# ORA, model & tool for Operational Reliability Prediction within Airbus
# ORA, l'outil Airbus de prédiction de la Fiabilité Opérationnelle


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## Résumé

Dans un marché de plus en plus compétitif pour les compagnies aériennes et les avionneurs, Airbus pour vendre ses produits doit assurer un avantage compétitif à la compagnie aérienne, client potentiel. Cet avantage inclut de bonnes performances de supportabilité et en particulier de fiabilité opérationnelle pour l'avion, la fiabilité opérationnelle caractérisant la ponctualité des opérations que doit assurer l'avion par rapport aux éventuels problèmes techniques. Depuis 2001, Airbus intègre dans sa démarche d'ingénierie concourante le métier de la supportabilité. Les spécialistes de supportabilité, en particulier au travers de l'expression / vérification d'exigences de fiabilité opérationnelle ont pour mission de tirer la conception vers le respect de ces exigences, synonyme de satisfaction client. Pour mener à bien cette activité, les spécialistes de supportabilité ont besoin d'un outil de prédiction de fréquence ou taux d'interruptions opérationnelles dues à un équipement ou groupe d'équipements. Cette fréquence est un événement dont la probabilité est comprise entre $10^{-7}$ et $10^{-4}$. L'outil de prédiction appelé ORA (Operational Reliability Analyser) utilise des techniques de sûreté de fonctionnement (théorie de la fiabilité, Analyse par arbres de défaillances) et intègre les principaux paramètres d'influence que peuvent estimer les spécialistes devant réaliser les analyses. Développé en 2003, ORA a été déployé dans le cadre du programme A400-M auprès de tous les spécialistes Airbus (20 utilisateurs européens) pour créer et mettre à jour tous les deux mois plus d'un millier d'analyses couvrant l'avion complet. De futurs développements devraient permettre d'assouplir certaines hypothèses de calcul afin d'élargir le périmètre des analyses menées et d'améliorer leur précision.

## Summary

In an even more competitive market for airlines and aircraft manufacturers, Airbus has to ensure to the potential customer airline a competitive advantage in order to sell its Airbus aircrafts. This benefit includes better supportability performances and in particular better operational reliability, which characterises the punctuality of aircraft operations facing failures. Since 2001, Airbus integrates supportability in its concurrent engineering process. In particular, Supportability Engineers have to drive the design towards the achievement of pre-defined quantitative operational reliability targets. To do so, Supportability Engineers need a tool to predict the operational interruption rate due to a specific equipment or set of equipment. This Operational Interruption rate to be estimated is a stochastic event whose probability is between $10^{-7}$ and $10^{-4}$. This tool called ORA (Operational Reliability Analyser) is using some RAMS technologies such as theory of reliability and Fault Tree Analysis. It integrates the main Operational Reliability influencing parameters that can be estimated by the specialists in charge of the analysis. ORA tool has been developed in 2003. For A400M needs, it has been deployed with corresponding support since 2004 to almost 20 Airbus supportability engineers across Europe. It has then enabled to perform and update on a two-monthly basis around 1000 analyses to cover the whole aircraft. Future developments should enable to go beyond current calculation assumptions and enlarge the scope and accuracy of the performed analyses.


## Context

### Design Supportability Engineering within Airbus

In an even more competitive market for airlines and aircraft manufacturers, Airbus has to ensure and commit itself (signed guarantees) towards a competitive advantage to its costumers for selling them its aircrafts. Competitive economical and operational performances include Direct Maintenance Costs but also Operational Reliability (Availability and Punctuality of the aircraft from a technical or reliability / maintainability point of view).
Supportability describes the ability of a system to meet and sustain operational needs-in service, which implies good reliability and maintainability, low operating costs and above all, an Airbus product designed with the operational environment in mind.
Since 2001, Airbus is integrating the supportability skill (maintainability, maintenance costs, operational reliability) and dedicated teams within its Concurrent Engineering philosophy and associated organisation (Integrated Design Teams).
In this context, the objective of Design Supportability Engineering is to drive the design in a way it keeps consistent with accepted and validated supportability requirements that have been identified and expressed at early stage of the design process in agreement with costumers. These requirements are defined by balancing the cost of developing and operating modern systems to meet customers' expectations in terms of support and operations. These expectations consist in:

- a maximal availability of aircraft within a fleet ensuring that each time the aircraft is used, it remains operationally reliable and completes its flight without interruption,
- a minimal operating cost including maintenance and support costs.

Requirements expressed as quantitative targets are mainly set by taking into account jointly in-service experience (to be realistic) and marketing analyses (competitive advantage for a relevant and meaningful performance).
Design Supportability Engineering specialists have also to verify on a regular basis (e.g. : two-monthly) these requirements (achievement of quantitative targets) all along the design process and report the current "supportability" status to the programme management. They also suggest solutions or ways of improvement if necessary to the design teams and report remaining issues to the programme management for further negotiation, decision, action, ….

### Consideration of Operational Reliability during the Design Phase

From a general point of view, Operational Reliability is the supportability discipline dealing with the impact of reliability / maintainability on aircraft operations in terms of punctuality and availability. From an Airbus & Airlines point of view, Operational Reliability is more precisely the frequency of technical events (failures and associated required maintenance tasks) leading to flight delays or cancellations, air diversions or In-Flight Turn-Backs.
Operational Reliability is one of the main operational performances controlled by the airline during the aircraft in-service life. At first, Operational Interruptions (delays, cancellations, In-Flight Turn-Backs, Diversions) induce for the airline high direct costs related to aircraft (fuel burnt, …), airport (taxes, …), flight crew (accommodations, extra time, …) and passengers (accommodations, financial compensations, …). Operational Interruptions can also induce high indirect costs (loss of image, impact on customers behaviour to choose an operator for next flights, …). But operational interruptions are above all very precisely monitored by the airline because this performance is very strongly correlated with the quality of the internal operational organisation (operations, maintenance, engineering) within the airline.
The Design Supportability Requirements for Operational Reliability are expressed by a quantified target at Aircraft level (e.g.: 99% for A380) corresponding to the mean percentage of departures

without any operational interruption for technical reason. This target at aircraft level is then broken down to system level in order to be manageable by supportability engineers. The iterative verification process of these targets all along the design phase will be performed by a bottom-up approach, from equipment to aircraft level through system level. This bottom-up process (consolidation of predicted results from equipment to aircraft level) is supported by a common Airbus Design Supportability Engineering Information System called LIR (Logistic Information Referential). LIR is implemented within Windchill™ Technology for effective product data management facilities.

**Prediction of Operational Interruption rate at equipment level**

The core verification & driving design process towards design supportability requirements is based on the prediction of the operational interruption rate due to a specific equipment or set of functionally inter-linked equipment. To perform this initial and basic prediction mainly at equipment level, the supportability specialist needs a relevant Operational Reliability model implemented in a dedicated software.
This model has to integrate in a relevant way all the influencing parameters of Operational Reliability performance. These parameters are related to the design, the maintenance and the operational profile at aircraft, system or equipment level. In further details, identified influencing parameters are:

- Equipment failure distribution with related parameters (intrinsic reliability with failure modes),
- Alarm policy (hidden or evident failures, time for failure detection),
- System architecture and fault tolerance (redundancies, maximal tolerated period in degraded mode),
- Fault Isolation or trouble-shooting process (mean time required for trouble-shooting, No Fault Fault rate or percentage of wrong fault diagnosis),
- Equipment repairing distribution with related parameters (mean time to access, mean time to remove / install, mean time to test, mean time to check, …),
- Human Error in maintenance (percentage of wrong repairing, influence of human performance on the time to repair),
- Operational profile (content of successive flights with corresponding time of flight and stop-over, failure criticality, equipment use during operational phases, time available for maintenance actions during stop-over, availability of maintenance facilities, spare and skill during stop-over),
- Maintenance strategy (repairing at first opportunity, differ repairing as much as possible, repair as soon as possible, acceptance of degradation mode for take-off by maintenance staff & flight crew),
- Scheduled maintenance (checked equipment with corresponding time interval).

All of these influencing parameters are estimated on average by the design supportability engineers by taking into account all relevant information:

- in-service data on existing aircrafts,
- knowledge of the current design and all other involved skills (e.g.: safety specialists, system designers, …) information,
- general assumptions validated by programme management and costumers (airlines partners), or provided by engineering judgement (traced assumptions),
- knowledge of future operations (aircraft mission attributes, types of major airlines customers, airports of departure / arrival, …).

It is a great challenge to define and implement a model for Operational Reliability estimation at equipment level which is as realistic as possible (confidence and accuracy of estimation) and integrates all relevant influencing parameters, but that can be predicted by the supportability specialists from the early stage of design phase.

## RAMS modelling and method to predict Operational Reliability

**RAMS Modelling (Reliability Block Diagram, Fault Tree Analysis, Markov Process, Petri Net)**

As the system architecture (redundancy, criticity of equipment failures from an operational or safety point of view) is one of the main influencing factors for Operational Reliability prediction at equipment level, it is necessary to integrate a formalism to model this architecture.
Different modelling solutions coming from RAMS disciplines can be envisaged [1, 2].
Reliability Block Diagram to model system function or Fault Tree Analysis to model system failure enables such modelling facilities. These modelling formalisms are supported by a lot of RAMS commercial tools with advantages and drawbacks [3, 4, 5, 6, 7, 8, …]. Each of these modelling formalisms is well known and quite intuitive to be used by Design Supportability Engineers.
Markov Process [3, 4, …] provides also a good formalism to model the dynamic failure / repairing process of a system composed of different equipment by modelling the transitions between these system degradation states. Unfortunately, the architectures and then combinations of failure to be taken into account for Operational Interruption Rate prediction even at equipment level are too complex to be modelled by Markov Process. These analyses indeed imply a large number of equipment ($n \leq 50$) inducing to consider $2^{50} > 10^{15}$ possible states at system level (number of states to be considered in the Markov process) with an unmanageable number of associated transition rates. Markov process provides a quite intuitive modelling formalism, but it does not provide a possible general solution for Operational Reliability prediction because of its combinatorial complexity (State Explosion).
Petri Nets and even more coloured Petri Nets formalism [5, …] provides a relevant way to model states transition which can be applied for failure / repairing dynamic process. Unfortunately, this technology, which is not dedicated to RAMS, does not provide any formalism to describe a system architecture. The criticality of combinations of failures have then to be described by non-intuitive Boolean expressions, which is not acceptable from a user point of view.

**RAMS Calculation Method (Theory of Reliability, Markov Process, Simulation)**

The prediction of Operational Interruption rate requires the modeling and analysis of dynamic failure / repair process at equipment and set of equipment level, as all the equipment involved in the same analysis are linked by tolerated and non-tolerated combinations of failures.

Markov Process [2] seems obviously the best technology candidate to solve this kind of problem from an analytical point of view. Unfortunately, as we have already seen (modelling aspect), it is not feasible to use this technology for Operational Reliability estimation because of combinatorial complexity or state explosion. Markov process technology has nevertheless been investigated with success within Airbus [9] for Operational reliability prediction on simple system architecture (simple redundancies). These first investigations have been done by implementing a dedicated Airbus Operational Reliability Model and using SUPERCAB tool for modelling and analysis of multi-phases markovian process [4]. Multi-phase Markovian processes are required to support the distinction between in-flight and on-ground phases.

Monte-Carlo simulation [5, 7, 8, …] is another technology for dynamic process implementation and analysis. In particular, some R&D activities have been performed within coloured Petri Nets technology by using MISS RdP tool for modeling and analysis [5]. Unfortunately, the use of simulation methods in general and Petri Nets in particular do not provide a satisfying solution to the initial problem (prediction of the operational interruption rate due to a specific set of equipment).
At first, simulation methods provide only confidence intervals as result and it is still very complex to get the minimal number of simulations to be performed to control at the end the accuracy of the final result which is the random variable mean value.
In addition, as the operational interruption rate due to a specific set of equipment (what we intend to predict) is a probability between $10^{-7}$ and $10^{-4}$ per take-off, the number of required

simulations to get sufficient result's accuracy leads to an unacceptable calculation time duration when applied to complex architectures.

From a first analysis of user (Design Supportability Engineers) and business (Prediction of Operational Reliability performance at equipment level) needs, it has been stated that, for the modeling aspect, Fault Tree Analysis was the most intuitive and comprehensive formalism that could cover all needs in terms of architecture modeling. Unfortunately, Fault Tree Analysis (as Reliability Block Diagram) does not enable by default to take into account dynamic equipment failure / repair process with inter-dependencies. It just provides at a time t, the probability of any event of the Fault Tree, knowing the probability of the elementary events.

## ORA (Operational Reliability Analyser) within Airbus

### General description

Before Airbus integration (2001), each of Airbus partners got its own internal tool for Operational Interruption rate calculation. These tools were using different technologies and modelling assumptions (Markov Process, Reliability Block Diagram, Monte-Carlo simulation, …).
After Airbus integration, it has been decided to develop a common tool for Operational Reliability assessment to be considered as the unique Airbus standard in the field. Common specifications in terms of modelling and calculation assumptions have then been defined to enable afterwards a subcontracted tool development.

### ORA Modelling

As a first step, the most relevant Operational Reliability influencing parameters from all initially identified have been retained for integration into the ORA model. It means:

- Equipment failure distribution with related parameters (exponential distribution with MTBUR),
- Alarm policy (hidden vs evident failures, Percentage of in-flight / on-ground failures),
- System architecture and fault tolerance (redundancies, maximal tolerated period in degraded mode),
- Fault Isolation or trouble-shooting process (mean time required for trouble-shooting, MTBUR),
- Equipment repairing distribution with related parameters (mean time to access, mean time to remove / install, mean time to test, …),
- Human Error in maintenance (normal distribution for human performance on the time to repair),
- Operational profile (mean flight and stop-over duration, number of flights in the mission, criticality of the equipment, equipment use during operational phases, time available for maintenance actions during stop-over),
- Maintenance strategy (differ repairing as much as possible and then assumer repairing without any operational impact, acceptance of degradation mode for take-off by maintenance staff & flight crew).

Some general realistic assumptions are assumed for Operational Reliability calculation in ORA tool:

- All equipment are operative at the beginning of the mission.
- The probability of double failures during a flight and ground phase is neglected.
- The probability that an equipment which is repaired during a ground phase fails during the same ground phase is neglected.

The criticality of an equipment or type of equipment for a specific mission is expressed by a criticality status (CS) taking a value among: GO, GOIF or NOGO.
In addition of the equipment CS information, two Fault Trees are managed by ORA to describe the tolerated degraded combination of failures (DM or Degraded Mode) and the non-tolerated combination of failures (TL or Total Loss).
Some simple but realistic assumptions on failure / repairing process have been assumed for Operational Reliability calculation depending on CS equipment status and Fault Trees content :

- The failure of any NOGO equipment implies TL state,
- All failed equipment are repaired in case of TL state and these equipment are repaired in parallel,
- In case of DM non-acceptance, only the just failed equipment is repaired,
- At the end of the tolerated period in DM, only the failed equipment at the origin of this tolerated period is repaired.

The expected calculated result from ORA is the frequency of Operational Interruptions due to a specific equipment or set of equipment. To perform this calculation, ORA is estimating the probability of having a delay at take-off greater than 15 minutes all along a finite sequence of flight and ground phases. The considered reasons of delay taken into account into the ORA model & tool in terms of probability calculation are “TL state & not enough time to perform the repair”, “Not accepted DM state & not enough time to perform the repair”, “Accepted DM state & not enough time configure the aircraft for accepted DM” (See Figure 1).

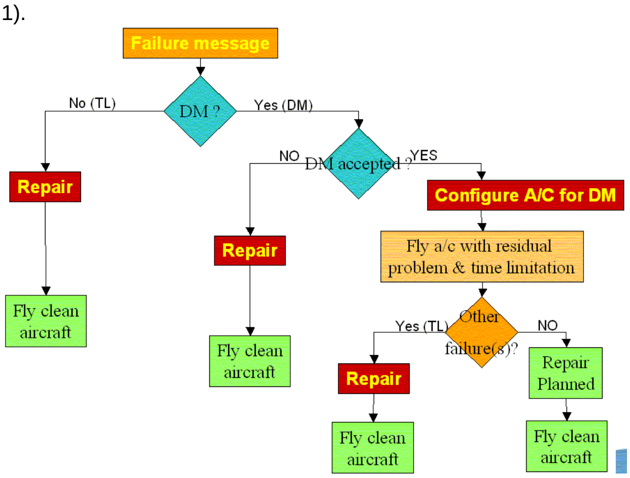


Figure 1: Causes of delay considered in ORA

The probability of having a TL or DM at the end of each flight and ground phase is provided by Fault Tree Analysis (See Figure 2). The elementary events of the Fault Trees are the failure of the equipment involved in the analysis.

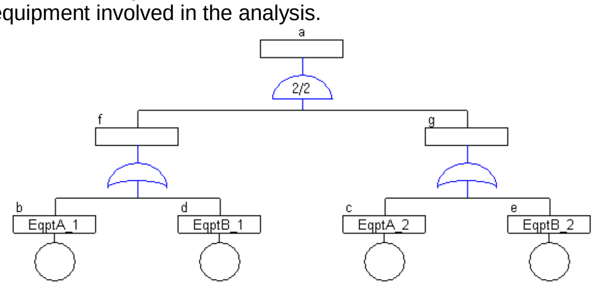


Figure 2: Example of TL Fault Tree

The probability of having to repair involved failed equipment considering DM and TL probability and having consequently an operational interruption is provided by the estimation of dedicated analytical stochastic formulas such as:

During Ground or Flight Phase :

$$\text{Proba (Repair)} = \text{Proba}\left(\left(\text{DM} \cap \overline{\text{TL}} \cap \overline{\text{DM Accepted}}\right) \cup \text{TL}\right)$$

$$\text{Proba (OI)} = \text{Proba}\begin{pmatrix}\left(\text{DM} \cap \text{DM Accepted} \cap \text{No Time for DM Activation}\right) \\ \cup \left(\left(\left(\text{DM} \cap \overline{\text{TL}} \cap \overline{\text{DM Accepted}}\right) \cup \text{TL}\right) \cap \text{No Time for Repair}\right)\end{pmatrix}$$

The evolution of the probability of the elementary events (failure of all the equipment involved in the analysis) all along the mission phases (failure / repairing process) by the estimation of dedicated analytical stochastic formulas such as:

After Flight :

$$\text{Proba(Eqpt Failed)} = \text{Proba(Eqpt Failed at T/O} \cup \text{Failure during Flight)}$$

On the Ground Phase :

$$\text{Proba(Eqpt Failed)} = \text{Proba(}\overline{\text{Eqpt Failed after flight}} \cap \text{Failure during Ground)}$$

Before Flight :

$$\text{Proba(Eqpt Failed)} = \text{Proba}\left(\left(\text{Eqpt Failed at T/O} \cup \text{On the Ground}\right) \cap \overline{\text{Repair}}\right)$$

These formulas really support the expected dynamic behaviour for Operational Reliability estimation. The estimation of these formula is obtained by using Cabtree (Fault Tree Analysis) and agreed simplifying assumptions to be consistent with general assumptions (refer to "ORA Modelling part") and keep an acceptable calculation time : less than 5 minutes for Operational Interruption rate calculation for a classical analysis.

## ORA Tool

After an international call for tender from Airbus specifications, Cab Innovation [4] proposal has been retained.
Finally, the developed ORA tool is based on an Airbus specific software integrating Cabtree commercial tool for Fault Tree modelling and analysis. Both layouts are Excel macros and lead to make all the analyses in Excel environment. This environment is consistent with Airbus needs in terms of deployment easiness (tool installation and associated training). Cab Innovation has also developed the Airbus specific layout providing the dynamic behaviour to support failure / repairing process.

In general terms, an ORA analysis is contained in an Excel file composed of five spreadsheets. A main spreadsheet is dedicated to user general interface for specifying all numerical values necessary for Operational Interruption rate calculation (See Figure 3). Two other spreadsheets are dedicated to the two Fault Trees required to assess the probability of TL and DM states. At last, two additional spreadsheets contain all the results of Operational Interruption rate calculation. These results are all intermediate numerical values obtained all long the mission duration or succession of flights and graphical representation of the evolution of main probabilities all along the mission duration (See Figure 4). The final calculated Operational Interruption rate (average value) is reported on the main spreadsheet (See Figure 3).

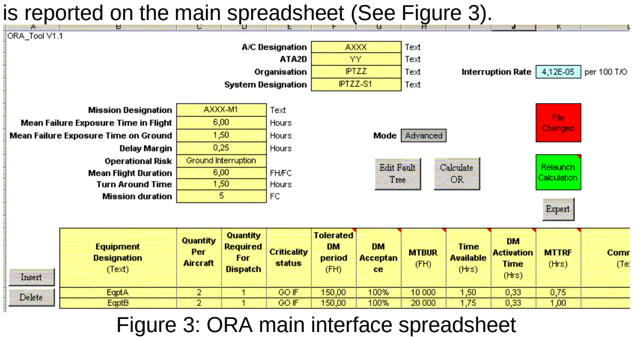

Figure 3: ORA main interface spreadsheet

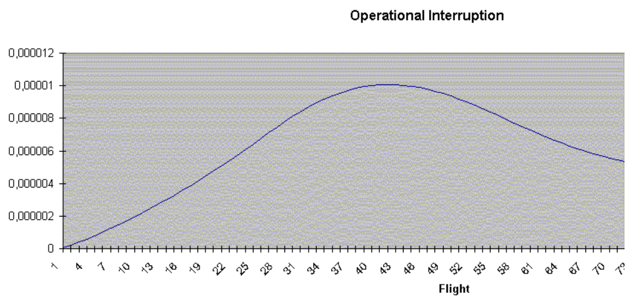


Figure 4: Example of graphical result (evolution of the probability of having an Operational Interruption all along the mission)

ORA tool has been developed in 2003. First version has been delivered on time during the summer 2003. After a validation phase based on theoretical analysis, existing tools inside Airbus and in-service data on existing programme (A340, A320), the deployment of ORA for A400M programme has started at the end of 2003.
Today, ORA tool has been deployed with associated support to almost 20 Supportability Engineers all across European Airbus sites (England, France, Germany and Spain) to generate almost 5000 Operational Reliability analyses each involving up to 50 equipments. Each elementary ORA analysis requires about 1 minute of calculation time for most of the cases.
Supportability Engineers will then have to update these initial calculations on a two-monthly basis.

## Conclusion

Airbus has made a great step towards a unique agreed and complete model & tool for Operational Interruption rate calculation. A first version of ORA tool supporting a simplified model has been developed and validated in 2003 before being deployed in Airbus world in 2004 for A400M programme and future projects.
The OR model implemented into ORA tool has therefore been applied on A400M programme for Operational Reliability demonstration in agreement with nations costumers. It has also been extended to demonstrate an additional target on Deployment Reliability (15 days of continuous operations with a single aircraft in full autonomy) and define the required spare kit to be put in the aircraft to achieve the target.
In addition, future R&D activities are already planned to go beyond this first step in terms of calculation assumptions (analytical formulas considered for calculation) and completeness of influencing parameters (maintenance strategy, …).
In parallel, R&D activities will be performed to extend and deploy with modification this Airbus ORA model tool towards all Risk Sharing Partners for aircraft development (Industrial Partners, Engine Manufacturers & Equipment Suppliers). These activities will be partly performed through VIVACE European Research Integrated Project.

## Abbreviations

CS: Criticality Status
DM: Degraded Mode
LIR: Logistic Information Referential
MTBUR: Mean Time Between Unscheduled Removals
MTTRF: Mean Time To Restore the Function
OI: Operational Interruption
OR: Operational Reliability
ORA: Operational Reliability Analyser
TL: Total Loss

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