using statistical data and information associated with different commercial aircraft. The analysis was carried out only for flights within, from, and to the US in 2006. Patera computed the risk for aircraft from a typical flux of space debris with a realistic distribution of inclinations; according to his estimation, the annual risk of collision for all US aviation traffic due to space debris is 3×10^{-4}.



Computer model of a commercial transport aircraft used to assess debris impact. Courtesy of Paul Wilde, Ph.D., P.E.

A Threat in Need of Assessment

A range of natural and manmade debris populating the space around Earth periodically enters the atmosphere, representing a hidden source of risk for aviation. Due to the relative speed of these objects and aircraft construction, a collision between relatively small fragments and aircraft, although assumed very remote, has an intrinsically high potential for multiple casualties.

Although there are a number of methodologies and tools to assess the risk for the public on the ground due to a reentering space debris event, there is nothing available for assessing the risk to aviation from combined space debris and meteoroids fluxes. The annual risk for passengers due to an airplane being hit by reentering space debris or by a meteoroid has never been precisely quantified. Moreover, there are no methodologies for real-time risk assessment that can be used by air traffic control authorities and civil protection organizations to activate emergency plans for impending reentries.

This is where IAASS, along with ACTA, Stanford University, Astos, HTG, French Space Agency CNES, the Paris Observatory, the Italian National Research Council, and Polytechnic University of Milano, comes in. These organizations partnered to develop an advanced tool that will enable assessment of the risk to aviation due to reentering space debris and meteorites. In short, ADMIRE will enable the evaluation of aviation risk not only on a single-event or annual basis but as an ongoing real-time assessment.

ADMIRE will assess aviation collision risk in real-time

ADMIRE Applications

The ADMIRE project has already aroused the interest of the FAA and of its European counterpart, Eurocontrol. After a year-long definition phase, it is ready to bid for US and EU funding.

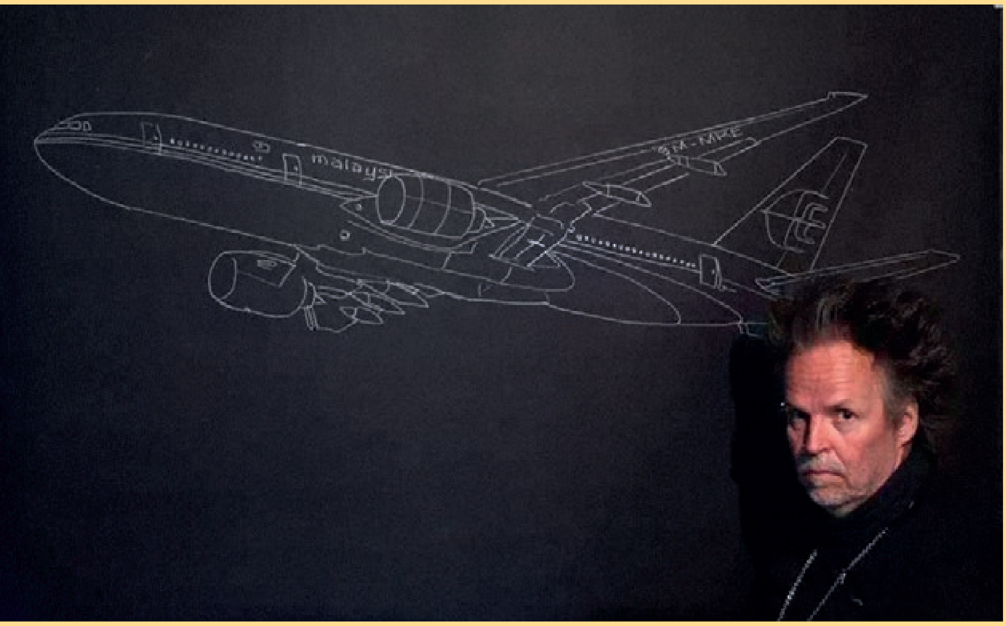
"The conceptual phase of the ADMIRE project is complete and we are ready to proceed with full development," says Sgobba.

Specifically designed to estimate the annual integrated debris and meteorite impact risk to aviation for regions of highest air traffic, such as Europe, East and West US, China, and Japan, ADMIRE intends to provide specific vulnerability models to help aircraft manufacturers mitigate the risk to aircraft in case of impact with a reentering object. Moreover, the determination of the total reentering flux could help insurance companies develop more accurate risk assessments for the aviation and liability of space assets.

According to Sgobba, ADMIRE is also going to assess the compliance of new space systems with reentry safety requirements, taking into account densities and vulnerabilities of ground population and aviation traffic as separate factors.

By integrating space debris reentry predictions with up-to-date aviation traffic density maps, ADMIRE can be expected to become a fundamental tool for civil protection and air traffic control authorities to make quick decisions for accident prevention.

Global air traffic paths. The image clearly shows that Europe, US, East China, and Japan are regions where the air traffic density is heightened. ADMIRE will focus especially on these regions to provide the aviation risk coming from space objects. – Credits: Michael Markieta/Arup



Rauli Mård

Somewhere (front cover) depicts Finnish artist Rauli Mård's imagining of the lost Malaysia Airlines Boeing 777. Mård aptly describes himself as an analog artist in a digital time, combining his fascination with American military jetplane design – "ever since the F-4 Phantom" – and his love of the fine art heritage. Mård's painting process begins with a precise outline followed by a detailed build up, using water-soluble crayons without water, layered in thin, partly transparent layers on black cardboard. He has always liked strong-colored skies and large canvases: "***Somewhere*** is 40x60 inches. I couldn't imagine any smaller size!"

Contact ***rauli@raulimard.com***
or visit ***www.raulimard.com***
to purchase the original.