DART – Distress Assistance with Real-Time Aircraft Telemetry

Hannes S. Griebel, Ph.D., FRAeS, MAPM, London, United Kingdom, ISASI Member MO7216
Daniel C. Smith, Ph.D., Honolulu, Hawai`i, United States

A significant number of aviation incidents and accidents occurred because the flight crews were unaware or misinformed about the status of their aircraft. In many of these cases, the pilots would have likely been able to prevent an accident, or at least been able to significantly improve the outcome, had they been able to derive actionable information from data hidden in the flight data recorders.

Introduction

The increasing availability of satellite data link bandwidth for secure flight deck communications increasingly enables airlines to improve their operational performance significantly. Considering this development, it is justifiable to look at ways this data and information could also be used to open up new avenues of assistance that either help prevent abnormal situations from occurring in the first place, or at least help crews to rectify them promptly. This approach may improve the chances of air crews to prevent situations from deteriorating to the point where a serious incident or accident becomes unavoidable.

1. The operational benefits of real-time flight data and available systems

Let us start by reminding ourselves of the typically available sources of data. First, there are crash-survivable flight data recorder data which are mandated by regulations and manufacturers. A real-time a transmission system could listen to the DFDR echoing what it is recording and send it. Those data are very carefully characterized by sampling rate and latency and formatted by a data acquisition unit.

Second, the DFDR data plus other airline-specified parameters are recorded in a quick access recorder (QAR) system that typically transmits data on the ground and may record on a removeable medium. These QAR data are typically used by Flight Operational Quality Assurance programs to improve operational safety and efficiency.[1]

[1] "FOQA is a voluntary safety program that is designed to make commercial aviation safer by allowing commercial airlines and pilots to share de-identified aggregate information with the FAA so that the FAA can monitor national trends in aircraft operations and target its resources to address operational risk issues (e.g., flight operations, air traffic control (ATC), airports)." (FAA, 2004)

Third, a part of the QAR system will format engine reports that may be transmitted in real time over ACARS, if urgent or required by contract, and if not sent in real-time, marked for transmission on the ground.

Fourth, ECAM/EICAS alert and warning messages transmitted typically by ACARS and presented to the flight crew trigger appropriate actions or precautions.

Fifth, operators are increasingly installing Aircraft Information Devices (AIDs) that may be interfaced to the same concentrated sources as the DFDR and QAR systems and to data communication systems. The AID typically processes data to and from Electronic Flight Bag (EFB) computers. The AID + EFB system is more easily configurable – from both regulatory and technical perspectives – than a QAR system. For example, the AID with real-time communication links, may be commanded from the ground – or manual flight deck trigger -- to send certain data in real-time over IP links – or ACARS. These IP links may be over any available medium such as Inmarsat's SwiftBroadband or Iridium's Certus for assured cockpit communications, or communications links shared with the Inflight Entertainment (IFE) system. Of course, those data are typically encrypted and/or sent over a VPN. Routinely, EFB's may send air data and engine parameters for flight path optimization, including adjustments for weather, by ground-based systems.

The goal of routinely transmitting aircraft data (for example, engine and systems performance) to the ground in real time, and by supplying their crews with information as the flight progresses (for example, updates to weather, traffic and more), is to gain benefits that exceed the costs of data transmission. A growing number of operators are learning how to leverage this technology for long-term economic, operational, and environmental benefits. Therefore, actionable information about flights in progress is becoming increasingly available.

With an IP connection open, the cost of sending a few parameters every minute can be very low. A system on the ground can sound alarms if one of these position/condition reports is not received on time, or one or more parameters exceed their normal operating range. It can also be interfaced with a system receiving alert messages over ACARS and a database of appropriate automated responses.

2. Potential for distress assistance and better outcomes

Distress Assistance with Real-Time Aircraft Telemetry (or DART, in short), is the concept for a programme to systematically enable an aircraft operator to use real time flight data already available, for the purpose of rendering assistance in abnormal situations. The primary way in which this works is by breaking the chain of causation that leads to an undesirable outcome and change it so that it leads to a more desirable outcome.

A common and relatively benign case may be a decision on whether or not to divert, and if so, where best to divert to. A notable such incident took place in 2018 over the Pacific Ocean, where a wide-body airliner diverted due to a recurring error message (reference withheld and case anonymized on request by the operator). In this case, dispatch and aircrew correctly followed procedure and were right to err on the side of caution. The total cost of the incident was estimated by the operator to amount to just over US$ 150,000. A read-out of the QAR and a diagnosis of the aircraft's systems, however, revealed that the error message was a false alarm. With access to certain data – and the ability to ask for selective transmission, including replay, ground personnel might have been able to verify the false alarm.

Similarly, an incident at Frankfurt International Airport caused the grounding of an airliner by over two hours, until a local maintenance crew was able to read out the QAR to confirm that a fault indication was, in fact, itself incorrect (anonymized on request of the flight crew and operator). The carrier had no maintenance personnel stationed at Frankfurt International Airport at the time of the incident, and no cost estimates were released in this case. Nevertheless, the reader may estimate the cost based on typical costs of a delayed departure for narrow-body airliners.[2]

There are other fairly common events where access to data can resolve issues and help plan maintenance work in borderline cases. These include flap extension at possibly excessive speed, degree of turbulence, vertical acceleration on landing (and was there a roll component), minor engine near-exceedances, and even cabin temperature.

A rarer but more dramatic situation would be the correct identification and isolation of faults when the aircraft starts acting and/or reacting unexpectedly to flight control inputs. A notable example is the well-publicised incident of QANTAS flight 32 (ATSB Transport Safety Report, Aviation Occurrence Investigation – AO-2010-089, 2010), where fragments of a ruptured IP turbine disc on an Airbus A380 caused a significant change in the aircraft's performance and flying characteristics, while severing several electrical harnesses inside the wing structure. This caused an abnormally high number of ECAM messages that the crew were only able to deal with because of five flight crew on duty that day, including a check captain and a supervising check captain. The additional crew could help with damage assessment while the captain and first officer focused on controlling an aircraft of which the operating characteristics had significantly changed from those of any normal configuration of this aircraft type.

In the most extreme circumstances, pilots have lost control in flight of an aircraft otherwise in good working order, both mechanically and electrically. In many such cases, no adverse circumstances affected the aircraft other than the incorrect situational awareness of the pilot flying, often triggered by a minor malfunction that would normally have been rectified easily. In such circumstances, it may be an off-duty on-call (OD-OC) crew responding to an unusual attitude alert, advising the crew flying the aircraft of the additional information available to them. In the notable case of China Airlines 006 (NTSB / AAR 86 / 03, 1986), the asymmetric thrust from a rolled-back no. 4 engine of the Boeing 747 operating the flight caused

[2] The trade group Airlines for America estimated $74.24 per minute in 2020. (Airlines for America, 2020)

an aircraft attitude upset that went unnoticed, and led to a rapid and uncontrolled descent during which g-forces exceeding 5g severely injured 2 passengers and caused significant mechanical damage to the airframe. Only after breaking through the cloud cover at around 11 000 feet was the captain able to orient himself and recover the flight. Although the captain noticed the increasing bank and pitch angles on the attitude indicator, he wrongly concluded that the indicators had failed. In this scenario, the no. 4 engine's deterioration preceding its flame-out, the lack of rudder input in response to an increasing turn and pitch rate immediately after flame-out, the discrepancy between the autopilot's roll inputs and the aircraft's roll- and turn rates, the subsequent exceedance of bank and pitch angles and the large variations in g-forces would have all been detectable by an automated flight data monitoring system, allowing an OD-OC crew to provide additional input to the flight crew that would have helped them rectify the situation at several stages before its nearly catastrophic deterioration.

While China Airlines 006 eventually landed safely, Air France 447 did not (Dossier BEA f-cp090601, 2012). In this well-publicised case, it was an unreliable airspeed that caused the crew of an airliner otherwise in good working order to make flight control inputs that led to the demise of the flight. While Air France 447 is similar to China Airlines 006 in that the lack of visual cues compounded the problem, it is notably different in so far as some telemetry was available through ACARS, except that no one picked it up until after the fact. Even then, the limited amount of data transmitted during the final minutes of the flight offered little clues as to what transpired that night. This highlights the necessity for a fully trained crew to remain available and alert to current events, and an assured and secured big data analysis system that can reliably alert the crew to potential departures from expected parameters, querying the aircraft for additional data sets and displaying them to the assistance crew in an actionable manner.

Atlas Air Flight 3591 is a recent and well publicised example that illustrates the limits of human intervention. Due to its proximity to its destination, Atlas Air Flight 3591 was so close to the ground that the flight deteriorated so rapidly (32 seconds) that an automated action would have been necessary to overcome the underlying training and situational awareness issues.

Lastly, DART offers the possibility to identify and discourage dangerous flying habits. In the recent case of the 2017 Learjet accident at Teterboro Airport (NTSB / AAR 19 / 02, 2019), the probable cause was determined to be the Pilot in Command's (PIC)'s "attempt to salvage an unstabilized visual approach, which resulted in an aerodynamic stall at low altitude." Contributing to the accident was "[…] the PIC's decision to allow an unapproved [second in command] to act as [pilot flying], the PIC's inadequate and incomplete pre-flight planning, and the flight crew's lack of an approach briefing. Also contributing to the accident were [the operator's] lack of safety programs that would have enabled the company to identify and correct patterns of poor performance and procedural noncompliance." (NTSB / AAR 19 / 02, 2019). A DART programme not only offers assistance when in distress, but also flags recurring departures from standard procedures, discouraging unsafe practices and allowing to identify training needs.

Certainly, in the cases of significant master caution alarms or warnings, it is appropriate to switch from low volume updates to streaming the whole, live FDR frames along with selected data beyond that. There are plenty of software systems that take FDR data and can reconstruct the appearance of the cockpit instruments in flight ops centres for pilots who may be on standby duty – and dispatcher.

As these examples illustrate, DART offers four avenues of breaking the chain of causation to improve the outcome of abnormal situations:

1. Provision of actionable information not otherwise accessible to air crews or dispatchers / maintenance.
2. Workload reduction when a breakdown in automation or change in flight characteristics as a result of the malfunction increases the workload of the pilot flying the aircraft. With real-time data, ground staff can ask fewer but better questions by voice calls.
3. Unbiased appraisal of the situation and related crew advise when the mental picture of the crew flying the aircraft begins to deviate from reality, or when a routine alert is followed by a non-standard response.
4. Long-term monitoring of flight data to discourage reckless behaviour and identify training needs.

Following ICAO's Global Aeronautic Distress and Safety System (GADSS) initiative in the aftermath of Flight MH370's disappearance and related regulation coming into force this decade, some airlines may in the future be required to install ejectable flight data recorders. But we believe the DART concept can have operational benefits that pay for themselves and even make ejectable flight data recorders unnecessary. (With DART you will know where your airplane went down.) We emphasize the larger point that DART can be an economical complement to ejectable flight data recorders because of operational benefits.

Recognizing the economic and safety potential of real-time flight data transmissions, EASA has commissioned a Quick Recovery of Flight Recorder Data study (Tender EASA.2020.HVP.06, 2021).

3. Analysis of requirements and prerequisites

Providing assistance based on real-time telemetry is not a new concept. Both in motorsports and space flight operations, real-time telemetry is often the only means by which assistance can be provided. A Formula 1 car is so small it can only carry the driver and no one else. Similarly, spaceships and space stations are often too small to carry anyone in addition to

the mission critical astronauts. Unmanned spacecraft, such as satellites and interplanetary probes, have no one on board to begin with, and must be operated entirely remotely.
To understand what is necessary to use real-time aircraft telemetry to improve the chances of a successful outcome (be it minimizing the cost of the outcome or maximizing survivability), we can therefore turn to experience gained in space mission operations and Formula 1 racing, and compare the key lessons learned to reports of selected, past aviation incidents and accidents where the provision of additional information, or the lack thereof, had a significant impact on the outcome of the situation (see above).

Taking this experience into account, we can learn the following lessons:
1. Distress assistance is not a root cause analysis,
2. Good training and well-established operating procedures are a key success factor, and
3. Integration with crew resource management is a key success factor.
4. Efficient and effective data processing and display is a key success factor.

Lesson 1: Distress assistance is not a root cause analysis.

While a party assisting a flight crew in an abnormal situation may well identify the root cause of an issue, whether or not they conclusively do is less important than gaining the consequential knowledge required to resolve the situation satisfactorily. The classic example of this prioritization is the recovery of an upset spacecraft attitude: with the main parabolic dish no longer pointing towards Earth, communication can be established by way of omnidirectional antennas aboard the spacecraft. While the data rate through these means of communication is low, sufficient telemetry and telecommanding can be communicated to restore accurate pointing towards Earth, and to avoid any attitude that may overheat the spacecraft by exposing the wrong panels to sunlight for too long. The root cause analysis can follow once the vehicle attitude is recovered. Similarly, the pilots aboard QANTAS Flight 32 had no knowledge of the burst stub oil pipe that caused the chain of events leading to the turbine disc failure, much less the manufacturing flaw causing it to fail in the first place (ATSB Transport Safety Report, Aviation Occurrence Investigation – AO-2010-089, 2010). Nor would that knowledge have been of much consequence to them. The consequential knowledge they needed to obtain was which of the ECAM error messages had to be taken seriously, which ones to leave for later, how the aircraft could be safely flown and which the best available runway was at the time of the incident. With a flow of data, flight ops and maintenance personnel on the ground could assess the data and talk with the crew or be on a party line with air traffic control even in the more likely event of just two pilots aboard the aircraft.

Lesson 2: Good training and well-established operating procedures.

This lesson should hardly come as a surprise to anyone. A DART programme is no different than any other operations programme or set of procedures in that it works best when its various elements are well rehearsed on a regular basis. To that end, space operations crews frequently train with spacecraft simulators (digital representations of the spacecraft in question) to practice emergency recovery procedures, fault isolation skills and crew cooperation. Similarly, dispatchers, maintenance crews and off-duty on-call flight crews can rehearse typical scenarios for quicker reaction times, and to establish a particular kind of operational culture that is accustomed to working in such an environment.

Lesson 3: Integration with crew resource management.

What QANTAS Flight 32 also demonstrated is that the five crew members in the cockpit that day were able to distribute the workload quickly, efficiently, and effectively between each other. DART is no different in this respect. On the contrary: the fact that the assisting party is not aboard the incident aircraft, but instead located in a facility many thousands of miles away, requires even greater discipline in Crew Resource Management (CRM). Current satellite voice communication services offer a telephony service at best, and future services may offer sufficient bandwidth for full-duplex video conferencing probably using entertainment / passenger connectivity bandwidth. But they will, inevitably, be connected through an electronic device that will suffer from the same limitations as any other such means of communications. Including microphone issues, bandwidth issues, general understandability issues and a certain risk of misunderstandings. This is nothing new in spacecraft operations. Even in the operations of interplanetary probes, a contributing party may be located in another control centre, at one of the Earth receiving stations or simply in an adjacent building.

Lesson 4: Efficient and effective data processing and display

Experience with space flight control centre development, but also battle space management for maritime and aerial defence, shows how critically important ergonomic design, efficient and effective data processing and their ergonomic display are. Even the best trained crew can only be as good as the consequential knowledge they can efficiently and effectively learn from the actionable information displayed to them, and the reliability and integrity of the underlying data sources. For example, the fatal accident of Alaska Air Flight 261 was attributed to a worn-out ACME nut that formed part of the horizontal trimming actuator and failed in flight (NTSB / AAR 02 / 01, 2002). The nut threads failed because insufficient lubrication caused excessive thread wear. This excessive wear put additional strain on the actuation motors, which in turn would have shown an excessive current draw on the power bus on every actuation of the electrical trimming system. Without prior knowledge of the accident sequence, this may be difficult to identify amongst the many thousands of parameters available. However, a big data analysis code may have been able to flag the correlation of trimming system actuation and above average current draw to engineers, who would then have had cause to inspect the system with the aim to identify the root cause of the additional force required to operate the system. During the accident flight, the increasing friction caused the actuation motors to get stuck initially, leading to a spike in the bus current draw. This information would have in turn allowed an engineer to advise the flight crew not to operate the trimming system, and to fly to a convenient airport for a straight in, high speed landing that requires minimal configuration changes impacting the aircraft's horizontal trim. Whether or not engineers might have come to the correct conclusion remains, of course, speculation. But at the time, the information was not available to anyone until after the accident, and so DART would have opened up a credible opportunity to safe the flight. For this opportunity to exist, however, it is important that the collected data is reliable, secure, available at an instant and processed quickly and efficiently. OD-OC crews and maintenance engineers must then be able to identify the malfunction quickly, for which ergonomic and well laid-out telemetry displays are of critical importance.

In terms of technical and economic requirements, we note that the required data volume is small by comparison with common IP applications, but may nevertheless generate significant cost when using exclusively safety-approved radio spectrum. The data stored in a standard, 1024-word DFDR can be streamed at all times inside of a 9.6kbps data link and could easily be streamed using safety-approved services in the L-band spectrum, such as, for example, Inmarsat's SwiftBroadband Safety or Iridium's CERTUS. The advantages of these services are the relatively small antenna footprint, resiliency against all kinds of weather, physical separation from other, non-safety related users and global coverage. Their downside, however, are their comparatively high price per megabyte of data.

Ka- and Ku-band satellite communication services, along with ground-based infrastructures such as the European Aviation Network, offer much lower data transmission costs, but share bandwidth with entertainment users, are susceptible to moisture attenuation in the atmosphere and rarely offer true global coverage.

With an IP connection open, the cost of sending a few parameters every minute can be very low – 10 bytes every second is only 36 KB/hr. A system on the ground can sound alarms if one of these position/condition reports is not receive on time. It can also be interfaced with a system receiving ECAM messages over ACARS and a database of appropriate automated responses.

ECAM warnings, including some not presented to flight crews in flight, can be triggers for later artificial intelligence / machine learning exercises. Think of them as ideas or faults to be investigated later. If so configured, the contents of a buffer of recent data could be expedited to the ground as would be needed in an emergency. In the case of emergency, it could be very important to have some data from before the start of the event.

Approximate data transmission costs for L-Band can be estimated from publicly advertised sources such as Satellite Phone Store. (Satellite Phone Store, 2021). Pricing is highly dependent on the monthly volume. ROM cost is on the order $1/MB. For IFE Ka-Band connections, industry sources say they strive for about $0.01/MB. With careful DART configuration, admittedly to be refined by testing, the added communication cost would be low even at L-Band but worth every dollar for an abnormal flight.

A key-technology to allow widespread use of real-time aircraft telemetry is therefore an onboard data processing system that can provide the most cost efficient and assured data routing, depending on the circumstances. Currently available real-time data transmission systems come integrated into the AID, part of the Electronic Flight Bag (EFB), integrated into the flight recorder, integrated into the satellite terminal or come stand-alone. To be economically viable, future systems supporting a DART programme should also dynamically query the aircraft's systems for relevant data depending on its current status, and dynamically route that data through assured and secured VPN channels across the best available network. In an emergency distress situation, the system may even route data through all available channels. Lastly, the system may prioritize certain types of data in accordance with current ICAO guidance (ICAO DOC 10054, 2019) and AEEC guidance (AEEC 681, 2021) for the timely recovery of flight data.

4. Establishment of a DART Programme

How a DART programme can best be setup so that it becomes economically advantageous depends on the circumstances of the operator. A commercial airline with a large fleet and their own maintenance section may wish to establish their own, in-house DART programme. Smaller commercial carriers with fewer resources may either rely on data analysis programmes offered by major aircraft manufacturers, or subcontract a third-party subscription service, of which a number have become available over the recent years.

Most of the basic elements of a DART programme already exist. A large carrier based in Asia (name withheld on request by the operator) already established a real-time telemetry programme in 2017, including a database and data analysis software developed in-house, with some aircraft transmitting data through modified AIDs. Similarly, a large European carrier ran trials of a comparable nature, transmitting flight data through an in-house developed EFB app that could be activated at the captain's discretion (name withheld on request by the operator). In the case of the European carrier, it is noteworthy that an agreement with the pilot's union had to be reached before the system could go live.

While major airframe manufacturers already have real-time and non-real-time telemetry analysis programmes in place, many smaller carriers, and operators of an older fleet, or operators of a small number of corporate business jets, have opted to go with third-party aftermarket suppliers which, aside from offering the required hardware, also offer service-level agreements for flight data storage, analysis and distress alerting functions. To remain commercially neutral, we chose not to name any such products by name in this paper.

As for training, simulation, crew resource management and flight data displays facilitating quick decision making, the author's company, CGI UK Ltd., has created, built and operated many highly successful and state-of-the-art solutions for space operations centres and defence related applications of a similar nature. The author has operated interplanetary spacecraft, and used simulators and training facilities, provided by CGI for this very purpose. While the defence related capabilities are classified, the basic principles are nevertheless the same: secure and assured data communication, processing, storage and dissemination systems that enable operators to obtain consequential knowledge in a quick, efficient and effective manner, thereby enabling a timely reaction to events as they unfold. DART is no different in this regard. To remain commercially neutral, we again refrain from mentioning specific product names and reference projects. We believe the demonstrable capability as evidenced by the routine application of these services across several sectors, especially space operations, provide sufficient evidence to prove the wider point that a DART programme can be established relying exclusively on proven and well-tested technology. The only new aspect is the combination of these elements with the intent of not only improving the economic performance of an aircraft operator, but also opening new avenues of intervention when consequential knowledge about an aircraft's status or performance may not otherwise be accessible in time to improve the outcome of a particular set of circumstances.

5. Conclusion

The analysis shows that data which can benefit an operator economically, can also be used to both help flight crews avoid abnormal or distress situations altogether, and to assist them in the event that an abnormal or distress situation cannot be prevented. Enabling technologies and processes already exist. However, the analysis also shows that such assistance can only be rendered effectively if it is integrated with crew resource management and associated training, and if the DART programme includes systematic big data analysis based on secure and assured data sources, ground support operations training and integration with existing FOQA and safety management systems. In essence, many of the same steps that are required to reap the economic and operational benefits of real-time aircraft data.

While the establishment of a DART programme requires expenses on top of and beyond the provision of data used to improve economic efficiency, preventing a single event can make it all worth it.

It is therefore not hard to imagine a future in which having a DART programme, much like FOQA today, is part of best industry practices and not having one may be seen as reckless.

We are very excited about EASA's project regarding flight data recovery (Tender EASA.2020.HVP.06, 2021), and look forward to the results of this study.

References

AEEC 681. (2021). *Timely Recovery of Flight Data (TRFD).* ARINC Industry Activities.

Airlines for America. (2020). *US passenger carrier delay costs*. Retrieved from https://www.airlines.org/dataset/u-s-passenger-carrier-delay-costs/

ATSB Transport Safety Report, Aviation Occurrence Investigation – AO-2010-089. (2010). *In-flight uncontained engine failure overhead Batam Island, Indonesia 4 November 2010 VH-OQA Airbus A380-842.* Canberra: Australian Transport Safety Bureau.

Dossier BEA f-cp090601. (2012). *Rapport final, Accident survenu le 1er juin 2009 à l'Airbus A330-203 immatriculé F-GZCP exploité par Air France vol AF 447 Rio de Janeiro - Paris.* Paris: Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile.

FAA. (2004). Advisory Circular 120-82. *Flight Operational Quality Assurance*.

ICAO DOC 10054. (2019). *Manual on Location of Aircraft in Distress and Flight Recorder Data Recovery.* Montreal: International Civil Aviation Organisation.

NTSB / AAR 02 / 01. (2002). *Aircraft Accident Report Loss of Control and Impact with Pacific Ocean Alaska Airlines Flight 261 McDonnell Douglas MD-83, N963AS About 2.7 Miles North of Anacapa Island, California January 31, 2000.* Washington D.C.: National Transportation Safety Board.

NTSB / AAR 19 / 02. (2019). *Aircraft Accident Report, Departure From Controlled Flight Trans-Pacific Air Charter, LLC Learjet 35A, N452DA, Teterboro, New Jersey, May 15, 2017.* Washington D.C.: National Transportation Safety Board.

NTSB / AAR 86 / 03. (1986). *Aircraft Accident Report China Airlines Boeing 747-SP, N4522V 300 Nautical Miles Northwest of San Francisco, California.* Washington D.C.: National Transportation Safety Board.

Satellite Phone Store. (2021, July 6). *Inmarsat BGAN Data Plans*. Retrieved from satellitephonestore.com: https://satellitephonestore.com/bgan-service

Tender EASA.2020.HVP.06. (2021). *Quick Recovery of Flight Recorder Data*. Retrieved from EASA: https://www.easa.europa.eu/research-projects/quick-recovery-flight-recorder-data